Addis Ababa Institute of Technology

School of Electrical and Computer Engineering

Telecommunication Engineering Graduate Program

Capacity Enhanced-Energy Efficient Base Station Deployment Using Genetic Algorithm

By: Tabor Birru

Advisor: Yihenew Wondie (PhD)

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Thesis Title

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Signed by the Examining Committee

Dr. Yihenew Wondie	______________________	____/____/2020
Advisor	Signature	Date
____________________________	______________________	____/____/2020
Internal Examiner	Signature	Date
____________________________	______________________	____/____/2020
External Examiner	Signature	Date
____________________________	______________________	____/____/2020
Chair Person	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.

Name: Tabor Birru

Signature: ____________________

Place: Addis Ababa

Date of Submission: _________________

Abstract

Unparalleled increasing demands for high capacity and consistent service quality on cellular network have been challenging for telecom operators. However, current deployed and existing radio access network is significantly behind the growth. This promotes operators to network upgrade, expansion and base station (BS) densification. Operators are also trying to mix macro and small cell on their radio access network as a potential solution to meet their customer demands by enhancing their network capacity and coverage extension. However, addition of the small cell on existing network increases energy consumption.

This thesis study considers energy efficient BS deployment for enhancement of LTE network capacity. For this purpose, small cell deployment underlay to the existing macro BS is used in outdoor scenario in 2x2 square kilometer area located in Addis Ababa. Candidate locations for the small cell first selected mainly based on traffic distributions in the selected area of study. Then radio propagation simulations performed using WinProp radio planning and simulation tool followed by Genetic algorithm based optimization to find out the optimal number and locations of the small cell obtaining enhanced capacity and improved energy efficiency with minimized additional power consumption. The result analysis is observed in MatLab implementation.

Finally, aggregate capacity and energy efficiency have been evaluated. The result shows that both the aggregate network capacity and energy efficiency increased with number of small cell. There is 77.94% capacity and 24.7% energy efficiency improvement as compared to the original macro BS only network, which respectively requires 82 and 59 small cells transmitting at 0.5-watt power. At the same time, improvement of capacity requires 18 small cell while it takes 23 and above small cell for energy efficiency to be improved. For small cell more than 59, the energy efficiency start declining which indicates small cell deployment beyond this value has no importance as it declines energy efficiency. The aggregate network capacity has improved by 66.99% when selection of the small cell limited on its impact on energy efficiency. The maximum energy efficiency achieved is 24.7%, 22.32%, 17.88% and 11.12% respectively for small cell transmitting at 0.5watt, 2watt, 5watt and 10watt. This result can possibly be improved further by using different techniques such as sleep mode and cell zooming operations.

Key Words: Energy efficiency, Base station deployment, small cell, Capacity enhancement, LTE

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Finally yet importantly, I would like to express my heartfelt gratitude to my beloved families.

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List of Acronym

1G	First Generation
2G	Second Generation
3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
AC	Alternating Current
BB	Base Band
BTS	Base Transceiver Station
CoMP	Coordinated Multi-Point transmission/reception
dB	decibel
dBm	decibel Milliwatt
DC	Direct Current
DG	Diesel Generator
eNodeB	Enhanced NodeB
EPC	Evolved Packet Core
E-UTRAN	Enhanced UTRAN
FDD	Frequency division Duplex
Gbps	Giga bit per second
GPRS	General Packet Radio Services
GSM	Global System for Mobile communication
ITU	International Telecommunications Union
LTE	Long Term Evolution
Mbps	Mega bit per second
MHz	Mega Hertz
PA	Power Amplifier
PLMN	Public Land Mobile Network
PM	Past Meridian
PSTN	Public Switched Telephone Network
QoS	Quality of Service
RAN	Radio Access Network
RF	Radio Frequency
RNC	Radio Network Controller
SINR	Signal-to-Interference-plus-Noise Ratio
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
UE	User Equipment
UMTS	Universal Mobile Telecommunication System

UTRAN	UMTS Terrestrial Radio Access Network
VoIP	Voice over Internet Protocol
WCDMA	Wide-Band Code Division Multiple Access

Chapter 1 Introduction

1.1. Background

Over the last few decades, mobile communication has been growing rapidly connecting billions of people all over the world [1]. Cellular networks have practiced unparalleled demands for higher data rates and reliable quality of service. This creates fundamental challenges for operators[2]. Growth of smartphones and internet capable devices such as laptops, tablets, unlimited data bundles offered by cellular operators and proliferation of data intensive applications like online video streaming, social networking are among the numerous factors contributed to the challenges. With increasing demand for data rate mobile services, cellular networks are evolving from structures with high-power macro BS covering large geographic area to small cell structure with low power BSs(BS) such as micro, pico and femto BS[3].

According to [4] the number of mobile subscription over the world is growing fast and forecasted to reach 8.8 billion by the year 2024. As a result, there will be a significant increase in mobile data and voice traffic. This fact forces telecom operators to increase the number of base transceiver station (BTS) to support the increased traffic load and to fulfil subscribers' needs. The deployment of new BSs increases energy consumption that maximizes operational expenditure (OPEX) of the operator.

According to[1],[5] about 57% of operator's power is consumed by conventional BSs, which rises the energy cost and carbon emissions. The rising energy costs and carbon emission led to an emerging trend of addressing energy-efficiency using different mechanisms that makes the planning, deployment and operation of BSs a key element for determining environmental impact of cellular network and operational expenditure with less amount of energy consumption. Figure 1.1 shows the power consumption of cellular network.

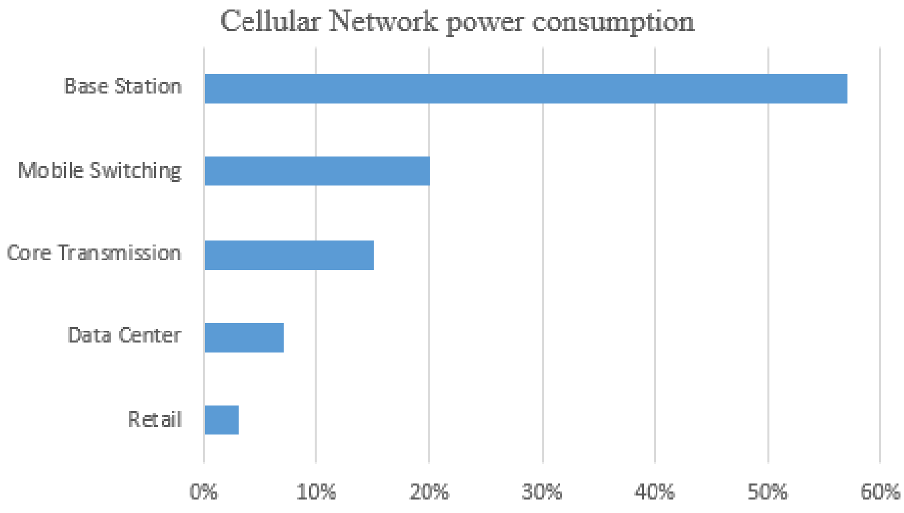


Figure 1.1 Cellular network power consumption[5]

In cellular network, energy efficiency could be enhanced by either increasing the network capacity while serving with same power consumption or providing same capacity with reduced power consumption [6]. As demand for mobile data service increase, operators' network becomes more congested which may lead to unwanted quality of service. In order to provide expected service quality, cellular operators' require enhancing their network capacity, which can be achieved by application of different techniques like additional BS deployment.

However, additional BS deployment leads to additional power consumption that may create negative impact on proposed profit. Thus, while enhancing capacity by addition of BSs, reducing additional power consumption becomes mandatory to achieve targeted profit.

In Ethiopia, there are more than about 7000 active macro BS available and according to sole service provider ethio telecom, over about 44.5 million active subscribers have been served as of December 2019. More than 22 million of the total subscribers are mobile broadband users with smartphone and tablet devices share 32.4% device portfolio.

To keep reliability of the network and to avoid service outage those BS have been supplied with power from different sources. As can see in Figure 1.2 commercial power, diesel generators, solar, battery and hybrid of two or more of these are among the sources. It shows that 43% of the BS are supplied from alternating current (AC) + diesel generator (DG), 37% supplied from AC only, 16% from solar, 2% from DG + Battery and the rest 2% from dual DG

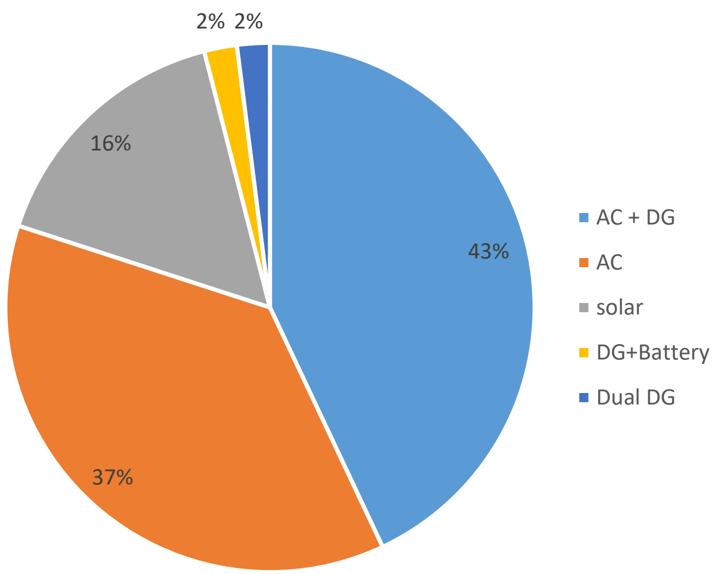


Figure 1.2 BS with their source type

The number of customers connected to these BSs, as well as the data traffic has been growing from time to time. Figure 1.3 below shows LTE traffic variations taken on one of BS existing in Addis Ababa. The traffic is measured from January 2017 to July 2019. It shows that the amount of data traffic volume has been increasing from year to year.

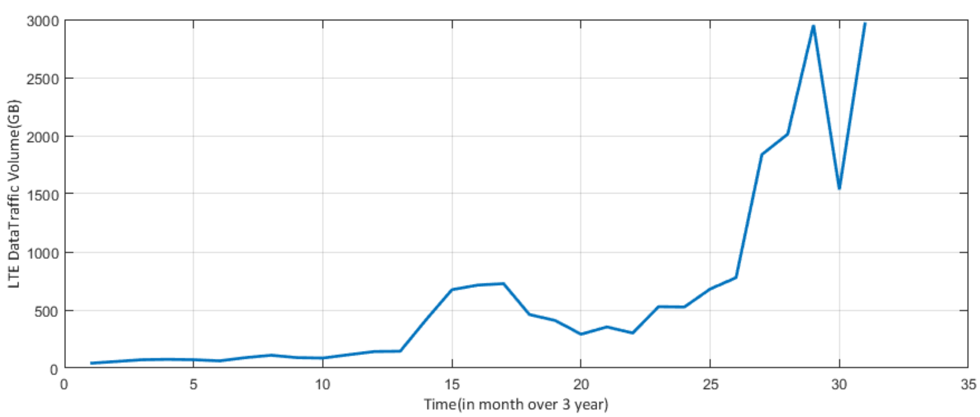


Figure 1.3 LTE traffic variation

Problem of network capacity due to increased subscriber and data traffic as well as the network energy efficiency in cellular radio network can be addressed by using different techniques. Among these, small cell deployment[7],[8] in addition to already serving macro BS is one way to enhance both capacity and energy efficiency if deployed with care.

1.2. Statement of the Problem

Within Information Communication and Technology (ICT) sector, wireless communication is one of the most successful technological innovation in modern world. Cellular networks have advanced significantly over the last decades and now offers data-oriented services such as browsing and video streaming[9]. Owning to this there is an increasing number of subscribers, demand for data service and high data traffic. This promotes the operators to:

- Network upgrade
- BS densification

Associated to network upgrade and densification, capital expenditure (CAPEX) and operational expenditure (OPEX) affects revenue. This is because upgrade and densification activities require additional BS. However, adding additional macro BS requires relatively larger space, cost and energy to install and operate the BS. As a result, operators mix low power small cell in their network as a potential solution to address issues of subscribers demand. Small cell deployment have been remained being a research topic for years and there are numerous research works on deployment of small cells for enhancement of capacity and energy efficiency. Even though ethio telecom have installed small cells at different locations as a solution to narrow capacity insufficiencies of the macro BS, the experience of using the small cells as well as research works on their deployment is less and not widely done in Ethiopia. Therefore, further study on enhancement of network capacity with energy efficient, systematic and effective small cell deployment is required.

In response to these problems, LTE system is selected as there is a target to make expansion on the network, and the study generally answers the following basic questions.

1. Can small cells be integrated in pre-existing macro cell network to improve both network capacity and energy efficiency?
2. Is it be possible to identify the optimal number of small cells required to enhance network capacity?
3. What is the energy efficiency and power consumption gains as compared to a network before the deployment of small cells?

1.3. Objective

1.3.1. General Objective

The general objective of this thesis is to study energy efficient BSs deployment to enhance total capacity of cellular radio network.

1.3.2. Specific Objectives

The specific objective of this thesis is

- To formulate and optimize capacity and energy efficiency of the network with small cell deployment.
- To evaluate the optimum set of small cells that can be deployed underlay to macro BSs achieving maximum energy efficiency.
- To study performance aspects of small cell in terms of capacity and energy efficiency.
- To compare the energy efficiency of a network with macro only and macro + micro.

1.4. Methodology

This section illustrates the detail methodology used for this study. The study uses both primary and secondary data sources. The primary data have been collected from ethio telecom Network Management Systems.

Different source such as books, 3GPP standardization documents, ITU-T standard documents, different literatures, articles and prior related research works used as secondary data sources. Figure 1.4 shows generalized methodology used in this study.

