



Addis Ababa University  
Addis Ababa Institute of Technology  
School of Electrical and Computer Engineering  
Genetic Algorithm-Based Small Cell Switch-Off at Low Load Traffic  
for Energy-Efficient Heterogeneous Network

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

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Addis Ababa, Ethiopia

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## Declaration

I, the undersigned, certify that this thesis is my original work and does not integrate without acknowledgement any material previously submitted for a degree or certificate at any other university or school of higher learning. To the best of my knowledge, it does not contain any previously published or authored work by another individual, save as acknowledged in the text.

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The above candidate has carried out research for the master's thesis under my supervision.

Adivisor: Dr.Yalemzewud Negash  
Signature: \_\_\_\_\_  
Date: \_\_\_\_/\_\_\_\_/ 2023

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## Abstract

The capacity of macro base stations (MBS) is insufficient to handle the growing traffic, particularly in densely populated cities like Addis Ababa, Ethiopia. To address this, small cells are deployed then the cellular network become heterogeneous cellular networks (HetNets). HetNets combines MBS with low power small cells to enhance system capacity. However, the increasing energy consumption of cellular networks poses a challenge, leading to a growing interest in energy efficiency among network operator.

To mitigate this, a technique called small base station (SBS) on or off switching is employed to conserve energy and improve network efficiency. By turning off or putting unused cells into sleep mode during periods of low traffic, power consumption can be reduced. When traffic or user demand increases, these cells can be switched back on to accommodate the higher demand.

The thesis proposes a switch-on and off technique based on traffic load fluctuations using a Genetic Algorithm (GA). It balances energy savings and network performance, returning the base station to operational status when traffic or demand increases. A simulation using Matlab (2021a) shows the algorithm can save 24% of energy consumption, enhancing system efficiency. The performance improvement of small cells is evaluated.

**Keywords:** Small cells, energy consumption, base station, HetNets, energy efficiency, Genetic Algorithm, network capacity.

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## List of Abbreviations

<b>BSs</b>	Base Stations
<b>CDMA</b>	Code Division Multiple Access
<b>CSI</b>	Channel System Information
<b>CSU</b>	Control system unit
<b>D2D</b>	Device-to-Device
<b>EE</b>	Energy Efficiency
<b>ERS</b>	Exponential Rank Selection
<b>FFR</b>	Fractional Frequency Reuse
<b>4G</b>	Four Generation
<b>5G</b>	Five Generation
<b>GA</b>	Genetic Algorithm
<b>HetNets</b>	Heterogeneous networks
<b>HSDPA</b>	High Speed Downlink Packet Access
<b>HLD</b>	High-Level Design
<b>IoT</b>	Internet of Things
<b>ICT</b>	Information Communication Technology
<b>KWh</b>	Kilowatt Hour
<b>LLD</b>	Low-Level Design

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<b>LRS</b>	Linear Rank Selection
<b>LTE</b>	Long Term Evolution
<b>MWh</b>	Megawatt hour
<b>MBSs</b>	Macro Base Stations
<b>NLOS</b>	Non-Line-Of-Sight
<b>OPEX</b>	Operational Expenditure
<b>PAv</b>	Power Availability rate
<b>PRS</b>	Performance Reporting System
<b>PS</b>	Packet Switch
<b>QoS</b>	Quality of Service
<b>RWS</b>	Roulette Wheel Selection
<b>SBS</b>	Small Base Station
<b>SC-FDMA</b>	Single Carrier Freq. Domain Multiple Access
<b>SINR</b>	Signal to Noise plus Ratio
<b>SUS</b>	Stochastic Universal Sampling
<b>ToS</b>	Tournament Selection
<b>TRS</b>	Truncation Selection
<b>UMTS</b>	Universal Mobile Telecommunications System
<b>W-CDMA</b>	Wideband Code Division Multiple Access

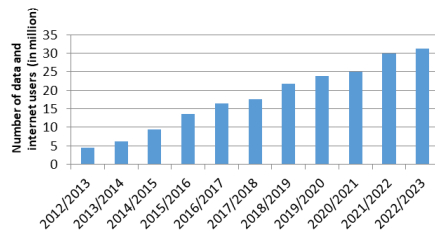
# 1 Chapter One

## Introduction

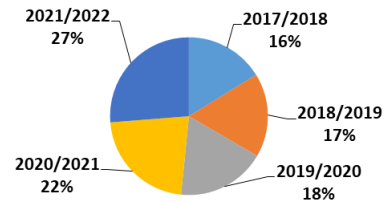
### 1.1 Background

The ability of the MBS to handle the increasing traffic is insufficient as the number of mobile broadband users rises[1]. A ethio telecom is one of the telecommunications service providers in Ethiopia, building telecommunication network infrastructure throughout the country with 7629 mobile base station sites for its customers. The number of subscribers who utilize the services has greatly increased from year to year. In the Figure 1 below, the statistically increasing demand for internet and data users is presented, as well as the total mobile network subscribers for consecutive five years are shown.

A viable approach to addressing the rising demand for mobile broad-



(a) Number of data and internet user from 2012/13 to 2022/23



(b) ethio telecom total subscriber growth in percent from year to year

Figure 1: *Number of data and internet user from 2012/13 to 2022/23 and ethio telecom total subscriber growth in percent from year to year respectively [2,3]*

band is the use of HetNets[1]. HetNets are replacing traditional homogeneous networks in cellular networks to meet user expectations and

the traffic growth that is constantly increasing. This new paradigm will boost total network capacity, user data rates, as well as network energy consumption[4].

HetNets can dramatically boost user performance, by reducing the gap between BSs and users, the user quality of service (QoS) in multi-tier HetNets has increased. However, when HetNets' cell density increases network energy usage also increases. BSs account for between 50 and 80% of the energy used in cellular networks [5]. This usage is mostly unaffected by traffic volume. Therefore, it is essential to lower a BS network's energy consumption. In this study, we present SBSs with on and off switch by GA depending on parameters (genes) such as cell load traffic, and load traffic of the neighbors at an idle time scale to reduce energy consumption in these multi-tier networks.

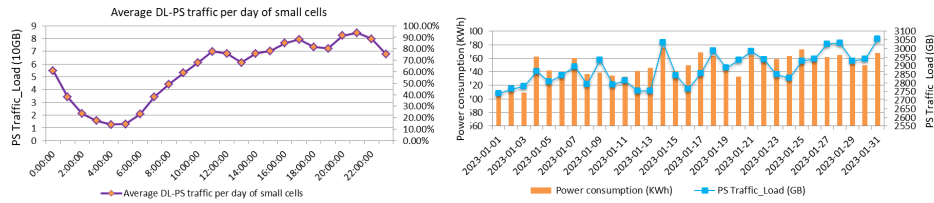
Traffic load, or the total number of users a BS serves, is referred to as an indicator of BS energy usage. The genetic switch-off algorithm is applied when the number of customers who need access to the services drops below the threshold capacity value of the MBS. This means that MBS can carry the traffic currently held by both MBS and SBSs as long as the switch-on GA is applied when the number of customers who access the services goes above the threshold capacity value of the MBS. Several idle SBSs that are surrounded by unattended users will turn on at once [6]. The network capacity is anticipated to fall between the upper and lower bounds following the switching operations. As a result, depending on the number of customers who access the services in the networks, we can use an on and off switching algorithm.

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## 1.2 Problem of statement

As more data and internet users increase, as seen in Figure 1 above, the MBSs' capacity to manage the growing traffic is insufficient. Due to the increasing number of data and internet subscribers with intelligent mobile devices with ubiquitous and always-on connectivity and machine-type communication, the dominant traffic type is shifting from mobile voice to mobile data and video. While the required data rate for voice signals is low, the data connections require much higher signal quality to provide the multi-megabit per second data rate. These require more network capacity to satisfy user service demand, especially in highly populated cities like Addis Ababa. A feasible strategy for meeting the increasing demand for mobile broadband services involves implementing HetNets. HetNets are replacing traditional homogeneous networks in cellular networks to meet user expectations and the traffic growth that is constantly increasing [7]. HetNets are an essential approach for reducing congestion on mobile networks by sharing traffic with higher-flowing access methods. Therefore, complementary small cells are needed to improve network capacity and satisfy user demand. Smaller cells are more efficient at supporting higher network capacities, with more BSs, radio resources can be reused more often per unit area, increasing the system's spectral efficiency. On the other hand, the increasing number of networks (base stations) leads to a significant increase in energy consumption challenges due to the fixed power consumption when demand is low. Since traffic demand experiences temporal and spatial fluctuations throughout the day. Service demand for capacity, as well as

user demography itself, varies over some time, as little as one day. A typical scenario as figure 2a shown below that service demand is high during the day, peaks in the evening, and becomes low at night. To optimize network energy consumption in such a situation, we need a cellular architecture whose cell size can adapt to current demand. For example, consider Figure 2a, the user traffic load graph. From the graph below, from 00:00 hours up to 4:00 hours, the traffic load decreases; between 3:00 and 5:00 hours, the network is only loaded by less than 20%. The traffic load increases from the morning 6:00 hours to 11:00 hours, then becomes highly loaded (70% and above) from 14:00 hours up to 23:00 hours. Figure 4b shows the average monthly Ethio telecom small cells' total energy consumption (KWh) and their packet switch (PS) traffic load; even if it is a monthly average power consumption, it shows what unbalanced traffic load and energy consumption support the above daily power consumption analysis in Figure 4a. During weekends and holidays, traffic volume varies by location. This variation in traffic load, which is both area- and time-dependent, can result in network over dimensioning during periods of low usage. In such scenarios, specific cells may be underutilized or even unnecessary. During times of reduced user activity, fewer cells can adequately handle traffic demand without compromising service quality. To reduce energy consumption in HetNets based on historical load data, we suggest implementing an on/off switching approach for small cells. This strategy aims to mitigate energy consumption challenges by efficiently managing active and inactive states.



(a) Daily average of traffic-load data in GB

(b) Monthly average small cells total energy consumption (KWh)

Figure 2: *Daily average of traffic-load data in GB and Monthly average small cells total energy consumption (KWh) respectively*

### 1.3 Objective

#### 1.3.1 General Objective

To improve the inefficient energy consumption problem in HetNets while maintaining network capacity and providing quality service for a user.

#### 1.3.2 Specific Objectives

To accomplish the overall objective, the following specific objectives have been identified:

- ◇ Taking EE measurements from system monitoring management and identifying the causes of energy inefficiency; To read and analyze existing literature reviews on small-cell energy-saving strategies;
- ◇ Taking EE measurements from system monitoring management and identifying the causes of energy inefficiency.
- ◇ collecting power consumption data for each site from the monitoring network system, and then analyzing it with traffic data that consumed this power.

- ◇ To create small grids that represent the target area's and to analyze energy consumption data based on hourly and daily usage and traffic load distribution.
- ◇ To determine when and which small cell should be switched on or off, depending on the above-analyzed data.
- ◇ To formulate an efficient energy consumption model.
- ◇ To compare the total network energy consumption in the case where all small cells are switched-ON with when some of them the switch-OFF.
- ◇ To evaluate the result concerning to existing network energy consumption and network energy consumption after optimized.

