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School of Electrical and Computer Engineering

# Green GSM Network Operation for Energy-Efficiency via Basestations Switching Technique: The Case of Addis Ababa, Ethiopia

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ELECTRICAL AND COMPUTER ENGINEERING DEPARTMENT

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Approval by Board of Examiners

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DECLARATION

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

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

Dr. -Ing. Dereje Hailemariam ____________

Advisor Signature

# Abstract

Green communication is an innovative research area to find information and communication technology (ICT) solutions that can greatly improve efficient utilization of resources such as energy and network equipments with minimum compromise in the users quality of service (QoS). Nowadays, the globe is facing a number of serious global warming problems; these problems have a significant negative impact in terms of the environment, global health, social and economic well being. The main causes of global climate change are growing need of energy, wastage, cutting trees, global industries, etc. From the global growing need of energy, 2 up to 10% are consumed by the global ICT industry in manufacturing, using, and disposal of ICT equipments. One third (1/3) of the total ICT's energy is consumed by the telecommunication equipments; cellular networks consume 90% of it. Basestations, in turn, consume 60 to 80% of the cellular network consumption. So, green communication researches are getting high interest recently years to minimize greenhouse gas emission and also operator energy bill.

Considering the densely deployed basestations in the city of Addis Ababa, Ethiopia, this thesis focuses on applying switching-off basestations during off-peak (low traffic) hours as one strategy to realize green cellular network while fulfilling the requirements of voice and data traffic. The study considers 26 Global System for Mobile communications (GSM) basestations in Addis Ababa around Leghare area. Based on the hourly traffic statistics obtained from the ethio telecom, which is the sole telecommunication network service provider in Ethiopia, the area has high traffic from 5:00 am to 11:00 pm and low traffic during night time which is from 11:00 pm to 5:00 am. The latter is considered as the off-peak hours in this thesis.

The basestations switching off technique is done by turning off basestations remote radio unit (RRU) and applying antenna electrical downtilt and azimuth angles change on active basestations by considering ethio telecom basestations operation and maintenance (OAM) system capabilities of both turning off and angles changes. The switching-off strategy requires first sub-clustering basestations from the selected 26 basestations which are called in this thesis as cluster that are needed to cover the area of Leghar. This is done by comparing the existing coverage radius of basestations which are expected to cover at peak hours with that of the maximum coverage radius of basestations which basestations can cover theoretically. Each sub-cluster members are grouped as one sub-cluster if they can able to cover each other during switching off. Secondly, the traffic capacity of the sub-cluster is compared with the traffic prediction of the off-peak hours to ensure that the sub-clusters (and hence, the total active basestations) can handle the generated traffic. Then, optimize the coverage area of the sub-clusters by modifying the basestations antenna electrical downtilt and azimuth angles.

The area of Leghar can be covered by 11 basestations out of 26 basestations during off-peak hours by applying the tilt and azimuth angles change. With acceptable coverage and service quality, the proposed solution of switched off basestations during off-peak hours yields above 10% energy saving for the all 26 basestations.

Key words: GSM, Green communication, power consumption, energy consumption, prediction, sub-cluster

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## Abbreviations

| | |
|---|---|
| AISG | Antenna Interface Standards Group |
| AGCH | Access Grant Channel |
| ARFCNs | Absolute Radio Frequency Channel Numbers |
| ARMA | Auto-Regressive-Moving-Average |
| ARIMA | Auto-Regressive-Integrated-Moving-Average |
| AuC | Authentication Centre |
| BBU | BaseBand Unit |
| BCH | Broadcast Channels |
| BS | Base Station |
| BSC | Base Station Controller |
| BTS | Base Transceiver Station |
| BSS | Base-Station Subsystem |
| CCCH | Common Control Channels |
| CDMA | Code Division Multiple Access |
| CoMP | Coordinated Multi-Point Transmission |
| CPICH | Common Pilot Channel |
| DBS | Distributed Base Station |
| DCCH | Dedicated Control Channels |
| DTX | Discontinuous Transmission |
| DPDCH | Dedicated Physical Data Channel |
| EDGE | Enhance Data rates for GSM Evolution |
| EIR | Equipment Identity Register |
| eNB | Evolved Node B |
| ESM | Energy-Saving Management |
| FACCH | Fast Associated Control Channel |

| | |
|---|---|
| FCCH | Frequency Correction Channel |
| FDMA | Frequency Division Multiple Access |
| GOS | Grade Of Service |
| GPRS | General Packet Radio Service |
| GSM | Global System for Mobile communications |
| GTP II | Second Growth and Transformation Plan |
| HetNet | Heterogeneous Network |
| HLR | Home Location Register |
| HSPA | High Speed Packet Access |
| ICT | Information and Communication Technology |
| IEEE | Institute of Electrical and Electronics Engineers |
| KPI | Key Performance Indicators |
| LLD | Low Level Design |
| LTE | Long Term Evolution |
| MBSFN | Multicast Broadcase Single Frequency Network |
| MAE | Mean Absolute Error |
| MAPE | Mean Absolute Percentage Error |
| MFE | Mean Forecast Error |
| MIMO | Multiple-Input Multiple-Output |
| MPE | Mean Percentage Error |
| MS | Mobile Station |
| MSC | Mobile Switching services Centre |
| MSE | Mean Squared Error |
| NSS | Network and Switching Subsystem |
| OMC | Operation and Maintenance Center |
| OPEX | Operational Expenditure |
| OSS | Operation and Support Subsystem |

| | |
|---|---|
| PCH | Paging Channel |
| PCU | Portable Control Unit |
| PSTN | Public Switched Telephone Network |
| QoS | Quality of Service |
| RACH | Random Access Channel |
| RCU | Remote Control Unit |
| RET | Remote Electrical Tilt |
| RMSE | Root Mean Squared Error |
| RRM | Radio Resource Management |
| RRU | Radio Resource Unit |
| RTU | Remote Terminal Unit |
| SACCH | Slow Associated Control Channel |
| SARIMA | Seasonal Autoregressive Integrated Moving Average |
| SCH | Synchronisation Channel |
| SDCCH | Standalone Dedicated Control Channels |
| SINR | Signal-to-Interference-plus-Noise-Ratio |
| SMS | Short Message Service |
| SON | Self-Organizing-Network |
| TCH | Traffic Channel |
| TDMA | Time Division Multiple Access |
| TP | Trigonal Pair |
| TRX | Transceivers |
| UMTS | Universal Mobile Telecommunications System |
| VLR | Visitor Location Register |
| WCDMA | Wideband Code Division Multiple Access |

# 1. Introduction

## 1.1. Background

Green communication is an innovative research area to find ICT solutions that can greatly improve efficient utilization of resources such as energy and network equipments with minimum compromise in the users quality of service (QoS). Green communications not only benefit the global environment but also make commercial sense for telecommunication operators supporting sustainable and profitable business [5].

The global greenhouse gas emissions from information and communication technology (ICT) are comparable with those of the aviation industry (2-3% of the world's manmade emissions) [1]. Technology analysts estimate that between 2 to 10% of the worldwide energy consumption is by the global ICT industry in manufacturing, using and disposal of ICT equipment [2]. As the use of ICT grows, its emissions are likely to increase despite improvements in efficiency of human day to day activity. It is estimated that ICT will be responsible for 3% of global emissions by 2020 [1].

The power consumption of cellular network is distributed across different functionalities of network like mobile switching, core transmission, data center, basestations, etc [2]. One third (1/3) of the total ICT's energy is consumed by the telecommunication equipments, the core network and basestations (BSs) consume 90% of cellular energy [4]. With the increase in the number of sites, due to larger capacity and bandwidth requirements, energy efficient solutions became a major concern for telecommunication operators. In addition to minimizing the environmental impact of the industry, cellular network operators are also well interested in reducing the energy consumption of their networks to reduce their operational expenditure (OPEX), and therefore increase profits.

Since basestations are the most energy intensive part of the cellular network, they consume 60 to 80% of cellular network power consumption. Basestation power consumption is the biggest power issue concerning cellular networks. It contributes to a large amount of $CO_2$ emission as well as to network's operating costs [3]. So, more and more researchers have focused on improving the energy efficiency of cellular network.

During the last decade, there have been tremendous growths on cellular networks in Ethiopia to fulfill subscribers' voice and data demand by dense deployment of basestations. This dense deployment is expected to continue for the next decade as ethio telecom growth and transformation plan (GTP) II is to reach 113 million customers by the year of 2020 [43]. Moreover, smart phones penetration and usage of data services are increasing in Ethiopia. Currently, there are above 6,000 basestations with a capacity to support up to 50 million subscribers. By rough estimate, the basestations number will be above 12,000 (double) to handle the 113 million subscribers. These dense deployments are causing (and will cause) high energy consumption and increase ethio telecom's operational expense (OPEX).

Therefore, saving power of basestations is the primary focus of green cellular network design and also designing green power strategies should be started at ethio telecom too.

## 1.2. Statement of the Problem

As discussed in the previous section, the dense deployment of basestations in ethio telecom's cellular networks has high energy consumption and also contributing to greenhouse gas emission. Hence, we need to start thinking about it and find ways that minimize the energy consumption in order to reduce ethio telecom's high OPEX cost of power consumption via the electricity bill.

Currently, above 6000 basestations are available in ethio telecom global system for mobile communication (GSM), wideband code division multiplexing access (WCDMA), long-term evolution (LTE) and code division multiplexing access (CDMA) cellular networks. Even though power consumption of basestations depends on the configuration parameters, operating frequency, cell type (indoors or outdoors antennas) and other parameters; ethio telecom basestations average power consumption is around 3000 watts [18]. Average energy consumption of one basestation (BTS) per day is 32.4kWh; around 2235.6kWh per month. By this, there is an average energy consumption of 13414MWh per month for all BTS. This is a huge amount of energy, as Ethiopia has a scarcity of energy currently. Ethio telecom pays estimated birr of around 112 Million per year for basestations only. Table 1.1 below shows power and energy consumption of a typical basestation.

**Table 1.1: Average energy consumption of basestation**

| Average Power Consumption (Watts) | Average Energy Consumption (kWh) | one BTS Energy Consumption per Month | 6000 BTSs Energy Consumption per Month | Electric Bill tariff per kWh | one BTS Electric Bill per Month (Birr) | 6000 BTSs Electric Bill per Month (M) | 6000 BTSs Electric Bill Birr per Year (M) |
|---|---|---|---|---|---|---|---|
| 3000 | 74.52 | 2235.6 | 13413600 | 0.6943 | 1552 | 9.31 | 111.76 |

So, it is necessary to find solutions to reduce the energy consumption of basestations and to make systems "greener" and save OPEX.

## 1.3. Objectives

### 1.3.1. General Objective

The general objective of this thesis is to propose green cellular network for the existing GSM cellular network basestations around Leghar area, Addis Ababa, during off-peak hours by scheduling basestations on/off in order to reduce basestations power consumption and also study its performance.

### 1.3.2. Specific Objectives

Specific objectives of the research are:

1. Schedul planning of basestations to switch off during off-peak hours.
2. User association, plan how users in switching off cells are handled using the active BSs.
3. Predict hourly traffic requirement of BSs.
4. Investigate ethio telecom basestations from energy consumption perspective point of view and show the challenges of applying energy saving on current basestations deployment.
5. Recommend energy-aware network solutions criteria and standardization (like 3GPP, ETSI, energy-aware standards, etc) to ethio telecom.

## 1.4. Methodologies

The thesis follows the following methodologies:

a. Literature review: is conducted to gain a fundamental understanding of cellular network power consumption reduction. The literature study covers existing articles, books, web resources and any other articles related to cellular network power consumption reduction.

b. Identify existing basestations supporting standards (like 3GPP, ETSI, energy-aware standards, etc) and their problem: it identifies ethio telecom's various basestation types, standards, power consumption, the capacity demand, their capability of supporting basestation power consumption reduction techniques, etc. From the energy-efficiency point of view, the most important feature of networking is underutilization. So sample basestations daily traffic per hour will be investigated to determine traffic volume fluctuations during day and night.

c. System modeling: the scheduling basestations switching on/off technique will have the following strategies:
   - Analysis radio frequency (RF) link budget design and coverage.
   - Determining of equivalent basestations to get Sub-cluster members.
   - Profiling basestations traffic capacity.
   - Off-peak hours traffic prediction for six months.
   - Determine required number of active basestations as per predicted idle traffic hours.
   - Scheduling basestations to switch off.
   - Optimizing the coverage with active basestations.
   - Measures network performance after switched off.

d. Simulation: analyze the impact of different parameters on the performance using atoll simulation tool.

e. Analysis and Interpretation of the results: summarizing in detail the techniques, the opportunities and the challenges of deployment of green cellular network design mechanisms. And recommend future works.

## 1.5. Scopes and Limitations

### 1.5.1. Scopes of the Thesis

In this thesis power consumption reduction of ethio telecom GSM basestations is studied and implemented using simulation tool by applying basestations scheduling switching on/off techniques during off-peak hours with minimum QOS constraints in the area of Leghar, Addis Ababa, Ethiopia.

### 1.5.2. Limitations of the Thesis

Due to limitation of finding accurate data from ethio telecom, the thesis has the following limitations:

- Limited to GSM network only and also not considered the effect of dual band in one antenna due to unable to get WCDMA and LET design documents from ethio telecom.
- Due to unavailability of data regarding the maximum Erlang traffic capacity of each basestation, theoretical analysis is used to find traffic capacity.
- Since the electric bill of the ethio telecom is not formally available, it is estimated by averaging the power consumption of different basestation models and multiplying with Ethiopian electric bill tariff.

## 1.6. Contributions

Contributions of this thesis work are:

1. Propose the idea of green cellular network to ethio telecom during off-peak hours by scheduling basestations off/on in order to reduce basestations power consumption.

2. Investigate and recommend ethio telecom basestation power consumption problems from operational point of view.

3. Recommend energy-aware network solutions criteria and standardization to ethio telecom.

4. Recommend future studies about energy-aware networks design.

### 1.7. Literature Reviews

There are different kinds of system developments, papers and thesis works done but this thesis literature review focuses on how to implement or apply switched off basestations during off-peak hours. In [17], the authors tried to get a solution for the problem of basestations in the third generation (3G) cellular network which are not energy proportional with respect to their carried traffic load. Their measurements showed that 3G traffic exhibits high fluctuations both in time and over space, thus incurring energy waste. In this paper, they proposed a profile-based approach to green cellular infrastructure. They profiled BS traffic and approximated network-wide energy proportionality using non-load-adaptive BSs. The instrument was to leverage temporal-spatial traffic diversity and node deployment heterogeneity, and power off under-utilized BSs under light traffic. Their evaluation on four regional 3G networks showed that this simple scheme yields up to 53% energy savings in a dense large city and 23% in a sparse, mid-sized city.

In [6], the authors proposed the concept of "Application of Cell Zooming in Outage Compensation". Cell zooming is achieved by adjusting the input power to the transmitter or the height of the transmitter. The study developed an algorithm based on Okumura-Hata propagation model to estimate the required height or power input to the transmitting antenna needed for the compensation. The results are fed to Atoll

Planning Software by Forsk to simulate the Received signal levels pattern. The results have revealed that it is possible to achieve outage compensation using cell zooming.

In [7], the authors proposed a novel cell expansion technique, where the coverage area of cells can expand and contract based on the traffic load. This is accomplished by switching off low load cell sites and compensating for the coverage loss by expanding the neighboring cells through antenna beam tilting. The multi-cell coordination was resolved by using either a centralized controller or a distributed self-organizing-network (SON) algorithm. The results showed that the centralized coordination algorithm can achieve a deterministic coverage pattern and a strong low-load energy saving (50%) and no high load saving (0%). Compared to the centralized algorithm, the lower-complexity distributed algorithm can achieve a comparable low-load saving (48%) and a higher high-load saving (20%).

In [8], when regional traffic is low, one key issue of energy saving management (ESM) in cellular networks is how to sleep several BSs and meanwhile guaranteeing regional coverage and service quality. The mechanism included selection of sleeping BSs based on trigonal pari (TP), a regional energy saving algorithm corresponding to TP through adjustments of down tilt and transmit power, and an integrated assessment model based on dynamic traffic. They simulated the mechanism in WCDMA/HSPA network under urban scenarios with multiple services. Results showed that with acceptable coverage and service quality, the ESM mechanism can save at least 34.83% of energy consumption for one sleeping BS.

In [10, 11], Holt-Winter's forecasting technique in cellular traffic forecasting was discussed and showed effective forecasting, the average RMSE was 15.85%. In [16], the exponential smoothing technique was applied to forecast traffic in a certain area considering daily and weekly variations. In [12], Autoregressive model was used to forecast hourly usage of social media, average mean absolute percentage error(MAPE) and RMSE was reduced by 6.98% and 23.95%. In [13, 14, 15], auto-regressive-moving-average (ARMA), auto-regressive-integrated-moving-average(ARIMA), seasonal autoregressive integrated moving average model (SARIMA) Models and Seasonally Adjusting ARIMA model were studied to make traffic series prediction. MAPE of SARIMA for one-step ahead prediction was 1.382%.

## 1.8. Thesis Layout

This thesis is composed of 8 chapters, including the present one. Chapters 2, 3 and 4 present the theoretical fundamentals of GSM, GREEN cellular network architecture and hourly traffic prediction in order to get the required general knowledge. Chapter 5 presents ethio telecom basestations architecture, configuration, supporting standards of energy saving and hourly basestations traffic analysis. Chapter 6 presents the proposed solution of scheduling basestations on/off strategy. In Chapter 7, there are detail simulation analysis and results. Finally, in Chapter 8, this work is finalized by drawing the main conclusions and recommendation for future works. Appendixes are also included at the end of this document.

# 2. Introduction to GSM

## 2.1. GSM Network Architecture

The GSM network architecture as defined in the GSM specifications can be grouped into four main areas as shown in Figure 2.1 (a) [19]:

- Mobile station (MS)
- Base-station subsystem (BSS)
- Network and switching subsystem (NSS)
- Operation and support subsystem (OSS)

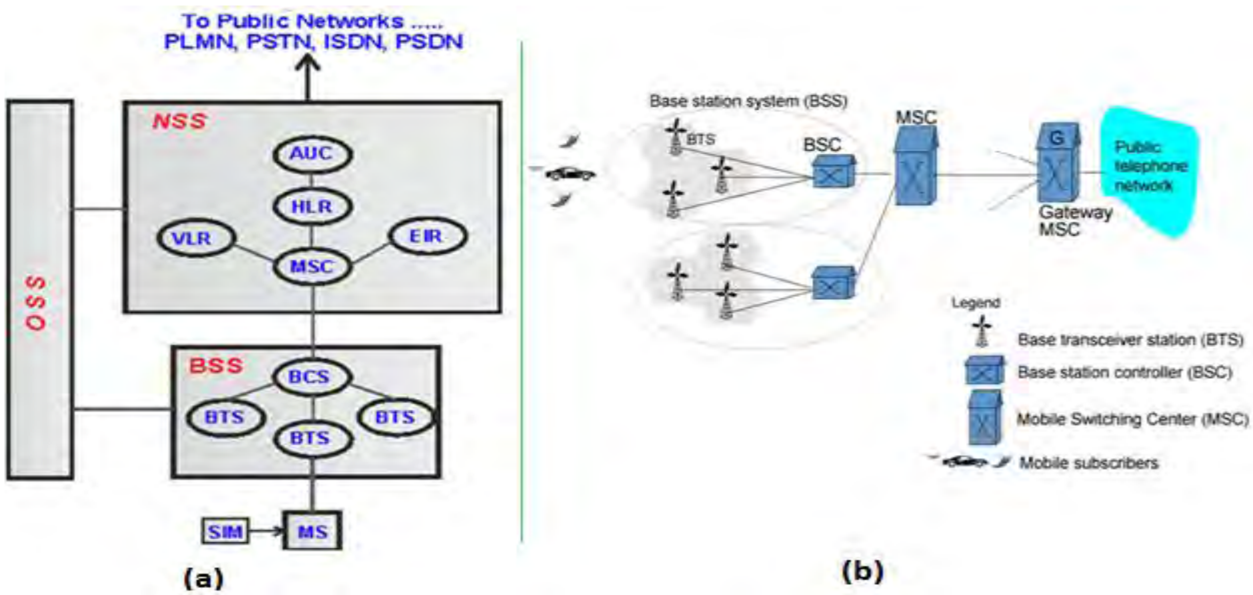



Figure 2.1: GSM network architecture [19].

### 2.1.1. Mobile station

Mobile stations (MS) are the section of a GSM cellular network that the user sees and operates, the two main elements are the main hardware and the subscriber identity module (SIM).

### 2.1.2. Basestation Subsystem (BSS)

The basestation subsystem (BSS) section is fundamentally associated with communicating with the mobiles on the network. It consists of two elements:

- Base transceiver station (BTS): The BTS used in a GSM network comprises the radio transmitter receivers, and their associated antennas that transmit and receive to directly communicate with the mobiles. The interface between the BTS and the mobile is known as the Um interface with its associated protocols.
- Base station controller (BSC): It controls a group of BTSs, and is often co-located with one of the BTSs in its group. It manages the radio resources and controls items such as handover within the group of BTSs, allocates channels and the like. It communicates with the BTSs over the Abis interface.

### 2.1.3. Network Switching Subsystem (NSS)

Network Switching Subsystem (NSS), also termed as core network, provides the main control and interfacing for the whole mobile network. The major elements within the core network include:

- Mobile switching services centre (MSC): is the main element within the core network area. The MSC acts like a normal switching node within a public switched telephone network (PSTN) or integrated services digital network (ISDN), but also provides additional functionality to enable the requirements of a mobile user to be supported. These include registration, authentication, call location, inter-MSC handovers and call routing to a mobile subscriber. It also provides an interface to the PSTN so that calls can be routed from the mobile network to a phone connected to a landline. Interfaces to other MSCs are provided to enable calls to be made to mobiles on different networks.

- Home location register (HLR): This database contains all the administrative information about each subscriber along with their last known location. In this way, the GSM network is able to route calls to the relevant basestation for the MS. When a user switches on their phone, the phone registers with the network and from this it is possible to determine which BTS it communicates with so that incoming calls can be routed appropriately. Even when the phone is not active (but switched on) it re-registers periodically to ensure that the network (HLR) is aware of its latest position.

- Visitor location register (VLR): This contains selected information from the HLR that enables the selected services for the individual subscriber to be provided. The VLR can be implemented as a separate entity, but it is commonly realized as an integral part of the MSC, rather than a separate entity. In this way access is made faster and more convenient.

- Equipment identity register (EIR): The EIR is the entity that decides whether given mobile equipment may be allowed onto the network. Each mobile equipment has a number known as international mobile equipment identity.

- Authentication centre (AuC): The AuC is a protected database that contains the secret key also contained in the user's SIM card. It is used for authentication and for ciphering on the radio channel.

#### 2.1.4. Operation and Support Subsystem (OSS)

The Operation and Support Subsystem (OSS) is an element within the overall GSM network architecture that is connected to components of the NSS and the BSC. It is used to control and monitor the overall GSM network and it is also used to control the traffic load of the BSS.

## 2.2. GSM Radio Interface and Channels

### 2.2.1. GSM Radio Interface

In GSM, MS is connected with the network via the radio channel. The specifications which are related to the radio channel signal transmission aim at Um interface.

As shown in Figure 2.2, the Um interface is a kind of radio interface. It is responsible for the communication between the mobile station and the BTS and provides the interworking link between them. Its physical connection is achieved via the radio waves. The Um interface is the most important interface among all the interfaces in GSM system. First of all, the complete and normative Um interface realizes full compatibility between MS of different venders and different networks. That is fundamental conditions needed in global roaming of the GSM system; second, the radio interface determines the rate of frequency spectrum utilization of GSM system [42].