Figure 1.4 Methodology

Detail description of the components of the methodology is presented as follow:

Literature review and data collection

In this study, literatures related to BS deployment aimed on capacity enhancement and energy efficiency were referred. Data such as traffic data, BS engineering data, energy related and other data related to the aim of this study collected, cleared and used.

System model

- Prepare mathematical formulation for capacity, power consumption for both macro and small cells separately and for a network consisting of the two types of BS.
- Formulate energy efficiency based on appropriate metrics.
- Formulate optimization problem to optimize required parameters.

Simulation, Evaluation and Optimization

Simulation involves radio propagation simulation of the network existing in the area of interest by using WinProp. This is required in order to get numerical value of path loss at each grid from every BS.

The optimization involves optimization of the small cell location and optimal number of the small cell for the enhancement of network capacity and energy efficiency. The below points summarize this.

- Simulate and evaluate capacity and energy efficiency of the network before and after deployment of small cell.
- Evaluate small cells required to fulfill objective of the optimization problem.
- Compare the energy gain of the network with deployment of small cell.

Result Analysis and Interpretation

- Analyze how the deployment of small cell improved the capacity and energy efficiency of the network.
- Analyze the energy efficiency aspect of small cell deployment by using selected metrics for energy comparison between two systems.

1.5. Related Works

Over past decade, several works have been done on deployment of energy efficient BSs. The work in [6] aimed at examining the energy efficiency aspects of small cell deployment in cellular network. The authors realized the deployment problem by choosing feasible candidate location of micro station and selecting optimum sets among the candidate location that maximizes the energy efficiency of the network while satisfying the increasing capacity demand of the network. They suggested Greedy algorithm that selects one micro BS to deploy at each iteration.

In [10], the area spectral efficiency (ASE) aspect of the micro BS deployment problem was investigated. The authors deployed the small BS, based on greedy algorithms, at the coverage age of macro BS and tried to optimize the number of micro BS that achieves the maximum ASE. The authors tested their work on additional BS requirements for an additional 10% increase of ASE and concluded that deploying small cells saved tangible amount of energy than deploying additional macro BSs to achieve the required ASE target.

The authors in [11] investigated the impact of femto cell on energy efficiency. The authors analyzed energy consumption by varying number of femto cells that could be deployed underlay to macro cell. In this work, the authors compared energy consumption of network before and after deployment of femto cell. The authors' achievement showed that good energy reduction gain was realized with femto cell deployment. However, the result relies on manual investigation where one variable assumed varying while keeping the other independent variables constant to get how the dependent variable (energy consumption and energy efficiency) is affected.

In [12], the authors investigated network capacity improvement by planning and deployment of small cell in unlicensed frequency band. In this work, the authors used multiobjective optimization to show capacity improvement. They tried to compare aggregate capacity and gain in percentage of the network before and after planning of small cell. The result showed improved aggregate capacity after small cell deployment.

In summary of the above indicated studies, all the studies realized and quantified that deployment of small cells has a positive impact on network capacity and energy efficiency if the deployment done very carefully. The authors followed different techniques to show how different small cells influenced the performance of the network in terms of capacity and energy efficiency. In the studies [6] and [10], an iterative greedy deployment algorithm is used. The algorithm selects assumed local finest values at each iteration aiming the overall sum of the local finest values obtain the global optimum. However, this may yield selection of non-optimal BS location that may lead to incorrect conclusion. In [12], interference between small cell and macro cell was avoided by taking different frequency bands which eases complexity than taking same frequency band both for small cell and macro cell deployment where complexity increases.

1.6. Scope and Limitation

1.6.1. Scope

This thesis mainly focuses on deployment of small cells underlay to existing macro BS and investigate its performance gains by selecting optimal locations of these cells that can enhance capacity and energy efficiency of the network. Technology wise, it focuses on LTE network in a 2x2 square kilometer area located in Addis Ababa. Unless it is mentioned specifically, small cell and micro cell (micro BS) used interchangeably and refers the same entity in this document.

1.6.2. Limitation

The focus of this thesis work is minimizing the number of small cells to be deployed under coverage area of macro BS network. While doing this, the optimal locations among the candidate is selected and deployed.

Performance evaluations in the process requires modeling of different parameters such as power consumptions. One limitation in this thesis work is power consumption modeling not made by taking the variations of power consumption with varying the transmit power. Rather it mainly depends on prier literature works.

In addition, evaluations made on the assumption that network delivers at its full load. Therefore, no traffic variation and load adaptive energy saving schemes considered.

1.7. Contribution

This work mainly important for telecom operators to minimize their capital and operational expenditure by selecting more energy efficient network architecture to deploy to serve their esteemed customers. It also gives network optimization ideas where there is a need to optimize their network to enhance its capacity to fit to the ever increasing data demands. The following are some of the points aimed this thesis contributes.

1. The aim of the BS deployment is selecting minimum possible number and location among candidates set to enhance network capacity and minimize additional power consumption. It introduces optimal BS deployment without going through usual iterative techniques that used in cellular network planning tool like WinProp.
2. The performance gains of small cell deployment underlay to the existed macro BS is investigated in terms of capacity and energy efficiency. Performance of the network with and without deployment of small cell compared. This helps for understanding of better performing network architecture for planning and deployment of cellular network.
3. Small cell deployment gives an energy efficient network optimization options for network operators like ethio telecom.

1.8. Thesis Layout

This thesis document organized in to five chapters. The first chapter concentrates on introduction of this thesis. It introduces problem statements, thesis objectives, methodologies used, previous works related to this thesis, scope and its contributions. Chapter 2 deals with background and overview of mobile cellular network in general. Particularly it focuses on LTE, small cell concepts, and network capacity and energy efficiency enhancement techniques that can be employed in cellular network. Basic concepts of genetic algorithm also briefly discussed in this chapter.

Chapter 3 addresses system models and assumptions used in this thesis work. In this chapter capacity and all related parameters used in formulation and calculation is included. It includes the network model, propagation models, SINR and overall capacity formulation. It also addresses energy efficiency measuring metrics and small cell deployment strategies. In addition, it gives detailed illustrations on performance metrics that to consider while proposing solution. Optimization problem formulation consisting the objective function with supposed constraints also considered.

The fourth chapter describes the simulation parameters and discusses relevant results obtained. Finally, chapter 5 finalizes the main points and results.

Chapter 2 Overview on Cellular Network and Genetic Algorithm

This chapter presents background of materials related to this thesis work. It begins with conceptual overview of cellular network, small cell concepts, power consuming components of BS followed by cellular network energy efficiency and capacity enhancement techniques.

2.1. Basic Concepts of Cellular Network

A cellular network is a wireless radio network where coverage is divided into a number of geographic coverage areas called cells[13] in which each cells include a fixed location transceiver known as BS. It enables UEs to communicate through radio interface. Initially, it was created to deliver only analog voice services. It has now grown noticeably with advanced technology and allow access to data services, Multimedia Message Services, VoIP, etc to end user. In general, typical cellular network architecture comprises mobile stations, radio access network, core network and external public networks such as PSTN and global internet network. Mobile station creates direct interface to subscriber for talking, texting and data services.

The RAN constitutes of radio access controller and one or more base transceiver station. RNC is responsible for radio resource management and configurations like channel assignment, handover control and power control. It also manages several BSs at a time and connect them to the core network while the base transceiver station creates an interface between the mobile station and RNC[2]. The main responsibility of core network is switching and controlling voice/ data calls between radio access network and other networks (PSTN, PLMN and global Internet). Development of cellular network shows enormous advancement from early first generation, which is analog in nature, to the late fourth generation.

First generation mobile networks, which was first introduced in Japan in 1979, were reliant upon analog radio systems that meant that users could only make phone calls. While the second generation, commonly known as GSM, was developed in 1990s to carry real time services in circuit switched manner, with data services only possible over circuit switched modem connection with very low data rates. The first step towards an IP based packet switched solution was taken with the evolution of GSM to GPRS[14].

A new access technology, third generation, called WCDMA was developed to reach higher data rates in Universal Mobile Terrestrial System (UMTS). In the third generation, circuits switched was emulated and packet switched connection was used for data services[14]. The Access network node in third generation is commonly known as NodeB. The third generation delivers higher data rate than generations prior to it. It can provide a speed up to 14.4 Mbps.

In fourth generation, LTE, all services carried by IP protocol where the IP address allocated when the mobile handsets switched on and released when mobile handsets switched off. Figure 2.1 summarizes generations in mobile communication.

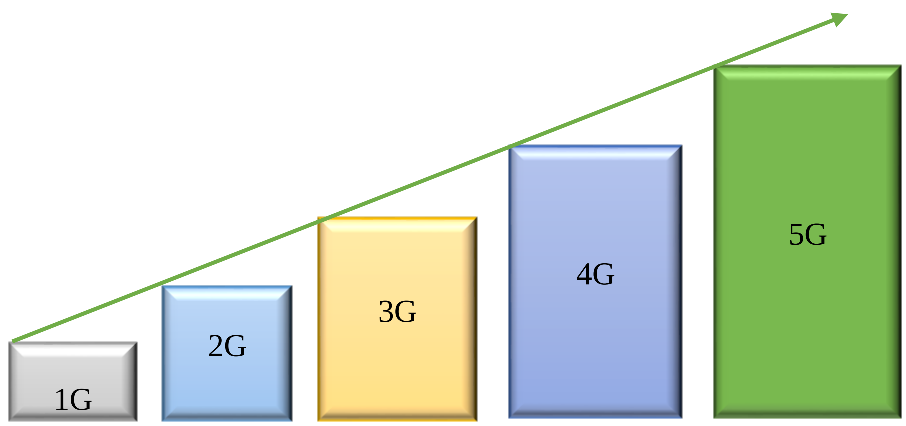


Figure 2.1 Generations in mobile system

Some basic concepts of LTE is discussed in section 2.2. below.

2.2. Long Term Evolution Basics

Long Term Evolution is a standard developed by 3GPP for wireless communication of high data rate and low latency with improved capacity and coverage performance. LTE technology offer significantly improved data rates over prior generations of wireless technologies. Faster broadband connections enable wireless carriers to support higher-level data services, including video streaming and messaging, business applications, mobile TV, and gaming[14].

LTE is based on an all IP packet switched network with high data rate and low latency supported mobile broadband access and multi-media applications. The main requirements for LTE access network are high spectral efficiency, high peak data rates, short round trip time as well as flexibility in frequency and bandwidth.

a) LTE Architecture

As depicted in Figure 2.2, LTE system architecture constitutes of four main domains namely user equipment (UE), evolved UTRAN (E-UTRAN), evolved packet core network (EPC) and service layer.

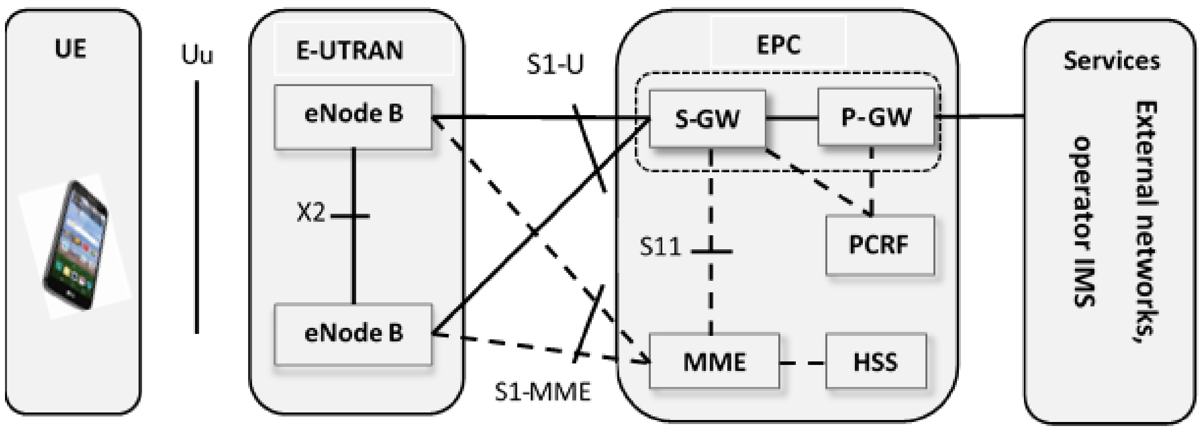


Figure 2.2 LTE System Architecture[15]

i. **User Equipment (UE)**

In 3GPP, UEs described as any devices that end user uses for communication. Hand held devices such as smart phone or a data card such as those used currently in 2G and 3G, or it could be embedded, e.g. to a laptop. UEs for LTE expected to support highest data rates. The UEs contains Universal Subscriber Identity Module (USIM) that is used for identification and authentication of users and it derive security keys to protect radio interface transmission. The radio interface between UE and E-UTRAN is known as Uu.

ii. E-UTRAN

The only node in the E-UTRAN is the evolved Node B (eNodeB). The eNodeB is a radio BS that controls all radio related functionalities such as controlling the usage of radio interface including allocating resource based on request, constant monitoring of resource usage and prioritizing and scheduling traffic according to required QoS. As depicted in Figure 2.3 below E-UTRAN is a mesh of eNodeBs connected to neighboring eNodeBs through X2 interface.

The eNodeBs act as a layer2 bridge connecting UE and the EPC being the aggregation node of the radio protocols to the UE. It also performs signal measurements by itself, controlling, and analyzing the radio signal strength measurements carried by UEs[14]. The S1 interface in Figure 2.3 connects the eNodeB to MME and S-GW. Specifically the S1 interface identified as S1-MME and S1-U respectively when used to connect eNodeB to MME and S-GW.

iii. Evolved Packet Core (EPC)

3GPP has decided to have flat architecture in LTE system and introduced an all packet switched core known EPC in their release 8 standard. As can see in Figure 2.2 the EPC is composed of four key elements: Serving Gateway(S-GW), Packet Data Network Gateway (P-GW), Mobility Management Entity (MME) and Home Subscription Server (HSS). All the constituents of EPC have their own functionalities[16].

