Addis Ababa University

Addis Ababa Institute of Technology

School of Electrical and Computer Engineering

Telecommunication Engineering Graduate Program

# Evaluation of Traffic Load-based Multi-Objective Optimization Techniques of Carrier Components for Throughput Improvement in LTE-Advanced Networks

By: Umerulfaruqe Shehseid

Advisor: Dr.-Ing.Dereje Hailemariam

A Thesis Submitted to the School of Electrical and Computer Engineering in Partial Fulfillment of the Requirements for the Degree of Master of Science in Telecommunication Engineering

September 29, 2023
Addis Ababa, Ethiopia

Addis Ababa University

Addis Ababa Institute of Technology

School of Electrical and Computer Engineering

# Evaluation of Traffic Load based Multi-Objective Optimization of Carrier Components for Throughput Improvement in LTE-Advanced Networks

By: Umerulfaruque Shehseid

Advisor: Dr.-Ing.Dereje Hailemariam

Signed by Examining Committee:

| | | |
|---|---|---|
| Dr.-Ing.Dereje Hailemariam<br>Advisor | Signature | Date |
| Dr.Beneyam Berehanu<br>Examiner | Signature | Date |
| Dr.-Eng.Yihenew Wondie<br>Examiner | Signature | Date |

Dean, School of Electrical and Computer Engineering

# 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.

―――――――――-

Signature

Umerulfaruque Shehseid

September 29, 2023

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

―――――――――-

Signature

Dr.-Ing.Dereje Hailemariam

September 29, 2023

# Abstract

The rapid growth of global data traffic is putting a strain on long term evolution(LTE) networks, which are struggling to keep up with demand. Carrier aggregation (CA) is a promising technique to improve the throughput of LTE networks by combining multiple carrier components to create a wider bandwidth. However, CA can also lead to traffic imbalance between the carrier components, which can degrade throughput.

This thesis proposes a multi-objective optimization technique based on genetic algorithm to balance the load across carrier components in LTE-Advanced networks. The proposed technique is evaluated using simulations in MATLAB and WinProp, a software tool for radio propagation analysis.

The data used in this study was collected from ethio telecom. The data includes engineering parameters such as azimuth, electrical and mechanical tilt, default transmit power, cell-level and user-level traffic. A hotspot area in Addis Ababa around Bole was selected for the study. The area has 22 eNodeBs and 66 cells.

Specifically, the joint Tx Power with Electrical Tilt technique provides a 2.41 bps/Hz improvement in spectral efficiency over the Tx Power technique, a 103.9 % improvement in cell edge throughput, and a 12.5 % reduction in load imbalance in the cell edge case. In the cell mid case, the improvement is 61.34 %, 14.53 %, and 8.3 %, respectively. And in the cell center case, the improvement is 18.84 %, 2.25 %, and 1.5 %, respectively and also for Signal-to-Interference and Noise Ratio (SINR) has improved with 105.72% and 63.51% for cell edge and cell center respectively.

The limitations of the study include the fact that the uplink side was not considered, more than three carrier components were not considered, and the load balance between non-CA and CA was not considered. The findings of this thesis can be used to improve the design and implementation of LTE-Advanced networks.

The recommendation of this study is that the operator should deploy the proposed technique, Significantly improve spectral efficiency, average throughput, and load imbalance, especially in the cell edge case.It is worthy to effectively use spectrum resources rather than adding more carrier components.

**keywords:** *load balance, Carrier Aggregation throughput,Tx power,Electrical Tilt,Multi-objective optimization, Carrier Component,per CC based optimization*

# Acknowledgments

First and foremost, I am grateful to Allah for granting me the ability to appreciate the marvels of art and science in our universe.

I would like to express my heartfelt appreciation to Dr.-Ing.Dereje Hailemariam for his exceptional support and guidance throughout my entire thesis journey. From the beginning, his patience, extensive knowledge, and encouragement have ignited my passion for telecommunication engineering. His systematic guidance, continuous motivation, diligent supervision, constructive feedback, and unwavering enthusiasm have been invaluable during the research and writing process of this thesis.

Similarly, I extend my sincere gratitude to Dr. Beneyam Berehanu for his outstanding support and valuable feedback. I am also thankful to Dr.-Eng.Yihenew Wondie for providing constructive comments and excellent follow-up during the preparation of the thesis proposal and progress report presentation.My deep thanks go to Dr.Yalemzewd Negash for his wonderfull support and coordination throughout the thesis work.

I am deeply grateful to my company, ethio telecom, for giving me the opportunity to participate in this program. Additionally, I would like to acknowledge the assistance of my friends and colleagues at ethio telecom who have helped me in gather valuable information during the data collection process, specifically in RAN Engineering Optimization and Planning, Wireless Network Performance, Operation and Maintenance, and Service Operation Center. Although the list is extensive,I would like to mention a few individuals:Habtamu Abayneh,Redamichael Jemberu,Yibeltal Adiss, Kifle Berhane,Sefefe Aragie,Ashenafi Bezabih,Ayele Jiso,Behailu Getachew,Gedlu Yimer,Taddege Asefa,Dr.Alexis Dowhuszko (Aalto University),Dr.Inam Ullah (Nokia Operator),Bekalu Metalign ,Fitsum Mergia,Bezuayehu Zerihun,and Mohammed Ebrahim.

The special thanks go to my brother and friend Getaneh Mollah, who has been with me from A to Z.God bless you Gech!!

Finally, I want to express my gratitude to my beloved wife, Kewniya Yimer, and my lovely kids Mieraj Umerulfaruque,Abdellah Umerulfaruque,and Firdewus Umerulfaruque. I am also thankful to my mother,Zehara Yusuf, and my brothers (Ustaz Hassen, Ahmed, and Aliy) and sisters (Habiba and Temir).Their unwavering support, motivation, patience, and countless contributions have been instrumental in my life and throughout this program.

# Contents

# List of Figures

# List of Tables

# Acronyms

| | |
|---|---|
| 2G | Second Generation |
| 3G | Third Generation |
| 3GPP | Third Generation Partnership Program |
| 4G | Fourth Generation |
| BHr | Busy Hour ratio |
| BTS | Base Transceiver Station |
| CA | Carrier Aggregation |
| CADS | Carrier Aggregation Deployment Scenario |
| CA-FT | Carrier Aggregation in Frequency and Time |
| CAO | Carrier Aggregation Optimization |
| CC | Component Carrier |
| dB | Decibel |
| dBm | Decibel per miliwatt |
| DCC | Downlink Component Carrier |
| DFC | Data Flow Capacity |
| DL | Downlink |
| DLr | DownLink ratio |
| eNB | eNodeB |
| FDD | Frequency Division Duplexing |
| GA | Genetic Algorithm |
| Gbps | Giga bit per seconds |
| HPBW | Half-Power Beam Width |
| FDD | Frequency Division Duplexing |
| GSMA | Global System Mobile Communication Association |
| IMT | International Mobile Telecommunications |
| INB-CA | Inter-Band Non-Contiguous Carrier Aggregation |
| ITU | International Telecommunication Union |
| LTE-A | Long-Term Evolution Advanced |
| MAC | Media Access Control |
| MIMO | Multiple Input Multiple Output |
| MME | Mobility Management Entitie |
| MOO | Multi-objective Optimization |
| MNO | Mobile Network Operator |

| | |
|---|---|
| NMS | Network Management System |
| OFDMA | Orthogonal Frequency Division Multiple Access |
| PCC | Primary Component Carrier |
| PDCP | Packet Data Convergence Protocol |
| ProMan | Propagation Manager |
| PRS | Performance Report system |
| PRB | Physical Resource Blocks |
| QOS | Quality of service |
| RAT | Radio Access Technology |
| RRC | Radio Resource Control |
| RRM | Radio Resource Managements |
| RR | Round Robin |
| RSRP | Reference Signal Received power |
| SE | Spectral Efficiency |
| SINR | Signal-to-Interference and Noise Ratio |
| TDD | Time Division Duplexing |
| Tx Power | Transmitter Power |
| UL | Uplink |
| WinProp | Wireless Propagation Program |

# 1 Introduction

## 1.1 Background and Motivation

The global demand for mobile data is increasing rapidly, and it is driven by the growing number of mobile subscribers and their rising the use of services demanding high -speed data rate. The Global System for Mobile Communications Association (GSMA) projects that the global mobile subscriber penetration rate will reach 76% by 2027, up from 70% in 2022. This trend is particularly evident in Africa, where the penetration rate is expected to reach 58% by 2027, up from 50% in 2022. Ethiopia is also experiencing an increase in mobile subscriber penetration, from 34% in 2022 to 47% by 2027[1].

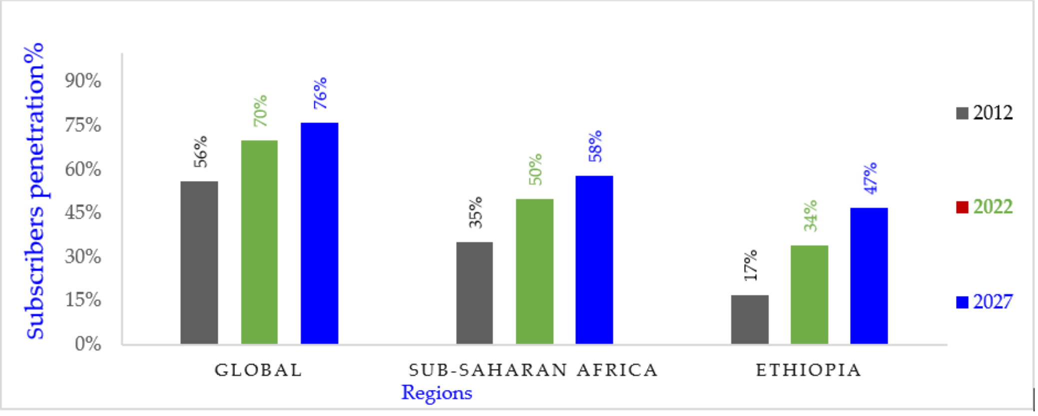


Figure 1.1: Subscribers penetration status by GSMA 2022 Report[1]

.

The growth of mobile data traffic is putting a strain on the existing mobile networks, and there is a need for investment in new infrastructure to meet the growing demand. One of the key challenges in meeting the growing demand for mobile data traffic is the limited throughput of Long-Term Evolution Advanced (LTE-Advanced) networks. LTE-Advanced networks are designed to provide peak data rates of up to 1 Gbps, but they can often struggle to meet the rising is demand, especially in areas with high traffic density [2].

Carrier aggregation (CA) is a promising technology that can be used to enhance the throughput of LTE-Advanced networks. CA combines multiple carrier frequencies to achieve peak data rates of up to 3 Gbps [3]. However, CA has some limitations, such as the need for careful planning and coordination, and the potential for traffic imbalance and increased complexity. This thesis will investigates the potential of CA to enhance the throughput of LTE-Advanced networks in Ethiopia operated by ethio telecom, a wireless and fixed network provider. The operator is facing a growing demand for mobile data in the capital city, Addis Ababa. The current network capacity is 143,674.35 Mbps, but the estimated monthly average mobile data flow capacity (DFC) in the Addis Ababa city is 28.34 PB/month, with a downlink ratio (DLr) of 80.81% and a busy hour ratio (BHr) of 8.47%. This means that the network is not able to meet the current demand, and it is expected to become even more congested in the future [4].

The traffic gap between primary carrier component (PCC) and secondary carrier components (SCC)is shown in Figure 1.2.The figure shows that the traffic on the SCC is much lower than the traffic on the PCC. This is a problem because it means that the network is not being utilized efficiently.

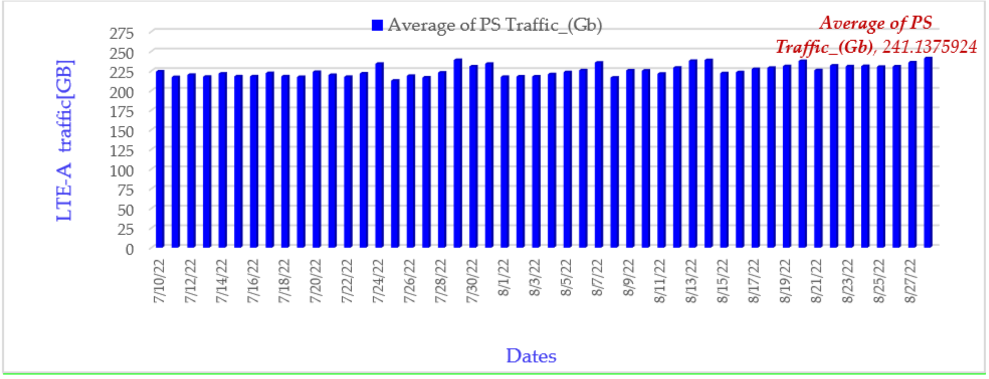


Figure 1.2: PCC and SCC traffic status

Ethio telecom is working to improve the throughput of its network after deploying CA by analyzing operated data and customer complaints. However, it can also lead to decreased throughput if not properly planned ,configured ,and optimized.

## 1.2 Statement of the Problem

The increasing demand for mobile data is putting a strain on mobile network operators (MNOs).CA is a promising technology that can be used to improve the throughput of wireless networks by combining multiple carrier frequencies. However, CA also introduces new challenges, such as load imbalance and throughput degradation.

In Ethiopia, ethio telecom has deployed three CCs in Addis Ababa to enhance network throughput. However, the company still experiences low throughput and Signal-to-Interference-and-Noise Ratio (SINR) due to load imbalance between the PCC and SCCs. This occurs when the PCC is heavily loaded while the SCCs are lightly loaded, as shown the data analyzed using ethio telecom network management system(NMS) data. This leads to network congestion, decreased throughput, and increased latency. This is a significant problem for ethio telecom, as it reduces the throughput of their network and can lead to customer dissatisfaction. Per

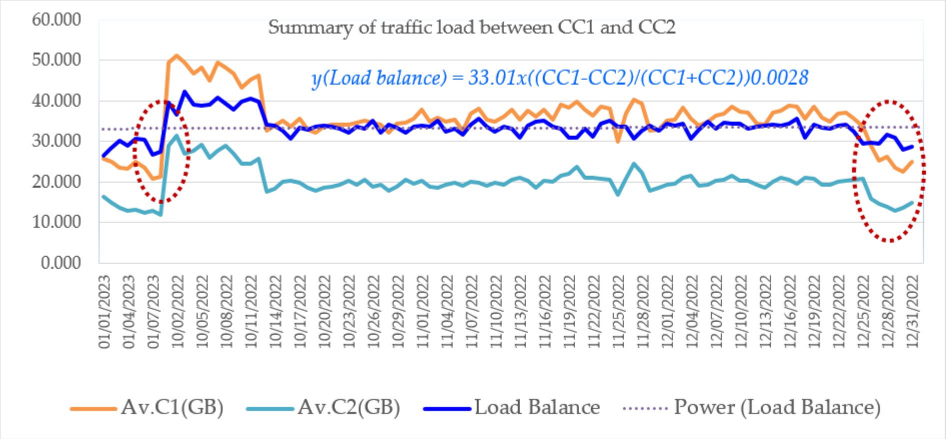


Figure 1.3: Load imbalance impacted traffic between CC1 and CC2

carrier component level traffic load balancing is a promising approach to address this problem. However, researchs on this topic are limited, and to the best of my knowledge, no paper has been published that addresses per CC based load balancing with CA using multi-objective optimization techniques in the context of Addis Ababa.

This thesis will fill this gap by evaluating the performance of different traffic load based multi-objective optimization techniques for throughput improvement in LTE-Advanced networks in Addis Ababa. The thesis will be conducted using simulations, and the results will be compared to the performance of a baseline network without load balancing. NMS data shows that the PCC is highly loaded, whereas the SCC is slightly loaded which came due to different reasons such as CA deployment complexity,poor Engineering planning,and traditional optimization cultures.

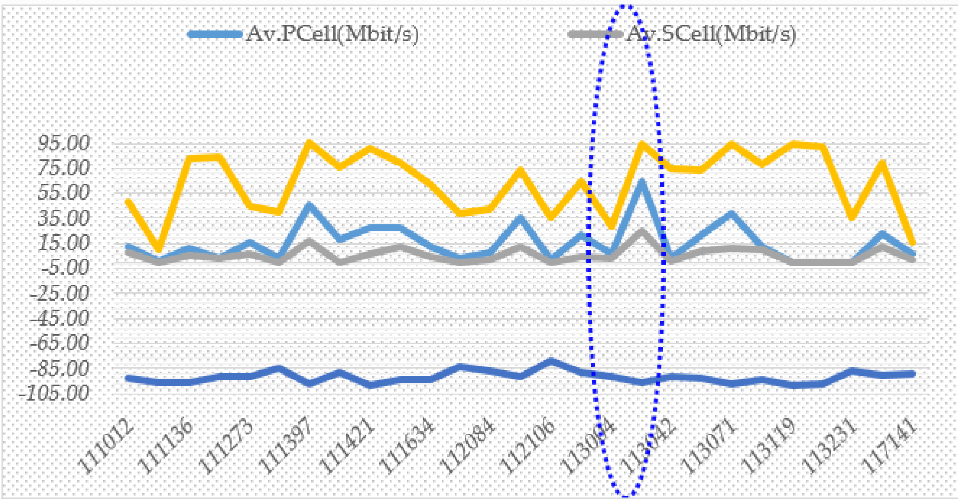


Figure 1.4: Load imbalance between PCC and SCC traffic load

## 1.3 Objective

The objective of this thesis is described below as general and specific objective.

### 1.3.1 General Objective

The main objective is to enhance the low throughput in LTE-Advanced network by optimizing load imbalance between PCC and SCC through per CC based different optimization techniques in a realistic CA deployment scenario in Addis Ababa. By formulating and applying a multi-objective genetic algorithm (GA) optimization problem.

### 1.3.2 Specific Objectives

The specific objective of this thesis are described below:

- To review related works from different literatures;
- To collect data from performance reporting system (PRS) and ethio telecom engineering parameters;
- To analyze data traffic distribution of Addis Ababa to select hotspot area;
- To evaluate the impact of electrical tilt and transmit (Tx) power on improving throughput;
- To minimize load imbalance between the PCC and SCCs to maximize throughput;
- To simulate a system model using WinProp for path loss analysis and conduct simulation work using MATLAB;
- To perform result analysis, evaluation, and comparison with proposed solutions.

## 1.4 Literature Review

Many researchers have tried to improve the performance of CA by using different methods and metrics. However, there are few papers that focus on load imbalance between carrier components (intra-frequency and inter-RAT). This work investigates load balancing strategies to improve CA performance special on inter band with the same eNB.

In the paper [3], a recent study used Atoll 3.3.0 software is used to simulate the performance of Inter-Band Non-Contiguous CA (INB-CA) in a LTE-A network. The study showed that INB-CA can improve throughput by up to 63.70 % compared to single-carrier LTE. The study also showed that INB-CA can improve SINR and RSRP. However, the study did not consider non-optimal network performance or evaluate the scenario after the deployment of CA. These are important factors that should be considered in future studies.

Paper in [4],[5] was conducted to determine the most effective network configuration to reduce high PRB utilization and improve user throughput. The study found that when PRB utilization exceeds 80 % , it can have a negative impact on user throughput. The study used Atoll tools to combine band 5 frequency division duplexing (FDD) and band 40-time division duplexing (TDD) in six specific sites, which reduced high PRB utilization and improved user throughput. The study found that the CA configuration decreased the PRB percentage by 44.50 % and increased the average RSRP value by 12.8 dBm, SINR by 5.14 dB, and throughput by 34.59 Mbps. However, the study did not address the impact of physical tuning on low throughput performance and the case of exchanging CA configuration for CA in-band.

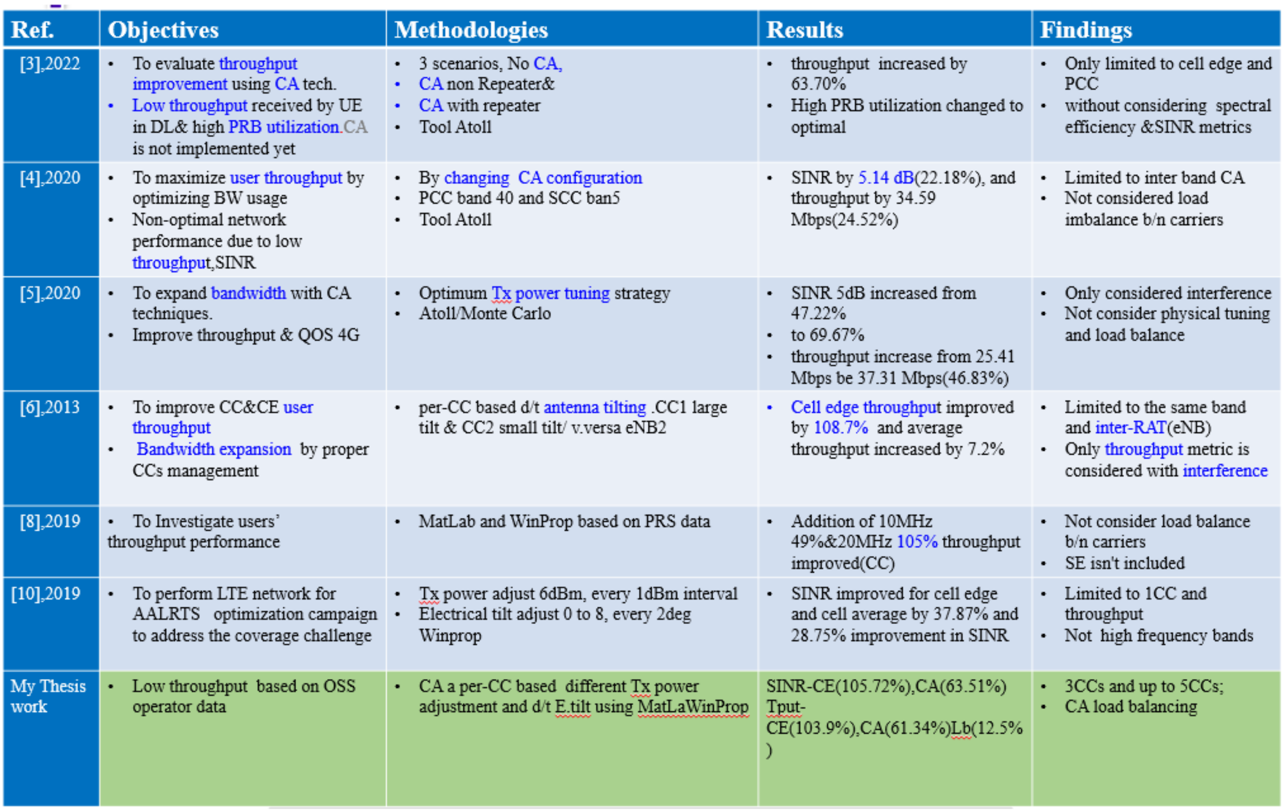
According to the 3GPP release in [6] and A study was conducted to evaluate the performance of CA networks and physical tuning techniques by optimization in [7]. Monte Carlo simulation and Atoll were used to evaluate the performance of CA networks and physical tuning techniques.RSRP, SINR, mean throughput, and number of rejected users were used to measure the performance of the networks.The results showed that CA networks can improve the signal level, RSRP, SINR, and mean throughput.The number of rejected users was also decreased.However, the study did not consider the impact of Tx power between PCC and SCC.

The limitations in paper [7] was addressed by the author in [8] CA technique can be improved by proper management of more than one CC and by adjusting the antenna tilting angles.A study investigated the performance of CA in terms of average user throughput and cell edge throughput by adjusting the antenna tilting angles using a genetic algorithm. The results showed that adjusting the antenna tilting angles can improve cell edge user throughput in both linear cell edge (9.4 %) and multi cell environments (27.2 %).However, the study did not consider combining offline mode parameter settings with power tuning, which could potentially further improve the performance of CA.The study also did not consider the impact of the study's findings in real-world networks.

In paper [9] ,[10] A study proposed a new method for optimizing transmit power and down tilt parameters in cellular networks using Bayesian optimization.The proposed method was compared to random search and showed that it outperformed random search. The study was conducted in a simulated environment and focused only on a single CC.Future studies should investigate the impact of resource sharing and the performance of the proposed method in real-world networks.