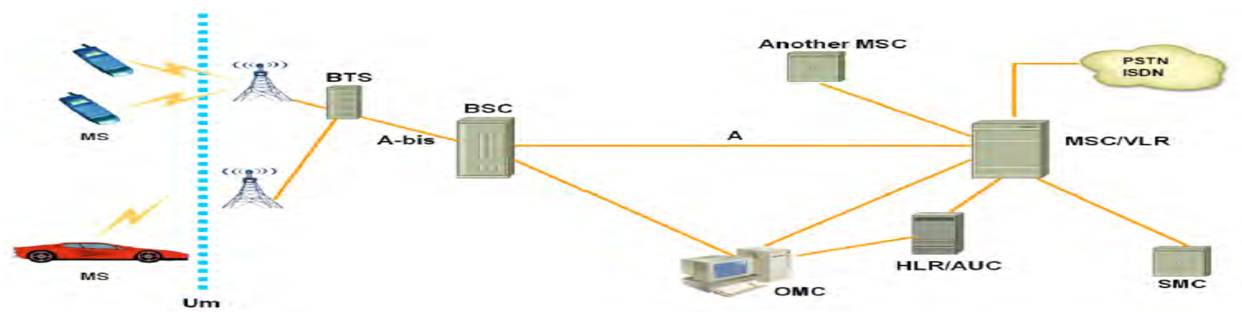



Figure 2.2: Um interface [42].

Um interface has three layers of hierarchical structure. These are the physical layer (it provides the radio link needed in transmission of bit stream), the data link layer (it controls the data transmission so as to ensure the reliable dedicated data links)and the network application layer (it includes various types of messages and programs for control and management of the services).

The GSM Um interface applies multiple access technology. With this technology, multiple subscribers can share the same public communication connection. They are frequency division multiple access (FDMA) and time division multiple access (TDMA) as shown below Figure 2.3.

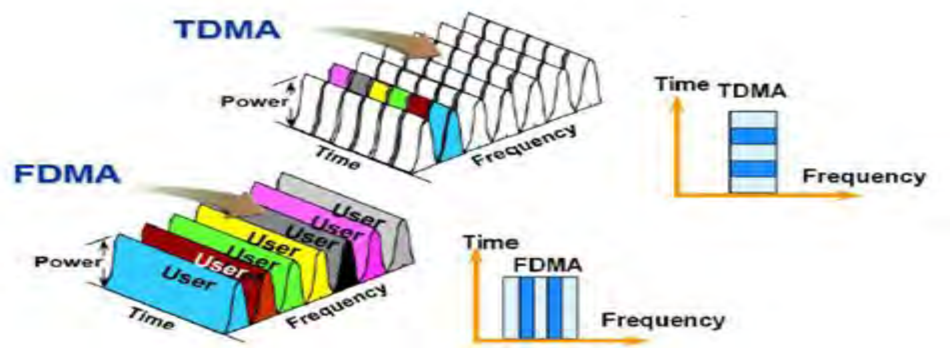



Figure 2.3: Multiple access technologies [42].

### 2.2.2. GSM Channels

GSM uses two frequency ranges, between [890, 915] MHz for uplink (UL) and [935, 960] MHz for downlink (DL) at GSM-900, and also between [1710, 1785] MHz for UL and [1805, 1880] MHz for DL (GSM-1800). So each frequency band is divided into carriers spaced by 200 kHz, which are numbered consecutively by the ARFCNs (absolute radio frequency channel numbers).Each 200 kHz carrier has 8 timeslots, allowing eight users to share it. The timeslots are numbered from 0 to 7, and have the duration of 576.92 μs, which is equivalent to 156.25 bits. A group of 8 timeslots is called frame, and it has the duration of 4.615 ms. Each subscriber accesses a specific timeslot in every frame of a frequency carrier, establishing a physical channel. The type of data that is transmitted over that physical channel depends on the mapping of the logical channels [34].

There are two types of channel, physical and logical Channels as shown below Figure 2.4. The physical channel is the medium over which the information is carried. The logical channel consists of the information carried over the physical channels. A physical channel (a time slot, defined by a fixed position (0-7) on a given TDMA frame) can be used to broadcast messages containing different kinds of information.

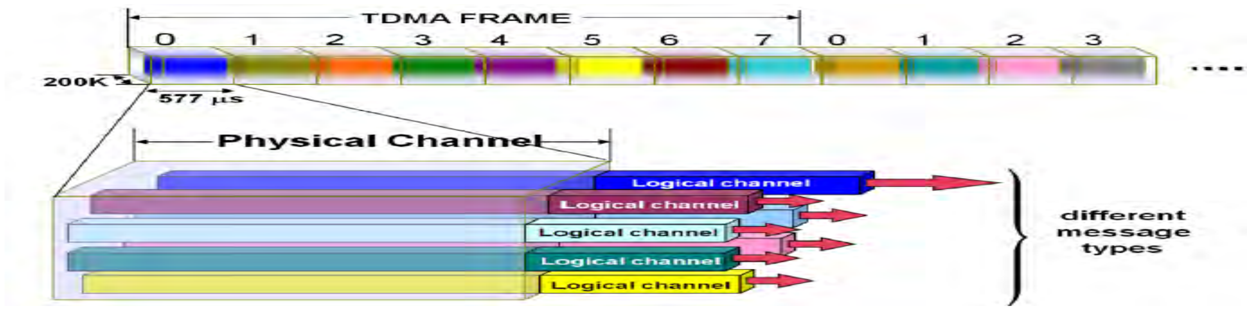



Figure 2.4: Physical and Logical Channels [42].

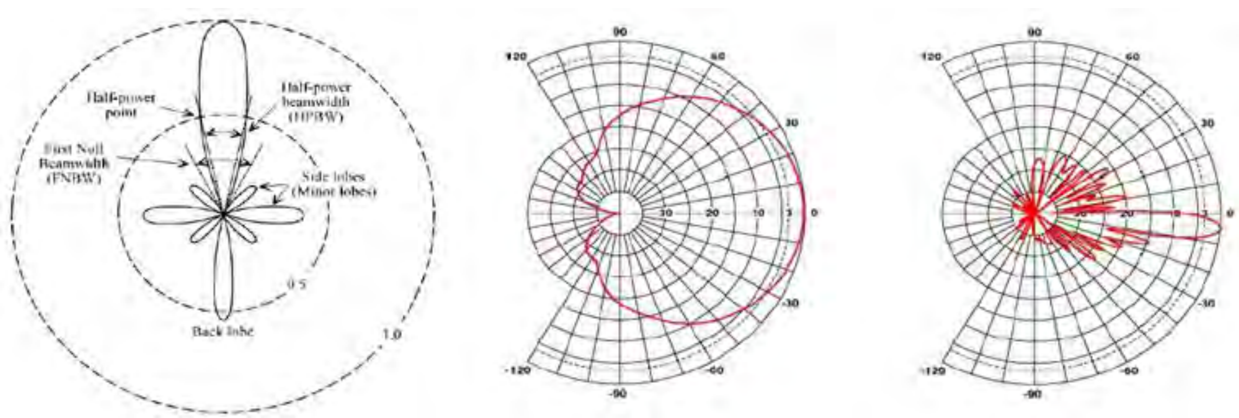
There are three types logical channels, broadcast, common control and dedicated control channels. The broadcast channels (BCH) are only used in the DL, they provide the MS with the information needed to establish the synchronization on both time and frequency, and broadcast control channel (BCCH), synchronization channel (SCH) and frequency correction channel (FCCH) are BCH channels. The common control channels (CCCH) are used to send information to a certain MS to initiate the setup stage before a channel is allocated to that MS, and paging channel (PCH), access grant channel (AGCH) and random-access channel (RACH) are CCCH channels. Finally, the dedicated control channels (DCCH) are bidirectional and transmit the signaling information that is necessary during a connection, such as the assurance that BS and MS stay connected during the authentication process, the information update of the signal quality received at the MS, or handover procedures. Standalone dedicated control channel (SDCCH), traffic control channel (TCH), slow associated control channel (SACCH), fast associated control channel (FACCH) and dedicated physical data channel (DPDCH) are DCCH channels.

## 2.3. Basestations Antenna

An antenna is used to transmit or receive electromagnetic signals through the space. Antenna parameters should be taken into account by network designers during planning because network performance depends on them and should be able to adjust them according to the needs of the system. These parameters are type of antenna, the radiation properties, how antenna parameters interact with the environment, where it will be mounted, etc. Hence, let's see few antenna parameters in the next sections.

### 2.3.1. Antenna Radiation Patterns Properties

Radiation properties of antennas are showing the antenna radiation pattern which graphically represents radiation intensity as a space function. Radiation patterns are usually represented in three-dimensional (3D) graph or by means of azimuthal (horizontal) or elevation (vertical) pattern [21]. The below Figure 2.5 shows (a) different radiation lobes, (b) horizontal pattern and (c) vertical pattern.




(a) Different radiation lobes (b) Horizontal pattern (c) Vertical pattern

**Figure 2.5: Example of an antenna radiation pattern [21, 24].**

Beamwidth expresses the angular width where most of the power is radiated. It is usually referred as 3dB beamwidth, considered the half radiated power which is 3dB below the main peak of the radiation pattern. Antennas are not able to radiate all power in one single direction; inevitably some of the power is radiated in other directions. These peaks are called side lobes and have a lower magnitude than main lobe. Besides these parameters, there are more that should be taken into account and have also influence on antenna design. One of these parameters are the nulls, which are referred to the radiated power at minimum value. For instance, this parameter can be useful to suppress interfering signals in some directions. Another parameter is the front-to-back ratio which is the difference between the value in the front direction and back direction.

Azimuth beamwidth of a BS is chosen in function of frequency re-use plan for the network. The typical configuration for BSs would be three sectors spaced 120 degree in azimuth plane with $65^0$ 3dB beamwidth, but this is not considered a strict configuration because coverage needs will depend on buildings or hills around.

In [30], **beamforming** is a general technique to control the radiation pattern of a radio signal transmitted from an antenna. Typically, this is done by means of using several elements and applying a proper antenna tilt.

### 2.3.2. Antenna Tilt

In [32], antenna tilt is defined as the angle between the main beam of the antenna and the horizontal plane. A tilt value of $0^o$ shows that the direction of the main beam is parallel to the ground and points towards the horizon.

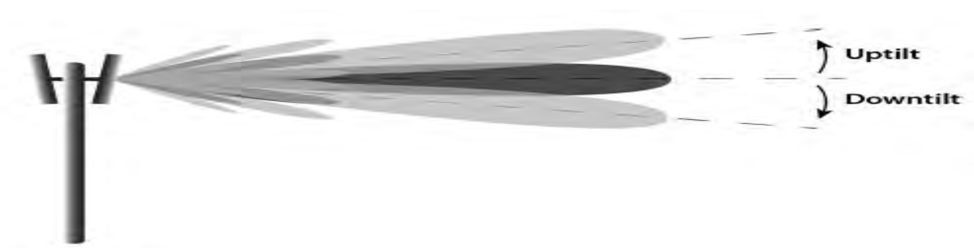



**Figure 2.6: Illustration of up-tilting and down-tilting [32].**

There are two methods of adjusting tilt, mechanical or electrical. Mechanical tilt implies adjusting the mounting brackets of the antenna in such a way that the whole antenna will be tilted in the desired direction, leaving the radiation pattern unchanged. Electrical tilt is achieved with a phase shifter in the feed network of the individual antenna's elements, which will allow for a uniform modification of the radiation pattern.

The below Figure 2.7 shows the effect of applying antenna tilt on radiation pattern.

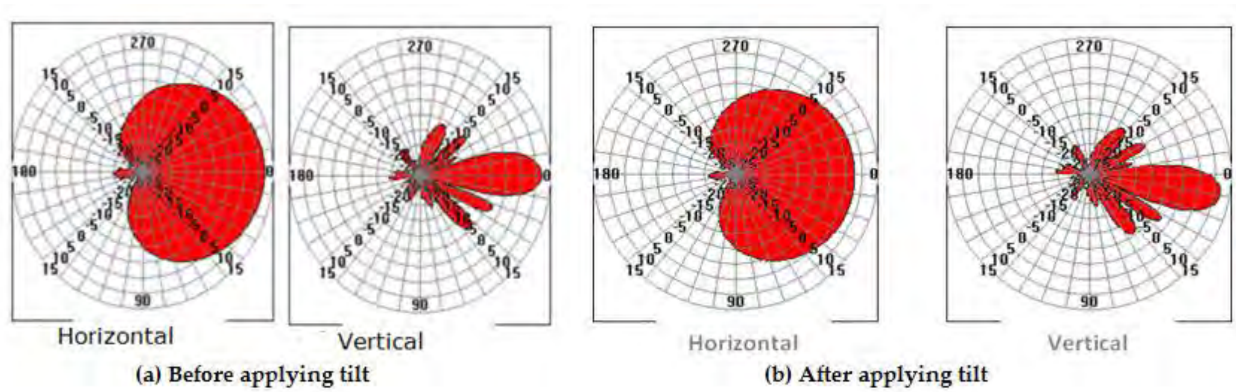



**Figure 2.7: Antenna radiation pattern before and after applying antenna tilt [31].**

As we can see from the above figure, when apply a tilt (electrical or mechanical) to an antenna, it changes the signal propagation, because it changes the 3D diagram. But this variation is also different depending on the type of electrical or mechanical tilt. Therefore, it is very important to understand how the irradiated signal is affected. The below figure 2.8 shows the effect of electrical and mechanical tilt.

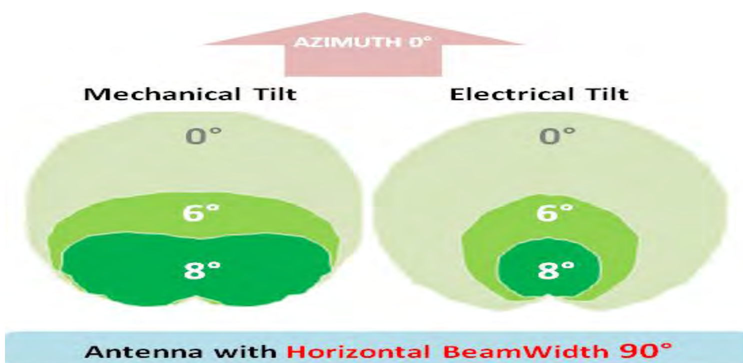



**Figure 2.8: Radiation diagram differences of applying mechanical & electrical tilt [31].**

The goal with the figures above is how each type of tilt affects the end result of coverage. Roughly, but that can be used in practice, the tilt angles can be estimated through simple calculation of the vertical angle between the antenna and the area of interest as show below Figure 2.9.

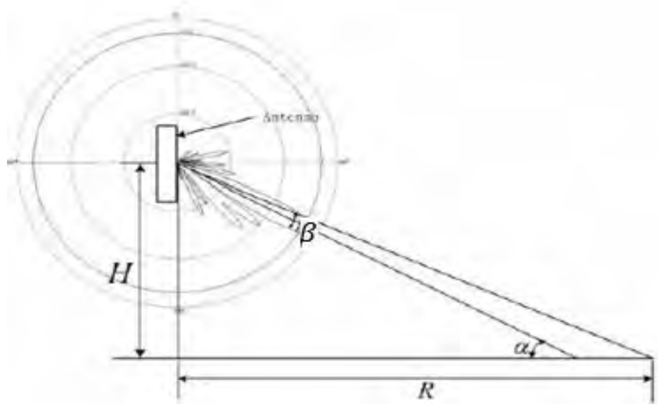



**Figure 2.9: Coverage of antenna with vertical downtilt angle [48].**

The basic formula to get the coverage area with tilt angle from the above Figure 2.9 is [48]:

$$\propto = \arctan\left(\frac{H}{R}\right) + \frac{\beta}{2} \qquad (2.1)$$

Where $\alpha$ is the sum of electrical and mechanical vertical down-tilt angle, β is the vertical half-power angle, H is the height of the antenna and R is radius of coverage.

Initially, basestation antennas had fixed electrical tilt. Since this is not a flexible solution, antennas with adjustable electrical tilt were introduced. There are different ways to adjust electrical tilt, however remote electrical tilt (RET) is used most.

### 2.3.3. RET Antenna System

RET antenna system can smartly control the vertical downtilt angle, horizontal azimuth angle, and automatically update the antenna data with realizing the alarm information which accord with the antenna interface standards group(AISG) version 2.0 standard through Iuant interface protocol which is relevant functional modules with the antenna control unit interface in the 3rd generation partnership project (3GPP) specification [33]. The below Figure 2.10 shows two-dimensional (2D) RET antenna and the photo of PCU (portable control unit (a)) which is used for adjusting the tilt from basestation room and RCU (remote control unit (b))which is used remotely from operation and maintenance center (OMC) room.

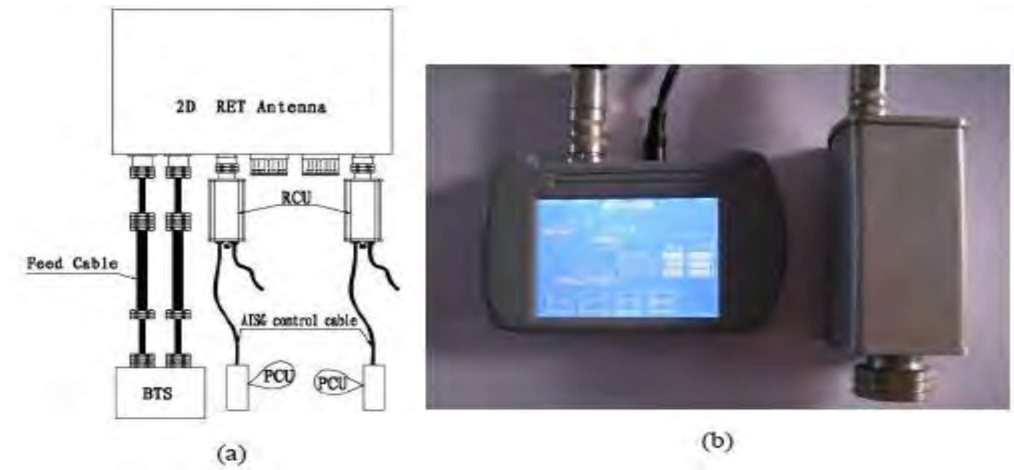



**Figure 2.10: Local control system (a) Schematic, (b) Photograph of PCU and RCU [33].**

## 2.4. Coverage and Capacity Planning

The coverage and the capacity planning are of essential importance in the whole radio network planning. The coverage planning determines the service range, and the capacity planning determines the number of to-be-used basestations and their respective capacities. Studying about them is required in this thesis because they will support to get the coverage and capacity of each selected basestations.

### 2.4.1. Coverage Planning

The target of the coverage planning is to find optimal locations for BSs to build continuous coverage according to the planning requirements. It requires studying link budget design and propagation path loss models.

#### 2.4.1.1. Link Budget Design

**Link budget design** is used for calculating the power levels required for cellular communication systems, and for investigating the basestation coverage in order to get the coverage radius of basestations. In order to plan a link budget equation, it is necessary to investigate all the areas where gains and losses may occur between the transmitter and the receiver and the below Figure 2.11 shows in detail about link budget design.

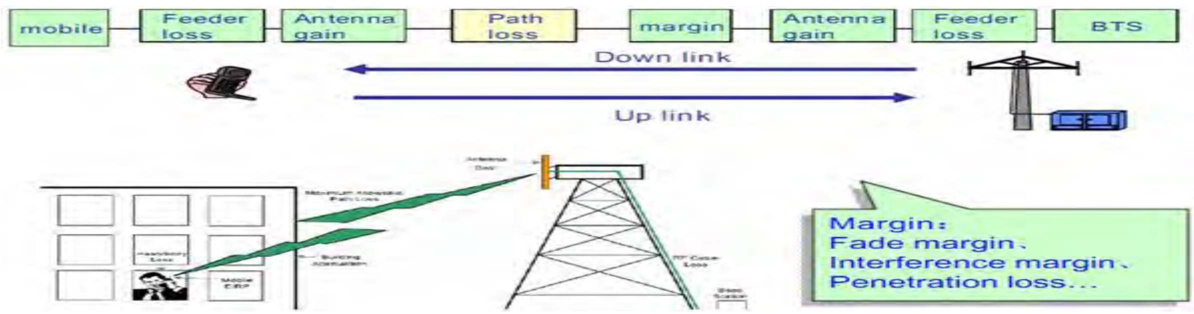



Figure 2.11: link budget model.

#### 2.4.1.2. Propagation Path Loss Models

**Propagation path loss models** play an important role in the design of cellular systems as they are used in the typical initial network design to determine the number of sites necessary to provide enough coverage. Path loss is reduction in power density level of an electromagnetic wave through the space [20].

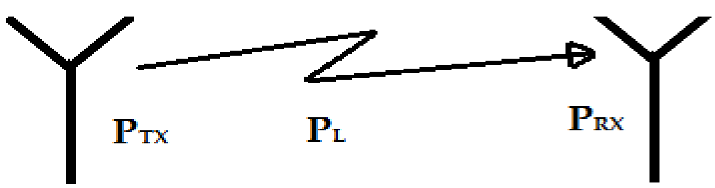



Figure 2.12: Path loss definition [20].

In order to predict the coverage in a desired area, many approaches have been designed by using propagation models [23]. Propagation models are mathematical expressions that attempt to model the environment as close as possible. Some of the models are:

1. COST-231-HATA model;
2. Okumura-Hata model;
3. Free space model;
4. Ericsson model;

As ethio telecom GSM network was designed by Okumura-Hata model [25], let's look this model in detail. The maximum path loss for downlink $L_{Pd}$ and uplink $L_{Pu}$ can be calculated based on the downlink and uplink service requirement:

For downlink: $L_{Pd} = P_{Btx} - L_{Bcom} - L_{Bf} + G_{Ma} - L_{in} - L_{Ph} - P_{Msen} - P_{margin}$ (2.2)

For uplink: $L_{Pu} = P_{Mtx} - L_{Ph} + G_{Ma} + G_{Ba} - L_{Bf} - P_{Bsen} - P_{margin}$ (2.3)

The path loss is described by:

$$L_P = 46.3 + 33.9 \log f - 13.82 \log h_b - a(h_m) + (44.9 - 6.55 \log h_b) * \log d + C \quad (2.4)$$

Where $a(h_m) = (1.11 \log f - 0.7)h_m - (1.56 \log f - 0.8)$

C=0dB for medium sized cities and suburban centers with moderate tree density. Formula (2.4) can be written as (2.5) where A is the fixed attenuation in Okumura-Hata model. Depending on value for A the formula (2.5) gives different pathloss for different frequencies stated in Table 2.1.

$$L_P = A - 13.82 \log h_b - a(h_m) + (44.9 - 6.55 \log h_b) * \log d \quad (2.5)$$

**Table 2.1: Fixed attenuation A in Okumura-Hata propagation model**

| Environment | Frequency (MHz) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 700 | 850 | 900 | 1700 | 1800 | 1900 | 2100 | 2600 |
| Urban | 144.3 | 146.2 | 146.8 | 153.2 | 153.8 | 154.3 | 155.1 | 157.5 |
| Suburban | 133.5 | 136.1 | 136.9 | 145.4 | 146.2 | 146.9 | 147.9 | 151.1 |
| Rural | 125.1 | 127.0 | 127.5 | 133.6 | 134.1 | 134.6 | 135.3 | 137.6 |

Resolving (2.5) according, $d$ gives the radius of the coverage area:

$$d = 10^{\frac{Lp - A + 13.82 \log\ h_b + a(h_m)}{44.9 - 6.55 \log\ h_b}} \qquad (2.6)$$

The coverage area can be calculated as following:

$$\boldsymbol{Coverage_{Area}} = \frac{\mathbf{9} * \sqrt{\mathbf{3}} * \boldsymbol{d^2}}{\mathbf{8}} \qquad (2.7)$$

Where A- fixed attenuation factor, $d$- cell radius, $f$- used frequency, $G_{Ba}$- RBS antenna gain (dBi), $G_{Ma}$- UE antenna gain (dB), $H_b$ – RBS antenna height (m), $L_{Bcom}$ – RBS combiner loss (dB), $L_{Bf}$ – RBS feeder and connector loss (db), $Lp$ – Path loss in Okumara-Hata model, $L_{Ph}$ – Body loss (dB) , $P_{Bsen}$ – RBS Sensitivity (dBm), $P_{Btx}$ – RBS transmit power (dBm), $P_{margin}$ – Shadow fading margin (dB), $P_{Msen}$ – UE Sensitivity (dBm), $P_{Mtx}$ – UE transmit power (dBm).