S-Gateway: The Serving Gateway deals with the user plane and interconnect the radio side and the EPC to serve UEs by routing the ingress and egress IP packets.

P-Gateway: The Packet Data Network Gateway interconnects the EPC and external IP network. It routes packets to and from the external network. P-GW also performs IP address / IP prefix allocation or policy control and charging[16].

HSS: Home Subscription Server is a central database that contains user and subscriber related information. It also supports mobility management, call and session setup, authentication and access authorization.

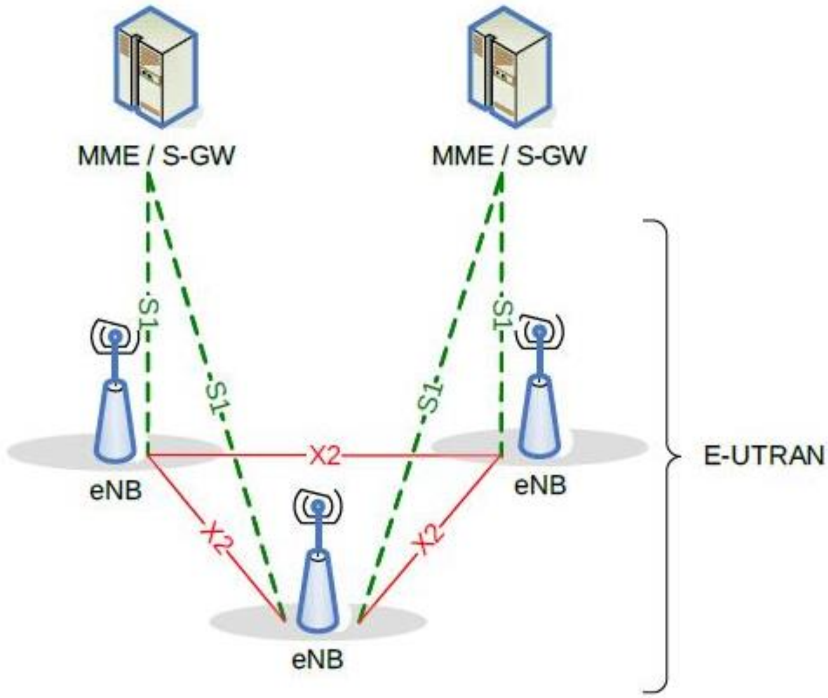


Figure 2.3 E-UTRAN Architecture[14]

Mobility Management Entity (MME): MME is a server in secure location in the operator's premises and it is the main control element in the EPC. MME is responsible to handle E-UTRAN access security and mobility related signaling. When a UE registers to the network for the first time, the MME initiates the authentication with the aid from the Home Subscription Server (HSS). It also responsible for retrieving subscription profile and the tracking and the paging of UE.

b) Spectrum Allocation in LTE

Choice of frequency spectrum is one of the main factors to be considered in cellular network deployment. Multiple band options are available for 2G, 3G and 4G/LTE networks. LTE frequency bands are divided as paired and unpaired bands. Paired bands are used by frequency division duplex (FDD), one for the uplink and one for the downlink, and time division duplex (TDD) uses unpaired bands. 3GPP LTE is developed to support both the TDD and FDD. Table 2.1 shows the FDD bands and related frequencies. LTE uses flexible frequency allocation with 1.4, 3, 5, 10, 15 and 20 MHz supported channel bandwidth options.

Table 2.1 LTE operating frequency band for FDD duplex mode[17]

FDD Bands and Frequencies					
LTE Band	**Frequency (MHz)**	**Uplink(MHz)**	**Downlink (MHz)**	**Duplex spacing (MHz)**	**Channel Bandwidth(MHz)**
1	2100	1920-1980	2110-2170	190	5, 10, 15, 20
2	1900	1850-1910	1930-1990	80	1.4, 3, 5, 10, 15, 20
3	1800	1710-1785	1805-1880	95	1.4, 3, 5, 10, 15, 20
4	1700	1710-1755	2110-2155	400	1.4, 3, 5, 10, 15, 20
5	850	824-849	869-894	45	1.4, 3, 5, 10
7	2600	2500-2570	2620-2690	120	5, 10, 15, 20
8	900	880-915	925-960	45	1.4, 3, 5, 10
10	1700	1710-1770	2110-2170	400	5,10,15,20
11	1500	1427.9-1447.9	1475.9-1495.9	48	5, 10
12	700	699-716	729-746	30	1.4, 3, 5, 10
13	700	777-787	746-756	-31	5, 10
14	700	788-798	758-768	-30	5, 10
17	700	704-716	734-746	30	5, 10
18	850	815-830	860-875	890	5, 10, 15
19	850	830-845	875-890	45	5, 10, 15
20	800	832-862	791-821	-41	5, 10, 15, 20
21	1500	1447.9 – 1462.9	1495.9 – 1510.9	48	5, 10, 15
22	3500	3410 – 3490	3510 – 3590	100	5, 10, 15, 20
24	1600	1626.5 – 1660.5	1525 – 1559	−101.5	5, 10
25	1900	1850 – 1915	1930 – 1995	80	1.4, 3, 5, 10, 15, 20
26	850	814 – 849	859 – 894	45	1.4, 3, 5, 10, 15

c) LTE Technologies

As compared to prior cellular networks, LTE come up with different new technologies. These technologies enabled the LTE to operate more reliably to provide high data rate, and proper spectrum utilization. Multi-input multi-output (MIMO), orthogonal frequency division multiplexing (OFDM) and single carrier frequency division multiple access (SC-FDMA) are the most important technological innovations introduced in LTE.

Multi input Multi output:- MIMO is one of the important technologies introduced in LTE to improve performance such as capacity by using multiple transmit and receive antennas to significantly improve the radio interface. MIMO employs multiple antennas on the receiver and transmitter to utilize multipath signal propagations effect that exist to transmit additional data. Figure 2.4 depicts simple MIMO system when Tx and Rx represent transmitter and receiver respectively.

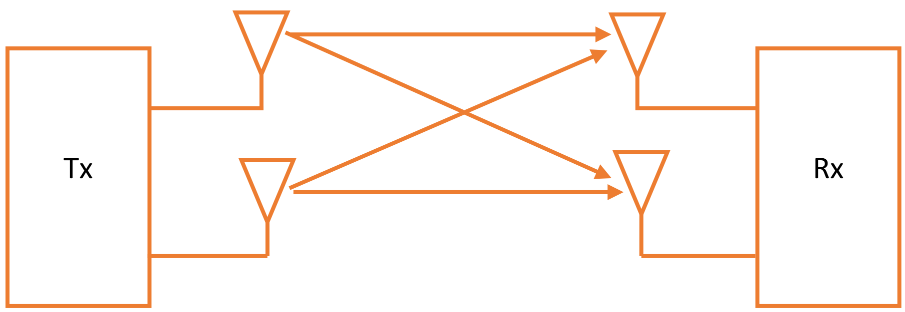


Figure 2.4 Multiple input multiple output

Orthogonal frequency division multiplexing: - OFDM is a multicarrier technology introduced in LTE in order to subdivide the available bandwidth into a multitude of orthogonal narrowband subcarriers that can be shared between multiple users. The OFDM solution leads to high Peak-to-Average Power Ratio (PAPR) requiring expensive power amplifiers with high requirements on linearity, increasing the power consumption for the sender[14]. 3GPP considered ODFM in the downlink direction of radio transmission.

The principle of the OFDM is based on the use of narrow, mutually orthogonal subcarriers. In LTE, the subcarrier spacing is typically 15 kHz regardless of the total transmission bandwidth[18]. Different subcarriers maintain orthogonality, as at the sampling instant of a single subcarrier the other subcarriers have a zero value, as depicted in Figure 2.5 below. The resources of OFDMA in LTE is into resource blocks (RBs). Each resource block has 180 kHz bandwidth with 12 subcarriers in every resource block.

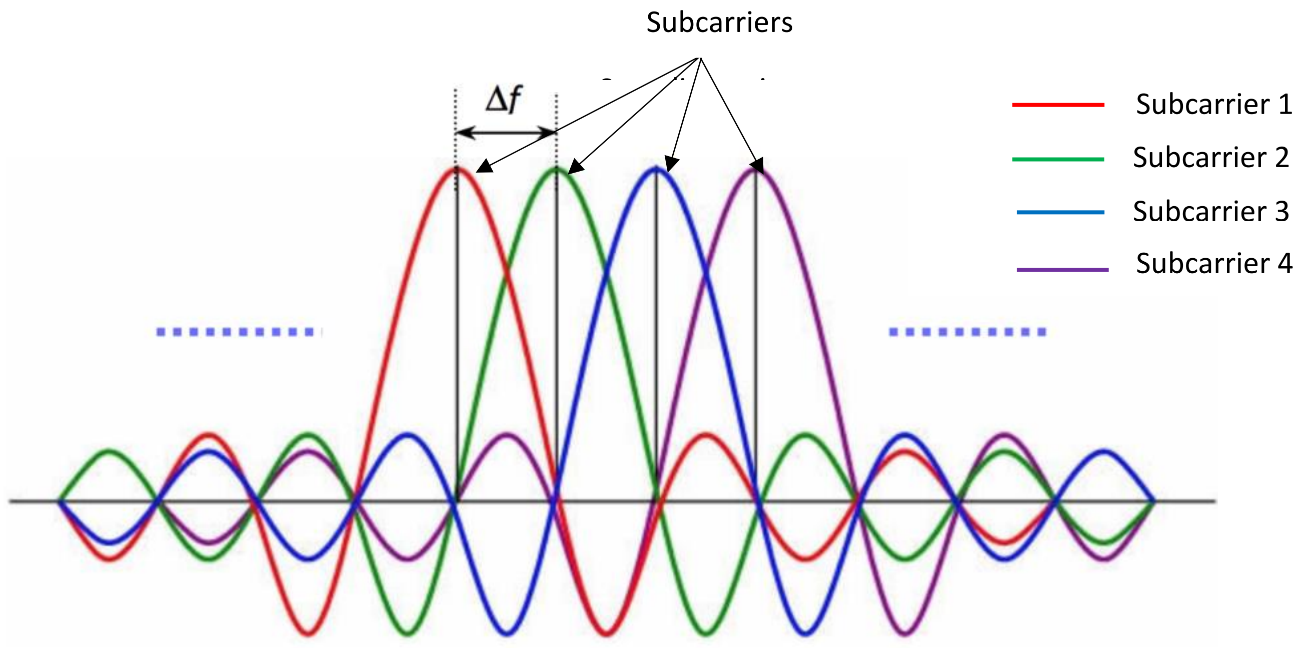


Figure 2.5 Adjacent subcarrier with OFDM[18]

Single carrier frequency division multiple access: - In LTE, the downlink and uplink transmission uses different multiple access. The uplink transmission requires minimized PARP to enable use of low cost, energy effective power amplifier in the user handset. 3GPP uses SC-FDMA for multiple access in the uplink direction. Similar to the TDMA systems in GSM, only one modulated symbol is being transmitted in SC-FDMA.

LTE has various advantages over previous cellular network technologies. These includes

- It offers improved spectrum utilization
- It support more users cell
- It provides high data rates
- Has low latency
- It provides higher data bandwidth
- Scalable bandwidth

2.3. Small Cell Concepts

A small cell is a miniature BS that breaks up a cell site into much smaller pieces to use multiple smaller cells instead of macro cell[19]. Small cells are normally used in densely populated urban areas, such as shopping centers, sports venues, airports and train stations and anywhere there is many people using data at a given point in time[19].

They used to offer improved coverage and enhanced capacity. Being small in size, low cost and low power consumptions makes them preferable to use for enhancement of capacity and coverage in today's macro cell environment. They are preferable for coverage radius of 50-200 meters and transmit power of 0.1 to 10 watt[20]. Their power consumption and coverage depends on their type and size. The type of small cell include femtocells, picocells and microcell[21].

Femto cell: - has smallest coverage area covering a radius of up to 50 meter. It typically used in indoor environment, which transmit power up to 100mW and can support up to 16 simultaneous users. Femto cells are suitable for enterprise area with building heights not greater than 10 meter and for residential consumers.

Pico cell: - Pico cell has larger in coverage area than femto cells covering average radius of about 200 meters and can be used in both indoor and outdoor environment supporting up to 130 simultaneous users. Its transmit power ranges from 250mW to 2W for outdoor deployment and 100mW or less for indoor environment. Pico cells are suitable for public hotspot areas and enterprise area with building heights greater than 10 meter and less than 200.

Micro cell: - The Micro cell have larger coverage area than pico covering a radius of up to 1km and deployed in urban and high-density areas of outdoor environments. Micro cells have a potential of supporting 200 simultaneous users. Table 2.2 shows the difference between conventional macro BS and well-known small cell types with characteristics such as transmission power, number of simultaneous users, maximum radius they can cover and suitable location for their deployment[20][21].

Table 2.2 Comparison between BSs

BS type	Power (w)	User	Cell radius (km)	Location	Installation
Macro	10-60	>200	More than 30	outdoor	Operator
Micro	0.5 to 10	200	≤ 1km	Indoor/outdoor	Operator
Pico	0.1 to 2	130	≤ 0.2	Indoor/outdoor	Operator
Femto	0.1	16	≤ 0.05	Indoor	Customer

Deployment of 3GPP small cell in general have the following benefits.

