

Energy assessment and optimization in second generation wireless access network, the case of ethio-telecom



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Declaration

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Abstract

For the last five years, the main concern of Ethio-telecom was the enhancement of existing wired and wireless network performance, so that new services being offered could work properly and be available to a larger number of customers. The solution adopted to achieve this goal has been advanced following massive improvements in international bandwidth, national fiber backbone infrastructure and mobile broadband services: as a result, it seems today wired and wireless networks are constantly working at rates that are hardly reached at rush hours.

Though, this rapid growth of mobile subscribers and number of base stations necessitate the need to study the relationship between traffic load and power consumption at a base station, research for more efficient solutions in terms of energy consumption has been disregarded. Thus, to allow a sizeable saving of economic resources and to realize sustainable development actions in the telecom industry, reducing the energy needs of the wireless cellular system shall be recognized as one of the main challenges in the telecommunication sector.

This thesis critically analyses the power consumption of Base Stations as per the traffic generated at urban-dense location of Addis Ababa City. A power consumption modelling of BSs is developed with real time traffic and which deals with real time traffic data on full load in per hour basis of two GSM BSs for two days each. The results revealed a linear relationship between the power consumption and traffic loads. As of findings, this paper vows an urgency to pursue an optimal capacity while designing wireless networks and also suggests an imperative pathway for energy efficient wireless communication.

Moreover, a dynamic management of network's resources is considered in this paper as a real time energy saving solution while preserving the Quality of Service (QoS) perceived by users, which allows switching ON/OFF a timeslot as a function of the instantaneous change of the load in the system. The proposed real time BS power saving schemes confirmed that Ethio-telecom can save up to 25% average energy for macro base stations & up to 10% gain for micro BSs by switching ON/OFF a resource or a timeslot from the BSC.

Key Words: - Wireless networks, Cellular System, power consumption model, Dynamic Network Management, 2G energy consumption reduction techniques, switching ON/OFF a resource.

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List of Acronyms and Abbreviations

2G	Second Generation
3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
AC	Air conditioners
A-Doherty	Advanced-Doherty
AMPS	Advanced mobile phone system
AuC	Authentication Centre
BBU	Baseband Processing Unit
BCCH	Broadcast Control Channel
BCF	Base Station Control Function
BS	Base Station
BSC	Base Station Controller
BSS	Base-Station Subsystem
BTS	Base Transceiver Station
CAPEX	Capital Expenditure
CBC	Charge Back Centre
CDMA	Code Division Multiple Access
CMCC	China Mobile Communication Corporation
CoMP	Coordinated Multi-Point
CPU	Central Processing Unit
DA/AD	Digital-to-Analog/Analog-to-Digital
DAC	Digital-to-Analog Conversion
DAGC	Digital Automatic Gain Control
DCS	Digital Cellular System (GSM1800MHz)
DPD	Digital Pre-Distortion
DSP	Digital Signal Processor
DTX	Discontinuous Transmission

EIR	Equipment Identity Register
EPS	Evolved Packet System
ET	Envelope Tracking
EUTRA	Evolved UMTS Terrestrial Radio Access
EUTRAN	Evolved UMTS Terrestrial Radio Access Network
FDMA	Frequency Division Multiple Access
FPGA	Field Programmable Gate Array
GGSN	Gateway GPRS support node
GHG	Global Greenhouse Gas
GMSC	Gateway MSC
GPRS	General Packet Radio Service
GSM	Global System for Mobile communications
GTP II	Government's Growth and Transformation Plan II
HLR	Home Location Register
ICT	Information and Communication Technology
IF	Intermediate Frequency
IMEI	International Mobile Equipment Identity
IMSI	International Mobile Subscriber Identity
IMT- 2000	International Mobile Telecommunications-2000
ITU	International Telecommunication Union
LNA	Low Noise Amplifier
LR	Location Registers
LTE	Long-Term Evolution
MIMO	Multiple-Input Multiple Output
MS	Mobile Station
MSC	Mobile Switching Centre
NMT	Nordic mobile telephone
NSS	Network and Switching Subsystem
OAM	Operation and maintenance
OFDMA	Orthogonal Frequency Division Multiple Access
OPEX	Operational Expense

OSS	Operation and Support Subsystem
PA	Power Amplifier
PCCH	Strong Paging Channel
PSTN	Public Switched Telephone Network
QoS	Quality of Service
RBSs	Radio Base Station
RF	Radio Frequency
RNC	Radio Network Controller
RRH	Remote Radio Heads
RRU	Remote Radio Unit
SDCCH	Strong Dedicated Control Channel
SGSN	GPRS Support Node
SIM	Subscriber Identity Module
SMSSC	SMS Serving Center
TACS	Total Access Communication System
TD-CDMA	Time Division- Code Division Multiple Access
TDMA	Time Division Multiple access
TD-SCDMA	Time Division Synchronous CDMA
TRAU	Transcoder and Adaptation Unit
TRX	Transceiver
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
VAD	Voice Activity Detection
VLR	Visitor Location Register
VOX	Voice-Operated Transmission
W-CDMA	Wideband Code-Division Multiple Access
WMSC	Wideband CDMA Mobile Switching Centre
ZTE	Zhongxing Telecommunication Equipment

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1. Introduction

1.1 Background

Recently, the mobile communication society has become aware of the large and ever-growing energy usage of mobile networks. Due to this growing demand for energy usage of mobile network, mobile network operators and mobile network device manufacturers are globally researching different ways to optimize their network performance from energy efficiency and capacity standpoints [1].

Some telecom operators undertaken the pressure to optimize this energy inefficiency was entirely on the device manufacturers' shoulders, which all have to be able to design and manufacture more energy efficient and elegant solutions for the operators to implement on their network. The other reason for the reduction of the energy consumption by the Base Station (BS) manufacturers is because telecom equipment's with high power efficiency provides a competitive advantage for the equipment suppliers.

However, during operation time, a lot of money in the mobile networks is being vanished in the form of energy consumption, particularly in the network's Radio Base Station (RBSs), because the RBSs are not being used in the most optimal and efficient way. Today, operating costs are also being jacked up because of the increase of the carbon footprint of the wireless networks [1] & [2]. This increase is due to the fact that the traffic volume of the network rises as the user base expands each day; together with the data volumes transferred by each customer are also increased.

Even though, the mobile communications sector today has around 0.2% of total carbon emissions within Information and Communication Technology (ICT) which has a footprint of about 2% [3], a significant increase can be expected in the near future as the technology and demand on the wireless network increase. An increase of the global number of mobile subscribers will lead to an increase of the energy consumption of the networks. Further, it can be expected that new technologies for mobile internet access such as notebooks and laptops with mobile broadband card will transfer fixed internet traffic to mobile radio networks [4], so that the power demand for the mobile network will grow more and more in a short duration.

It is well noted that, the cellular network market in Ethiopia has shown a rapid growth and Ethio-telecom has made a massive improvement in international bandwidth, national fibre backbone infrastructure and mobile broadband services for enhancement of existing and new wired and wireless network performance. With the advent of additional technologies in the expansion projects and the increase in the number of sites, for a 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 shall be involved in reducing the energy consumption of their networks to reduce their operational expenditure, and therefore increase profits.

Basically, there are two ways for operator to reduce energy wastage: the first is to find appropriate solutions to the energy efficiency challenges for already existing networks (Brownfield), efficiently minimizing idle capacity of base stations and the second is by designing future networks from energy (and cost) efficiency perspective (Greenfield perspective) [5]. Besides, energy efficiency cannot only be improved in the base station equipment by the device manufacture's only, but also by adopting appropriate energy efficient solutions on the site level to save energy based on the nature of the users.

1.2 Statement of the Problem

Generally, the ICT sector contributes with 2% of global greenhouse gas (GHG) emissions annually [2] – [4], which is a value that exceeds the GHG emission of the aviation sector [6]. As ICTs become more widely available, these percentages are likely to grow to approximately 2.8% of global emissions, by 2020 [7]. In addition, ICT alone is responsible for a percentage between 2% and 10% of the world power consumption [8].

In Ethiopia, explosive growth of mobile demand has been observed over the last decade. [9] a statistic shows the number of mobile subscribers per 100 inhabitants to Ethio-Telecom network in Ethiopia from the 2010/11 fiscal year to the 2016/17 fiscal year for an increase from 12.9 to 61.6 in every inhabitant, subscribed to ethio telecom's mobile service. With this increase in the demand of mobile subscription, the base station density also remarkably grown and the energy consumption increased too.

As per the Government's Growth and Transformation Plan II (GTP II), the country could have some 103 million mobile subscribers by 2020, as well as 56 million internet subscribers. This

increase in the traffic volume of the mobile subscriber and the number of connected smart devices will lead the mobile operator to be challenged with higher operational costs and constrained carbon footprint in providing more capacity to its customer. Analogous to adopting different expansion telecom project to achieve the GTP II goal set by the Federal Government, ethio telecom shall also consider practicable cost reduction solutions to reduce the operational costs, in which the energy consumption bill has a big share.

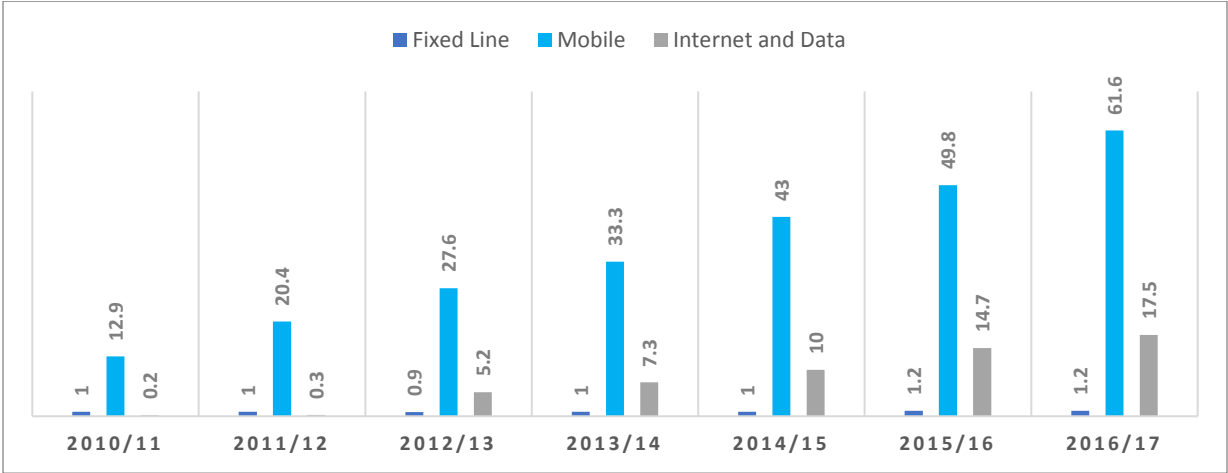


Figure 1: Telecommunication penetration rate/density for ethio telecom, 2010-2017 [9]

It is well known that radio access nodes are particularly energy-hungry, in which their energy consumption can reach more than the 80% of the total energy in the entire access network [8]. Even though different energy saving mechanisms is available in the several commercial products for RBS, Ethio-telecom did not give enough attention as an alternative energy saving solutions for their normal network operation. Therefore, this research will give consciousness for our telecom operator to have a well-organized energy consumption data sheet to be used for the analysis in the operational consumption of cellular devices in the operator premises and to use an appropriate energy saving solutions.

The thesis mainly focuses studying the different modules and network elements power consumption provided by different telecommunication Vendor Company in Ethiopia and the result will further be taken to highlight a possible energy reduction strategy and technology for second-generation network under operations by using built-in software power-saving features.

1.3 Objective of the Thesis

1.3.1 General Objectives

The general objective of the thesis is to conduct a power measurement at site and model the relationship between the energy consumed with instantaneous daily traffic profile in the existing GSM base stations. Once identifying the metrics of the energy consumption of the second-generation cellular system, calculate the profit that might be obtained by applying forecasting based dynamic time slot sleep method on a realistic GSM network.



Figure 2: Objective in picture--- Energy saving depending on traffic profile for 24 Hours [11].

1.3.2 Specific Objectives

The Specific objectives of the thesis are:

- Take a brief review on the energy consumption of cellular wireless system.
- Determine and analyse the different components in the second-generation wireless network topology of Ethio-telecom in terms of their energy consumption.
- Model the relationship between the power consumption and the daily traffic profile of sampled macro and micro base stations.
- Implement power saving solutions to sampled base stations under operation in Ethio-telecom to make realistic input parameters available for the total network power consumption in mobile communication networks. In addition, specifically study energy saving solutions and

techniques for the most energy consuming components of remote radio unit, the power amplifier.

- To recommend some topics in the efficient energy consumption methodology that needs further investigation in the future so that it can be implemented in the existing network, which may yields a good result.

1.4 Literature Review

So far, many researchers have examined and assessed the energy consumption of wired and wireless access networks and some of them also proposed different techniques to be used for efficient energy consumption. Short literature surveys of some of the related papers with the subject matters are reviewed here:

According to [10], it stressed that cellular network operators should be pressured to meet the demands in environmental conservation and Operational Expense (OPEX) reduction. It also recommends cellular network operators should attempt to shift toward green practices using two main approaches:

- ✚ The first approach using energy-efficient hardware to reduce the energy consumption of BSs.
- ✚ The second approach is promoting the intelligent management of network elements under operation based on **traffic load variations**.

Apart from offering recommendations for future research, this study comprehensively analysed energy related literature and the potential of renewable energy solutions for cellular BSs.

Besides, the article predicted that the GSMA number of green BSs would increase much more by 2020, which reflects the growing awareness of cellular network operators about the significant economic and ecological influence of their networks in the coming years. So that, the network operators which are not yet implement the green base stations strategies (Figure: 3), should capture the power consumption of the entire system, so that they can assess the energy efficiency of a wireless network and goes for further solutions to reduce their higher operation expense and the negative effect to the environment.



Figure 3: Deployment and locations of green cellular BSs around the world [10].

The thesis work under **reference [11]** investigated the energy consumption of mobile access networks which have recently received increased attention in research carried out in both industry and academia. This thesis also contributes to the mainstream discussion on the importance of reduction in energy consumption to achieve economic and environmental benefits. Particularly it has addressed the possible ways to minimize the energy consumption on the BS sites. In the thesis, some factors in evolution of mobile networks were discussed from energy and power consumption perspective. Based on the discussion a simple methodology was proposed in order to model the power consumption on network of base stations. The thesis work also investigated the potential energy savings when deploying femto-cells along with macro base stations in WCDMA network. It was determined how the load sharing between femto-cells and macro cells will contribute to the overall energy consumption of the network.

Achieved gain can be fully exploited in green field deployments but part of the energy saving potential can be utilized also in existing networks through macro cell breathing: decreased macro cell load due to femto-cells results in larger macro cell coverage and in dense macro cell deployments part of the base stations can be switched off.

The analytical results concluded that in order to save the energy and avoid the service degradation problem; it is recommended to shut down the underutilized BSs instead of deploying the new networks with less base stations (green field networks). It recommends the switching ON/OFF of the BSs should be done based on the already available daily traffic patterns.

Reference [12] explains some of the significant achievements obtained by China Mobile Communication Corporation (CMCC) for applying different energy saving mechanisms. Besides, it presented the best energy-saving technologies that have been used for existing second-generation network in China. Shortly, the following advantages are obtained by CMCC:

- ✓ By installing RRUs near the antennas, which can eliminate 3dB feeder loss existed in the traditional base station, enabling lower power amplifier output power requirements, thereby improving the coverage performance or reducing machine power consumption.
- ✓ RRU remote pull-away separates the functions from the relevant power consumptions, and a RRU exhausts low power consumption than a traditional base station does, which enabled to design some renewable energy (wind, solar, etc.) based RRU.
- ✓ Applying GSM distributed base stations system, the multi-carrier technologies help the GSM network to enable GSM base stations to smoothly evolve into LTE (long-term evolution) and effectively protect existing investments.
- ✓ Due to frequent changes of carrier-frequency load in the traffic channels, the power consumption of the base station system is quite volatile. Therefore, they adopted a dynamic power control scheme in their network.

Reference [13] considered applying switching-off base stations during off-peak (low traffic) hours as one strategy to save the energy consumption of a cellular network cluster of twenty-six Global System for Mobile communications (GSM) base stations in Addis Ababa around Leghare area, which is a traffic dense area. In the study, they obtained the hourly traffic statistics of the selected cluster around Leghare from ethio telecom for analysis and they become aware of a high traffic from **5:00 am** to **11:00 pm** and low traffic during the night-time from **11:00 pm** to **5:00am**. In which, the latter is considered as the off-peak hours in this study.

As per this paper, a base stations switching-off technique is considered by turning off base stations remote radio unit (RRU) and applying antenna electrical down tilt and azimuth angles change on the active base stations using operation and maintenance (OAM) system capabilities for both turning off the base stations and angles changes to reimburse the coverage of the switched-off base stations with minimum compromise in the user's quality of service (QoS). For performance evaluation of base stations scheduling on/off techniques, an Atoll radio network-planning tool is used to compare the coverage and service quality of the user before and after applying the solution.

Once, the coverage area of the cluster is optimized by switching off some of the redundant base stations and modifying the base stations antenna electrical down tilt and azimuth angles to cover the whole area by a limited number of base stations only, it is possible to cover the twenty-six base stations under investigation just using only eleven base stations. So that, the proposed solution resulted above **10%** energy saving for the whole twenty-six base stations with acceptable coverage and service quality to users.

The main drawback of literature #4 under Reference [13]:

- ✓ The quantitative amount of the energy gained using proposed techniques is not defined.
- ✓ The proposed energy saving solution can only be used for densely populated urban environments, where a group of base stations can be found and straightforward to make a sub-cluster and make a traffic handoff to the nearest base stations easily.
- ✓ It only considered off-peak (low traffic) hours and does not consider traffic situation of each carrier frequency (under-utilized carries) in the daytime.

1.5 Scopes and Limitations

1.5.1 Scopes of the Thesis

In this thesis, power assessment of the second-generation base stations (GSM & DCS) under real time will be studied and its relation with the daily traffic load will be modelled using auto-regression techniques implemented using MATLAB tool. Once the base station power consumption versus daily traffic load is obtained, by applying dynamic sleep mode on the frequency carriers or time slot level, the energy gained by applying this technique will be justified numerically.