### 2.4.2. Capacity Planning

Capacity planning aim is to define the radio resources needed and to get maximum number of transceivers (TRX) at basestation to maximally support users with a certain level of QoS. Erlang-B and Erlang-C traffic models are used for circuit-switched (CS) speech of a certain length. Typically, Erlang-B is used.

**Basestations traffic capacity calculation**: Traffic capacity is the size of available resources for carrying traffic. Usually, the limiting capacities are TCH and SDCCH channels. The other channels hardly get congested except in a case of extreme traffic or as a result of equipment fault. GSM capacity planning procedures are [41]:

1. Confirm the input information which includes traffic model, packet switched (PS) (general packet radio service(GPRS)/enhanced data rates for global

evolution(EDGE)) configuration planning and subscriber analysis as shown below figure:

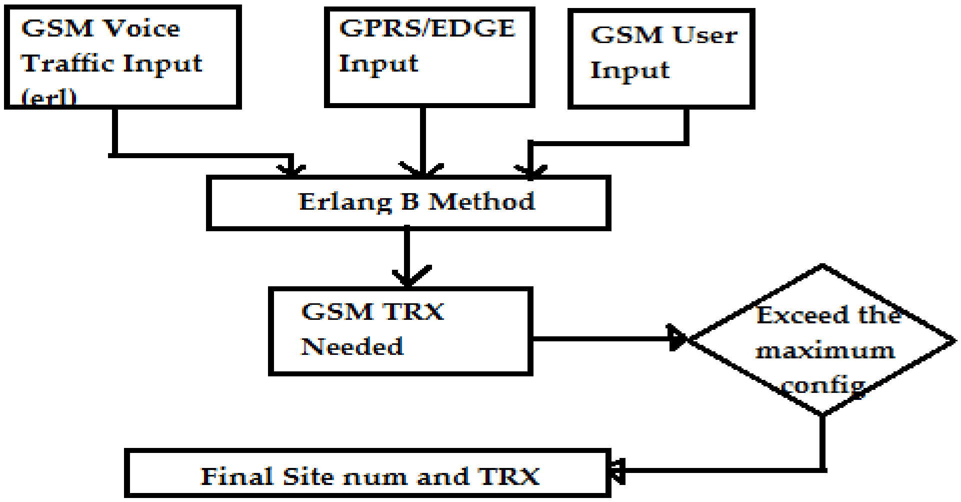



**Figure 2.13: GSM Capacity Dimension Procedure [41].**

The following are input parameters:

a) Estimated number of GSM Users

b) GSM Voice Traffic Input (example: 25mErl per CS user)

c) GPRS/EDGE input (example: 0.1kbps per PS user)

d) FR (full rate) and HR (half rate)

2. Using ErlangB table, get TRX number needed in different scenarios using grade of service (GOS).

3. Based on ErlangB table and subscriber analysis, we can get the configuration of each basestation.

### 2.4.3. Interference Types and Frequency Reuse

Interference is the major limiting factor when evaluating the performance of cellular radio systems. Sources of interference could be another mobile at the same cell, a call in progress in a neighboring cell or other basestations operating in the same frequency band. Interference on voice channels causes cross talk due to an undesired transmission.

On control channels, interference leads to missed and blocked calls due to errors in the digital signaling. Interference is more severe in urban areas, due to large number of basestations and mobiles. It has been recognized as a major bottleneck when looking for increasing capacity and is often responsible for dropped calls. The two major types of system-generated cellular interference are co-channel interference and adjacent channel interference [26].

In reality, there are areas of overlap between adjacent cells that create inter-cell interference. To minimize it, a reuse frequency with a factor of reuse is commonly used. Figure 2.14 shows an example of frequency reuse with factor 1:7.

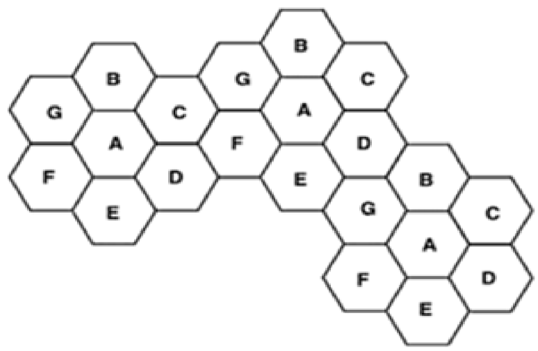



**Figure 2.14: Frequency reuse pattern with factor 1:7.**

Frequency reuse, or, frequency planning, is a technique of reusing frequencies and channels within a communication system to improve capacity and spectral efficiency. Cellular radio systems such as GSM and universal mobile telecommunications service (UMTS) rely on an intelligent allocation and reuse of channels throughout a coverage region. Each cellular basestation is allocated a group of radio channels to be used within a small geographic area called a cell. Basestations in adjacent cells are assigned channel groups which contain completely different channels than neighboring cells [27].

## 2.5. Optimization Techniques

GSM radio network pre- and post launch optimization is a useful mechanism to ensure good performance after commercial launch for the service [28]. Radio frequency optimization is a process of changing basestations parameters by soft (cell reselect offset, BTS power) and hard (e.g. electrical tilt, mechanical tilt, azimuth, etc) mechanisms. The following are optimization techniques:

- Defining missing neighbor relations;
- Proposing new sites or sector additions with before and after coverage plots;
- Proposing antenna azimuth changes;
- Proposing antenna tilt changes;
- Proposing antenna type changes;
- BTS equipment/filter change;
- Re–tuning of interfered frequencies;
- Adjusting handover margins (power budget, level, quality, umbrella HOs);
- Adjusting accessibility parameters (RX Lev Acc Min, etc.);
- Changing power parameters;

### 2.6. Cellular Network Performance Measures

The performance of a cellular network is assessed in terms of key performance indicators (KPI) based on network management systems. Performance and QoS evaluation are the most important to the mobile operator as the revenue generation and customer satisfaction are directly related to network performance and quality [29].

The three leading elements of any mobile network KPIs are capacity, quality and coverage. Consequently, during network optimization, the main goal to achieve is to maximize coverage and capacity while meeting the QoS as illustrated in Figure 2.15 and KPI are described in detail in the below sections.

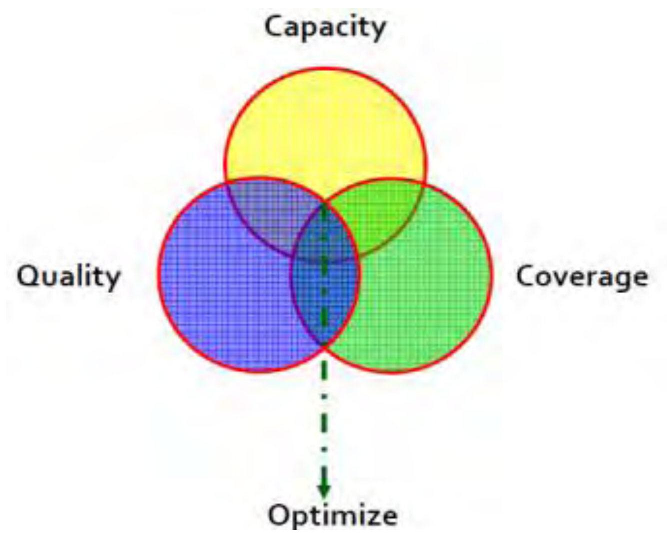



**Figure 2.15: Concept of network optimization [29].**

1. Coverage Based KPI'S

Coverage is simply the distance that a wireless network can transmit data at a given data rate subject to the regulations in its frequency band and the standard under which it operates. The coverage area of a cell is denoted as the area where the received BCCH power does not fall under the receiver sensitivity of the mobiles. The following are coverage-based KPIs: signal coverage rate, service coverage reliability and handover failures.

2. Capacity Based KPI'S

The capacity of a given network is measured in terms of the subscribers or the traffic load that it can handle. The capacity of a cell gives the number of users or simultaneous calls (in the case of speech service) the links can handle. Here, the number of calls is independent of the coverage and can be controlled by the number of carriers the operator allocates to the cell. Hence, carrier assignment is a key parameter for efficient GSM network design and has to be handled carefully to ensure that the basestation can cope with the offered traffic on its whole service area. The capacity of a cell/cluster can be studied by running reports on the following KPIs which includes: carried traffic, throughput capacity, TCH congestion and blocking, SDCCH congestion and blocking, etc.

3. Quality Based KPI'S

In any operational communication network, QoS is one of the important concerns from both customers and providers point of view. It is a measurable set of parameters that define the level of service that a service provider can be accountable. In the ITU-T Recommendation E.800, QoS is defined as the collective effect of service performance, which determines the degree of satisfaction of a user of the service. QoS can also be defined as the capability of the cellular network providers to provide a satisfactory service to end users. The quality of a radio network can be evaluated by examining KPIs such as: signal quality (RX QUAL), speech quality index (SQI), dropped call ratio (SDCCH and TCH), MS and BTS power levels, etc.

# 3. Green Cellular Network

## 3.1. Introduction

As it was discussed in the introduction chapter, green communication is an innovative research area to find ICT solutions that can greatly improve resource efficiency such as energy and network equipments with minimum compromising in users QoS. Green cellular network design mainly focuses in energy aware traffic adaptive solutions and minimizing of power consumption of each equipment inside a site.

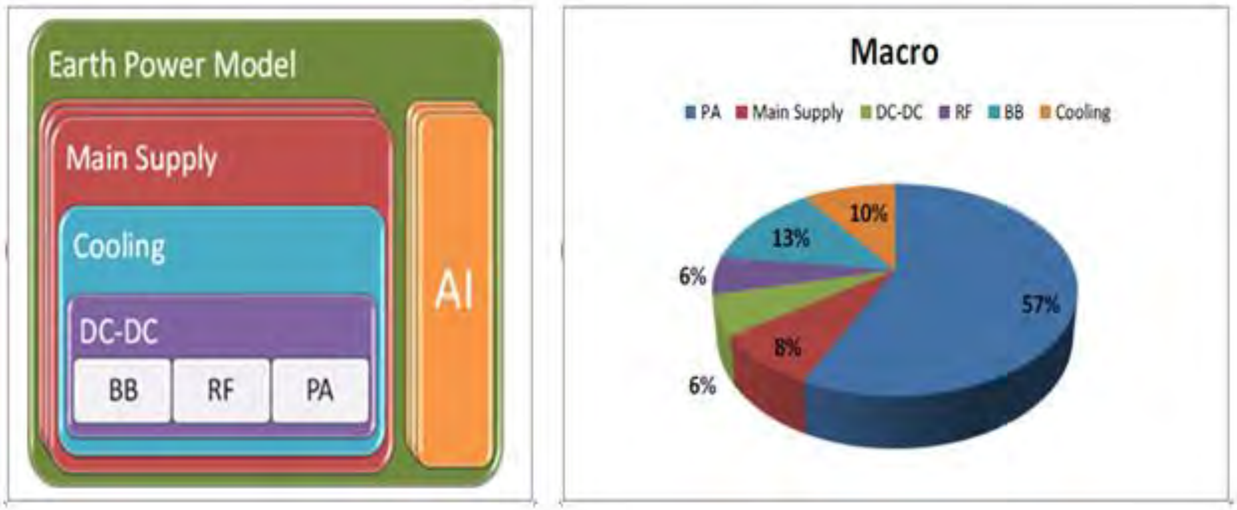
Energy aware traffic adaptive solutions are studied based on the reduction of traffic in some areas due to day-night behavior of users and their bandwidth usage way. Knowing the duration and the timing of off-peak hours are crucial in order to increase the energy efficiency of the network. It is also possible to use the same resource for different users by adapting of the bandwidth usage.

It is also important to have some insight about the power consumption of each equipment inside a site and their contribution for the overall site power consumption. There are studies in order to find energy savings by investing in technological development of the most consuming equipments.

## 3.2. Basestation Power Consumption Breakdown

Studying power consumption at component and system level allows quantifying how energy savings on specific components enhance the energy efficiency at the node and network level which is also called the power model [46].

Figure 3.1 shows a simplified block diagram of a complete BS that can be generalized to all BS types including macro, micro, pico and femto (a) and their power consumption percentage (b). A TRX comprises an antenna interface (AI), a power amplifier (PA), a radio frequency (RF) small-signal transceiver section, a baseband (BB) interface including a receiver (uplink) and transmitter (downlink) section, a DC-DC power supply, an active cooling system, and an AC-DC unit (main supply) for connection to the electrical power grid. Various TRX parts are analyzed in the below sections.




(a) (b)

**Figure 3.1: Block diagrams of a BS and power consumption percentage [30].**

### 3.2.1. Antenna Interface (AI)

The influence of the antenna type on power efficiency is modeled by a certain amount of losses, including the feeder, antenna band-pass filters, duplexers, and matching components. For macro BS a feeder loss of about feed = 3 dB needs to be added, while the feeder loss for smaller BS types is typically negligible. The feeder loss of macro BSs may be mitigated by introducing a remote radio head (RRH), where the PA is mounted at the same physical location as the transmit antenna.

### 3.2.2. Power Amplifier (PA)

Typically, the most efficient PA operating point is close to the maximum output power (near saturation). Unfortunately, non-linear effects and orthogonal frequency-division multiplexing (OFDM) modulation with non-constant envelope signals force the power amplifier to operate in a more linear region, i.e., 6 to 12 dB below saturation. However, this high operating back-off gives rise to poor power efficiency PA, which translates to a high power consumption $P_{PA}$.

### 3.2.3. Small-Signal RF Transceiver (RF-TRX)

The Small-Signal RF Transceiver comprises a receiver and a transmitter for uplink and downlink communication. The linearity and blocking requirements of the RF-TRX may differ significantly depending on the BS type, and so its architecture. Parameters with highest impact on the RF-TRX energy consumption ,$P_{RF}$, are generally the required bandwidth, the allowable signal-to-noise and distortion ratio (SiNAD), the resolution of the analogue-to-digital conversion, and the number of antenna elements for transmission and/or reception.

### 3.2.4. Baseband Interface

The baseband engine (performing digital signal processing) carries out digital up/down-conversion, including filtering, fast fourier transform (FFT)/inverse fast fourier transform (IFFT) for OFDM, modulation/demodulation, digital-pre-distortion (only in DL and for large BSs), signal detection (synchronization, channel estimation, equalization, compensation of RF non-idealities), and channel coding/decoding. For large BSs the digital baseband also includes the power consumed by the serial link to the backbone network. The silicon technology significantly affects the power consumption $P_{BB}$ of the BB interface. The increasing leakage puts a limit on the power reduction that can be achieved through technology scaling. Apart from the technology, the main parameters that affect the BB power consumption are related to the signal bandwidth, number of antennas and the applied signal processing algorithms.

### 3.2.5. DC-DC, Cooling and Main Supply

Losses incurred by DC-DC power supply, main supply and active cooling scale linearly with the power consumption of the other components and may be approximated by the loss factors DC, main supply, and cool, respectively.

## 3.3. Basestations Power Consumption Model

To assess the energy efficiency of the BSs, power consumption models are used for expressing instantaneous power consumption of macro and micro basestations. Some components of site power consumption are permanent over time, while others will depend on some parameters such as BS Tx power or traffic load.

Power consumption formula of the macrocell basestation (in Watt) [35] is:

$$P_{el/macro} = n_{sector} \cdot (P_{el/recto} + F.(n_{Tx}.(P_{el/amp} + P_{el/trans}) + P_{el/proc})) + P_{el/link} + P_{el/airco} \quad (3.1)$$

with $n_{sector}$ the number of sectors, $F$ the load factor, $n_{Tx}$ the number of transmitting antennas, and $P_{el/rect}$, $P_{el/amp}$, $P_{el/trans}$, $P_{el/proc}$, $P_{el/link}$, and $P_{el/airco}$ the power consumption (in Watt) of the rectifier, the power amplifier, the transceiver, the digital signal processing, the microwave link, and the air conditioning, respectively. The total energy consumption ($E_{BTS}$) of one site is given by [36]:

$$E_{BTS} = P_{el/macro} \cdot t \quad (3.2)$$

Where, t is the total time of usage (i.e. duration of power supply). Then the total energy consumption ($E_T$) for the all sites is given by:

$$E_T = \sum_i^k E^i{}_{BTS} \quad (3.3)$$

For i = 1 to k and k > 0. k is the number of sites in the network.

### 3.4. Possible Energy Saving Techniques

Promising ways to reduce energy consumption of mobile networks are dynamically reduce the number of active network elements to follow adaptively the variation of traffic. The possible techniques are described in the below sections:

#### 3.4.1. Dynamic Bandwidth Management

It is based on a stepwise adaptation of the bandwidth usage to the required traffic load, i.e. by an adaptation of the maximum number of resource blocks that are used during each LTE subframe [37]. The total transmitted maximum output power can be decreased when less resource blocks are used for scheduling user data. It is found that this technique provides approximately 25% energy saving and combines well with radio hardware improvements providing more than 50% energy saving [30].

#### 3.4.2. Dynamic Sectorization of BSs

In urban networks, the macro BSs are close to each other and capacity might be limited by interference in busy hour periods. In lightly loaded situations, when interference is low, the receivers typically operate with a high margin over thermal noise. In such cases, some extra loss on the radio links can be tolerated and macro BSs can switch to fewer but larger sectors, for instance, from three-sector to omni-cell configuration by changing the beam-width of the remaining sectors [37].

#### 3.4.3. Basestations On/Off Switch Schemes

**1. In Single-Layer Networks**

This section describes how to save power by switching off a number of BSs when the load conditions are such that the BSs remaining on can serve the demands from the users by which only have to increase the emitted power by a few watts, something negligible in the total BS energy consumption. The proposed scheme would allow configuring, on a given network and taking into account the traffic profile of this network has to handle, a number of sites that can be put into idle mode. Since the optimal configuration can be defined in advance based on system layout, no further coordination is necessary between BSs but should define which BSs have to go down and up [37].

2. **Efficiency Analysis of heterogeneous networks (HetNets)**

HetNets are in the focus of network modernization especially in densely populated urban environments. In such networks, there is a coverage layer dimensioned basically to serve conversational services and low data traffic, and a capacity layer dimensioned to serve high data traffic demands and large user throughput as shown Figure 3.2. The energy consumption of the system can be greatly reduced if the empty small cells are switched off (or sent to sleep mode).

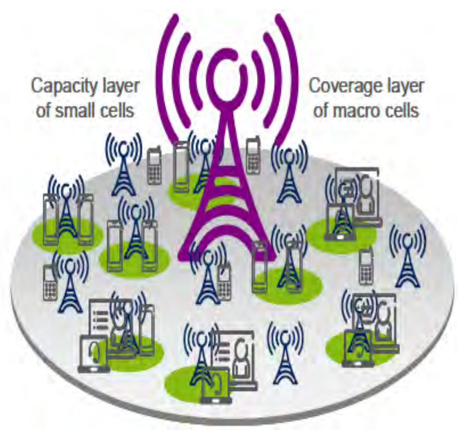



**Figure 3.2: Illustration of Hetnets concept.**

Thus, there should be an intelligent network management mechanism to switch on and off Basestations depending on the traffic load, reshaping at the same time the cell topology, always maintaining QoS, so the user will not notice any change.

### 3.4.4. Adaptive Scheduling

In [37], there are four points of approach for adaptive scheduling of green radio resource management (RRM):

1. The 1st approach is exploited the dynamics in scheduling by putting the BS in sleep mode by utilizing MBSFN (multicast broadcast single frequency network) frames, where both data and control signaling can be potentially disabled. The main idea here is to dynamically configure the MBSFN frame ratio according to the traffic conditions. This scheme brings about a gain of about 20-30% in terms of Joule/bit when compare with no MBSFN scheduling is used.

2. The 2nd approach is utilizing adaptive discontinuous transmission (DTX) and power control such as using sleep modes or reducing transmits power or combinations of both. The proposed technique can have a gain of as much as 45% when compare to no power control and DTX is used.

3. The 3rd approach, trade-off spectrum efficiency (SE) with energy efficiency especially in lightly loaded scenarios is described. In particular, it is exploited the delay characteristics of a specific application to reduce the transmit power. Such a technique increases the delay experienced by the application, but this is acceptable as long as it is within the delay constraints of the QoS requirements. This approach brings about gains from 0-20% when compare to no adaptive scheduling is used depending on traffic load.

4. The finally approach is the RRM from the multi-radio access technology (RAT) (Multi-RAT networks combine several RATs to deliver the service to users (e.g UMTS, LTE, Wi-Fi)) management point of view. Since, different RATs have different energy efficiencies of delivering their payloads, it is quite obvious that there exists a trade-off in which it can be adapted the users camped on a particular RAT based on the traffic load

of the system. The main idea here is to use vertical handovers (VHOs) to migrate users from one RAT to another depending on the traffic load of the system. Such a dynamic migration of users brings a maximum gain of about 45% with respect to the scenario in which inter-RAT handovers for improving EE aren't utilized.

### 3.4.5. Adaptive MIMO Muting and Advanced CoMP

Multiple-input and multiple-output (MIMO) muting, turning off one or several RF transceivers, would give considerable amount of energy saving in low traffic situations. It does not completely switch off the whole BS but deactivate some of analog RF transceivers when traffic is low; therefore it is still possible to maintain cell coverage by keeping a BS operational. MIMO muting may decrease total transmission power where detail number depends on hardware implementation. This causes cell edge users to suffer from worse signal-to-interference-plus-noise-ratio (SINR) than ones in normal operation. It is proposed in [37], the adaptive MIMO muting with CoMP (coordinated multi-point, the main idea of CoMP is as follows: when a MS is in the cell-edge region, it may be able to receive signals from multiple cell sites and the MS's transmission may be received at multiple cell sites regardless of the system load) as a solution for energy-saving in the Energy Aware Radio and network technologies (EARTH) project. To improve throughput of cell-edge MSs under MIMO muting condition, it uses CoMP instead of turning on antennas again. This would result in an improved energy efficiency as well as cell-edge throughput. Figure 3.3 shows the comparison between a normal single-cell operation and a proposed energy saving operation where CoMP is applied with MIMO muting.