- Offload traffic from macro cell and deliver dedicated capacity to homes, enterprises and urban hotspots. Offloading improves network performance and quality of service.
- Because less devices share bandwidth of single cell small cells allow higher data rate for end users.
- Backhaul of small cells rely on already existed infrastructure. Thus, the need for site rental and backhaul provisioning is less.
- Extend coverage at the edge of macro cell where the signal strength from the macro BS is weak.
- Lower power consumption and have potential of improving energy efficiency.

2.4. Cellular Network Capacity and Energy Efficiency Enhancement Techniques for LTE

2.4.1. Capacity Enhancement Techniques

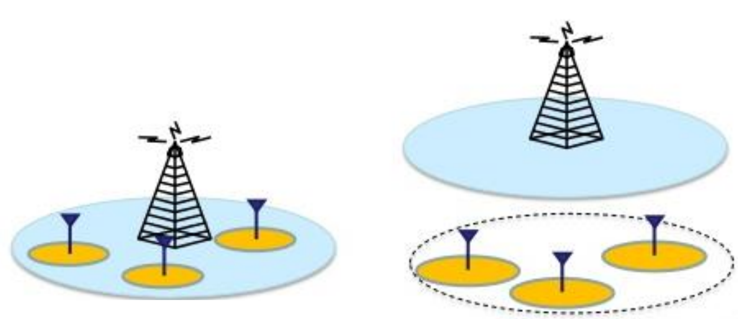
There are different techniques of enhancing cellular network capacity. Carrier Aggregation, Site densification, MIMO and small cell deployment are among the techniques.

Carrier Aggregation: - Carrier aggregation is a technology introduced by 3GPP release 10 to combine two or more carriers of in the same or different frequency bands into one channel to enhance user data rate. [22]. Each aggregated carrier is referred to as a component carrier, CC. The component carrier can have a bandwidth of 1.4, 3, 5, 10, 15 or 20 MHz and a maximum of five component carriers can be aggregated. Hence, the maximum aggregated bandwidth is 100 MHz. In FDD, the number of aggregated carriers can be different in DL and UL. However, the number of UL component carriers is always equal to or lower than the number of DL component carriers. The individual component carriers can also be of different bandwidths.

Site Densification: - Due to the increase in data traffic volume, network capacity becomes exceeding the maximum capacity provided by pre-existed sites. In this situation, user experience will be affected and additions of new sites becomes necessary. Adding macro sites in densely populated areas raises issues such as insufficient space for installing antennas and cabinets, high space rental fees, and difficulty of finding suitable sites. In a dense urban environment, deploying macrocell is becoming harder.

Small Cell Deployment: - Due to points raised in section 2.3, small cell deployment brings advantages of increasing network capacity. Since they hold small places, rental fees, insufficiency of getting new installing place is minimal and suitable than macro BS for densification, too.

Small cell deployment scenario can be overlay or underlay to macro BS. When small cells installed where signal strength is weak at the edge of the area covered by conventional macro BS, it is called the small cell is overlay to macro BS. This type of deployment is used to enhance network coverage and throughput of mobile users at the edge. When small cell deployed in the network area already covered by macro BS, the small cell is said underlay to macro BS. This type is preferred mainly when these cell are required to improve network capacity and fill coverage holes that may happen, for example, due to shadowing from building. Figure 2.6 below depicts the two types of deployment scenarios. In figure 2.6a small cells and the macro cell coexists in a single carrier while in figure 2.6b small cell uses dedicated carrier.



a) Small cell underlay to macro BS

b) Small cell overlay to macro BS

Figure 2.6 Small cell deployment scenario [21]

Even though the deployment of small cell brings advantages, it is not free of challenges. Additional small cell deployment brings additional interference, which might affect user experience negatively.

MIMO: - MIMO is also one of the important LTE technology to enhance network capacity by allowing multiple antennas to transmit and receive simultaneously.

2.4.2. Energy Efficiency Enhancement Techniques

In cellular network, the concept of energy efficiency can be considered at planning and deployment, and operation levels. Numerous techniques available to improve energy efficiency of cellular radio network. Improving energy efficiency of hardware component, turning off BS components, renewable source usage, cell zooming and small cell deployment are some among numerous techniques.

Improving energy efficiency of hardware components: - BSs, which consumes about 57% of the total energy consumed by cellular network is the most energy hungry device***.*** Among different components that constitutes BSs, power amplifier consumes most of the energy, about 65%[5], supplied to this device. The power amplifier operate in a more linear region of power curve from 6 to 12dB below saturation[23]. As an option to improve the energy efficiency of power amplifier, techniques like clipping and digital pre-distortion with Doherty-architecture[8],[23], GaN (Aluminum Gallium nitride) based power amplifiers considered more promising by taking the power efficiency levels to over 50%[8].

Turning off components during off-peak hour: - From capacity point of view, dimensioning of number of BSs required in cellular radio network planning is based on estimation of peak hour traffic demands. In practical scenario, traffics varies from hour to hour in a day. There are hours in a day when there is very low traffic demands and high traffic demands. However, the BSs planned for high traffic demands kept active 24/7 whether they have or not have traffics to serve. It is believed that there will be good energy saving if some resources or the entire BS having low traffic load turned off.

In the literature [7],[24], component or BS turn off technique during non-peak traffic hour is discussed. Approaches in turning off normally try to minimize or save power consumption by monitoring traffic load in the radio network and based on the load it then decide whether to turn off 'certain elements such as power amplifier, cooling elements, signal processing units or the entire BS during off-peak hour[7]. Turning off components or BS operation is also known as sleeping mode. Sleeping of BS can be done dynamically or statically[24],[25].

Adoption of dynamic sleep mode operation requires automated methods to switch off and ON components or the BSs between off-peak and peak hours of the day. This enables the BS activity to be adapted to the traffic demand avoiding the waste of energy due to the peak dimensioning[25].

Using renewable energy resources: - BSs located at off-grid sites regularly rely on powers from diesel generators which is expensive and generates carbon dioxide (CO_2) emission[7]. Such sites may also be very remote and air transportation like helicopters required to physically transporting fuel for the generators, which adds cost for the operators. In such cases, renewable energy such as solar and wind energy is more viable to reduce the network expenditure cost.

Cell Zooming: - cell zooming is one of an ongoing research work for energy efficient operation of cellular network. Cells zoom in and zoom out depending on load to balance traffic load and reduce energy consumption. Implementation of cell zooming requires different techniques which includes physical adjustment, BS cooperation and relaying[26]. The physical adjustment involves increasing or decreasing transmit power, antenna height adjustment and tilting. When the traffic load in a certain cell increases, the cell will zoom in to reduce the coverage area and therefore avoid possible congestion. The "service hole" will be taken care of by the neighboring cells with less traffic, which are supposed to zoom out.

Cell zooming requires zooming server which sets zooming parameters based on traffic load distribution, user requirement and channel state information[26]. The cell zooming server first sense state information of the network, such as traffic load, channel conditions, user requirements, and so on. After collecting the information, the cell zooming server will analyze whether there are opportunities for cell zooming and make decisions. If a cell needs to zoom in or zoom out, it will coordinate with its neighbor cells with the help of the zooming server.

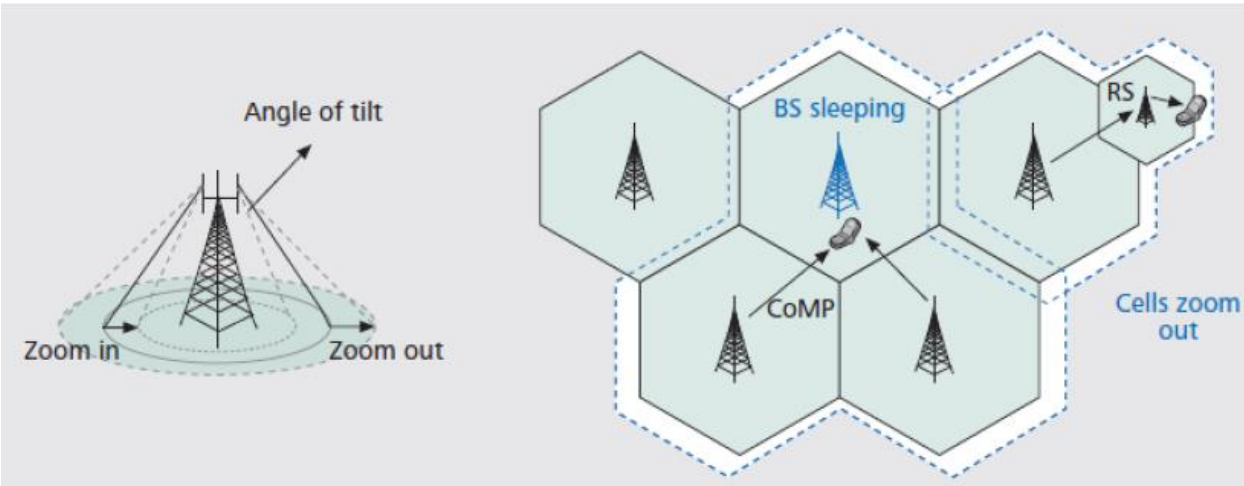


Figure 2.7 Techniques to implement cell zooming[26]

Deploying small cells: - Another way to tackle the problem of energy efficiency is deploying small cells including micro, pico and femto cells in cellular radio network [3],[7], [27]. These cells serve small areas, as compared to macro BS, with dense traffic with low power consumption. Small cells are available for user deployment and support plug-and-play feature[7], [28]. In small cell deployment, the propagation distance between nodes in the network and between nodes becomes short and their deployment is very close to the end user. Because of these, small cell deployment reduces energy consumption in network as compared to conventional macro BS.

2.5. Overview of Genetic Algorithm

GA is search based optimization technique based on the principles of natural selection. It is used to find feasible solutions and converge to the near optimum. GA can yield global finest solution and avoid probability of being held to local optima. The basic elements of genetic algorithm are the genes, the chromosomes and the populations.

The chromosome consist of genes and determines characteristics of the individuals (set of possible solutions). The population consists set of chromosomes, which participates to the evolution process. Performance of GA is determined by size of population where too small size population led to local optimum solution while time complexity increase as population size increases too much.

GA implementation follows different steps. Initialization of population, fitness evaluation, selection and crossover, and mutation are among fundamental steps considered[30].

Initialization: Initialization involves random generation of the initial population, allowing complete range of possible solutions.

Fitness evaluation: Fitness value of each chromosome is calculated according to the fitness function.

Selection and crossover: This involves selection of chromosomes that have higher fitness value from current population and exchange gene fragments among selected chromosomes for creation of new generation.

Mutation: Mutation procedure is another way to generate high-diversity populations by randomly changing some genes according to a given mutation probability.

Termination: Repeat the above selection, crossover and mutation process until the fixed number of generations is reached or the best fitness value is no longer increasing

Chapter 3 Assumptions, System Models and Optimization Problem Definition

This section presents an overview of the system model, capacity, energy consumption model, deployment area and the necessary mathematical formulations and tools used also presented in this chapter.

3.1. General Description

For the purpose of this study, about 2x2 kilo meter area taken in the capital city, Addis Ababa. The chosen area extends from Mesqel square and includes areas between Mesqel square to around Wello-Sefer. In this area, fourteen live macro BS are already existing, as can see in Figure 3.1, in the period of this study with the BSs configured with 2G, 3G and LTE network. All existing macro BS are three sectored with each sectors having its own configuration in terms of antenna azimuth angle, antenna down tilt and so on. Small cell candidate sites will be selected in the coverage area of these macro sites with selection criterions described later in this chapter.

Users at some pixel in the area can be served from either macro BS or small cell. Set of macro BS is given by $B = \{1, 2, 3, \dots, 14\}$ where 14 is the total number of macro BS installed in the study area in which each has three sectors. Every sector of the macro BSs is considered as cell. Thus, the number of cells in the total M macro BS is 3xM, which can generally be expressed as

$$J = \{1,2,3, \dots ,42\} \; where \; Mc \; is \; equals \; 3 \; xM.$$

The candidate small cells also denoted as $C = \{1, 2, 3, \dots, N\}$ where N is total number of small cell selected as candidates in the study area. Unlike macro BS, small cell assumed to use omnidirectional antenna. The overall set of cells in the study area is the union of the set containing all the macro and the small cells. It can be written as $L = J \; U \; C = \{l_1, l_2, l_3, \dots, l_{3M+N}\}$.

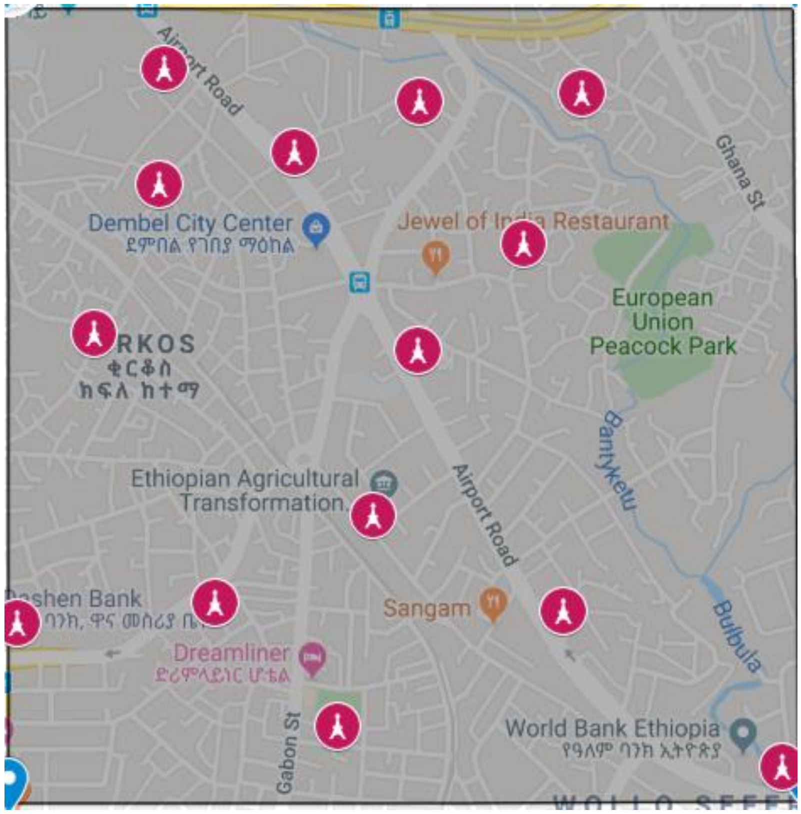


Figure 3.1 Macro BS relative location

Figure 3.2 depicted below generalize the major tasks going to be performed. Mathematical formulation include power consumption, capacity and energy efficiency modeling. The power consumption modeling bases on reference materials and it is used to highlight power consumption modeling in BS. More importantly, it is used to estimate amount of power consumption of the BS under preferred transmission power taken.