1.5.2 Limitations of the Thesis

- ✓ Due to limitation of finding accurate daily power consumption data for each technology from Ethio-telecom, the thesis is limited to GSM network only and didn't consider the effect of dual band in one antenna due to unavailability of daily power log sheet data from Ethio-telecom.
- ✓ It is assumed that, only voice calls will be directed to GSM base station.
- ✓ Even though, more accurate decision could be reached if site measurement is conducted in different scenarios (based on number and type of base stations and traffic load), power measurement is made in only two (macro and micro) base stations in Addis Ababa due to operator fear that a system disturbance may appear during power measurement.

1.6 Contributions

This thesis is different from the literatures reviewed earlier due to it assess and optimize the energy consumption of the existing 2G wireless network base station of Ethio-telecom. Most importantly;

- Most importantly, it relates the energy consumption and real time user's traffic profile of GSM/DCS base stations under operation in Ethiopia, rather than academic energy assessment and solution schemes.
- Energy saving solutions & techniques in Remote Radio Unit (RRU) for GSM/DCS will be presented in detail.
- Give an idea on lowering operational expenditures by using proposed energy saving schemes.
- The metrics developed for power consumption versus traffic load will help Ethio-telecom to set long-term research goals for reducing energy based on the actual consumption.

1.7 Methodologies

The thesis pathways the following methodologies:

1.7.1 Literature Review: is conducted to expand a primary understanding of cellular network power consumption. The literature survey will cover existing articles, books, web resources and any other articles related to cellular network power consumption and their reduction strategies.

1.7.2 Study and Investigations: studying the cellular network architecture of Ethio-telecom, and particularly assessment of the energy consumption of the second-generation cellular network using the traffic volume fluctuations during day and night.

1.7.3 System Modelling: Determine the relationship between power consumption of micro and macro base stations and their respective daily traffic profile. The system model will be then interpreted further from the energy-efficiency point of view.

1.7.4 Simulation: analyse the impact of idle resources on base station power usage guarantying the required QoS.

1.7.5 Analysis and Interpretation of the Results: summarizing the opportunities and challenges of the operation of existing cellular network with proposed energy saving mechanism. And highlight techniques that need further study in the future.

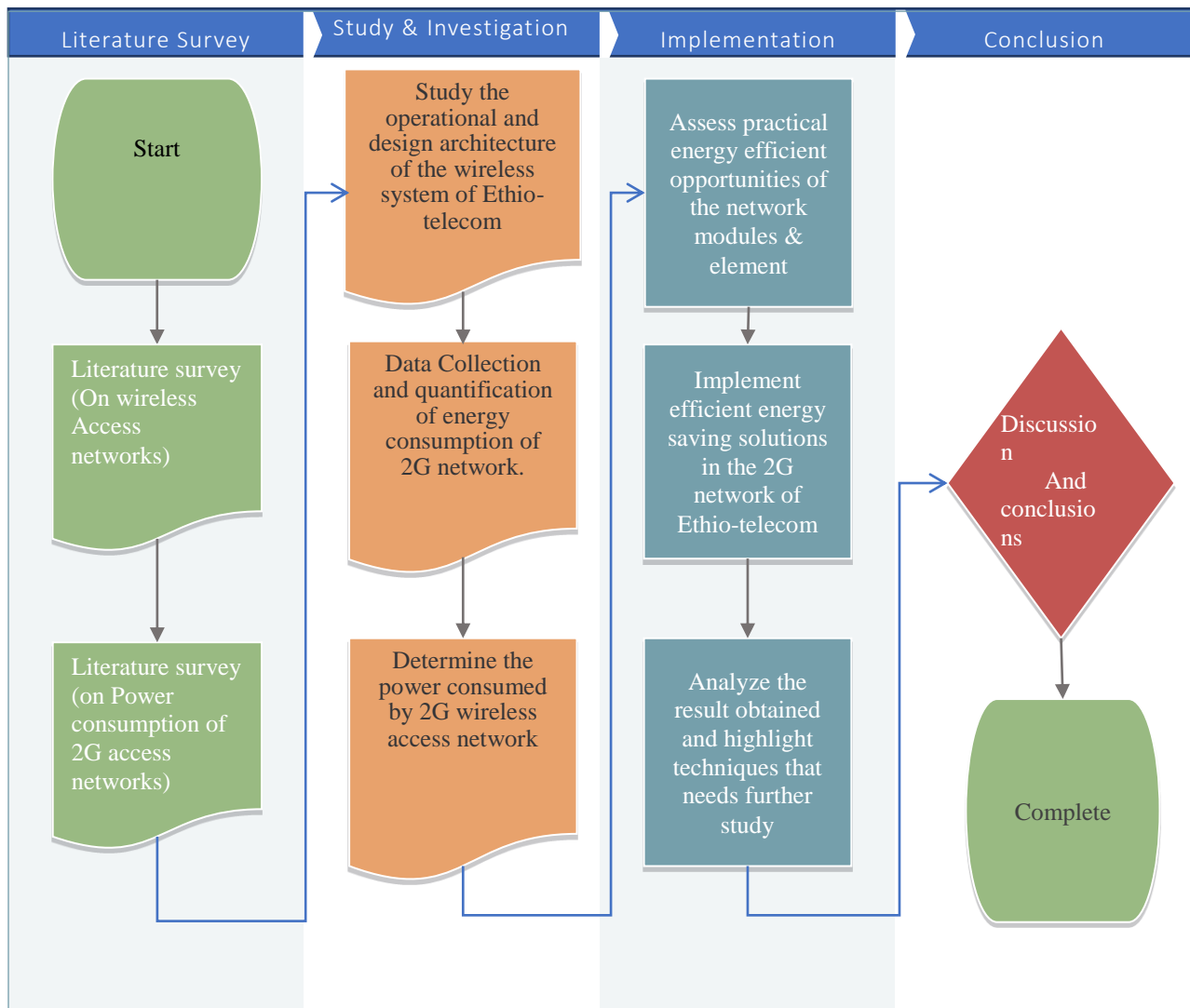


Figure 4: Work methodology flow chart

1.8 Thesis Layout

The thesis work in this document is organized to give a clear flow and understanding regarding the subject matter. This thesis is composed of seven chapters, including the present one. Chapter two presents a brief survey of GSM network and explain the components of GSM network. Chapter three presents the theoretical base station power consumption and their connections in micro and macro base stations. Chapter four explains different kinds of cellular power saving techniques which are more efficient and practicable in operational base stations. In chapter five and six data collection, power measurement and analysis of the power assessment and its optimization in the real traffic data will be presented in more detail with reasonable explanation. Finally, conclusion is given followed by points of recommendation on future works in chapter seven.

2. Brief Survey of Second-Generation Wireless Network

2.1 Background on Wireless Communication

These days, wireless communication system has become an essential part of various types of wireless communication devices, which permits user to communicate even from remote operated areas [14]. There are many devices used for wireless communication like mobiles phones, cordless telephones, Zigbee wireless technology (IEEE 802.15.4), General Packet Radio Service (GPS), Wi-Fi, satellite television and wireless computer components. Current wireless network under operation includes, second generation, third generation, fourth generation and fifth-generation systems, Bluetooth, Wi-Fi technologies and others.

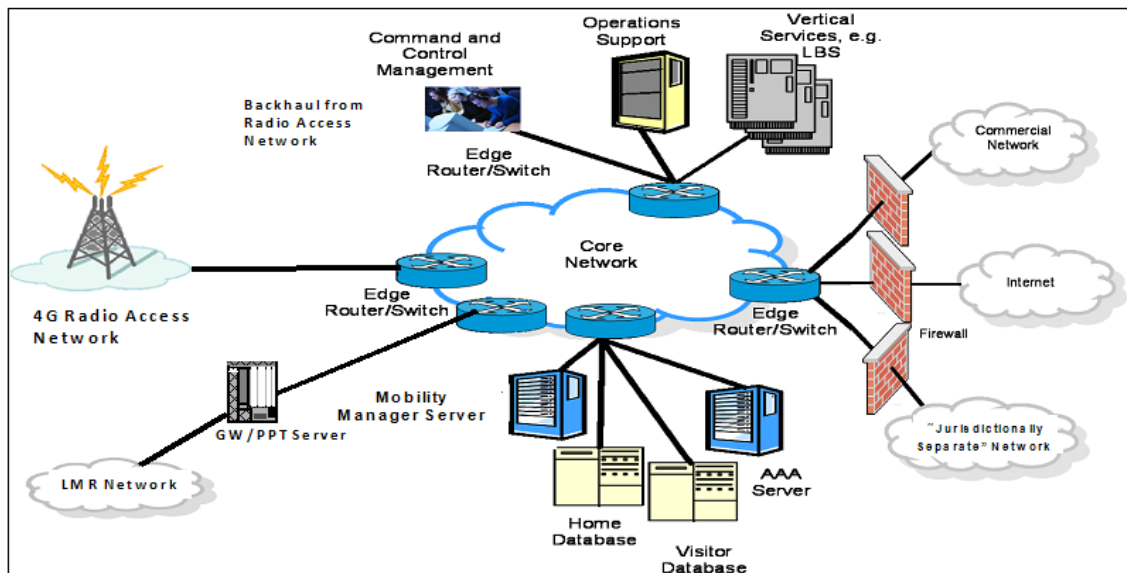


Figure 5: Wireless Communication system Architecture [15]

2.2 Cellular Network

A cellular network is a radio network distributed through cells where each cell includes a fixed location transceiver known as base station. These cells together provide radio coverage over larger geographical areas. A user equipment (UE), such as mobile phones, is therefore able to

communicate even if the object or the equipment is moving through cells during signal transmission.

Cellular networks give subscribers advanced features over alternative solutions, including increased capacity, small battery power usage, a larger geographical coverage area and reduced interference from other signals. The popular cellular technologies include the Global System for Mobile Communication (GSM), General Packet Radio Service (GPRS), Code Division Multiple Access (CDMA), Universal Mobile Telecommunications System (UMTS) and Long-Term Evolution (LTE) [16].

The above cellular network technologies support a hierarchical structure formed by the Base Transceiver Station (BTS), Mobile Switching Centre (MSC), Location Registers (LR) and Public Switched Telephone Network (PSTN). The BTS enables cellular devices to make direct communication with mobile phones [17]. The unit acts as a base station to route calls to the destination Base Station Controller (BSC). The BSC then coordinates with the mobile switching centre to interface with the landline-based PSTN, Visitor Location Register (VLR), and Home Location Register (HLR) to route the calls toward different base station controllers.

Cellular networks maintain information for tracking the location of their subscribers' mobile devices. In response, cellular devices are also equipped with the details of appropriate channels for signals from the cellular network systems. These channels are categorized into two fields;

- Strong Dedicated Control CHannel (SDCCH): Used to transmit digital information to a cellular mobile phone from the base station and vice versa.
- Strong Paging CHannel (PCCH): Used for tracking the mobile phone by Mobile Switching Center (MSC) when a call is routed to it.

The base station is responsible for monitoring the level of the signals when a call is made from a mobile phone. When the user moves away from the geographical coverage area of the base station, the signal level may fall down to their lowest value based on mobile phone sensitivity. This can cause a base station to make a request to the MSC to transfer the control to another base station that is receiving the strongest signals without notifying the subscriber; this phenomenon is called handover. Cellular networks often encounter environmental disruptions like a moving tower crane, overhead power cables, or by frequencies of other interrupting devices [18].

2.3 A Brief History of Cellular Generations [1G, 2G, 3G & 4G]

Mobile phone technology is continuously evolving, seemingly at an accelerating rate of innovation and enhancement of existing system. Examining the strides taken from 1G to 4G [18] & [19], the technologies have both created new usage patterns and learned from unexpected use cases. Here's a brief description of different mobile telephone network technologies applied in different cellular operators. Figure 6 shows the global nature of wireless subscribers of different technologies from 2005 to 2019.

Wireless Subscribers by Technology, 2005-2019

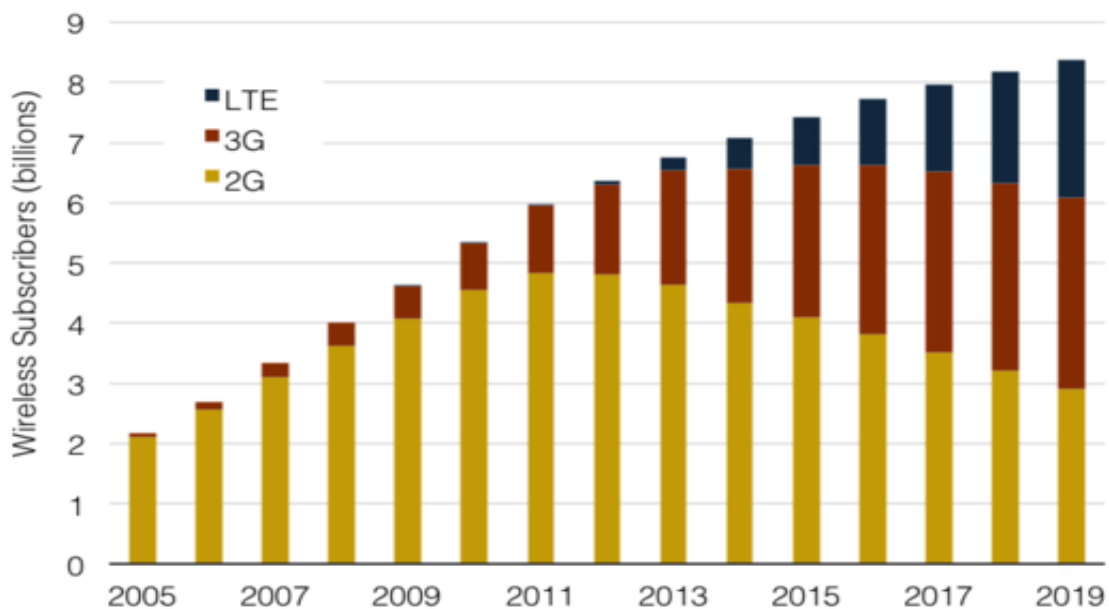


Figure 6: Global Wireless Subscribers by Technology, 2005-2019[20]

2.3.1 First Generation Cellular Network [1G]

The first-generation mobile communication which was introduced in 1980s was based on the analogue system [18]. The most popular analogue first generation (1G) system was advanced mobile phone system (AMPS) which was launched in the United States. Nordic Mobile Telephone (NMT), Total Access Communication System (TACS) and some other analogue systems were also introduced in 1980s across the Europe. All of the standards in 1G use frequency modulation techniques for voice signals. The spectrum within cell was divided into number of channels which was not efficient in terms of the available radio spectrum, and this placed a limitation on the

number of calls that could be made at any time. Analogue systems were based on circuit switching technology and offers only voice communication and no data communication were available in the beginning. After the introduction of 1G technology, mobile communications have undergone significant changes and experienced enormous growth and the number of subscribers reached nearly 20 million by 1990 worldwide.

2.3.1.1 Key features and facilities of 1G

- Based on analogue system and uses cordless telephone.
- Theoretically, it supports nearly data speed of up to 2.4kbps.

2.3.1.2 Basic disadvantages of 1G

- Mainly used for voice service only, there is no any data communication services at all.
- Low capacity and poor handoff.
- Less secure and poor voice link.

2.3.2 Second Generation Cellular Network [2G]

An improvement to 1G communication came into existence in the form of second generation (2G) technology which was introduced in late 1980's and was based on low-band digital data signalling [18]. The analogue technology in the first generation was replaced by digital access techniques such as TDMA (Time division multiple access) and CDMA (code division multiple access). The most popular 2G wireless technology is known as Global Systems for Mobile Communications (GSM). It uses TDMA technology to support multiple users. The TDMA breaks down data transmission, such as a phone conversation, into fragments and transmits each fragment in a short burst, assigning each fragment a time slot. With a cell phone, the caller does not detect this fragmentation. During development over more than 20 years, GSM technology has been continuously improved to offer better services to its users. CDMA uses spread spectrum technology to break up speech into small, digitized segments and encodes them to identify each call. The CDMA distinguishes between multiple transmissions carried concurrently on a single wireless signal. It carries the transmissions on that signal, freeing network room for the wireless carrier and providing interference-free calls for the user. The CDMA breaks down calls on a signal

by codes, whereas TDMA breaks them down by time. The result in both cases is an increased network capacity for the wireless carrier and a lack of interference for the caller.

2.3.2.1 Key features and facilities of 2G

- Improved Spectrum efficiency.
- Offers data rate of up to 64kbps.
- Better system capacity and network coverage.
- Roaming facility, voice and data services.
- Greater security.

2.3.2.2 Basic disadvantages of 2G

- It does not support high data rates.
- Weaker digital signal and unable to handle complex data.

2.3.3 Third Generation Mobile Communication [3G]

The third generation (3G) brought great transformation in mobile communication world. The 3G fulfils the specifications of International Mobile Telecommunications-2000 (IMT- 2000), the official International Telecommunication Union (ITU) which intended to provide wireless access to global telecommunication system [19]. To meet the IMT-2000 standards, a system is required to provide peak data rates of at least 200kbit/s. The most important IMT-2000 proposals were the Universal Mobile Telecommunications System (UMTS) to be considered as the successor to GSM. The UMTS uses the Wideband Code-Division Multiple Access (W-CDMA), Time Division- Code Division Multiple Access (TD-CDMA), or time division synchronous code division multiple access (TD-SCDMA) air interfaces. The WCDMA is the most popular air-interface technology for the UMTS. The main components of the UMTS system include BTS, RNC (Radio Network Controller), apart from WMSC (Wideband CDMA Mobile Switching Centre) and Serving GPRS Support Node (SGSN)/ gateway GPRS support node (GGSN). The W-CDMA gives additional advantages of high transfer rate, and increased system capacity and communication quality by statistical multiplexing. The WCDMA utilizes efficiently the radio spectrum, because the CDMA technique enables all base stations to use the same frequency. In the WCDMA system, the data is split into discrete packets, which are then transmitted using packet switching technology, and the packets are reassembled in the accurate sequence at the receiver end by using the code that is sent

with each packet. The UMTS systems are designed to provide a range of data rates, depending on the user's circumstances, providing up to 144 kbps for moving vehicles, up to 384 kbps for pedestrians and up to 2 Mbps for indoor or stationary users. The 3G basically focused on multimedia applications such as video calling, video conferencing for mobile phones, improved capacity, worldwide roaming service, low operational and service cost, better compatibility, and high-speed data.