According to [4], [11], A study investigated the impact of different carrier configurations on users' throughput performance in a cellular network with capacity and quality issues. The study used WinProp and MATLAB to simulate the performance of the cellular network. The study showed that the addition of more CC can improve users' throughput performance. The study found that the addition of 10 MHz CC over 20 CC provides 49 %, and 20 MHz provides 105 % throughput gains at cell center. Two 20 MHz CC provide over 100 % throughput gain at the cell center, compared to 1 CC at 1800 MHz. However, the study did not focus on load balance and spectral efficiency, and it did not consider Intra-band non-contiguous CC.

Previous studies have explored various techniques to optimize CA throughput in LTE-Advanced networks.These techniques have been evaluated using different methods and assumptions, resulting in varied results based on factors such as environment, technology, input data, cell size, algorithms, and methodology. From the above related papers methods for system level simulation have be taken. There main difference from this research is, the realistic deployment scenario is considered in addition to the existing sites information.



| Ref. | Objectives | Methodologies | Results | Findings |
|---|---|---|---|---|
| [3],2022 | • To evaluate throughput improvement using CA tech.<br>• Low throughput received by UE in DL& high PRB utilization.CA is not implemented yet | • 3 scenarios, No CA,<br>• CA non Repeater&<br>• CA with repeater<br>• Tool Atoll | • throughput increased by 63.70%<br>• High PRB utilization changed to optimal | • Only limited to cell edge and PCC<br>• without considering spectral efficiency &SINR metrics |
| [4],2020 | • To maximize user throughput by optimizing BW usage<br>• Non-optimal network performance due to low throughput,SINR | • By changing CA configuration<br>• PCC band 40 and SCC ban5<br>• Tool Atoll | • SINR by 5.14 dB(22.18%), and throughput by 34.59 Mbps(24.52%) | • Limited to inter band CA<br>• Not considered load imbalance b/n carriers |
| [5],2020 | • To expand bandwidth with CA techniques.<br>• Improve throughput & QOS 4G | • Optimum Tx power tuning strategy<br>• Atoll/Monte Carlo | • SINR 5dB increased from 47.22%<br>• to 69.67%<br>• throughput increase from 25.41 Mbps be 37.31 Mbps(46.83%) | • Only considered interference<br>• Not consider physical tuning and load balance |
| [6],2013 | • To improve CC&CE user throughput<br>• Bandwidth expansion by proper CCs management | • per-CC based d/t antenna tilting .CC1 large tilt & CC2 small tilt/ v.versa eNB2 | • Cell edge throughput improved by 108.7% and average throughput increased by 7.2% | • Limited to the same band and inter-RAT(eNB)<br>• Only throughput metric is considered with interference |
| [8],2019 | • To Investigate users' throughput performance | • MatLab and WinProp based on PRS data | • Addition of 10MHz 49%&20MHz 105% throughput improved(CC) | • Not consider load balance b/n carriers<br>• SE isn't included |
| [10],2019 | • To perform LTE network for AALRTS optimization campaign to address the coverage challenge | • Tx power adjust 6dBm, every 1dBm interval<br>• Electrical tilt adjust 0 to 8, every 2deg Winprop | • SINR improved for cell edge and cell average by 37.87% and 28.75% improvement in SINR | • Limited to 1CC and throughput<br>• Not high frequency bands |
| My Thesis work | • Low throughput based on OSS operator data | • CA a per-CC based different Tx power adjustment and d/t E.tilt using MatLaWinProp | SINR-CE(105.72%),CA(63.51%)<br>Tput-CE(103.9%),CA(61.34%)Lb(12.5%) | • 3CCs and up to 5CCs;<br>• CA load balancing |

Figure 1.5: Summary of the reviewed literatures

## 1.5 Methodology

The research methodology will be conducted in a systematic and rigorous manner.A literature review will be conducted to identify the gaps in the existing literature on LTE-Advanced networks, CA, and the impact of CA on network performance.Data on the LTE-Advanced network in Addis Ababa will be collected. WinProp will be used to simulate the path loss for the 1800 MHz and 2600 MHz frequency ranges.MATLAB will be used for system level simulation to calculate the throughput value.The SINR obtained from the path loss analysis will be used to define the metrics for the study, such as SINR, throughput, and spectral efficiency. The results of the simulations will be analyzed based on different CA scenarios. The benefits of using CA in LTE-Advanced networks will be identified, and conclusions and recommendations for future research will be drawn.

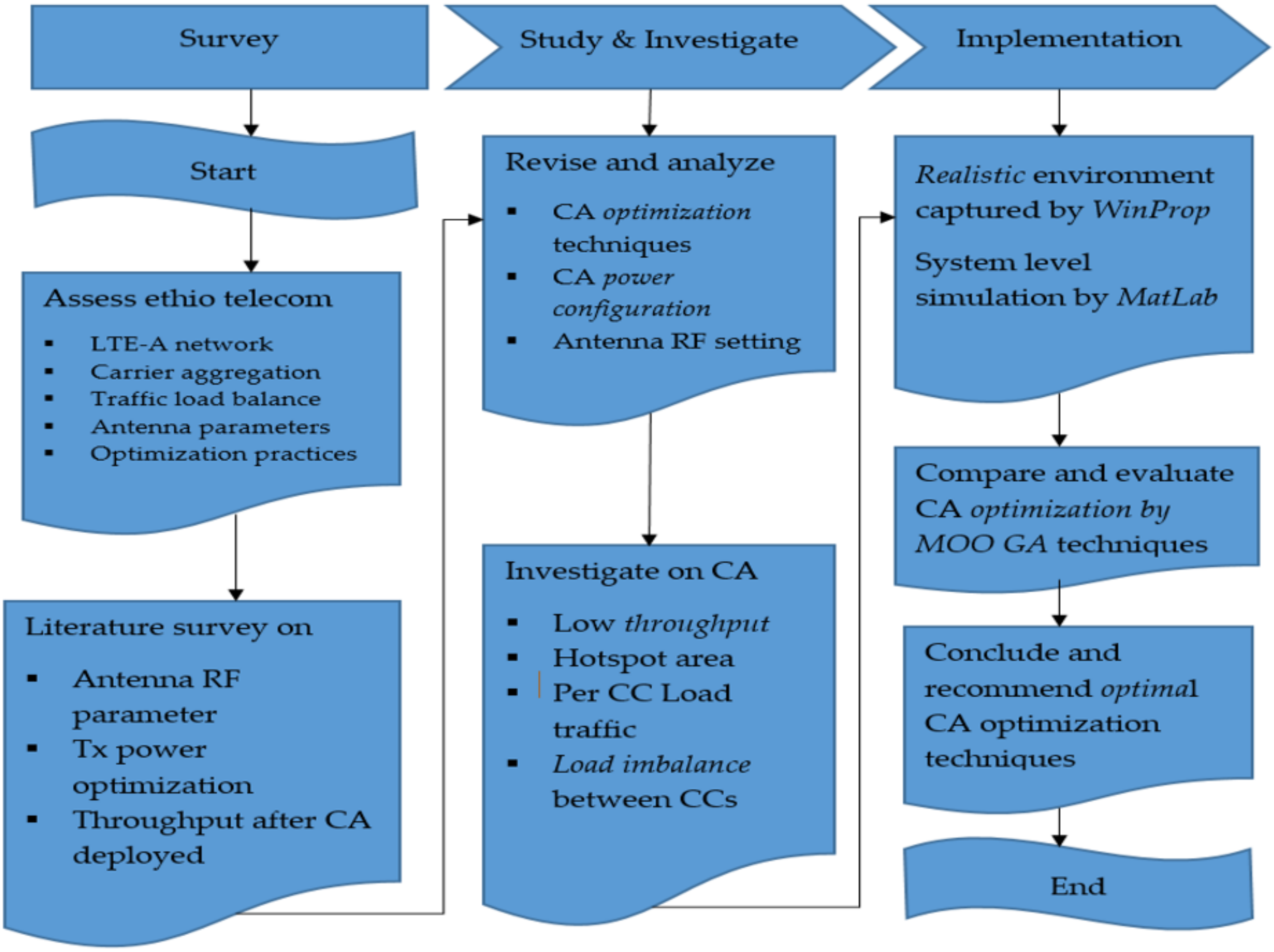


Figure 1.6: General methodology for thesis work

## 1.6 Scope and Limitation

### 1.6.1 Scope of the Thesis

The research aims to improve the average user throughput by reducing the load imbalance between different carriers in a densely populated area. It will evaluate the performance of

different techniques using metrics such as SINR, Spectral efficiency, and throughput, focusing on LTE-Advanced CA downlink in Addis Ababa.

### 1.6.2 Limitation of the Thesis

This study examines the most effective methods for improving CA throughput and load balancing techniques in Addis Ababa. It will focus on optimizing CA throughput techniques using up to two carrier frequencies and two carrier components, while disregarding other factors such as fairness and dynamic traffic distribution across carriers, the challenges of using CA in unlicensed spectrums, or the impact of mobility on CA performance and self-automation for CA load balancing.

## 1.7 Contributions

This thesis work proposes a new multi-objective optimization technique based on per CC based algorithm to balance the load across carrier components in LTE-Advanced networks. The results of the evaluation show that the proposed technique can significantly improve spectral efficiency, average throughput, and load imbalance, especially in the cell edge case. This work is significant because it provides a new and effective way to address a major challenge in LTE-Advanced networks. The findings of this Thesis can be used by ethio telecom and other telecom operators to improve the design and implementation of their LTE-Advanced networks.

## 1.8 Thesis Layout

This paper is organized in the following manner: Chapter 1 provides an overview of the background, motivation, problem statement, objectives, methodologies, literature reviews, contributions, scope, and limitations of the study. Chapter 2 explains the background of LTE-Advanced and CA, along with the deployment of CA in the cellular network. Chapter 3 focuses on optimization approaches with regard to load balance and evaluation methods. Chapter 4 develops a system model for the selected hotspot area. Chapter 5 discusses and evaluates different techniques. Chapter 6 contains the conclusion and explores potential future research directions.

# 2 Carrier Aggregation in LTE-Advanced

## 2.1 Overview of LTE-Advanced Network

LTE-Advanced is an enhancement to the fourth generation (4G) mobile network technology, LTE. It offers a number of features that can improve the throughput and bandwidth of LTE networks, including carrier aggregation, and Multiple Input Multiple Output (MIMO). It is a major step forward in the evolution of mobile communication networks. It offers a number of features that can improve the throughput, bandwidth, and capacity of LTE networks, which is essential to meet the growing demand for mobile data.

According to [11], LTE-Advanced networks have been deployed in many countries and offer a number of benefits over traditional LTE networks. These benefits include faster data speeds, wider coverage, and increased capacity. LTE-Advanced networks can provide data rates of up to 1 Gbps, which is significantly faster than the maximum data rate of 300 Mbps offered by traditional LTE networks. LTE-Advanced networks can also offer wider coverage than traditional LTE networks, which means that users can stay connected to the network even when they are in rural areas or indoors. Additionally, LTE-Advanced networks can support more users and more traffic than traditional LTE networks.

LTE-Advanced, also known as Release 10, enhances LTE by meeting the International Mobile Telecommunication (IMT) -Advanced specifications. This is accomplished by improving CA, relaying, and multiple antenna transmission on both the uplink and downlink. CA combines multiple frequency bands to create wider channels, which can increase the data throughput. Relaying allows base stations to cooperate to improve the signal strength and coverage of the network. Multiple antenna transmission uses multiple antennas to transmit and receive data, which can improve the spectral efficiency of the network [12].

### 2.1.1 LTE-Advanced Architecture

LTE-Advanced networks use CA to combine multiple frequency bands and increase the data rate. The eNB manages the broadcast messages, Mobility Management Entities (MMEs), and Radio Resource Managements (RRMs) to provide users with faster data speeds and better overall performance [13]. The eNB is a key part of the CA process, as it coordinates with the other components of the LTE-Advanced network to ensure that the best possible data rate is achieved. This is done by managing the broadcast messages, which are sent to all users in the network, as well as the MMEs and RRMs, which are responsible for managing the mobility of users and the radio resources in the network, respectively.

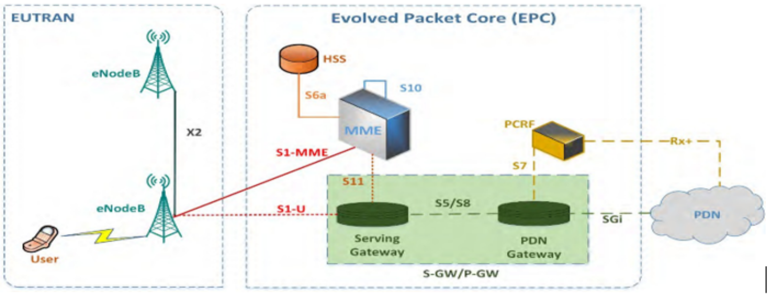


Figure 2.1: Network Architecture of LTE-Advanced [12]

.

### 2.1.2 Frame Structure

LTE-Advanced uses Orthogonal Frequency Division Multiple Access (OFDMA) to transmit data, dividing the available spectrum into RBs. Each RB is further subdivided into subcarriers, the fundamental units of data transmission in OFDMA. The number of subcarriers in an RB can vary depending on the modulation technique employed. The eNB gives each UE a minimum of 180 kHz of frequency bandwidth, meaning each RB can include up to 12 subcarriers used by the UE [14].

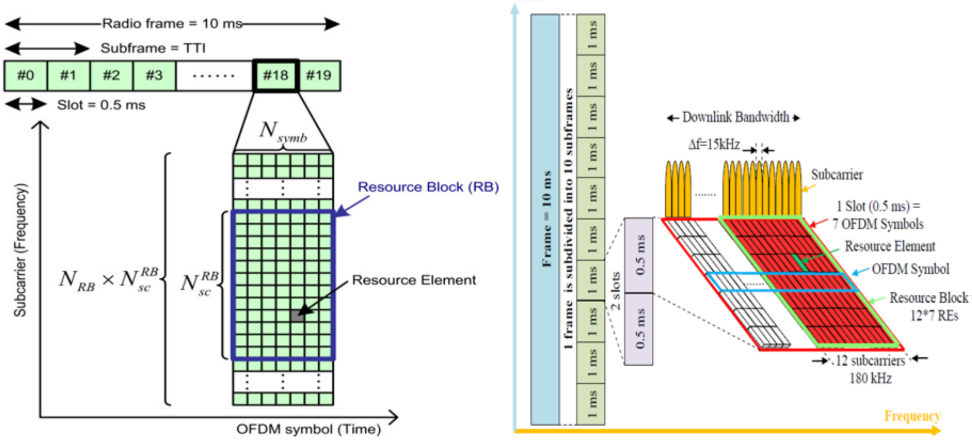


Figure 2.2: Time-frequency resource block structure of LTE-Advanced (b)Time Domain structure with OFDMA Symbol[11] [15]

.

## 2.2 Carrier Aggregation and Benefits

### 2.2.1 Carrier Aggregation

CA is a technique that allows operators to combine multiple frequency bands to create wider channels, which can increase the data throughput. CA has been evolving over time, and the latest generation of CA, known as CA in frequency and time (CA-FT), allows operators to combine two or three frequency bands in both frequency and time slots. CA is considered as LTE-A's most important feature because it boosts data speeds, broadens DL coverage, and enables operators with fragmented spectrum to make better use of spectrum resources. CA has been implemented all over the world since its launch in 2013 [13].

The fundamental significance of CA is that it allows operators to increase the data throughput of their LTE-Advanced networks without having to acquire new spectrum. This is important because spectrum is a scarce resource, and it is becoming increasingly expensive to acquire. CA can also be used to improve the coverage and capacity of LTE-Advanced networks. It is already being used by many operators in their commercial LTE-Advanced services[13]. It is cited as one of the key technologies for meeting the growing demand for mobile data and providing users with the best possible experience. The LTE-Advanced standard specifies that each of the CCs is limited to 20 MHz of bandwidth, and aggregation of up to five allows a maximum of 100 MHz of total signal bandwidth, which gives a fivefold increase in channel capacity and data speed.

### 2.2.2 Carrier Aggregation in ethio telecom Mobile Network

CA has been introduced for ethio telecom's 4G LTE-Advanced mobile network in metropolitan areas, including the country's capital, Addis Ababa. A method called CA combines different frequency bands to produce a broader bandwidth, which can give users higher data rates. Inter-band carrier aggregation is a technology used by ethio telecom, which mixes frequency channels that are not next to one another.

By combining additional frequency bands, ethio telecom is able to attain a broader bandwidth. In practical deployment settings, CA has been demonstrated to be effective at increasing the throughput of LTE-Advanced networks.

According to a 3GPP research, CA can boost throughput by as much as 100 % in rural areas and up to 70 % in urban areas [15]. In its LTE-Advanced mobile network, ethio telecom mainly uses the low frequency bands 2600MHz (Band 7) and 1800MHz (Band 3). To bring the maximum number of aggregated carrier components to 3CC, the 800MHz (Band 20) frequency carrier was recently re-farmed as a third band. As a result, ethio telecom can now combine up to three frequency bands to obtain a bandwidth of up to 50MHz.

To investigate the impact of user location on CA system performance a study was conducted in [16]. The study found that users at the cell edge may experience lower throughput than users in the center because they are farther away from the base station and may not be able to receive as many RBs. The study also found that the number of RBs that a user can receive depends on the frequency bands that are available at the user's location. The results of this study suggest that CA system performance can be affected by user location. Operators should consider this when deploying CA systems and should ensure that users at the cell edge have access to sufficient RBs to achieve the desired throughput.

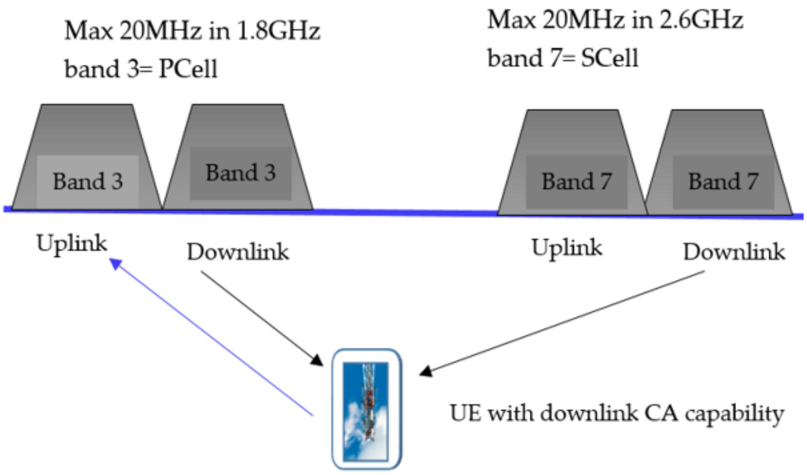


Figure 2.3: Downlink carrier aggregation with band 3 and band 7 [17]

.

### 2.2.3 Benefits of Carrier Aggregation

According to 3GPP specification, CA can improve the performance of LTE-Advanced networks in a number of ways, including significantly higher throughput, coverage expansion, load balancing, and more effective use of spectrum. In addition, CA can also help to improve network carrier load balancing and frequencies can be combined regardless of spectrum regulations.

Overall, CA is a powerful technology that can significantly improve the performance of LTE-Advanced networks.The effective use of the available spectrum to make better use of underutilized spectrum, which can aid in reducing congestion and enhancing performance. Improving network carrier load balancing to assist MNOs in distributing the load among CCs [18].

### 2.2.4 Carrier Aggregation Techniques

CA can be classified into three types: intra-band contiguous, intra-band non-contiguous, and inter-band. The simplest and most efficient type is intra-band contiguous, which allows eNBs to use their entire bandwidth. Intra-band non-contiguous can increase coverage but is less efficient.

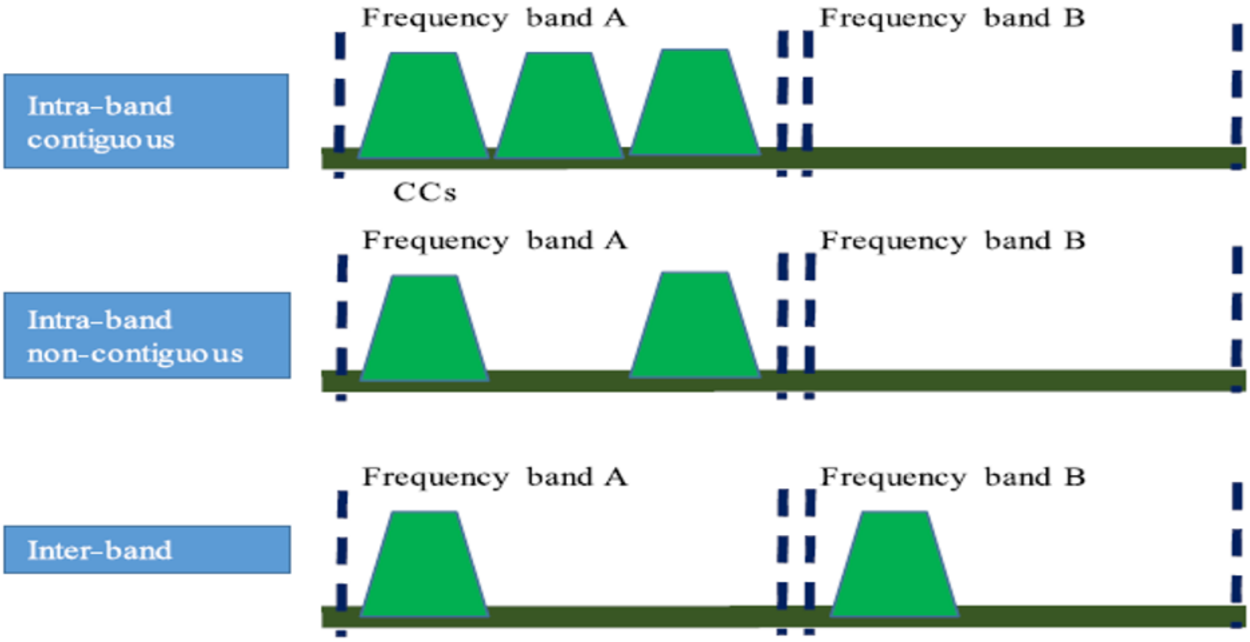


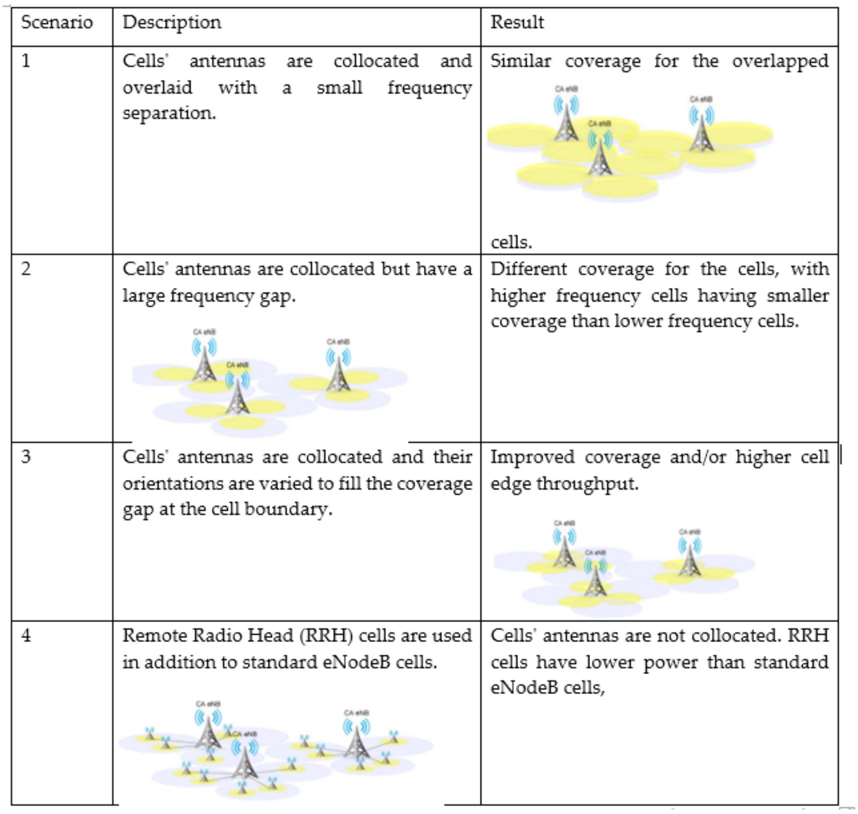
Figure 2.4: Different types of CA techniques [19]

.