#### 1.4 Literature Review

Several energy-saving techniques revolve around the idea of turning off SBSs during times of low traffic. This approach offers the advantage of saving a substantial amount of energy. To switch off SBSs Various algorithms and methods have been suggested in the literature. Author [8] presents the use of coordinated multipoint for MBS switching off without compensating nearby BS transmission power adjustment. The authors of [9] suggested a viable switching-on/off-based energy-saving algorithm that can be implemented distributively. The algorithm's main idea was to turn off a BS one by one in order to have the least amount of impact on the network by employing network impact, which takes into consideration the additional load increments provided to its nearby BSs. In [10], a novel energy-efficient cellular access network architecture

based on the principle of ecological proto-cooperation was proposed, indicating that BSs can make intelligent decisions based on thresholds for switching between different power modes based on traffic conditions cooperatively and dynamically. A transmission power increase is also necessary to compensate for the areas with switched-off BSs. An author [11] proposed a cell-switching technique based on directional antenna technology. Three sections of a cell can be switched separately from one another. Furthermore, if the UE locations have a Gaussian distribution, more adaptable cell changeover operations are possible. The author [12] investigated device-to-device [D2D] coupling in a heterogeneous network to account for switching loss and avoid coverage gaps. Fuzzy Q-Learning, which infers instruction from the surrounding environment, was presented as a solution to the challenging switching problem. The author [13] developed a joint power control and switching problem that was integrated with a dynamic BS power-modified model. The method did not solve the switching problem across a traditional period like a day, week, or month; it simply did so at a single time unit. An author [14] study a realistic case study of Addis Ababa LTE network to design and explore the performance gain of system capacity and energy efficiency with HetNets deployment approach using the multi-objective GA optimization problem. The author considered LTE network planning and deployment approach. [15] Study energy efficient BSs deployment to enhance total capacity of cellular radio network. Limited to modeling of power consumption that does not account for variations in power usage due to changes in transmit power.

A reinforcement learning-based switch operation for small cell BSs was

presented in [16]. The choice of which set of cells to turn off can be a challenging problem to solve analytically because it involves considering a variety of features and is affected by a variety of factors and parameters. We arrive at complex scenarios from the realm of multi-objective optimization problems as a result of the diversity of parameters with conflicting purposes. The on/off switching problem is described by the author [17] as a satisfaction game in which BSs attempt to satisfy specific performance requirements to prevent often switching BSs. A utility function, in which the load of each BS is paired with the load of other BSs, is used to measure a BS's satisfaction. This utility function incorporates the BS's load and power consumption. Since none of the players can be completely happy at once, the unsatisfied players decide to lower their criteria and create a game using the new thresholds.

A regret-based satisfaction algorithm and a satisfaction equilibrium search technique are used to solve the game. Random on/off approaches and switches occur regularly. In practice, such constant on/off switches are not tolerated by BSs. On the other hand, they switch less frequently in the suggested satisfaction approaches. For this reason, BSs in the suggested techniques have the partiality to maintain modes unless they are completely satisfied. [18] According to the author, a dynamic switching algorithm with switching criteria based on traffic load was introduced. With this system, BSs can dynamically change the number of transmitters to be enabled depending on user traffic and necessary channels without sacrificing service quality. According to the author [19], a dynamic switching algorithm with switching criteria based on traffic load was introduced. With this system, BSs can dynamically change the number of

transmitters to be enabled depending on user traffic and necessary channels without sacrificing service quality

## 1.5 Methodology

In order to do this thesis, we used data collected for Addis Ababa's small cell networks' downlink real data traffic and power consumption from ethio telecom's network monitoring and management system, especially from the performance reporting system (PRS) and power availability rate (PAV). Several pieces of literature are reviewed on related topics (on HetNets power consumption optimization through different methods and algorithms). The target region was determined, and the target area was picked up using knowledge from the research that was reviewed in the literature. The hotspot zones are identified within the study region and number of small cells used in this research is determined. traffic load of each small cells and macro cell are analyzed hourly for seven days consequently including yearly holiday. Then, a GA is developed and used to deliver a set of optimal solutions to a problem based on system capacity and EE maximization. System capacity and EE are used as performance measures to assess the optimization's performance gain.

## 1.6 Assumptions

We present the main features that classify the switched off small cells, in particular those are compared based on the following criteria[20].

- i. *Architecture*: Indicates whether the intelligence of an algorithm is placed in a centralized entity governing a particular area or dis-

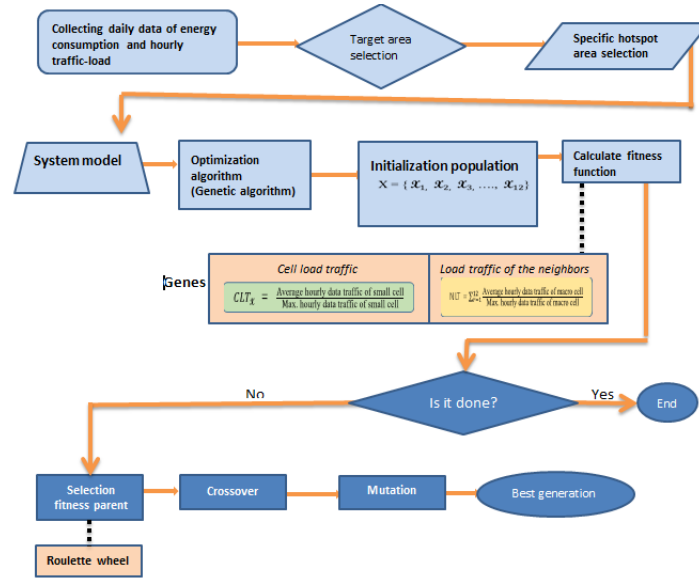


Figure 3: Methodology block diagram

tributed among the BSs. We consider a centralized system with  $X$  LTE small cells and  $N$  user equipment (UEs) distributed randomly. We assume that the macro cell controls the small cells based on the traffic load data that is obtained from each small cell through the control channel. The macro cell must do this since it remains in the ON state to provide quality services and coverage so that it can continue to serve users UE, where UEs stands for the set of all users in a network zone.

- ii. *Layer*: Indicates whether the algorithm is proposed for the macro cell layer also for the small cell layers. In ethio telecom system model, we consider a two-tier HetNets with a macro cell (tier 1) and small cells (tier 2). Since the macro cells locations should be carefully designed to maintain their capacity, in this model, the macro cells are considered to be regularly deployed as hexagonal cells. On

the contrary, small cells are deployed based on the traffic demand to boost the network capacity.

- iii. **Switch decision:** Indicates the main parameters which trigger the switched decision. The parameters (genes) used for giving decisions are cell load traffic and load traffic of the neighbors of each cell. The algorithm calculates the fitness function of each cell and selects the SBS with a low traffic load as a candidate for switching off cells.
- iv. *Interference Management:* Wireless communication involves mobile users interacting with Base Stations (BSs) to transmit and receive real-time data. Network service providers operate on designated spectrums, which can be divided into disjoint or non-interfering radio signals using techniques like frequency division, time division, and code division. But Interference in communication networks limits the benefits of cellular technology, affecting service providers' quality of service and revenue. The common types of interference that occur in the above scenario are cross-tier interference and co-tier interference, even if the Small cells are assumed to be deployed on a dedicated carrier[21].

## 1.7 Network Model

The system consists of  $N$  UEs spread evenly among  $X$  LTE small cells with fully overlapping coverage regions. It visualized as follows in the figure. *Channel model:* The channel model of a small base station refers to the mathematical representation of the wireless communication channel between the base station and the user equipment (UE) or mobile

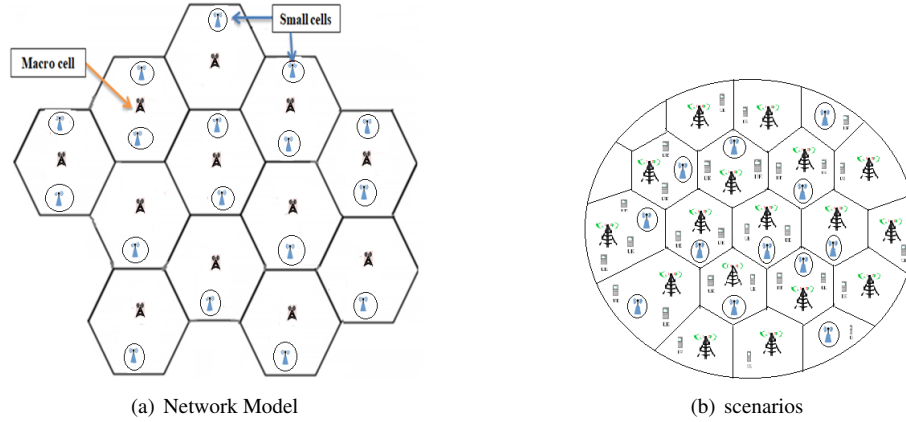


Figure 4: *Network model and scenarios respectively*

device. It describes how the wireless signals propagate through the environment, taking into account factors such as distance, obstacles, interference, and fading[22]. Several channel models are commonly used to simulate and analyze wireless communication systems, including SBSs. Some of the widely known channel models include:

*Path Loss Models:* These models describe the attenuation of signal strength with distance. The Free-Space Path Loss (FSPL) model and the Two-Ray Ground Reflection model are examples of such models. The pathloss calculation depends on the LOS probability, the pathloss exponent, and the distance to the transmitter. Free Space Loss: The transmitted power is  $P_t$ , and the received power is  $P_r$ . The free space path loss is:

$$L_{fsl} = P_t - P_r \quad \text{Where} \quad P_r = \frac{P_t * \lambda^2}{(4\pi * d)^2} \quad (1.1)$$

In dB:

$$L_{fsl} = P_t - P_r = 21.98 - 20 * \log_{10}(\lambda) + 20 * \log_{10}(d) \quad (1.2)$$

If a user is receiving a LOS signal from the transmitter, then its pathloss is calculated as:

$$P_{loss} = 46.3 + 33.9 * \log_{f_c} - 13.82 * \log h_{te} - a(h_{re}) + (44.9 - 6.55 \log h_{te}) \log(d) \quad (1.3)$$

where  $f_c$  is the carrier frequency,  $d$  is a distance,  $h_{te}$  the effective heights of the small BS and  $h_{re}$  effective heights user antennas. When studying the channel model of a small base station, it's essential to consider the specific scenario, frequency bands, and environmental conditions.

*Interference Management:* It is crucial in multi-tier HetNets due to potential cross-tier and co-tier interference, which can lead to temporary signal loss, reduced receiver performance, and degradation in output quality. These interference can be caused by other communication systems, radio frequency emissions, and jamming [22]. The below shows the two interference type clearly.

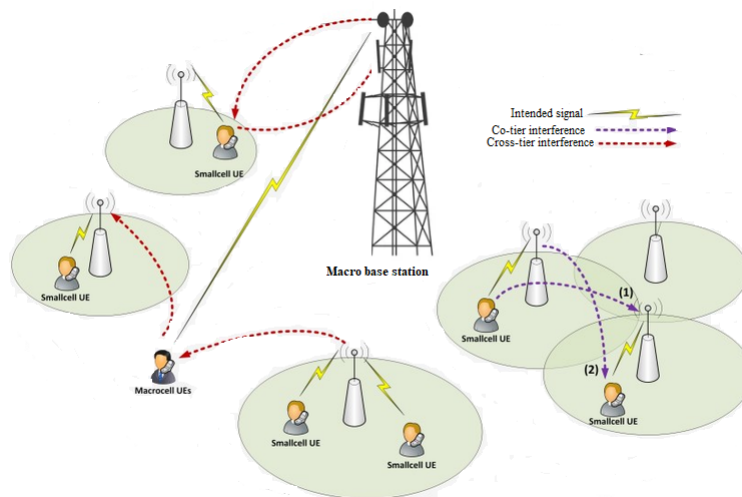


Figure 5: Different cases of inter(cross-tier) and intra(co-tier) tier interference in uplink and downlink scenarios[22]

- i Cross-Tier Interference Mitigation: Cross-tier interference occurs when communication signals from one tier of cells interfere with signals from another tier. For instance, in a HetNets with macrocells and small cells, interference might arise between macrocells and small cells. To mitigate cross-tier interference, techniques such as frequency separation, power control, interference coordination, dynamic spectrum access, beam forming, and antenna techniques can be employed.
- ii Co-Tier Interference Mitigation: Co-tier interference occurs when communication signals from cells within the same tier interfere with each other. In scenarios where cells are densely deployed, interference between neighboring cells can significantly degrade network performance. Advanced antenna systems, such as beam forming and interference rejection techniques, can focus transmission and reception in desired directions, reducing the impact of cross-tier interference.