2.3.3.1 Key features and facilities of 3G

- Faster data rates and supports multimedia applications such as video and photography.
- Value added services like Global Positioning System (GPS), video call and conferencing.
- High speed mobile internet access and increased capacity.

2.3.3.2 Basic disadvantages of 3G

- Requires 3G compatible handsets and the cost of upgrading to 3G devices is expensive.
- Power consumption is high and requires closer base stations which are expensive.

2.3.4 Fourth Generation Mobile Communication [4G]

The Fourth generation (4G) is an emerging technology in the field of communication. As the data requirements increased, efforts were made to improve the downlink and uplink throughput rates by employing higher modulation techniques [19]. Third Generation Partnership Project (3GPP) launched the Long-Term Evolution (LTE) project in November 2004 in order to ensure the continued competitiveness of the UMTS in the future. As LTE is considered as the evolution of universal mobile telephone system (UMTS), hence LTE's equivalent components are thus named evolved UMTS terrestrial radio access (EUTRA) and evolved UMTS terrestrial radio access network (EUTRAN). The basic architecture of LTE contains a separate IP connectivity layer for all the IP based services and Evolved Packet System (EPS) which handles the overall communication procedure.

LTE is completely an IP based system. Since, there are provisions in LTE for inter-operation with existing systems, there are also various paths available to connect to LTE. An operator with a GPRS network or a Non- 3GPP system can connect also to the LTE network easily, so that there is no compatibility issue, in which LTE is all-inclusive. By using Orthogonal Frequency Division

Multiple Access (OFDMA), LTE is able to provide download rates of 100Mbps for multi-antenna (2x2), multiple-input multiple output (MIMO) for the highest category terminals. For these terminals upload rate is about 50 Mbps. Moreover, it provides better mobility, efficient radio usage, high level of security, flexible spectrum utilization, reduced delay/latency, cost efficient deployment and various other advantages which make LTE more reliable and user friendly.

2.3.4.1 Key features and facilities of 4G

- ✓ High spectral efficiency and High voice quality.
- ✓ Easily access internet, streaming media, video calling etc.
- ✓ Very low latency and simple protocol architecture.
- ✓ Efficient multicast/broadcast.

2.3.4.2 Basic disadvantages of 4G

- ✓ Higher data prices for consumers.
- ✓ It is very expensive and hard to implement.
- ✓ Complex hardware and power usage are more.

2.4 Details on Global System for Mobile Communication /GSM/

A GSM network comprises of many functional components. Their functions and interfaces are explained here in detail. It can be broadly divided into different modules [21], these are:





2.4.1 Mobile Station (MS)

2.4.2 Base-Station Subsystem (BSS)

2.4.3 Network and Switching Subsystem (NSS)

2.4.4 Operation and Support Subsystem (OSS)

There are also some additional components of the GSM architecture which comprise of databases and messaging systems functions:

-  Home Location Register (HLR)
-  Visitor Location Register (VLR)
-  Equipment Identity Register (EIR)
-  Authentication Centre (AuC)

- ✚ SMS Serving Center (SMSSC)
- ✚ Gateway MSC (GMSC)
- ✚ Charge Back Centre (CBC)
- ✚ Transcoder and Adaptation Unit (TRAU)

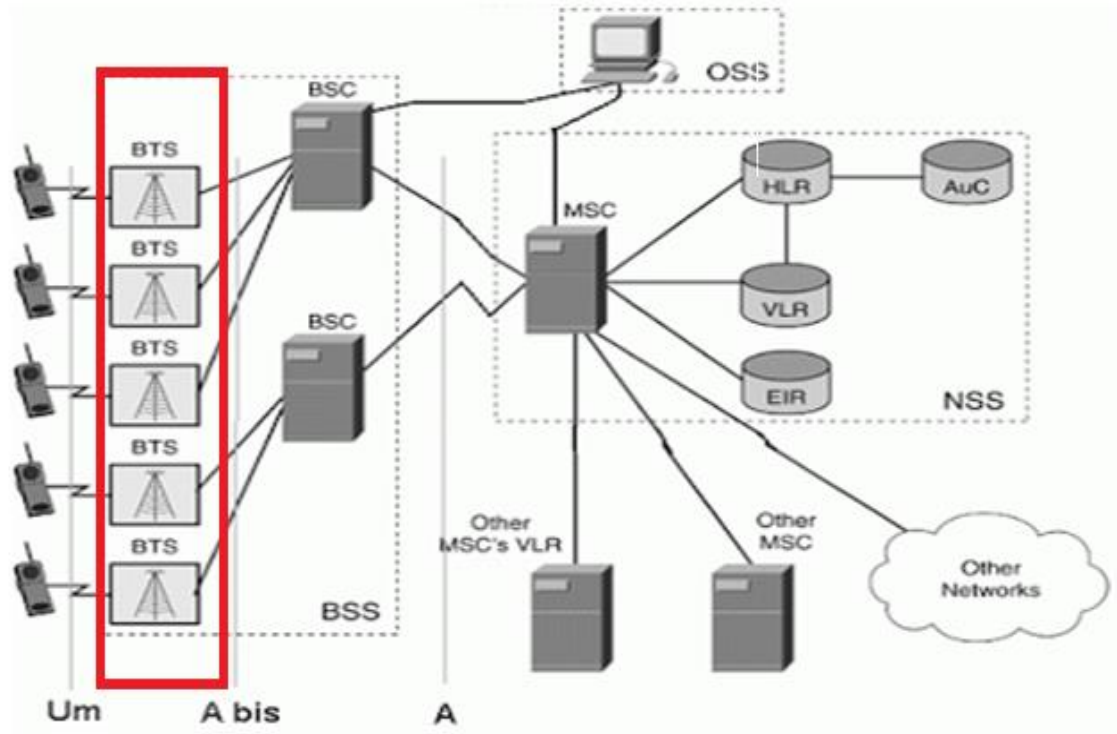


Figure 7: General architecture for GSM [21]

2.4.1 Mobile Station

The mobile station consists of a physical equipment, such as the radio transceiver, display and digital signal processors, and a smart card called the Subscriber Identity Module (SIM). The SIM provides personal mobility information, so that the user can have access to all subscribed services irrespective of both the location of the terminal and the use of a specific terminal [22].

The mobile equipment is uniquely identified by the International Mobile Equipment Identity (IMEI). The SIM card contains the International Mobile Subscriber Identity (IMSI), identifying the subscriber, a secret key for authentication, and another user information. The IMEI and the IMSI are independent, thereby providing personal mobility.

2.4.2 Base-Station Subsystem

The Base Station Subsystem is composed of two parts, the Base Transceiver Station and the Base Station Controller. These communicate across the specified Abis - interface, allowing (as in the rest of the system) operation between components made by different suppliers [22].

2.4.2.1 Base Station Transceivers

The Base Transceiver Station houses the radio transceivers that define a cell and handles the radio link protocols with the Mobile Station. In a large urban area, there will potentially be a large number of BTSs deployment [23]. The requirements for a BTS are reliability, portability, and minimum deployment cost.

From the general architecture, BTS is the last network element that process the signal and information prior to transmitting through antennas to the air interface. BTS is for GSM, CDMA, or any second-generation wireless technology and the same Node B does that for UMTS or any other third-generation wireless technology. Both BTS and Node B are physically located in geographically remote locations and provide the signal coverage to those geographical areas.

BTS consists of Baseband Processing Unit/BBU/, Base Station Control Function (BCF), Physical Transmission Interface (E1/T1 port or Ethernet port), TRX (Transceiver) and PA (Power Amplifier), Antenna and Feeder Systems, Combiners, Duplexer and Power Supply and Alarm Extension Unit. Operation and Maintenance (O&M) channel, signal and user data flow through Abis interface via E1/T1 or IP in the physical layer [Figure 8]. The data from BSC is processed at the baseband processing unit and the processed data is sent to RF (Radio Frequency) conversion or RF modulation at the TRX and Power Amplifier. Next, the RF modulated data stream is sent through combiners and duplexer to the Antenna system for EM (Electro Magnetic) wave conversion. Then, it is transmitted to the air interface after applying some more gain to the signal at the Antenna. The BCF is doing some control of the BTS and its other functions, but the main radio related control is performed at the BSC.

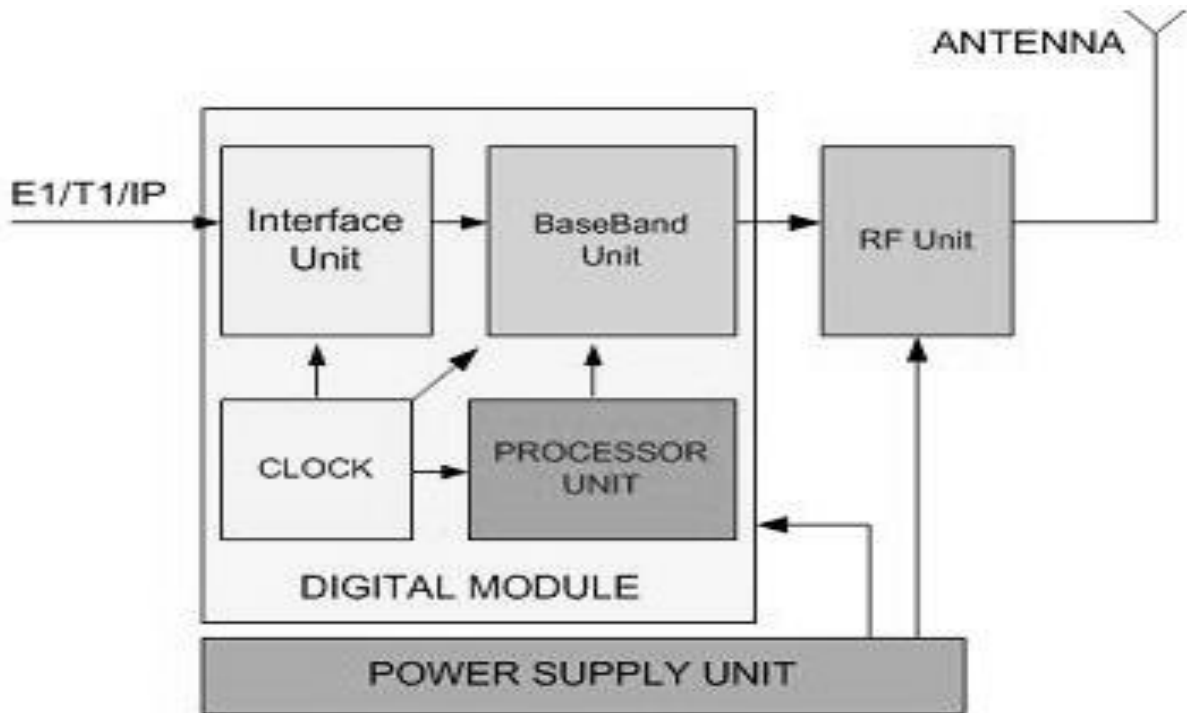


Figure 8: Inputs for BTS components [21]

2.4.2.2 Base Station Controller

The Base Station Controller manages the radio resources for one or more BTSs. It handles radio channel setup, frequency hopping, and handovers, as described below [24]. The BSC is the connection between the mobile and the Mobile service Switching Center (MSC). The BSC also translates the 13-kbps voice channel used over the radio link to the standard 64 kbps channel used by the Public Switched Telephone Network or ISDN.

2.4.2.3 Functions of BTSs and BSC in GSM

BTSs

- Encoding, encrypting, multiplexing, modulating, & feeding the RF signals to the antenna
- Trans-coding and rate adaptation
- Time and frequency synchronizing
- Voice through full or half-rate services
- Decoding, decrypting, and equalizing received signals

- Random access detection
- Timing advances
- Uplink channel measurements

BSC

- Control of frequency hopping
- Performing traffic concentration to reduce the number of lines from the MSC
- Providing an interface to the Operations and Maintenance Center for the BSS
- Reallocation of frequencies among BTSs
- Time and frequency synchronization
- Power management
- Radio Resource Management
- Handover Management

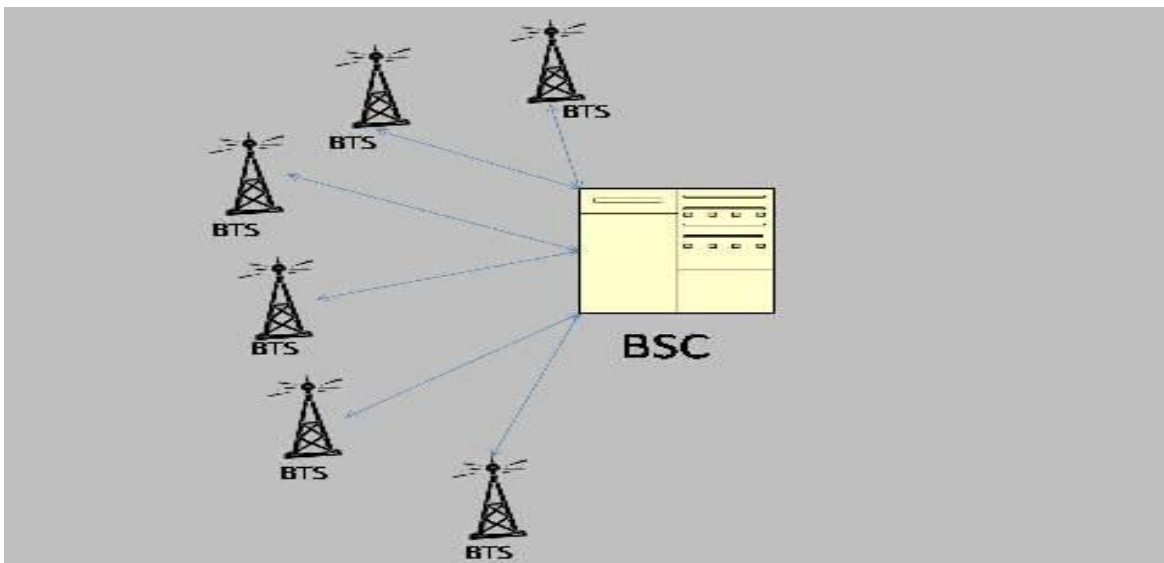


Figure 9: BSC components

2.4.3 Network and Switching Subsystem

The central component of the network subsystem is the MSC [24]. It acts like a normal switching node of the PSTN or ISDN, and in addition provides all the functionality needed to handle a mobile subscriber, such as registration, authentication, location updating, handovers, and call routing to a

roaming subscriber. These services are provided in conjunction with several functional entities, which together form the Network Subsystem. The MSC provides the connection to the public fixed network (PSTN or ISDN), and signalling between functional entities uses the ITUT Signalling System Number 7 (SS7), used in ISDN and widely used in current public networks.

The Home Location Register (HLR) and Visitor Location Register (VLR), together with the MSC, provide the call routing and (possibly international) roaming capabilities of GSM. The HLR contains all the administrative information of each subscriber registered in the corresponding GSM network, along with the current location of the mobile. The current location of the mobile is in the form of a Mobile Station Roaming Number (MSRN) which is a regular ISDN number used to route a call to the MSC where the mobile is currently located. There is logically one HLR per GSM network, although it may be implemented as a distributed database.

The Visitor Location Register contains selected administrative information from the HLR, necessary for call control and provision of the subscribed services, for each mobile currently located in the geographical area controlled by the VLR. Although each functional entity can be implemented as an independent unit, most manufacturers of switching equipment implement one VLR together with one MSC, so that the geographical area controlled by the MSC corresponds to that controlled by the VLR, simplifying the signaling required. Note that the MSC contains no information about particular mobile stations - this information is stored in the location registers.

The other two registers are used for authentication and security purposes. The Equipment Identity Register (EIR) is a database that contains a list of all valid mobile equipment on the network, where each mobile station is identified by its International Mobile Equipment Identity (IMEI). An IMEI is marked as invalid if it has been reported stolen or is not type approved. The Authentication centre is a protected database that stores a copy of the secret key stored in each subscriber's SIM card, which is used for authentication and ciphering of the radio channel.

2.4.4 Operation and Support Subsystem

The operations and maintenance centre (OMC) are connected to all equipment in the switching system and to the BSC [24]. The implementation of OMC is called the operation and support system (OSS).

Here are some of the OMC functions:

- Administration and commercial operation (subscription, end terminals, charging and statistics).
- Security Management.
- Network configuration, Operation and Performance Management.
- Maintenance Tasks.

The OSS is the functional entity from which the network operator monitors and controls the system. The purpose of OSS is to offer the customer cost-effective support for centralized, regional and local operational and maintenance activities that are required for a GSM network. An important function of OSS is to provide a network overview and support the maintenance activities of different operation and maintenance organizations.

2.5 GSM Radio Transmission Aspects

For the GSM-900/1800MHz systems, two frequency bands for each system have been made available as show below [25];

- ✚ 890 - 915 MHz for the GSM 900 uplink (direction MS to BS)
- ✚ 935 - 960 MHz for the GSM 900 downlink (direction BS to MS)
- ✚ 1710-1785 MHz for the GSM/DCS1800 uplink (direction MS to BS)
- ✚ 1805-1880 MHz for the GSM/DCS1800 downlink (direction BS to MS)

Using Frequency Division Multiple Access (FDMA), the 25 MHz bands in each GSM system are divided further into 124 pairs of frequency duplex channels with 200 kHz carrier spacing. Since it is not possible for a same cell to use two adjacent channels, the channel spacing can be said to be 200 kHz interleaved. Each RF channel is subdivided into eight different timeslots, i.e., 0 to 7, by using a Time Division Multiple Access (TDMA) techniques. A set of these eight timeslots is referred as a TDMA frame. Each frame lasts 4.615ms. The physical channels are further mapped to various logical channels carrying user traffic and control information between the MS and the BTS. By employing eight time slots, each channel transmits the digitized speech in a series of short bursts: a GSM terminal is only ever transmitting for one eighth of the time [26].