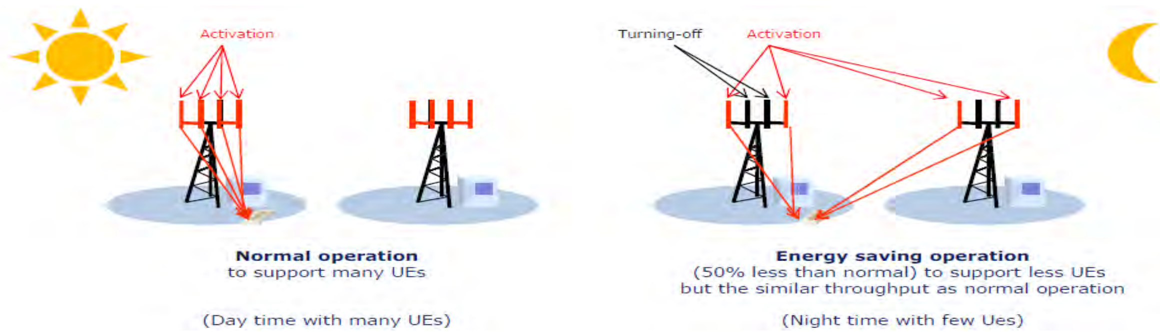



**Figure 3.3: A normal single-cell operation and a proposed energy-saving operation where CoMP is applied with MIMO muting [37].**

## 3.5. 3GPP Operational Proposal and Implementation Aspects

3GPP has introduced X2 control plane functions dedicated to energy saving [38]. This function allows decreasing energy consumption by enabling indication of cell activation/deactivation. Two functionalities can be used as primary functions indicating sleep mode to neighboring cells and requesting waking up sleeping cell. These procedures are illustrated in Figure 3.4.

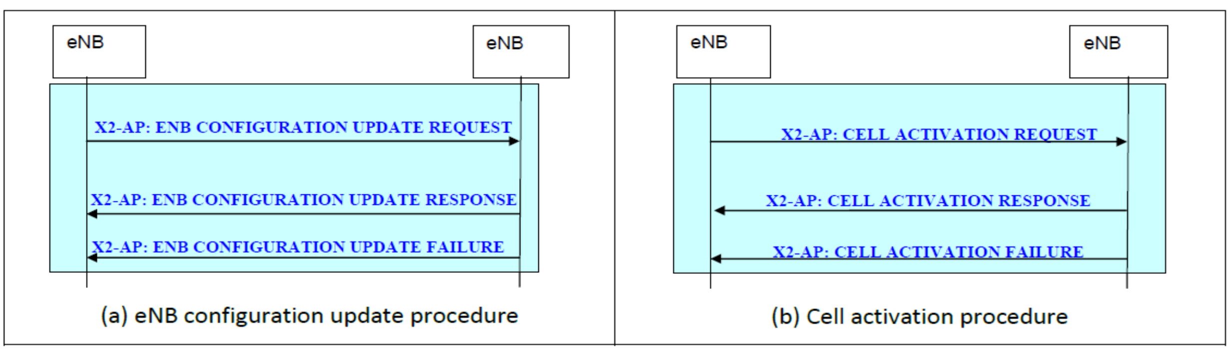



**Figure 3.4: Basestation activation and deactivation configuration procedure [38].**

**Static and dynamic modeling of on/off schemes:** static model applies only one on/off scheme a day, dynamic model allows several transitions depend on the load.

**Cell switch-off:** The decision on cell switch-off is typically based on cell load information. The evolved NodeB (eNB) may initiate handover actions in order to off-load the cell being switched off and indicate its reason. All peer eNBs are informed by the eNB owning the concerned cell about the switch-off actions over the X2 interface, by means of the eNB configuration update procedure. The eNB configuration update procedure is illustrated in Figure 3.4 (a). The purpose of this procedure is to update application level configuration data needed for two eNBs to interoperate correctly over the X2 interface. This procedure also includes the indication of cells entering dormant state for energy saving purposes [38].

# 4. Hourly Traffic Prediction

## 4.1. Introduction

Prediction plays a crucial role in business, industry, government, and institutional planning because many important decisions depend on the anticipated future values of certain variables. Cellular network traffic profile during days is not flat and the peak hour could never be reached or it could be for a very small fraction of the day. Cellular traffic flow shows three kinds of variations: daily variations, weekly variations and incidental variations. By knowing the traffic variations, for instance using a prediction technique, radio resources can be adapted to the required traffic in order to save energy. Some traffic prediction models have been proposed for cellular networks. Before going to different models, let's first see what a time series is.

## 4.2. Time Series

**Time series modeling**: is carefully collect and rigorously study the past observations of a time series to develop an appropriate model which describes the inherent structure of the series and used to generate future values for the series. A univariant time series $\{X_T\}$ is a series of observations of a variable over discrete intervals of time. Typically these observations are equally spaced in time.

$$\{X_T\} = (X_1, X_2, X_3, \dots, X_t) \quad (4.1)$$

**Time series components**: an important step in analyzing time series data is to consider the types of data patterns, so that the models most appropriate to those patterns can be utilized. A time series in general is supposed to be affected by four main components. These components are: trend, cyclical, seasonal and irregular (random) components as shown in the below Figure 4.1.

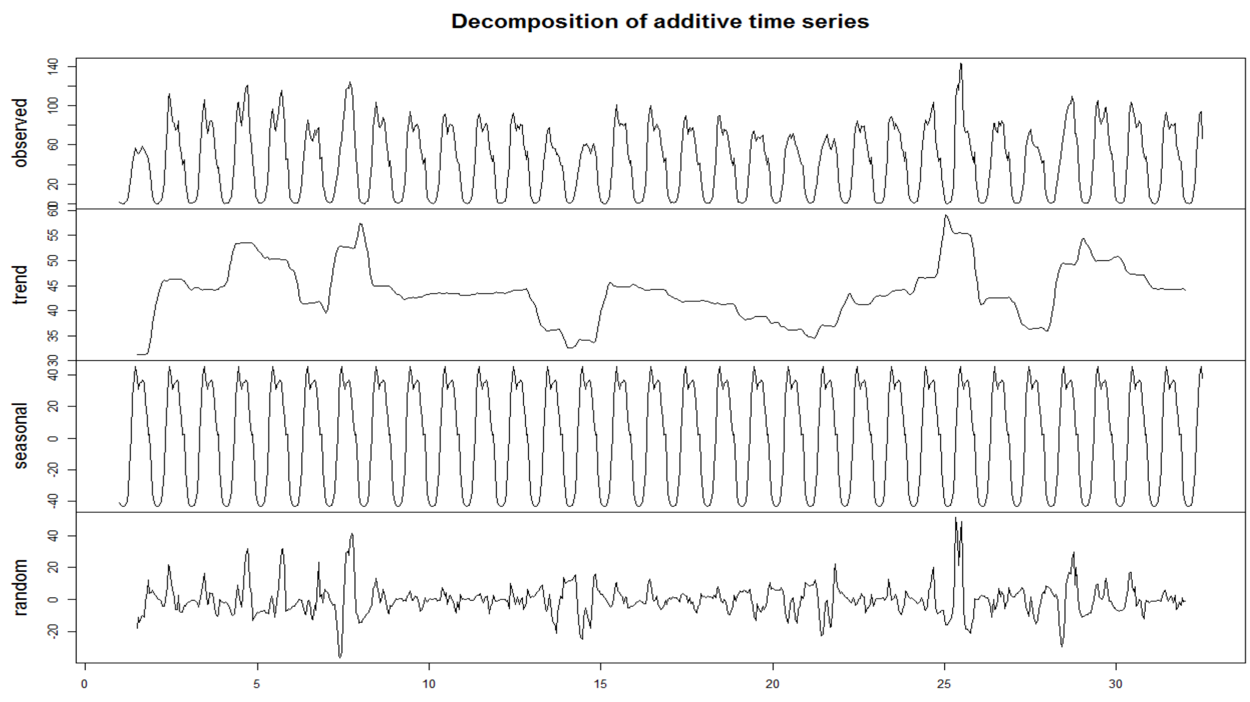



Figure 4.1: Time Series Components.

**Stationary and Non-Stationary Time Series**: Stationary Time Series has a fixed mean and constant variance. It can be weakly or strictly stationary. Non-stationary Time Series is any time series without a constant mean over time.

## 4.3. Time Series Models

There are different kinds of time series models, some of them are [47]:

1. **Moving Averages Model**: is the arithmetic average of the n most recent observations.
2. **Weighted Moving Averages Model**: looks at past data and tries to logically attach importance to certain data over other data, weighting factors must add to one, it can weight recent data higher than older or specific data above others.
3. **Exponential Smoothing Model**: schemes weight past observations using exponentially decreasing weights, whereas in single moving averages the past

observations are weighted equally. In other words, recent observations are given relatively more weight in forecasting than the older observations.

4. **Holt-Winters Forecasting Model**: are often used with seasonal time series. It generalizes the exponential smoothing model. Traffic in a cell has a periodic behavior and it can be analyzed as an historical series. It can be represented by a trend plus an irregular component.
5. **Autoregressive Moving Average (ARMA) Models**:

**Autoregressive Model**: are based on the current value of the series, $Z_t$, can be explained as a function of p past values, $Z_{t-1}$, $Z_{t-2}$. . .$Z_{t-p}$, where p determines the number of steps into the past needed to forecast the current value.

**Moving Average Model**: a moving average model of order q assumes the white noise, $w_t$, are combined linearly to form the observed data. A moving average term in a time series model is a past error (multiplied by a coefficient).

By combining the AR (p) and MA (q) models, the **ARMA** (p,q) model can be defined. The ARMA model can better explain data which depends on past disturbances as well as linear dependence with past values. $Z_t$ is an ARMA (p,q) process:

$$Z_t = \sum_{i=1}^{p} \emptyset_i \, z_{t-i} + \epsilon_t - \sum_{i=1}^{q} \theta_j \, \epsilon_{t-j} \quad (4.2)$$

$\{Z_t\}$ are the observations at time t.

**Differencing**: It may be necessary to examine differenced data when there is seasonality. Seasonality usually causes the series to be non-stationary because the average values at some particular times within the seasonal span (night, for example) may be different than the average values at other times. For instance, the traffic of cellular network is smaller at mid-night.

**Seasonal differencing**: is defined as a difference between a value and a value with lag that is a multiple of S. Seasonal differencing removes seasonal trend.

**Non-seasonal differencing**: If trend is present in the data, it may need non-seasonal differencing. Often a first difference (non-seasonal) will "detrend" the data.

**Differencing for Trend and Seasonality**: When both trend and seasonality are present, both non-seasonal first difference and seasonal difference can be applied.

**Autoregressive Integrated Moving Average (ARIMA) Model**: the ARMA models, described above can only be used for stationary time series data. Time series, which contain trend and seasonal patterns, are also non-stationary in nature. The model is generally referred to as an ARIMA (p, d, q) model.

**Seasonal Autoregressive Integrated Moving Average (SARIMA) Model**: By adding the possibility for differencing at a single lag and seasonal lag as well as allowing for seasonal components in the ARMA model, the SARIMA model can be defined, sometimes is called seasonally adjusted ARIMA model. Seasonal ARIMA has ARIMA(p,d,q)(P,D,Q) [m] model structure.

### 4.4. Prediction Performance Measures

While applying a particular model to some real time series, first the raw data is divided into two parts (training set and test set). The observations in the training set are used for constructing the desired model. Often a small subpart of the training set is kept for validation purpose and is known as the validation set (test set). The test set observations are kept for verifying how accurate the fitted model performed in predicting these values. The following are prediction performance measures:

- The mean forecast error (MFE): It is a measure of the average deviation of forecasted values from actual ones. $\boldsymbol{MFE} = \frac{\boldsymbol{1}}{\boldsymbol{n}}\sum_{\boldsymbol{t=1}}^{\boldsymbol{n}} \boldsymbol{e_t}$ , $\mathbf{e = y - f}$ is the forecast error and n is the size of the test set.
- The mean absolute error (MAE): It measures the average absolute deviation of forecasted values from original ones.
- The mean absolute percentage error (MAPE): This measure represents the percentage of average absolute error occurred. $\boldsymbol{MAPE} = \frac{\boldsymbol{1}}{\boldsymbol{n}}\sum_{\boldsymbol{t=1}}^{\boldsymbol{n}} \left|\frac{e_t}{y_t}\right| * \mathbf{100}$
- The mean percentage error (MPE): represents the percentage of average error occurred, while forecasting. $\boldsymbol{MPE} = \frac{\boldsymbol{1}}{\boldsymbol{n}}\sum_{\boldsymbol{t=1}}^{\boldsymbol{n}} \left(\frac{e_t}{y_t}\right) * \mathbf{100}$
- The mean squared error (MSE): It is a measure of average squared deviation of forecasted values. $\boldsymbol{MSE} = \frac{\boldsymbol{1}}{\boldsymbol{n}}\sum_{\boldsymbol{t=1}}^{\boldsymbol{n}} (\boldsymbol{e_t}^{\mathbf{2}})$
- The root mean squared error (RMSE): It is the square root of MSE.

# 5. Ethio telecom BSs Architecture, Configuration and Supporting Standards

Studying of ethio telecom basestations deployment and supporting standards help to know how to implement the proposed solution of switching on/off.

## 5.1. Basestations Architecture and Configuration

Above 6000 basestations are available in ethio telecom GSM, WCDMA, CDMA, and LTE networks. The basic architecture and configurations of selected BS sites are:

- The BTS model is Huawei distributed BS (DBS)3900 with configuration of baseband unit (BBU)3900 and remote radio unit (RRU)3929, RRU3936 and RRU3826 models, the detail configuration can be found in Appendix B.
- Basestations are clustered in to different zones.
- There are different layer of Cells (1, 2 or 3 layers) (GSM, WCDMA and LTE).
- All have three sectors.
- They support mechanical and electrical down-tilt.
- The typical power consumptions range from 484.13 watts to 3525.33 watts during normal traffic and from 582.13 watts to 4506.44 watts for maximum power consumption during high traffic.

The detail and brief description about the technical specification of the basestation equipments are described in the below sections.

### 5.1.1. Ethio telecom BTS Technical Specification

The BTS type of the selected sites of GSM network is Huawei DBS3900 series with BBU3900 and RRU3929, RRU3936 and RRU3826 models [40].

#### 5.1.1.1. DBS3900

It is abbreviated form distributed basestation (DBS). DBS3900 dual-mode basestation is the fourth generation basestation developed by Huawei. It features a multi-mode modular design and supports three working modes: GSM mode, GSM+UMTS dual mode, and UMTS mode through configuration of different software. In addition, the DBS3900 supports smooth evolution to the LTE.

The DBS3900 can control the power on/off of boards through software, disabling of RF channels through software, voltage adjustment of PA power supply, and the rotation speed of the fan. This enables reducing power consumption based on the actual traffic load. The below Figure 5.1 shows DBS3900 location in the network:

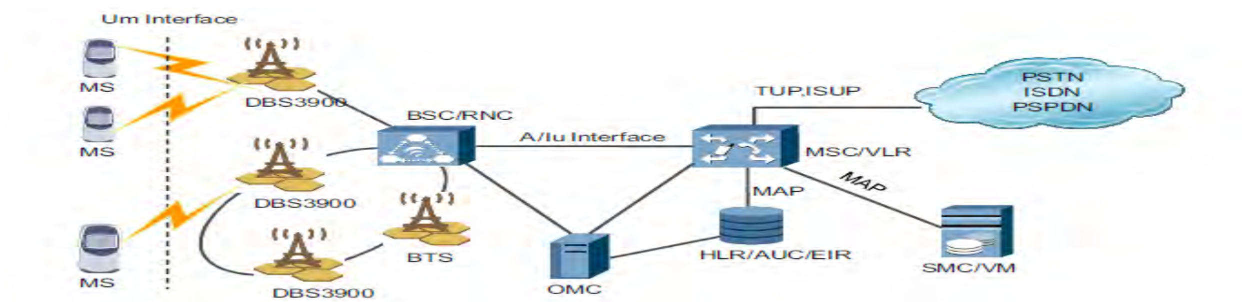



**Figure 5.1: DBS3900 location in the network [40].**

A DBS3900 consists of BBU and RRUs. With RRUs remotely installed, DBS3900 can be deployed in various scenarios; an example is shown below Figure 5.2:

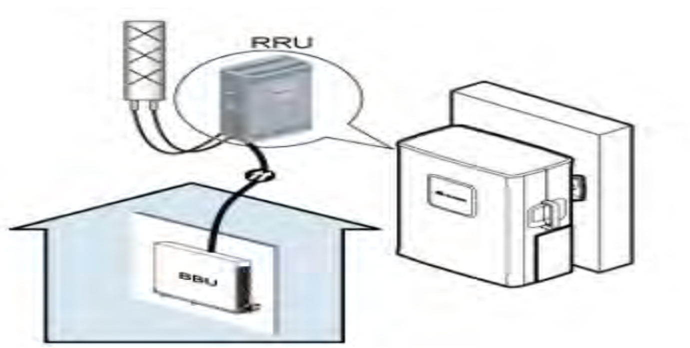



**Figure 5.2: one of DBS3900 deployment scenarios [40].**

#### 5.1.1.2. Logical and Physical Structure of the BBU3900

The BBU3900 is a modular design, consists of the following **logical subsystems**:

- Control Subsystem: are implemented by the WCDMA main processing transmission unit (WMPT).
- Baseband Subsystem: are implemented by the WCDMA basedband processing unit (WBBP).
- Transport Subsystem: are implemented by the WMPT and universal transmission processing unit (UTRP).
- Power Module: it converts +24 V DC or -48 V DC power into the power required by the boards and provides external monitoring ports.

The below Figure 5.3 shows the logical structure of the BBU3900:

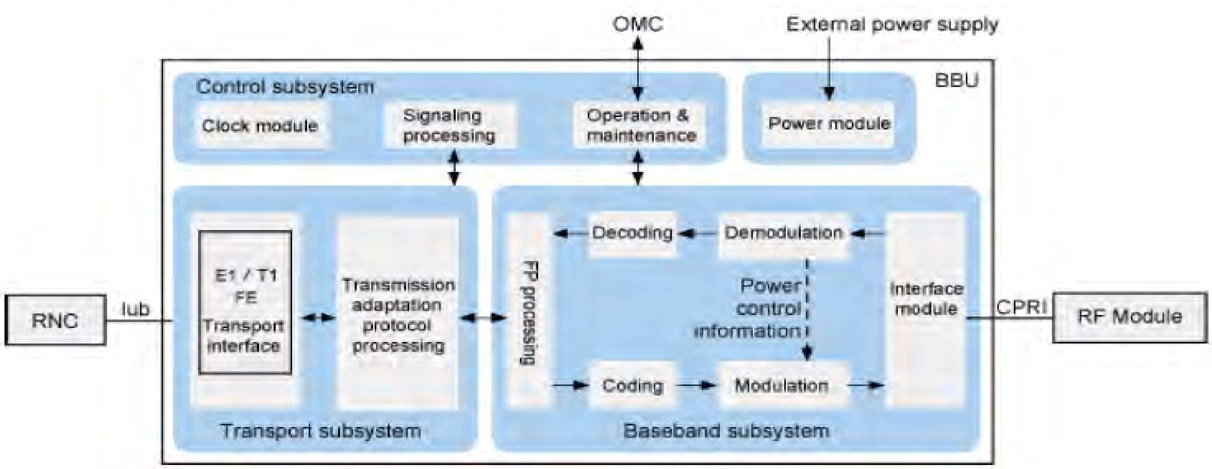



Figure 5.3: Logical structure of the BBU3900.

**Physical (slot) structure of BBU3900**: The BBU3900 can be configured with the boards such as the GSM timing and main control unit (GTMU), WMPT, WBBP, UTRP, universal power and environment interface unit (UPEU), universal environment interface unit (UEIU), universal E1/T1 lightning protection (UELP), universal FE lightning protection (UFLP), and universal BBU fan unit type A (UBFA) as shown below Figure 5.4.

| | | | |
|---|---|---|---|
| UBFA | Slot 0 WBBP/UTRP/UELP/UFLP | Slot 4 WBBP/UTRP/UELP/UFLP | PWR1 UPEU/UEIU |
| | Slot 1 WBBP/UTRP | Slot 5 GTMU | |
| | Slot 2 WBBP/UTRP | Slot 6 | PWR2 UPEU/UEIU |
| | Slot 3 WBBP/UTRP | Slot 7 WMPT | |

**Figure 5.4: Physical (Slot) structure of BBU3900.**

**Power consumption of BBU3900**: the below Figure 5.5 shows power consumption of BBU3900 with different RRU configuration:

| | Configuration | Typical value (W) |
|---|---|---|
| Power consumption | 1BBU3900+1RRU3004 | 200 |
| | 1BBU3900+2RRU3004 | 320 |
| | 1BBU3900+6RRU3004 | 800 |

**Figure 5.5: Power consumption of BBU3900 with different RRU configuration.**

### 5.1.1.3. RRU Technical Specifications

#### 5.1.1.3.1. Logical and Physical Structure of the RRU

The RRU has different models (RRU3929, RRU3826 and RRU3936), it is a modular design, consists of the interface module, TRX, PA, filter, Low Noise Amplifier (LNA), extended interface, and power module. The below Figure 5.6 shows the logical structure of the RRU3929, RRU3826 and RRU3936 (the difference between the models are the number of PAs and LNAs).

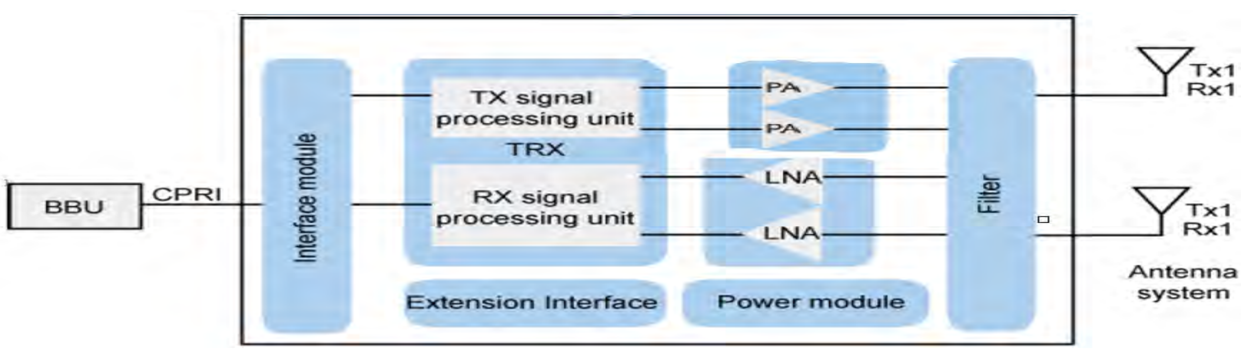



**Figure 5.6: Logical structure of the RRU3929, RRU3826 and RRU3936.**

#### 5.1.1.3.2. Power Consumption of RRU

Power consumption of RRU is different depend on the configuration parameters, operating frequency, cell type (indoors or outdoors antennas) antenna mode, network mode, etc. The below table shows an example of RRU power consumption:

**Table 5.1: Example of Power consumption of DBS3900**

| Mode | Configuration | Output Power per carrier (W) | Typical Power Consumption (W) | Maximum Power Consumption (W) |
|---|---|---|---|---|
| GSM | 3*2 | 20 | 675 | 795 |
| | 3*4 | 20 | 915 | 1260 |
| | 3*6 | 20 | 1005 | 1530 |
| UMTS | 3*1 | 20 | 585 | 675 |
| | 3*2 | 20 | 660 | 840 |
| LTE | 3*1 | 2*40 | 990 | 1290 |
| GSM+UMTS | GSM 3*2 + UMTS 3*1 | 20/20 | 850 | 1030 |
| | GSM 3*3 + UMTS 3*1 | 20/20 | 1060 | 1360 |
| | GSM 3*4 + UMTS 3*1 | 20/20 | 1105 | 1495 |
| GSM+LTE | GSM 3*2 + LTE 3*1 | 20/2*40 | 1305 | 1660 |
| | GSM 3*3 + LTE 3*1 | 20/2*40 | 1155 | 1525 |
| | GSM 3*4 + LTE 3*1 | 20/2*40 | 1215 | 1660 |

NOTE: The typical power consumption and the maximum power consumption are measured when the basestation works at a temperature of 25°C. The typical power consumption for GSM is reached when the basestation works with 30% load and power control and DTX are enabled. The maximum power consumption for GSM is reached when the basestation works with 100% load.