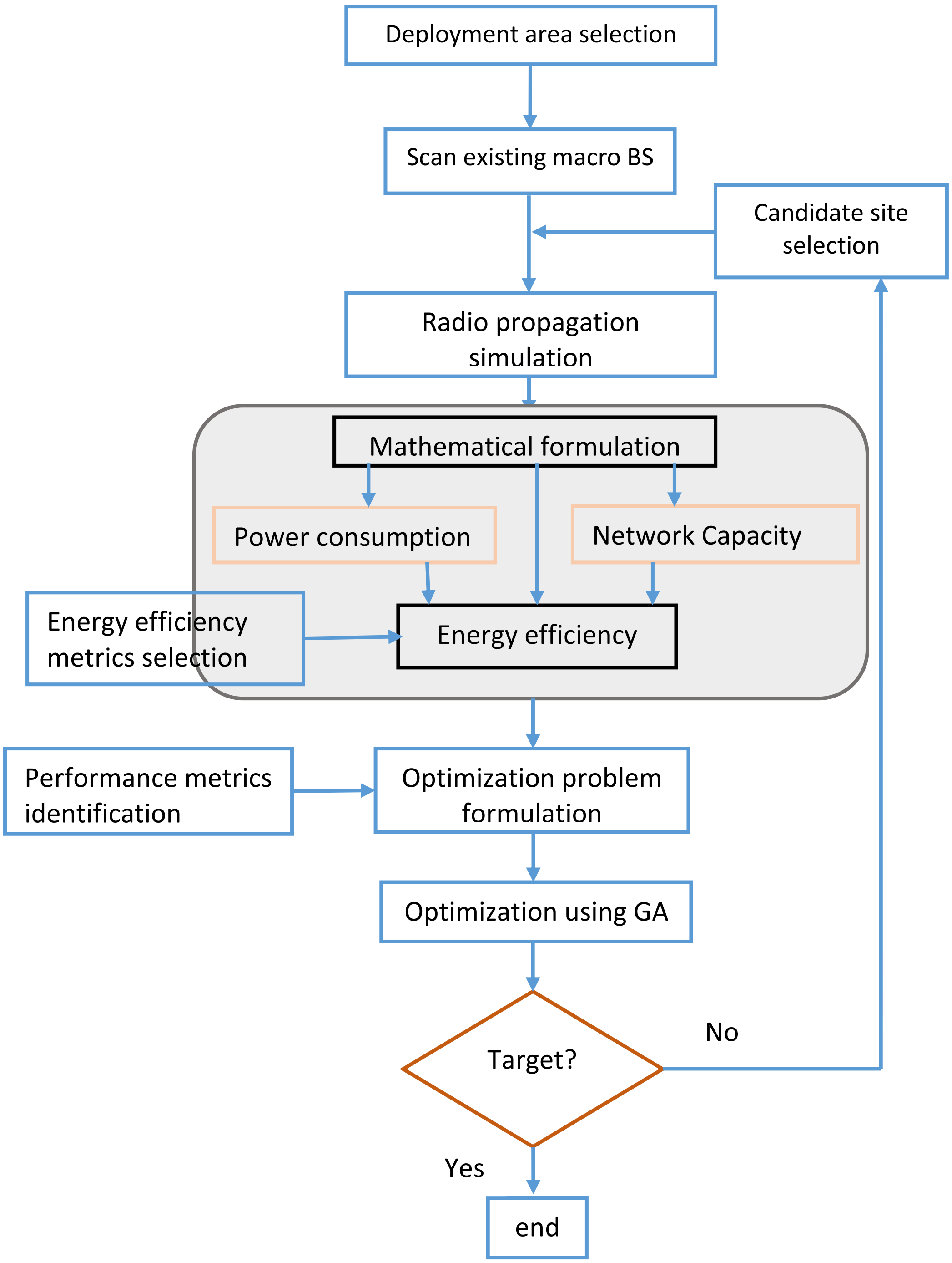


Figure 3.2 System Model

3.2. Power Consumption Model

In order to quantify power consumptions in BS systems, modeling the consumption is required. The consumption of a BS is the overall sum of its component consumptions that is broken into two categories, static and dynamic. The power consumed by components such as cooling, base band unit, rectifiers are always existed independent of traffic carried by BS and are called static power consumption. In addition, the power consumed by radio units is called dynamic and varies based on the traffic load.

Power consumption modelling is a mathematical formulation that averages power consumption of all the components to a single equation that binds dependent and independent variables. In this regard, the total required input power is the sum of all the powers consumed by each components of typical BS, which can be summarized as dependent and independent components. When the power consumption varies with data traffic it is called traffic dependent, otherwise traffic independent[29]. Figure 3.3 shows interdependence between power consumption and data traffic. Equation (3.1) thus gives total power consumption where $P_{consumption}$ stands for the total power consumed by BS and $P_{independent}$ and $P_{dependent}$ respectively indicate traffic independent and traffic dependent power consumption of given BS.

$$P_{consumption} = P_{independent} + P_{dependent} \qquad 3.1$$

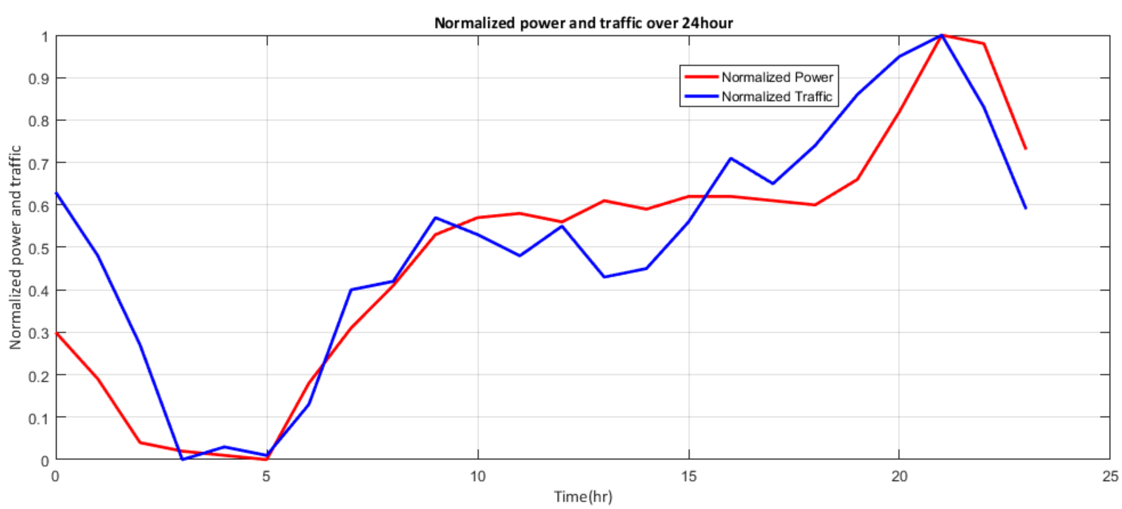


Figure 3.3 Normalized power and data traffic

The power consumption by remote radio unit is considered as traffic dependent. So dependent power consumption is the same as the power consumption obtained from radio unit. Traffic dependent power consumption for BS depends on the number of sectors and number of transceiver antennas configured. If BS is configured with N number of sectors and M number of antennas per sector, its power consumption becomes

$$P_{dependent} = P_{\sec tor1} + P_{\sec tor2} + .. = N * M * P_{\sec tor} \quad 3.2$$

The traffic independent power consumption is the sum of power consumed by the base band unit and other environment monitoring units including the cooling power consumption.

$$P_{independent} = P_{BBU} + P_{cooling} + \mathrm{P}_{rectifier} + others \quad 3.3$$

According to [30],[31],[32] the total power consumption(Pc) modeled linearly as shown below with the first term indicating traffic independent power consumption and the second term gives the traffic dependent power consumption which varies with traffic supported in a given time.

$$P_c^{mc} = P_s^{mc} + \alpha^{mc} P_{tx}^{mc} \quad 3.4$$

$$P_c^{sc} = P_s^{sc} + \alpha^{sc} P_{tx}^{sc} \quad 3.5$$

Superscript **mc** and **sc** represent macro cell and small/micro cell, where $\boldsymbol{P_c^{mc}}$ and $\boldsymbol{P_c^{sc}}$ respectively represent total power consumption of macro and small cell, with P_s, $\boldsymbol{\alpha}$ and P_{tx} respectively stands for static power consumption, load scaling-factor and transmit power. These parameters have different value for macro and small cell. In [32],[6] these values are obtained for BSs under full load state. However, in the context of this study, the load-scaling factor , α, will be modified at least for macro BSs to fit to its current load. Modification of the load-scaling factor follows the following steps.

1. Collecting daily traffic data on hourly basis.
2. Determining the maximum (T_{max}) and average (T_{ave}) daily data traffic for every macro BSs.
3. Determining load factor. Load factor determination for each of the BSs is done by taking ratio of average traffic to maximum traffic, that is,

$$Load\ factor = \frac{T_{\mathrm{ave}}}{T_{\max}}$$

4. The new traffic load-scaling factor, which is a constant multiplier for transmission power, is estimated by multiplying load factor result obtained on 3 with numerical value 15.9 taken from literatures for full load BS.

After obtaining factor $\boldsymbol{\alpha}$ for each, corresponding power consumption is calculated based on equation (3.4). Table 3.1 shows the power consumption obtained by the aforementioned steps. The overall network power consumption with hybrid deployment of macro and small cell given by equation (3.6) where M and N stands for number of macro and small cells respectively.

$$P_{tot} = M * P_c^{mc} + N * P_c^{sc} \qquad 3.6$$

According to Huawei documentation[33], [34] LTE BS power consumption reaches its maximum when the BS works with 100% load and it is said to have 1455w power consumption at this load.

Table 3.1 Macro BS power consumption

BS	Traffic Load	Modified traffic Load-scaling(α^{mc})	MBS Power Consumption
B1	0.656	10.428	1129.32
B2	0.557	8.848	1066.12
B3	0.579	9.202	1080.28
B4	0.83	13.194	1239.96
B5	0.907	14.429	1289.36
B6	0.64	10.176	1119.24
B7	0.875	13.916	1268.84
B8	0.629	9.999	1112.16
B9	0.826	13.132	1237.48
B10	0.81	12.872	1227.08
B11	0.707	11.243	1161.92
B12	0.753	11.967	1190.88
B13	0.47	7.467	1010.88

B14	0.567	9.011	1072.64
Macro BS Total Power			16206.16

3.3. System Capacity

One advantage of small cells is to increase throughput of users since they can be placed easily very close to the users. Since most of users' data is in the downlink, the link from BS to user equipment is considered for calculation of network capacity. The maximum throughput of each macro BS in the deployment area is as shown in Figure 3.4. In the figure, it shows that the maximum throughput is about 60 Mbps, which is obtained by taking daily traffic of the BSs.

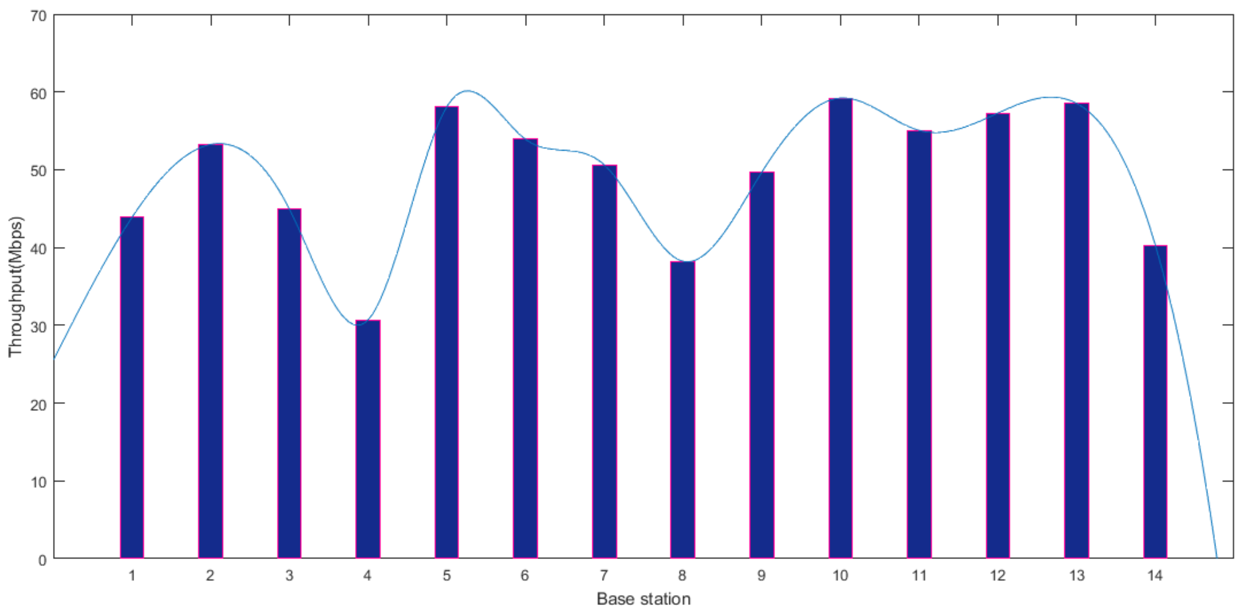


Figure 3.4 Throughput per BS site

Figure 3.5 depicts procedures used for network capacity calculation. Formulation of user throughput and overall system capacity is based on Shannon capacity. The basic components in formulating and calculating network capacity is also discussed below.