The GSM system distinguishes between traffic channels (used for user data) and control channels (reserved for network management messages). Having the Traffic Channel/Full-Rate Speech (TCH/FS) used to carry speech at 13 kbps. TCHs for the uplink and downlink are separated in time by 3 burst periods, so that the mobile does not have to transmit and receive simultaneously. TCHs are defined using a 26-frame multi-frame (i.e. a group of 26 TDMA frames). The length of a 26-frame multi-frame is 120ms, which is how the length of a burst period is defined (120ms / 26 frames / 8 burst periods per frame). Out of the 26 frames, 24 are used for traffic, one is used for the Slow Associated Control Channel (SACCH) and one is currently unused (see Figure below).

The transmission bit rate is 271 kb/s (bit period 3.79 microseconds). To allow for time alignment errors, time dispersion etc, the data burst is slightly shorter than the time slot (148 out of the 156.25-bit periods available within a time slot).

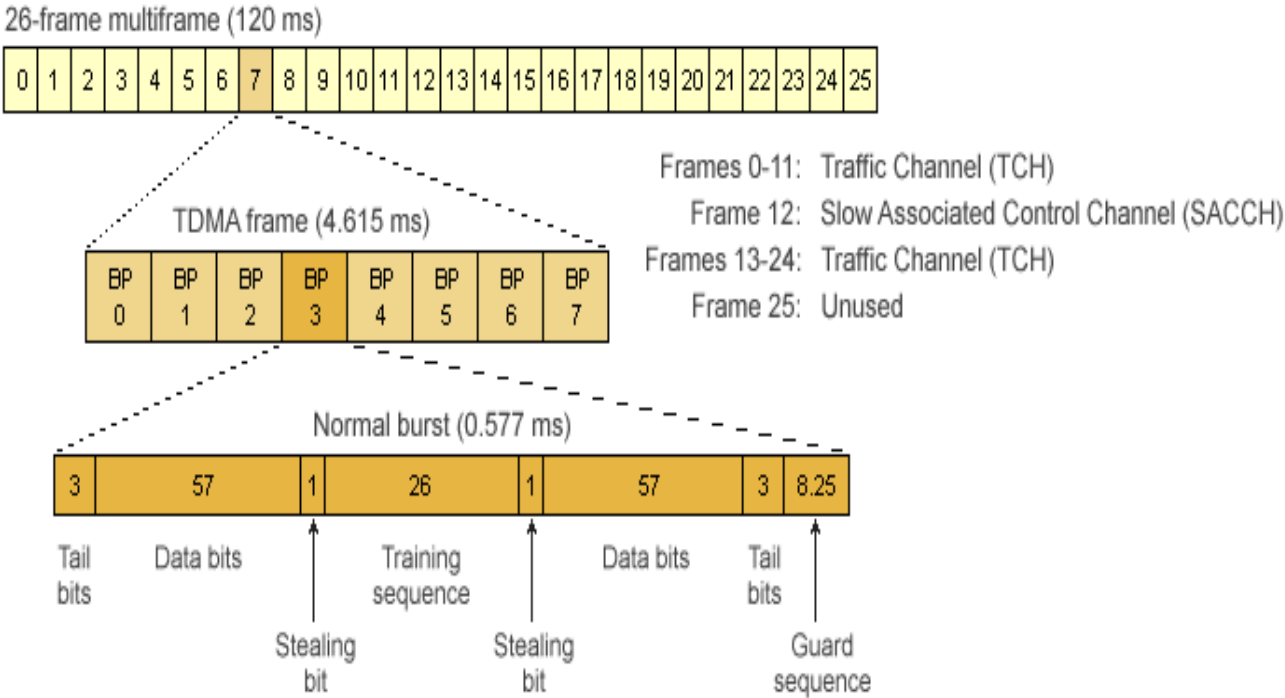


Figure 10: TDMA frame structure [27]

There are two types of channel, physical and logical Channels in TDMA frame structure. 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.

There are three types of 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 signalling 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.

2.6 GSM Sequence of Operations

In GSM systems, BBU communicates with the BSC via the *Abis interface*, while RRU communicates with mobile terminals through the *Um interface*. According to the current second-generation network architecture of Ethio-telecom, remote radio over optical fibre system is used: in which, the BBU include the baseband processing board, master, transmission equipment, monitoring units, and clock component modules. And the RRU includes the transceiver, and power amplifier component modules. The BBU is installed indoors in the control room, while the RRU is installed outdoor near antennas to minimize the feeder losses.

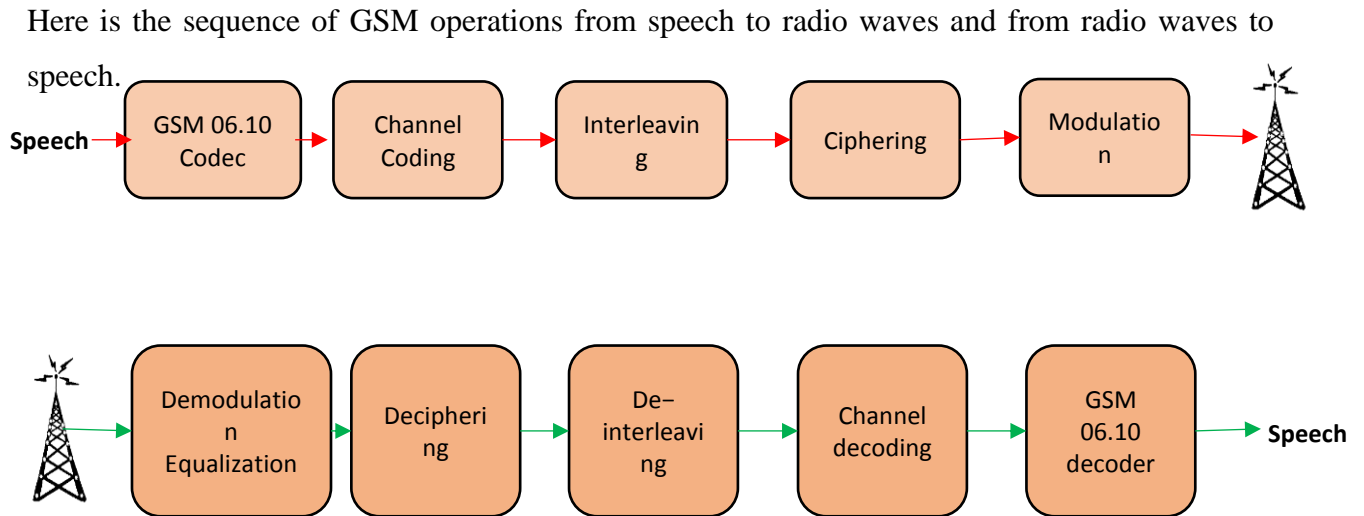


Figure 11: GSM sequence operations from speech to radio waves and vice versa [27]

2.6.1 GSM 06.10 codec

The full rate speech codec in GSM is described as Regular Pulse Excitation with Long Term Prediction (GSM 06.10 RPE-LTP). Basically, the encoder divides the speech into short-term predictable parts, long-term predictable part and the remaining residual pulse. Then, it encodes that pulse and parameters for the two predictors. The decoder reconstructs the speech by passing the residual pulse burst through the long-term prediction filter, and then through the short-term predictor.

2.6.2 The GSM Channel Coding/De-coding

Channel coding introduces redundancy into the data flow in order to allow the detection or even the correction of bit errors introduced during the transmission.

2.6.3 Interleaving / De-interleaving

Interleaving is meant to decorrelate the relative positions of the bits respectively in the code words and in the modulated radio bursts. The aim of the interleaving algorithm is to avoid the risk of losing consecutive data bits. GSM blocks of full rate speech are interleaved on 8 bursts: the 456 bits of one block are split into 8 bursts in sub-blocks of 57 bits each. A sub-block is defined as either the odd- or the even-numbered bits of the coded data within one burst. Each sub-block of 57 bit is carried by a different burst and in a different TDMA frame.

De-interleaving consists in performing the reverse operation. The major drawback of interleaving is the corresponding delay: transmission time from the first burst to the last one in a block is equal to 8 TDMA frames (i.e. about 37ms).

2.6.4 Cipherring / Decipherring

A protection has been introduced in GSM by means of transmission cipherring. The cipherring method does not depend on the type of data to be transmitted (speech, user data or signaling) but is only applied to normal bursts. Decipherring follows exactly the same operation.

2.6.5 Modulation / Demodulation

This is an interface between the channel encoder and the communication channel. It maps the coded information sequence into signal waveforms that can be transmitted over the channel. Consider the coded sequence is to be transmitted one bit at a time at some uniform rate R bits/s. Digital demodulator: The demodulator processes the channel-corrupted transmitted waveforms and reduces them to a sequence of numbers (digits) that represent estimates of the transmitted coded data symbols (binary or M-ary).

3. Theoretical BS Power Consumption & Their Connections

3.1 Theoretical Power Consumption

In order to find the theoretical power consumption of a base station, let us consider a circular covered area by a base station, which is called a cell. Each cell is further divided in to a number of equivalent sectors. Each sector is covered by a sector antenna, which is a directional antenna with a sector-shaped radiation pattern. Some equipment is used commonly for each sector such as the digital signal processing (responsible for system processing and coding), the power amplifier, the transceiver (responsible for receiving and sending of signals to the mobile stations), and the rectifier, which are the main power consuming components. The power consumption of these components should be multiplied with the number of installed sectors, n_{sector} when determining the power consumption of the specific base station.

The power consumption of the rectifier depends on the internal and ambient temperature of the base station cabinet [28]. To model the power consumption of the power amplifier, the efficiency, η of the power amplifier is first defined as the ratio of the RF output power $P_{out/amp}$ (in Watt) to the electrical input power $P_{el/amp}$ of the power amplifier [29]. The $P_{out/amp}$ corresponds to the input power P_{TX} of a single sector antenna resulting in the following equation for the amplifier efficiency η ;

$$\eta = \frac{P_{TX}}{P_{el/amp}} \quad (3.1)$$

Based on equation 3.1 we can determine the power consumption $P_{el/amp}$ of the power amplifier as follows:

$$P_{el/amp} = \frac{P_{TX}}{\eta} \quad (3.2)$$

Once the power consumption of the different components of the base station is known, the power consumption P_{el} of the entire base station can be easily determined using the above formulas as follows:

$$P_{el} = n_{sector} * (nTx * (P_{el/amp} + P_{el/trans}) + P_{el/proc} + P_{el/rect}) + P_{el/micro} + P_{el/aircond} \quad (3.3)$$

With n_{sector} the number of sectors in the cell, $P_{el/amp}$, $P_{el/trans}$, $P_{el/proc}$, $P_{el/rect}$, $P_{el/micro}$ and $P_{el/aircond}$ are the power consumptions of the power amplifier, the transceiver, the digital signal processing, the rectifier, the microwave link (if present) and the air conditioning, respectively.

In case multiple-input-multiple-output (MIMO) is used, the base station needs the same number of power amplifiers and transceivers based on the number of transmitting antennas. In order to take the power consumption of this extra equipment into account, the power consumption of the power amplifier and the transceiver is multiplied by the number nTx of transmitting antennas for one sector. MIMO has also an influence on the digital signal processing which is, compared to the transceiver, is negligible [30].

3.2 Energy Consumption of BS Components

3.2.1 Rectifier:

The rectifier converts the signal from AC to DC. The efficiency of the rectifier is mostly about 92% for a conventional rectifier and is about 97% for the case of latest products in the market, for amperage loads between 40-90% [31]. For lower amperage loads, there are controller schemes that monitor the amperage load in order to turn off (or standby) a subset of amplifiers, so the average amperage load will increase among the rest of the amplifiers, achieving maximal efficiency [32].

The power consumption of the rectifier relates with its output power P_{Rout} and its efficiency (η_R).

Which is given by the following formula:

$$P_R = \frac{P_{Rout} * (1 - \eta_R)}{\eta_R} \quad (3.4)$$

3.2.2 Baseband Digital Signal Processing Circuit

The Baseband Digital Signal Processing Circuit is considered as having a constant power consumption for power analysis purpose [33]. Its approximate power consumption is $P_{SP} = 150$ W for conventional BSs and $P_{SP} = 110$ W for latest types of BSs.

3.2.3 Power Amplifier (PA)

In radio-frequency (RF) PAs, such as the one used in cellular BSs and broadcast transmitters, a very important parameter is the efficiency which is given by;

$$\eta_{PA} = \frac{P_{PAout}}{P_{PAin}} \quad (3.5)$$

Traditional PAs have an efficiency of about 15% [33]. The remaining or excessive energy is transformed into heat. Specialist design techniques are used to improve efficiency all the time, such as Digital Pre-Distortion (DPD), Doherty and Envelope Tracking (ET) which can lift the efficiency up to 60%. The PA could be in four possible states: switching state, transmitting state, turned off state and idle state. During switching state, the PA commutes from active to inactive and vice versa.

3.2.4 Feeder

The feeder is the cabling system connecting the base band unit to the antenna. In conventional BSs, antennas and equipment are a few meters apart, and connected through a coaxial cable. The signal attenuation of such a feeder is typically about 3 dB, which is half of the transmitted power will be dissipated. Nowadays, Remote Radio Heads (RRH) technology is used instead [34]: where a very small cabinet holds the BS radio frequency devices very close to antennas, and then it is connected to the (possibly remotely) baseband signal processing equipment by means of optical fibers. Its efficiency can be evaluated as:

$$\eta_F = \frac{P_{out}}{P_{PAout}} \quad (3.6)$$

3.2.5 Cooling System

In electronic equipment and circuits, power dissipation is generally a stated condition. Electronics also have specific margins of operative temperature and in order to keep the temperature of most components of the BS within specified design limits we need to cool the sites. Air conditioners (AC) are often the choice for radio sites, especially for indoor sites.

3.3 Parameter to Quantify the Power Consumption and Efficiency

If multiple technologies are compared among each other, it is very difficult to determine which one is the most energy efficient: one technology could have higher power consumption but also a higher range, another one could have a smaller range but also a lower power consumption etc. Therefore, the power consumption per covered area PC_{area} (in W/m²) is defined to quantify the power consumption and efficiency for different technologies:

$$PC_{area} = \frac{P_{el}}{\pi R^2} \quad (3.7)$$

Where, P_{el} the power consumption of the entire base station (in Watt) and R the covered range (in meter or radius of the coverage area). This parameter allows us to compare the energy efficiency of different wireless technologies and to determine which one is the most energy-efficient. The lower PC_{area} , the more energy-efficient the considered technology is. The normalization to the area allows us to make a fair comparison between the different technologies in terms of energy efficiency. As the area of the cells have different shapes, for this analysis it is assumed that the cells are circular [35].

3.4 Base Stations Power Supply Scenarios

As per the information received from Ethio-Telecom Engineering Office, there are five power scenarios under operation [36] which are implemented in Ethio-telecom cellular network. The detail connection and analysis are given below;

3.4.1 Scenario 1: Sites connected to grid only.

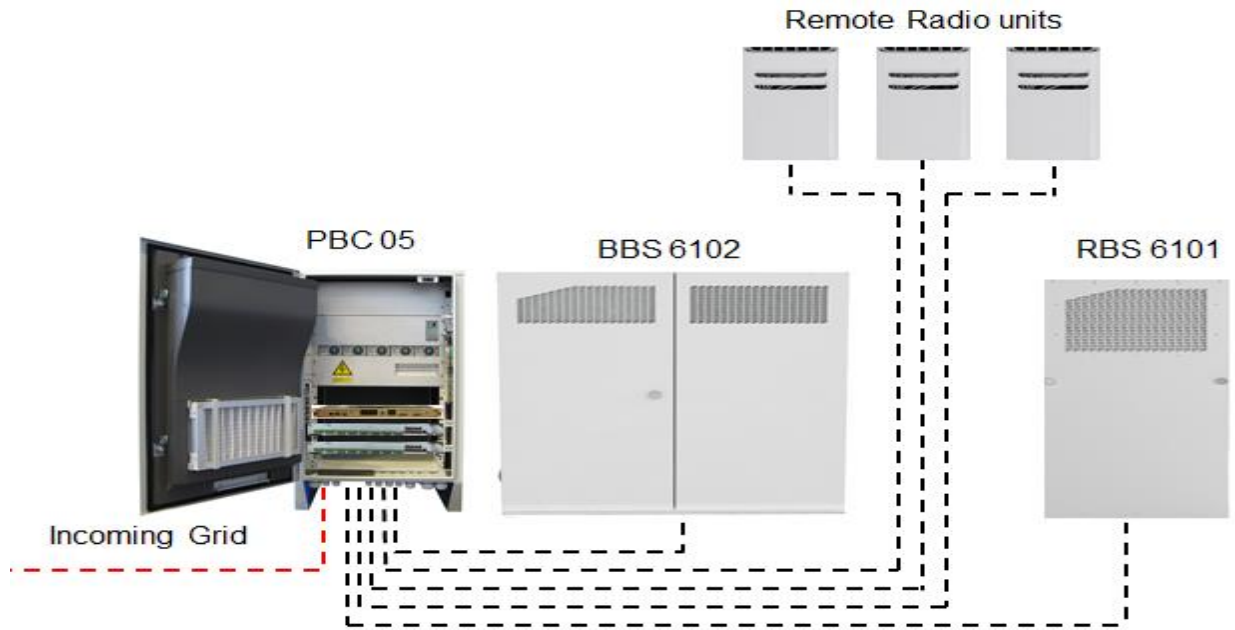


Figure 12: Schematic drawing grid only sites [36]