Intra-band CA combines carriers that are in the same frequency band, while inter-band CA combines carriers that are in different frequency bands. Contiguous CA combines carriers that are close together in a frequency band, while non-contiguous CA combines carriers that are not close together [18],[19].

### 2.2.5 Carrier Aggregation Deployment Scenarios

The PCC is the main carrier that a user equipment (UE) is connected to. It is responsible for managing the RRC connection and security parameters. The PCC is only changed during the handover process. SCCs are additional carriers that can be added or removed by the network to accommodate the UE's traffic requirements. They are often used for bandwidth expansion. A few possible deployment scenarios are shown in Figure 2.5.



| Scenario | Description | Result |
|---|---|---|
| 1 | Cells' antennas are collocated and overlaid with a small frequency separation. | Similar coverage for the overlapped cells. |
| 2 | Cells' antennas are collocated but have a large frequency gap. | Different coverage for the cells, with higher frequency cells having smaller coverage than lower frequency cells. |
| 3 | Cells' antennas are collocated and their orientations are varied to fill the coverage gap at the cell boundary. | Improved coverage and/or higher cell edge throughput. |
| 4 | Remote Radio Head (RRH) cells are used in addition to standard eNodeB cells. | Cells' antennas are not collocated. RRH cells have lower power than standard eNodeB cells, |

Figure 2.5: Different types of CA deployment Scenario(CADS) [20]

.

## 2.3 Carrier Aggregation Throughput Enhancement

### 2.3.1 Carrier Aggregation Techniques for Throughput Enhancement

Radio spectrum is a finite resource, so it is important to use it effectively. Carrier aggregation is a technique that allows mobile network operators to do this by combining multiple frequency bands to create a wider bandwidth. This can result in faster data rates for users. SCCs can be dynamically added or removed depending on user demand. This allows operators to maximize the use of their spectrum while providing users with the best possible service [21].

### 2.3.2 Inter-band and Intra-band Carrier Aggregation Techniques

For intra-band contiguous and non-contiguous carrier aggregations with two or more component carriers, the nominal channel spacing between two adjacent E-UTRA component carriers is determined as follows:

$$N_{\text{channel\_spacing}} = \left\lfloor \frac{(BW_{ch1} + BW_{ch2} - 0.1|BW_{ch1} - BW_{ch2}|)}{2 \times 0.3} \right\rfloor \times 0.3 \text{ [MHz]} \qquad (1)$$

where: $N_{\text{channel\_spacing}}$ is the channel spacing in MHz. $BW_{ch1}$ is the bandwidth of channel 1 in

MHz. $BW_{ch2}$ is the bandwidth of channel 2 in MHz. $|BW_{ch1} - BW_{ch2}|$ is the absolute difference between the bandwidths of channels 1 and 2 in MHz. 0.1 is a guard band to ensure that there is no overlap between the channels. $2 \times 0.3$ is the guard band in MHz.

## 2.4 Antenna Overviews

### 2.4.1 Antenna Parameters in Carrier Aggregation

The region outside of an antenna where a plane wave is created by the radiated wave is known as the far-field. The zone between the antenna and the receiver where the distance is larger than 2D2 / where D is the maximum linear dimension of the antenna and is the operational wavelength, is referred to as the far-field. The ratio of a given radiation direction's intensity to the average radiation intensity is known as directivity. It measures how effectively an antenna concentrates radiated power in a specific direction. Decibels (dB) are commonly used to express directivity. The average radiation intensity is equal to the total power radiated Prad by the antenna divided by 4.

$$D = \frac{4\pi U}{P_{\text{rad}}} \tag{2}$$

**Efficiency**

- Conductor loss or dielectric loss may cause the antenna's power to be lost. Thus, the ratio of the antenna's input power Pin to its total power Prad can be thought of as its antenna efficiency.

$$\eta = \frac{P_{\text{rad}}}{P_{\text{in}}} \tag{3}$$

**Gain**

- The relationship between an antenna's efficiency and directivity is called its gain; nevertheless, conductor or dielectric loss reduces the power density radiated in a particular direction.The operating frequency has a significant impact on the antenna's efficiency and gain characteristics.

$$D = \frac{4\pi U}{P_{\text{in}}} \tag{4}$$

**Half-Power (3dB) Beam width**

- An antenna's beam width is the primary angular range of the main lobe of its radiation pattern. The half-power beam width (HPBW) is the angle between the radiation pattern's regions where the power has fallen by 3 dB (or 50 %) from its peak value. An antenna's angular resolution is frequently described using the HPBW.

**Bandwidth**

- The range of frequencies within which an antenna's performance complies with a given standard is referred to as the bandwidth.

**Antenna Tilt**

- is the angle that the antenna's main beam is below the horizontal plane. The terms down tilt and up tilt is also used to describe positive and negative angles, respectively [20][22]. According to Figures 2.6, the antenna down tilt can be changed physically or electrically.

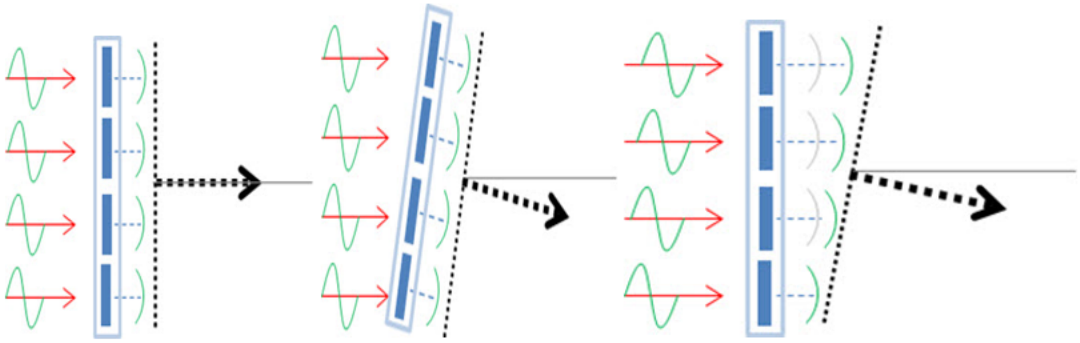


Figure 2.6: Mechanical tilt [20] (a) Without tilt (b) Mechanical Tilt (c)Electrical Tilt [11]

.

Three techniques exist for modifying an antenna's electrical tilt: remote electrical tilt (RET), variable electrical tilt (VET), and fixed electrical tilt. Without site visits or tower ascents, the NMS can remotely modify the electrical tilt angle due to RET. Operations costs may be reduced as a result.

### 2.4.2 Antenna Radiation Pattern

The computation of the horizontal and vertical radiation patterns in 3GPP LTE simulations uses two formulas.

$$A_h(\phi) = -\min\left[12\left(\frac{\phi}{\phi_{3\mathrm{dB}}}\right)^2, A_m\right] \tag{5}$$

$$A_v(\phi) = -\min\left[12\left(\frac{\theta}{\theta_{3\mathrm{dB}}}\right)^2, SLA_v\right] \tag{6}$$

where: $SLA_v$ is the side lobe attenuation. $A_m$ is the front-to-back attenuation. Anechoic chamber testing is frequently used to evaluate antenna properties. However, diffraction and scattering from the antenna's surroundings have an impact on how well it performs in the field. Attenuation of nulls, front-to-back attenuation, and side lobe attenuation are three essential characteristics of an effective antenna layout.

### 2.4.3 Electrical and Mechanical Tilt

With reference to Figure 2.10, the formula for the angle w (i, k) between the line of sight from the eNB antenna to the UE antenna and the horizontal plane is as follows.

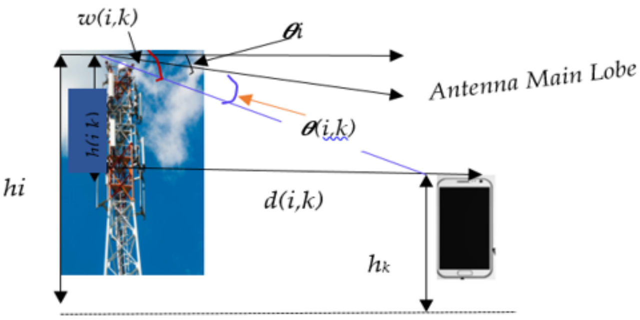


Figure 2.7: Layout of eNB antenna parameters in the vertical plane [23]

.

$$W(i,k) = \arctan\left(\frac{h(i,k)}{d(i,k)}\right) \tag{7}$$

where $h(i,k)$ denotes the height difference between user $k$'s antenna and eNB$_i$'s antenna. $d(i,k)$ denotes the distance between user $k$ and cell $i$.

$$\theta(i,k) = W(i,k) - \theta(i) \tag{8}$$

where $\theta(i)$ is the electrical down tilt angle of eNB$_i$ in radians.

## 2.5 Impact of Carrier Aggregation on Different Layers

According to 3GPP [6], [24],the Radio Resource Control (RRC) signaling needs to be modified to support the multiple carriers in carrier aggregation. The Medium Access Control (MAC) layer also needs to be modified to support the multiple carriers in carrier aggregation. This includes changes to the MAC protocols that are used to schedule the data transmissions, as well as the MAC procedures that are used to manage the data transmissions. The physical layer (PHY) also needs to be modified to support the multiple carriers in carrier aggregation. This includes changes to the PHY protocols that are used to transmit and receive the data, as well as the PHY procedures that are used to manage the data transmissions.

### 2.5.1 Physical Layer

In [18], CA requires some changes to the MAC and physical layer protocols. The base station can add or remove secondary cells by changing the RRC Connection Reconfiguration signals or sending a MAC activation/deactivation control element [25]. The RLC layer provides the logical channels. If CA is enabled, the MAC layer will partition the data into various downlink carriers, also known as Downlink Component Carriers (DCC) or other symbols with a similar meaning. The MAC layer will inform the RLC layer about transmission opportunities while taking into account all carriers.

### 2.5.2 MAC Layer

CA requires changes to the MAC and physical layer protocols. The base station can add or remove secondary cells by changing the RRC Connection Reconfiguration signals or sending a MAC Activation/Deactivation control element. The Radio Link Control (RLC) layer provides the logical channels. If CA is enabled, the MAC layer will partition the data into various downlink carriers and inform the RLC layer about transmission opportunities[12].

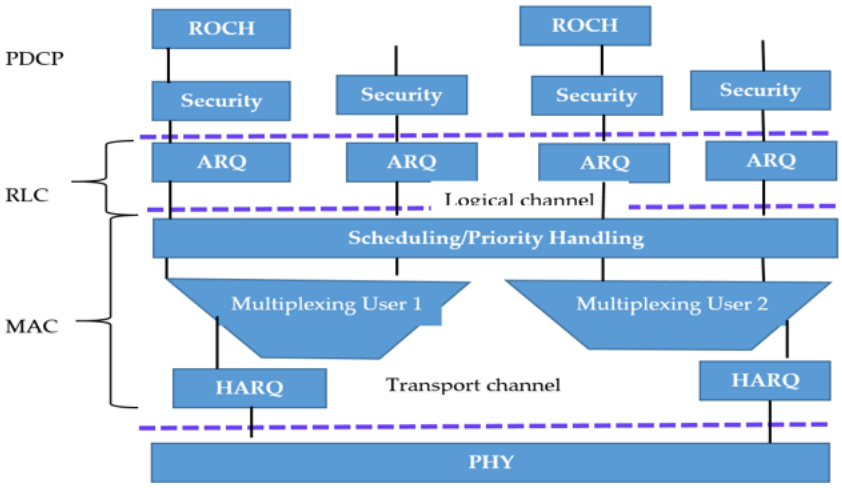


Figure 2.8: MAC structure with CA[12]

## 2.6 Methods for Throughput Enhancement by Carrier Aggregation

Overall, CA is a powerful technology that can significantly improve the performance of LTE-Advanced networks. It offers a number of advantages, including increased throughput, extended coverage, load balancing, and more efficient use of spectrum. There are a number of ways to improve user throughput by CA, including:

- Combining more frequency bands: The more frequency bands that are combined, the wider the bandwidth will be, and the faster the data rates will be.
- Using advanced CA techniques: There are a number of advanced CA techniques that can be used to improve throughput.
- Optimizing CA configuration: The CA configuration can be optimized to improve throughput.

## 2.7 Carrier Aggregation Challenges

CA is a complex technology that needs to be carefully planned and optimized strategically. MNOs must make sure that their hardware and software are up to date and that their network architecture can support CA.It optimization can enhance the performance of CA in areas with low throughput by modifying the antenna characteristics and CC power setting.

To accomplish this, the eNBs antenna tilt and Tx power can be modified to focus the signal in particular places. For example, MNOs can slant the antenna downward to focus the signal on users who are nearer the eNB. To reach users who are farther from the eNB, they can additionally boost the Tx power and different algorithm in schedules [26]. CA load balancing per CC based different electrical tilt and Tx power, recognized as the most advanced in throughput improvement and minimize load imbalances issues so far, will be discussed in detail in the next chapter.

# 3 Carrier Aggregation Optimization Techniques

## 3.1 Carrier Aggregation Optimization

Optimizing CA network performance involves intelligently selecting the most suitable carriers to combine, allocating users to the most appropriate carriers, and scheduling traffic effectively. This process is called Carrier Aggregation Optimization (CAO), which can be done either before or after the network is deployed. Pre-optimization ensures that the network is configured in the best possible way, while ongoing optimization improves the network's performance as traffic patterns change. There are various techniques available for CAO, such as MOO and GA, which can help to improve the throughput, latency, and robustness of CA networks. By using the right techniques, CAO can ensure that CA networks can deliver the best possible performance to users [20].

According to [11, 20] by carefully adjusting the azimuth and tilt of an antenna, mobile network operators can improve the coverage, capacity, load balancing, and interference of their networks. The tilt of an antenna is the angle it makes with the horizon, and it can be adjusted electrically or mechanically. The optimal azimuth and tilt settings will vary depending on the specific application and environment.

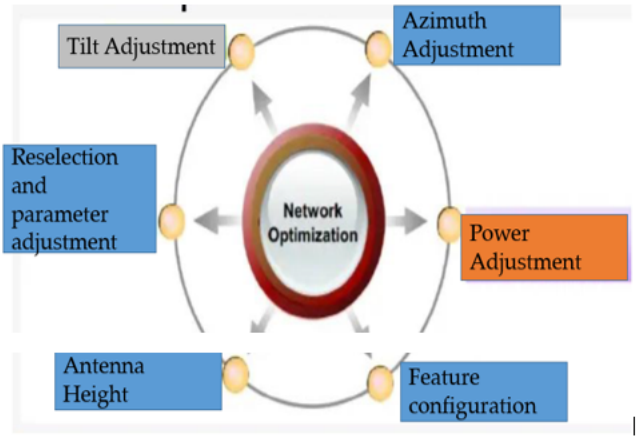


Figure 3.1: Network optimization methods[11]

.

## 3.2 Load Balance in Carrier Aggregation

One way to improve the performance and reliability of CA networks is to implement load balancing [27]. This technique involves distributing traffic across multiple carriers to prevent load imbalances and inefficiencies. Load balancing can be achieved through user-based, carrier-based, or hybrid methods, depending on the specific network and traffic conditions. By utilizing load balancing, network operators can ensure that their CA networks operate at optimal levels, providing a better user experience. Two inter-carrier load balancing strategies can be used to effectively divide incoming CA and non-CA traffic between carriers. It's important to note that the optimal load-balancing technique may vary depending on the specific network and traffic conditions [27].

Load balancing is a system that distributes the traffic of non-CA users among aggregated carriers. According to [28], this can help to reduce inefficiencies caused by load imbalances between carriers. CA gain is large at low load, but it decreases as the number of scheduled users increases. There are two inter-carrier load balancing strategies that can be used to effectively divide incoming CA and non-CA traffic between the two carriers [29]. Load balancing is a valuable technique for enhancing the efficacy and dependability of a CA network. By distributing traffic more evenly across carriers, it is possible to improve throughput by redirecting traffic from overloaded to underutilized carriers. The optimal approach for this technique will vary depending on specific network and traffic conditions, and it can be accomplished in a centralized,

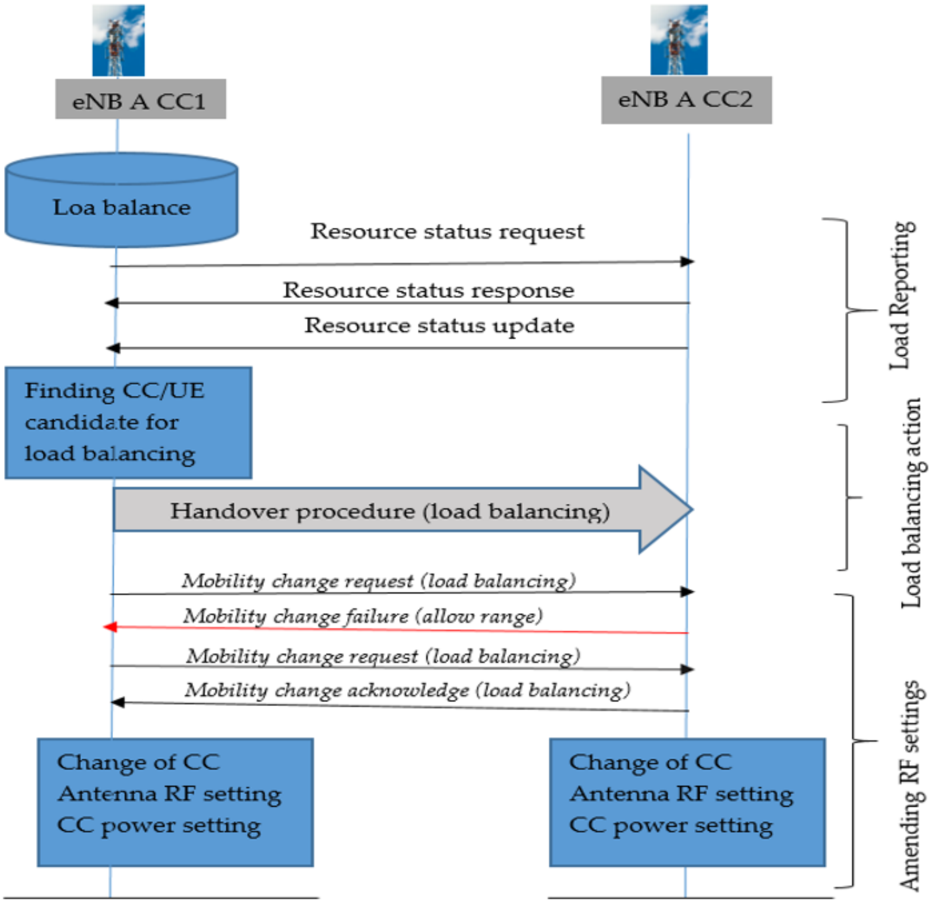


Figure 3.2: Load balancing approach[28]

.

distributed, or hybrid manner. According to a reliable source [30][31], load balancing can be particularly effective when traffic is unevenly distributed in a region and concentrated mostly in the coverage area of one cell. Additionally, dynamic adjustments in Tx power can assist in balancing the load between carriers, minimizing interference, and improving the handover process. By modifying the Tx power of carriers in real-time based on current traffic conditions, network operators can enhance CA throughput and ensure an exceptional user experience.

## 3.3 Carrier aggregation Throughput Optimization Techniques

The 3GPP has established a set of recommendations for optimizing carrier aggregation throughput. In [20] ,[30], Among these recommendations are dynamic adjustments to Tx power, which can be utilized to balance the load between carriers and enhance signal quality in areas experiencing high traffic. Additionally, antenna tilting can be implemented to direct the signal towards areas with high demand, thereby improving throughput for users in those areas [32].

MOO algorithms can also be employed to identify solutions that optimize multiple objectives, such as throughput and fairness. GAs can also be utilized to find solutions that are resilient to changes in traffic conditions. The optimal algorithm for carrier aggregation optimization is contingent upon the specific network conditions and objectives at hand. However, some of the most commonly used algorithms include MOO algorithms, GAs, and machine learning algorithms. When the PCC is heavily loaded, it may be advantageous to offload some of the traffic to the SCCs [33].This can be executed by adjusting the Tx power of the carriers or by using antenna tilting. By utilizing these techniques, network operators can enhance the throughput of their CA networks and provide an improved user experience[32].

### 3.3.1 Tx power Optimization Techniques

Tx can be used to balance the load between the PCC and the SCCs by adjusting the transmit power of the different carriers [34]. This can be done in a number of ways, such as:

**Decreasing the transmit power of the PCC:** This will cause some of the traffic to be transferred to the SCCs. **Increasing the transmit power of the SCCs:**This will help to improve the signal quality on the SCCs and make them more attractive for users.This can be done to achieve a balance between the transmit power of the PCC and the SCCs.The best way to adjust the transmit power of the different carriers depends on the specific network conditions and objectives.

However, Tx is a versatile technique that can be used in a variety of situations.It can be used to improve the performance of CA networks in a number of ways, such as by reducing congestion, improving throughput, and increasing the reliability of the network. Tx can be implemented in a number of ways, such as using static or dynamic algorithms. Static Tx algorithms are simpler to implement, but they may not be as effective as dynamic Tx algorithms. Dynamic Tx algorithms are more complex to implement, but they can be more effective in adapting to changes in the network conditions.

Tx power optimization is a technique that can be used to improve the throughput and coverage of a CA network. It can be used to balance the load between the CCs, offload traffic from the PCC to the SCCs, improve the signal quality in areas with high load, and reduce interference.

The best RF parameter to decide Tx power depends on the specific network conditions and CCs. Some of the most commonly used RF parameters for Tx power optimization in CA networks include RSSI, SINR, and C/I. By considering the factors mentioned above, network operators can improve the throughput of their CA networks by optimizing the Tx power [29].

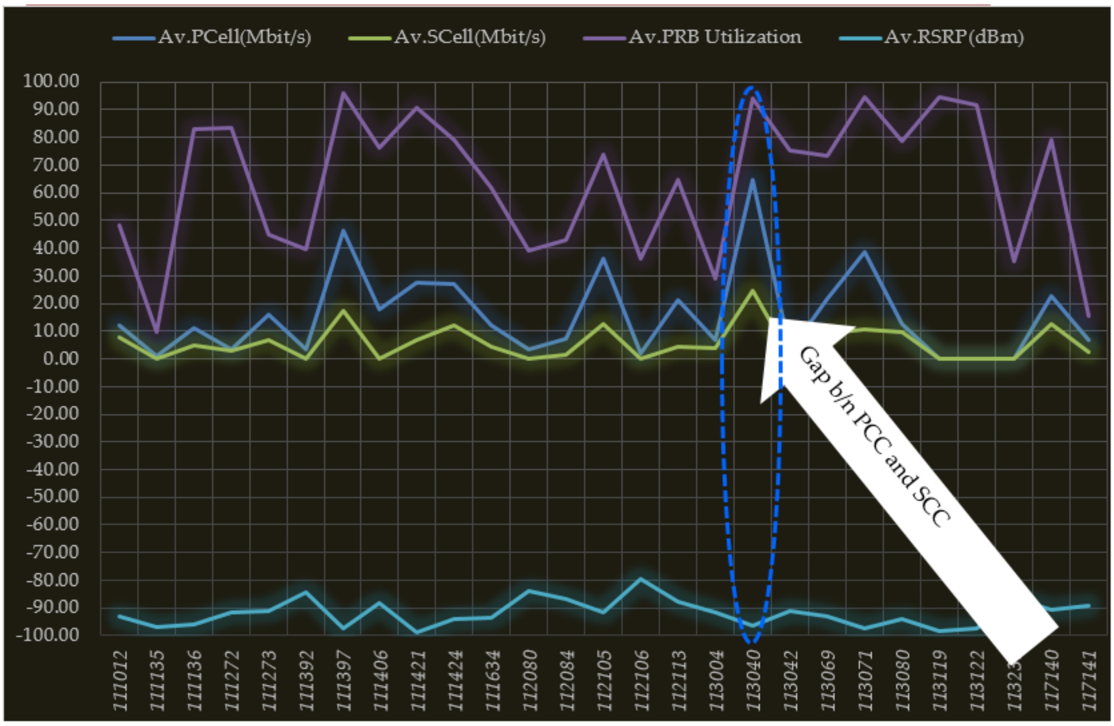


Figure 3.3: Impact of Tx power for traffic load between PCC vs SCC

### 3.3.2 Electrical Tilt Optimization Technique

Electrical tilt optimization is a technique used to improve the coverage and performance of a cellular network by adjusting the tilt angle of an antenna. The tilt angle is the angle between the antenna and the horizontal plane. A higher tilt angle means that the antenna is pointing more downwards. The 3GPP recommends using a higher tilt angle for lower frequencies than for higher frequencies. This is because lower frequencies have a longer wavelength, which means that they can diffract around obstacles more easily. This makes them more suitable for areas with high buildings or other obstacles [16].