*Cell selection method:* Cell selection in homogeneous networks is less critical than in HetNets due to power disparity. High-power MBS transmits, causing overloading and service loss, resulting in decreased total system throughput. To address this, a bias is introduced to the handover margin trigger mechanism, allowing users to artificially attach to small cells for extended periods, boosting their range. This approach, known as cell range expansion (CRE), is more efficient than conventional cell selection methods due to shared resource technology and different transmit power levels of nodes like MBS and SBSs. A biased user association ensures adequate service quality for all users, balancing signal quality

from the users' perspective and load balancing from the BSs' perspective [23].

## 1.8 Traffic Model

*Mobility management* Mobile network mobility refers to the movement of mobile devices and users within a network, affecting the flow of network traffic. This concept is crucial for efficient resource allocation and maintaining network quality [24]. The geographical position and duration of an active call impact the network resources needed to sustain calls. Mobility management, which includes location and handover management, is essential for mobile wireless networks to retain connections as users transition from service areas [25, 26].

There are two forms of mobility for mobile devices: intra-system (intra-domain) and inter-system (inter-domain). Intra-system mobility involves movements between different cells within the same system, while inter-system mobility involves mobility between diverse backbones, protocols, technologies, or service providers. Integration of these networks offers continuous connection to the most suitable access network, but it can lead to technological disparities and network protocol heterogeneity.

Intelligent handover transfers ongoing communication sessions or connections between cells while maintaining a seamless user experience. Two types of handover exist: hard handover, when a channel source cell is released before the channel in the destination is engaged, and soft handover, when the source cell continues to operate alongside the target cell for some time. Soft handover can improve service by establishing parallel connections between multiple channels, especially in areas with

inadequate coverage.

## 1.9 Problem Formulation

We consider a centralized system with N LTE small cells and X user equipment (UEs) distributed based on traffic distribution. The small base station (SBS) switch off procedure is launched iteratively based on the GA to find an optimal matching between the network topology and the traffic load conditions. Each cell is considered as a chromosome with 2 encoding parameters (genes): cell load traffic, and load traffic of the neighbors cell. The algorithm calculates the fitness function of each cell and selects the SBS with low traffic load as a candidate for switch off. Then the mechanism tries to re-associate the UEs of a SBS to its neighbors. If the number of communication nodes of the small base station is X and the overall energy of the small cell network is y when the EE of the X communication nodes is optimal, the following relationship exists between the two:

$$y = f(X_1, X_2, X_3, \dots, X_{12}) \quad (1.4)$$

In formula (3), set  $X_1, X_2, X_3, \dots, X_{12}$  stands for small cell network, and set y represents the overall energy of the small cell network.

$$P_{x_i} = y \quad (1.5)$$

$$P_{x_i} = P_{X_1} + P_{X_2} + P_{X_3} + \dots + P_{X_{12}} \quad (1.6)$$

$$P_{x_i} = P_{total} \quad (1.7)$$

$$P_{total} = P_{BB} + P_{RF} + P_{PA} + P_{overhead} \quad (1.8)$$

$$P_{total} = P_{Static} + P_{Dynamic} \quad (1.9)$$

$$P_{total} = P_{Static} + \alpha P_{transmission} \quad (1.10)$$

Therefore, the EE optimization process of the small cell network can be transformed into a mathematical calculation process using the GA to solve the optimal solution of the formula (1.10). The number of independent variables in formula (1.10) is X. To find the optimal solution to the EE optimization problem of small cell networks, it is necessary to construct the energy consumption model. Based on the relationship of related variables in the model, We employ a linear power model where the total power consumption of each small cell changes linearly concerning the average transmission power. The power consumption is modeled as the sum of the two parts. The first part describes the static power consumption, which is consumed by the regular operation of the small cells. The second part is the dynamic power consumption, which depends on the cell load. This is given by:

$$P_{macro} = (P_{Static} + P_{Dynamic}) \quad (1.11)$$

Total power consumption for a macro cell is the sum of fixed power consumption,  $P_{Static}$  due to system operations, i.e., cooling, back-end network maintenance, and dynamic (load-dependent transmission power),  $P_{Dynamic}$ . The macro cell acts as a controller, and thus it always remains in ON state to serve the users by scheduling the small cells. Moreover, a macro cell serves a user directly when none of the other small cells is in ON state. Generally, the total power consumed by a small cell can be determined as follows, For a small cell  $c \in C$  in a state  $s \in S$ , total power

consumption can be calculated as follows,

$$P_{cst} = (K(P_a + P_{tx} + P_{rx} + P_r) + P_{cs} + P_b) \quad (1.12)$$

where  $P_a, P_{tx}, P_{rx}, P_r, P_{cs}, P_b$  are signal amplification power, transmission power, signal reception power, signal rectification power, cooling power, and back-end connection power, respectively of a small cell. Here,  $K$  represents the number of antennas in a small cell. In traffic aware sleep state,  $P_{tx} = 0, P_r = 0$  and also  $P_a = 0$ . Putting the values of these parameters in Eq. (1.12) for a state, power consumption of a small cell  $c$  can be calculated for that state. In OFF state, all the components are in inactive mode. However, a small control system unit(CSU) device is needed to receive the wake-up signal. This control system unit device consumes negligible amount of power which concludes that power consumption in OFF state,  $P_{cOFF} \approx 0$  [27].

*A Linear Power Model:* We employ a linear power model as proposed in where the total power consumption of each small cell changes linearly with respect to the average transmits power. The power consumption is modeled as the sum of the two parts. The first part describes the static power consumption, which is consumed by the regular operation of the small cells. The second part is the dynamic power consumption, which depend on the cell load[28]. This is given by:

$$P_{total} = (P_s + \alpha * P_{tx_{max}}) \quad (1.13)$$

where

$P_{total}$  is a total power consumption of each small cell,

$P_s$  is the static power consumption of each small cell,

$\alpha$  is slope of traffic load and

$P_{tx_{max}}$  is the maximum power transmission of each small cell.

## 1.10 Scope and Limitations

### 1.10.1 Scope of the Thesis

This thesis examines the energy consumption of HetNet in the Ethio telecom LTE cellular network, focusing on the downlink. To achieve this, GA techniques are employed for implementation. The analysis considers the hourly-based traffic load data of the small cell LTE network, as well as the downlink energy consumption of specific sites in the designated area(Meskel square).

### 1.10.2 Limitations of the Thesis

Even though we used realistic data for analysis and simulation, our study has several limitations. To name a few, The data set for analyzing Addis Ababa's small cell power usage is primarily taken from the network monitoring system (PAV), as small cell networks are not fully deployed across the city. Due to this, it is difficult to select residential areas rather than business areas.

We considered it only when the intelligence of an algorithm is placed in a centralized MBS governing SBSs within the coverage area.

One MBS gives service simultaneously to 600 users. we use 510 users and 127 users of small cells simultaneously, where small cells have different numbers of users.

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## 1.11 Contribution of the Thesis

The thesis contributes by doing GA-Based Small Cell Switch-Off at Low Load Traffic for Energy-Efficient HetNet. GA is a search-based optimization approach based on the principles of genetics and natural selection. It is routinely used to find optimum or near-optimal solutions to the high consumption power of SBSs. For a near idle or idle traffic load, GA selects the idle SBSs to switch off, and for a near idle SBS, GA selects the SBSs to traffic-aware sleep. We used adaptive macrocell expansion (cell zooming) and small-cell sleeping mechanisms to cover the traffic load from nearby sleeping small cells in the area of the macrocell and save more power.

## 1.12 Organization of the Thesis

This thesis comprises five chapters. Chapter one provides background, problem statement, objectives, literature review, scope, methodology including how to formulate an optimization problem for EE analysis. Chapter two describes over view of cellular network, Chapter three explains GA and its terminology. Chapter four discusses the simulation and performance analysis findings. Finally, chapter five concludes the thesis and outlines future research directions.

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## 2 Chapter Two

### 2.1 Overview of Cellular Networks

A homogenous network is a typical network that includes similar macro-BSs and nodes with identical power transmission ranges. A heterogeneous network is one that has distinct transmit power ranges for each of its BSs. There might be two or more transmission power ranges. The HetNets, which are made up of several types of BSs with varied transmit power ranges, have had a substantial influence on the network's EE performance. Small BSs covered by HetNets have showed that the overall power consumption of the HetNets may be reduced due to their low-powered radio communication equipment [12]. It stands to reason that employing low-power devices in a HetNets network will help the network use less electricity than a homogenous network. Microcells, picocells, femtocells, and distributed antenna systems (remote radio heads) are examples of heterogeneous components differentiated by their transmit powers, coverage regions, physical size, backhaul, and propagation characteristics. This transition creates several possibilities for capacity enhancement as well as numerous new obstacles for coexistence and network management.

#### 2.1.1 Homogeneous Cellular Network

Homogeneous Cellular Networks are cellular networks in which all the BSs have similar characteristics and are deployed uniformly across the coverage area. This notion contrasts with HetNets, which deploy many types of BSs with differing capabilities and coverage regions [29].

Figure 6 shows a Homogeneous Cellular Network deployment, consist-

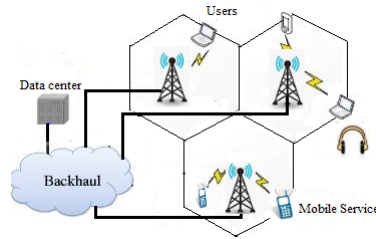


Figure 6: *Deployment of Homogeneous Cellular Network [29].*

ing of multiple cells with similar characteristics, ensuring uniform coverage and service availability. Each cell has a BS with a tower symbol, allowing seamless handover and improved user experience. This uniformity simplifies network management, optimizes resource allocation, and improves QoS provisioning. Understanding the principles and challenges of homogeneous networks is crucial for designing efficient and high-performing cellular networks. This deployment strategy simplifies resource allocation, interference management, and cooperative communication.

### 2.1.2 HetNets

HetNets refer to cellular networks composed of different types of BSs with varying characteristics and coverage areas. These networks combine macrocells, microcells, picocells, and femtocells to provide enhanced coverage, capacity, and quality of service (QoS) to users. HetNets can also reduce the energy consumption of communication network, alleviate the low utilization of spectrum and improve the utilization of network resources.

*Deployment of BSs:* In HetNets, BSs with different coverage areas and

capacities are strategically deployed to meet the varying demands of users. Figure 7 illustrates a hypothetical scenario where macrocells, microcells, picocells, and femtocells are deployed in a HetNet. Macro cells

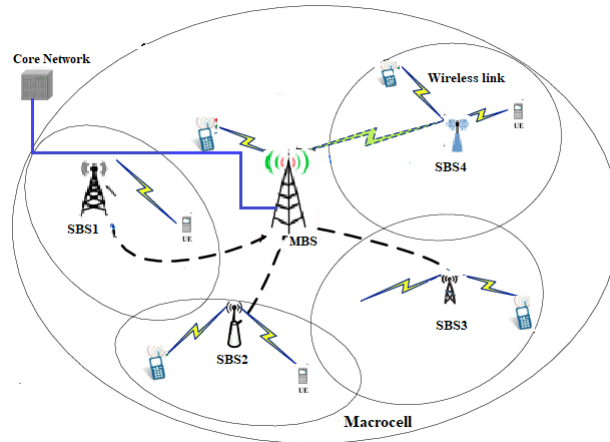


Figure 7: Architecture of HetNets [30].

are large-scale BSs that cover a wide area and provide coverage to a large number of users. When LTE-Advanced was designed and standardized, it was primarily aimed at macro base station networks with standardized, carefully thought-out, and deployed high-power nodes, where coverage, mobility, and the supply of high throughput across significant areas were at the core of its needs [31].