3.4.2 Scenario 2: Sites connected to the grid and a backup diesel generator.

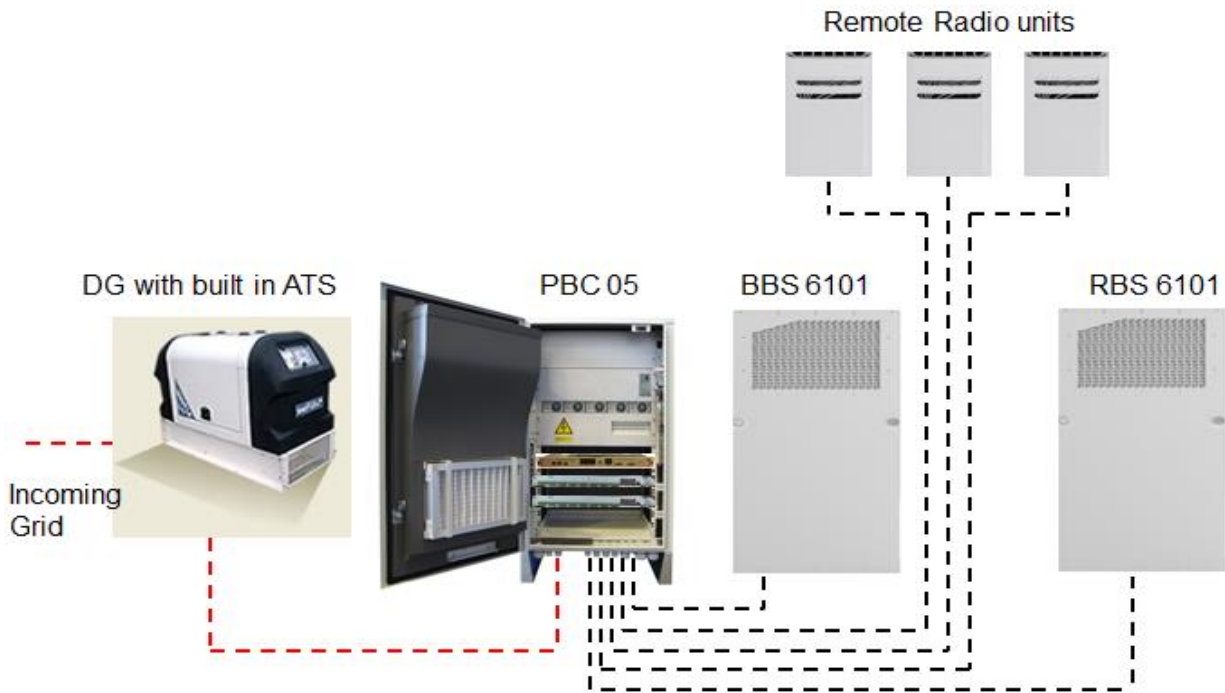


Figure 13: Schematic drawing grid with backup diesel generator sites

3.4.3 Scenario 3: Sites running on standalone/pure solar solution.

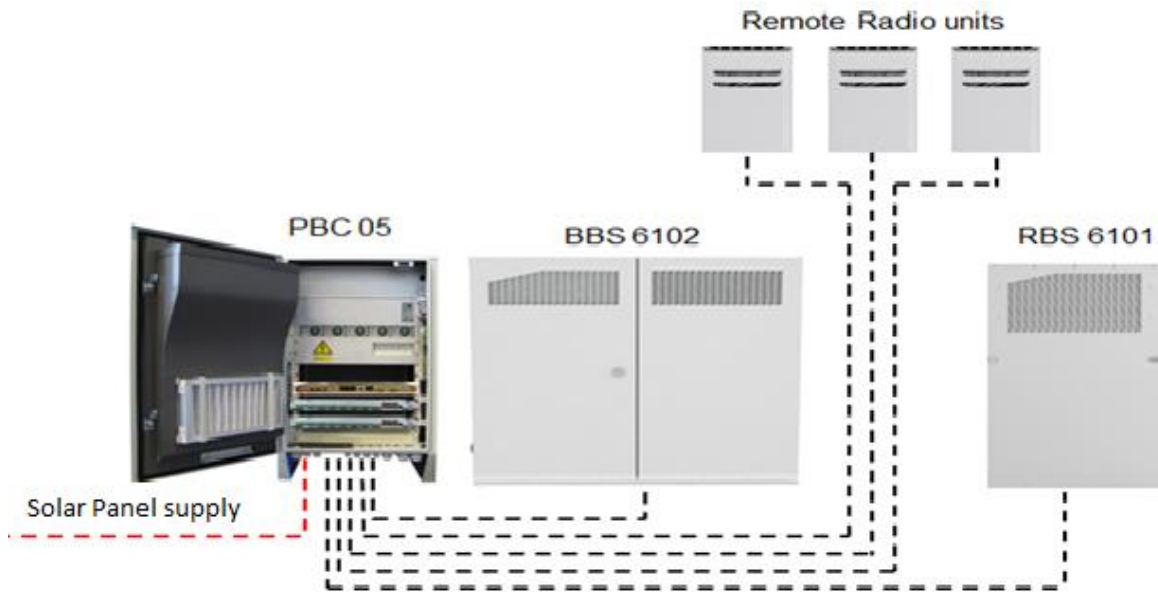


Figure 14: Schematic drawing for pure solar solution sites

3.4.4 Scenario 4: Sites running on solar solution with backup diesel generator.

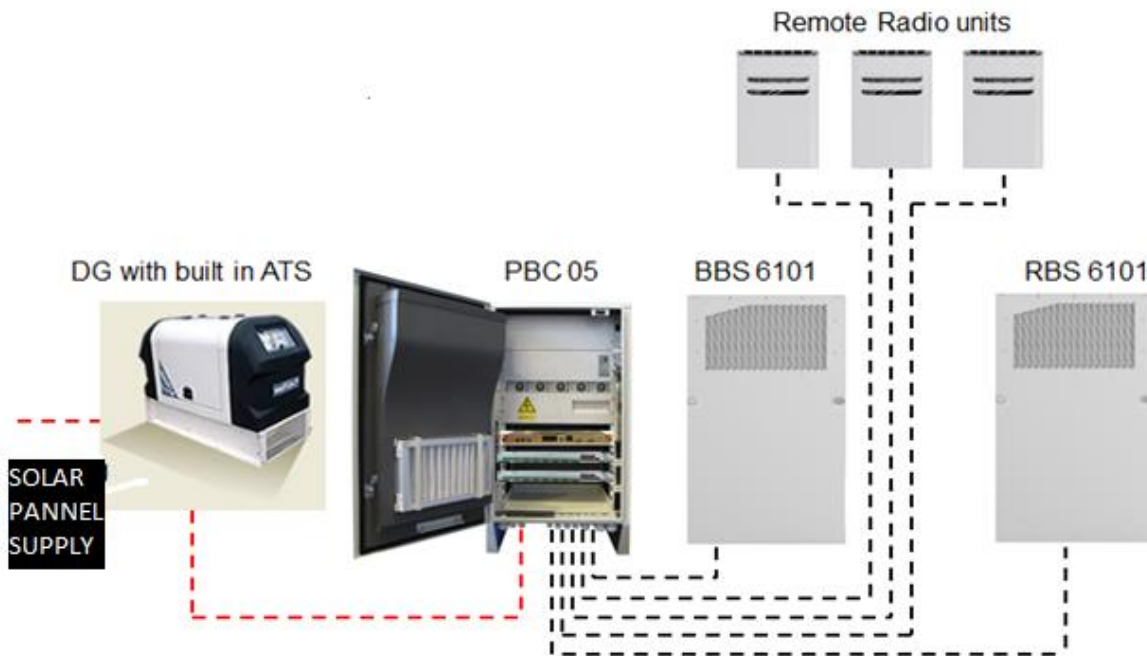


Figure 15: Schematic drawing for pure solar solution with diesel generator sites

3.4.5 Scenario 5: Sites running on hybrid operation between batteries & diesel generator.

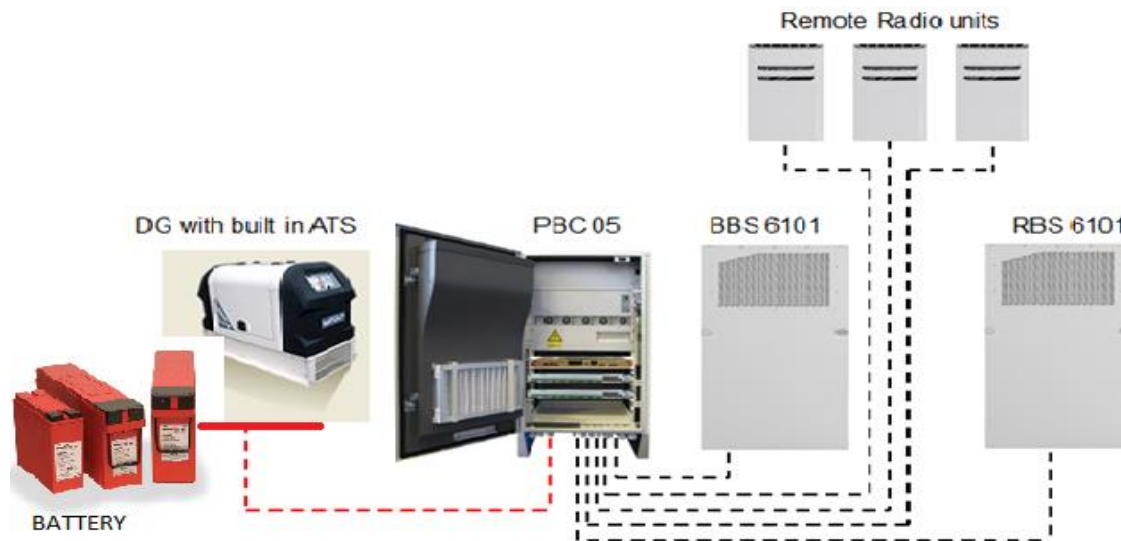


Figure 16: Schematic drawing for batteries and diesel generator solution sites

3.5 Capital and Operational Expenditures of Telecom Operator

In the first five year of mobile network deployment the capital expenditure (CAPEX) is very high, and after these periods the operational expenditure (OPEX) come to visible for the next fifteen years. Now, the mobile communications industry is undergoing a move from reducing CAPEX to managing OPEX in terms of reducing operational costs and enhancing operation efficiencies by redefining a new business mode, mainly be an appropriate measurement of the energy consumption and their optimization.

Cellular networks in particular estimated to be responsible for 0.5% of worldwide electrical energy consumption [42]. As most of the energy produced today is still generated from non-renewable energy sources (only a smaller share for renewable energy source), networks are correspondingly responsible for a significant amount of CO₂ emissions.

Network energy consumption is an important cost for operators. In mature markets, energy costs account for 10-15% of the total network operating expenses (OPEX) and can reach up to 50% in developing markets with a high number of off-grid sites, where only a poor-quality electricity grid is available [43].

The trend is upwards. In recent years, the largest network operators reported a growth of 15 - 35% in their network energy consumption [44], the main reason being growing demand for coverage and capacity.

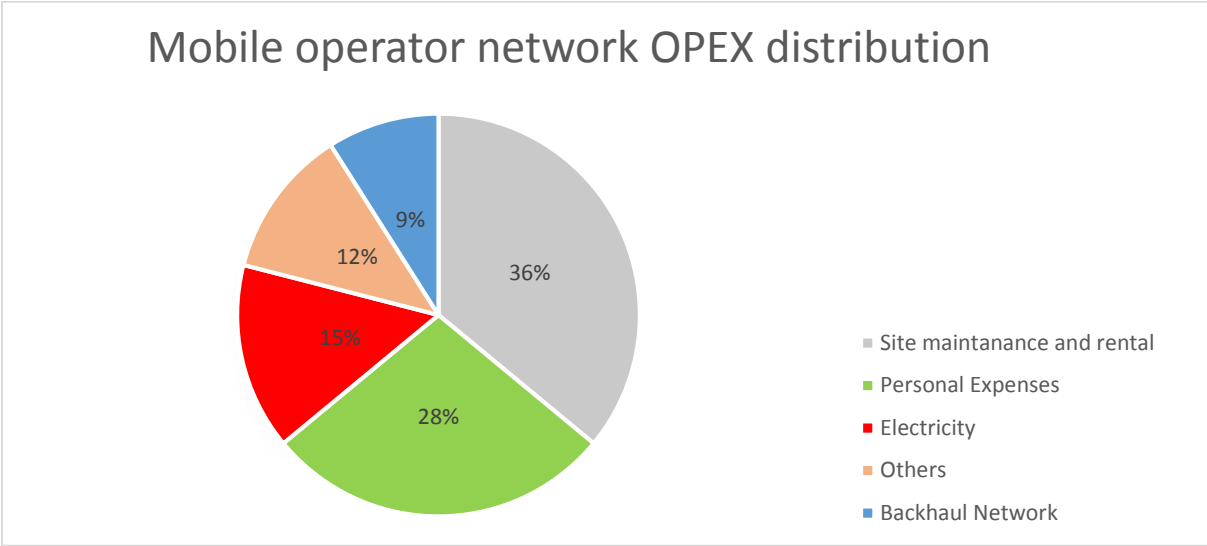


Figure 17: mobile operator network OPEX distribution [45]

With this increase of traffic in the network, flattening the total network energy consumption, or even reducing it, will be a major objective for operators over the next decade in order to minimize adverse environmental impacts, meet emission targets, limit energy costs and stay profitable. The profit means in the thesis document; due to optimizing the network’s energy consumption, the operator will save a significant amount of expenses from monthly electricity bill, so that this money will be used for further investment in network’s capacity and quality improvement.

The other advantage is due to energy saving of the base station, the carbon emission of the cellular network will be reduced and the environment will be conserved. In multi telecom operator’s situation, this will create a competitive advantage for subscription, which come along a commercial advantage.

4. Power Saving Strategies in a Base Station

4.1 Introduction

Generally, the power consumption of BTS equipment and air-conditioning equipment takes more than 90% of the power consumption of the radio access network [37]. In addition to paying a high cost for power to have a network with a large capacity, wide coverage, and good performance, the operator needs also to conform to the social responsibility of energy saving, emission reduction, and environment protection to evolve with the Government policies to eradicate impacts due to a climate change.

By introducing the solution of intelligent power consumption decrease to the base station sub-system equipment and adopting the advanced power control algorithm, the vendor can help the operator to solve this problem. Intelligent power consumption decrease refers to the solution of decreasing power consumption of the BTS or even a coverage area through hardware or software without deteriorating network performance and BTS hardware performance. Therefore, intelligent power consumption decrease aims to decrease the BTS power consumption of a base station.

The BTS power consumption includes cabinet power consumption and TRX power consumption [38];

- Cabinet power consumption

The cabinet power consumption, a small part of the BTS power consumption, which is consumed by the TRX supporting system and basic site control and transmission equipment.

- TRX power consumption

The TRX power consumption constitutes a primary part of the BTS power consumption. The power consumption of TRXs is related to factors such as number of configured TRXs, traffic volume, output power, and working mode. The TRX power consumption includes:

- ✚ Dynamic power consumption of the power amplifier: power consumed by the power amplifier for carrying services.

- ✦ Static power consumption of the power amplifier: power consumed by the static current that ensures the normal operation of the power amplifier. Dynamic power consumption of the power amplifier and static power consumption of the power amplifier constitute the power consumption of the power amplifier.
- ✦ Baseband power consumption: power consumed by Digital Signal Processor (DSP), Field Programmable Gate Array (FPGA), and Central Processing Unit (CPU).
- ✦ Power consumption of the Radio Frequency (RF) signal: power consumed by the digital intermediate frequency (IF) circuit, Digital-to-Analog/Analog-to-Digital (DA/AD) circuit, and low-power RF signal circuit.

4.2 Intelligent Power Consumption Decreasing Mechanism

Using intelligent power consumption decreasing mechanism, power consumption of the power amplifier, baseband unit, and power consumption of the RF signal can be decreased. Therefore, decreasing the power consumption of base station components will also decrease BTS power consumption as a general.

Intelligent power consumption decrease can save energy, reduce emission, and save capital expenditure (CAPEX) and operational expenditure (OPEX) by decreasing the BTS power consumption. In the case of the BTSs with storage battery and other power backups, intelligent power consumption decrease can prolong the serving time of the storage battery and shorten the serving time of the generator. Intelligent power consumption decrease can also prolong the serving time of cells and reduce the number of storage batteries, saving CAPEX/OPEX.

The technologies that are involved in the intelligent power consumption decrease are [38]:

- 4.2.1 TRX power amplifier intelligent shutdown,
- 4.2.2 TRX power amplifier intelligent shutdown on the timeslot level,
- 4.2.3 Intelligent combiner bypass,
- 4.2.4 Channel allocation algorithms concerning power consumption decrease,
- 4.2.5 Discontinuous transmission (DTX),
- 4.2.6 Intelligent adjustment of TRX working voltage,

4.2.1 TRX Power Amplifier Intelligent Shutdown

The TRX power consumption is mainly generated by the power amplifier. When there is no traffic, only static power consumption of the power amplifier is generated, that is, the dynamic power consumption is zero. When there is traffic, dynamic power consumption is generated. The dynamic power consumption increases with the TRX output power.

Generally, a cell is not always in the busy state. When the TRX Power Amplifier Intelligent Shutdown feature is enabled in the BSC, only some TRXs carrying the traffic in a cell are turned ON, and the power amplifiers of the TRXs not carrying traffic are shut down. That is, the power amplifiers of the TRXs whose dynamic power consumption is zero are shut down. Therefore, the BTS power consumption is reduced.

The TRX Power Amplifier Intelligent Shutdown feature has no adverse effect on network quality. If the mobile station is assigned with channels of TRXs whose power amplifiers are shut down, however, the MS takes a longer time to access the network, because switching on the power amplifiers of the TRXs is time consuming.

To minimize the impact of TRX power amplifier intelligent shutdown on the network quality, the parameters can be specified at the BSC. The traffic volume on weekends and holidays are higher than on weekdays, and the busy hours in weekends and holidays are more than weekdays. We can set at the BSC so that the BSC disables the TRX Power Amplifier Intelligent Shutdown feature from the specified date. You can also set an enabling parameter, so that the TRX Power Amplifier Intelligent Shutdown feature is enabled again from the specified date.

However, the TRX whose power amplifiers can be shut down must meet the following conditions:

- The TRX should work normally.
- The maximum operation interval of the TRX is greater than ***Protect Time TRX Power On***.
- After the TRX is shut down, an idle standalone dedicated control channel (SDCCH) is still available for use in this cell.