#### 5.1.1.3.3. Antenna Capabilities

**Table 5.2: Antenna capabilities for an RRU**

| Type | Tower mounted amplifier (TMA)capabilities | RET antenna capabilities |
|---|---|---|
| RRU | Supported | Supports AISG2.0 |

#### 5.1.1.3.4. Compliance Standards

The following table lists the compliance standards for an RRU.

**Table 5.3: Compliance standards for an RRU**

<table>
<tr><th>Type</th><th>Operating Environment</th><th>Anti-Seismic Performance</th><th>Protection Rating</th></tr>
<tr><td rowspan="5">RRU3929 and RRU3936</td><td>3GPP TS 45.005</td><td rowspan="5">NEBS GR63 zone4</td><td rowspan="5">IP65</td></tr>
<tr><td>3GPP TS 25.141</td></tr>
<tr><td>3GPP TS 36.141</td></tr>
<tr><td>3GPP TS 36.141</td></tr>
<tr><td>ETSIEN 300019-1-4 V2.1.2 (2003-04) Class 4.1 "Non weather protected locations</td></tr>
<tr><td rowspan="2">RRU3826</td><td>3GPP TS 25.141</td><td rowspan="2">NEBS GR63 zone4</td><td rowspan="2">IP65</td></tr>
<tr><td>ETSIEN 300019-1-4 V2.1.2 (2003-04) Class 4.1 "Non weather protected locations</td></tr>
</table>

## 5.2. Ethio telecom BSs Supporting Energy Efficiency Mode Characteristics

To find characteristics of basestations, it is necessary to study the following parameters:

- Hourly basestations traffic analysis
- Network systems hardware and software capability for supporting energy saving

### 5.2.1. Hourly Basestations Traffic Analysis

From the energy-efficiency point of view, the most important point of networking is underutilization, so this section investigates sample basestations daily traffic per hour to determine traffic volume fluctuations during days and nights. The below figures easily describe this.

- The below four figures from (a) to (d) show sample basestation traffic variation **per week for a mouth**: Week 1 is from 09/03/2015 to 15/03/2015, Week 2 is from 16/03/2015 to 22/03/2015), Week 3 is from 23/03/2015 to 29/03/2015 and Week 4 is from 30/03/2015 to 05/04/2015.

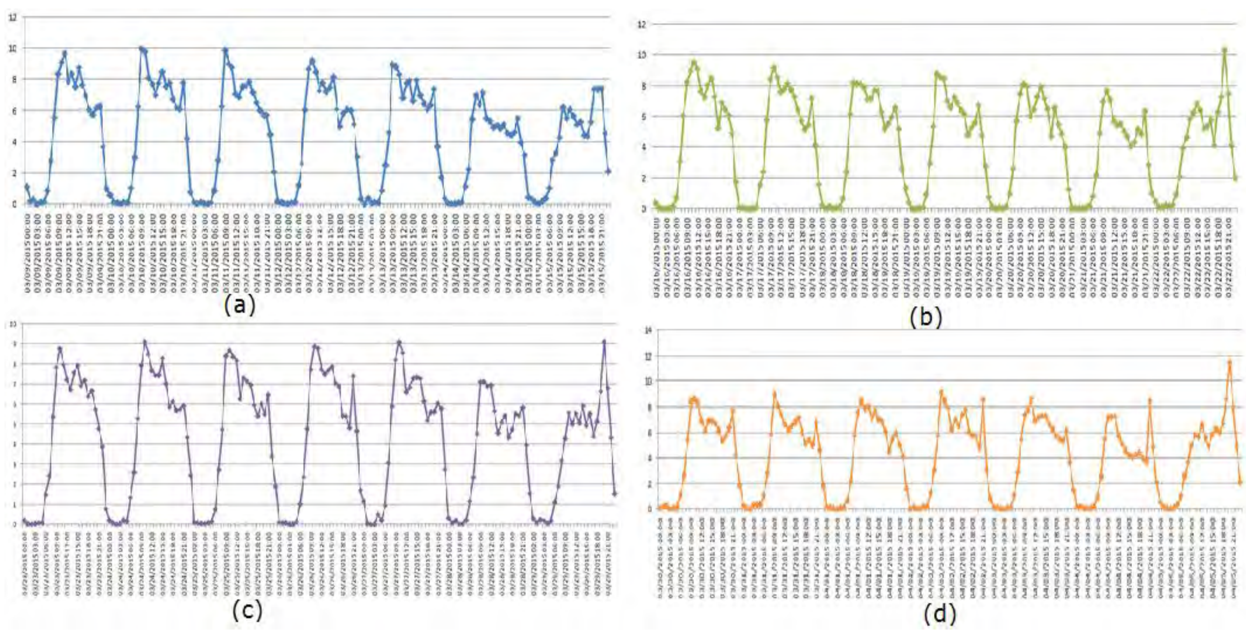



**Figure 5.7: (a) Week 1, (b) Week 2, (c) Week 3 and (d) Week 4.**

As per the above four figures, the traffic variation shows almost similar trend for every day and also every week.

- The below figure shows the whole 26 basestations traffic variation per hour for randomly selected two and half days.

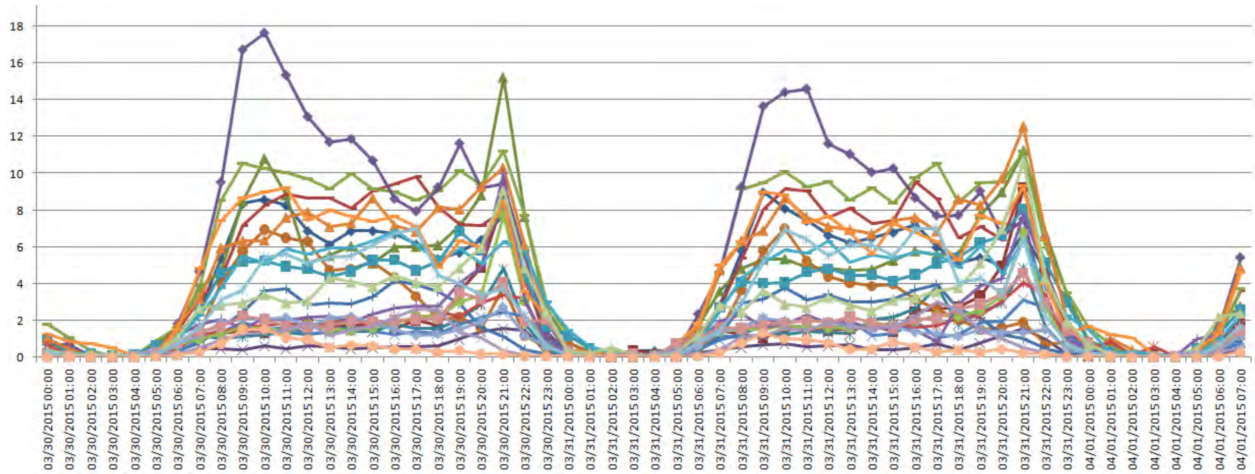



**Figure 5.8: Two and half days traffic statistics.**

As per figure 5.8, the whole basestations show similar characteristics as the above Figure 5.7 characteristics. Therefore, it is almost zero Erlang (there is no traffic) starting from 11 PM to 5 AM at night. Such strong temporal diversity indicates the under-utilization of BSs, resulting in system-wide energy inefficiency at BSs.

### 5.2.2. Network Systems Capabilities for Supporting Energy Saving

Network systems have the following capabilities in terms of hardware and software:

- Basestations OAM (BSC) provide intelligent out-of-service function. Before they become out of service, it hands over the UEs to other 2G or 3G cells by gradually reducing the cell common pilot channel (CPICH) power to avoid service interruption. The following capabilities are optional features in low level design (LLD):
    - TRX power amplifier intelligent shut down
    - Dynamic cell power off
    - Active backup power control
- RET with AISG2.0 specification is implemented for all basestations in order to control antenna azimuth and electrical tilts remotely.

- All basestations and control systems fulfill international standards of green power technology of energy saving.
- Huawei network elements and software which are required for the implementation of intelligent power consumption decrease are listed below tables:

**Table 5.4: Network elements involved in intelligent power consumption decrease**

| MS | BTS | BSC | MSC | MGW | SGSN | GGSN | HLR |
|---|---|---|---|---|---|---|---|
| involved | involved | not involved | not involved | not involved | not involved | not involved | not involved |

**Table 5.5: Software versions of GBSS products that support intelligent power consumption decrease**

| Product | | | Version |
|---|---|---|---|
| BSC | BSC6000 | | V900R008C01 and later releases |
| BTS | BTS3012 | DTRU | BTS3000V100R001C07 and later releases |
| | | QTRU | BTS3000V100R004C02 and later releases |
| | BTS3012AE | DTRU | BTS3000V100R001C07 and later releases |
| | | QTRU | BTS3000V100R004C07 and later releases |
| | BTS3006C | | BTS3000V100R001C07 and later releases |
| | BTS3002E | | BTS3000V100R001C07 and later releases |
| | DBS3900 GSM | | BTS3000V100R008C01 and later releases |
| | BTS3900 GSM | | BTS3000V100R008C02 and later releases |
| | BTS3900A GSM | | BTS3000V100R008C03 and later releases |

# 6. Proposed Solution of Switched off BSs During Off-peak Hours by Scheduling

## 6.1. Introduction

The techniques of basestations switching on/off scheduling during off-peak hours strategy solution should have to satisfy three requirements:

- Communication coverage (i.e., each location is covered by at least an active BS).
- Minimal on/off switching of each BS (i.e., it is avoided powering on/off each BS frequently. BSs are switched off only from 11PM up to 5AM).
- Planned grade of service (2%) should be affected with minimum value.

The proposed solution will have the following strategies (techniques):

- RF link budget design and coverage Analysis.
- Determining of equivalent basestations to get sub-cluster members.
- Basestations traffic capacity profiling.
- Off-peak hours traffic prediction for six months.
- Determine required number of active basestations as per predicted off-peak hours traffic capacity required.
- Scheduling basestations to switched off.
- Optimizing the coverage with active basestations.
- Measures network performance after switched off

The solution requirements which ethio telecom basestations need to fulfill are:

- Link budget design
- Basestations longitude and latitude

- Antenna height
- Mechanical and electrical down tilt angle
- Azimuth angle
- At least two weeks hourly traffic statistics for traffic prediction to have view the weekday and weekend traffic characteristics
- Erlang traffic capacity of each basestation

Assumptions of this solution:

- The traffic is uniformly distributed during off-peak hours.
- It has only one band per antenna.

## 6.2. Selected Site Description

The study considers 26 GSM basesstation sites which are assigned as one cluster (cluster 12 based on ethio telecom GSM LLD doc and are controlled by one BSC) and are located around “Leghar” area which is hot spot at day time and ideal at night and also is considered as urban area.


**Figure 6.1: Top view of ethio telecom selected sites basestations.**

The top view of selected BSs is shown above Figure 6.1. The average distances between basestations are between 400 to 500m but the maximum distance is 770m and the minimum is 200m. BSs of four different networks (GSM 900, GSM 1800, UMTS and LTE) are found, but our focus is only GSM because of limitation of getting design documents for the others.

### 6.3. Ethio telecom RF Link Budget Design and Coverage Analysis

There are two scenarios in this proposal to determine the communication ranges:

- Normal communication range: determine using maximum path loss which is given in LLD.
- Maximum communication range: determine using standard link budget equation to determine maximum path loss.

The below table has link budget design of ethio telecom which is useful to determine normal and maximum communication ranges:

**Table 6.1: Ethio telecom Link Budget Design**

| **Link Budget** | | |
|---|---|---|
| **Morphology** | **Urban** | |
| UL/DL | UL | DL |
| Frequency Band (MHz) | 900/1800 | |
| Propagation Model | Okumura-Hata | |
| Equipment Selection | DBS3900 GRRU | |
| **EIRP Calculation** | | |
| Max. TX Power(MS/TOC) (dBm) | 33 | 43 |
| Antenna Gain (dBi) | 0 | 18 |
| BS Combiner Loss (dB) | - | 0 |
| Feeder Loss (dB) | - | 0.5 |
| External Combiner Loss (dB) | 0 | |
| Terminal Cable Loss (dB) | 0 | |
| Dual-Polarization Antenna Loss (dB) | - | 0 |
| BTS Rx/Tx Diversity Gain (dB) | 3 | 0 |

| | | |
|---|---|---|
| EIRP (dBm) | 33 | 60.5 |
| **Slow Fading Margin (dB)** | | |
| Slow Fading Margin (dB) | 8.68 | |
| Area Coverage Probability (%) | 95.00% | |
| Slow Fading Standard Deviation (dB) | 8 | |
| Edge Coverage Probability (%) | 8.68 | |
| **Max Path Loss (dB)** | | |
| Receiver Sensitivity (dBm) | -113 | -104 |
| Antenna Gain (dBi) | 18 | 0 |
| Noise Figure Improved (dB) | 0 | - |
| Connector Loss Between Antenna and TMA (dB) | - | 0 |
| TMA Insertion Loss (dB) | - | 0 |
| DL Min Required Rx Level (dBm) | - | -65 |
| Interference Margin (dB) | 1 | |
| Fast Fading Margin (dB) | 3 | |
| Body Loss (dB) | 3 | |
| Penetration Loss (dB) | 20 | |
| Allowed Max Path Loss (dB) | 115.96 | 113.96 |

### 6.3.1. Determine Normal Radius by Allowed Maximum Path Loss in LLD

For GSM 900: normal communication range is determined by Okumura-Hata model pathloss equation (2.6) by using given maximum path loss in the link budget design:

Where$L_p$ is given 115.96db for uplink and 113.96db for downlink, A=66.9+26.16log900, $d$ is coverage radius and $h_b$ is each basestation height.

The below Table 6.2 has normal communication range together with maximum communication range in the next section.

### 6.3.2. Determine Maximum Radius by Standard Link Budget Equation

In order to find maximum communication range, a typical link budget Equations (2.2) and (2.3) is used.

First, downlink maximum path loss is determined from LLD link budget design Table (6.1) above and it is given $G_{Ba}$= 18, $G_{Ma}$=0, $P_{Btx}$ =43, $P_{Bsen}$ =-104, all Losses= $L_{Bcom}$+ $L_{Bf}$+ $L_{Ph}$ + $P_{margin}$ + other losss=3+3+8.68+1+20=35.68

Therefore, $Lpd$=43+18-0.5- (-104)-35.68

.ʻ. $Lpd$ =128.82dB

But for Uplink: it is given $P_{Mtx}$= 33, $G_{Ba}$=0, $G_{Ma}$=18, $P_{Bsen}$= -113, all Losses= $L_{Bcom}$+ $L_{Bf}$+ $L_{Ph}$ + $P_{margin}$ + other losss=3+3+8.68+1+20=35.68

.ʻ. $Lpu$=128.32dB

As path loss $Lpd$ and $Lpu$ is found above; next, the maximum communication range can be found using the above standard path loss Equation (2.6). And the below Table (6.2) has summarized normal and maximum communication radiuses of the 26 basestations.

**Table 6.2: Normal and maximum communication ranges (radiuses)**

| BS | Antenna Height (hb) | normal uplink coverage radius (m) | normal downlink coverage (m) | maximum uplink coverage radius (m) | maximum downlink coverage radius (m) |
|---|---|---|---|---|---|
| BS01 | 36 | 537 | 470 | 1220 | 1261 |
| BS02 | 16.5 | 416 | 368 | 900 | 929 |
| BS03 | 32 | 516 | 452 | 1162 | 1201 |
| BS04 | 30.5 | 508 | 445 | 1140 | 1178 |
| BS05 | 26 | 481 | 423 | 1070 | 1105 |
| BS06 | 24.5 | 472 | 415 | 1045 | 1079 |
| BS07 | 28 | 493 | 433 | 1101 | 1138 |
| BS08 | 35 | 532 | 466 | 1206 | 1246 |
| BS09 | 38.5 | 550 | 481 | 1254 | 1297 |
| BS10 | 46.5 | 588 | 514 | 1359 | 1406 |

| | | | | | |
|---|---|---|---|---|---|
| BS11 | 24.5 | 472 | 415 | 1045 | 1079 |
| BS12 | 42 | 567 | 496 | 1301 | 1346 |
| BS13 | 43 | 572 | 500 | 1314 | 1359 |
| BS14 | 27.5 | 490 | 431 | 1094 | 1130 |
| BS15 | 46 | 586 | 512 | 1353 | 1400 |
| BS16 | 32 | 516 | 452 | 1162 | 1201 |
| BS17 | 22 | 456 | 401 | 1003 | 1035 |
| BS18 | 31 | 510 | 448 | 1147 | 1186 |
| BS19 | 45.5 | 584 | 510 | 1347 | 1393 |
| BS20 | 33 | 521 | 457 | 1177 | 1216 |
| BS21 | 47 | 591 | 516 | 1366 | 1413 |
| BS22 | 26 | 481 | 423 | 1070 | 1105 |
| BS23 | 42.5 | 570 | 498 | 1308 | 1353 |
| BS24 | 32 | 516 | 452 | 1162 | 1201 |
| BS25 | 24.5 | 472 | 415 | 1045 | 1079 |
| BS26 | 21 | 449 | 395 | 985 | 1017 |

## 6.4. Determine Basestations Sub-cluster Members and Traffic Profiling

The overall soultion takes a sub-cluster-based; i.e., location and traffic-dependent profiling approach. The entire network is divided into sub-clusters, so that BSs in each local sub-cluster cell can replace each other when serving user clients. Once the sub-cluster is established, sub-cluster dependent traffic profiling will be done to gets traffic capacity of each BS and also the aggregate sub-cluster traffic capacity.

### 6.4.1. Sub-cluster Based Location Dependent Profiling

BSs are clustered so that BSs in each sub cluster-cell can be equivalent (equal). Whether BSs are equivalent or not are determined by using the below Equation 6.1 [17]. The equation requires location information and transmission range of each BS to decide.

Location coordinates can be found from deployed ethio telecom LLD and transmission ranges of BSs for normal and maximum radiuses can be found from Table 6.2.

Sub cluster size: Specifically, let the distance between two BSs i and j be d(i, j), then BSs i and j are equivalent if:

$$r_i + d(i,j) \leq R_j \qquad OR \qquad r_j + d(i,j) \leq R_i \tag{6.1}$$

Where $r_i$ and $r_j$ are the normal communication ranges, and $R_i$ and $R_j$ are the maximum possible communication range of i and j, respectively.

Table 6.3 below shows sample basestations equivalence:

**Table 6.3: Sample basestations equivalence**

| | BS1 | BS2 | BS3 | BS4 | BS5 | BS6 | BS7 | BS8 |
|---|---|---|---|---|---|---|---|---|
| BS02 | Equal | | | | | | | |
| BS03 | Not Equal | Equal | | | | | | |
| BS04 | Equal | Equal | Not Equal | | | | | |
| BS05 | Equal | Equal | Equal | Equal | | | | |
| BS06 | Not Equal | Not Equal | Equal | Not Equal | Not Equal | | | |
| BS07 | Not Equal | Not Equal | Not Equal | Equal | Equal | Not Equal | | |
| BS08 | Not Equal | Not Equal | Not Equal | Not Equal | Equal | Equal | Equal | |
| BS09 | Not Equal | Not Equal | Not Equal | Not Equal | Not Equal | Not Equal | Equal | Equal |
| BS10 | Not Equal | Not Equal | Not Equal | Not Equal | Not Equal | Equal | Equal | Equal |
| BS11 | Not Equal | Not Equal | Not Equal | Not Equal | Not Equal | Not Equal | Not Equal | Equal |

Manually, sub-cluster cell formation procedures are the following:

- The first BS from the top of the Table 6.3 is shown above (i.e, from BS1) is selected as the first member of the first sub-cluster.
- To form the second member of the sub-cluster, the column of the first member is checked, and if equivalent BS to the above selected BS is found, it will be the second member.
- If the next BS is equivalent to the above two BSs by checking the row of this BS, it is added as a third member and this checking continues until it reaches BS26. If not-equivalent basestation is found, it will be skipped and it can be the next sub-cluster member.

The set of sub-clusters which are formed using the above procedures are:

- S1 = {BS01, BS02, BS05}
- S2 = {BS03, BS06, BS13}
- S3 = {BS04, BS07}
- S4 = {BS8, BS9, BS10, BS11, BS12}
- S5 = {BS14, BS15, BS16}
- S6 = {BS17, BS18, BS21}
- S7 = {BS19, BS20, BS23}
- S8 = {BS24, BS25}

But BS22 and BS26 don't have any sub-cluster member, so they are always active.

### 6.4.2. Basestations Traffic Capacity Profiling

Now, developing a profiling scheme will be done that finds the envelope of aggregate traffic capacity of a sub-cluster. Given the traffic profile in each sub-cluster, the aggregate capacity of all active BSs has to be large enough to accommodate predicted traffic.

Since number of TRX quantity is given in ethio telecom LLD, it needs to get Erlang actual traffic capacity of each basestations, the procedures are:

1. Using ErlangB table, get Erlang capacity from given TRX of each basestation sector.
2. Subtract SDCCH capacity (SDCCH usage per subscriber is approximately 3.56m erlangs) to get Erlang traffic of each basestation sector.

As an example, Erlang actual traffic capacity for BS01 sector one is done:

**Step 1**: Number of TRX = 8

Total number of traffic channel is = number of TRX* 8 Time slot – two which are used for control channel

Total number of traffic channel is =8*8-2=62

From erlang table with 2% of blocking probability, erlang capacity of 51.53 is found.

**Step 2**: As total traffic allowed/subscriber is 25merlang. Total number of subscriber/sector is: Divide the total erlang i.e. 51.53 erlang/ 25m erlang = 2062 subs.

**Step 3**: The actual traffic is:

- Actual traffic = total – SDCCH usage
- SDCCH traffic = 2062 *3.56 m erlang = 7.34erlang
- So actual traffic = 51.53 – 7.34 = 44.19 erlang

Next, the aggregate traffics of each sub-cluster are found one by one using above procedure, and they are shown in the below tables (Table 6.4):

### Table 6.4: Aggregate traffic of each sub-cluster

S1 = {BS01, BS02, BS05}

| Base stations | Aggregate BS traffic capacity |
|---|---|
| BS01 | 126 |
| BS02 | 107 |
| BS05 | 94 |
| Total | 327 |

S2 = {BS03, BS06, BS13}

| Base stations | Aggregate BS traffic capacity |
|---|---|
| BS03 | 94 |
| BS06 | 107 |
| BS13 | 120 |
| Total | 321 |

S3 = {BS04, BS07}

| Base stations | Aggregate BS traffic capacity |
|---|---|
| BS04 | 75 |
| BS07 | 94 |
| Total | 169 |

S4 = {BS8, BS9, BS10, BS11, BS12}

| Base stations | Aggregate BS traffic capacity |
|---|---|
| BS08 | 94 |
| BS09 | 107 |
| BS10 | 81 |
| BS11 | 75 |
| BS12 | 120 |
| Total | 477 |

S5 = {BS14, BS15, BS16}

| Base stations | Aggregate BS traffic capacity |
|---|---|
| BS14 | 75 |
| BS15 | 132 |
| BS16 | 113 |
| Total | 320 |

S6 = {BS17, BS18, BS21}

| Base stations | Aggregate BS traffic capacity |
|---|---|
| BS17 | 132 |
| BS18 | 113 |
| BS21 | 100 |
| Total | 345 |

S7 = {BS19, BS20, BS23}

| Base stations | Aggregate BS traffic capacity |
|---|---|
| BS19 | 94 |
| BS20 | 94 |
| BS23 | 63 |
| Total | 251 |

S8 = {BS24, BS25}

| Base stations | Aggregate BS traffic capacity |
|---|---|
| BS24 | 119 |
| BS25 | 88 |
| Total | 207 |

## 6.5. Off-peak Hours Traffic Prediction for Six Months

Predicting off-peak hourly traffic is needed to get the required traffic capacity of off-peak hours for six months in order to estimate the number of active basestations of the sub-cluster. The following requirements are needed for the prediction:

- Required data: to predict any statistical data, the minimum number of observed data should be 50, since in most practical applications the data exhibit a lot of random variation so the observed data shall be greater than two times the season (here, the season is 24 hours) [24]. For this prediction, 504 (3 weeks hourly data) is used for observation and 240 (10 days hourly data) for checking accuracy and predict for six months.