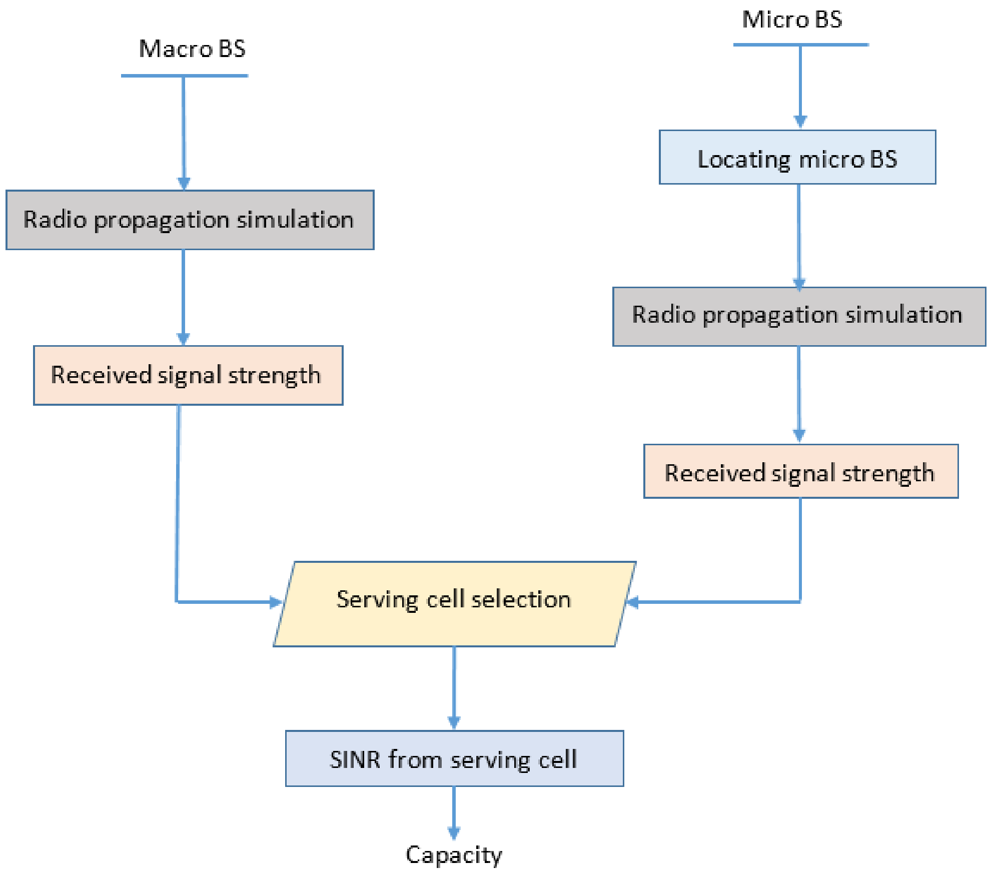


Figure 3.5 Capacity calculation approach flowchart

Propagation Model: In wireless communication system, information is exchanged between transmit and receive antenna via propagation of radio waves. The strength of transmitted signal becomes weak as it propagates through the environment[35]. The signal strength difference, measured in units of power, between the transmitter and receiver is called path loss (PL)[35], [36]. To quantify and determine PL radio propagation models are used. These models classified as empirical and deterministic model. While empirical models based on measurement data, the deterministic model is site-specific requiring enormous number of geometry information about the site and is accurate and better for real network scenario than empirical models. Thus, in this thesis work, deterministic model, specifically called dominant path model, is used.

Dominant path loss model: Dominant path model is on the fact that not all power rays between the transmitter and receiver contribute with similar energy to the total power received; only few propagations paths are dominant in terms of energy input. It concentrates only on the dominant paths and does not calculate the paths with small energy contribution. Likewise, it does not consider all the details of the database, requiring less time to pre-process it.

The dominant path model follows two steps to computes path loss[37]. Determining dominant path (geometry) and loss predictions along the path. The path loss (PL) along the path is thus given as:

$$PL = 20\log\left(4\pi/\lambda\right) + 20p\log(D) + \sum_{i=0}^{n}\alpha(\varphi, \iota) + \sum_{j=0}^{m}w_j - \Omega \quad 3.7$$

Where;

p: visibility factor for line of sight and non-line of sight conditions between current pixel and transmitter

$\alpha(\varphi, \iota)$: determine loss in dB due to interaction and changing direction of propagation

φ: angle between former direction and new direction of propagation

λ: Wavelength in meter

D: separation distance in meter between transmitter and receiver

w_j: Transmission loss of wall j

Ω: Wave-Guiding factor

Penetration Loss: Penetration loss indicating fading of radio signals from indoor terminal to a BS (eNodeB in LTE system) due to obstruction by building. It depends on building nature and environment type of the coverage area. Table 3.2 below shows penetration loss for different environment.

Table 3.2 Penetration loss range for different[38]

Environment	Penetration loss (dB)
Dense Urban area	19-25
Urban area	15-18
Suburban area	10-14
Rural area	6-8

Thermal Noise: Thermal noise is a loss due to heat and can be formulated as

$$N = KBT \tag{3.8}$$

Where K is Boltzmann constant (1.38 *10^{-23} J/K), T is the absolute Temperature in kelvin and B is channel bandwidth.

Shadow fading: shadow fading (SF) indicates the fading due to obstruction like building. Since it changes slowly, it is called "slow fading"[39]. Shadow fading is modeled with lognormal distribution with time and location at certain time and location.

Receive Power: receive power is the signal strength received at the receiver end.

$$P_{rx} = P_{tx} + G_{tx} - PL - otherLosses \tag{3.9}$$

Where P_{tx} delivered power for transmission of information, G_{tx} transmitter antenna gain, PL is path loss respectively. Losses such as penetration loss and shadowing loss, encountered as the signals travels from transmitter to receiver taken as others losses.

A user is assumed associated to the best server BS among the available possible BSs. The best server can be either macro or small cells. Its selection is based on the received signal level in which the best server serving a user is the cell from which received power is the highest. User at pixel k is served from cell j of macro BS M when received power from the cell is greater than maximum of all other received power form others cells. The relation is expressed as (3.10) where P_{rk}^{sci} is the received power at pixel k from micro cells and $P_{rk}^{Mj\prime}$ is received power at pixel k from all macro BS cell other than j.

$$P_{rk}^{Mj} > \max(P_{rk}^{Mj'}, P_{rk}^{sci}) \qquad 3.10$$

Likewise the user at pixel k is served from small cell i when

$$P_{rk}^{sci} > \max(P_{rk}^{Mj}, P_{rk}^{sci'}) \qquad 3.11$$

In general, the received power (P_{rk}) from serving cell can be expressed as

$$P_{rk} = \max(P_{rk}^{MJ}, P_{rk}^{sci}) \qquad 3.12$$

SINR

In wireless communication, signal strength received at the receiver is weak as compared to the transmitted signal strength. The quality of the signal at the receiver is measured by taking factors such as thermal noise, and interfering strength of other simultaneous transmissions. One way of measuring quality of wireless connection in wireless communication is by using SINR.

SINR indicate how the desired signal is stronger as compared to the sum of interference and noise power. Determining the SINR requires the following main points.

- Determining whether the user is serving from macro cell or small cell. All other cells other than serving cell becomes interfering cells
- Calculating signal strength received from the serving cell
- Calculating the interference signal strength from all the interfering cells. Based on deployment scenario and frequency use, the interfering cell may include macro cells and small cells. That is macro cell transmission may interfere small cell transmission and vice versa.
- Calculating the thermal noise power

Mathematically SINR is given as

$$SINR = \frac{P_{rx}}{Interference\ power + Noise\ power} \qquad 3.13$$

Where interference power is the sum of all received signal power other than the desired signal. When macro BS and small cell shared the same frequency channel and the small cell installed underlay to the macro BS, signals from both macro BS and small cell interfere to each other.

For a user at pixel k serving from cell 'j' of macro BS, SINR is given as

$$SINR^{Mj} = \frac{P_{rk}^{Mj}}{\sum_{\substack{j=1, \\ j' \neq j}}^{Mc} P_{rk}^{Mj'} + \sum_{i=1}^{N} C_x P_{rk}^{sci} + No} \quad 3.14$$

Where

P_{rk}^{Mj}: Received power from macro BS serving cell

P_r^{sc} : Received signal power from small cells interfering serving macro cell

$P_r^{Mj'}$: Received signals from other macro BSs cells interfering the serving cell

C_x: indicate a vector showing small cells with x ranges from one to maximum of small cells to be deployed at candidate site

N_o: Noise power

Likewise, for a user located at pixel k serving from small cell 'i', SINR is given as

$$SINR^{sci} = \frac{P_{rk}^{sci}}{\sum_{j=1}^{M} P_{rk}^{Mj} + \sum_{\substack{i=1 \\ i' \neq i}}^{N} C_x P_{rk}^{sci'} + No} \quad 3.15$$

Where P_r^{sci} is received power from serving small cell.

In general, SINR at pixel k is given by

$$SINR_k = \frac{P_{rk}}{\sum_{j=1}^{M} P_r^{Mj} + \sum_{i=M+1}^{N} C_x P_r^{sci} - P_{rk} + No} \quad 3.16$$

Finally, the capacity measured by bit per second at the pixel points is quantified by Shannon capacity, which is the basic method to calculate channel capacity. Given bandwidth, B, of the channel, generic Shannon formula is given as

$$C = B * \log 2(1 + SINR) \quad 3.17$$

Due to several limitation in implementation, standard Shannon capacity approximation in (3.17) cannot be reached practically. In practical system, bandwidth and signal to interference plus noise ratio affected by different implementation inefficiencies[15]. To account those inefficiencies a modified Shannon formula is used[12] [15]. The modified Shannon formula for capacity at pixel k is given by

$$C_k = B_{PRB} * \min\left[S_{\max},\ B_{eff} * \log 2\left(1 + \frac{SINR_k}{SINR_{eff}} \right) \right] \tag{3.18}$$

The overall capacity of a network in a given area is the aggregate sum of capacity of users at each pixel points. Therefor it is expressed as

$$C_{Net} = \sum_{k=1}^{N_k} C_k \tag{3.19}$$

Where N_k *is the total number of test points* in the given network

From (3.18), S_{max} *is* maximum spectral efficiency given by bits/s/Hz. B_{eff} is a parameter for correcting overhead effects to bandwidth efficiency, which is reduced due to various issues. The parameter $SINR_{eff}$ used for adjusting SINR implementation efficiency. Because of adjacent channel leakage ratio and filter implementation, bandwidth occupancy is reduced by 10%. Cyclic prefix reduced the bandwidth approximately by 6.6% for system bandwidth level efficiency while 6% is approximated due to pilot assisted channel estimation overhead. In addition, ideal channel estimation for dual antenna transmission took about 11%.

$\mathrm{B_{PRB}}$ is resource block bandwidth, which is a product of number of resource block, and bandwidth of single resource block. In LTE, resource block is the smallest unit of resources that can be allocated to a user. It contains 12 subcarriers each having 15kHz bandwidth. This implies a resource block has a bandwidth of 180 kHz.

Adjacent Channel Leakage Ratio (ACLR) shown in Table 3.3 defined as the ratio of the transmitted power to the power in the adjacent radio channel. Both powers are measured after a receiver filter[40].

Cyclic Prefix is a guard interval between successive symbols to reduce intersymbol interference and provide robustness. Cyclic prefix reduce data capacity since already being transmitted data is retransmitted again.

Table 3.3 System bandwidth efficiency[15]

Impairments	System BW_{eff}
Adjacent channel leakage ratio	0.9
Cyclic prefix	0.93
Pilot overhead	0.94
Dedicated and common control channel	0.715
Total	0.562

3.4. Energy Efficiency Modeling

Energy efficiency may refers to as how much energy it takes to achieve certain amount of work[23]. It can also be defined as reducing the amount of energy required or the use of energy in an optimum manner to achieve certain service or to perform specific task. Different metrics are used to measure and quantify energy used and its level of efficiency in devices like BSs or systems like cellular radio network.

3.4.1. Measuring Energy Efficiency

In cellular network, certain amount of energy is consumed to transport bit information from BS to mobile users. There is also energy requirement for radio signals to cover and provide network connectivity over certain areas. In dense urban areas like Addis Ababa, the amount of information bits are more or equally important to the area that the network covers. However, for sparsely populated area, the likes of rural areas, area coverage is more important. Energy efficiency in cellular network can be measured at one of the following levels[8].

Component level: component level measurement involves specific buildup component of BS. These includes design and implementation of hardware like power amplifier, coolers etc. components level is quantified by taking the ratio of the output to the input power.

Equipment level: This is defined to evaluate performance of an individual equipment. Equipment level sometimes called link level. It include energy-aware transmission and resource management schemes such as power control.

Network level: Network level measurement of energy efficiency at network level involves topological methods from planning and deployment to operation. It assess the performance of the network equipment like BS while also considering features and properties related to capacity and coverage of the network[5]. It includes systematic planning stage deployment by using small cells like small cell and dynamic BS on/off based on awareness of its traffic.