- There should not be any packet traffic channel on the TRX.
- No channel under conversion shall exist on the TRX.
- The TRX shall not carry the broadcast control channel (BCCH).

If the TRX Power Amplifier Intelligent Shutdown feature is enabled in a cell, the BSC predicts the number of channels that the cell requires in the next one minute based on the history channel usage when the TRX Power Amplifier Intelligent Shutdown feature is not prohibited. If the number of channels that the cell requires is smaller than that of the remaining channels after a TRX is shut down, and the number of the remaining channels is greater than the value of ***Reserved Idle Channel***, the BSC attempts to shut down a TRX having no PDCH and whose channel usage is the lowest.

- If no channels carried by the TRX are seized, the BSC shuts down the TRX.
- If TCHs carried by the TRX are seized, the BSC hands over the services on the TRX to other TRXs, and then shuts down the TRX.
- If SDCCHs carried by the TRX are seized, the BSC does not shut down the TRX until the SDCCHs are released.

The BSC preferentially allocates channels carried on operating TRXs to the MS. If there is no channel available carried by the operating TRX in the cell, the BSC allocates channels carried by the TRX that is shut down to the MS. The BSC notifies the BTS to switch on the power amplifier of the TRX, and then activates the channels carried on the TRX and allocates the channels carried by the TRX to the MS. To speed up channel assignment, the parameter ***Reserved Idle Channel*** is configured. When the number of idle TCHs is smaller than the value of this parameter, the BSC notifies the BTS to switch ON a TRX that is shut down.

Baseband power consumption, RF signal power consumption, static TRX power consumption, and dynamic TRX power consumption constitute the power consumption of the TRX board. When the power amplifiers on a TRX board are all shut down, the BTS can shut down the low-power RF signal circuit of the RF signals to further reduce the TRX power consumption.

The TRX Power Amplifier Intelligent Shutdown feature is a prerequisite for TRX low-power signal intelligent shutdown. That is, the TRX low-power signals are shut down only after the power amplifiers of the TRX are shut down. We can also enable the low-power signal intelligent shutdown feature when the traffic volume is low, for example, at night.

Generally, the TRX Power Amplifier Intelligent Shutdown feature is used together with channel allocation optimization. The channels on the BCCH TRX are preferentially assigned so that the utilization of the non-BCCH TRX channels is decreased and the overall power consumption of the BTS is reduced. In addition, the BTS allocates channels based on the priorities of TRXs. Channels on the TRXs with high priorities are preferentially assigned to MSs. In this way, the BSC centralizes busy channels into a few TRXs so that as many idle TRXs as possible can be shut down.

With this feature, the BSC decreases the BTS power consumption by shutting down idle TRXs in a cell when the traffic is low. Therefore, it is recommended that this feature can be used at night when the traffic is constantly low. On the BSC, you can set a daily period in which this feature is enabled or dates during which this feature is disabled. It is also advised the telecom operator to disable this feature during festivals to ensure sudden traffic processing.

4.2.2 TRX Power Amplifier Intelligent Shutdown on Timeslot Level

The TRX Power Amplifier Intelligent Shutdown on the Timeslot Level feature is supported in the transceiver unit and the power consumption of the power amplifier on the timeslot level would become nearly zero.

If only one timeslot has traffic and the other seven timeslots are idle, the power amplifier will work only in the timeslot with the traffic and is shut down in the other seven timeslots. The power amplifier on the double-transceiver unit is switched on or shut down during the time on the timeslot level.

In this manner, when timeslots are idle, the power consumption generated by the power amplifier can be reduced during the fixture of offset voltage in the linear area. TRX power amplifier intelligent shutdown on the timeslot level does not affect channel assignment and traffic. Therefore, it has no adverse effect on network quality.

The power supply of the power amplifier is controlled inside the BTS, and the power amplifier can be switched on or shut down during the normal traffic processing procedure. This is achieved by the vendor technology of high-speed power supply control of power amplifier, where the power amplifier can be switched on or shut down in a very short time (close to 0s).

The power amplifier is a field-effect transistor. One of the main factors that affect the life cycle of the field-effect transistor is the high temperature caused by high electrical current. When the power amplifier is shut down, there is no current and the accumulated heat will be released. Therefore, when intelligent power amplifier shutdown on the timeslot level is enabled, the lifetime of the power amplifier will also be preserved.

Compared with the TRX Power Amplifier Intelligent Shutdown feature, the TRX Power Amplifier Intelligent Shutdown on the Timeslot Level feature enables the switch on and shutdown of the power amplifier on the timeslot level. When there are idle timeslots, the TRX that cannot be shut down by using the TRX Power Amplifier Intelligent Shutdown feature can be just shut down using the TRX Power Amplifier Intelligent Shut Down on the Timeslot Level feature. Therefore, the power consumption of power amplifier can be reduced to the greatest extent. The TRX Power Amplifier Intelligent Shutdown on the Timeslot Level feature is controlled by BSC.

4.2.3 Intelligent Combiner Bypass

Intelligent Combiner Bypass (ICB) applies only to double-transceiver units. When the non-BCCH TRX is idle, the BCCH TRX is in ICB mode with a capacity of one TRX. The lowest voltage is used by power amplifier on the BCCH TRX, and the output power of a single power amplifier on the BCCH TRX is 15W/10W.

After Power Burst Technology (PBT) is used on the BCCH TRX, the output power at the top of the cabinet of the BCCH TRX is the same as that of a single power amplifier, that is, 60W/40W.

As shown in figure 17 below, to meet the coverage requirement of the cell, the output power on the TRX port must be 30W. Generally, the output power of the TRX is 60W. After the combination, the output power of both TRXs is 30W so that the coverage requirement of the cell is met. When the traffic volume is lower than that in a cell, the output power of each TRX can be reduced to 15W if the PBT mode is used, so that the combination output power remains 30W.

In this case, the cell capacity is reduced in the lower setup. The TRX power, however, decreases from 60W to 15W. As a result, the power consumption of the TRX is greatly reduced and the power consumption of the BTS is lowered.

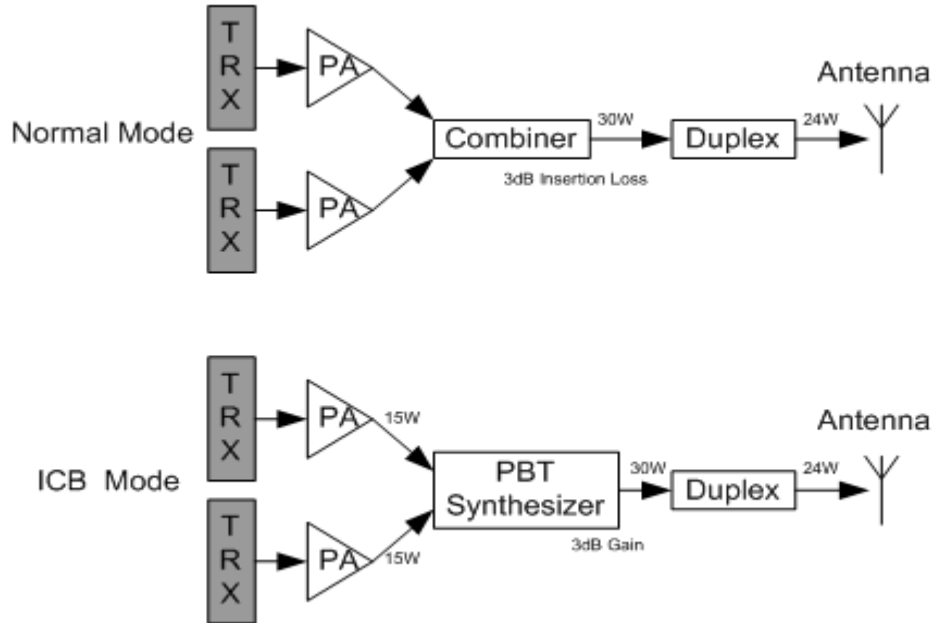


Figure 18: Intelligent combiner bypass Principle [38]

Enabling the ICB feature saves energy only if either of the following conditions is met:

- The output power of the TRX is 60W and the static power level is 0 or 1.
- The output power of the TRX is 40W and the static power level is 0.

To enable the intelligent combiner bypass feature, we should set in the BSC of the TRX that is on the same double-transceiver unit as the BCCH TRX to a low level. This ensures that the BCCH TRX is selected preferentially to enter the ICB mode when the cell has spare capacity. In this manner, power consumption is decreased.

4.2.4 Channel Allocation Algorithms Concerning Power Consumption Decrease,

The BTS power consumption can be decreased through proper channel allocation. The channel allocation algorithms concerning intelligent power consumption decrease include preferential allocation of channels on the BCCH TRX and preferential allocation of channels on the TRX with a good power-saving performance.

4.2.4.1 Preferential Allocation of Channels on the BCCH TRX

Regardless of whether channels on the BCCH TRX are seized, signals are transmitted with full power. When channels carried on the BCCH TRX are seized, normal bursts are transmitted; when channels carried on the BCCH TRX are idle, dummy bursts are transmitted. TRX power amplifier intelligent shutdown on the timeslot level, power control, and DTX cannot be applied to BCCH TRX. With the introduction of preferential allocation of channels on the BCCH TRX, the BSC preferentially allocates channels on the BCCH TRX to the MS to reduce the utilization rate of channels carried by non-BCCH TRXs so that intelligent power consumption decrease can be applied to the non-BCCH TRXs.

4.2.4.2 Preferential Allocation of Channels on the TRX

With different power-saving performance of various chips, TRXs produced at different periods and of different types have different power-saving capabilities. When there are TRXs with different power-saving performance in a cell, you can preferentially use the TRXs with good power-saving performance and apply power-saving technology to the TRXs with poor power-saving performance to decrease the BTS power consumption.

When a TRX is powered on, the TRX reports its power-saving performance to the BSC and then the BSC preferentially allocates the channels on the TRXs with good power-saving performance to the MS.

4.2.5 Discontinuous Transmission (DTX)

Discontinuous transmission (DTX) is a method of momentarily powering-down, or muting, a mobile or portable wireless telephone set when there is no voice input to the set. This optimizes the overall efficiency of a wireless voice communications system [39].

In a typical two-way conversation, each individual speaks slightly less than half of the time. If the transmitter signal is switched ON only during periods of voice input, the duty cycle of the telephone set can be cut to less than 50 percent. This conserves battery power, eases the workload of the components in the transmitter amplifiers, and frees the channel so that time-division multiplexing (TDM) can take advantage of the available bandwidth by sharing the channel with other signals.

A DTX circuit operates using Voice Activity Detection (VAD). Sophisticated engineering is necessary to ensure that circuits of this type operate properly. In wireless transmitters, VAD is sometimes called voice-operated transmission (VOX).

4.2.6 Intelligent Adjustment of TRX Working Voltage

Currently, main GSM equipment vendors are at least able to support one of the two techniques, “Time slot based on the PA cut-off” and “Load based TRX / PA cut-off” [12].

1. In the evening, the carrier frequencies without carrying traffic can be closed using “Load based TRX / PA cut-off” according to the statistics and prediction of communication volumes.
2. In the case of low traffic, through granular management, “Time slot based on the PA cut-off” can be performed to improve the energy efficiency in the RF communication channels.

Either load or time slot based TRX / PA cut-off is implemented through the software-controlled adjustment to either the switching regulator of TRX or PA offset based on the network communication volume. The adjustment to TRX switch is mainly to open or close the PA working voltage, while the adjustment to PA offset switch is mainly to open or close PA bias voltage to control the biasing current of the PA.

4.3 Practical Power Consumption Saving Mechanisms

Now a days, there are different kinds of practical power saving mechanisms to be implemented in a live network with considerate traffic analysis and judgement. Among these;

4.3.1 Dynamic cell power off

4.3.2 Enhanced BCCH power consumption optimization

4.3.1 The Dynamic Cell Power Off

The Dynamic Cell Power Off feature is widely used in dual-band networks where the GSM900 and 1800 MHz cells are served by the same BSC. The Dynamic Cell Power Off feature enables a BSC to dynamically power off or power on all the TRXs in a cell that has a co-coverage cell based on traffic load within a specified period [40].

In a multiband network, the 900 MHz cell provides network coverage, whereas the 1800 MHz cell absorbs network traffic (increased capacity). To reduce power consumption on a multiband

network, the Dynamic Cell Power Off feature is introduced. If the traffic volume is low and the 900 MHz cell can take over all services running on the 1800 MHz cell within a specified period, the 1800 MHz cell can be powered off, thereby reducing BTS power consumption.

4.3.1.1 Benefits of Dynamic Cell Power Off feature

The Dynamic Cell Power Off feature enables a BSC to dynamically power off idle network equipment when traffic volume is low, thereby reducing power consumption.

4.3.1.2 Technical Description of Dynamic Cell Power Off feature

When traffic volume is low, all the TRXs in the 1800MHz cell are disabled, and the 900 MHz cell provides services for all subscribers in the coverage area of the 1800 MHz cell, thereby reducing the power consumption of the entire network. When traffic volume increases, all the TRXs in the 1800 MHz cell are powered on to meet the traffic requirement in the coverage area. Figure 18 shows the overall principles of this feature.

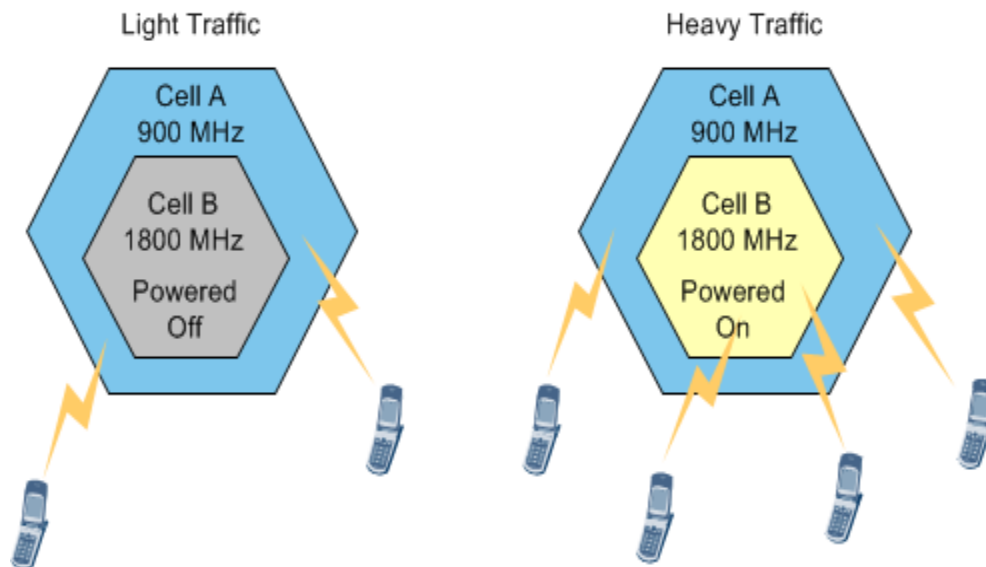


Figure 19 : Overall principles of Dynamic Cell Power Off [40]

4.3.2 Enhanced BCCH Power Consumption Optimization Feature

In the GSM system, to prepare for possible cell selections, cell reselections, and MS handovers, all timeslots on the BCCH TRX always transmit signals at the configured power, regardless of whether the timeslots are idle or not, to ensure that MSs can accurately measure the downlink receive level in a cell. Therefore, the radio frequency (RF) module housing the BCCH TRX is one of the BTS components that consume the most power.

To decrease the power consumption of the BCCH TRX, the vendor introduces the Enhanced BCCH Power Consumption Optimization feature [41]. With this feature, the transmit power of non-BCCH timeslots on the BCCH TRX can be decreased during off-peak hours. This helps decrease the BTS power consumption as well.

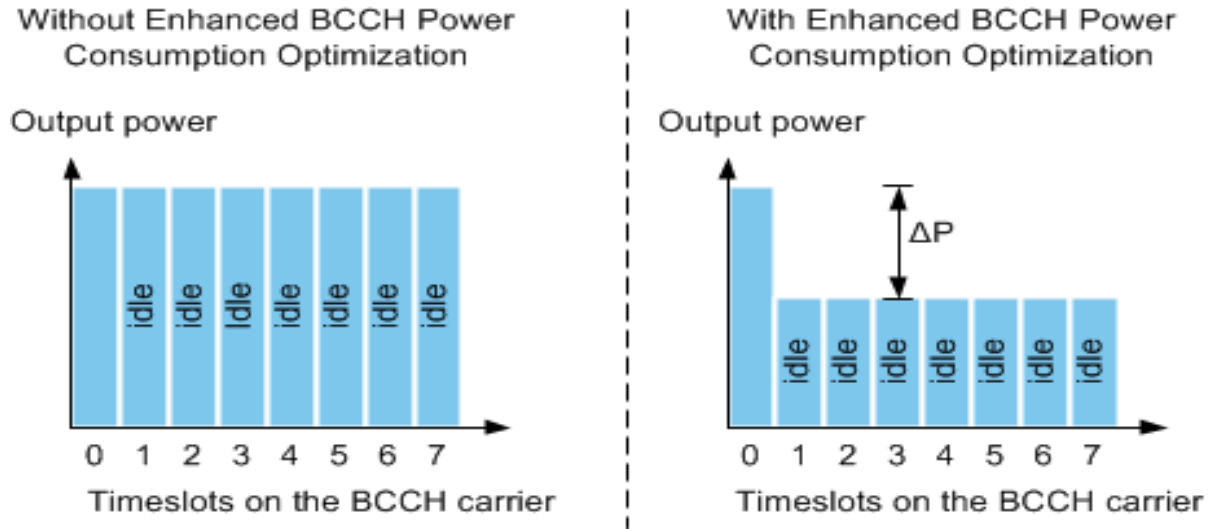


Figure 20: Reducing the transmit power [41]

4.3.2.1 Benefits Enhanced BCCH Power Consumption Optimization Feature

This feature provides the following benefits:

- Reduces the BTS power consumption.
- Reduces the network interference and allows tight frequency reuse patterns by reducing the transmit power of non-BCCH timeslots on the BCCH TRX.