The 3GPP recommends using a higher tilt angle for areas with high demand than for areas with low demand. This is because a higher tilt angle will help to focus the signal in the area where it is needed most. The best RF parameter to decide the electrical tilt initial value depends on the specific network conditions. This includes factors such as the frequency band, the terrain, and the distribution of users. The negative side and challenges of electrical tilt optimization include: It can be difficult to optimize the tilt angle for all areas of a network. This is because the network conditions can vary greatly from one area to another. It can be expensive to install and maintain tilt-capable antennas. This is because tilt-capable antennas are more complex than non-tilt-capable antennas. It can be difficult to coordinate the tilt angle of multiple antennas. This is because the tilt angle of each antenna can affect the performance of the other antennas.

In general, increasing the tilt angle and transmit power can improve the coverage and performance of a cellular network. An electrical tilt approach for improving the coverage and performance of cellular networks[30] [35] [36]. The approach involves tilting the antenna to modify the phasing signal, which is expected to improve the signal strength in areas with high demand without affecting the data. According to [30] argues that antenna tilt can be used to improve the coverage and interference characteristics of a network, and to provide load-balancing between nearby cells.In [36] proposes a method for optimizing the CA configuration to achieve equal transmit power and equal coverage regions for the various CCs.

### 3.3.3 Joint Tx power with Electrical Tilt Techniques

An optimization strategy is proposing in[35], that to increase the network's frequency bandwidth. This can improve the performance of CA by increasing the number of resources available to users. Efficient handling of multiple different CCs in addition to the enhanced bandwidth is discussed in [37].The paper proposes a method for optimizing the CA configuration to achieve equal transmit power and equal coverage regions for the various CCs. This can improve the load balance and throughput of the network.While the use of transmit power and antenna tilt to improve the coverage and performance of cellular networks is discussed in [38],[39]. The paper proposes a method for jointly optimizing the transmit power and antenna tilt to achieve the desired coverage and performance goals.

According to[30], [38], provides and evaluates various self-configuration algorithms for base station antenna tilt and transmit power. The goal is to improve the SINR measured at the UE. The paper shows that joint optimization of transmit power and antenna tilt can improve the performance of the network. Overall, these papers highlight the importance of transmit power and antenna tilt for improving the performance of cellular networks. However, more research is needed to develop and evaluate these techniques in different network conditions.

$$P = k \cdot I \cdot A \cdot G \cdot \cos(\theta) \cdot N \cdot n \cdot t \cdot p \tag{9}$$

where: $P$ is the received power in watts. $k$ is a constant that depends on the antenna gain and the free-space path loss. $I$ is the transmitted power in watts. $A$ is the antenna area in square meters. $G$ is the antenna gain in decibels (dB). $\theta$ is the tilt angle in radians. $N$ is the number of eNBs. $n$ is the number of cells per eNB. $t$ is the transmit power range in watts. $p$ is the electrical tilt range in radians. The equation shows that the received power is proportional to the transmitted power, the antenna gain, and the number of eNBs and cells. The received power is also inversely proportional to the antenna area, the tilt angle, the transmit power range, and the electrical tilt range [40]. The formula can be used to calculate the received power for a specific network configuration. The received power can then be used to evaluate the performance of the network in terms of load imbalance and throughput.

## 3.4 Algorithm for Carrier Aggregation Optimization

The performance of CA can be affected by a number of factors, such as the number of carriers aggregated, the transmit power of the base stations, and the distribution of users in the network. Algorithms can be used to find the best way to use CA to improve the performance of a cellular network. There are three main types of algorithms: heuristic, greedy, and optimal.

Heuristic algorithms are based on trial and error and can find good solutions quickly, but they may not always find the best solution. Greedy algorithms make locally optimal decisions at each step and can also find good solutions quickly, but they may not always find the best solution. Optimal algorithms find the best solution to the optimization problem, but they can be computationally expensive to run. The best type of algorithm to use depends on the specific network conditions and objectives. The choice of algorithm for CA optimization depends on a number of factors, such as the complexity of the optimization problem, the available computational resources, and the desired trade-off between performance and efficiency.

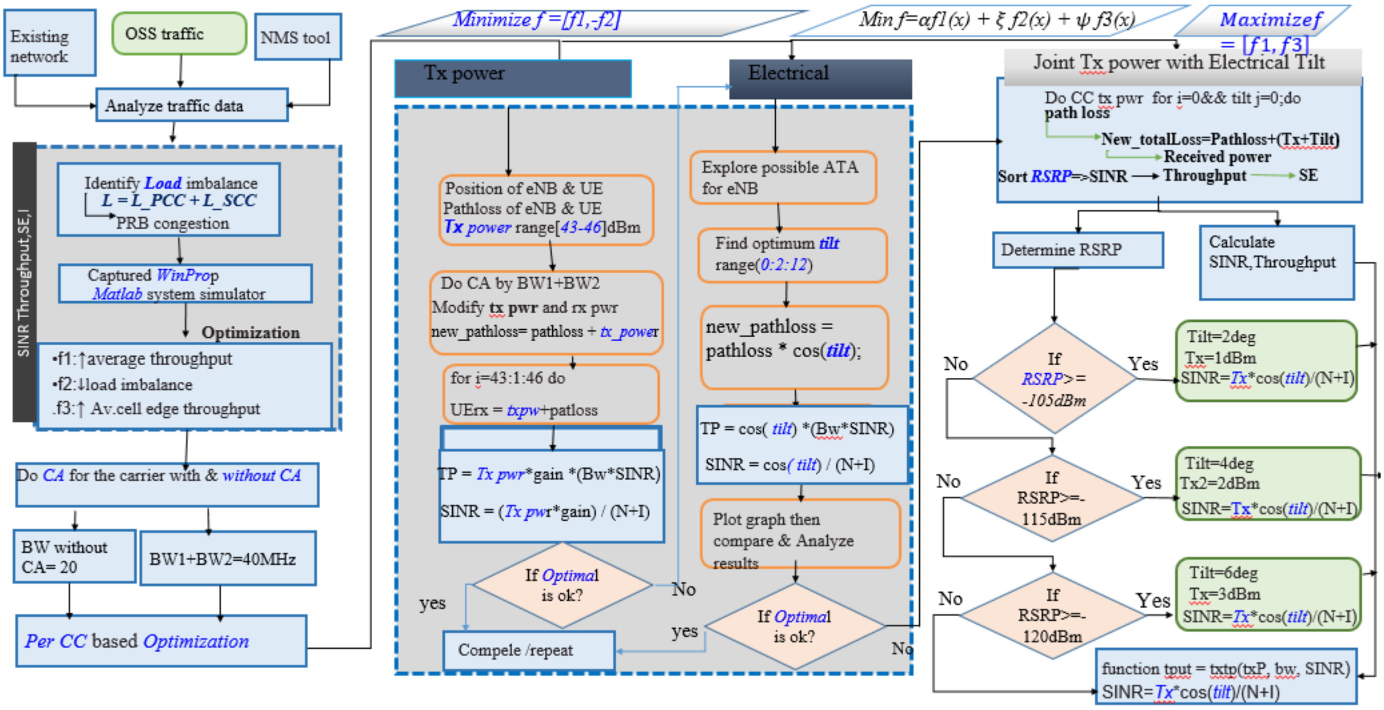


Figure 3.4: Modified carrier aggregation load balancing algorithm approach[9–11]

.

For example, if the optimization problem is complex and the available computational resources are limited, then a heuristic algorithm may be the best choice. If the optimization problem is less complex and the available computational resources are more abundant, then a greedy algorithm or an optimal algorithm may be a better choice. Overall, algorithms can be used to improve the performance of CA by taking into account the factors that affect the performance of CA. The choice of algorithm depends on a number of factors, such as the complexity of the optimization problem, the available computational resources, and the desired trade-off between performance and efficiency.

As[19],[41, 42] discusses the use of genetic algorithms for CA optimization. Genetic algorithms are a type of metaheuristic algorithm that can be used to find good solutions to optimization problems. They are particularly well-suited for CA optimization because they can handle discrete and continuous parameters, and they can produce multiple optimum solutions. Introduces the concept of multi-objective optimization for CA optimization. MOO problems involve optimizing multiple objectives, such as throughput and traffic load balance. This can be challenging, as the different objectives may conflict with each other.

The mentioned papers show that algorithms can be used to improve the performance of CA in terms of load balance. The choice of algorithm depends on the specific network requirements.

For example, if the network is heterogeneous, then a multi-objective optimization algorithm may be the best choice.

$f_1$ = Load imbalance

=> difference between PCC and SCC load traffic of eNBs in the LTE-A network for the study area

$f_2$ = Average throughput

=> target areas' total aggregate throughput

$f_3$ = Cell-edge performance

=> cell-edge areas user's performance These areas are the weakest places of the target area networ

It is possible to make a relation among the specified functions here above, that $f_3$ is a weighted sum of $f_2$. In other words, both metrics are linearly interrelated. So, maximizing balanced load is also maximizing average throughput for a given hotspot area. In order to find the best trade-off between the traffic load balance and average throughput, following the multi-objective optimization problem, is proposed as follows:

$$\begin{aligned} \text{minimize} \quad & f = [f_1, -f_2] \\ \text{subject to} \quad & Pk_1, Pk_2 \geq 1 \\ & \alpha_k^1, \alpha_k^2 \in [1, 12] \end{aligned} \tag{10}$$

Similarly, for the cell-edge performance which is 10th percentile of all pixel throughput, can be found by the proposed formulation as follows:

$$\begin{aligned} \text{minimize} \quad & f = [f_1, -f_3] \\ \text{subject to} \quad & Pk_1, Pk_2 \geq 1 \\ & \alpha_k^1, \alpha_k^2 \in [1, 12] \end{aligned} \tag{11}$$

The possibility to control the power and down-tilt angle in all cells and in both CC. When optimizing the power and angles in each cell, we can do it simultaneously in all cells (Jacobi method) or sequentially cell-by-cell (Gauss-Seidel method). The steps at which the power and angles have not been optimized because the aim was to demonstrate the concept. The aim of the optimization problem is to balance the load between PCC and SCC, where load is defined as the percentage of PRBs that are available in each CC [43].

Let us assume that $CC$ is the index of the cell, $TxCC_1$ and $TxCC_2$ is the Tx power of cell

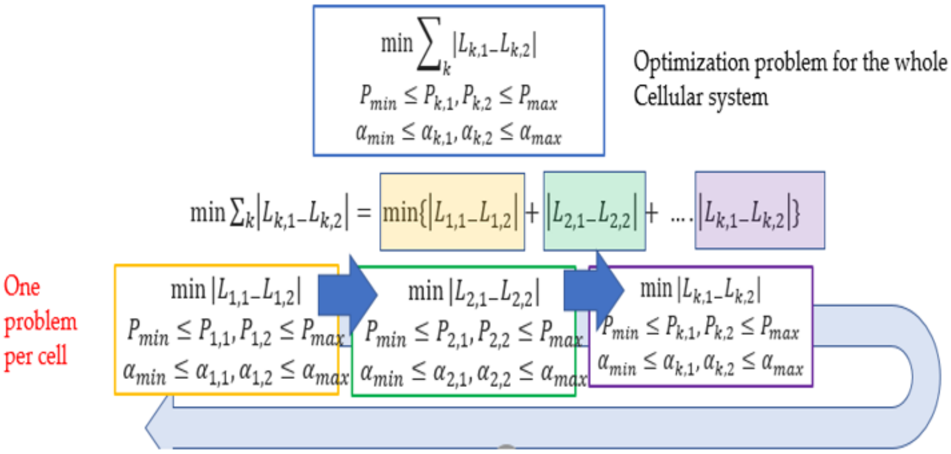


Figure 3.5: Optimization problem for both Tx power and tilt scenarios

.

$CC$ in PCC and SCC, respectively, and $\alpha_C C^1$ and $\alpha_C C^2$ are the down tilt angle in PCC and SCC of cell $CC$. The objective is to maximize a utility function.

$$U_{\text{sum}} = U1 + ... + UCC, \quad \text{where} \quad UCC = |L, CC1 - L, CC2| \tag{12}$$

$$min \sum_{CC=1}^{CC} |L, CC1 - L, CC2| Pmin \le PCCu \le Pmax$$

$$Amin \le \alpha_{CC1}, \alpha_{CC2}$$

$$min \sum_{CC=1}^{CC} |L, CC1 - L, CC2| Pmin \le PCCu \le Pmax$$

$$Amin \le \alpha_{CC,n}, \alpha_{CC2}$$

The algorithm that proposed is defines the combinations of powers and angles that could be tested, as an approximation of the optimization problem that was presented. The mathematical expression explains the problem that I want to solve. The algorithm that I proposed is a procedure (step-by-step) to approximate the value of the mathematical problem that was proposed.

$\text{LCC}_1 = f(Tx \text{ power}, Electrical \text{ down-tilt angle})$

$\text{LCC}_2 = f(Tx \text{ power}, Electrical \text{ down-tilt angle})$

where:$LCC_1$ is the load in the PCC $LCC_2$ is the load in the SCC $f$ is a function that maps the Tx power and Electrical down-tilt angle to the load in the PCC and SCC.The scheduled that defines if a new incoming user is allocated resource in the PCC or SCC can be represented by a rule.

Different factors that affect the Tx power and Electrical down-tilt angle affect the load in the PCC and SCC ("LCC,1" and "LCC,2"). For example, the scheduled that defines if a new incoming user is allocated resource in the PCC or SCC should have a pre-defined rule (e.g., always go to PCC until is fully loaded, and then start loading SCC; or allocate resources in the CC in which the SINR is best [44].

The three objective functions mentioned are indeed valid for multi-objective optimization. They are all conflicting, meaning that it is not possible to optimize all of them simultaneously. However, it is possible to find a solution that optimizes one or two of the objective functions, while still achieving a good value for the third objective function [42].

To do this, we can use a multi-objective optimization algorithm. There are a variety of different multi-objective optimization algorithms, each with its own advantages and disadvantages. Some of the most common algorithms include:

- **Weighted sum:**This algorithm assigns weights to each objective function, and then finds the solution that minimizes the weighted sum of the objective functions.
- **Pareto optimization:**This algorithm finds the set of solutions that are not dominated by any other solution. This set is called the Pareto front.
- **Genetic algorithms:** These algorithms use a process of natural selection to find solutions to optimization problems.
- **Particle swarm optimization:**These algorithms are inspired by the behavior of flocks of birds or schools of fish. The best algorithm to use will depend on the specific problem and the desired solution. However, all of the above algorithms can be used to find solutions that optimize the three objective functions in the cellular network problem.

## 3.5 Performance Metrics for Carrier Aggregation Optimizations

CA is a feature that allows a UE to connect to multiple LTE carriers simultaneously, as stated in [4]. This can boost the UE's data rate and expand its bandwidth by load balancing, resource sharing, joint frequency domain scheduling across several frequencies, and providing additional bandwidth, which leads to a higher peak data rate.

### 3.5.1 UE Capabilities

According to [45], [46], the eNodeB uses UE Category information to properly communicate with all of the UEs (user equipment) connected to it. The UE category defines the combined UL and DL performance capability of a UE. UE devices must be defined in the supported UE category so that the consumer is aware of the device's capabilities before using it. The UE category is a 3-bit number that indicates the maximum data rate that a UE can support in the UL and DL. The UE categories range from 1 to 19, with UE Category 1 being the lowest and UE Category 19 being the highest.

The UE category is determined by the UE's hardware and software capabilities. The UE's hardware capabilities include the number of antennas, the transmit power, and the receiver sensitivity. The UE's software capabilities include the operating system and the radio access technology (RAT) stack. (Average User Throughput) is the average user throughput is the sum of all active users within a cell area. Average user throughput is calculated as the difference between the number of active users' total transmitted bits and the total amount of time for transmission.

**Average Cell Throughput:**is the average aggregated throughput of all a cell's active and inactive users is used to determine the average cell throughput.When there are fewer users in the cell, more users will have a greater number of RBs with higher channel quality, which can increase the cell throughput. When there are more users in the cell, fewer users will have fewer RBs with good channel quality, which results in lower cell throughput.

**Cell edge User Throughput:** is in the cell area, users are evenly dispersed. The user is regarded as a cell-edge user if the distance between the associated eNB and the user exceeds the threshold value. In consideration of their low SINR and significant attenuation, these users' throughputs differ from those of cell-center users.

**Spectral efficiency:** CA can be used to improve the throughput of a network by increasing the spectral efficiency, reducing the overhead, and minimizing the latency. CA can aggregate carriers with different characteristics, carriers that are located in different geographical areas, and carriers that are used by different users. This can improve the efficiency, coverage, and fairness of resource allocation in the network.

CA can be used to improve the throughput of a network by increasing the spectral efficiency, reducing the overhead, and minimizing the latency. CA can aggregate carriers with different characteristics, carriers that are located in different geographical areas, and carriers that are used by different users.

# 4 Techniques for Load Balancing and Throughput Improvement

In this chapter, the thesis presents the proposed approach, system model, performance metrics, and optimization problems.

## 4.1 System Model

To make a system or process simpler and easier to understand, models are used. The model may be mathematical, logical, or physical, and it may depict the system at a certain instant in time or place. Modelling can be used to forecast the system's behavior and advance our understanding of the natural system.

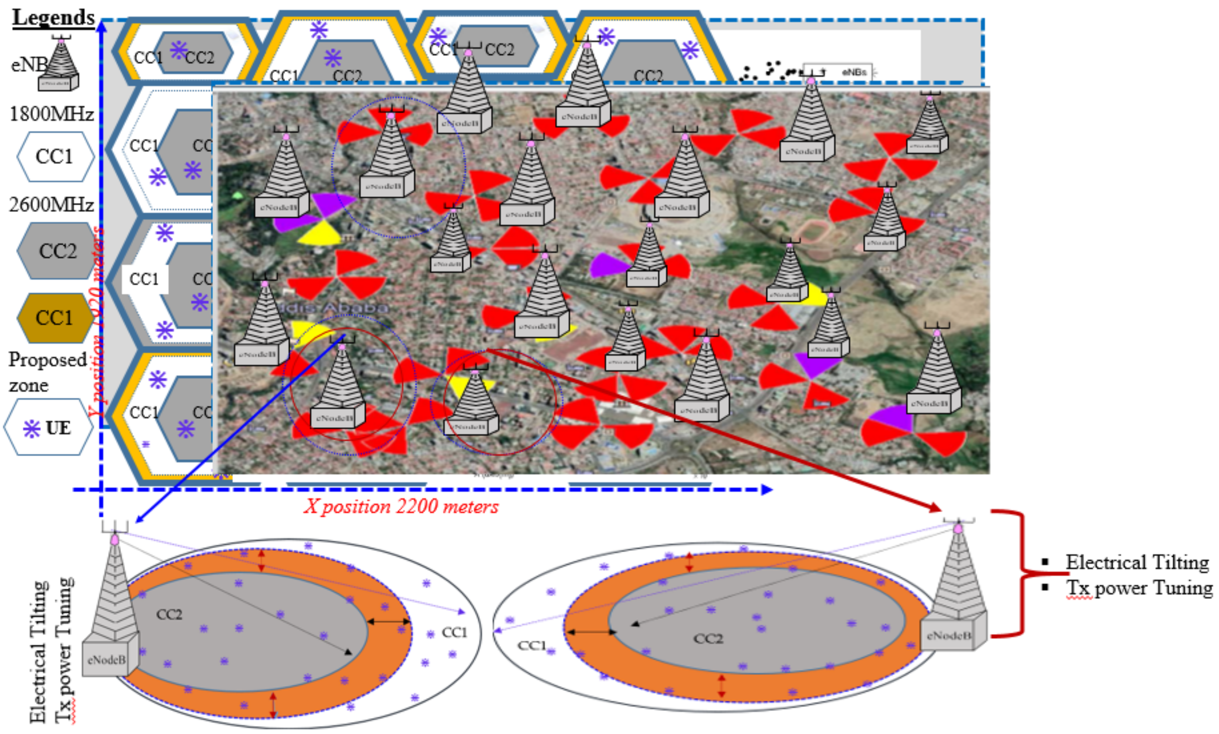


Figure 4.1: System model

.

## 4.2 Network Simulation Tools

A simulation study was conducted to evaluate the performance of macro sites in the downlink using WinProp, a propagation modeling tool. The system-level simulation was done in MATLAB. The antenna pattern for each tilt of the antenna in both planes was developed using the AMan software module, and the antenna patterns were then converted to a 3D pattern by extrapolating the patterns in both planes [39, 47].

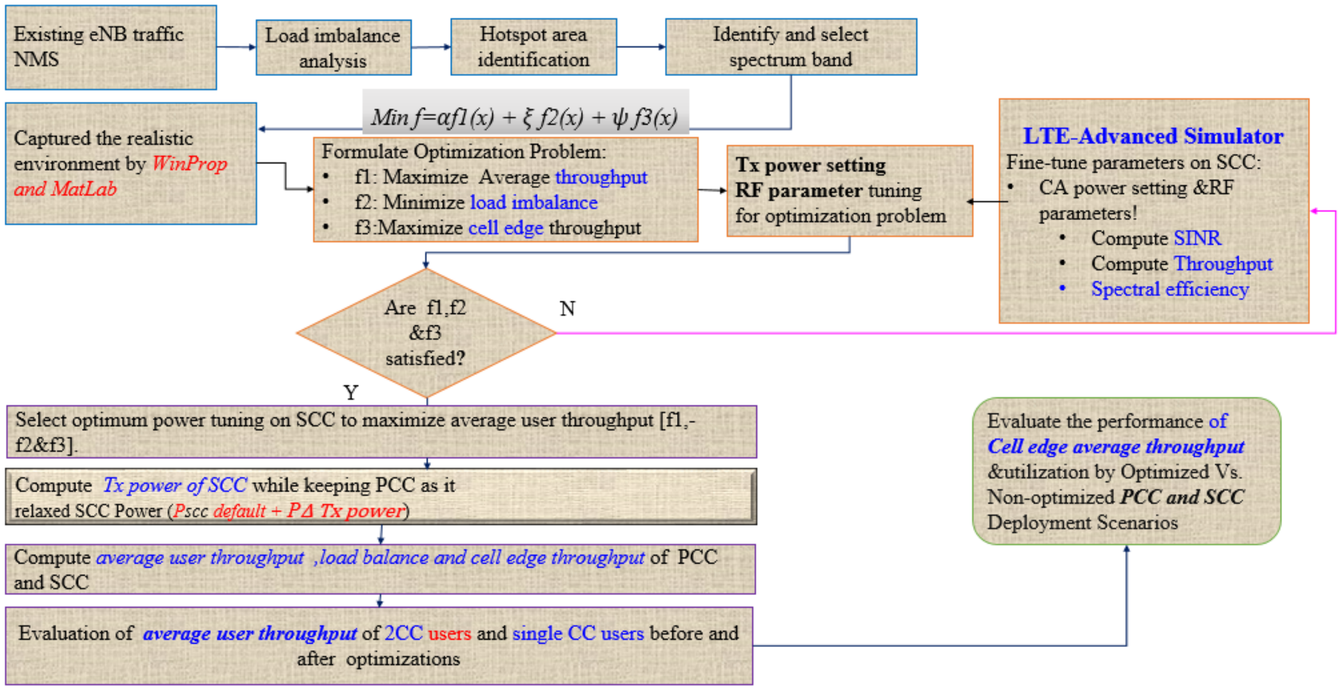


Figure 4.2: Proposed Approaches

.