- Prediction model: as per literature review, seasonally adjusting ARIMA model is selected because it has good accuracy results.

- Software: R-software is used for the prediction, this software can able to predicted the forecasting model by analysis the given observations data (for example: it generates the output of ARIMA(1,0,2)(2,0,1)$_{24}$).

One sub-cluster group is selected as a sample and does the prediction procedures one by one but it will be summarized for the others. The selected sub-cluster is S4 = {BS8, BS9, BS10, BS11, BS12}.

Note: The compiled R-software program/code is found at Appendix A for this prediction.

Prediction procedures are as follow:

1. Plot original data with its components are shown below figure:

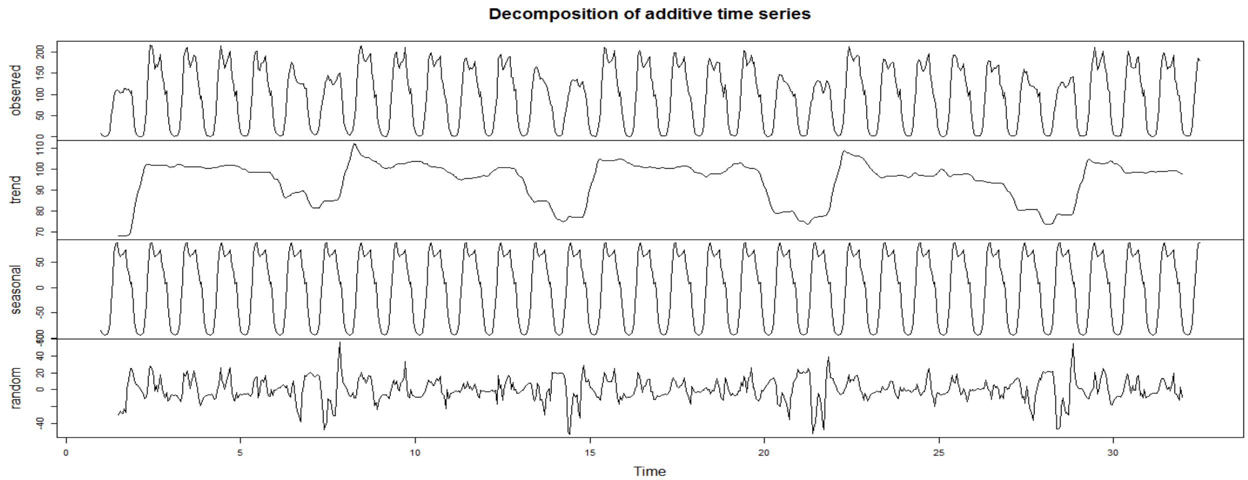



**Figure 6.2: Decomposed plot of original data.**

2. Subtract the seasonal data from the original, the result is shown in the below figure:

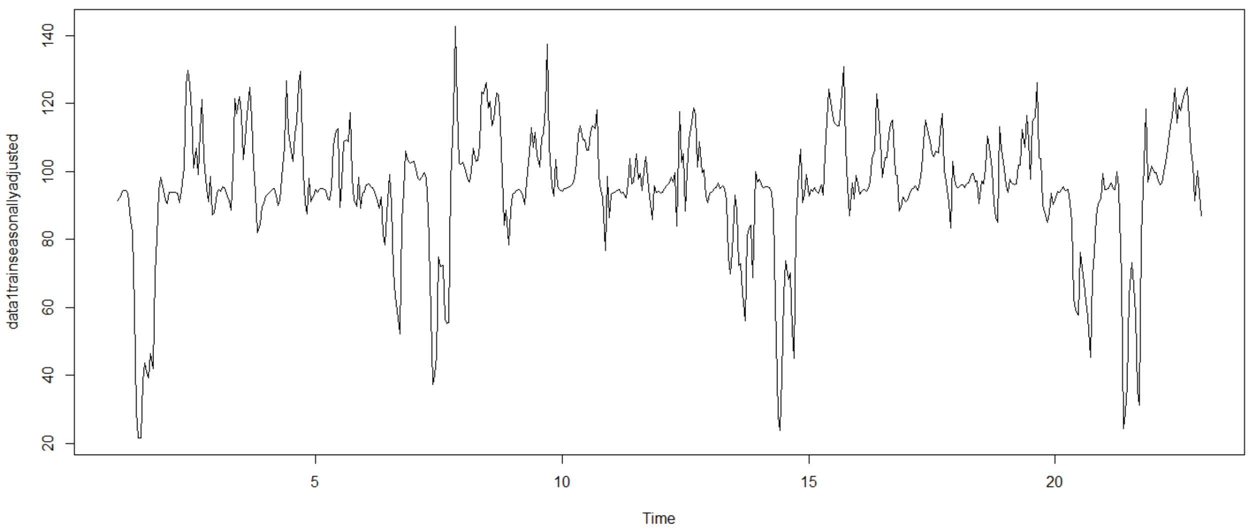



**Figure 6.3: Plot of original data after subtracting seasonal data.**

3. Predict using auto-ARIMA Model by R-software and the software generate the result automatically and it is found ARIMA(1,0,2)(2,0,1)$_{24}$, the plot of the prediction is:

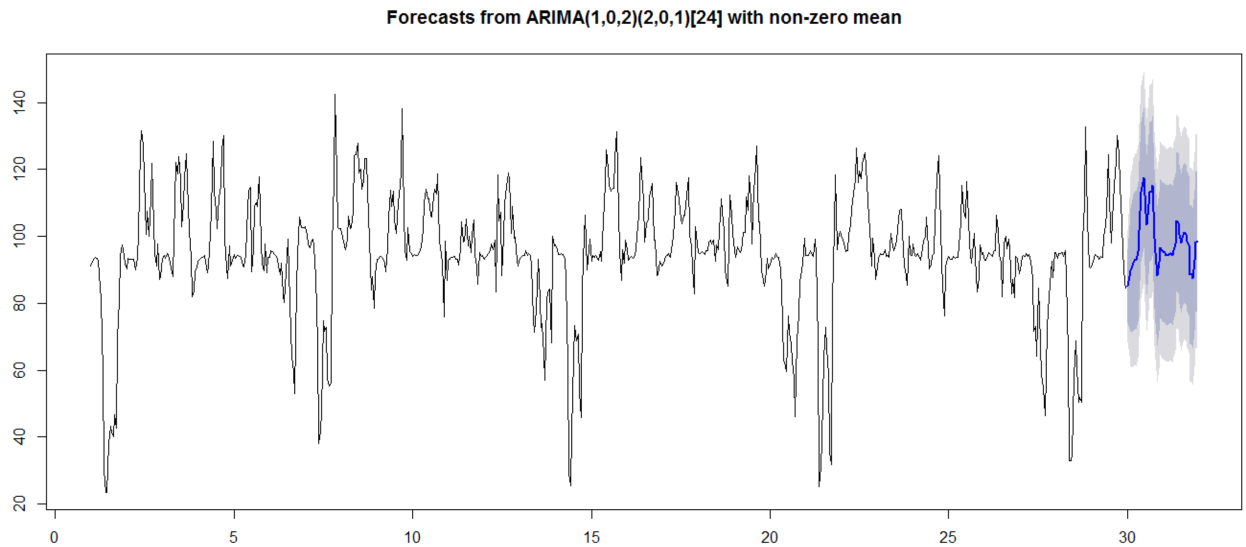



**Figure 6.4: Predict using auto-ARIMA Model.**

4. The predicted values of subtracted data are shown below:

| | Point Forecast | Lo 80 | Hi 80 | Lo 95 | Hi 95 |
|---|---|---|---|---|---|
| 15.00000 | 97.06957 | 86.65214 | 107.4870 | 81.137491 | 113.0016 |
| 15.04167 | 110.16178 | 95.20736 | 125.1162 | 87.290975 | 133.0326 |
| 15.08333 | 116.36954 | 97.77887 | 134.9602 | 87.937565 | 144.8015 |
| 15.12500 | 111.51945 | 91.12395 | 131.9150 | 80.327223 | 142.7117 |
| 15.16667 | 102.22573 | 80.85351 | 123.5979 | 69.539742 | 134.9117 |
| 15.20833 | 97.30261 | 75.04577 | 119.5595 | 63.263710 | 131.3415 |
| 15.25000 | 100.07180 | 76.51205 | 123.6315 | 64.040268 | 136.1033 |
| 15.29167 | 106.34381 | 81.00001 | 131.6876 | 67.583814 | 145.1038 |

**Figure 6.5: Predicted values of subtracted data.**

5. Return the predicted value by adding seasonal data to get original data.
6. Check predicted value with the original test value by using the below figures:

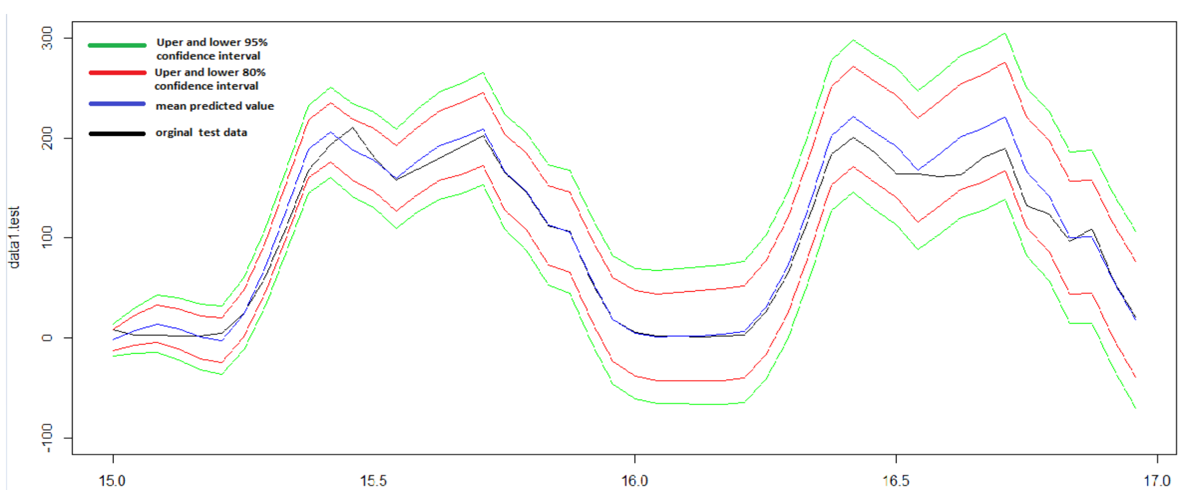



**Figure 6.6: Plot of predicted value with the original test data.**

- The accuracy measures are shown below:

```
Training set error measures:
                     ME     RMSE      MAE        MPE     MAPE      MASE        ACF1
Training set 0.05717442 7.473314 4.748916 -0.6329853 5.779822 0.4093622 0.005919173
```

**Figure 6.7: Prediction accuracy measures.**

As per the above figure, the prediction has good accuracy.

7. Select the better confidence interval: Hi 80% confidence interval is the better one as per the below Table 6.5:

**Table 6.5: Select the better confidence interval**

| Mean Prediction | HI.80 | Original data | Comparing mean predicted with original data | Comparing HI.80 with original data |
|---|---|---|---|---|
| 77.13969 | 102.4835 | 60.2628 | Good | Good |
| 124.2339 | 151.3902 | 113.4428 | Good | Good |
| 168.1944 | 196.7659 | 167.8336 | Good | Good |
| 186.9958 | 216.5819 | 192.9332 | Bad | Good |
| 181.5197 | 211.9652 | 210.8232 | Bad | Good |
| 172.7667 | 204.156 | 180.0653 | Bad | Good |
| 168.1384 | 200.6557 | 158.0193 | Good | Good |
| 177.9409 | 211.674 | 168.3193 | Good | Good |
| 184.4614 | 219.3186 | 180.0027 | Good | Good |
| 182.2149 | 218.0242 | 190.4605 | Bad | Good |
| 182.9898 | 219.6344 | 202.0945 | Bad | Good |

Next, how many active basestations are required will be done from the above prediction data at the next section.

## 6.6. Determine Required Number of Active BSs as per Predicted Off-peak Hours

As per the soution strategy to minimize on/off switching, each BS needs to switch on and off at most once during 24 hours duration, it is selected from 11PM up to 5AM for 6 hours of off-peak hours based on ethio telecom hourly traffic characteristics.

The procedure of determining the numbers of active basestations are:

- Check predicted hourly traffic with the summation of each basestation traffic capacity of the sub-cluster members by adding one by one.
- Check the above for every day from 11PM up to 5AM for six month and select the highest.

As per the above procedure, the required active basestations of the selected sub-cluster are shown below Table 6.6:

**Table 6.6: The number of required active basestation at off-peak hours**

| Hours | Predicted traffic utilization at off-peak hours | Number of required active BTSs per hour | Number of required active BTSs per off-peak hours |
|---:|---:|---:|---:|
| 0 | 24 | 1 | 2 |
| 1 | 35 | 1 | 2 |
| 2 | 44 | 1 | 2 |
| 3 | 40 | 1 | 2 |
| 4 | 33 | 1 | 2 |
| 5 | 32 | 2 | 2 |
| 23 | 81 | 2 | 2 |
| 0 | 63 | 2 | 2 |
| 1 | 57 | 2 | 2 |
| 2 | 57 | 2 | 2 |
| 4 | 60 | 2 | 2 |
| 5 | 65 | 2 | 2 |
| 23 | 98 | 2 | 2 |

Two basestations for the selected sub-cluster at ideal hours are required.

Next, for the whole 26 basestations will be done. As per prediction, the numbers of required basestations for each sub-cluster are shown below Table 6.7:

**Table 6.7: The numbers of required basestations for each sub-cluster**

| Sub-clusters | Required numbers of active BSs |
|---|---|
| S1 = {BS01, BS02, BS05} | 1 |
| S2 = {BS03, BS06, BS13} | 1 |
| S3 = {BS04, BS07} | 1 |
| S4 = {BS8, BS9, BS10, BS11, BS12} | 2 |
| S5 = {BS14, BS15, BS16} | 1 |
| S6 = {BS17, BS18, BS21} | 1 |
| S7 = {BS19, BS20, BS23} | 1 |
| S8 = {BS24, BS25} | 1 |

## 6.7. Scheduling Basestations to Switched Off

The following are scheduling basestations procedures:

- Grouping basestations based on their geographical position: it is better to group symmetric basestations which helps to minimize next section optimization procedure if the required numbers of active basestations are more than one.
- Basestation switched off is done by scheduling the required number of basestations daily. The soution tries to make the schedule equally distributed between basestations.

The sample scheduling will be done for the above selected sub-cluster and for the other sub-clusters will be summarized by Table 6.9.

1. Grouping: as per the below figure, the symmetric groups are BS08 and BS11, BS09 and BS12, and BS10 can be grouped to four basestations one by one.

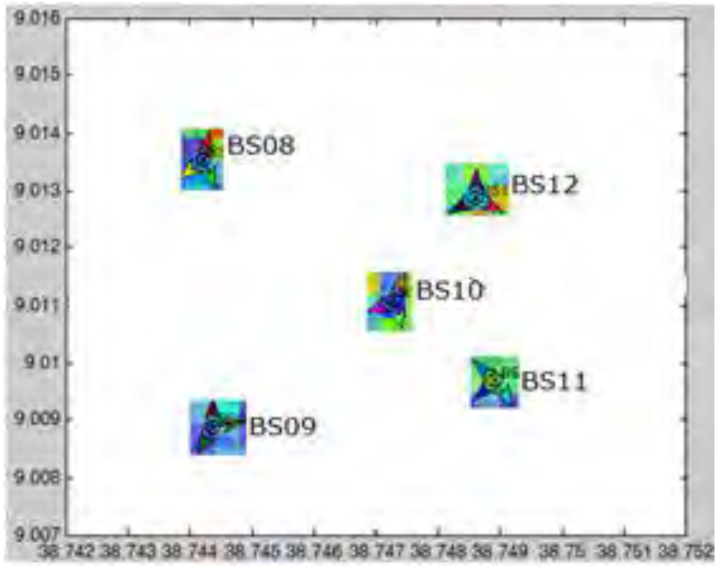



**Figure 6.8: Selected sub-cluster basestations.**

2. The below Table 6.8 shows the schedule of active basestations:

**Table 6.8: The schedule of active basestations**

| Days | Active BSs |
|---|---|
| Day1 | BS08 and BS11 |
| Day2 | BS10 and BS08 |
| Day3 | BS09 and BS12 |
| Day4 | BS10 and BS11 |
| Day5 | BS08 and BS11 |
| Day6 | BS10 and BS09 |
| Day7 | BS09 and BS12 |
| Day8 | BS10 and BS12 |

The below Table 6.9 summarizes the scheduling of active basestaions for all 8 sub-clusters for three days since most sub-clusters has three members and also most required number of active basestation is one:

**Table 6.9: Scheduling of active basestaions for all 8 sub-clusters for three days**

| Days | Sub-cluster 1 | Sub-cluster 2 | Sub-cluster 3 | Sub-cluster 4 | Sub-cluster 5 | Sub-cluster 6 | Sub-cluster 7 | Sub-cluster 8 |
|---|---|---|---|---|---|---|---|---|
| Number of BSs in the sub-cluster | 3 | 3 | 2 | 5 | 3 | 3 | 3 | 2 |
| Required Numbers of active BSs | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 |
| Sub-Cluster members | BS01, BS02, BS05 | BS03, BS06, BS13 | BS04, BS07 | BS8, BS9, BS10, BS11, BS12 | BS14, BS15, BS16 | BS17, BS18, BS21 | BS19, BS20, BS23 | BS24, BS25 |
| Day1 | BS01 | BS03 | BS04 | BS08, BS11 | BS14 | BS17 | BS19 | BS24 |
| Day2 | BS02 | BS06 | BS07 | BS10 BS08 | BS15 | BS18 | BS20 | BS25 |
| Day3 | BS05 | BS13 | BS04 | BS09, BS12 | BS16 | BS21 | BS23 | BS24 |

## 6.8. Optimizing the Coverage with Active Basestations

The following procedures are required to optimize:

1. Determine approximate coverage area of each sub-cluster by drawing rectangular coverage area on voronoi diagram (it is possible to approximate coverage area of BSs using voronoi diagram [45], voronoi diagram gives a good approximation of the coverage area of each BS by a 2-dimensional non-overlapping polygon) to get the new expected coverage coordinates (vertexes) of active BS sectors.
2. Determine new azimuth angle: select compensation BSs sectors from sub-cluster active BSs in order to determine new azimuth angle. They are selected based on their better azimuth angel direction (i.e.; in the direction of compensation).
3. Determine new electrical downtilt angle using Equation (2.1) $\left(\propto = \arctan\left(\frac{H}{R}\right) + \frac{\beta}{2}\right)$

Where $\alpha$ is the sum of electrical and mechanical vertical down-tilt angle, $\beta$ is the vertical half-power angle (it is between 5 to 20 depend on antenna model, 16 is used for this solution), H is the height of the antenna and R is radius of coverage.

For two days schedule of the selected sub-cluster BSs will be done as a sample below:

1. First, determine coverage areas of all BSs by using voronoi diagram by Matlab code as shown below Figure 6.9.

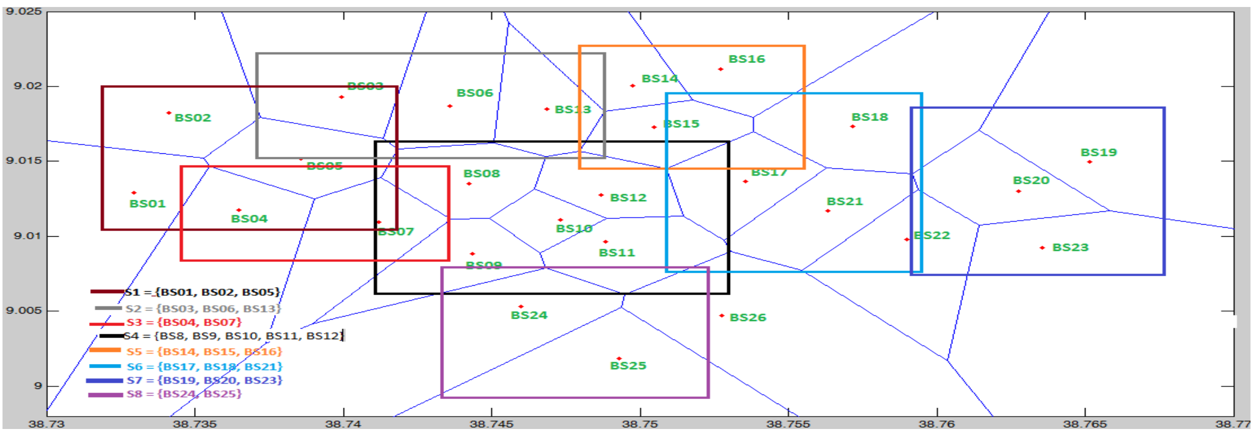
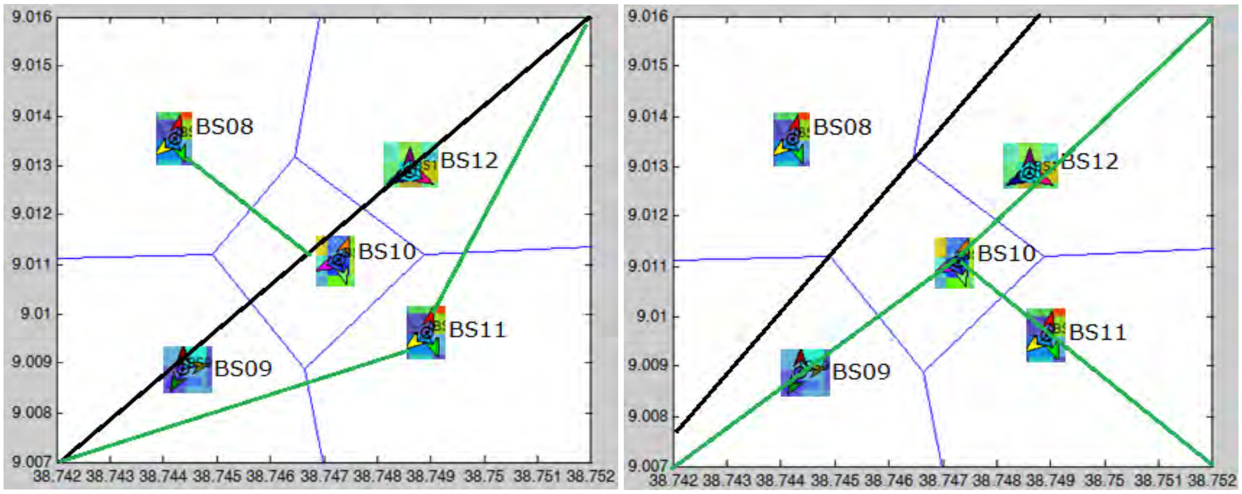



**Figure 6.9: Approximate rectangular coverage area of each sub-cluster on voronoi diagram.**

2. Second, approximate coverage area of the selected sub-cluster as shown below Figure 6.10 which is get manually from the above figure and compensation basestations sectors are selected as follow. From the below figure (a) which is the first day of active basestations schedule, , it is selected BS08_G02 sector to cover in the direction of BS11, the other BS08 sectors are stay as they are because of their azimuth angles have not easily changed and from BS11, G01 and G03 sectors are selected. From the below figure (b) which is the second day of active basestations schedule, all BS10 sectors are selected and BS08 sectors will be the same without changing their configuration. Table 6.10 summarize for the all 26 basestations expected new azimuth and electrical down tilt angles for one day.