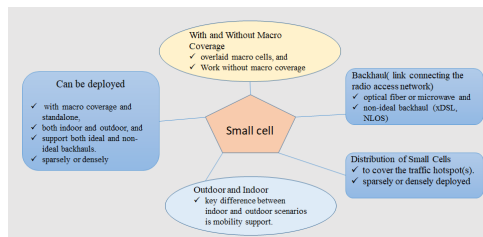
### 2.1.3 Small Cell Networks Overview

Small Cell Cellular Networks (SCCNs) are networks that use small-scale base stations (BSs) to improve coverage, capacity, and performance in high-density areas. These networks are designed to meet the growing demand for wireless connectivity in high-density areas and provide targeted coverage in specific locations. Small cells are compact BSs with

a smaller coverage area compared to traditional macrocells and are typically deployed in areas with high user density, such as urban centers, stadiums, shopping malls, and transportation hubs. They can be classified into microcells, picocells, and femtocells, with microcells covering larger areas and picocells having a smaller coverage area.

Small cells are part of network densification, adding more base station connections to the current wireless infrastructure. They are commonly used in regions with high urban population densities, such as retail malls, stadiums, airports, and railway stations, where many people access data simultaneously. The primary objective of small cells is to enhance edge data capacity, speed, and overall network efficiency of macro cells. They are included in Release 9 of the 3GPP LTE specification in 2008 [32].

*Femtocells:* With a 50-meter radius, femtocells have the smallest cover-



(a) Small cell deployment scenario.



(b) Deployment of small cells in a dense urban environment.

Figure 8: *Small cell deployment scenario and Its Deployment in dense urban respectively.*

age regions. It can accommodate up to 16 concurrent users and has a 100 mW maximum transmit power, which is often utilized inside. Femto-cells are suitable for both residential and commercial regions with buildings no taller than ten meters.

Cell Type	Output Power	Cell Radius	User	Locations
Femto Cell	0.001 to 0.25	0.010 to 0.1	1 to 30	Indoor
Pico Cell	0.25 to 1	0.1 to 0.2	30 to 130	Indoor / Outdoor
Micro Cell	1 to 10	8 to 30	> 2000	Outdoor
Macro Cell	10 to >50	0.2 to 2.0	100 to 2000	Indoor / Outdoor

Table 2.1: Characteristics of macro and lower nodes (small cells)

*Picocells:* The pico cell has a larger service area than the femtocells, with an average radius of about 200 meters, and can support up to 130 simultaneous users. It can be applied both inside and outside. Its transmission power ranges from 250 mW to 2 W for outdoor deployment and from 100 mW to less for indoor use. Pico cells are suitable for areas with taller buildings in business and public hotspot areas. In areas with business and public hotspots and building heights greater than 10 meters but less than 200, picocells are ideal.

*Microcells:* Microcells, which are used in high-density urban and rural areas, have a range of up to 1 km and a larger coverage area than picocells. Microcells may be able to accommodate 200 users at once. Table 1 compares conventional macro-BS and popular small cell types based on factors such as transmission power, the number of concurrent users, the greatest coverage radius, and the ideal deployment location [33].

**Benefits of Small Cell Networks:** Small Cell Cellular Networks offer several benefits, including [34]: Small cells improve coverage in areas with weak or no signal, increase network capacity, and provide higher data rates by bringing the network closer to users. They also help offload traffic from macrocells, distributing load more evenly across the network, reducing congestion and improving overall network efficiency.

**Power Consumption of Small Cells:** Small cells, compact base stations deployed in high-density areas, significantly impact the power consumption of wireless networks. Factors influencing power consumption include transmit power, traffic load, backhaul connectivity, and environmental conditions. Higher transmit power results in increased energy consumption, as more power is needed for signal transmission. Higher traffic load requires more processing power and data transmission, leading to increased energy consumption. Backhaul connectivity, such as fiber optics, typically has lower power requirements than wireless options. Environmental conditions, such as temperature and weather, can also affect power consumption, with extreme temperatures requiring additional power for cooling mechanisms and adverse weather conditions affecting signal quality.

**Small Cells Switching Strategy:** This thesis introduces an energy-efficient solution for cellular networks using a 3-level base station switching approach. The technique uses advanced threshold computation methods to achieve optimal energy efficiency (EE). The BSs are transitioned between active, traffic-aware sleep and switch-off modes based on traffic levels, ensuring service quality [36,37]. Small cells, low-powered radio access nodes, are used to enhance network capacity in high-user density areas. Shutting down idle cells can lead to energy savings and optimize power consumption. A procedure involving GA-based optimal solutions is proposed to achieve this. In cases where some small cells are turned off, neighboring active MBSs take over service provision, increasing power control. Resources from turned-off small cells are shared with active MBSs, allowing them to serve users within the turned-off cell's coverage. This strategy doesn't increase con-

nection failure probability or interference levels [38,39,40].

#### **2.1.4 Switching Off Small Cells Advantages**

Switching off small cells can be done for various reasons, including low demand, maintenance, interference, cost-efficiency, and emergency situations. These decisions can be made to conserve energy, reduce interference, or allocate more capacity to macro cells for critical communications. The reasons for switching off small cells vary depending on network operator policies, technology, and local regulations. Network operators must carefully plan and manage both types of cells to optimize resource usage [41].

#### **2.1.5 Working States of Small Cells**

Small cell operating states and energy-saving measures vary based on network design, equipment, and deployment circumstances. The goal is to balance network performance and energy usage for optimal operation while minimizing environmental effects. Two-state switching approaches are time-consuming and may cause connection disruptions during surges in user demand. A network cell sleeping technique based on traffic-aware Offload and sleep phases is developed to minimize energy consumption and switch power in small cells. This strategy reduces switching delays and improves overall energy use and transitioning to small cells. The inclusion of traffic-aware Offload and sleep states in the ON and OFF states minimizes switching time delays and increases EE. The addition of one intermediate state (traffic-aware Offload and sleep) allows for quick cell activation, decreasing cell switching. A GA-based system is used to identify the mode factor of each Small Base Station

(SBS) through the macro base station controller [42,43].

$$Switching\ mode = \begin{cases} 0.05 > ON\ state \\ 0.05 \leq traffic\ aware\ sleep\ State \\ 0\ Switch\ OFF\ State \end{cases}$$

*ON state:* The small cell is fully operational (100%) and actively serving user devices in its coverage area in this state. It transmits and receives data and control signals in the same way as a typical cell site does. In this state, all hardware components in the small cell BS are completely operational. All traffic is served within the maximum capacity of BS. This range, however, might change depending on traffic demand.

$$P_{total} = (P_s + \alpha P_{tx_{max}}) \quad (2.1)$$

*traffic-aware Offload and sleep State:* This implies that the optimization process takes into account traffic conditions. This is the energy-saving state of the small cell. When the small cell detects no active connections and no pending control signals, it can enter traffic-aware Offload and sleep mode to save power. During traffic-aware Offload and sleep mode, the small cell turns off or reduces the power of some of its components, such as the power supply, back-end connection, and core CSU remain in active mode. However, other components like the power amplifier, transmitter, and receiver are being switched off. An SBS in a traffic-aware Offload and sleep state, consumes around 15% of power, while the rest of the power (around 80%) can be saved. However, it takes around 10 s to wake up. This reduces energy consumption significantly. However, if there's an increase in traffic demand, the small cell might

reduce its sleep time or stay in idle mode to ensure quick response to connection requests.

$$P_{total} = (P_s + \alpha P_{tx_{max}}) \quad \text{when} \quad \alpha \leq \frac{1}{4} P_{tx_{max}} \quad (2.2)$$

*Switch OFF State:* No power will be consumed in the OFF state, an SBS in this state is in completely inactive mode. However, it takes around 30 s to turn on.

$$P_{total} = (P_s + \alpha P_{tx_{max}}) \quad \text{when} \quad \alpha = 0 \quad (2.3)$$

There are two main operational modes for small cell BSs: open access mode, in which the BS allows access to all users of the operator's network, and closed access mode, which allows only registered users to access the small cell. The hybrid access mode, in which a limited amount of small cell resources are available to non-registered users, can also be used. The energy-saving procedures employed in small-cell BSs can vary significantly based on the access control mechanism. For instance, in the case of SLEEP mode schemes for closed-mode small cells, the BS hardware might need to verify whether the subscriber requesting access to resources is registered or not before switching itself ON. A small cell draws 1726 W from the power socket and can transmit up to 0.25 W, and a macrocell site consists of three sectors and consumes a total power of  $M_{macro} = 6.7$  kW. No dynamic power-saving modes for macro cells are assumed; the power consumption remains fixed irrespective of the supported traffic. An average spectral efficiency of 1.7 b/s/Hz per macrocell sector is assumed, and by considering 20 MHz carrier bandwidth, the

total energy consumption per annum (= 8760 h/year) of the network can be written as

$$Total\ Consumed\ Energy = (M_{MBS} * P_{MBS}) + (X_{SBS} * P_{SBS}) * 8760 [Wh] \quad (2.4)$$

### *How to Acquire System Information and Wake Up When traffic aware Sleeping and switched off?*

When a SBS is turned off, the normal transmission between the SBS and UEs is suspended. Hence, information from nearby UEs, such as channel system information (CSI) and traffic load, cannot be acquired by the SBS from the uplink signals. To guarantee the effectiveness of traffic-aware Sleeping and switched off, the SBSs need to be aware of the environment even when they are in sleep mode and switched off so that they can be activated promptly. Waking up an SBS is performed with the assistance of neighboring MBSs. When a SBS is switched off, the neighboring MBSs record their own system loads and use such information as the criterion for mode switching. This way, the neighboring MBSs know when and under what conditions a SBS should be turned on and can inform the SBS to do so [9]. Alternatively, a SBS can wake itself up periodically to detect the environment. It returns to sleep when the criteria for switching on are not satisfied [42]. Under this model, the wake-up interval, which determines the wake-up frequency, is a key design factor. Consider a HetNets with one MBS and multiple small-cell SBSs. The MBS is always active to guarantee coverage, while the SBSs can be dynamically switched on or off. The SBSs can operate in two modes: standby mode and deep switched-off mode. We consider both high and low-mobility scenarios. In the high mobility scenario, the

number of users in a small cell has a larger variation compared to that in the low mobility scenario. The standby mode outperforms the deep sleep mode when the wake-up interval is short since it can closely capture the dynamics of traffic load. When the wake-up interval becomes large, the SBSs cannot obtain the load information on time. The standby mode loses its advantage while it consumes more energy, resulting in a lower EE compared to deep sleep. As expected, a short wake-up interval is preferred in the high-mobility scenario. As another option, system information can also be obtained with auxiliary devices when a SBS is in sleep mode. A counting element is used to count the number of accumulated tasks during a sleep period, and a SBS wakes up when the number of tasks exceeds a threshold. To address the problem of obtaining CSI from nearby UEs, a possible approach is to deploy a radio receiver at a BS to capture the pilot or uplink UE signals and forward the obtained CSI to the network controller. Then, the network controller can activate the BS when necessary, e.g., when a large number of users with good channel conditions are nearby.