WinProp offers a variety of propagation models for metropolitan environments, including empirical and ray optical models and the system-level simulation was done in MATLAB. It is a commercial propagation modeling tool that has been used in a variety of research activities. The antenna pattern for each tilt of the antenna in both the horizontal and vertical planes was developed using the AMan software module in this study. The antenna patterns were then converted to a 3D pattern by extrapolating the patterns in both planes and used by[4, 8, 10, 11, 39, 42].

## 4.3 Propagation Model

This study used the WinProp simulation tool to calculate the propagation of cellular signals in a real-world, dense urban LTE-A network in Addis Ababa. The propagation was calculated for both the 1800MHz and 2600MHz frequency bands, and the results were expressed as a multiplicative mechanism of different components [39]. The clutter map, which represents the type of terrain, was used to calculate the propagation for each pixel in the map at a precision of 5 meters.

### 4.3.1 Path Loss Model

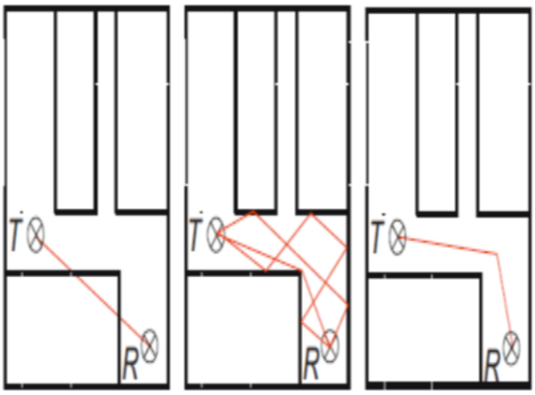
In this thesis study, the UDPM propagation model is employed, as in [48]. It is advised to gather empirical model speed and optical ray model correctness. In addition to the Ray Optical Mode, the prediction also depends on the vector database. It works by taking into account the usual path loss between the transmitter and receiver. This is calculated using the following equation:

$$P_L = 20\log\left(\frac{4\pi}{\lambda}\right) + 20\rho\log(d) + \sum_{i=0}^{n}\alpha(\phi, i) - \frac{1}{c}\sum_{k=0}^{c}\omega_k \tag{13}$$

Where $P_L$ is the path loss in dB of a path with a length of $d$ (meter). $\lambda$ (meter) is the wavelength. The factor $\rho$ 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 $\omega_k$ is called wave guiding factor.

### 4.3.2 Dominant Path Model

The Dominant Path Model does not rely on every small detail in the vector database, unlike ray-optics models. Instead, it emphasizes the important paths and avoids calculating numerous insignificant paths. This model allows for easy calibration using reference data [49]. The Dominant Path Model can be divided into two stages: identifying the main path and estimating the path loss along that path. There are 1082 eNBs serving the LTE-Advanced coverage area in Addis Ababa. For this study, we considered 22 eNBs (66 cells) that are located around the



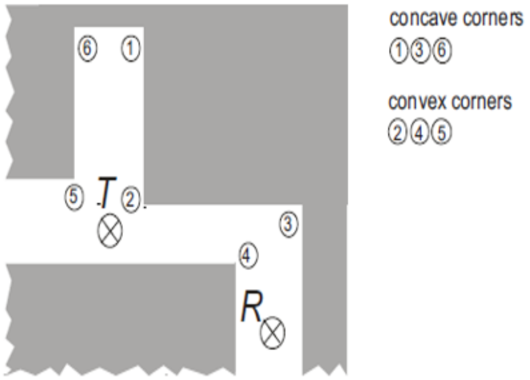


Figure 4.3: Empirical Models (left), Ray Tracing (center) and Dominant Path Model (right)[10, 50]

.

Figure 4.4: Buildings (gray), Transmitter (T), Receiver (R) and Different Types of Corners[10, 50]

.

Bole area. The site layout is shown in Figure 4.5.

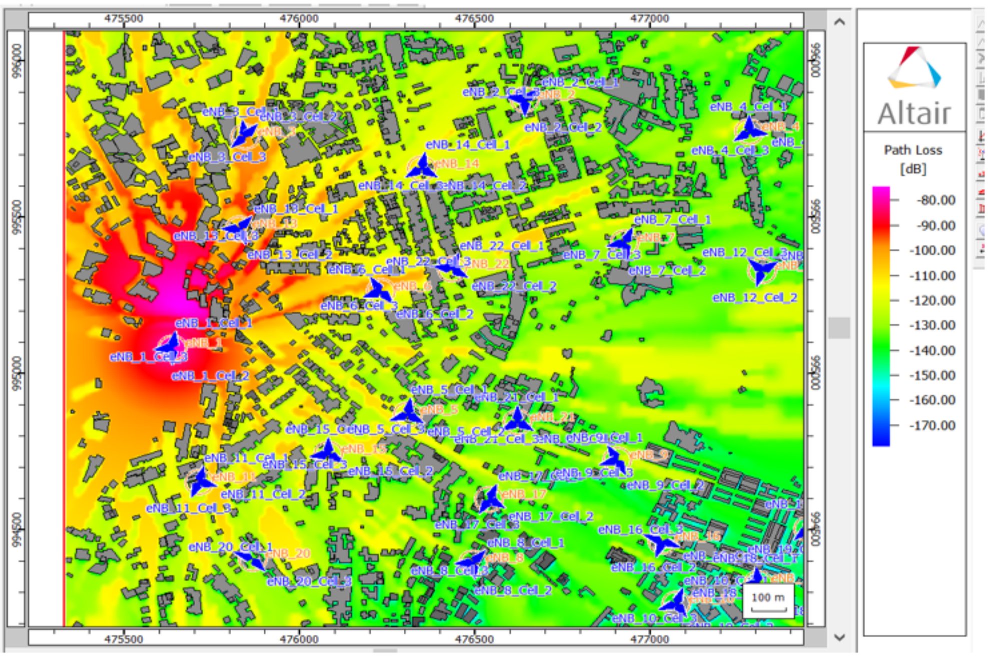


Figure 4.5: Path loss simulation result using WinProp tool

.

### 4.3.3 Shadow Fading

The obstructions along a signal path vary, resulting in varying signal attenuation. Shadow fading is used to model the path loss caused by these obstructions, which can significantly attenuate the signal power between a mobile user and an eNB. A lognormal distribution is frequently used to simulate the shadowing effect[24].

### 4.3.4 UE and eNB Locations

The number of users in the simulation was determined based on the capacity of Addis Ababa's LTE Advanced network. The number of active users was assumed to be 10 % of the total, or 361 users per cell. This gives a total of 23,826 users for the 66 cells. 80% of the users were clustered in macro cell clusters, with each cluster having a radius of 500 meters and containing 90 to 120 users per iteration (30 to 40 users per cell). The remaining users were distributed over the whole area in order to be accessed by the cells. Static system-level simulations were performed for 500 iterations to investigate network performance.

The distribution of users for the first iteration is shown in Figure 4.6, with the positions of the eNodeBs based on the information in Table 4.1.

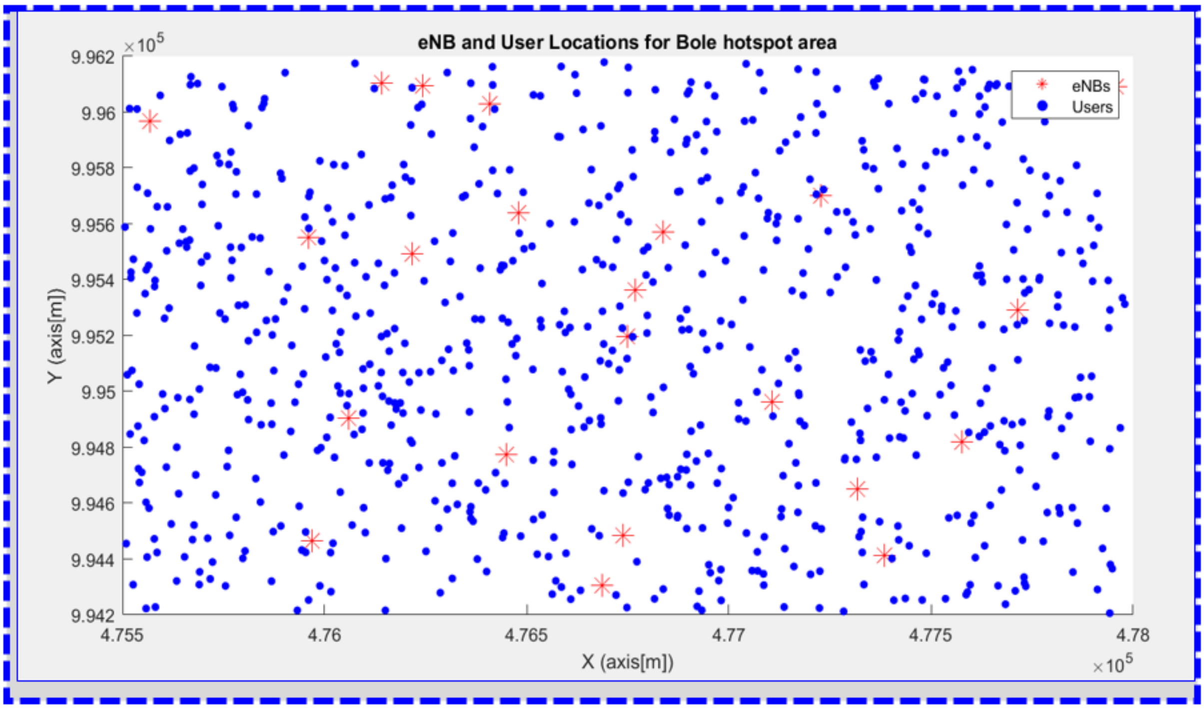


Figure 4.6: Users and eNB location

.

## 4.4 Carrier Component Selections

The papers discuss the importance of downlink radio resource management (RRM) in mobile networks. The authors of [26] propose the Circular Selection (CS) system, in which CCs are distributed to users in a circular fashion. To balance the load, they suggest using the CC coupling approach. The authors of [30] study the performance of two users in a three-cell network, where the users are both connected to the same primary cell (PCell) at 1800 MHz, but they are connected to different secondary cells (SCells) at 2600 MHz. They show that the throughput and number of resource blocks (RBs) that a user receives depends on its location relative to the cells.

## 4.5 Carrier Aggregation User Equipment Selection Criterias

CA UE selection criteria are the rules that are used to select the carriers that will be aggregated. The most common criteria are signal strength, channel quality, interference, and frequency band. In addition to these common criteria, CA UE selection criteria may also take into account the user's data usage profile, location, and battery level.

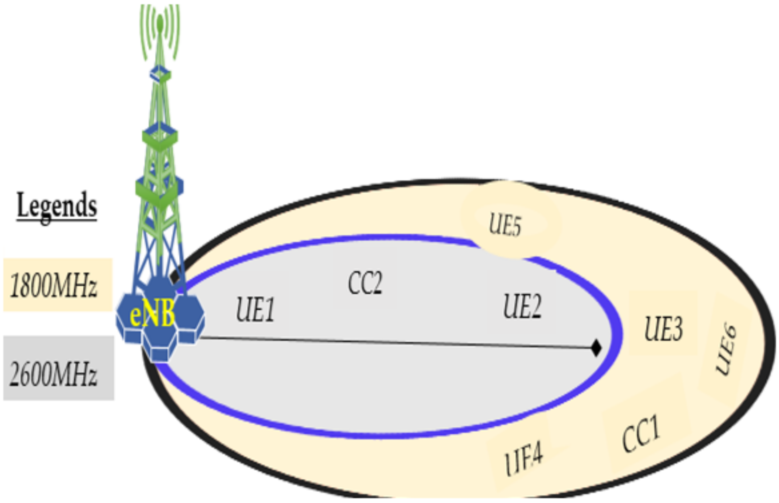


Figure 4.7: CC selection and user locations[28]

.

## 4.6 Resource Scheduling

The packet scheduler is responsible for distributing resources to users by ensures that all users have access to the resources they need and avoiding congestion. Three popular resource scheduling methods are Round Robin (RR), maximum rate, and proportional fair. RR scheduling is the simplest of these methods. It allocates resources to users in a round-robin fashion, without considering the user's channel conditions[51, 52].

## 4.7 Target Area Selection

The hotspot area is found at Bole sub city in Addis Ababa, which covers 4.4 Km2 (1.92Km 2.20Km) in 100m resolution. There are 22 eNBs with tri-sector, which gives 66 cells.

High traffic follow regions are found in the selected hotspot area by analysing LTE-Advanced traffic data from January to February 2023. Three categories of data are used to describe the information: high traffic (more than 360 GB/month), medium traffic (between 160 and 360 GB/month), and low traffic (less than 160 GB/month). Figure 4.1 shows that 55 cells (83.33 %) out of 66 cells have high data traffic. This indicates that only 16.67 % of all cells have medium data traffic. Table 4.1 shows the information of some of the selected sites and cells, such as the cell's height in meters, longitude and latitude in degrees, data usage in GB/month, azimuth in degrees, and down tilt information.

Figure 4.8: Geographic observation and Hotspot area eNB with user demand distribution[28]

.

Table 4.1: Congested Table

| eNB | Sector | Cell | Longitude | Latitude | Height | Azim | M-Tilt | E-Tilt | DL.Traffic(GB) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 38.7875 | 9.0091667 | 36 | 50 | 0 | 7 | 257.508 |
| | 2 | 2 | 38.7875 | 9.0091667 | 36 | 180 | 3 | 8 | 207.349 |
| | 3 | 3 | 38.7875 | 9.0091667 | 36 | 280 | 0 | 9 | 100.038 |
| 2 | 1 | 4 | 38.78024 | 9.00809 | 38 | 351 | 0 | 5 | 197.021 |
| | 2 | 5 | 38.78024 | 9.00809 | 38 | 40 | 0 | 9 | 262.445 |
| | 3 | 6 | 38.78024 | 9.00809 | 38 | 230 | 3 | 10 | 109.103 |
| 3 | 1 | 7 | 38.79333 | 9.00824 | 36 | 0 | 0 | 11 | 187.844 |
| | 2 | 8 | 38.79333 | 9.00824 | 36 | 100 | 0 | 11 | 245.397 |
| | 3 | 9 | 38.79333 | 9.00824 | 36 | 235 | 3 | 8 | 117.009 |

## 4.8 Performance Metrics

### 4.8.1 Signal-to-Interference Noise Ratio Performance Analysis

Using the UDPM included in the WinProp propagation modelling tool, the path loss is computed for the simulated region. The propagation 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.

$$\mathrm{SINR}^{i}_{k,n} = \frac{P^{n}_{i} G^{n}_{i,k}}{\sum_{j \neq i} P^{n}_{j} G^{n}_{j,k} + P_{\mathrm{TN}}} \tag{14}$$

where $P_{\mathrm{TN}}$ = thermal noise power on the considered RB (15)

$G^{n}_{i,k}$ = channel gain for $\mathrm{UE}_k$ supplied by $\mathrm{eNodeB}_i$ on $\mathrm{RB}_n$ (16)

$P^{n}_{i}$ = downlink transmission power allocated by the base $\mathrm{station}_i$ for the $\mathrm{RB}_n$ (17)

In logarithmic ways of explanation

$$\begin{aligned}
\log(SINR^{i}_{k,n}) &= \log(P^{n}_{i}) + \log(G^{n}_{i,k}) - \log(\sum_{j\neq i} P^{n}_{j} G^{n}_{j,k} + P_{\mathrm{TN}}) \\
&= \log(P^{n}_{i}) + \log(G^{n}_{i,k}) - \log(\sum_{j\neq i} P^{n}_{j} G^{n}_{j,k}) - \log(P_{\mathrm{TN}}) \\
&= \log(P^{n}_{i} G^{n}_{i,k}) - \log(\sum_{j\neq i} P^{n}_{j} G^{n}_{j,k}) - \log(P_{\mathrm{TN}})
\end{aligned}$$

$$SINR_{CA} = \frac{\sum_{i=1}^{N_{CC}} P_i g_i}{\sum_{i=1}^{N_{CC}} \sum_{j=1, j\neq i}^{N_{CC}} P_j g_j + N} \tag{18}$$

$$\begin{aligned}
Where: SINR_{CA} &= \text{signal-to-interference-plus-noise ratio (SINR)} \\
N_{CC} &= \text{number of carrier components} \\
P_i &= \text{power of the i-th carrier component} \\
g_i &= \text{gain of the i-th carrier component} \\
N &= \text{noise power}
\end{aligned}$$

The results of the UE throughput are determined by mapping the SINR results using a modified Shannon formula[9, 20].

## 4.9 Spectral Efficiency Performance Analysis

Data transmission capacity over a specific bandwidth is known as spectral efficiency. A method for increasing spectral efficiency is CA, which enables the utilisation of many frequency bands simultaneously. The formula for calculating spectral efficiency in CA is:

$$\eta_s = \frac{B \log_2(1 + \mathrm{SINR})}{W}$$

where:

$\eta_s$ is the spectral efficiency

$B$ is the bandwidth

SINR is the signal-to-interference-plus-noise ratio

$W$ is the channel width

In general, the quantity of aggregated carriers leads to a rise in the spectral efficiency of CA. The channel conditions, the kind of modulation, and the coding scheme employed are some other variables that might impact spectral efficiency.

## 4.10 Throughput Performance Analysis

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[13][19].

$$TP = \begin{cases} min(S_{\max}, BW_{\text{eff}} \log_2(1 + \frac{\text{SINR}}{\text{SINR}_{\text{eff}}}) N_{\text{RB}} BW_{\text{PRB}}), & \text{if SINR} \geq \text{SINR}_{\min} \\ 0, & \text{if SINR} < \text{SINR}_{\min} \end{cases} \tag{19}$$

$$\text{where} \quad S_{\max} = \text{maximum achievable spectral efficiency per PRB} \tag{20}$$

$$\text{SINR}_{\min} = \text{minimum required SINR} \tag{21}$$

$$BW_{\text{eff}} = \text{bandwidth efficiency} \tag{22}$$

$$\text{SINR}_{\text{eff}} = \text{SINR implementation efficiency} \tag{23}$$

$$ThroughputPCC = N_{\text{RB}} \cdot TotalRB \cdot effBW \cdot \log_2(1 + \frac{\text{SINR}_{\text{PCC}}}{\text{SINR}}) \tag{24}$$

The SINR to throughput mapping parameters for 1x2 MIMO configurations are based on link-level simulations done in paper[19], and also used in paper[13], as presented in Table 4.2 as shown below.

Table 4.2: Assumptions for Parameters

| **Parameter** | **Assumption** |
|---|---|
| SINRmin (dB) | -10 |
| BWeff | 0.62 |
| SINReff | 1.8 |
| Smax (b/s/Hz) | 4.4 |

## 4.11 Multi-Objectives Optimization Problem Formulation

### 4.11.1 Traffic Load Balance Optimization Problems

MNOs optimize their networks to get the highest throughput possible within service areas. This involves locating eNBs in the most advantageous locations and selecting optimization techniques to balance the load on each eNB carrier, increase throughput, and provide coverage in the service region.

In multi-objective optimization, there is a trade-off between different metrics, such as throughput and traffic load balance. This means that we cannot improve one metric without degrading the other. In LTE-Advanced mobile networks, the three key objectives of network optimization problems are raising aggregate average throughput, balancing load, and improving cell edge performance. Two important optimization problems are raising average system throughput and minimizing carrier load imbalances. The mathematical formulation of this problem would be:

$$\begin{aligned} \text{minimize} \quad & \sum_{n=1}^{N} \text{traffic load on carrier } n && (25) \\ \text{subject to} \quad & \sum_{n=1}^{N} \text{number of users on PCC} = \sum_{n=1}^{N} \text{number of users on SCC} && (26) \\ & \text{traffic load on each carrier} < \text{capacity of each carrier} && (27) \end{aligned}$$

The decision variables are the number of users on each carrier and the traffic load on each carrier. The constraints are that the number of users on each carrier must be equal and the traffic load on each carrier must be less than the carrier's capacity.

### 4.11.2 Average Throughput Optimization Problem

$$\begin{aligned} \text{Minimize} \quad & f = [f_1, -f_2] && (28) \\ \text{Similarly, for the cell-edge performance} \quad & f = [f_1, -f_3] && (29) \\ \text{where} \quad & f_1 = \text{traffic load balance} && (30) \\ & f_2 = \text{average throughput} && (31) \\ & f_3 = \text{cell-edge performance} && (32) \end{aligned}$$

$$r_i = \sum_{n=1}^{N} R_n \tag{33}$$

$$R_n = \eta_i N_{\text{RB}} \log_2 \left(1 + \frac{P_{\text{tx}} - \alpha_n L_n}{I_n}\right) \tag{34}$$

$$R_n = \eta_{\text{BW}} \eta_{\text{RB}} N_{\text{RB}} \log_2 \left(1 + \frac{P_{\text{tx}} - \alpha_n L_n}{I_n}\right) \tag{35}$$

$$\text{Maximize} \quad \frac{\sum_i R_i}{\sum_i N_i} \tag{36}$$

$$\text{subject to} \quad \sum_i N_{\text{PCC}} = \sum_i N_{\text{SCC}} \tag{37}$$

$$\text{traffic load on each carrier } < \text{capacity of each carrier} \tag{38}$$

In this case, the decision variables would be the number of users assigned to each carrier, and the traffic load on each carrier. The constraints would be that the total number of users on the PCC and SCC must be equal, and the traffic load on each carrier must be less than the capacity of the carrier.

### 4.11.3 Cell Edge Throughput Optimization Problem

The objective of this problem is to maximize the throughput of users at the edge of the cell, while ensuring that the network is stable and that all users experience a minimum level of throughput.

$$\text{Maximize} \quad \sum_i R_{\text{cell-edge, i}} \tag{39}$$

$$\text{subject to} \quad \sum_i N_{\text{PCC}} = \sum_i N_{\text{SCC}} \tag{40}$$

$$\text{traffic load on each carrier } < \text{capacity of each carrier} \tag{41}$$

$$R_{\text{cell-edge, i}} > \text{threshold} \tag{42}$$

$$P_{\text{rx},1} - P_{\text{rx},2} < \text{Rx Power Threshold or } P_{\text{rx},1} - P_{\text{rx},3} < \text{Rx Power Threshold} \tag{43}$$

where $R_{\text{cell-edge, i}}$ is the cell edge throughput of user $i$. $N_{\text{PCC}}$ is the number of users assigned to the PCC carrier. $N_{\text{SCC}}$ is the number of users assigned to the SCC carrier. threshold is the minimum required cell edge throughput. $P_{\text{rx},1}$, $P_{\text{rx},2}$, and $P_{\text{rx},3}$ are the first, second, and third strongest received signal powers at user $i$.

The cost function is defined as a weighted sum of the objective functions:

These optimization objective functions and cost function can be used to develop load balancing algorithms that adjust the Tx power and electrical tilt of the cells to balance the load between the PCC and SCC carrier aggregation cells.

### 4.11.4 Measurement of Calculating Load Balance Factors(Fi)

The traffic load factor is the ratio of the volume of traffic carried by a component carrier to the combined volume carried by all aggregated carriers. It can be used to assign resources to the various component carriers and monitor how well the carrier aggregation system is working. A problem, such as PCC congestion, could arise if the traffic load factors start to change.

$$\text{Traffic load factor} = \frac{\text{Traffic on PCC}}{\text{Total traffic on PCC and SCC}} \tag{44}$$

$$\text{High Traffic}_{\text{PCC}} = \frac{\sum_i C_i}{\max\limits_i \sum_i C_i} \geq 70\% \tag{45}$$

$$\text{Low Traffic}_{\text{PCC}} = \frac{\sum_i C_i}{\max\limits_i \sum_i C_i} \leq 70\% \tag{46}$$

where: $C_i$ is the traffic on carrier $i$. The total traffic on PCC and SCC is the sum of the traffic on the PCC and SCC carriers.