A suitable energy efficiency measuring metrics is very important to provide quantified information about the energy efficiency of the network. Selection of the level depends on the goal. If the goal is to measure one of the components in the BS, PA for example, components level measurement is used.

Different energy efficiency measuring metrics can be used to quantify the efficiency level of the power consumption. At the network level, energy efficiency is generally measured in average power consumption required to serve user or power required to cover certain network area.

For BS in rural areas, demand for voice service is assumed greater than demand for data usage. In such a case, the amount of power consumption that is required to cover certain area becomes more important and the energy efficiency level can be quantified by taking total power consumption per unit area.

For data users the amount of information bits per second is more important. BSs consume certain amount of power to deliver the information to the users. According to [28],[6] the ratio of capacity and total power consumption is used. In this study too, the energy efficiency of the network is formulated as the ratio of total network capacity, C_{Net}, to the total power consumption, P_{tot}.

$$EE = \frac{C_{Net}}{P_{tot}} \tag{3.20}$$

$$EE = \frac{\sum_{k=1}^{N_k} C_k}{M * P_c^{mc} + N * P_c^{sc}} \tag{3.21}$$

Where $N_{k,}$ C_k, M and N stands for number of test points, throughput at test points, number of macro and small cells respectively.

The comparison between the energy efficiency of the macro BS only network and the energy efficiency after the small cells being deployed can be done by energy consumption gain. Energy consumption gain (*ECG*) is given as equation (3.22) below where EE_{tot} is the energy efficiency with the deployment of small cells and $EE_{macro}$is the energy efficiency of the network before the small cells being deployed. Energy consumption gain below one indicate deploying the micro cell have undesirable effect on energy efficiency as it means that the energy efficiency after micro cell deployment is reduced than network consisting only macro BS. If ECG is greater than one, it means deploying small cells have improved overall energy efficiency of the network. Similar concepts can be taken to easily identify whether the deployment of small cell has improved the aggregate capacity of the network as compared to original macro BS only network.

$$ECG = \frac{EE_{tot}}{EE_{macro}} \tag{3.22}$$

3.5. Tools

In this study, network simulation, radio propagation simulation, is used for obtaining signal loss. The radio simulation done both for existing macro BSs in the area of interest and for small cell candidate sites are first selected within the coverage area of macro BSs. WinProp and MatLab are the main tools used in this thesis work. While the WinProp is for radio simulation, the MatLab is for system level simulation and Plotting. The aim of radio propagation simulation is to obtain propagation loss and MatLab simulation is to observe effects of small cell and identify optimal number of small cell.

WinProp:- WinProp is radio propagation modeling tool used for estimation of path loss in different environmental scenarios (rural, urban, indoor, tunnels, etc...) and for network planning of different air interfaces (LTE, 3G, 2G, etc...) using propagation models like dominant path model. WinProp requires topography and 3D building database. Apart from propagation modeling, it can provide network simulation results. It has different graphic user interfaces including ProMan, WallMan, AMan and CMan.

3.6. Small cell Deployment Scenario

Small cell can be customer deployed or operator deployed where there is a need to enhance network performance in terms of capacity, quality and coverage extension. In addition to these, the network operators also deploy small cells to reduce their operational expenditure that mainly due from operational level power consumption.

It is possible to put the small cells either underlay to the existed macro BS or overlay to the macro BS based on interest of performance gains required in the network. They can be deployed at the edge when coverage extension is more important. However, since enhancing network capacity is one of the aims of this study, it is more important to deploy the small cells underlay to the existing macro BS than to deploying them at the edge of the areas covered by these macro BSs. Therefore, outdoor deployment scenario using similar frequency band as the existing macro BS is considered and their deployment follows the following steps.

1. **Candidate site selection: -** In BS deployment, it is important to identify as many feasible locations as possible. The initial numbers of the small cells limited based on the identified feasible locations. Among the possible feasible locations, candidate site need to be selected or all the feasible locations can be considered as candidates if they were selected properly by considering traffic distributions and they are not too much in number. Figure 3.6 shows traffic distribution in the selected deployment area based on traffic volume, which was classified into three, specifically lower, medium and higher. Traffic distribution with high volume were primarily selected to make the cell very close to those high demand users to minimize distance between the data users and the serving BSs. When the cell closes to the users, they will have good probability to be selected and they offload the traffic from macro BSs so that energy consumption is minimized. Locations for candidate sites should not overlap with that of existing macro BS and the steps for the candidate site selection described as below.
    - Get traffic distribution

- Select points with high traffic demand
- Select hotspot and shopping areas

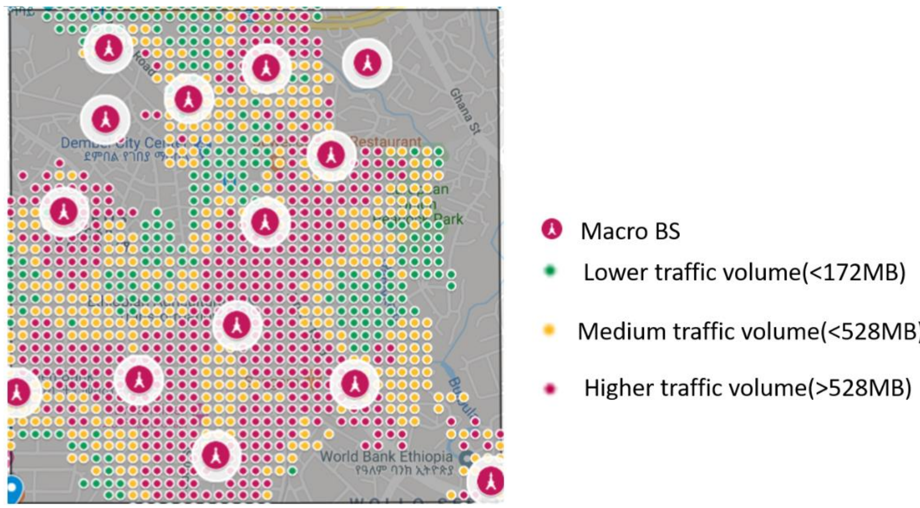


Figure 3.6 Traffic distribution

2. Initial placement and simulation

After the candidate site selection, initial placement and first stage simulation on WinProp comes next to obtain path losses at each pixel points. The candidate micro sites location represented as (xi, yi) where the values denote the actual geographic earth coordinate.

Related to this, 149-candidate small cell sites were selected and deployed with minimum 50 meter inter site distance. In Figure 3.7, the dots represent the small cells candidate site. However, the configuration on the WinProp is not shown here for clarity purpose.

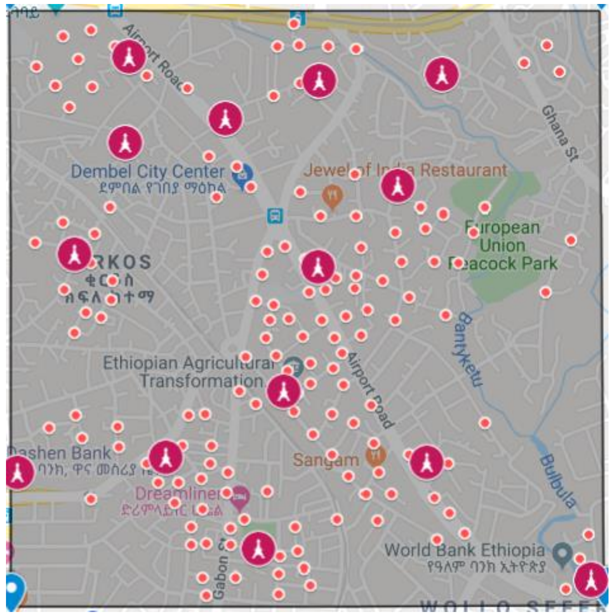


Figure 3.7 Small cell candidate site

3. Optimization

Finally, after completion of WinProp simulation for both macro and small cells optimization process carry on. The optimization is required to minimize the number of small cell while keep enhancing network capacity and energy efficiency.

3.7. Optimization Problem Formulation

This section describes the problem formulation for the optimization process with brief description on objective functions related to the performance metrics and the proposed algorithm used in this thesis work.

3.7.1. Objective Functions

In optimization problem, there should be a mechanism for evaluating individual values whether they fit or not to defined problem. Function that offer this mechanism is called fitness function or objective function. The objective function here focuses on three performance metrics. These are; aggregate network capacity, number of small cell and network energy efficiency denoted f_1, f_2 and $f_3$respectively as described below.

Table 3.4 Summary of Performance parameter

Performance Metrics	Objective
Total Capacity	*Maximizing*
Number of Small cell	*Minimizing*
Energy efficiency of the system	*Maximizing*

Decision variable (C_x)

The network in this study incorporate 14 macro BS and 149 assumed possible small cell candidate locations defined using geographical coordinates. Some of the candidate locations may not be good enough to be chosen for the intended objectives. Selection among the candidates is indicated by the decision variable, which is a binary variable indicating whether a candidate small cell is selected or not. A binary number 1 shows the small cell is selected to be deployed and 0 implies the small cell is not selected.

$$C_x = \begin{cases} 1, if\ candidate\ x\ is\ selected \\ 0, otherwise \end{cases} \tag{3.23}$$

- **Network capacity (f_1)**

  In cellular network, daily traffics vary between off-peak and peak hours. During off-peak hour, the demand gets low and high at peak hour. Macro BSs that have already installed in areas of interest are enough to handle the off-peak hour data. However, sometimes macro BSs are insufficient to handle peak hour traffics. Therefore, in order to fill the insufficiency gap of the macro BS, small cells can be considered as a solution. In this study, small cell are used and the aggregate network capacity, which is the sum of capacity from macro and small cell is given by section 3.3. The objective function here is to maximize the aggregate capacity,C_{Net} and it is expressed as

$$f_1 = \max C_{Net} \tag{3.24}$$

- **Number of micro cell (f_2)**

Deployment of small cell aimed to increase network capacity when there is a demand in area of deployment. However, deploying alone does not guarantee that network capacity increases. The network capacity is affected by the intensity of interference, which increases as far as the number of small cells installed increases. In order to minimize effect of interference on network capacity, number of small cells needed for the requirement of capacity demand should properly selected among identified candidate sites. Determining the number and respective locations of small cell to be deployed can improve network capacity by reducing radio interference of neighboring BSs and reducing their number will increase energy efficiency. Therefore, optimizing locations and number of small cell that underlay to the conventional macro cell is important. The objective function here is formulated to minimize number of small cells required to satisfy capacity constraint. The total small cell selected is the arithmetic sum of binary numbers 1 and 0, where N_s and C_x stands respectively for number of small cell and candidate small cell.

$$f_2 = \min \sum_{x=1}^{Ns} C_x \qquad 3.25$$

- **Network energy efficiency (f_3)**

Maximizing network energy efficiency is realized by either increasing network capacity while consuming same power or by providing same capacity with minimized power consumption. In this study, network capacity is assumed to increase by deployment of additional small cell. However, the deployment of additional small cell will increase the power consumption, which increases with increased number of small cell. Therefore, maximizing energy efficiency requires enhancement of network capacity and reduction of additional power consumption that may resulted from deployed small cells. The additional power consumption can be reduced by minimizing number of small cell via selecting the best among the possible candidates.

Network energy efficiency is given by the ratio of network capacity to total power consumption as already defined in section 3.4. With this definition, an energy efficient cellular radio network topology is the network that satisfies capacity constraints and at the same time consumes the minimum possible energy to deliver required level of information bits. The objective function in this approach is to maximize the energy efficiency defined in equation (3.21), which can be expressed as follows.

$$f_3 = \max\left(\frac{C_{Net}}{M * P_c^{mc} + \sum_{x=1}^{Ns} C_x * P_c^{sc}}\right) \quad 3.26$$

3.7.2. Optimization Problem

Maximizing energy efficiency requires enhancement of total capacity while reducing number of small cells at the same time. The optimization problem is thus to produce f_1, f_2 and f_3 that more generally expressed as (3.27).

$$\min\left[-f_1, f_2, -f_3\right] \quad 3.27$$

The problem is subjected to different constraints such as number of micro cell and network capacity. The maximum number of small cell shall not be greater than the number of candidates. In addition, network capacity and energy efficiency with the deployment of small cells should not fall below respective initial values. If it is not an increase for them, both capacity and energy efficiency should remain unchanged. If either capacity or energy efficiency increase as one of them start decreasing for some selected small cell, the number of small cell for which capacity or energy efficiency start declining limits required number of small cell. In any case, the number of the small cell cannot be greater than the number of possible candidates assumed. In addition, the network capacity resulted with selection of small cell should not be less that the initial value defined. According to results from WinProp simulation and calculated capacity for the existed macro BS based network, the initial capacity of the network in the area is defined as 243Gbps. Thus the constraints for the optimization function becomes

Co1: $\sum_{i=1}^{N} C_x \leq$N

Co2: $C_x \epsilon \{0,1\}$

Co3: $C_{Net} \geq C^M$

With Co1: limits the number of the candidate location that can be considered. It shows that the total sum of 1's cannot exceed the total number of possible candidate small cell. In this study, N equals 149.

Co2: indicates the domain of the decision variable with binary values either 0 or 1. These two numbers can be considered as lower and upper boundaries of f_2.

Co3: indicate the current maximum possible capacity of the network before micro cell deployment. The value of C^M is pre-defined capacity for network consisting only macro BSs. The new total capacity C_{Net} must be greater than the initial value.

Chapter 4 Simulation Parameters, Result and Discussion

As per system models and performance metrics described in chapter 3, simulations for defined small cell deployment scenario will analyzed and discussed in this chapter.