5. Data Collection and Power Measurement at a Base station

5.1 Introduction

There are a number of reasons why different mobile network operators and mobile network device manufacturers are together globally researching different ways to optimize their network performance from the energy efficiency and capacity standpoint. The pressure to optimize the energy efficiency is not entirely on the operator's shoulders, but also on the device manufacturers, who all have to be able to design and manufacture more compelling solutions for the operators to implement and for the consumers to purchase. In Ethiopia, there are around Six Thousand Nine Hundred Nineteen (6919) second generation base stations. Among these, 40% of them are GSM900MHz and remaining 60% are Hybrid of Digital Cellular System (DCS), (GSM1800MHz) & GSM900MHz base stations.

It is well-known that radio access nodes are particularly energy-hungry, in which their energy consumption can reach more than the 80% of the total energy in the entire access network. This motivated me to conduct a research in the field of green wireless network operation where the main goal is to develop a traffic volume to power consumption model and to propose an optimization strategy that include energy efficiency aspects in the normal network operation.

Since, Base Station is responsible for maximum power consumption of the overall network. Let us start our investigation by analysing component by component based on their power consumption dependency. Here are some of the main base station components;

Base Station Components

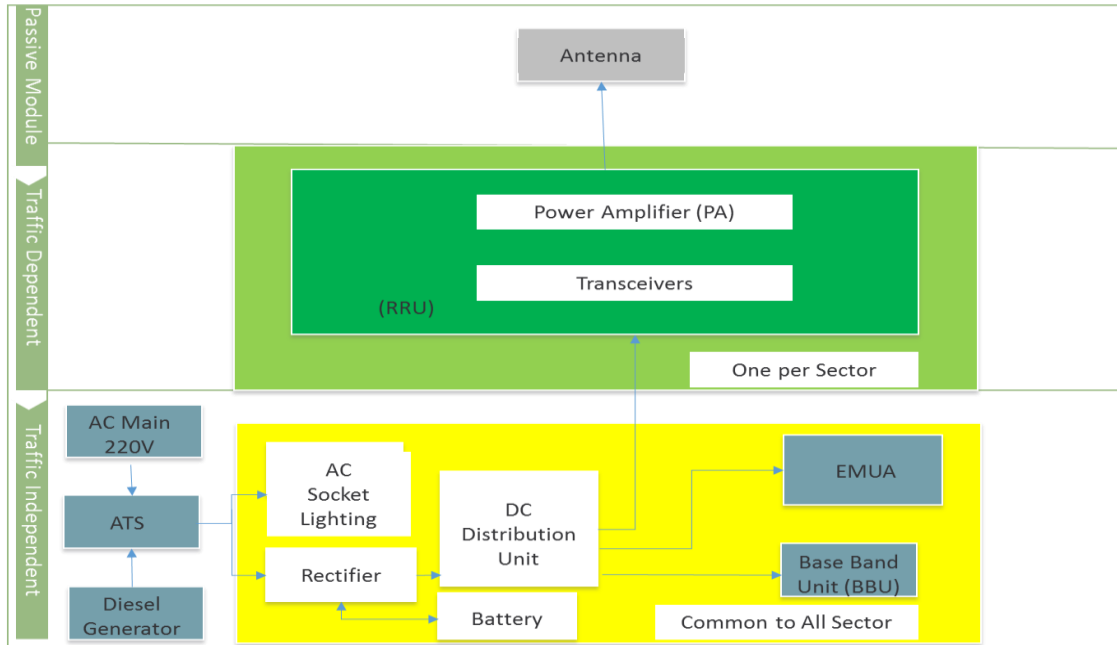


Figure 21: Main base station components.

5.2 Power Consumption Model Parameters

Table 1: Parameters of the power consumption model

Components	Power consumption parameter
Base Band Unit	P_{bbu}
Remote Radio Unit	P_{rru}
Rectifier	P_{re}
Air Conditioner	P_{ac}
Incandescent Bulb	P_{ib}
Environmental Monitoring Unit Type-A (Connect to the operator's network for platform control and medium access control)	P_{emua}
Entire Base Station Power	P_{BS}

The power consumption of an entire BS is the sum of the power consumed by its components and it is given by:

$$P_{BS} = P_{bbu} + P_{rru} + P_{re} + P_{emua} + \sum_{j=1}^J P_{ac}(j) + \sum_{m=1}^M P_{ib}(m) \dots\dots (5.1)$$

Since the measured current values for some components at the base station did not vary with traffic load the power consumed at a base station can be divided into two categories: traffic dependent and traffic independent. Measured current values for some of base station components such as the Environmental Monitoring Unit Type-A (EMUA), Air Conditioner (AC), and Base Band Unit (BBU) were traffic load independent, with insignificant variation between the load and the measured current. However, the measured current values for the radio unit were traffic load dependent. Therefore, the total base station power would become:

$$P_{BS} = P_{Traffic Dependent} + P_{Traffic Independent} \quad (5.2)$$

Thus;

$$P_{Traffic Independent} = P_{bbu} + P_{re} + P_{emua} + \sum_{j=1}^J P_{ac}(j) + \sum_{m=1}^M P_{ib}(m) \quad (5.3)$$

$$P_{Traffic dependent} = P_{rru} \quad (5.4)$$

For a particular three sectored technology;

$$P_{Traffic dependent} = P_{rru Sector I} + P_{rru Sector II} + P_{rru Sector III} \quad (5.5)$$

In order to find the interdependence between base station power consumption and the carried traffic load, site power consumption measurements were conducted at fully operated high traffic and low traffic base station sites around British Embassy, Kebena (Yeka Cluster 11) (With site ID: 112110 with GPS Coordinates 9° 1' 36.048" N and 38° 46' 33.024" E) and around legetafo (Yeka Cluster 08) (Site ID: 112223 with GPS Coordinates 9° 5' 45.852" N & 38° 47' 35.88" E) for two days for each sites. The power consumption measurements were made under different transceiver configurations and with a BS architecture of two different cellular access technologies: **GSM 900MHz** and **GSM 1800MHz**. The BTS type of the selected sites of GSM network is Huawei DBS3900 series with BBU3900 and RRU3929, RRU3936 and RRU3826 models.

DBS3900 is abbreviated form distributed base station (DBS). DBS3900 dual-mode base station is the fourth-generation base station 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.

5.3 Measuring Setup and Results Analysis

To determine the load, measurements are performed for an actual micro and macro BS in the urban area of around Addis Ababa city for working and weekend days. The group of load-independent components i.e., the rectifier, the air conditioning and the microwave link are not included in this measurement, as there is no variation in the current measurement. For the Remote Radio Unit (RRU), the voltage from the rectifier is constant (i.e. approximately in average 54V DC) and thus the current is measured at an hourly basis for the two base stations for 24 hours.

5.3.1 Measuring Setup

The power consumption $P(t)$ (in Watt) at a certain time 't' is then determined as in equation:

$$P(t) = V * I(t) \quad (5.6)$$

Where, V is voltage (in Volt) which is constant for this case and I(t) be the current at any time t (in Ampere). The current is measured with a multi-channel measuring instrument, AC/DC current clamp as per the following measuring setup.

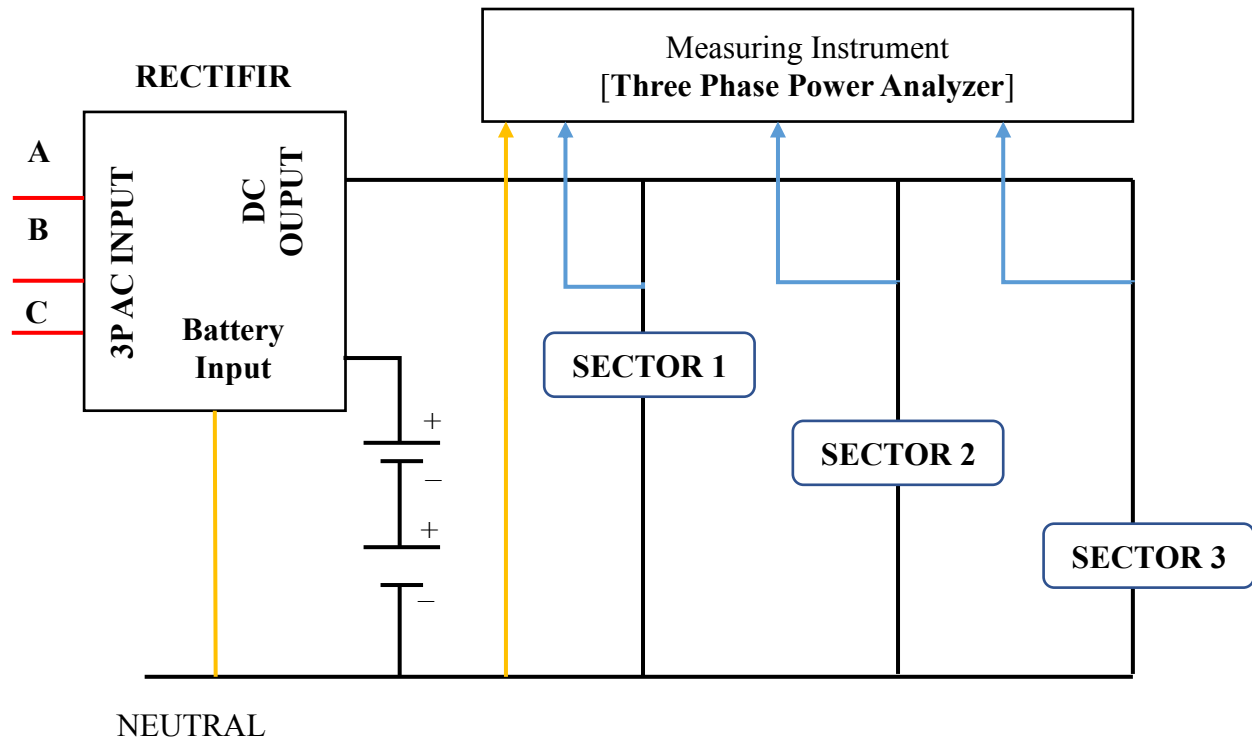


Figure 22: Block diagram of measurement setup used for measuring instantaneous current.

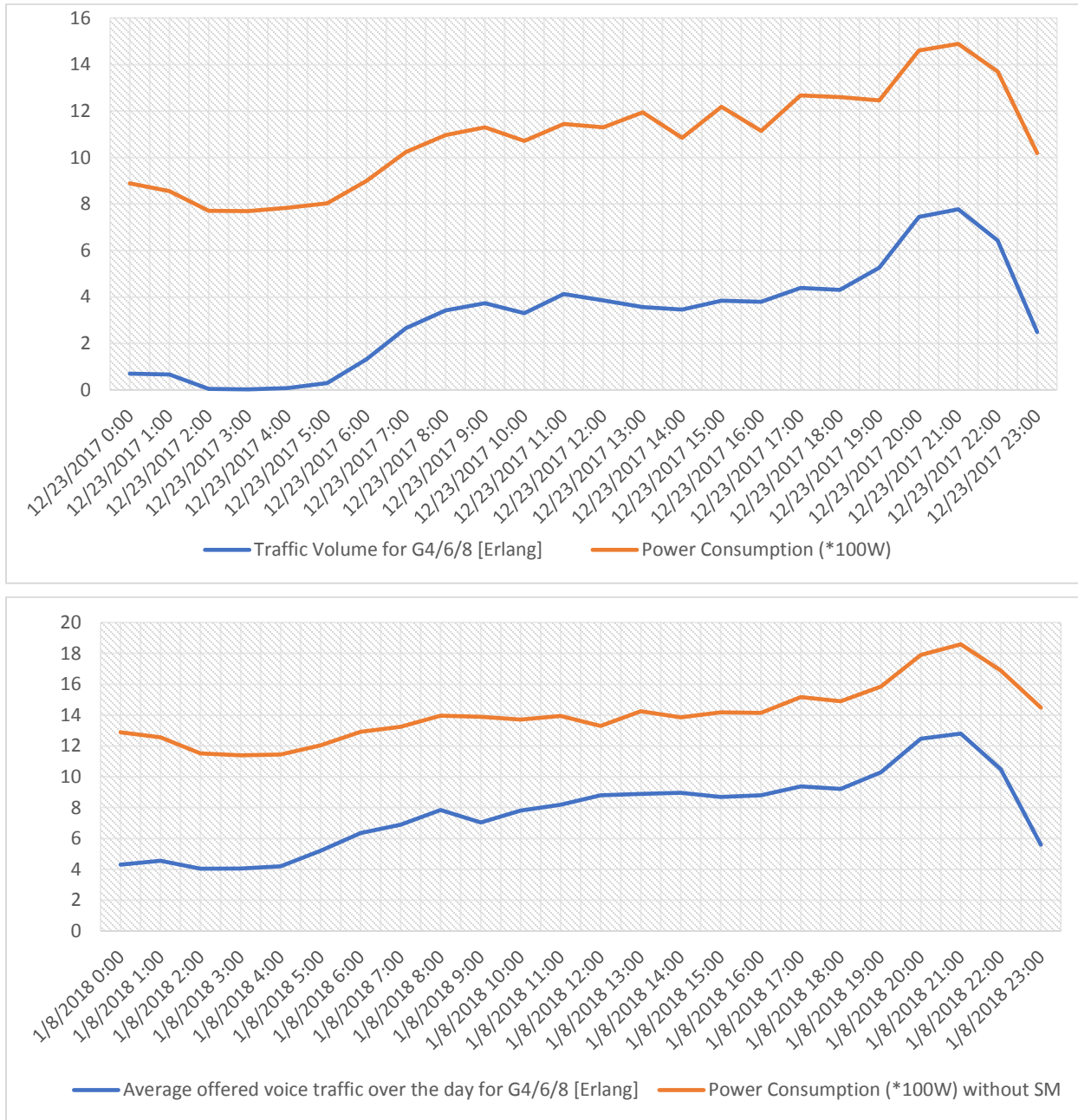
Once the power consumption of the radio units is obtained through measurement at the site, we requested Ethio-telecom engineering department to offer us a six-month traffic volume including five months before and one month after the measurement date for the particular site IDs mentioned above. Thus, we plotted the data obtained and found that there is a relationship between the BS power consumption and the traffic load on the specified time and date.

From the traffic profile data, cellular networks can be dimensioned according to peak hour traffic that is the maximum expected number of requests that the system should be able to satisfy. On the other hand, we have found that the traffic profile during days is not at the peak hour could never be reached or it could be for a very small fraction of the day. More in details, obtained cellular traffic profile data shows three kind of variations in the system:

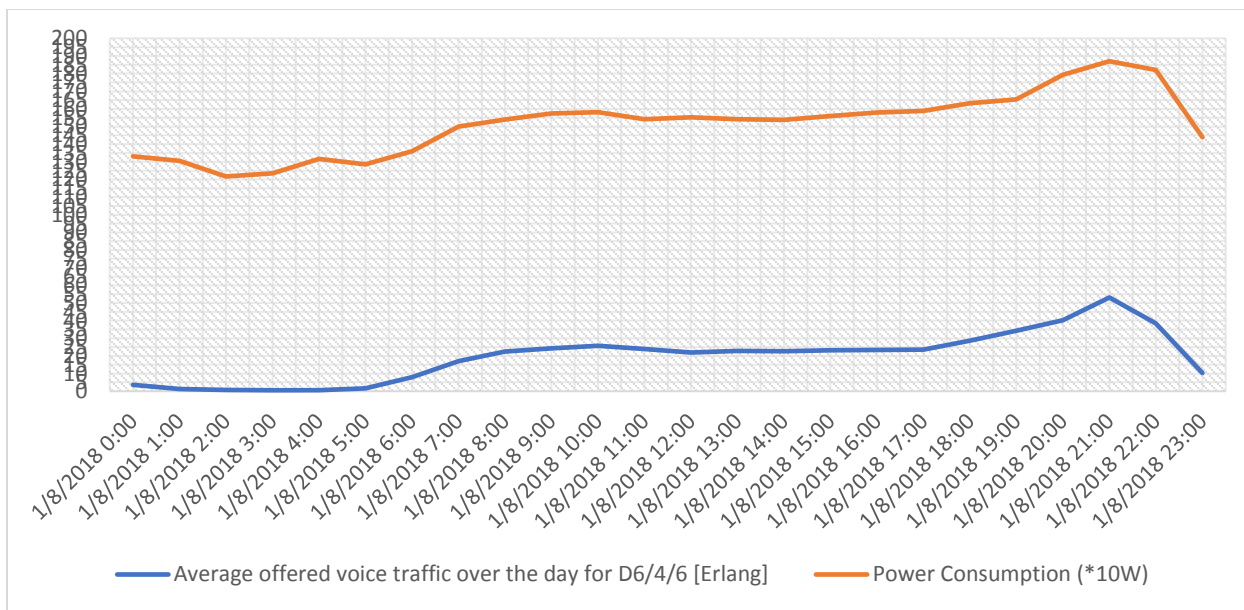
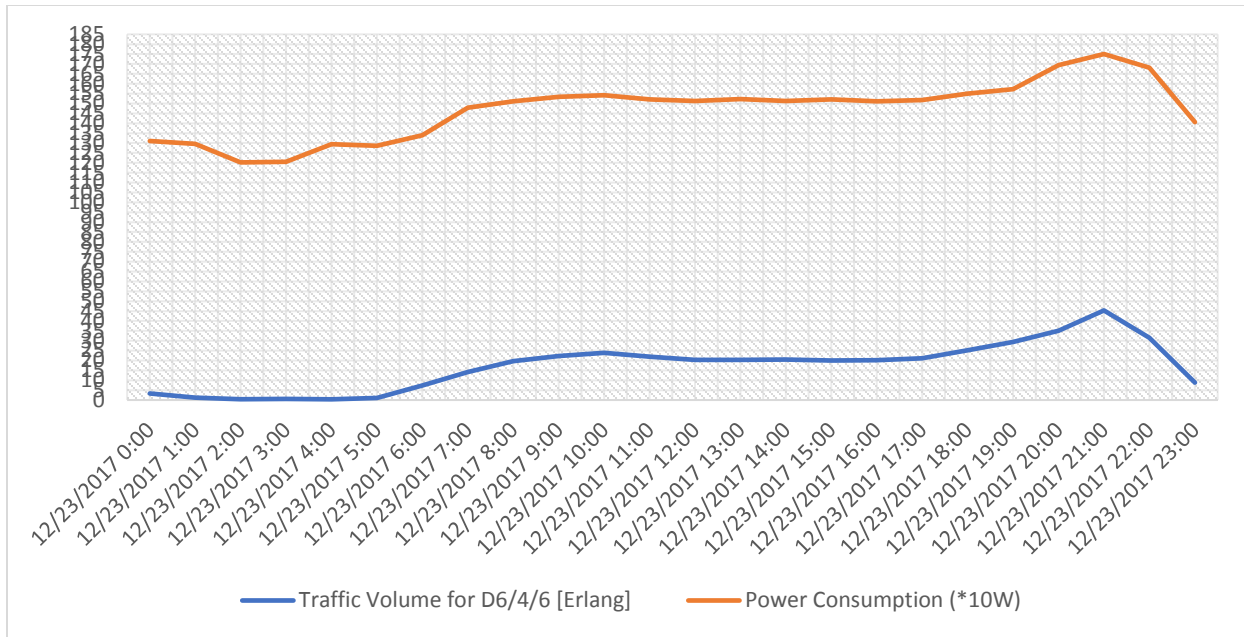
- Daily variations, i.e. the difference between busiest hours and minimum load like night time.
- Weekly variations, i.e. the difference between average traffic in work days and during weekend.
- Incidental variations, i.e. the peak of traffic due to special events.