#### 2.1.6 Cell Zooming

Cell zooming is the adaptive adjustment of cell size based on traffic load. Traffic load in cellular networks can have significant spatial and temporal fluctuations due to user mobility and the bursty nature of many data applications. For instance, for a cellular network in a city, the traffic load in the daytime is relatively heavy in office areas and light in residential areas, while the opposite happens in the evening. The phenomenon of traffic load fluctuation implies that some SBSs can be switched off when

the traffic load is light. Cell zooming is a promising technology that guarantees a reduction in the amount of resources used. Cell zooming has certain advantages, such as the fact that it is primarily utilized for two purposes: load balancing and energy conservation. Load balancing is accomplished by transferring traffic from cells under heavy load to cells under mild load. Cell zooming, on the other hand, may be utilized to save energy. Cell zooming differs from power control in several ways. Power control is primarily concerned with link-level performance, whereas cell zooming is concerned with network-level performance. In power control, transmit power is consumed, but in cell zooming, the entire network's energy is consumed. Finally, as previously stated, power control does not actively vary its cell size, whereas cell zooming does by increasing the transmit power of the control signal. In a cellular network, user allocation is done based on the spectral efficiency of the BSs. First, we must determine the spectral efficiency of BSs. The user is assigned to the BS with the best spectral efficiency [44]. Consider a HetNets in which the coverage of MBSs overlaps the SBSs and traffic load fluctuates over time and space. Assume that all SBSs are assumed to have the same energy consumption. Each SBS has two working modes: active mode with power consumption  $P_a$  and sleeping mode with power consumption  $P_{slp}$ , where  $P_a$  is usually much larger than  $P_{slp}$ . UEs arrive at the network randomly, and each UE will be associated with one SBS upon its arrival. The sojourn time for each UE is exponentially distributed, and the data rate requirement for each UE is denoted by  $A_i$  for UE  $i$ . The spectral efficiency is  $\eta_{ij}$  when UE  $i$  is associated with SBS  $j$ .

Therefore, the bandwidth needed is given by:

$$W_{ij} = \frac{A_i}{\eta_{ij}} \quad (2.5)$$

*Technique of cell zooming:* In our system model, HetNets, which includes MBS and SBSs, The MBS only provides coverage, and the SBSs dynamically adjust transmit power to achieve cell zooming. We focus on downlink transmission, in which each user is associated with its nearest SBS in initialization. The MBS is located in the center of the HetNets. The SBSs are located based on traffic load distribution. Each SBS forms a circular coverage area of radius  $R_s$  around itself. The users are located based on random distribution. Each SBS can expand the radius, reduce the radius, sleep, and even be switched off as shown below. Each SBS coverage area is divided into L concentric circle zones. The cellular radius  $R_s$  is defined by the formula (2.6), and the corresponding transmit power  $P_t$  is defined by the formula (2.7), where R is the coverage radius when the maximum transmission power of the SBS is  $P_{max}$ . Assuming that the maximum transmit power of each SBS is  $P_{max}$ . All users are within the coverage of the MBS, and any user may be within the coverage of several SBSs, but each user can choose only one of the SBSs to access [45].

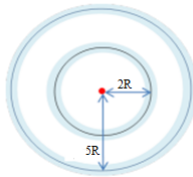


Figure 9: Cell zooming methods

$$R_s \in \left\{ \frac{R}{L}, \frac{2R}{L}, \frac{3R}{L}, \dots, \frac{(L-1)R}{L}, R \right\} \quad (2.6)$$

$$P_t \in \left\{ P \left( \frac{1}{L} \right)^\varphi, P \left( \frac{2}{L} \right)^\varphi, P \left( \frac{3}{L} \right)^\varphi, \dots, P \left( \frac{L-1}{L} \right)^\varphi, P \right\} \quad (2.7)$$

The channel between the transmitter and the receiver is modeled by

$$\sqrt{(1+d)^\varphi h} \quad (2.8)$$

Where  $h$  is rayleigh fading channel coefficient and  $(1+d)^\varphi$  represents a non-singular path-loss model; where  $d$  and  $\varphi$  are the transmission distance and the path-loss exponent, respectively. At the receiver side, there is also AWGN with normalized power  $\delta^2$ .

*Cell Load:* Before switching off a BS, it is necessary to consider the load level of its neighboring cells otherwise UEs transferred from sleeping cell to active neighbors may experience poor QoS and may be eventually dropped.

## 2.2 Network EE

EE refers to the efficient utilization of energy resources to achieve a desired outcome or perform a specific task while minimizing energy waste. In the context of communication networks, EE is a crucial consideration as the demand for wireless services continues to increase, leading to higher energy consumption by network infrastructure. There are primarily two ways to improve EE in a mobile network [46]:

- 1) Reduce base station (BS) power consumption, either by using more power-efficient hardware or by using more advanced software to

adapt power consumption to traffic conditions and balance energy consumption and performance.

- 2) By the use of intelligent network deployment tactics such as a larger density of SBSs.

Because these nodes are closer to mobile consumers, the usage of small BSs leads to decreased power consumption. As a result, network deployments based on smaller cells such as micro, pico, or even femtocells are viewed as a potential option to minimize a cellular network's total power consumption. However, as some study suggests, the construction of such a HetNets should be approached with caution, as distributing a high density of small cells will overload and reduce the EE of the central BS. Energy can also defined as the total amount of work done that is measured in joules. EE is measured by the throughput of a system per unit of power consumption [47,48]. The throughput is the amount of data transferred from the BSs to the mobile users in a specific service area (if considering an area). Where Power, is defined as how many data rates are transferred at what energy or how fast they can be done. The unit of power is the watt, and a watt is equal to one joule divided by one second. It can be expressed as follows: Power consumption is the amount of power in Watts used by each BS in a network. Therefore, EE can be described as how many bits of data per second can be transferred from a transmitter to a receiver over the course of total power consumption. This can be shown as follows:

$$\text{Energy Efficiency}(EE) = \frac{\text{Total number of data transferred}(in\ bits/s)}{\text{Total power consumption}(in\ Watt)} \quad (2.9)$$

EE is measured in bits/sec/watt or commonly known as bits/joule. The maximum throughput of  $N^{th}$  user in small cell tier can be defined in terms of Shannon capacity

$$R = W_N \log_2(1 + \text{SINR}_N) \quad (2.10)$$

Where  $W_N$  is assigned bandwidth of  $N^{th}$  user. Improving EE in networks is important for several reasons:

*Environmental Impact:* Reducing energy consumption helps lower greenhouse gas emissions and mitigates the environmental impact of communication networks.

*Operational Cost Reduction:* Energy accounts for a significant portion of the operational expenses in network deployments. By improving EE, operators can lower their energy bills and reduce overall operational costs.

*Extended Battery Life:* EE is particularly important for mobile devices, as it directly impacts their battery life. Energy-efficient network designs and protocols help prolong the battery life of smartphones, tablets, and other wireless devices.

To achieve EE, various strategies and techniques can be employed at different levels of the network:

*Network Planning and Deployment:* Careful planning and optimization of network infrastructure can minimize energy consumption. This includes efficient placement of BSs, using advanced antenna technologies, and optimizing the density and configuration of small cells.

*Radio Resource Management:* Effective management of radio resources, such as power control, adaptive modulation and coding, and interfer-

ence management, can significantly improve EE by reducing unnecessary transmissions and minimizing interference.

*Sleep Mode and Power Management:* Introducing sleep modes and power management techniques for network components, such as BSs or small cells, allows them to enter low-power states when the traffic load is low. This reduces energy consumption during periods of low demand.

*Dynamic Spectrum Access:* Utilizing dynamic spectrum access techniques, such as cognitive radio or spectrum sharing, allows more efficient use of available spectrum resources, reducing the energy required for transmission and reception.

*Optimized Routing and Traffic Management:* Routing algorithms and traffic management schemes that consider EE as a metric can help minimize energy consumption in network communication, especially in multi-hop wireless networks.

*Intelligent Control and Optimization:* Utilizing advanced optimization techniques, such as GA, machine learning, or artificial intelligence, can optimize network configurations, resource allocation, and power control to achieve better EE.

### 2.2.1 Strategies for Optimizing EE

To optimize the EE of small cells, various strategies can be employed[49,50]:

- i. *Power Management:* Implementing intelligent power management techniques can help minimize energy consumption during periods of low traffic. Power-saving modes can be activated when small cells are not heavily utilized, reducing power consumption without compromising service quality.

- ii. *Sleep Mode*: Small cells can be configured to enter sleep mode during periods of inactivity. This allows them to conserve power by temporarily turning off unnecessary functions while still maintaining the ability to quickly wake up and serve user traffic when needed.
- iii. *Interference Avoidance*: Interference management techniques can be employed to reduce unnecessary signal transmissions and minimize power consumption. By optimizing frequency allocation and implementing interference coordination strategies, small cells can reduce the energy spent on unnecessary signal processing and transmission.
- iv. *Energy-Efficient Hardware*: Selecting energy-efficient hardware components and utilizing advanced radio technologies can contribute to reducing power consumption in small cells. Energy-efficient amplifiers, low-power processors, and advanced modulation schemes can be utilized to improve overall EE.

In small base station, we typically find several power-consuming components. The area covered by one base station is called a cell. Each cell is further divided into several sectors. Each sector is covered by a sector antenna, which is a directional antenna with a sector-shaped radiation pattern. Some equipment is used per sector, such as the digital signal processor(responsible for system processing and coding), the power amplifier, the transceiver(responsible for signal generation and receiving and sending of signals to the mobile stations), and the rectifier. The power consumption of these components should be multiplied by

the number of supported sectors when determining the power consumption of the base station. A small cell has different types of components that consume different amounts of power. For each small cell, power consumption can be divided into four major parts, which are as follows: *Rectifier*: It is used to convert AC signals to DC signals and consumes around 7.5% of total power.

*Signal Processor*: The signal processing circuit consumes approximately 10% of the total power.

*Power Amplifier and Feeder*: According to a power amplifier and feeder, they consume a significant amount of total power, which is around 50–80%, and this range fluctuates based on the changing total load and the user equipment’s distance. An increase in the user equipment’s distance or total load results in high power consumption.

*Cooling System*: Research work depicts that cooling systems’ power consumption range is almost 10–25 percent of total power, which is also influenced by the environment and total load. When the surrounding temperature is high, the cooling system requires more power to balance the small cells’ operating system temperature with the surroundings.

Furthermore, a high traffic load necessitates an increase in processing operations, which raises the temperature of small cells.

### 2.2.2 EE Metrics

EE metrics are essential for evaluating the environmental sustainability and cost-effectiveness of HetNets. These metrics assist network operators in making informed decisions to enhance EE and reduce carbon emissions. One fundamental metric is EE, which quantifies the ratio of

the network’s delivered data rate to its total energy consumption. EE is often expressed as bits per Joule (bps/Joule) or throughput per Watt (bps/Watt). A higher EE value indicates better energy utilization. Additionally, EE considers the network’s EE under different load conditions, providing insights into energy utilization during varying traffic periods. In an Orthogonal Frequency Division Multiple Access (OFDMA) system, each user is assigned one or more subchannels for data reception or transmission. The data rate for user  $N$  is denoted as  $N_r$ . Consequently, the overall data rate of all users in one cell can be determined by considering the assigned subchannels and their respective data rates[50,51].

$$c = \sum_{n=1}^N N_r \quad (2.11)$$

The maximum data rate, denoted as  $C_n$ , is defined as the Shannon capacity of the  $n^{th}$  user in a wireless communication system. This capacity is influenced by the Signal to Interference plus Noise Ratio (SINR) experienced by the user and the bandwidth allocated to them. If we represent the assigned subchannel bandwidth for the  $n^{th}$  user as  $W_n$  and the receiving SINR at user  $n$  as  $\gamma_n$ , then the maximum achievable data transmission rate can be determined by considering these factors.

$$C_n = W_n * \log_2(1 + \gamma_n) \quad (2.12)$$

In this context, our focus is on achieving energy-efficient communication. The goal is to maximize the amount of data transmitted using a specific amount of energy. We will consider the energy consumed over a duration

*Deltat* with a given transmit power  $P$ , i.e.