Equation (44-46) defines the traffic load factor, which is a measure of how much traffic is on a particular carrier relative to the total traffic on both carriers and it defines the thresholds for high and low traffic, respectively. A carrier is considered to be under congested if the traffic load factor is less than 70 %, and it is considered to be over congested if the traffic load factor is greater than 70 %.

## 4.12 Deployment Scenario, Parameters, and Assumptions

To investigate the performance of different topologies, 792 users were randomly dropped 3000 times in different 5x5 m2 pixels in the service area (4.4 km2) following the uniform or no uniform spatial traffic distribution. This means that 3000 snapshots were used in the static system level simulator to increase the statistical quality of the study. The target is to solve the LTE-Advanced network low throughput challenge by optimizing the existing network using antenna parameters and electrical tilt or by adding a new number of CCs.

Simulations are based on ethio telecom 's current configuration as well as commonly used 3GPP parameters. The antenna height, azimuth and down-tilt configuration are based on Table 4.1. The parameters and assumptions used in a simulation study of an LTE-A network

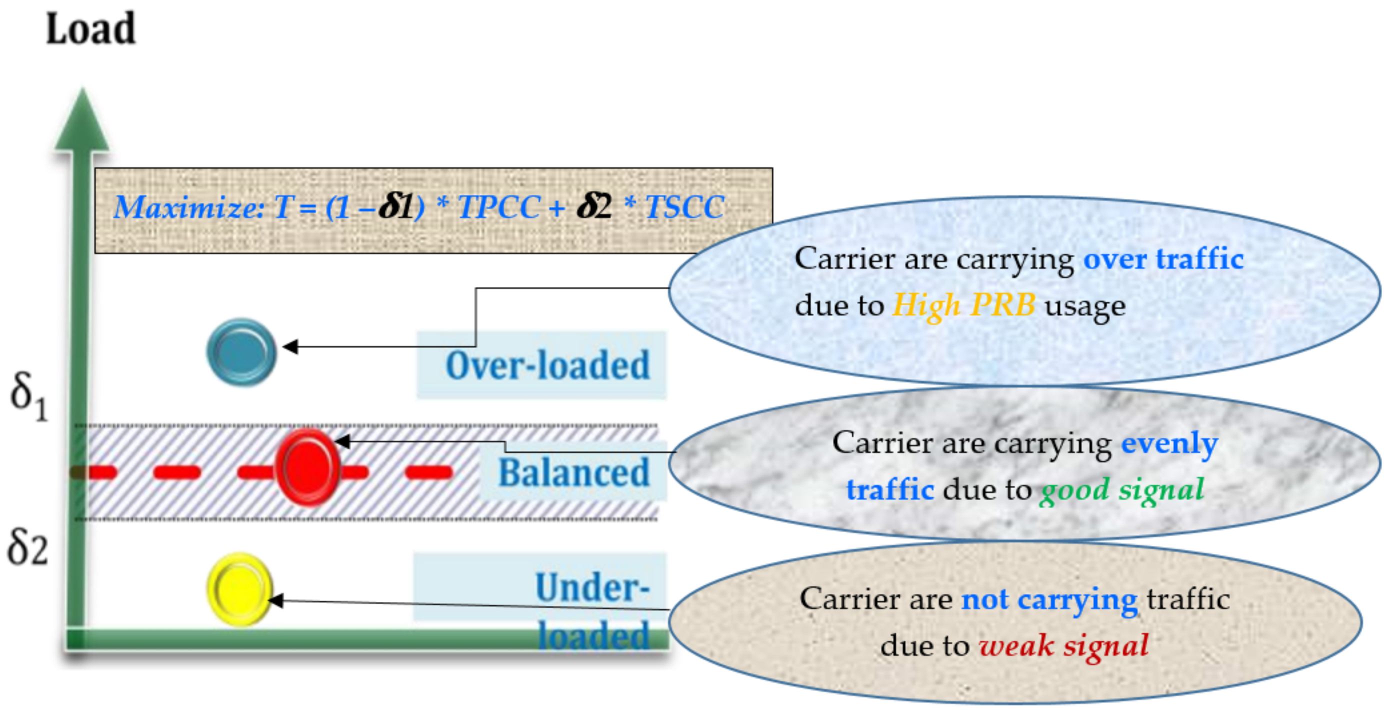


Figure 4.9: Load balance factor thresholds distribution

.

in Addis Ababa. The study considered two carrier frequencies (1800 MHz and 2600 MHz), two bandwidths (20 MHz and 40 MHz), one and two component carriers, a resource block size of 180 kHz, transmit power of 43-46 dBm or 20-40 watts, Kathrein 742212 antenna patterns, round robin resource scheduling, 5m resolution of prediction, SINRmin of -10 dB, BWeff and SINReff of 0.6 and 1.8 respectively, 8 dB shadow fading for eNBs, realistic ethio telecom configuration scenario for antenna height, azimuth and tilt, 792 users at a height of 1.5 m, eNodeBs antenna gain of 18 dBi, UE antenna gain of 0 dBi, UE noise figure of 9 dB, long-normal fade shadow of 6 dB, and thermal noise density of -174 dBm/Hz.

### 4.12.1 Techniques for Load Balancing

To do the optimization problems which are stated earlier, the following Techniques are performed.

### 4.12.2 TX Power Optimization Technique

CA can improve the data throughput and coverage of the device. However, it can also lead to load imbalance issues, where some cells are overloaded with traffic while others are underutilized. There are two main ways to address load imbalance issues in carrier aggregation networks: transmit power tuning and dynamic load balancing. Transmit power tuning involves adjusting the transmit power of the carrier components in each cell. Dynamic load balancing algorithms can be used to distribute the traffic more evenly across the CCs.

Table 4.3: Maximum Electrical Tilt for different frequencies

| **Frequency (MHz)** | **3GPP** | **ITU** |
|---|---|---|
| 1800 | 0.01 W (10 dBm) | 0.01 W (10 dBm) |
| 2600 | 0.005 W (7 dBm) | 0.003 W (6 dBm) |
| 3500 | 0.003 W (6 dBm) | 0.002 W (5 dBm) |
| 4500 | 0.002 W (5 dBm) | 0.001 W (4 dBm) |
| 5000 | 0.001 W (4 dBm) | 0.001 W (4 dBm) |
| 6000 | 0.001 W (4 dBm) | 0.001 W (4 dBm) |
| 7000 | 0.001 W (4 dBm) | 0.001 W (4 dBm) |

For 2600 MHz 0.005 W (7 dBm) 0.003 W (6 dBm). The 3GPP and ITU standards for TX power increment interval thresholds can be used to improve the performance of a network by spacing the power levels sufficiently apart to avoid interference between different users. In the case of 2CCs operating 1800 MHz (PCC) in high loaded traffic and 2600 MHz lightly loaded (SCC), the TX power increment interval threshold for the PCC will be 0.01 W (10 dBm) and for the SCC can be lower, such as 0.003 W (6 dBm).

### 4.12.3 Electrical Tilt Optimization Technique

The 3GPP standards recommend that the tilt angle of an antenna be adjusted to maximize the coverage area. The tilt angle can be adjusted from 0 degrees to 12 degrees, depending on the desired coverage area. A study found that most of the cells (59.1 %) had the same electrical tilt of 6 degrees, while about 40.1 % of the cells had the same electrical tilt of 8 degrees. The remaining cells had different tilt values.

The most common tilt angle in the study was 6 degrees, which is likely because it provides a good balance between coverage area and interference. The 8-degree tilt angle is also common, but it may not be ideal for all situations. The remaining cells have different tilt values, which may be due to specific factors such as the terrain or the distribution of users.

### 4.12.4 Joint Tx power with Electrical Tilt Optimization Techniques

The transmit power is low and the electrical tilt is high. This means that the antenna is tilted towards the ground, which reduces the coverage area but increases the signal strength in the area that is covered. This combination is useful for areas where there are a lot of obstacles, such as

buildings or trees, that can block the signal.

**f1 (maximize average throughput):** This objective aims to improve the average throughput of all users in the network. f2 (minimize load imbalance): This objective aims to reduce the difference in throughput between users in different parts of the network.

**f3 (maximize cell edge throughput):** This objective aims to improve the throughput of users at the cell edge, where the signal strength is weakest. The throughput simulation result summary can be used to evaluate the performance of the three load balance optimization techniques with respect to these three objectives.

f1 (maximize average throughput) The Tx Power with electrical tilt technique consistently outperforms the other two techniques in all three scenarios. This means that it can improve the average throughput of all users in the network.

**f2 (minimize load imbalance):** The Tx Power with electrical tilt technique also provides the greatest throughput improvement in the cell edge case, where the signal strength is the weakest. This means that it can help to reduce the difference in throughput between users in different parts of the network.

**f3 (maximize cell edge throughput):** The Tx Power with electrical tilt technique provides a moderate throughput improvement in all three scenarios. This means that it can help to improve the throughput of users at the cell edge, but it may not be the best option if this is the only objective.

Overall, the Tx Power with electrical tilt technique is a good choice for optimizing the throughput in LTE-Advanced networks with respect to all three objectives. It can improve the average throughput, minimize load imbalance, and maximize cell edge throughput.

The Tx Power with Electrical Tilt technique is the best choice for optimizing the throughput in LTE-Advanced networks if all three objectives are important. However, if only one objective is important, then the best choice may be different. For example, if f2 (minimize load imbalance) is the only objective, then the Electrical Tilt technique may be the best choice.

The Tx Power with Electrical Tilt technique can be used to achieve all three objectives. However, the relative importance of each objective may vary depending on the specific network conditions. For example, if the network is heavily loaded, then f2 (minimize load imbalance) may be more important than f3 (maximize cell edge throughput). One way to combine these objectives is to use a weighted sum approach. In this approach, each objective is assigned a weight, and the objective function is to minimize the weighted sum of the objective functions. For example, the objective function could be:

min f1(x) + w2 f2(x) + w3 f3(x)

where x is the vector of decision variables, w1, w2, and w3 are the weights, and f1, f2, and f3 are the objective functions.

The weights can be chosen to reflect the relative importance of each objective.Another way to combine these objectives is to use a multi-objective optimization algorithm. This type of algorithm searches for a solution that optimizes all of the objectives simultaneously [48, 53].

There are many different multi-objective optimization algorithms available, and the choice of algorithm will depend on the specific problem. The Tx Power with Electrical Tilt technique is a good starting point for optimizing the throughput in LTE-Advanced networks. However, it is important to consider the specific network conditions and objectives when choosing a load balance optimization technique.

# 5 Simulation Results and Discussions

Using the simulator tools created to apply the models mentioned in the previous chapter, this chapter reviews the simulation results and evaluates the suggested scheme. Accurate digital terrain data was collected, network simulation tools were found for the system's implementation, the configuration procedure on the eNB and network levels was then used to determine the coordinated sectors in each cluster, and finally, the simulation results for the selected LTE-A system were acquired. An analysis of some of the simulation results showed that the simulator was constructed using WinProp and MatLab simulation tools.

## 5.1 Simulation Results and Discussions

The effectiveness of CA throughput optimisation approaches on system throughput, SINR, and SE performance is assessed. In order to understand the benefits of load balancing using per-CC-based CA optimisation approaches in LTE-Advanced networks, three different optimisation techniques (deployment scenarios) are examined.

## 5.2 Simulation Scenarios

Three scenarios are proposed and presented in Table 5.1 for evaluating the impacts of transmit (Tx) power and electrical tilting implementation on carrier CA throughput optimisation between PCC and SCC on system throughput performance. The scenarios from previous chapters are used to guide the simulation. The situation of Addis Ababa at this time is reflected in the first simulated scenario.

Table 5.1: Simulation Scenarios and mechanisms

| Scenarios | Mechanisms | Metrics |
|---|---|---|
| 1 | Tx power technique only | SINR, Throughput, Spectral efficiency |
| 2 | Electrical Tilt Technique | No tilted (0 deg), 2 deg tilted, 5 deg tilted |
| 3 | Electrical Tilt with High Tx Power | SINR, Throughput, Spectral efficiency |

## 5.3 Load Balance Simulation Results

### 5.3.1 Signal-to-Interference Noise Ratio Performance Analysis Results

**Impact of Transmit Power Technique on Load Balance:** This is comparing the load balance of the existing network to the load balance of tuned networks with the impact of Tx power. The cumulative distribution function (CDF) in Figure 5.1 shows the SINR results for

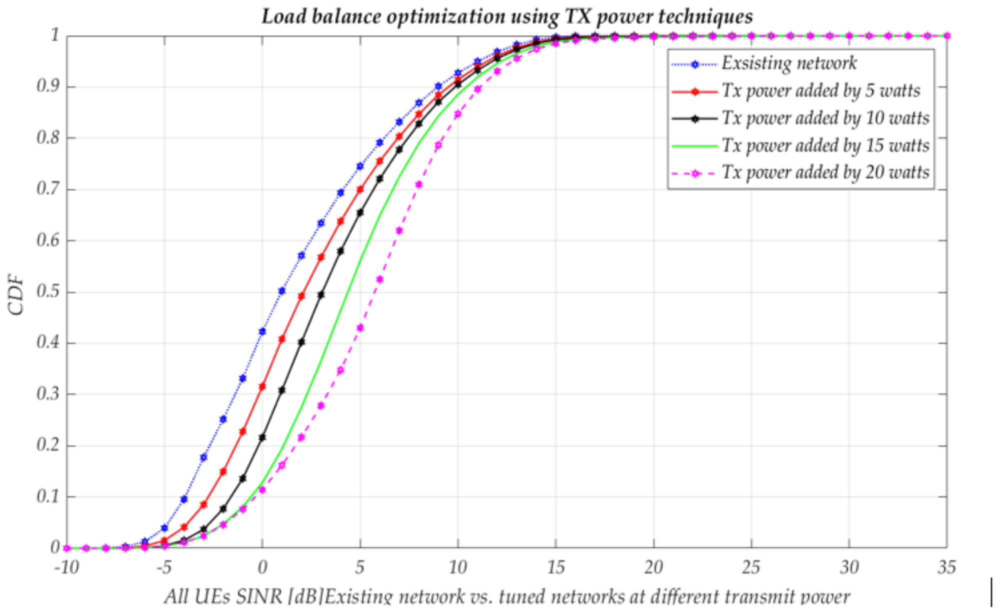


Figure 5.1: Impacts of Tx power technique on CA load balance optimization on different transmit powers

.

the Tx power optimization techniques. The figure shows that the SINR for the Tx power is evaluated for different iterations, starting from 0 watts (existing network), 1 watt, 2 watts, and 20 watts. This is done by considering some predefined power thresholds, which is similar to the approach used in [4][11]. However, in order to save computation time and complexity, only

Table 5.2: SINR improvement with different transmit power

| | | | | | | |
|---|---|---|---|---|---|---|
| 10th%-ile | -3.90dB | -4.3dB | -1.8dB | 0.0dB | 0.2dB | ↑4.12dB |
| 50th%-ile | 0.32dB | 1.04dB | 2.6dB | 3.9dB | 4.11dB | ↑3.79dB |
| 90th%-ile | 9.35dB | 10.5dB | 11.2dB | 11.6dB | 11.73dB | ↑2.38dB |

the minimum Tx power, average Tx power, and maximum Tx power (i.e., 0 watts, 5 watts, 10 watts, 15 watts, and 20 watts) are considered.The Tx power for different threshold is displayed below. According to figure 5.1 and figure 5.2 the results of this study show that increasing the Tx power can significantly improve the SINR in CA mobile networks. The improvement is most pronounced at the 10th percentile, where the SINR is increased by 4.12 dB. This means that even the weakest users are able to achieve a better SINR with the proposed technique. The improvement is also significant at the 50th percentile, where the SINR is increased by 1.95 dB. This means that the majority of users are able to achieve a better SINR with the proposed technique. The improvement is less pronounced at the 90th percentile, where the SINR is increased by 1.04 dB. This is because the users at the 90th percentile are already receiving a good SINR with the existing technique.

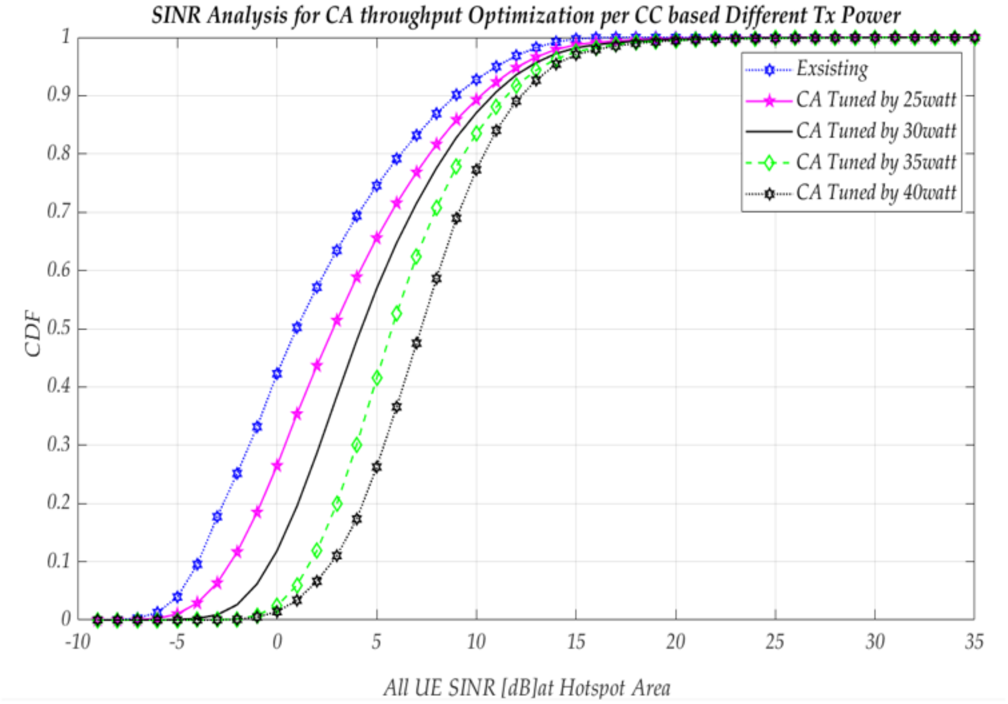


Figure 5.2: Different Tx power range for SINR user CDF

.

The results of this study are consistent with the results of previous studies. These studies have shown that increasing the Tx power is an effective way to improve the SINR in wireless networks. However, this study is the first to show that the improvement is most pronounced at the 10th percentile. This suggests that the proposed technique is especially beneficial for weak users. The results of this study have important implications for the design of CA mobile networks. Network designers can use these results to optimize the Tx power of their networks to improve the SINR for all users.

The CDF versus SINR from Table 5.2 shows that at 10 %-ile and 90 % -ile, the SINR values are less than -3dB and 10dB for existing network and 4.12dB and 2.38dB improvement is obtained for the proposed scenario respectively.

**Impacts of Electrical Tilt Techniques on Load Balance:** Electrical tilt optimization technique is lower than that of the Tx power optimization technique and the combined Tx power and electrical tilt optimization techniques. This is because the Electrical tilt optimization technique does not take into account the effects of the antenna tilt, which can significantly improve the SINR.

Tuned networks versus existing networks at various transmit powers. Therefore, it can be seen that TX power approaches are optimised and have improved pixel SINR. It is also clear that, compared to the present network scenario, the CDF of all pixel SINR values has increased in the Tx power technique. From this point of view, it is clear that the user experienced an improvement and that the load balance-based optimisation strategy improves system performance more effectively.

The result obtained due to Tx power optimization technique yields a value of twice that of the existing SINR value as we show in figure below. In the current (existing )network, the 90 % and 80 % users can get 9.75dB and 6.56dB SINR values respectively. In the optimized tx power technique, the 90 % and 80 % users can get 15.45dB and 13.56dB respectively.

The results of the simulation in figure 5.3 show that the optimized CA achievable SINR is significantly higher than the existing network CA achievable SINR. This is especially true for cell edge users, who experience the greatest improvement. The results also show that the optimized CA achievable SINR is close to the 3GPP standard metrics, which is an important consideration for the deployment of the optimized CA technique.

In summary, the results of the simulation show that the optimized CA technique can significantly improve the SINR in wireless networks. This improvement is most pronounced for cell edge users, who are the most likely to experience poor SINR. The results also show that the optimized CA technique is in line with the 3GPP standard metrics, which is an important consideration for its deployment. Performing all and every iteration for Tx power adjustment is too difficult from computation time and analysis perspectives. So to handle this issue, it is

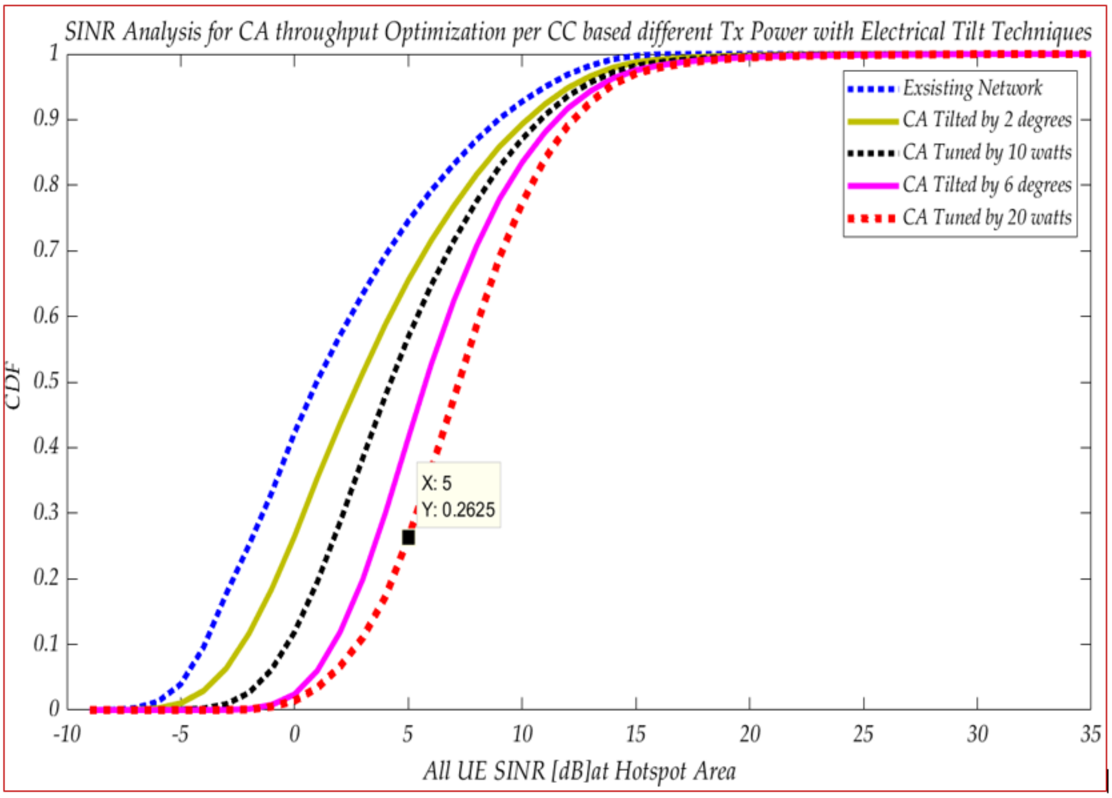


Figure 5.3: Impacts of Tx power and Electrical tilts on SINR user CDF at different thresholds

.

better to define some threshold values which will be added or subtracted depend of CC power setting profile (i.e. 0watt,1watt,5watts,10watts, 15watts,and 20watts). Since SINR is one of the main performance indicator in this work. Hence, compare the SINR value of the existing network and the new optimized Scenarios. Adjust/modify the Tx power of CC power settings again and again up to n iterations until acceptable improvement in SINR found.