(a) (b)

**Figure 6.10: Approximate coverage area of selected sub-cluster with compensation direction.**

**Table 6.10: Compensation of basestations sectors with new azimuth and electrical angles**

| Day | Active BSs | Base Station Sectors | expected coverage Longitude point | expected coverage Latitude point | Old Electrical Tilt angle | Existing coverage Radius | Expected new coverage radius | Calculated New Electrical Tilt angle | Final new Electrical Tilt angle | New Azimuth angel | Old Azimuth angel |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Day1 | BS01 | BS01_G1 | 38.7325 | 9.02 | 4 | 2062 | 2850 | 3.723698 | 3 | 10 | 0 |
| | | BS01_G2 | 38.7425 | 9.015 | 8 | 411 | 1484 | 4.389652 | 4 | 78 | 105 |
| | | BS01_G3 | NOK | NOK | 5 | 1031 | NA | NA | NA | NA | 280 |
| | BS03 | BS03_G1 | NOK | NOK | 3 | 611 | NA | NA | NA | NA | 45 |
| | | BS03_G2 | 38.748 | 9.018 | 5 | 458 | 1356 | 2.351862 | 2 | 99 | 125 |
| | | BS03_G3 | NOK | NOK | 5 | 916 | NA | NA | NA | NA | 295 |
| | BS04 | BS04_G1 | NOK | NOK | 4 | 1747 | NA | NA | NA | NA | 0 |
| | | BS04_G2 | 38.744 | 9.012 | 1 | 1747 | 2573 | 0.679145 | 0 | 88 | 115 |
| | | BS04_G3 | NOK | NOK | 3 | 582 | NA | NA | NA | NA | 195 |
| | BS08 and BS11 | BS08_G1 | NOK | NOK | 10 | 668 | NA | NA | NA | NA | 10 |
| | | BS08_G2 | 38.74731 | 9.01109 | 7 | 501 | 932 | 5.150655 | 5 | 128 | 110 |
| | | BS08_G3 | NOK | NOK | 4 | 501 | NA | NA | NA | NA | 240 |
| | | BS11_G1 | 38.752 | 9.016 | 3 | 467 | 1256 | 1.11749 | 1 | 26 | 10 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 1 | | | |
| | | BS11_G2 | NOK | NOK | 1 | 1404 | NA | NA | NA | NA | 150 |
| | | BS11_G3 | 38.742 | 9.007 | 2 | 702 | 1507 | 0.931402 | 0 | 249 | 225 |
| | BS14 | BS14_G1 | 38.7457 | 9.0225 | 2 | 787 | 1309 | 1.203516 | 1 | 342 | 15 |
| | | BS14_G2 | 38.756 | 9.02 | 6 | 262 | 948 | 1.661595 | 1 | 90 | 90 |
| | | BS14_G3 | 38.7515 | 9.0145 | 4 | 393 | 1038 | 1.517597 | 1 | 162 | 195 |
| | BS17 | BS17_G1 | 38.757 | 9.019 | 5 | 630 | 1333 | 3.945531 | 3 | 33 | 5 |
| | | BS17_G2 | 38.756 | 9.0135 | 4 | 1260 | 1528 | 3.824882 | 3 | 94 | 150 |
| | | BS17_G3 | 38.754 | 9.0075 | 4 | 1260 | 1947 | 3.647382 | 3 | 176 | 230 |
| | BS19 | BS19_G1 | 38.625 | 9.0175 | 10 | 324 | 15717 | 2.165868 | 2 | 341 | 10 |
| | | BS19_G2 | NOK | NOK | 5 | 1303 | NA | NA | NA | NA | 80 |
| | | BS19_G3 | 38.7625 | 9.0075 | 3 | 868 | 1746 | 1.492765 | 1 | 199 | 300 |
| | BS24 | BS24_G1 | NOK | NOK | 4 | 1833 | NA | NA | NA | NA | 10 |
| | | BS24_G2 | 38.752 | 8.95 | 6 | 611 | 6799 | 3.269665 | 3 | 174 | 120 |
| | | BS24_G3 | NOK | NOK | 4 | 916 | NA | NA | NA | NA | 240 |

### 6.9. Performance Metrics

The solution performance will be seen from two points of view, from QOS and energy saving points. In this section, energy saving result will be seen and QOS will be shown using simulation tool in the next chapter. Energy saving will be evaluated by computing Equations from 3.1 to 3.3 and the below Equation 6.1.

Percentage of network energy savings: assuming the network energy consumption during BS switching off is $E_{NEW}$ and BSs are all active or in "always-on" mode ($E_{AO}$), then percentage energy savings achieved with respect to the "always-on" mode is given by:

$$E_{ES} = \left(1 - \frac{E_{NEW}}{E_{AO}}\right) * 100\% \quad (6.1)$$

Table 6.11 shows the overall result of energy saving of 3 scheduled days for all sub-clusters:

**Table 6.11: Overall result of energy saving of 3 scheduled days for all sub-clusters**

| | Number of RRUs | RRU Energy consumption during high traffic | RRU Energy consumption during low traffic | AC Energy consumption | BBU Energy consumption | Total Energy consumption | Hours |
|---|---|---|---|---|---|---|---|
| Number of RRUs during peak hours of the three days | 918 | 3800520 | 0 | 105300 | 37440 | 11829780 | 18 |
| Number of active RRUs off-peak hours of Day1 | 387 | 0 | 348300 | 35100 | 5280 | 388680 | 6 |
| Number of active RRUs off-peak hours of Day2 | 387 | 0 | 348300 | 35100 | 5280 | 388680 | 6 |
| Number of active RRUs off-peak hours of Day3 | 396 | 0 | 356400 | 35100 | 5280 | 396780 | 6 |
| all BSs active during peak hours | 918 | 3800520 | 0 | 105300 | 37440 | 11829780 | 18 |
| all BSs active during Off-peak hours | 918 | 0 | 826200 | 35100 | 12480 | 2621340 | 6 |
| Percentage energy saving | | | | | | 10.0144487 | |

As per the above Table 6.11, around 10% energy saving is found. This is an important signal that switching modes can indeed be a useful tool for energy-efficient networking. The result provides a tangible incentive for ethio telecom to implement switching modes in their networks.

# 7. Simulation Results and Analysis

The aim of this chapter is to present the evaluation guidelines specifying both the simulation methodology used in assessing the overall performance of the proposed basestations scheduling on/off techniques for greener cellular networks. The simulation results which are done based on Atoll radio network planning tool which will show acceptable coverage and service quality areas in order to compare before and after applying the soultion will be discussed below sections in detail.

## 7.1. Overview of Atoll Software

Atoll is a scalable and flexible multi-technology network design and optimization platform that supports wireless operators throughout the network lifecycle, from initial design to deployment and optimization. It can be used to plan both radio and microwave links networks. Atoll can support the following technologies:

- GSM/GPRS/EDGE
- UMTS/HSPA
- Multi-RAT projects
- CDMA2000 1xRTT/EV-DO
- LTE
- TD-SCDMA
- WiMAX/BWA

The Atoll working environment is powerful and flexible. It provides a comprehensive and integrated set of tools and features that allows operators to create and define radio-planning project in a single application. Atoll includes advanced multi-technology network planning features, and a combined single-RAN, multi-RAT GSM/UMTS/LTE

Monte Carlo simulator and traffic model. Operators can save the entire project as a single file, or you can link your project to external files.

### 7.2. Simulation Parameters

The simulation parameters which are used for performance evaluation of basestations scheduling on/off techniques are listed in Table 7.1. There are parameters which are assumed as they are not found from ethio telecom design document.

**Table 7.1: Simulation Parameters**

| Site | BS08 | BS08 | BS08 | BS09 | BS09 | BS09 |
|---|---|---|---|---|---|---|
| Transmitter | BS08_G1 | BS08_G2 | BS08_G3 | BS09_G1 | BS09_G2 | BS09_G3 |
| Transmitter Type | Intra-network (Server and Interferer) | Intra-network (Server and Interferer) | Intra-network (Server and Interferer) | Intra-network (Server and Interferer) | Intra-network (Server and Interferer) | Intra-network (Server and Interferer) |
| Antenna | 65deg 17dBi 0Tilt 900MHz | 65deg 17dBi 0Tilt 900MHz | 65deg 17dBi 0Tilt 900MHz | 65deg 17dBi 0Tilt 900MHz | 65deg 17dBi 0Tilt 900MHz | 65deg 17dBi 0Tilt 900MHz |
| Height (m) | 35 | 35 | 35 | 38.5 | 38.5 | 38.5 |
| Azimuth (°) | 10 | 120 | 240 | 0 | 75 | 210 |
| Mechanical Downtilt (°) | 1 | 5 | 8 | 5 | 8 | 8 |
| Additional Electrical Downtilt (°) | 10 | 7 | 4 | 2 | 0 | 3 |
| Cell type | Macro Cell 900 | Macro Cell 900 | Macro Cell 900 | Macro Cell 900 | Macro Cell 900 | Macro Cell 900 |
| EIRP (dBm) | 60.5 | 60.5 | 60.5 | 60.5 | 60.5 | 60.5 |
| Main Propagation Model | Okumura-Hata | Okumura-Hata | Okumura-Hata | Okumura-Hata | Okumura-Hata | Okumura-Hata |
| Main Calculation Radius (m) | 1206 | 1254 | 1359 | 1045 | 1301 | 1206 |
| Main Resolution (m) | 50 | 50 | 50 | 50 | 50 | 50 |
| Required TRXs | 6 | 6 | 6 | 8 | 6 | 6 |
| Number of TRXs | 5 | 6 | 6 | 7 | 5 | 5 |

### 7.3. Simulation Scenarios and Coverage Predictions

Two scenarios are used,

1. Checking the coverage change for selected sub-cluster basestations before and after changing electrical down tilt and azimuth angles.
2. Checking for all selected basestations before and after changing electrical down tilt and azimuth angles.

1. Checking the coverage change for selected sub-cluster basestations before and after changing electrical down tilt and azimuth angles.

A coverage prediction displays the results of defined coverage conditions. It is calculated using the path loss matrices and is based on coverage conditions and coverage resolutions. After calculation, Atoll displays the results as a graphical representation of the pixels for which the defined coverage conditions are satisfied. Atoll offers the following general coverage predictions, available for all technologies:

• Coverage by transmitter
• Coverage by signal level

a. Coverage Prediction by Transmitter

A coverage prediction by transmitter allows predicting which server is the best at each pixel. The below figures show before and after switched off and also applying the tilt and azimuth angles change:

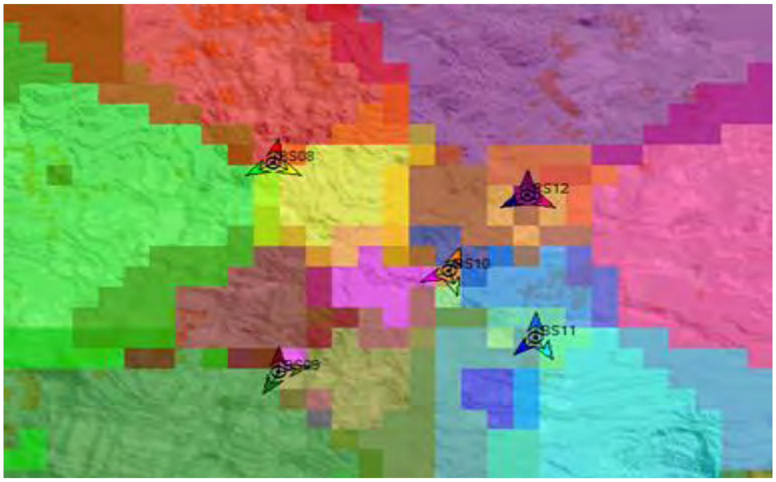



**Figure 7.1: Coverage prediction by transmitter before switched off.**

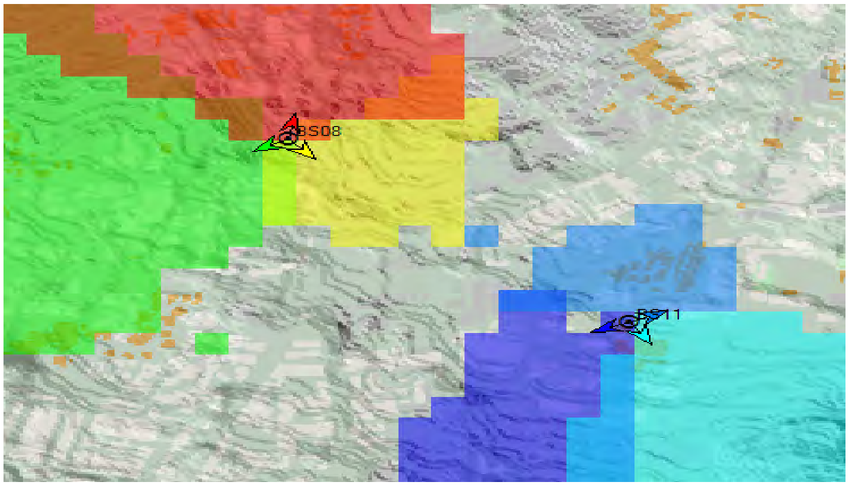



**Figure 7.2: Coverage prediction by transmitter after switched off.**

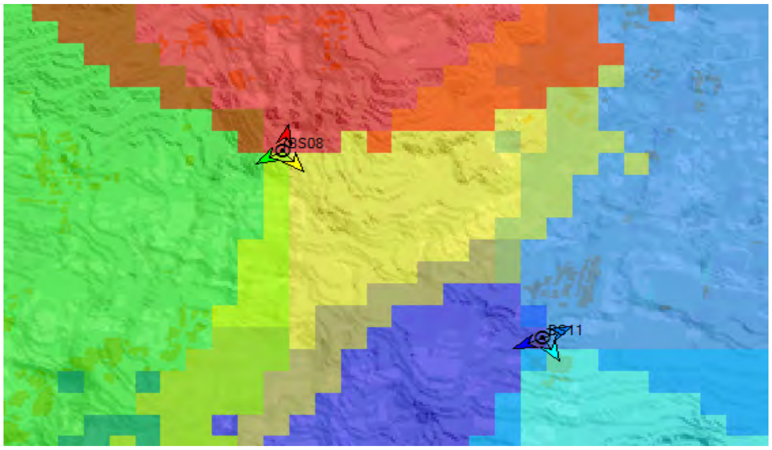



**Figure 7.3: Coverage prediction by transmitter after switched off and also after applying the tilt and azimuth angles change.**

As shown in the Figure 7.3, the area is covered by two basestations after switched off and applying the tilt and azimuth angles change.

b. Coverage by C/I level

The coverage by C/I level study enables to determine C/I levels for transmitters sharing either an identical channel or an adjacent channel with other transmitters as a function of the carrier-to-interference ratio. The best signal level is shown in figure 7.4 with different colors. This legend shows the prediction property of each signal level. The below figures show before and after switched off and also applying the tilt and azimuth angles change:

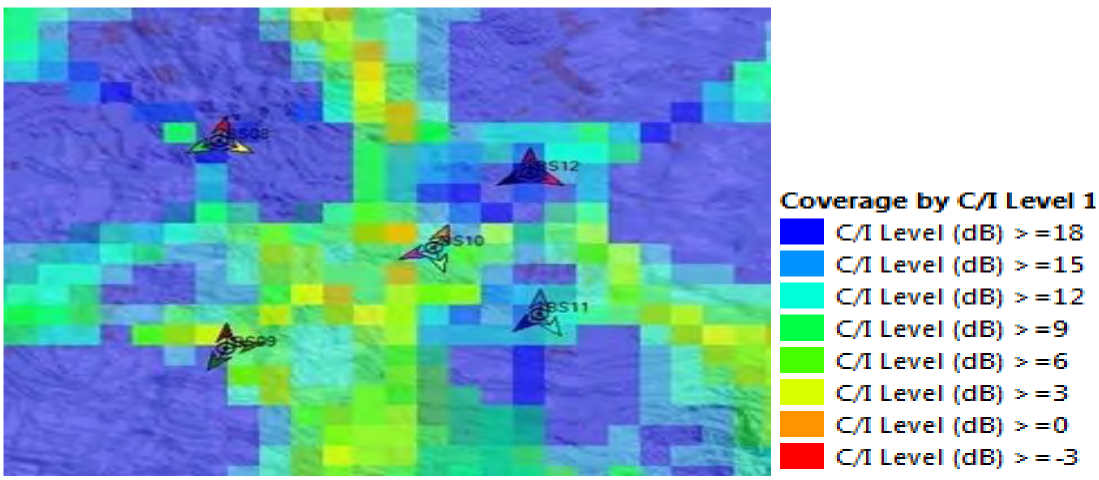



**Figure 7.4: Coverage prediction by C/I level before switched off**

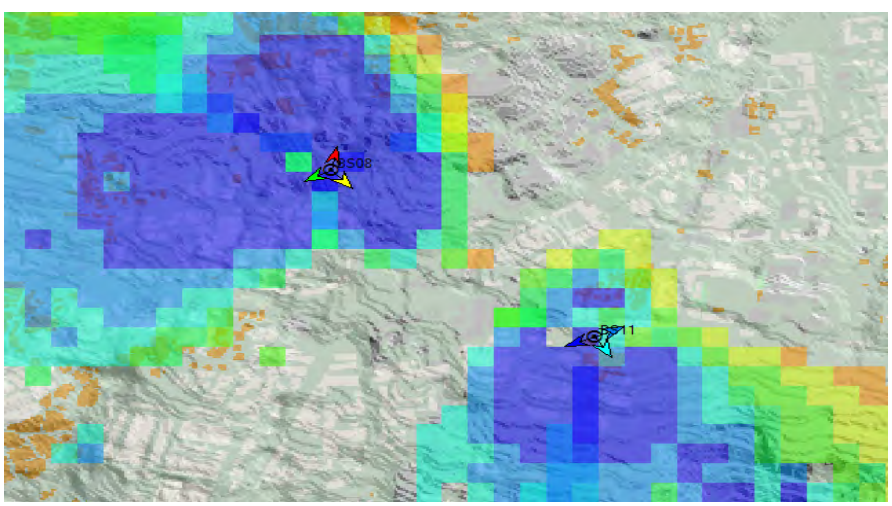



**Figure 7.5: Coverage prediction by C/I level after switched off**

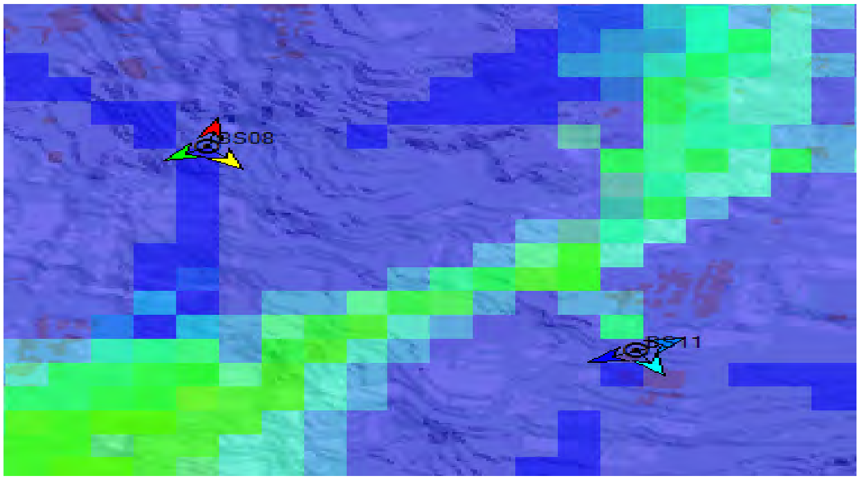



**Figure 7.6: Coverage prediction by C/I level after applying the tilt and azimuth angles change.**

From the above Figure 7.6, 56.61% of the focus zone area has C/I level above 18dB. The theoretical value of expected for a network based on the GSM 900 band and a 3/9 cell repeat pattern is >9dB. From the coverage prediction by C/I level results, 81% of the focus zone area has a C/I level greater than 9dB.