$$\Delta E = \Delta t * P \quad (2.13)$$

The EE can be expressed as

$$EE = \frac{c}{\Delta e / \Delta t} \quad (2.14)$$

which is equivalent to

$$EE = \frac{c}{P} \text{ bit/s/watt.} \quad (2.15)$$

In a HetNets, when  $x_i$  SBSs are deployed within one macro cell, the overall average cell EE can be calculated as follows:

$$EE = \frac{c_{MBS} + \sum_{n=1}^L c_{x_i}}{P_{MBS} + \sum_{n=1}^L P_{x_i}} \quad (2.16)$$

Where  $c_{MBS}$  average data rate of MBS,  $c_{x_i}$  represents the average data rate of SBS.

$$EE_{cell \text{ only}} = \frac{\sum_{n=1}^L c_{x_i}}{\sum_{n=1}^L P_{x_i}} \quad (2.17)$$

### 2.3 Signal-to-Interference-plus-Noise Ratio (SINR)

Signal-to-Interference-plus-Noise Ratio (SINR) is a crucial metric used in wireless communication systems to evaluate the quality and reliability of the received signal. It represents the ratio of the desired signal power to the combined interference and noise power at a specific receiver. SINR is a fundamental factor in determining the achievable data rates and overall performance of wireless networks[52]. The signal to

interference plus noise power ratio (SINR)  $\gamma_{x,n}$  of a user  $n$  served by the small cell  $x$  is denoted as:

$$\gamma_{x,n} = \frac{P_r^{x,n}}{\sum_{n=1}^N (P_r^{x,n}) + \delta^2} \quad (2.18)$$

Where  $P_r^{x,n}$  received power of  $x$  SBS by user  $n$  and  $\delta^{2,n}$  the additive white Gaussian noise power level in the communication link. The spectral efficiency of a user  $n$  served by the small cell  $x$  can be expressed as  $C_{n,x} = \log_2(1 + \gamma_{x,n})$ . To maximize the achievable sum data rate, the served users must share the total bandwidth of the attached cell. So the achievable system sum data rate can be expressed as

$$\gamma_{x,n} = \sum_{x=1}^X \sum_n \frac{w_x}{|n_x|} \log_2(1 + \gamma_{x,n}) \implies \text{when user bandwidth share} \quad (2.19)$$

where  $n_x$  is the user set of the small cell  $x$ ,  $|n_x|$  represents the number of served users in the small cell  $x$ , and  $W_x$  is the system bandwidth. The EE is defined by the ratio of the total user rate and the total power consumption which can be expressed as following:

$$\gamma_{x,n} = \frac{\sum_{x=1}^X \sum_n \frac{w_x}{n_x} \log_2(1 + \gamma_{x,n})}{\sum_{x=1}^X (I_x((P_s + \alpha * P_{tx_{max}}) + (1 - I_x)P_{sleep})} \quad (2.20)$$

where  $I_x$  is binary decision variable. Small cell is in “on” state when  $I_x = 1$  and small cell is in “off” state when  $I_x = 0$ . Higher SINR values indicate better signal quality and reduced interference, resulting in improved communication performance. As SINR increases, the receiver can more accurately decode the received signal, leading to higher data rates and improved signal reliability. In practical scenarios, interference

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from other users, neighboring cells, or other wireless devices can significantly impact SINR. Therefore, managing interference and optimizing the SINR is crucial for achieving efficient and reliable wireless communication.

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## 3 Chapter Three

### 3.1 GA Definition and Explanation

GA are a type of optimization technique inspired by the process of natural selection. They are used to find solutions to complex optimization and search problems. In the context of sleep patterns, a GA could be applied to optimize an individual's sleep schedule, considering various factors to find an optimal pattern that maximizes restfulness and productivity. It is a subset of Evolutionary Algorithms, a group of search and optimization engines inspired by the natural process of evolution. To find the best solution(s) to a given computing problem that maximizes or minimizes a specific function, GA are a sort of optimization method [53]. The goal of this study is to maximize the energy efficiency of heterogeneous networks, i.e., to ensure that the value of network nodes is non-negative. The solution that corresponds to the maximum value of the fitness function during the iteration process is chosen as the subject of the following iteration for repeated calculation, and the fitness value at this point is equal to the optimal maximum value. This is how the GA solves the optimal problem. A GA is a self-learning system that remembers data from earlier attempts to solve a problem to generate new, improved ones. The five distinct phases of a GA are initialization, fitness assignment, selection, crossover, and mutation. These various divisions live up to their names. The goal of this study is to maximize the energy efficiency of ultra-dense heterogeneous networks, i.e., to ensure that the value of network nodes is non-negative. The solution that corresponds to the maximum value of the fitness function during the iteration process is

chosen as the subject of the following iteration for repeated calculation, and the fitness value at this point is equal to the optimal maximum value. This is how the improved GA solves the optimal problem. Following the determination of the fitness function, the energy of the ultra-dense heterogeneous network is encoded using mixed coding. The ultra-dense heterogeneous network's communication nodes in the practical application are not entirely independent of one another[54,55]. The initialization phase involves the creation of a set of random potential solutions. Then their level of fitness is evaluated after this set. Once evaluated, a selection is made to determine which potential solutions advance to the following set. After this selection is finished, a new set is produced by combining the parent solutions into a fresh set and allowing the resulting child solution to undergo mutation. A new collection of potential answers is generated, and this new set is then examined to determine whether it contains the right response. If so, the GA is finished, and the solution is provided. If not, it returns for another assessment of its fitness, and the cycle repeats. This is seen in the diagram below.



Figure 10: Steps of GA

### 3.2 GA Terminology

*Initialization:* The evolutionary process begins with initialization, wherein an initial population of candidate solutions is generated. There are many different methods of initializing populations, but with GA the most popular method of initialization is simply to create a population of randomly

initialized binary strings. Once the initial population has been created, the evolutionary generational cycle begins.

*Selection:* At each generational step, a pool of parents is chosen from the parent population based on the fitness values of each individual using a selection mechanism, such that the fittest individuals will have a greater probability of passing on genetic material to subsequent generations. This selected population (known as the “parent” population) then forms the basis for all subsequent optimizations during the generational step.

*Variation:* Once the parent population is fully populated via the selection process, a child population is created which will form the basis of the next generation. This child population is generated by variation operators, which are performed on individuals from the parent population. The most prominent such methods are crossover and mutation.

*Crossover:* Crossover takes pairs of parents from the parent population (usually random selection with replacement, such that the same parent can be selected multiple times to produce children). These parents then have some of their genetic information swapped between them. Crossover of two parent chromosomes is usually done in a single-point manner, where a single crossover point on both chromosomes is randomly selected and then all subsequent genetic information is swapped between individuals.

*Mutation:* While crossover simply swaps pre-existing information between pairs of candidate solutions, mutation in Evolutionary Algorithms is typically the standard method of introducing “new” genetic material into the population. Once the child population has been created via

crossover, mutation in canonical GA then occurs on all children in a “bit-flip” fashion by randomly changing codons on the chromosome between 0 and 1. Evaluation: Once the child population has been created, all children then need to be evaluated in order to assign a fitness value by which they can be judged against their peers. This fitness is used to sort/rank a population and to impose probabilities for both selection and replacement phases of the search process, such that the fittest members of the population have a higher probability of passing on genetic material. Fitness function: The fitness function is the function that the algorithm is trying to optimize [52]. It is used here because the fitness function tests and quantifies how ‘fit’ each potential solution is. The fitness function is one of the most pivotal parts of the algorithm. Continuing the analogy of natural selection in biological evolution, the fitness function is like the habitat to which organisms (the candidate solutions) adapt. It is the only step in the algorithm that determines how the chromosomes will change over time, and can mean the difference between finding the optimal solution and finding no solutions at all.

*Replacement:* The final act of the generational step is to replace the old “N” population with the new “N+1” child population. While many methods exist, the most typical replacement method is Generational Replacement, wherein the entire previous generation is replaced with the newly generated child population. Termination: A GA will typically terminate after a predefined number of generations, or if some stopping criterion has been met (e.g. fitness is above some threshold, error rate is below some threshold, etc). The fittest solution in the population is then returned as the overall best solution.

### 3.3 Selection Methods of GA

Six different selection methods are considered, namely: the roulette wheel selection (RWS), the stochastic universal sampling (SUS), the linear rank selection (LRS), the exponential rank selection (ERS), the tournament selection (TOS), and the truncation selection (TRS). Here are six selection methods commonly used in GA[53,54, 55]:

*Fitness Proportionate Selection (Roulette Wheel Selection):* This method selects individuals based on their fitness values. The probability of selecting an individual is proportional to its fitness. It is called "roulette wheel selection" because the selection process can be visualized as spinning a roulette wheel. The better the fitness, the higher the chance of being selected

*Rank Selection:* In rank selection, individuals are selected based on their rank or position in the population rather than their actual fitness values. Individuals are sorted according to their fitness, and the probability of selection depends on their rank. This method can be useful when large fitness differences need to be put into perspective.

*Tournament Selection:* Tournament selection involves randomly selecting a subset of individuals from the population and then selecting the best individual from that subset as a parent. This process is repeated multiple times to create the desired number of parents. Tournament selection helps maintain diversity in the population by giving a chance for less fit individuals to be selected.

*Truncation Selection:* Truncation selection selects the top individuals in the population based on their fitness values. Only a certain proportion of the best individuals are chosen as parents for the next generation. This

method promotes convergence towards better solutions but may reduce diversity.

*Stochastic Universal Sampling:* Stochastic universal sampling is a variation of fitness proportionate selection. Instead of selecting individuals based on probabilities, multiple equally spaced pointers are placed on a roulette wheel, and the wheel is spun once to select parents. This method ensures a more diverse selection than roulette wheel selection.

*Elitism:* Elitism involves preserving a certain number of the best individuals from the current generation unchanged in the next generation. This ensures that the best solutions are not lost during the evolution process and can help maintain or improve the quality of the solutions. These selection methods provide different approaches to balance exploration and exploitation in the search for optimal solutions within a GA framework.

### 3.3.1 Roulette Wheel

A roulette wheel selection method is a popular approach used in GA to select individuals for recombination, a crucial step in the GA process. It is a stochastic selection method where the probability of selecting an individual is proportional to its fitness. The method is inspired by real-world roulettes but adapted to create a weighted version. The larger an individual's fitness, the more likely it is to be selected for recombination[56]. Here are the steps to operate a roulette wheel selection in a GA:

1. *Chromosome Representation:* In a GA, a population of individuals is represented by chromosomes, which are typically fixed-length arrays containing binary variables. Each bit of the variable maps to

- a parameter or characteristic of the individual.
2. *Fitness Calculation:* Each individual in the population is evaluated based on its performance in the given problem domain, and a fitness value is assigned to measure its fitness level.
  3. *Fitness Proportional Probabilities:* For each individual in the population, the probability of selection is calculated as a function of its fitness. The probabilities are generated such that higher fitness individuals have a greater chance of being selected.
  4. *Probability Normalization:* The probabilities calculated in the previous step are normalized to the interval  $[0, 1]$ , ensuring that the sum of probabilities for all individuals in the population equals one.
  5. *Roulette Wheel Selection:* Once the probabilities are computed and normalized, the selection process begins. Random numbers are generated, and the individuals are selected based on the probabilities as if they were positioned on a roulette wheel. The higher the fitness of an individual, the larger its corresponding section on the roulette wheel, and the more likely it is to be selected.
  6. *Recombination:* The selected individuals, acting as parents, undergo recombination (crossover) to produce new offspring. This process mixes their chromosomes to create new solutions for the next generation.

Finally, we can sum up the considerations made above and develop a method that satisfies the requirements we set. In a population with  $n$  individuals, for each chromosome  $x$  with a corresponding fitness value

$f_x$ , we compute the corresponding probability of selection as:

$$P_x = \frac{f_x}{\sum_{i=1}^k x_i} \quad (3.1)$$

We can then simply treat the probability distribution as the one from which we sample the parents we choose for recombination.