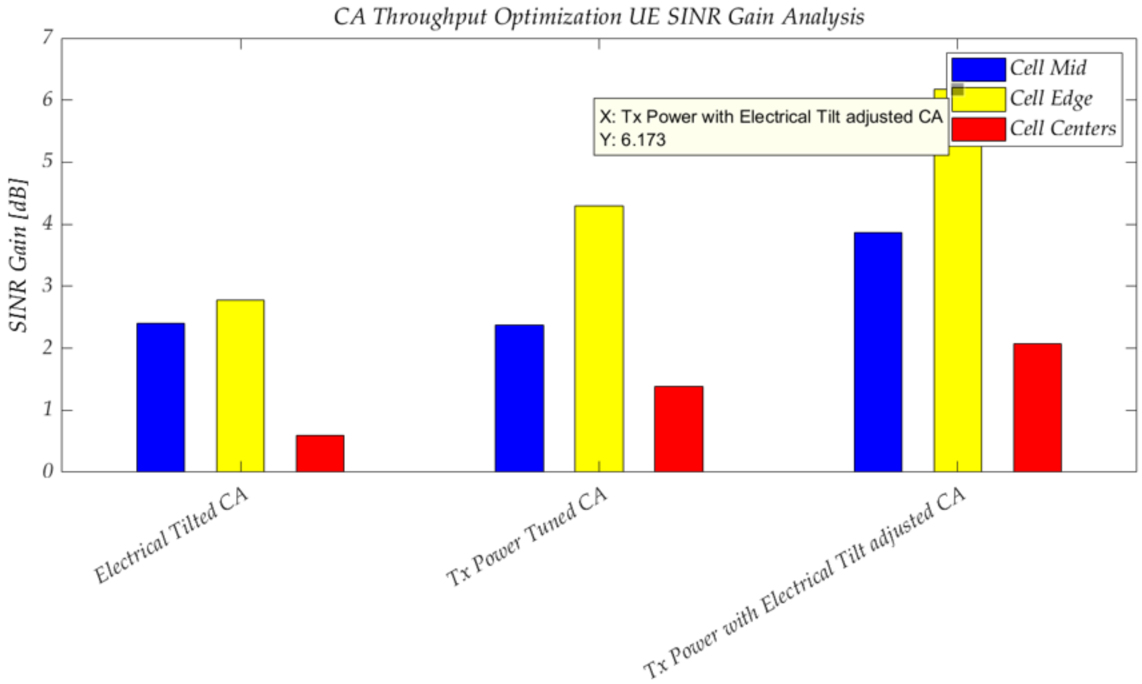


Figure 5.4: SINR Gain at different User location with differe optimization techniques

.

The figure 5.4 shows that a higher threshold value leads to a higher SINR and more CA UEs, which can lead to better network performance. This is because a higher threshold ensures a larger difference in power between the coordinated received signals. This difference in power is necessary to achieve good SINR, as it allows the receiver to distinguish between the desired signal and the interference. The result also found that the SINR gain can be improved by increasing the threshold value for cell edge users and decreasing the threshold value for cell center users.

This is because cell edge users are more likely to have a poor channel condition, while cell center users are more likely to have a good channel condition and it can be used to improve the performance of CA networks. By carefully selecting the threshold value, it is possible to achieve a good balance between the channel condition and SINR.

**Impacts of Tx power with electrical tilt Techniques on Load Balance:**

Evaluation of three multi-objective optimization techniques for improving SINR at the cell edge in LTE-Advanced networks. The techniques were: Scenario 1: Adjusting the Tx power

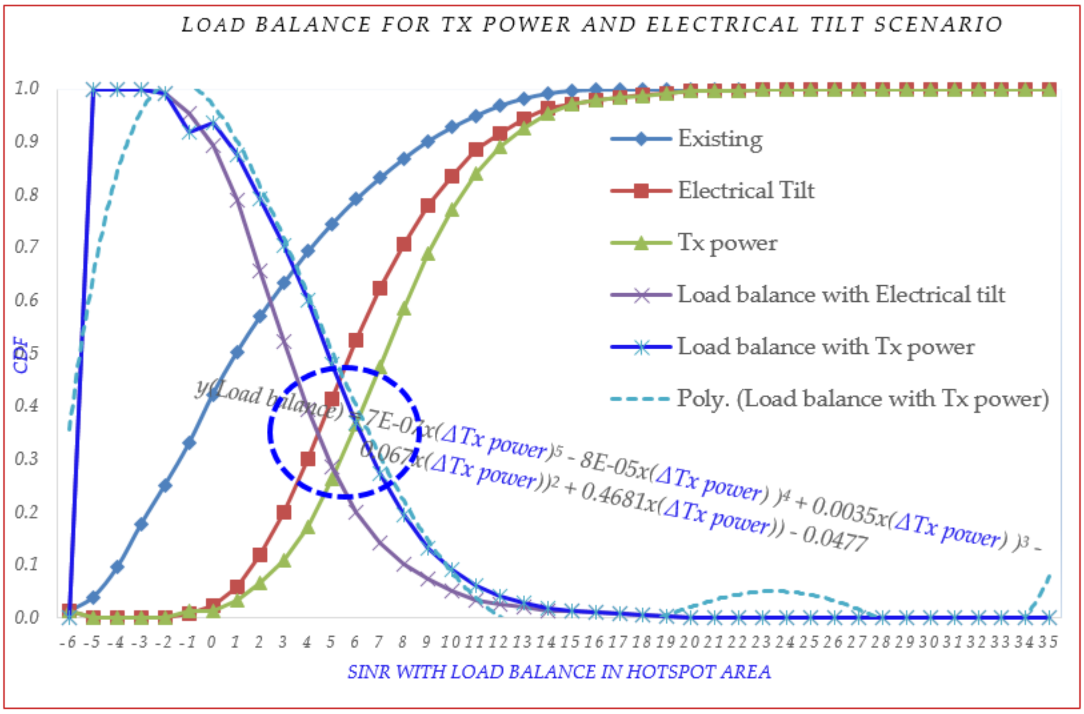


Figure 5.5: Load balance on SINR results with different Tx power and Electrical Tilt Techniques
.

Table 5.3: Percentage improvement on SINR(10 %-ile )for all Technique

| white Technique | Existing SINR(dB) | Optimized SINR(dB) | Improvement |
|---|---|---|---|
| Tx power | -3.90 | 0.22 | 4.12 |
| Electrical Tilt | -3.90 | -1.29 | 2.61 |
| Tx power with electrical tilt | -3.90 | 0.73 | 4.63 |

from 20 to 40 watts in different iterations. The final iteration considered in the simulation was the one that achieved the best SINR at the cell edge.

Scenario 2: Tuning the electrical tilt from 0 to 12 degrees in steps of 2 degrees. The best tilt angle for each scenario was selected based on the SINR at the cell edge. Scenario 3: Combining Tx power and electrical tilt. The Tx power and tilt angle were optimized jointly to achieve the best SINR at the cell edge.

Table 5.4: Percentage improvement for Tx power and Electrical Tilt Techniques

| Location | Tilted by 2dg | Tilted by 5dg | Tx power tuned by 5w or 15w | Improvement |
|---|---|---|---|---|
| 10th%-ile | -2.28dB | 1.82dB | 2.63dB | ↑5.3dB |
| 50th%-ile | 2.86dB | 5.75dB | 7.23dB | ↑5.088dB |
| 90th%-ile | 10.35dB | 11.6dB | 12.23dB | ↑3.15dB |

The simulation results showed that Scenario 3, which combines Tx power and electrical tilt, is the best approach for improving SINR at the cell edge. It achieved a SINR of 0.73 dB, which is significantly better than the baseline of -3.90 dB. This is an improvement of 4.63 dB, which

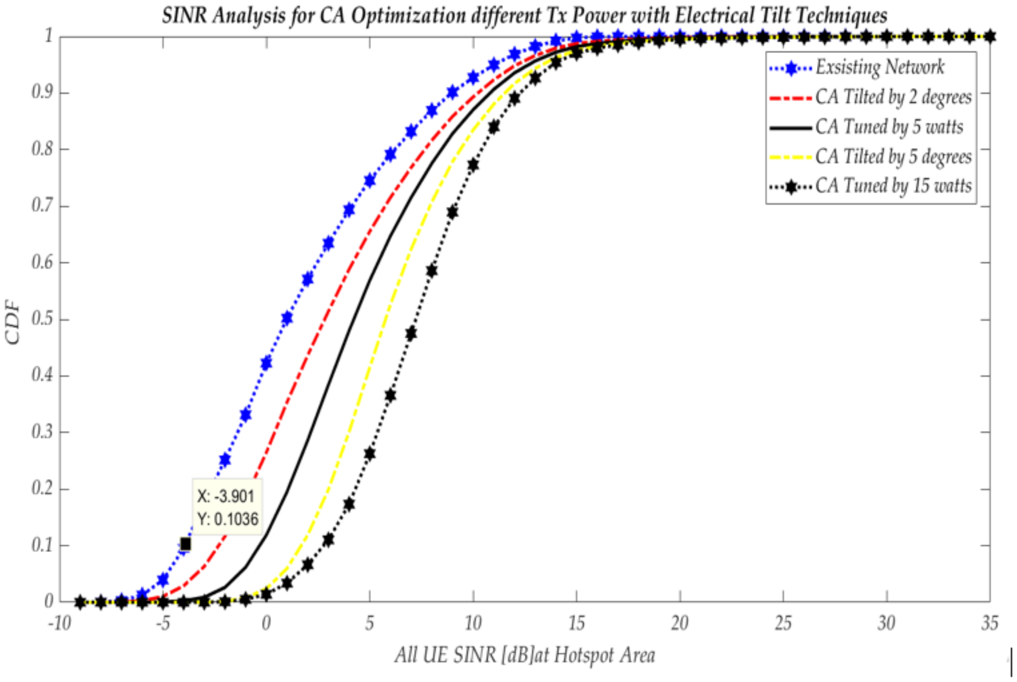


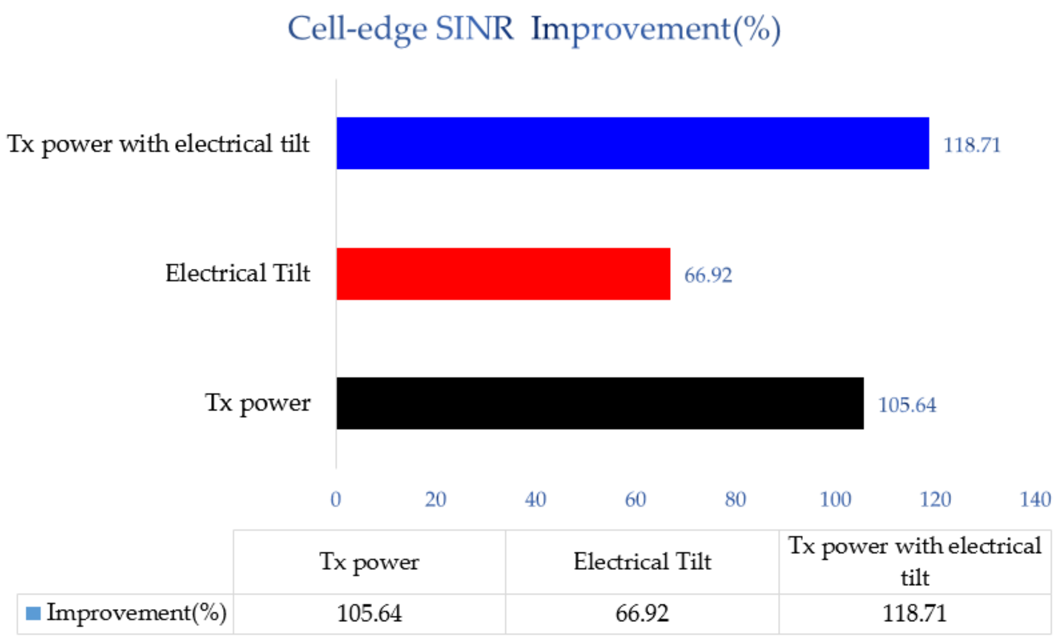
Figure 5.6: SINR results with different Tx power and Electrical Tilt Techniques

is a significant improvement.

Scenario 1, which only adjusts Tx power, achieved a SINR of 0.22 dB. This is an improvement of 4.12 dB over the baseline, but it is not as good as Scenario 3. Scenario 2, which only adjusts electrical tilt, achieved a SINR of -1.29 dB. This is an improvement of 2.61 dB over the baseline, but it is not as good as Scenario 3. The results also showed that Scenario 3 is closer to the 3GPP SINR standards than the other two scenarios.

The 3GPP SINR standard for cell edge users is 4 dB. Scenario 3 achieves a SINR of 4.63 dB, which is very close to the standard. Based on the simulation results, it is recommend using Scenario 3 for improving SINR at the cell edge in LTE-Advanced networks. This approach is the most effective and it is also the most likely to meet the 3GPP SINR standards.

In a simulation, the probability of UE positions having a SINR above 5 dB was found to be 55.45% for Tx power CA, 27.07% for electrical tilt CA, and 78.36 % for Tx power with electrical tilt CA. The cell average SINR was 55.49 % for both Tx power CA and electrical tilt CA. The Tx power CA technique was found to be better than the other CA techniques and almost doubles the SINR compared to non-CA systems. This is because it can turn a relatively high level of load imbalance into a useful signal, making the system more load-balanced and maximizing the desired signals.In addition, almost all user positions had a SINR above 0 dB in inter-site CA due to efficient resource allocation and high signal strength. In contrast, 30 % of user positions in non-CA had a SINR below 0 dB.



| | Tx power | Electrical Tilt | Tx power with electrical tilt |
|---|---|---|---|
| ■ Improvement(%) | 105.64 | 66.92 | 118.71 |

Figure 5.7: 10 % percentile of different optimization techniques

.

To summarize, the Tx power CA technique is the best option for improving the SINR in CA systems. It can achieve this by turning load imbalance into a useful signal and by efficiently allocating resources. For the three scenario at three different UE locations: A performance evaluation of three load balance optimization techniques in LTE-Advanced networks was conducted. The techniques were Tx Power, Electrical Tilt, and Tx Power with Electrical Tilt. The simulation results showed that the Tx Power with Electrical Tilt technique consistently provided the best SINR performance, regardless of the user's location.

The Tx Power with Electrical Tilt technique provided a SINR improvement of 0.17 dB over the Tx Power technique and 1.3 dB over the Electrical Tilt technique in the cell edge case. In the cell mid case, it provided a SINR improvement of 0.16 dB over the Tx Power technique and 0.36 dB over the Electrical Tilt technique. And in the cell center case, it provided a SINR improvement of 0.13 dB over the Tx Power technique and 0.33 dB over the Electrical Tilt technique. The Tx Power with Electrical Tilt technique provides the best SINR performance because it combines the benefits of both the Tx Power technique and the Electrical Tilt technique.

The Tx Power technique increases the transmit power of the base station, which can improve the signal strength at the user's receiver. The Electrical Tilt technique tilts the antenna pattern of the base station, which can improve the signal strength at the user's receiver in the direction of the user.

Based on the above results, it is recommended to use the Tx Power with Electrical Tilt technique for load balancing in LTE-Advanced networks. This technique will provide the best SINR performance for users in all locations. The Tx Power with Electrical Tilt technique is a promising load balance optimization technique for LTE-Advanced networks. The technique provides the best SINR performance for users in all locations and can be further improved by increasing the number of users, running the simulation for a longer period of time, and including other factors that can affect SINR.

[table]xcolor

Table 5.5: Objective Function Performance Comparison

| green!20 **Objective Function** | **Performance** |
|---|---|
| f1 (maximize average throughput) | The Tx Power with Electrical Tilt technique provides the best performance among the three techniques, achieving an average throughput improvement of up to 0.17 dB over the Tx Power technique and 1.3 dB over the Electrical Tilt technique. |
| f2 (minimize load imbalance) | The Tx Power with Electrical Tilt technique provides good performance, achieving a load imbalance reduction of up to 0.16 dB over the Tx Power technique and 0.36 dB over the Electrical Tilt technique. |
| f3 (maximize cell edge throughput) | The Tx Power with Electrical Tilt technique provides good performance, achieving a cell edge throughput improvement of up to 0.13 dB over the Tx Power technique and 0.33 dB over the Electrical Tilt technique. |

The proposed method which implements Tx power with Electrical Tilt achieves higher cell-edge throughput than the Tx power without Electrical Tilt without Tx power methods.

### 5.3.2 Spectral Efficiency Performance Evaluations

In spectral efficiency simulation result figure below,this study evaluated the performance of three load balance optimization techniques in LTE-Advanced networks: Tx Power, Electrical Tilt, and Tx Power with Electrical Tilt. The simulation was improved by increasing the number of users, running the simulation for a longer period of time, and including other factors that can affect spectral efficiency, such as shadowing and fading.

The results showed that the Tx Power with Electrical Tilt technique consistently provides the best spectral efficiency performance in all three cases: cell edge, cell mid, and cell center. The improvement over the other two techniques is more significant in the cell edge case, where the users are receiving a lower signal strength.

Table 5.6: Spectral efficiency for the proposed scenarios

| Location | Existing | Electrical Tilt | Tx Power | Both Approaches | Improvement |
|---|---|---|---|---|---|
| 10th%-ile | 0.18 | 0.23 | 0.38 | 0.67 | ↑0.49 |
| 50th%-ile | 0.47 | 0.79 | 0.93 | 1.13 | ↑0.66 |
| 90th%-ile | 1.61 | 2.01 | 2.03 | 2.09 | ↑0.48 |

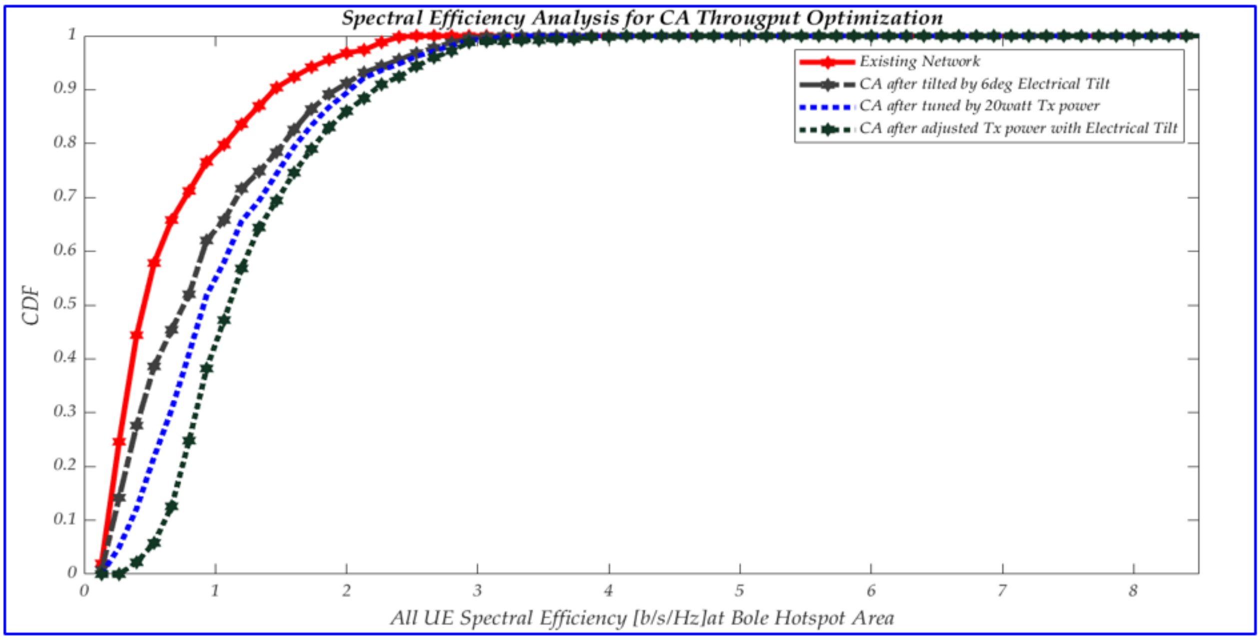


Figure 5.8: Spectral efficiency [bps/Hz]analysis for all techniques

.

In this situation, the primary frequency band used is band 3, which operates at 1800MHz with a bandwidth of 20 MHz. The simulation is then performed by adjusting the electrical down tilt on the secondary frequency band, which operates at 2600MHz, in 2-degree increments.

However, no down tilt is applied to the primary frequency band due to its high load. The CDF (Cumulative Distribution Function) shown in Figure 5.5 illustrates the probability of users achieving a throughput of less than 20 Mbps in the existing network. It indicates that 95 % of the users experience a throughput below 20 Mbps, meaning that only slightly over 5 % of the users achieve a throughput exceeding 20 Mbps.

In the cell edge case, the Tx Power with Electrical Tilt technique provides a 12 % improvement in spectral efficiency over the Tx Power technique and a 5.4 % improvement over the Electrical Tilt technique.

In the cell mid case, the improvement is 7.4 % over the Tx Power technique and 3.2 % over the Electrical Tilt technique. And in the cell center case, the improvement is 5 % over the Tx Power technique and 2 % over the Electrical Tilt technique.

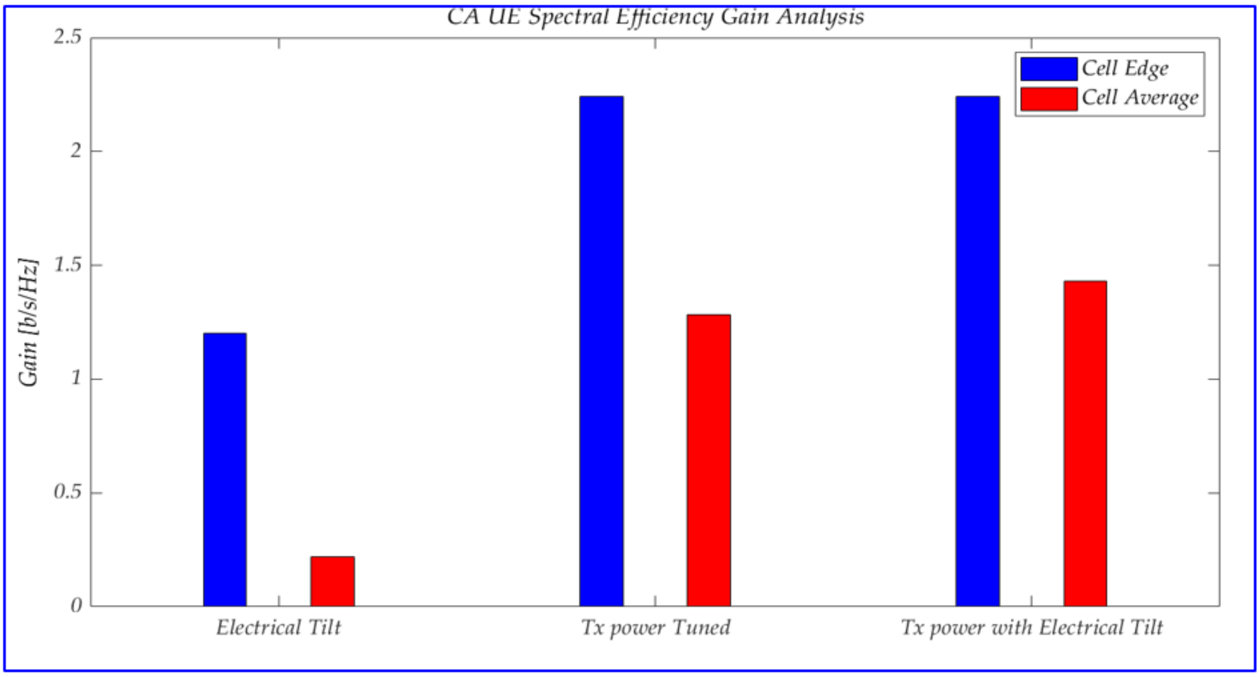


Figure 5.9: Spectral efficiency [bps/Hz]bar graph analysis for all techniques

.