4.1. Simulation Parameters

Outdoor deployment scenario considered with the small cells deployed underlay to the existing macro BSs. For the small cells, antenna height of about 10 meters above ground and constant power consumption assumed. Constant and single valued transmission power is used for macro BS and the energy efficiency of macro BS is tested for different transmission power that adds to constant non-traffic dependent power. Other parameters for macro BS's radio propagation simulation are based on planning and current configuration data collected from the service provider.

Candidate locations for small cell selected near streets, both main road and feeder streets close to residential users and shopping areas where traffic assumed high. They placed separated minimum 50 meter because the more they close the more interference challenge and if they placed more far apart, the possibility of having more candidates to test on the required performance metrics would be less. As a result, this may create unoptimal result than having more candidates to test. For both BS types, similar carrier frequency were taken and users assumed uniformly distributed. Table 4.1 summarizes the simulation parameters used.

Table 4.1 Network simulation parameters

Simulation parameters and assumptions		
Parameter		Value /Assumption
Deployment scenario		Outdoor small cells deployed underlay to macro network
Simulation	Radio propagation modeling	Using WinProp, 5m resolution
	System level simulation	Using MatLab
Propagation model		Dominant path loss model

Building penetration	20dB
B_{eff}	0.56
$SINR_{eff}$	2
S_{max}	4.4
Data PRB	100 RBs for 20MHz bandwidth
Channel Bandwidth	20MHz
Prediction height	1.5m
Macro Cell Parameters	
Frequency	1800MHz
Antenna Height	Variable, and values taken same as already configured value
Transmission Power	46dBm
Antenna Gain	18dBi
Antenna Pattern	Kathrein 742215, sectored antenna
Shadow Fading	8 dB
Small Cell Parameters	
Micro cell candidate locations	149 locations
Frequency	1800MHz
Antenna Height	Omni-directional antenna locating 10m above ground
Antenna Gain	5 dBi[6]
Transmit Power	38 dBm
Shadow Fading	4dB
Genetic Algorithm Parameters	
Population size	200
Snapshot	200
Number of variables	149
Power Model Constants	
Macro BS	P_s^{mc}= 712.2, α^{mc}= 15.9 [32],[6]
Small cell	P_s^{sc}= 106, α^{sc}= 5.5 [32],[6]

4.2. Results and Discussion

4.2.1 Network Capacity

It is believed that deploying small cell boosts user throughput as they can be placed very close to the user location. However, some of the locations where the small cell assumed to be deployed may not be good location to enhance aggregate capacity of the network. Because of interference, some candidate locations may have negative impact on network performance; even it may worsen the overall performance of the system.

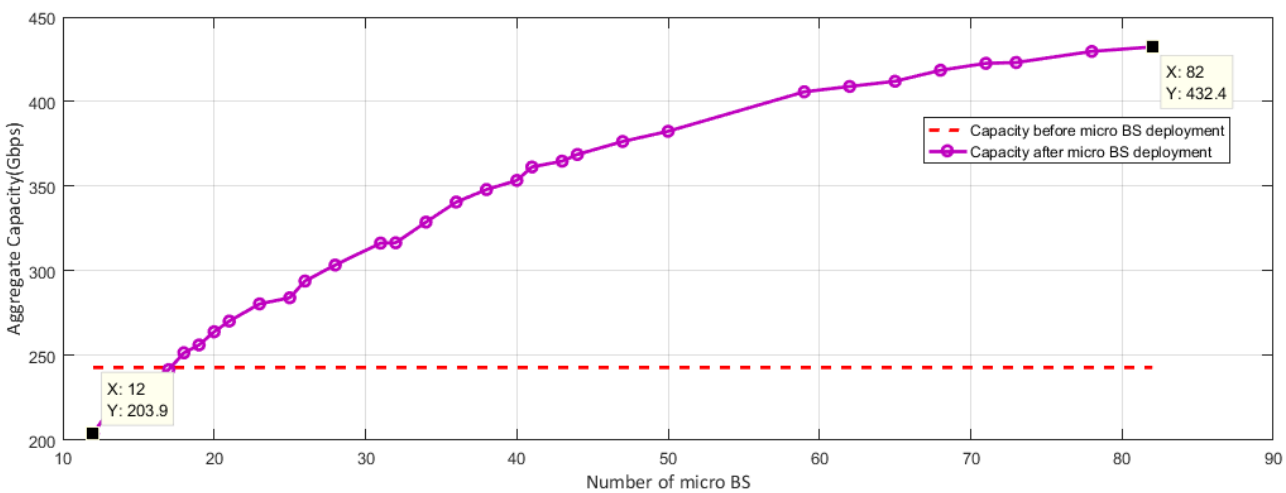


Figure 4.1 Aggregate capacity with small cell deployment

Figure 4.1 portrays how aggregate capacity of the network have changed with deployment of small cell. In Figure 4.1, the horizontal dotted line indicates the initial capacity of the network before deployment of small cell that were obtained by using equation (3.18) after WinProp simulating the existing network to get path loss. The path loss values were taken as an input to calculate necessary parameters such as received power and SINR. As can see in the figure, the aggregate capacity increases up to some point as number of small cell increases. Different aggregate capacity values obtained for different number of small cell. From 149-candidate small cell, combination of 82 selected to take the capacity to 432.4Gbps that is the maximum value obtained in this study.

The capacity increment slowed down for the highest number of small cell selected as compared to the lower number of the small cell. For instance, there is a change of 113.2Gbps between 47 and 18 small cell among the selected 82 small cell while the change is only 67.5Gbps between 82 and the first 47 small cell selected. In general, the network capacity improved for small cell counted 18 and above, where the capacity improved by 3.58% and 77.94% respectively for 18 and 82 small cell, that is the minimum and maximum capacity that could obtained.

4.2.2 Energy Efficiency

As already mentioned in previous chapters, energy efficiency is measured by taking the capacity and total power consumption obtained after deployment of small cell. Figure 4.2 describes energy efficiency of network with deployment of small cell. It shows an increase in energy efficiency of the network with number of small cell until optimal energy efficiency value has obtained. The dotted red straight line in the figure shows the initial point of energy efficiency before the deployment of small cell.

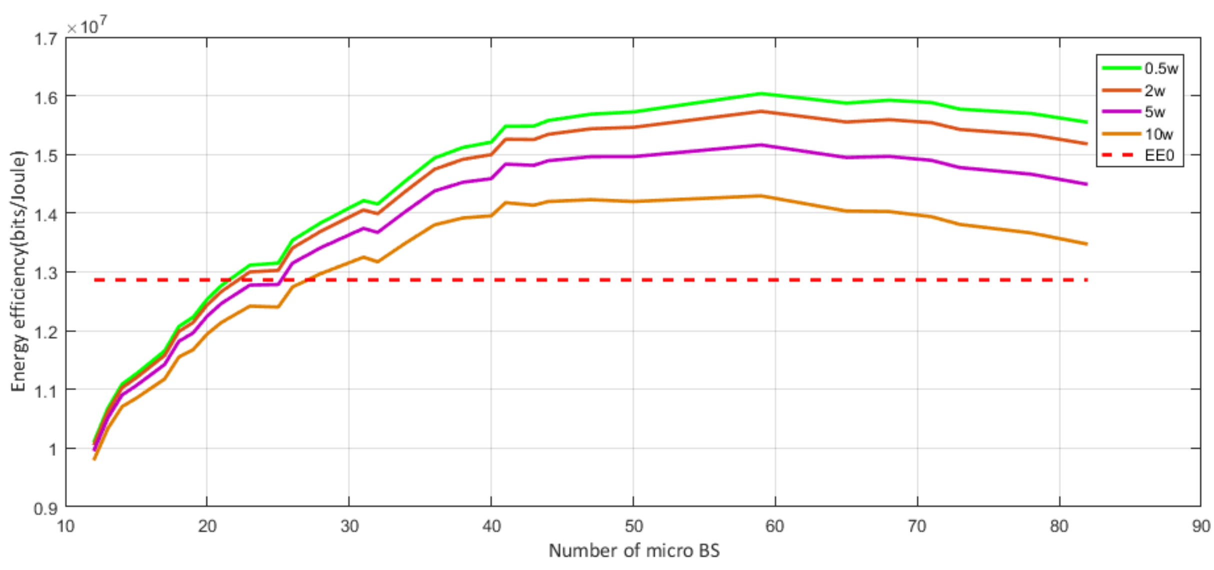


Figure 4.2 Energy efficiency with small cell deployment

As in aggregate capacity, different energy efficiency values are obtained for different deployed number of small cell. Some of the small cells has improved the energy efficiency while some others produced unwanted result where their deployment reduced the energy efficiency value. For example, energy efficiency has improved for 23 or above small cell while it is less than the initial value for small cell less than 23 in any case. From Figure 4.2, it can be observed that energy efficiency achieved quickly and falls slowly for small cell transmitting at lower power than small cell transmitting at higher power. From Figure 4.2, small cell transmitting at lower power can achieve better energy efficiency than BS transmitting at higher power. The same amount of energy efficiency obtained at different number of small cell. For instance, to improve energy efficiency by 17% it requires 36, 40 and 47 small cell transmitting respectively at 0.5watt, 2watt and 5watt when the same amount cannot achieved by BS transmitting at 10watt. From Figure 4.1 and Figure 4.2, it can be observed that aggregate capacity of the network remains increasing until it reaches to its maximum while the network energy efficiency falls below its maximum achieved value. The maximum energy efficiency achieved is 24.7%, 22.32%, 17.88% and 11.12% respectively for BS transmitting at 0.5watt, 2watt, 5watt and 10watt.

Table 4.2 Performance comparison

	Macro only	**Maximum possible value after small cell deployment**	**Improvement**	**Number of small cell achieving maximum value**
Aggregate capacity(Gbps)	243	432.4	77.94%	82
Network EE(bits/Joule)	1.286*10^7	1.6036*10^7	24.7%	59

Table 4.2 above compares capacity and energy efficiency of the network after micro deployment with the original macro only network. After deployment of small cell, the energy efficiency has improved by 24.7% where 59 small cell required achieving this improvement. At the same time, the aggregate capacity has improved by 77.94%, which requires 82 small cell for its achievement.

The improvement of the aforementioned performance metrics can easily be observed by employing capacity and energy consumption gains. Table 4.3 shows capacity and energy consumption gain with deployment of small cell. Energy efficiency improvement requires 23 or more small cell stations while 18 small cell enough for the capacity improvement.

Table 4.3 Capacity and Energy consumption gain with small cell deployed

Number of Small cell	Capacity gain	Energy Consumption gain			
		0.5watt	2watt	5watt	10watt
12	0.839	0.785	0.781	0.773	0.761
15	0.951	0.876	0.871	0.86	0.844
18	1.036	0.939	0.932	0.919	0.898
20	1.087	0.975	0.967	0.952	0.929
23	1.155	1.02	1.011	0.993	0.966
26	1.21	1.053	1.043	1.022	0.991
31	1.302	1.105	1.093	1.068	1.03
40	1.455	1.183	1.166	1.134	1.085
44	1.518	1.211	1.193	1.158	1.104
50	1.574	1.223	1.202	1.163	1.104
59	1.67	1.247	1.223	1.179	1.112
68	1.723	1.238	1.212	1.164	1.091
78	1.768	1.221	1.193	1.14	1.062
82	1.779	1.209	1.18	1.127	1.048

Chapter 5 Conclusion and Future Works

5.1. Conclusion

With rapid growth of mobile communication, cellular networks have practiced unparalleled demands for higher data rates and reliable service quality. Due to this increasing demand, networks are evolving from structures with high power macro BS to small cell structure with low power BSs. The small cell structure is advantageous to enhance network capacity with lower power consumption. With small cell deployment, not only the network capacity and energy efficiency bettered, but also the deployment and operation costs. This is because small cells are miniature in size and lessens land acquisition cost.

In this thesis work, deployment of small cell in the coverage area of macro BS has been performed with objective of enhancing network capacity with more energy efficient network architecture. Potential deployment methods, energy efficiency measuring metrics were studied. Small cell candidate locations were identified based on high demands and other criteria.

Performance metrics in relation to the deployment of small cell were identified with the potential metrics being number of small cell, network capacity and energy efficiency of the system. Optimal numbers of small cells were selected by using genetic algorithms. The algorithm selects combinations of small cell with best locations that fulfil the required performance metrics. In this thesis work, both WinProp and MatLab used for radio propagation and system simulation respectively.

The aggregate network capacity increased to a maximum of 77.94% for a maximum 82-selected small cell. The obtained optimal energy efficiency is 24.7% when transmitting at 0.5watt. When transmitting at moderate power, the maximum energy efficiency of 17.88% achieved with 59 small cell. Since energy efficiency declines for selected BS more than 59, we can conclude the deployment is energy efficiency limited. With this, 66.99% network capacity improvement achieved. The overall results shows that it is better to use lower transmission power for small cells than using higher transmission power for better energy efficiency.

5.2. Future Works

Although numerous studies have been made on small cell deployment, the present thesis focuses on studying small cell deployment in selected area of Addis Ababa under outdoor deployment scenario where the small cell placed underlay to existing macro BS aiming to enhance network capacity with a more energy efficient network architecture. The small cells were selected after preparing their candidate locations. Ones these BSs selected, they always remain active whether they have or not have data users to serve. This study improved further in the future by considering proactive way of planning and deploying the small cell.

This study was limited to deployment of small cell for enhancement of network capacity and energy efficiency. For this purpose, the small cell were deployed under the coverage area of preexisting macro BS. However, it can be implemented where extension of network coverage is required. In addition, energy efficiency evaluation was done with the assumption that the network operates at full load. Conversely, traffic varies between its maxima, during peak hour, and minima during off peak hour. With this, energy efficiency can be improved by considering operation level evaluation methods such as sleeping mode and cell zooming techniques.

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