### 3.3.2 principles of Roulette Selection

The principles of Roulette Selection, also known as fitness proportionate selection, in the context of GA are as follows[56]:

*Stochastic Selection:* Roulette selection is a stochastic selection method

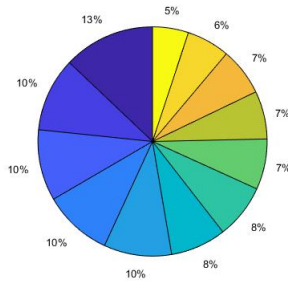


Figure 11: *Fitness probability for selection of an individual based on its fitness*[56].

used in genetic algorithms for selecting potentially useful solutions for recombination. It is inspired by real-world roulette wheels found in casinos, where each candidate solution represents a pocket on the wheel. The size of the pockets is proportionate to the probability of selection of the solution based on its fitness value.

*Fitness-Based Probability:* In roulette selection, the fitness function assigns a fitness value to each individual in the population. The fitness level is used to associate a probability of selection with each chromo-

some. The probability of selecting an individual is proportional to its fitness. Higher fitness individuals have a greater chance of being selected, similar to a larger pocket on a roulette wheel having a higher probability of being chosen.

*Selection Diversity:* Roulette selection allows for diversity in the selection process. While individuals with higher fitness values are more likely to be chosen, there is still a chance for weaker solutions to survive the selection process. This diversity is beneficial as it provides an opportunity for weaker solutions to potentially contribute useful features or characteristics during the recombination phase.

*Normalization:* To create a valid probability distribution, the probabilities of selection are normalized to the interval [0, 1]. This normalization ensures that the sum of probabilities for all individuals in the population equals one.

*Probability Calculation:* The probability of selecting an individual is calculated by dividing its fitness value by the total fitness of all individuals in the population. The formula for the probability of selection for an individual is:

$$P(i) = \frac{fitness}{\sum fitness} \quad (3.2)$$

*Random Selection:* The selection process involves generating a random number in the interval [0, S], where "S" is the sum of relative fitness values of all individuals. The population is then traversed, and the corresponding relative fitness values are summed. When the sum becomes greater than the random number generated, the corresponding individual is selected for recombination.

By following these principles, roulette selection efficiently chooses indi-

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viduals for recombination in GA, allowing for an effective search of the solution space.

## 4 Chapter Four

### 4.1 Simulation and Performance Discussion

In this thesis, we consider the traffic data and energy consumption of a LTE cellular network. We take two scenarios: the Marco cell and the small cell. We prepared the data (traffic load data and energy consumption data) accordingly for simulation, as modeled in Chapter 1. But, before proceeding to the simulation result, here are the traffic characteristics of the small base station on different days. Thus, working days (taken on Monday traffic load), weekend holidays (taken on Saturday traffic load), and yearly holidays (taken on Easter traffic load) are shown in the graph below, respectively. As seen from Figure 13 above, on a

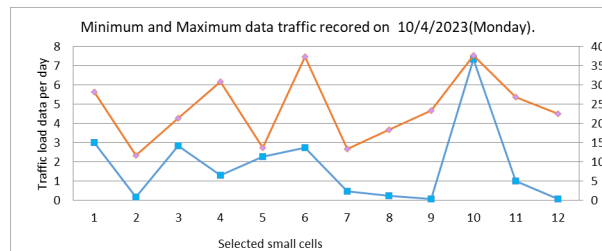


Figure 12: *Small cell traffic data(GB) on normal working day (Monday)*

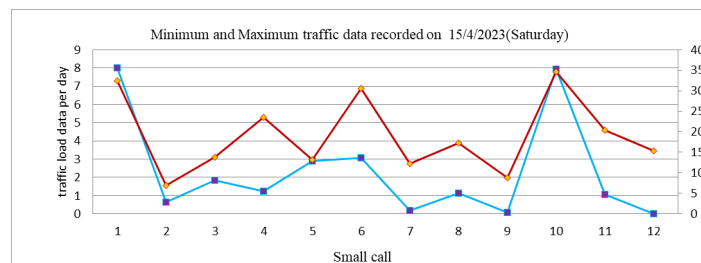


Figure 13: *Small cell traffic data (GB) on weekend holiday day(Saturday)*

normal working day, only five SBSs give 2 GB of service per day, while

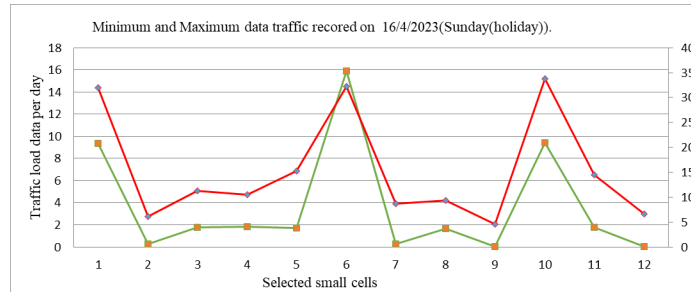


Figure 14: *Small cell traffic data(GB) on yearly holiday day(Easter)*

other small cells give less than 2GB within 24 hours (per day). When we see Figure 14, the weekend holiday traffic data of small cells shows that only four small cells give above 2 GB, but these four small cells are more loaded than on a normal working day. Even if the site selected a business area, some business organizations (hotels, supper markets, markets, sports fields, and others) may work on Saturday, so it may load more. Also, the other eight small cells are relatively more loaded than small cells on normal working days. Finally, in Figure 15, the traffic data on the yearly holiday (Easter day) shows that only three small cells give service more than 2GB per day, but they are the most heavily loaded of the two above. Generally, the traffic load data depends on the days and areas where it fluctuates.

#### 4.1.1 Simulation scenario

We consider an LTE coverage area to have dimensions of 3x3 km, and the area, specifically Meskel Square, contains 12 small cells and 12 macro cells. We take the energy consumption of selected small cells and their neighboring macro cells from the ethio telecom network system monitoring (PRS and PAV), and we take their real traffic data for

consecutive seven days, including working days, weekend holidays, and the yearly holiday (Easter), on an hourly basis. By analyzing (preparing) the collected data for MATLAB simulation by using a GA, here are some preprocessing and data preparation steps:

*Simulation parameters:* the simulation parameters are shown in a table 5.1 below.

*Defining Chromosome* The term chromosome refers to a numerical

project	Parameter value	Instruction
Number of small cells	12	decided number of small cell for this thesis
Static power consumption	1726	Power consumption when the circuit state is stable
Maximum transmission power	0.25 Watts(24dBm)	Transmission energy consumption of all working devices in the network
Frequency	2GHz	through which SBS communicate with MBS
Slope of the load	$\alpha$	transmission Power consumption coefficient when number of user changed
Band width	20 MHz	Maximum bandwidth through which a communication signal can effectively pass
Crossover probability	0.8	taken for parental gene exchange
Mutation probability	0.1	Advisable mutation rate taken between 0.001 to 0.1
Multipath fading	An exponential distribution with a mean of 1	Influence of external electromagnetic waves
Shadow fading	A lognormal distribution with a standard deviation of 8	The shadow effect caused by obstructions reduces the signal strength

Table 4.1: *Simulation parameters of lower nodes (small cells)*

value or values that represent a candidate solution to the problem that the GA is trying to solve [53]. Each candidate solution is encoded as an array of parameter values, a process that is also found in other op-

timization algorithms. For  $X$  ( $X = 12$ ) number of small cells in the above-described network zone, each UE has  $X$  choices for the association. However, it must be associated with a small cell that is currently assumed to be working in the ON state. Each small cell can be in any of the three states,  $s \in S$  (state of small cell or the Node)[54]. Based on this strategy, we define the chromosome of this model as follows:

$$\text{chromosome} = (g_1, g_2) \quad \text{where } g \text{ represent gene.} \quad (4.1)$$

$\text{chromosome} \in (ON, \text{traffic aware handoff and sleep}, OFF)$  is a combination of genes( $g$ ), denoting the current state of the small cell  $X$  at time instants  $t$ . Here,  $1 \leq x \leq X$  is used as the small cell index in a chromosome. The chromosome structure proposed in this work comprises two genes with distinct sizes and characteristics: Cell load traffic (CLT), encoded on 7 bits, and neighbor load traffic (NLT), stored on 9 bits depending on number of user designed to serve (127 people and 511 people respectively). A small cell and a macrocell are represented by each chromosome. Following the definition of the chromosome, we must define the population size. The starting population set,  $X$ , is chosen as follows.

$$\text{Population}(P) = (X_1, X_2, X_3, \dots, X_{12}) \quad (4.2)$$

**Fitness Function** Define the fitness function, population variables, and other GA parameters such as the number of bits per gene. A small cell needs 7 bits (it gives service for 127 users simultaneously). Macrocell, represented by 9 bits (it gives service for 511 users simultaneously), pop-

ulation size (Npop), mutation rate (), selection process, mating process, and convergence condition are going to be defined.

*Cell load traffic CLT*: The  $CLT_i$  rate the traffic intensity in  $X_i$ , the fitness function of this parameter is:

$$CLT_X = \frac{\text{Hourly average data traffic of small cell}}{\text{Hourly maximum data traffic of small cell}} \quad (4.3)$$

Where hourly average data traffic of small cell is total data rate required to satisfy each connected  $UE_s$  and is hourly maximum data traffic of small cell total bandwidth assigned to  $X_i$ . *Neighboring load traffic (NLT)*: The  $NLT_i$  represents the average load traffic of surrounding  $X_i$ .

$$NLT_X = \sum_{j=1}^J \left( \frac{\text{Hourly average data traffic of neighbors cell}}{\text{Hourly maximum data traffic of neighbors cell}} \right) \quad (4.4)$$

The cumulative sum of individual fitness value of all the genes represents the overall fitness function value of chromosome. This value is calculated by:

$$\alpha = \sum \text{Weight} * CLT_x * NLT_x \quad (4.5)$$

Where,  $\text{weight} = [W_{CLT} \text{ and } W_{NLT}]$  weight gives the importance level or the weight placed upon each objective  $i$  with  $\sum_{i=1}^2 = 1$ . In this thesis, we use the given weights,  $W_{CLT} = 0.63$  for cell load traffic and remaining 0.37 for neighbor load traffic. The values of each function are normalized between 0 and 1. In this study, the best values to switch off a *SBS* are both the fitness functions  $CLT_i$  and  $NLT_i$  converge to 0. So, the  $X_i$  with the minimum fitness value is selected as a candidate cell for switch off. The population is then evolved and evaluated across successive generations based on the GA operators such as selection, crossover

and mutation.

*Initialization of population:* Generate an initial population based on

S.No.	CLT/100	NCL /100	Binary CLT	Binary NLT
1	67	75	1000011	001001011
2	53	66	0111111	001001100
3	46	57	0111001	001001000
4	71	73	1000010	001001100
5	52	78	0111110	001001110
6	63	63	1000001	001001011
7	49	71	1000000	001010000
8	55	67	0111100	001010111
9	57	55	1000011	001001011
10	61	81	0111101	001010001
11	75	89	10001111	001010101
12	58	93	0111010	001010110

Table 4.2: Population generation

the range of decision variables and the decided population size. As explained above, the decision variables are Cell load traffic and Neighbor cell load traffic, while the population size is 12. For any given continuous value of the variables, they are first converted to binary to form the chromosomes and population. After that decode chromosomes in the population to represent the decision variables in the solution space. Hence we use the below formula to decode the genes which further will be used in calculating  $\alpha$ (slope of traffic load):

$$CLT_i = CLT_i + Decimal * (binaryCLT_i) \frac{(CLT_{high} - CLT_{low})}{2^7 - 1} \quad (4.6)$$

$$CLT_i = CLT_i + Decimal * (binaryCLT_i) \frac{(CLT_{high} - CLT_{low})}{2^9 - 1} \quad (4.7)$$

Once the decision variables have been decoded, calculate the  $\alpha$  (slope of traffic load) of each chromosome.