2. Checking for all selected basestations before and after changing electrical down tilt and azimuth angles.
    a. Coverage Prediction by Transmitter

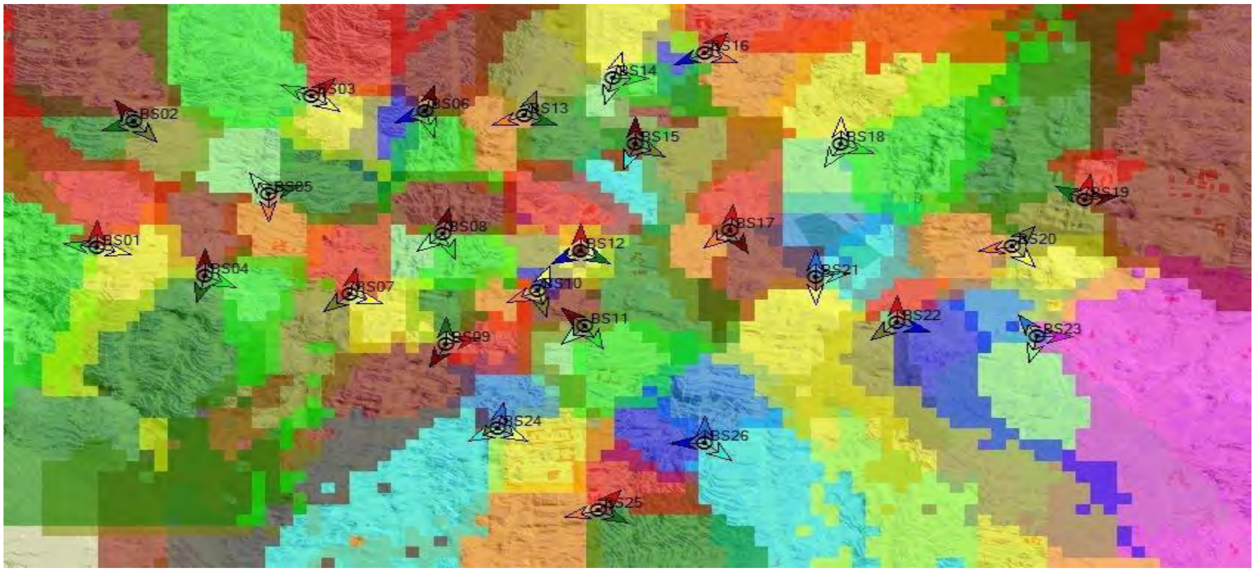


**Figure 7.7: Coverage prediction by transmitter before switched off.**

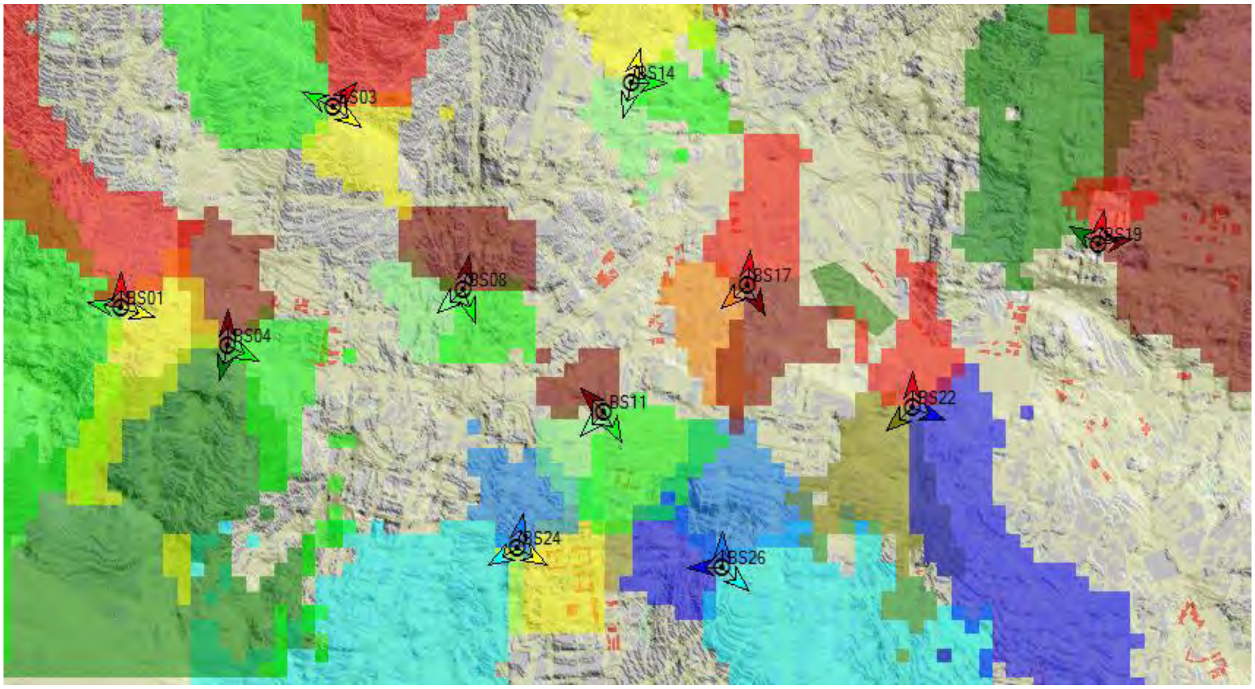


**Figure 7.8: Coverage prediction by transmitter after switched off.**

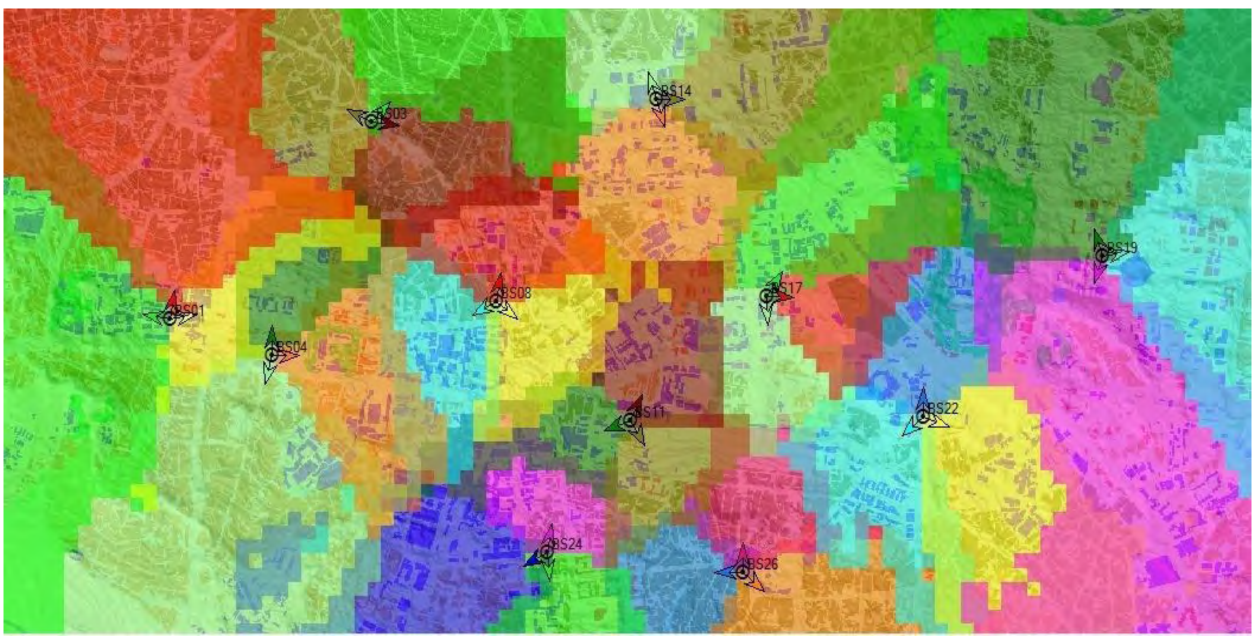


**Figure 7.9: Coverage prediction by transmitter after applying the tilt and azimuth angles change.**

As shown in the Figure 7.9, the area is covered by 11 basestations after switched off and applying the tilt and azimuth angles change. The coverage by transmitter prediction results show that the whole Leghar area is full covered with no noticeable holes.

b. Coverage by C/I level

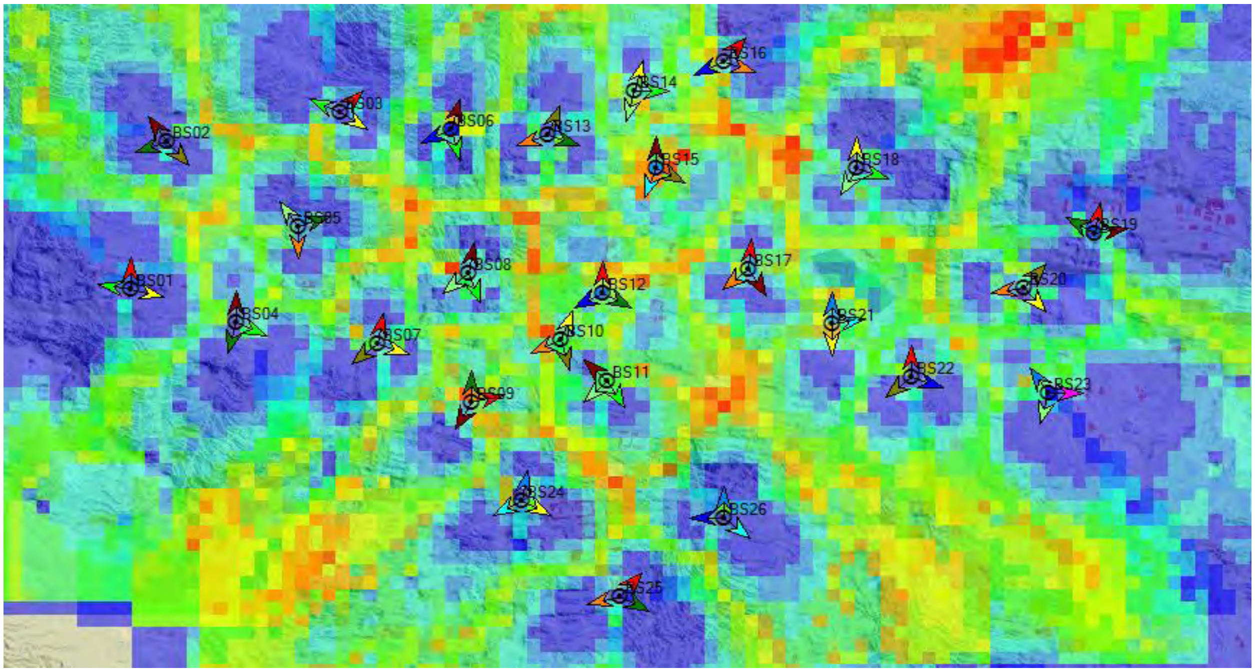



**Figure 7.10: Coverage prediction by C/I level before switched off.**

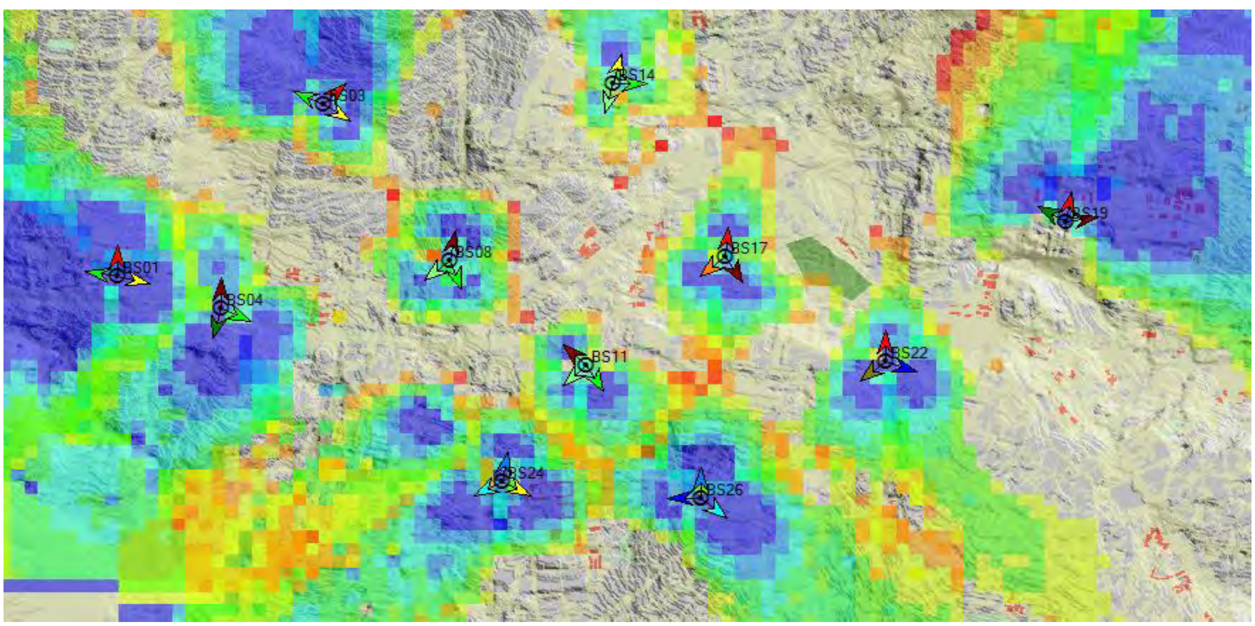



**Figure 7.11: Coverage prediction by C/I level after switched off.**

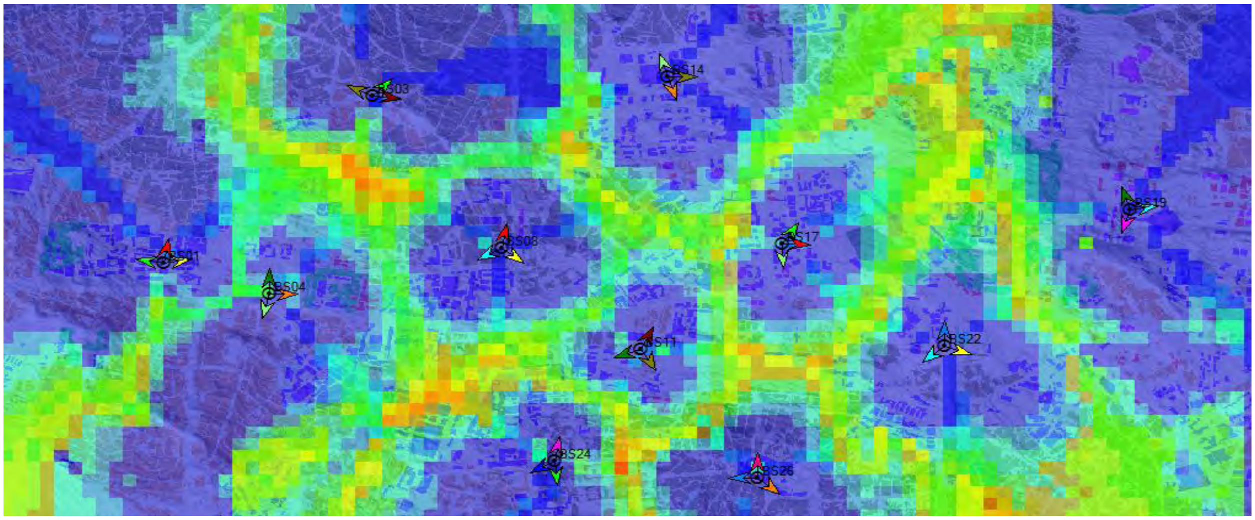



**Figure 7.12: Coverage prediction by C/I level after applying the tilt and azimuth angles change.**

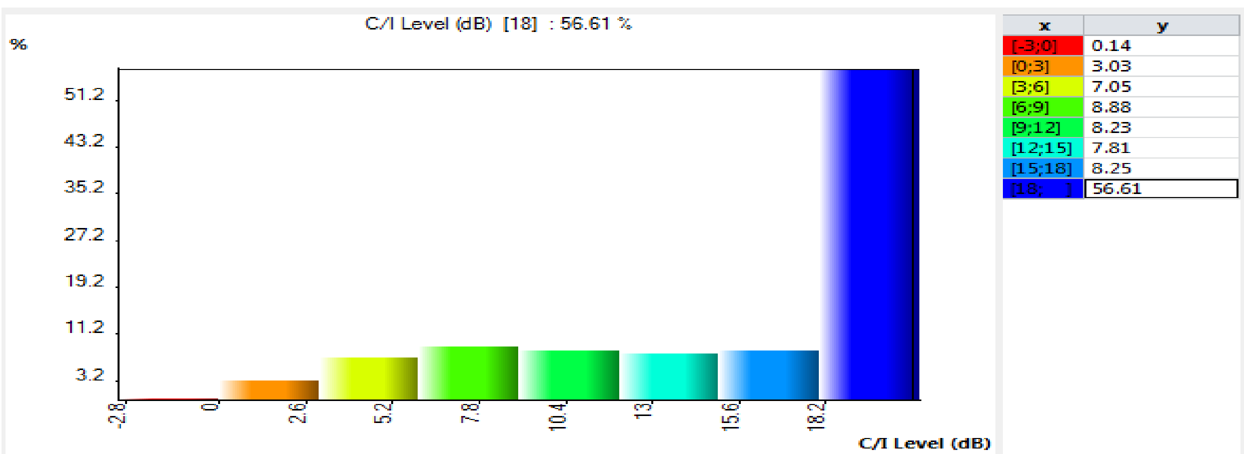



**Figure 7.13: Histogram based on C/I Level of Covered Areas.**

As shown in the Figure 7.9, the area is covered by 11 basestations after switched off and applying the tilt and azimuth angles change. The coverage by transmitter prediction results show that the whole Leghar area is full covered with no noticeable holes. From the above Figure 7.13, from the coverage prediction by C/I level results, 56.61% of the Leghar area had C/I level above 18dB and 81% of the Leghar area has a C/I level greater than 9dB. As a conclusion, with acceptable coverage and service quality as per atoll simulation tool results, the active basestations can cover the switched off area.

# 8. Conclusions and Future Works

## 8.1. Conclusions

This thesis intends to apply one of green cellular network strategies to reduce BSs energy consumption by scheduling switched off basestations during off-peak hours in ethio telecom GSM network for the selected 26 sites. This work explores the possibility to save energy in cellular networks through basestations switching off technique by turning off basestations remote radio unit (RRU) and applying antenna electrical downtilt and azimuth angles changes on active basestations by considering ethio telecom basestations operation and maintenance (OAM) system capabilities of both turning off and angles change.

The first of the investigation was identifying various ethio telecom basestations from energy consumption perspective point of view and show the challenges of applying energy saving on current deployed basestations. So, the current ethio telecom basestations are power consuming and the lay-out architecture is not easy for implementing basestations switching technique. The good points are software and hardware are capable of energy saving strategies with RET system implemented and the daily traffic per hour fluctuation result show that there is underutilization of basestations capacity during off-peak hours which fulfills to start implementing one of energy saving strategy. The solution to minimize energy consumption of basestation is to follow different standardization group releases on energy efficiency such as 3gpp, ETSI, Telecommunications Industry Association (TIA), Alliance for Telecommunications Industry Solution (ATIS) and China Communication Standard Association (CCSA) and also it is better to follow heterogeneous network architecture which has both a coverage layer dimensioned basically to serve conversational services and low data traffic, and a capacity layer dimensioned to serve high data traffic demands and large user throughput.

The second of the investigated solution indentifies good traffic forecasting model for ethio telecom GSM network. After comparing different forecasting models, seasonal adjusted ARIMA model ($ARIMA(1,0,2)(2,0,1)_{24}$) has good prediction results. And also the forecasting performance evaluation presents small forecasting error values that confirm the capable of fitting and forecasting the traffic of our model.

The area of Leghar can be covered by 11 basestations out of 26 basestations during off-peak hours by applying the tilt and azimuth angles change. With acceptable coverage and service quality, the proposed solution of switched off basestations during off-peak hours yields above 10% energy saving for the all 26 basestations.

## 8.2. Future Works

As future works, it is recommended to do the following studies on basestations power consumption cases:

1. Study and apply switched off basestations during off-peak hours for all network scenarios (GSM, WCDMA, LTE and CDMA) with different bands for Ethio telecom case.
2. Study and apply different green cellular network design strategies which are described in Chapter 3 for Ethio telecom core and access networks.
3. Design new standards for different core and access network components to minimize power consumption.

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# Appendix

## Appendix A

### Seasonally Adjusting prediction for one month R-program

```
#To insert the statistical data1 to R using Excel which is saved as CSV (Comma delimited)
data1 <- read.csv(file.choose(), header=TRUE)
class(data1)                              #prints the vector of names of classes an object
inherits from
names(data1)                              #Get and Set rows and clulum Names
attach(data1)                             #attach can be used to make objects accessible
library(forecast)                         #Loading/Attaching and Listing of Packages
library(TSPred)
library(tseries)
plot(TotTraff, type="l", lwd=2, col="red", xlab="time", ylab="maximum traffic per erlang",
main="Hourly traffic usage" )             #drawing total hourly traffic usage
abline(h=mean(TotTraff), col="blue")      #drawing mean value of total traffic
summary(TotTraff)
tsdata1<-ts(data1$ TotTraff, start=c(1, 1), freq=24)    #change the original data to time series
head(tsdata1)
class(tsdata1)
time(tsdata1)
plot(tsdata1)
decompose(tsdata1)           #decompose the time series data in to seasonal, trend and random
plot(decompose(tsdata1))
#training data which is got from the original data
data1.train = window(tsdata1, start = c(1,1), end = c(31,12))
plot(data1.train)
data1.test = window(tsdata1, start = c(1,1))    #test data which is got from the original data
plot(data1.test)
data1traindeco<-decompose(data1.train)
#subtract seasonal data from original data to seasonally adjusted data
data1trainseasonallyadjusted<-data1.train-data1traindeco$seasonal
plot(data1trainseasonallyadjusted)
#train the seasonal adjusted data using auto.arima
arima1= auto.arima(data1trainseasonallyadjusted, trace=TRUE, test="kpss", ic="aic")
summary(arima1)
```

```
arima1.forecast= forecast.Arima(arima1, 756)          #predict using auto arima model
arima1.forecast                                       #to see the predicted data
plot(arima1.forecast)
data1testdeco<-decompose(data1.test)
#return to the original format for the mean after predicted using seasonal adjusted data
data1testdes=arima1.forecast$mean+data1testdeco$seasonal
#return to the original format for upper 80% after predicted using seasonal adjusted data
data1testdesup=arima1.forecast$upper[ ,1]+data1testdeco$seasonal
#return to the original format for lower 80% after predicted using seasonal adjusted data
data1testdeslw=arima1.forecast$lower[ ,1]+data1testdeco$seasonal
#return to the original format for upper 95% after predicted using seasonal adjusted data
data1testdesup2=arima1.forecast$upper[ ,2]+data1testdeco$seasonal
#return to the original format for lower 95% after predicted using seasonal adjusted data
data1testdeslw2=arima1.forecast$lower[ ,2]+data1testdeco$seasonal
plot(data1.test, ylim=c(-100, 300))                              #plotting the prediction
lines(data1testdes, col="blue")
lines(data1testdesup, col="red")
lines(data1testdeslw, col="red")
lines(data1testdesup2, col="green")
lines(data1testdeslw2, col="green")
#saving the seasonally adjusted forecast
write.csv(arima1.forecast, file="predictedforBS0809101112.csv")
#saving the data which is returned to original format
write.csv(data1traindecodes, file="predictedforBS0809101112_seson.csv")
```

# Appendix B

## Ethio telecom detail LLD

The below Table shows ethio telecom detail LLD:

| | | |
|---|---|---|
| Huawei ID | 111001 | 111001 |
| Sector ID | 111001-D1 | 111001-D2 |
| Site Type | Existing | Existing |
| Swap Cluster | Cluster8 | Cluster8 |
| PAC Cluster | P_Cluster9 | P_Cluster9 |
| BSC Name | 111168.BSC_03.HW.KKTEL.SAAZ.AA | 111168.BSC_03.HW.KKTEL.SAAZ.AA |
| Subcity | 3_Addis Ketema | 3_Addis Ketema |
| BTS NAME | 111001_WL_GUL_BSCRNC3.HW.MSLMY.WAAZ.AA | 111001_WL_GUL_BSCRNC3.HW.MSLMY.WAAZ.AA |
| GSM Cell Name | 111001_MESALEMIA_D1 | 111001_MESALEMIA_D2 |
| PAC Cluster | P_Cluster9 | P_Cluster9 |
| Celltype | DCS1800 | DCS1800 |
| CI | 10015 | 10016 |
| BSC ID | 203 | 203 |
| Layer of The Cell | 2 | 2 |
| Sector Type | D1 | D2 |
| Logical Site Name | 111001-D | 111001-D |
| Longitude | 38.72548 | 38.72548 |
| Latitude | 9.03251 | 9.03251 |
| Azimuth(*) | 0 | 65 |
| Height(m)(*) | 32 | 32 |
| Antenna Type(*) | 27010880 | 27010880 |
| Mechanical Downtilt(*) | 2 | 5 |
| Electrical Downtilt(*) | 3 | 9 |
| Total Downtilt | 5 | 14 |
| LAC | 11020 | 11020 |
| RAC | 2 | 2 |
| NCC | 6 | 1 |
| BCC | 2 | 4 |
| BSIC | 62 | 14 |
| BCCH | 719 | 702 |
| TCH | 723,730,734,736,738,740,864,866, | 851,874, |

| | | |
|---|---|---|
| HSN | 48 | 48 |
| MAIO | 0;0;0;0;0;0;0;0; | 0;0; |
| Interim TRX Qty. | 8 | 8 |
| Final TRX Qty. | 9 | 3 |
| BTS Type | DBS+3*RRU3929+6*RRU3936+3*RRU3826 | DBS+3*RRU3929+6*RRU3936+3*RRU3826 |
| Interim Power | 40.79 | 40.79 |
| | 1275.078883 | 1275.078883 |
| SDCCH8 NO. | 6 | 1 |
| Static PDCH NO. | 2 | 2 |
| MAX Dyn.PDCH | 39 | 13 |