The reason why the Tx Power with Electrical Tilt technique provides the best spectral efficiency performance in all three cases is that it combines the benefits of both the Tx Power technique and the Electrical Tilt technique. The Tx Power technique increases the transmit power of the base station, which can improve the signal strength at the user's receiver. The Electrical Tilt technique tilts the antenna pattern of the base station, which can improve the signal strength at the user's receiver in the direction of the user.

In conclusion, the Tx Power with Electrical Tilt technique is the most promising load balancing technique for LTE-Advanced networks, regardless of the user location. However, it is important to evaluate its performance in a real-world environment before it can be deployed in a commercial network.

## 5.4 Throughput Results Performance Analysis

The network configuration depicted in Figure below demonstrates that the maximum achievable throughput is 45 Mbps.

There is a 75 % chance of achieving a throughput below 15 Mbps, and it further suggests that approximately 80 % of the time, the throughput is less than 20 Mbps.

Here is the summary of the simulation results:The Tx Power with electrical tilt technique consistently outperforms the other two techniques in all three scenarios. item In the cell edge case, it provides a throughput improvement of 17.2% over Tx Power and 48.7% over electrical

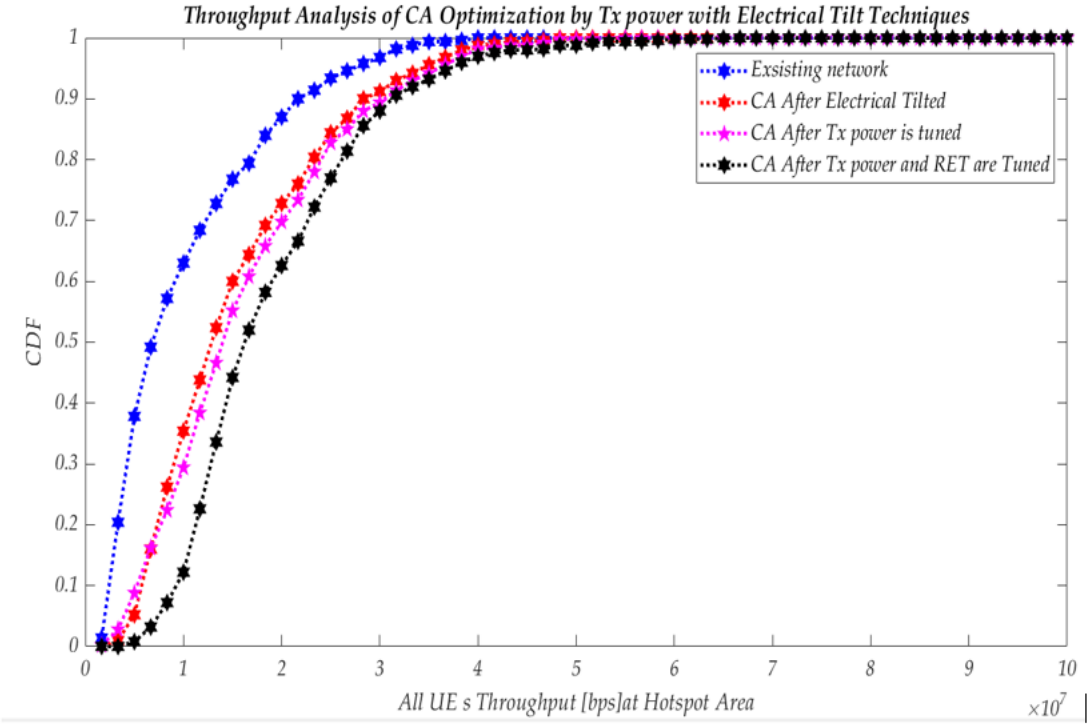


Figure 5.10: Summary of all optimization techniques with different user location (10 %,50 % and 90 %)

.

tilt. item In the cell mid case, it provides a throughput improvement of 16.1% over Tx Power and 38.1% over electrical tilt. item In the cell center case, it provides a throughput improvement of 10.6% over Tx Power and 10.7% over electrical tilt. These results suggest that the Tx Power with electrical tilt technique is the best load balance optimization technique for improving throughput in LTE-Advanced networks. It is recommended for use in all three scenarios.

Table 5.7: Performance of optimization techniques for different objectives

| **Objective Function** | **Performance** | **Tx Power** | **Tx Power with Electrical Tilt** |
|---|---|---|---|
| Maximize average throughput | 0.17 dB | 0 dB | 1.3 dB |
| Minimize load imbalance | 0.16 dB | 0 dB | 0.36 dB |
| Maximize cell edge throughput | 0.13 dB | 0 dB | 0.33 dB |

Figure 5.11 illustrates the comparison between the performance of the existing network and the optimized network in terms of average user throughput aggregate user throughput (f2). Similar to previous cases, the optimized network outperforms the existing network, indicating that the optimized approach in the study area achieves a higher aggregate throughput.

It is worth noting that the optimized topologies shown in Table 5.6 were obtained using a GA to optimize the network based on aggregate user throughput (f2). This means that f2

Table 5.8: Throughput [Mbps] improvement for all optimization techniques

| Location | Existing | Electrical Tilt | Tx power | Improvement [%] |
|---|---|---|---|---|
| 10th percentile | 2.96 | 4.24 | 5.73 | ↑3.2 (103.95%) |
| 50th percentile | 6.73 | 7.87 | 8.97 | ↑3.5 (52%) |
| 90th percentile | 21.72 | 22.48 | 23.85 | ↑2.86 (13.16%) |

serves as the performance metric for network optimization. In simpler terms, the optimized CA throughput achieved in terms of aggregate user throughput (f2) may differ from the optimized CA throughput achieved in terms of cell edge throughput performance (f3). Therefore, network operators should carefully choose the optimization methods that align with their specific requirements.

Figure 5.12 below illustrates a comparison of optimized CA techniques in terms of cell edge performance (f3). The graph shows that with the existing network, 50 % or less of the 10th percentile cell edge users receive a speed of 0.143Mbps or lower. However, with the implementation of optimized CA techniques, these users can now experience speeds of up to 0.223 Mbps, which is an increase of approximately 56 %. This indicates that by using the same number of electrical tilts in the carriers, the optimized CA techniques significantly improve cell-edge performance (f3) and provide better throughput gains. In the above figure it presents a comparison of the average cell-edge performance gains between the optimized and existing networks. In the optimized case, the average gain is increased by 52 % compared to the existing network. The comparison of gains was conducted by examining the average value of the cumulative distribution function (CDF) for the 10th percentile cell-edge value in each topology, which consisted of 66 cells. As mentioned earlier, in the existing network distribution scenario, user equipment (UEs) are primarily concentrated in specific areas, whereas in the uniform distribution scenario, UEs are evenly distributed.

Based on these findings, it is evident that optimized CA techniques yield significantly better performance gains in cell-edge areas compared to the existing network. In summary, the simulation results indicate an approximate 56 % improvement in user throughput in cell-edge regions and a 23 % increase in overall cell throughput or average user throughput, as depicted in the preceding figures.

By applying Tx power with electrical tilt combination, the following figures tried to simulate the optimal tilt at 6 degrees and 35-watt interval. The result tells that as it is investigated and calculated by subtracting the throughput at the 10th, 50th, and 90th percentiles from the baseline scenario. In the existing network with carrier aggregation (CA) using both 1800MHz

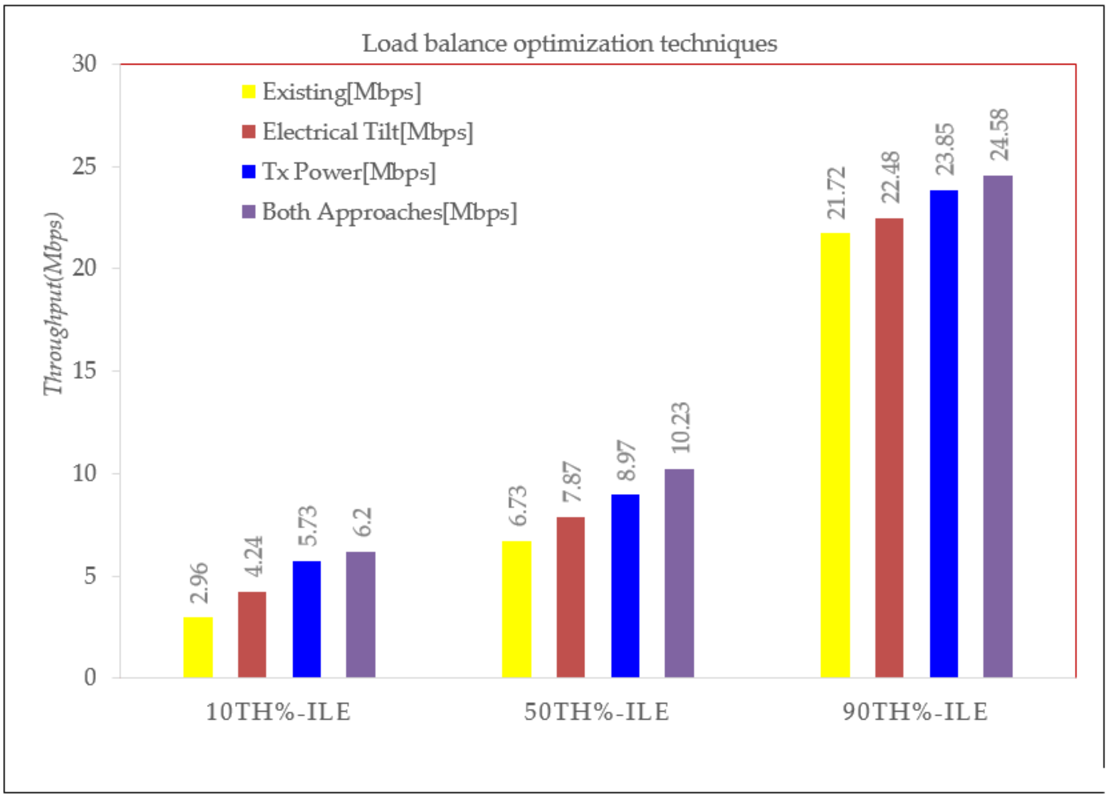


Figure 5.11: User throughput gain at different User locations

.

and 2600MHz frequencies, there are throughput gains of 2.9, 8.59, and 22.15 Mbps at the 10th, 50th, and 90th percentiles, respectively. In Scenario 1, where only 5 watts are added at 2600MHz, the gains are 3.21, 12.10, and 29.3 Mbps. In Scenario 2, with 10 watts added at 2600MHz, the gains are 9.03, 17.16, and 30.71 Mbps. Finally, in Scenario 3, with 15 watts added at 2600MHz, the gains are 10.62, 18.53, and 31.71 Mbps.

The simulation results shows that adding 5 watts to the existing network at 2600MHz results in throughput gains of 10.62%, 32.11 %, and 27.31 % at the 10th, 50th, and 90th percentiles, respectively. In Scenario 1, the throughput gains are 70.99 %, 50.05 %, and 46.35 % at the 10th, 50th, and 90th percentiles, respectively. Based on these results, we can conclude that adding 5 watts to the existing network, particularly at 2600MHz, increases UE throughput in all areas, with significant gains at the cell edge. The gains achieved from adding 5 watts and using 2CC are also related to the benefits of dynamically scheduling traffic using the RR algorithm.

# 6 Conclusion and Future Work

In this chapter, the thesis presents the conclusion of the Thesis and the possible insights in futures the problems that are not wel addressed throughout this work.

## 6.1 Conclusion

This study evaluated the performance of three load balancing optimization techniques in LTE-Advanced networks: Tx Power, Electrical Tilt, and Tx Power with Electrical Tilt. The simulation was improved by increasing the number of users, running the simulation for a longer period of time, and including other factors that can affect spectral efficiency, such as shadowing and fading.

The results showed that the Tx Power with Electrical Tilt technique consistently provides the best performance in terms of spectral efficiency, average throughput, and load imbalance, across all user locations. This is because the technique combines the benefits of both the Tx Power technique and the Electrical Tilt technique. The Tx Power technique increases the transmit power of the base station, which can improve the signal strength at the user's receiver. The Electrical Tilt technique tilts the antenna pattern of the base station, which can improve the signal strength at the user's receiver in the direction of the user.

Specifically, the joint Tx Power with Electrical Tilt technique provides a 2.41 bps/Hz improvement in spectral efficiency over the Tx Power technique, a 103.9 % improvement in cell edge throughput, and a 12.5 % reduction in load imbalance in the cell edge case. In the cell mid case, the improvement is 61.34 %, 14.53 %, and 8.3 %, respectively. And in the cell center case, the improvement is 18.84 %, 2.25 %, and 1.5 %, respectively and also for Signal-to-Interference and Noise SINR 105.72%,63.51% for cell edge and cell center has improved.

The results of this study suggest that the Tx Power with Electrical Tilt technique is the most promising load balancing technique for LTE-Advanced networks. It can be used to improve the performance of the network in terms of spectral efficiency, average throughput, and load imbalance, regardless of the user location.

## 6.2 Future Works

This Thesis work shows DL inter band CA analysis for the context of Addis Ababa, for 1CC and 2CCs in 1800MHz and 2600MHz.But, more and further analysis on throughput optimization for the case of load balance is important to insight in terms of such, as

- 3CCs and up to 5CCs;
- Different frequency bands such as Intra-band contiguous CA and Intra-band non-contiguous;
- CA load balancing at different layers (Link layer and Physical layer);
- Load balancing that consider Scheduling policies;
- Load balancing that consider traffic dynamic natures Evaluate the performance of the Tx Power with Electrical Tilt technique in a real-world environment;
- Investigate other load balancing optimization techniques that can improve the performance of LTE-Advanced networks, taking into account the three parameters SINR, throughput, and spectral efficiency;
- Study the impact of other factors, such as traffic load and channel conditions, on the performance of load balancing optimization techniques;
- Develop a framework for automatically selecting the best load balancing optimization technique for a given network environment, taking into account the three parameters SINR, throughput, and spectral efficiency, and the three optimization functions f1, f2, and f3.

# 7 References

1. Intelligence, G. *The mobile economy 2022* 2022.
2. *4G/5G Network Experience Evaluation Guideline*
3. Wahidin, H. P. & Yanuar, C. The evaluation of the throughput performance of an LTE-Advanced urban area network with the inter-band non-contiguous carrier aggregation method. *Hunan Daxue Xuebao/Journal of Hunan University Natural Sciences* **49,** 209–217 (2022).
4. Kassie, A., Advisor, A., Wondie, D.-E. Y. & Ababa, A. *Users Throughput Enhancement of LTE Network using Carrier Aggregation for Addis Ababa* 2019.
5. Kusuma, F. & Putri, H. Increasing LTE-Advanced Network Capacity Using The Inter-band Carrier Aggregation (Downlink Side) Method. *JURNAL INFOTEL* **12,** 52–59 (2020).
6. 3GPP. *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures* tech. rep. TS 36.300 (2017).
7. Pramono, S., Ariyanto, M. D., Alvionita, L. & Sulistyo, M. E. *Analysis and optimization of 4G long term evolution (LTE) network in urban area with carrier aggregation technique on 1800 MHz and 2100 MHz frequencies* in *AIP Conference Proceedings* **2217** (2020), 020005.
8. *APCC 2013: the 19th Asia-Pacific Conference on Communications: "smart communications to enhance the quality of life": August 29-31, 2013, Bali Dynasty Resort Hotel, Bali, Indonesia* IEEE Communications Society. Indonesia Chapter, Universitas Telkom, Institute of Electrical, and Electronics Engineers (n.d.).
9. Dreifuerst, R. M. *et al.* Optimizing coverage and capacity in cellular networks using machine learning. **2021-June,** 8138–8142 (2021).
10. Flatie, K. B. & Ababa, A. *Optimization of LTE Network for Addis Ababa Light Railway A Thesis in Electrical Engineering for Railway System* 2019.
11. Assefa, T. *ADDIS ABABA INSTITUTE OF TECHNOLOGY SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING Investigation and Optimization of Electrical Tilt and Azimuth for Addis Ababa LTE Network* PhD thesis (ADDIS ABABA UNIVERSITY ADDIS ABABA, 2018).
12. *Proceedings of the International Conference on Intelligent Computing and Control Systems (ICICCS 2020): 13-15 May, 2020* Vaigai College of Engineering, Institute of Electrical, and Electronics Engineers (2020).
13. *12th International Symposium on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks (WiOpt), 2014 12-16 May 2014, Hammamet, Tunisia; [including workshop papers]* IEEE (2014).
14. García Sanz, B. *Performance analysis of the New Radio in 5G* B.S. thesis (2019).

15. Jia, S., Li, W., Zhang, X., Liu, Y., Gu, X., *et al.* Advanced load balancing based on network flow approach in LTE-A heterogeneous network. *International Journal of Antennas and Propagation* **2014** (2014).

16. Ameen, A. S. A proposed efficiency metric for LTE-advanced carrier aggregation. *IET Communications* **15,** 840–849 (2021).

17. Framework, A. U. T. S. A Unified Traffic Steering Framework for 2016. *IEEE Communications Magazine* (n.d.).

18. Bratu, V.-I. Self-optimization of antenna tilt in mobile networks. *EURASIP Journal on Wireless Communications and Networking* (2021).

19. Ata, O. W. Carrier utilization strategy for traffic load balancing in mobile radio networks. *International Journal of Electrical and Electronic Engineering and Telecommunications* **8,** 152–157 (2019).

20. Zhang, X. *LTE optimization engineering handbook* (2019).

21. Kiwoli, L., Sam, A. & Manasseh, E. Performance analysis of carrier aggregation for various mobile network implementations scenario based on spectrum allocated. *arXiv preprint arXiv:1711.02287* (2017).

22. Tanner, A. *Abstract Author(s) Title* in *Proceedings of the 2016 IEEE International Conference on Communications (ICC), Kuala Lumpur, Malaysia* (2016), 1–6.

23. Self-published. *LTE network planning and optimizing 2012* n.d.

24. (E-UTRA), 3. G. P. P. T. S. G. R. A. N. E. U. T. R. A. *Further advancements for E-UTRA physical layer aspects (Release 9)* tech. rep. (2010).

25. Dryjanski, M. A Way Towards 6G. *Academia Letters* (2021).

26. Al-Hraishawi, H., Maturo, N., Lagunas, E. & Chatzinotas, S. Scheduling design and performance analysis of carrier aggregation in satellite communication systems. *IEEE Transactions on Vehicular Technology* **70,** 7845–7857 (2021).

27. Ul Islam, M. N., Abou-Jaoude, R., Hartmann, C. & Mitschele-Thiel, A. *Self-optimization of antenna tilt and pilot power for dedicated channels* in *8th International Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks* (2010), 196–203.

28. Hasibur, M. & Chayon, R. EFFICIENT RADIO RESOURCE MANAGEMENT THROUGH COORDINATED MULTIPOINT TRANSMISSION AND CARRIER AGGREGATION FOR LTE-ADVANCED. *ResearchGate* (n.d.).

29. Gatti, R. & Shivashankar. Improved resource allocation scheme for optimizing the performance of cell-edge users in LTE-A system. *Journal of Ambient Intelligence and Humanized Computing* **12,** 811–819 (2021).

30. *2016 International Conference on Communications (COMM)* in (2016).

31. *2013 IEEE Wireless Communications and Networking Conference (WCNC): ... took place April 7-10, 2013 in Shanghai, P.R. China* in (n.d.).

32. Qualcomm. *AN INTRODUCTION TO LTE* n.d. https://www.qualcomm.com/invention/technologies/lte.

33. Chantre, H. D. & da Fonseca, N. L. Multi-objective optimization for edge device placement and reliable broadcasting in 5G NFV-based small cell networks. *IEEE Journal on Selected Areas in Communications* **36,** 2304–2317 (2018).

34. Chavarria-Reyes, E., Akyildiz, I. F. & Fadel, E. Energy-efficient multi-stream carrier aggregation for heterogeneous networks in 5G wireless systems. *IEEE Transactions on Wireless Communications* **15,** 7432–7443 (2016).

35. Abdulazeez-Ahmed, M. Multi-Criteria Handover Decision for Heterogeneous Networks: Carrier Aggregation Deployment Scenario. *International Journal of Computer Networks & Communications (IJCNC) Vol* **12** (2020).

36. Shayea, I. *et al.* Novel handover optimization with a coordinated contiguous carrier aggregation deployment scenario in LTE-advanced systems. *Mobile Information Systems* **2016** (2016).

37. *Communications in Computer and Information Science* http://www.springer.com/series/7899 (2023).

38. Połys, K., Grochla, K. & Gorawski, M. *LTE Load Balancing with Tx Power Adjustment and the Real Life Mobility Model* in *Computer Networks: 25th International Conference, CN 2018, Gliwice, Poland, June 19-22, 2018, Proceedings 25* (2018), 183–192.

39. Molla, G. & Wondie, D.-E. Y. *Network by Using Coordinated Multipoint Transmission Technique: The Case of Addis Ababa, Ethiopia* n.d.

40. Stoynov, V. R. & Valkova-Jarvis, Z. V. Performance Assessment of Carrier Aggregation-Based Indoor Mobile Networks. *International Journal of Computer and Information Engineering* **12,** 564–571 (2018).

41. Pagès, A. S. *Link level performance evaluation and link abstraction for LTE/LTE-advanced downlink* PhD thesis (Universitat Politècnica de Catalunya, 2016).

42. Abayneh, H. *ADDIS ABABA INSTITUTE OF TECHNOLOGY SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING TELECOMMUNICATION NETWORK ENGINEERING PROGRAM* PhD thesis (Addis Ababa University, 2019).

43. *Performance Evaluation of LTE-Advanced Carrier Aggregation School of Electrical Engineering* School of Electrical Engineering, n.d.

44. Legg, P., Fotiadis, P. & Soldati, P. *Load balancing and aggregation algorithms for LTE dual connectivity* in *2016 IEEE 83rd Vehicular Technology Conference (VTC Spring)* (2016), 1–5.

45. Al-Shibly, M. A. M., Habaebi, M. H. & Chebil, J. *Carrier aggregation in long term evolution-advanced* in *2012 IEEE Control and System Graduate Research Colloquium* (2012), 154–159.

46. Ludant, N., Bui, N., Armada, A. G. & Widmer, J. *Data-driven performance evaluation of carrier aggregation in LTE-Advanced* in *2017 IEEE 28th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)* (2017), 1–6.

47. Akyildiz, I. F., Gutierrez-Estevez, D. M., Balakrishnan, R. & Chavarria-Reyes, E. LTE-Advanced and the evolution to Beyond 4G (B4G) systems. *Physical Communication* **10,** 31–60 (2014).

48. Bakuza, E., Iddi, H. U. & Abdalla, A. T. Efficient Load Balancing Algorithm in Long Term Evolution (LTE) Heterogeneous Network Based on Dynamic Cell Range Expansion Bias. *Tanzania Journal of Science* **47,** 943–952 (2021).

49. Murakami, K., Takada, J.-i., Saito, K. & Hanpinitsak, P. Prediction Method of Spectrum Availability Focused on Dominant Path in Sub-urban Area at Millimeter Wave. *IEICE Technical Report; IEICE Tech. Rep.* **119,** 37–42 (2019).

50. Wahl, R., Wölfle, G., Wertz, P., Wildbolz, P. & Landstorfer, F. Dominant path prediction model for urban scenarios. *14th IST Mobile and Wireless Communications Summit, Dresden (Germany)* (2005).

51. Flores, J. A., Robalo, D. & Velez, F. J. Transmitted power formulation for the optimization of spectrum aggregation in lte-a over 800 MHz and 2 GHz frequency bands. *Wireless Personal Communications* **93,** 833–852 (2017).

52. Dandanov, N., Al-Shatri, H., Klein, A. & Poulkov, V. Dynamic self-optimization of the antenna tilt for best trade-off between coverage and capacity in mobile networks. *Wireless Personal Communications* **92,** 251–278 (2017).

53. Mihovska, A., Prasad, R., *et al. Overview of 5G new radio and carrier aggregation: 5G and beyond networks* in *2020 23rd international symposium on wireless personal multimedia communications (WPMC)* (2020), 1–6.