S.No.	CLT/100	NCL /100	Binary CLT	Binary NLT	Chromosome
1	67	75	1000011	001001011	1000011001001011
2	53	66	0111111	001001100	0111111001001100
3	46	57	0111001	001001000	0111001001001000
4	71	73	1000010	001001100	1000010001001100
5	52	78	0111110	001001110	0111110001001110
6	63	63	1000001	001001011	1000001001001011
7	49	71	1000000	001010000	1000000001010000
8	55	67	0111100	001010111	0111100001010111
9	57	55	1000011	001001011	1000011001001011
10	61	81	0111101	001010001	0111101001010001
11	75	89	10001111	001010101	1000111001010101
12	58	93	0111010	001010110	0111010001010110

Table 4.3: Population generation

*Alpha function:* The alpha function is the function that the algorithm is

S.No.	Chromosome	CLT/100	NCL/100	$\alpha$
1	1000011001001011	74.37	77.21	0.0615
2	0111111001001100	72.93	78.23	0.0735
3	0111001001001000	63.27	74.12	0.0815
4	1000010001001100	73.26	78.23	0.082
5	0111110001001110	68.82	80.29	0.0864
6	1000001001001011	72.15	77.21	0.093
7	1000000001010000	71.04	82.35	0.0951
8	0111100001010111	66.6	89.56	0.1158
9	1000011001001011	74.37	77.21	0.1178
10	0111101001010001	67.71	83.38	0.1215
11	1000111001010101	78.81	87.45	0.1264
12	0111010001010110	64.38	88.53	0.1564

Table 4.4: Decoding decision variables

trying to optimize [36]. It is used here because the alpha function tests and quantifies how ‘fit’ each potential solution is. It is the only step in the algorithm that determines how the chromosomes will change over time, and can mean the difference between finding the optimal solution

and finding no solutions at all.

*Variation:* Once the parent population is fully populated via the selection process, a child population is created which will form the basis of the next generation. This child population is generated by variation operators, which are performed on individuals from the parent population. The most prominent such methods are crossover and mutation.

*Crossover:* Crossover takes pairs of parents from the parent population (usually random selection with replacement, such that the same parent can be selected multiple times to produce children). These parents then have some of their genetic information swapped between them. Crossover of two parent chromosomes is usually done in a single-point manner, where a single crossover point on both chromosomes is randomly selected and then all subsequent genetic information is swapped between individuals.

*Mutation:* While crossover simply swaps pre-existing information between pairs of candidate solutions, mutation in Evolutionary Algorithms is typically the standard method of introducing “new” genetic material into the population. Once the child population has been created via crossover, mutation in canonical GA then occurs on all children in a “bit-flip” fashion by randomly changing codons on the chromosome between 0 and 1. We usually set it to a low value, such as 0.1 or 0.001.

*Evaluation:* Once the child population has been created, all children then need to be evaluated in order to assign a fitness value by which they can be judged against their peers. This fitness is used to sort/rank a population and to impose probabilities for both selection and replacement phases of the search process, such that the fittest members of the popu-

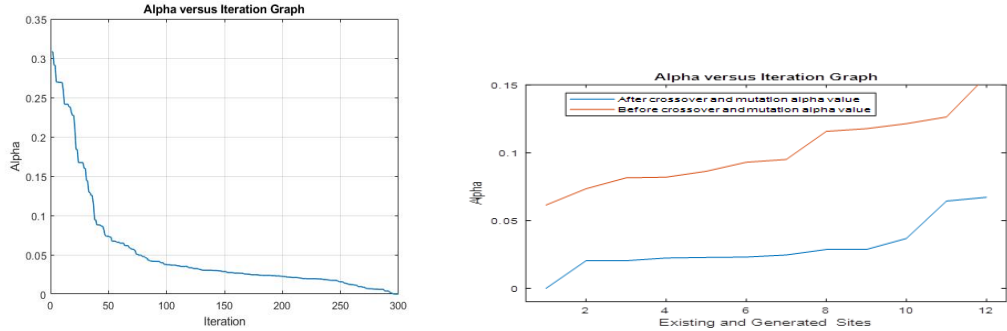
lation have a higher probability of passing on genetic material.

*Replacement:* The final act of the generational step is to replace the old “N” population with the new “N+1” child population. While many methods exist, the most typical replacement method is Generational Replacement, wherein the entire previous generation is replaced with the newly generated child population.

*Termination:* A GA will typically terminate after a predefined number of generations, or if some stopping criterion has been met (e.g. fitness is above some threshold, error rate is below some threshold, etc). The fittest solution in the population is then returned as the overall best solution.

*Termination:* The algorithm proceeds through multiple generations, and the process of selection, crossover, and mutation continues until a termination condition is met. This condition could be a fixed number of generations, achieving a satisfactory solution, or some other criterion.

Using binary code to represent chromosome structures in a GA is a simplified way of mimicking the process of natural evolution. However, it’s worth noting that the choice of encoding, such as binary code, can affect the algorithm’s performance and efficiency, especially for complex problems with high-dimensional solution spaces. In some cases, other encodings like real-valued vectors or permutations might be more appropriate. The choice of encoding depends on the specific problem being solved and the characteristics of the solution space.



(a) Alpha versus iteration simulation graph      (b) Simulation graph of transmission power before and after GA applied

Figure 15: *Simulation graph of transmission power before and after GA applied*

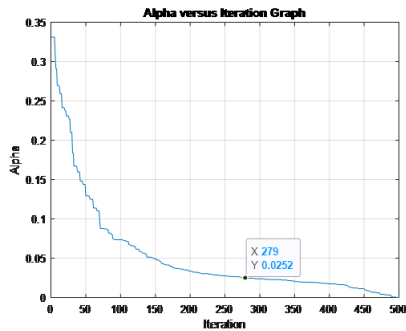
#### 4.1.2 Result Discussion

From the simulation graph result, the transmission power decreases after the GA is applied, and we can see how the alpha reduces at every iteration, giving us our optimal solution. The results show that the alpha value that converges to zero presents the optimal solution. So from the figure, our converging point is  $\approx 0.05$ . Since our target is to sleep or switch off small cells when the transmission power is minimum or zero. At  $\alpha = 0.05$  the transmission power is 0.0125 or 11 dBm it is below specified traffic aware handoff and sleep threshold therefore we can sleep five small sites as shown below in the table by violet color. At  $\alpha = 0.0039$ , the transmission power of a small cell is  $P_t = 0.004 * 0.25 = 0.001watt$ , which is 0 in dBm. So here we successfully switched off two sites that have zero dBm as shown in the table by red color.

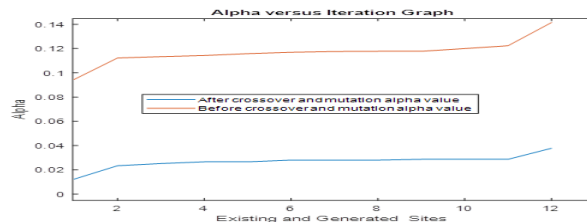
When we increase iteration from 300 to 500 we get the following result. The methods proposed then detect whether SBSs are active (ON), traffic-aware sleep, and switched off. Three Matlab models are used to

Alpha value@ Iteration = 0	Alpha value@ Iteration = 300	Existing power	Optimized Power
0.0615	0.0012	1726.016	1726.001
0.0735	0.0032	1726.019	1726.001
0.0815	0.0042	1726.021	1726.005
0.082	0.0066	1726.021	1726.007
0.0864	0.0204	1726.022	1726.007
0.093	0.0264	1726.024	1726.009
0.0951	0.0287	1726.024	1726.009
0.1158	0.0615	1726.029	1726.01
0.1178	0.0736	1726.03	1726.011
0.1215	0.0943	1726.031	1726.019
0.1264	0.144	1726.032	1726.028
0.1264	0.1482	1726.04	1726.033

Table 4.5: At iteration 300 simulation result table



(a) Alpha versus iteration simulation graph



(b) Simulation graph of transmission power before and after GA applied

Figure 16: Simulation graph of transmission power before and after GA applied

evaluate the power savings of this method to a network in which all small BSs stay active regardless of traffic conditions in the region, and the results are presented below. Three-mode mode factor The BS operation model is computed using a threshold value that is first set at  $\alpha > 0.05$ ,  $\alpha \leq 0.05$ , and  $\alpha = 0$ . As seen from the simulation result table 5.6 above when alpha less than 0.05 (traffic aware offload and sleep) threshold 10 SBSs can be sleep, which saves energy 80% out total power consumption of each site. we have no switched off site here.

Alpha value@ Iteration = 0	Alpha value@ Iteration = 500	Existing power	Optimized Power
0.0615	0.0068	1726.016	1726.002
0.0735	0.0132	1726.019	1726.004
0.0815	0.0132	1726.021	1726.004
0.082	0.018	1726.021	1726.005
0.0864	0.019	1726.022	1726.005
0.093	0.0224	1726.024	1726.006
0.0951	0.0231	1726.024	1726.006
0.1158	0.0252	1726.029	1726.007
0.1178	0.0378	1726.03	1726.01
0.1215	0.0582	1726.031	1726.015
0.1264	0.088	1726.032	1726.022
0.1264	0.2911	1726.04	1726.073

Table 4.6: At iteration 500 simulation result table

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## 5 Chapter Five

### Conclusion and Future Work

#### 5.1 Conclusion

This thesis mentions the issue of insufficient capacity in MBS and how it is solved when small cells are integrated into MBS to make HetNets, which boost capacity. However, this integration leads to an increase in energy consumption, which presents a challenge. To address this challenge, the thesis introduces a switch-on-and-off technique for small cells based on traffic load. It employs GA to optimize energy usage while ensuring a balanced network traffic load. The primary objective of improving energy efficiency in HetNets is to conserve energy, reduce operational costs, and promote environmentally friendly communication. This technique intelligently switches off hardware components during idle conditions, thereby modulating energy consumption based on traffic load variations. The switching control includes three states: ON state, traffic-aware sleep, and switch-off state. Simulation experiments were conducted to examine the effectiveness of the GA-based small cell traffic-aware sleep technique at low load and the small cell switch-off technique at no load or idle, aiming for energy-efficient HetNets. The simulation results demonstrate that the on-off switching of SBSs (SBS) is an effective approach for achieving energy and cost savings. Based on these findings (assuming number of SBSs traffic aware sleep and switched off), it is possible to save 24% of the total energy consumption of SBSs which increase energy efficiency to 92.57%.

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## 5.2 Future Work

In the future, there is potential to expand this study by exploring alternative algorithms for optimizing the energy consumption of small cells. Further improvements can be made to enhance energy efficiency, taking into account traffic demand and network efficiency. However, due to the limitations of scope and time constraints, these enhancements were not possible within the current study. The following points outline potential areas for future extension of this thesis:

- ◇ We considered only centralized architecture cellular network system deployment; because of time, we do not cover distributed architecture cellular network system deployment.
- ◇ In our case, the system was deployed in an open-access configuration scheme. Based on that, we wrote this thesis. However, if the system is deployed in a closed-access or hybrid-access configuration scheme, it may require another parameter consideration, so we do not cover this point.
- ◇ When the user equipment is connected to a macro base station that is located farther away from the user equipment than the switched-off SBS, the power consumption of the user equipment may increase. Thus, even if downlink power consumption is decreased by switching off some small cells, uplink power consumption is somewhat increased. In this thesis, some uplink power consumption when the user equipment is connected to a macro base station is not covered.
- ◇ The algorithm was developed based on the number of small cells in

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a given service area as a binary linear integer programming problem. Thus, in more complex system models, when more parameters like coordinated multipoint transmission, reception, and others are considered, it is necessary to develop heuristic schemes that are computationally efficient.

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