Such variations may have also different distribution according to the season of the year and the location that are being considered.

The following figures give the minimum and maximum daily power consumptions with the carried traffic for voice services for weekend and working days for both macro and micro sites.



Graph 1: Base station power consumption under real traffic load for G4/6/8

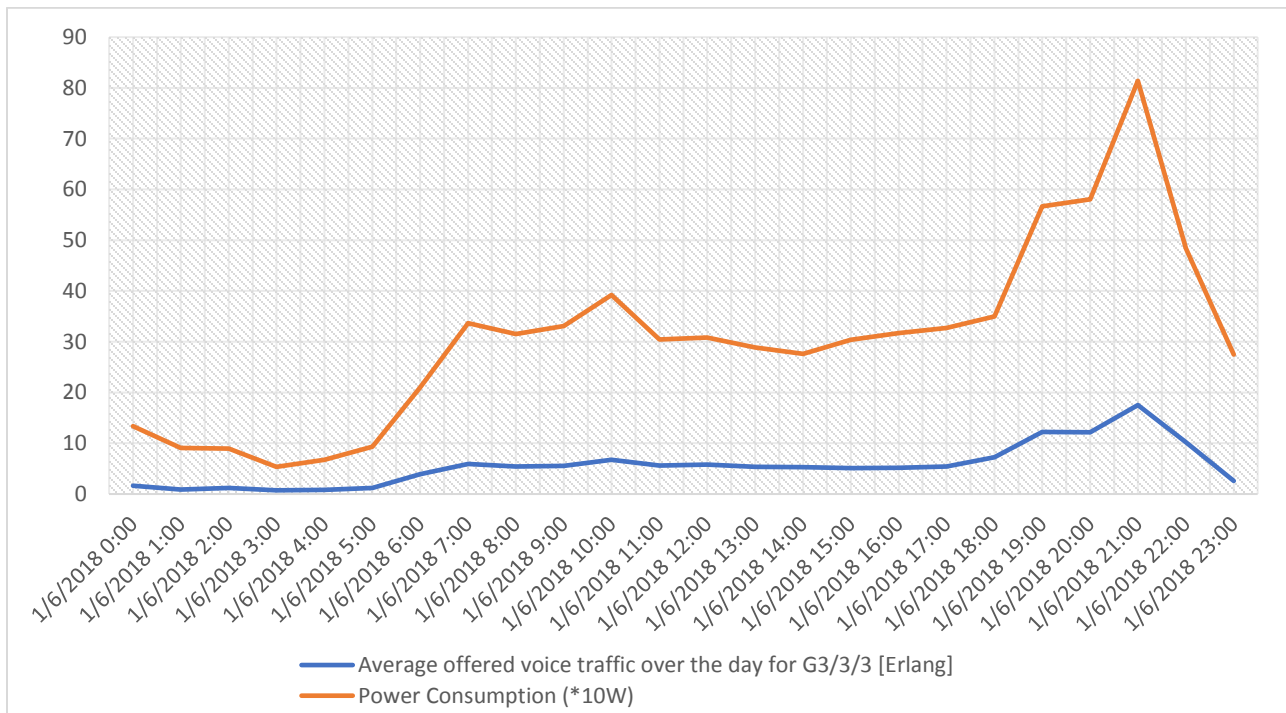
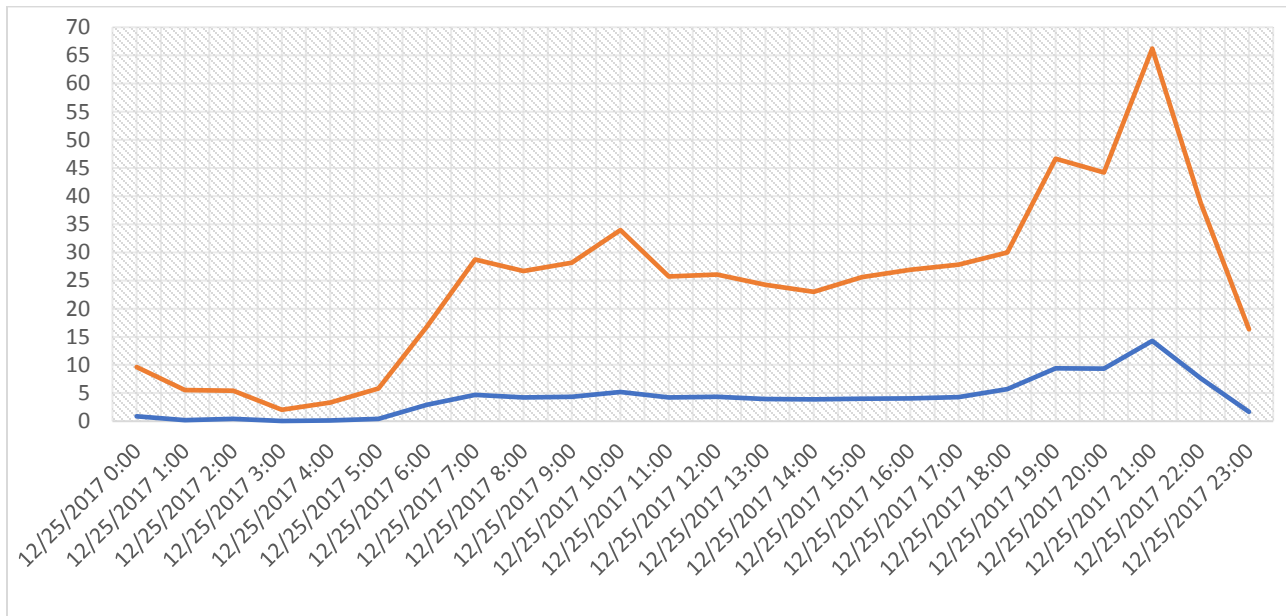


Graph 2: Base station power consumption under real traffic load for D6/4/6

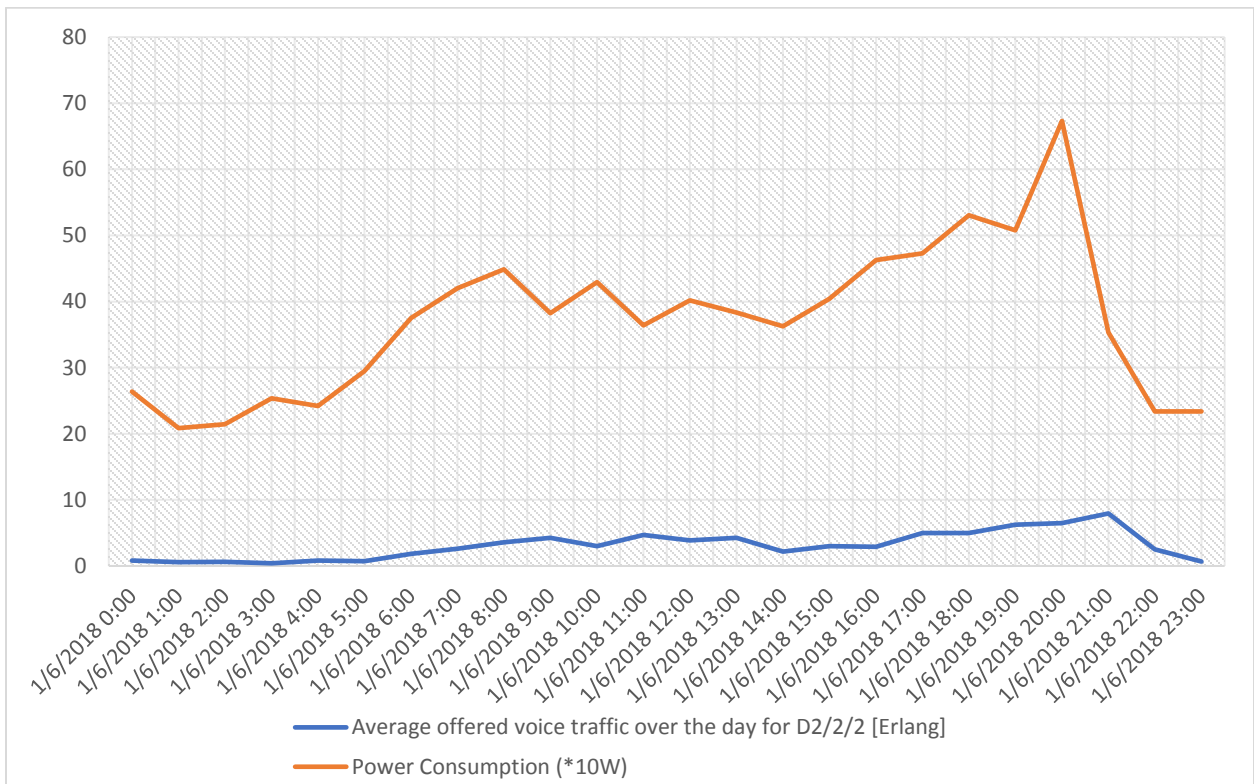
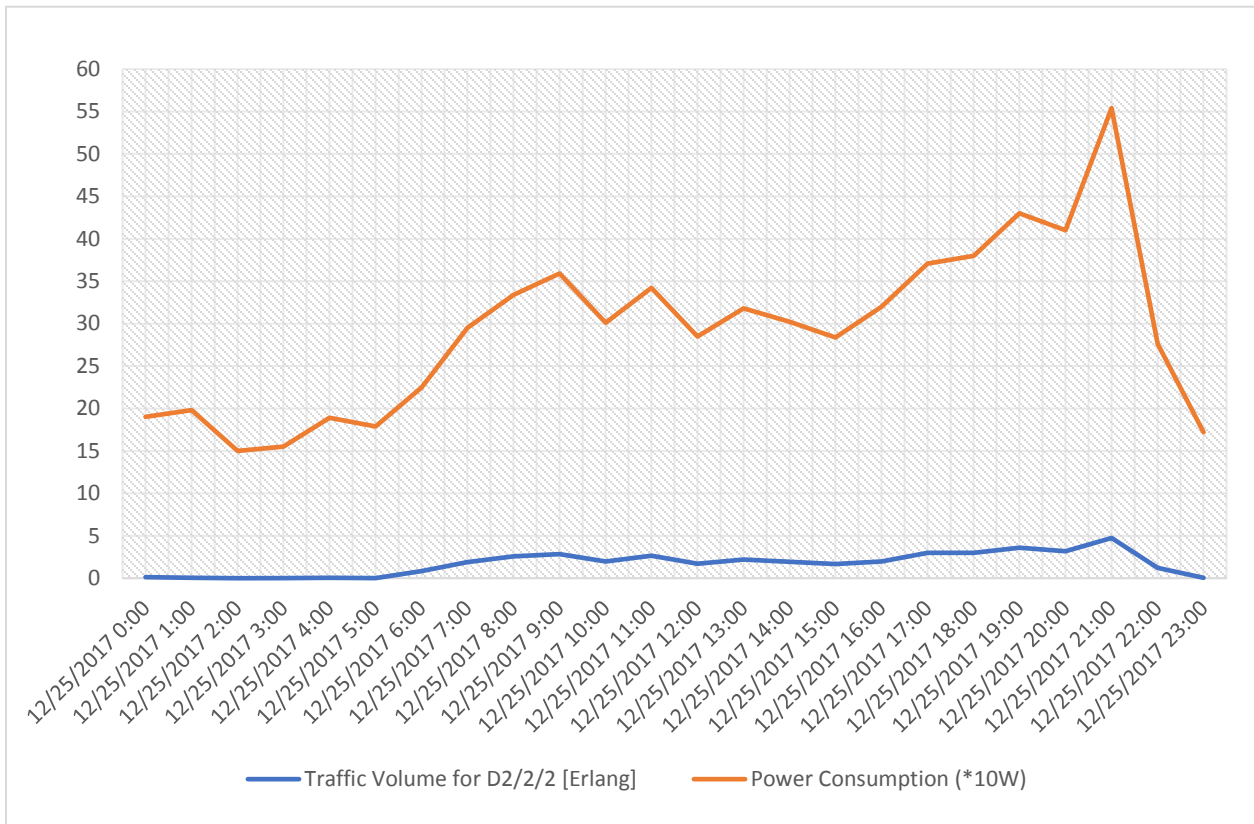
5.3.2 Discussion of Results for Site ID: 112110

It seems that in both measurement the instantaneous current varies accordingly with the carried voice traffic, so that it is enough to conduct the result analysis in one of the measurements. If we consider Graph 2; It was found that the traffic load is high during 08:00-11:00 and 18:00-21:00 hours. The high and low traffic load was recorded to be 45.3 and 0.365 Erlang for D6/4/6 respectively and 7.7722 and 0.025 Erlang for G4/6/8 respectively. It was found that also the BS power consumption varies from 1.20 KW to 1.75KW for D6/4/6 and 769.2W to 1488.7W for

G4/6/8. Having the PA operate in its linear response region typically helps to avoid distortion of the signal, which is also why the peak value is restrained to exist in this region.



Graph 3: Base station power consumption under real traffic load for G3/3/3



Graph 4: Base station power consumption under real traffic load for D2/2/2

5.3.3 Discussion of Results for Site ID: 112223

It seems that in both measurement the instantaneous current varies accordingly with the carried voice traffic, so that it is also enough to conduct the result analysis in weekday. It was found that the traffic load is high during 07:00-11:00 and 17:00-21:00 hours. The high and low traffic load was recorded to be 4.7416 and 0.0 Erlang for D2/2/2 respectively and 14.2737 and .0445 Erlang for G3/3/3 respectively. It was found also that the BS power consumption varies from 150W to 554W for D2/2/2 and 20.3W to 662W for G3/3/3. Knowing the duration and the timing of off-peak hours are also crucial in order to increase the energy efficiency of the network.

5.3.4 Measurement Comparison with similar scenario

Different comparison methods are used to check whether the obtained values for higher traffic base stations are right or not. Among these;

5.3.4.1 System measurement of different base stations

From the BSC, the power consumption of each cell can be measured regardless of the site configuration and found to be the minimum is around 3500W and maximum is 5400W. However, in any carrier the radio unit consumes configuration the radio unit consumes around 50-80% of the energy. This justifies, the site measurement is correct and it should be at least greater than 1750W.

5.3.4.2 Reference of the same types of power assessment of base stations [46]

As a reference, a power measurement of the same type of technology and configuration is compared with our measurement result, and as per our assessment, it is reasonable that the measured power in all the three sectors are in the order of KW.

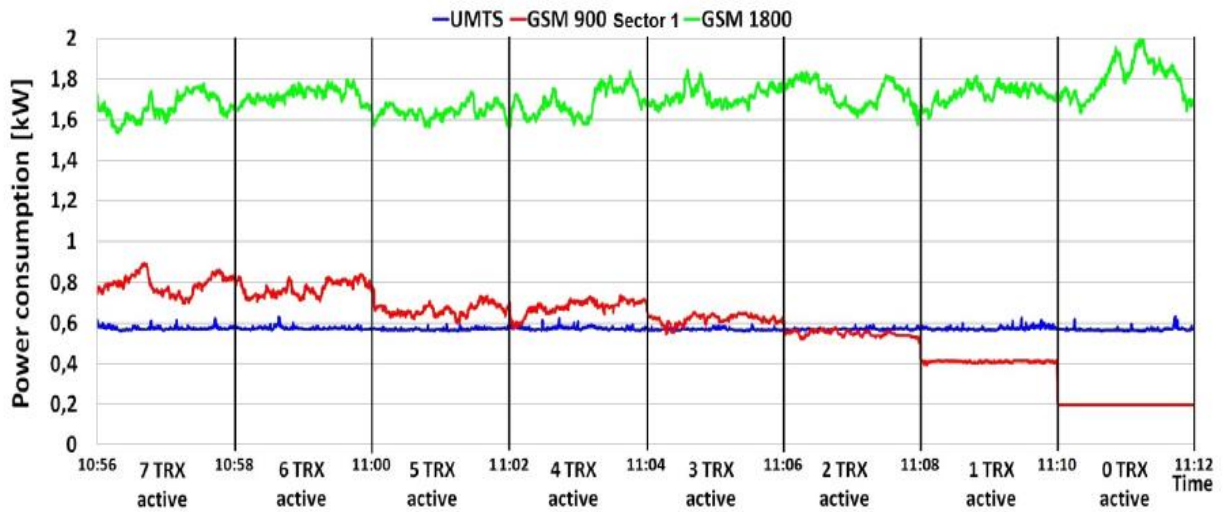


Figure 23: Power consumption of BSs during deactivation of TRXs in GSM900 BS [46]

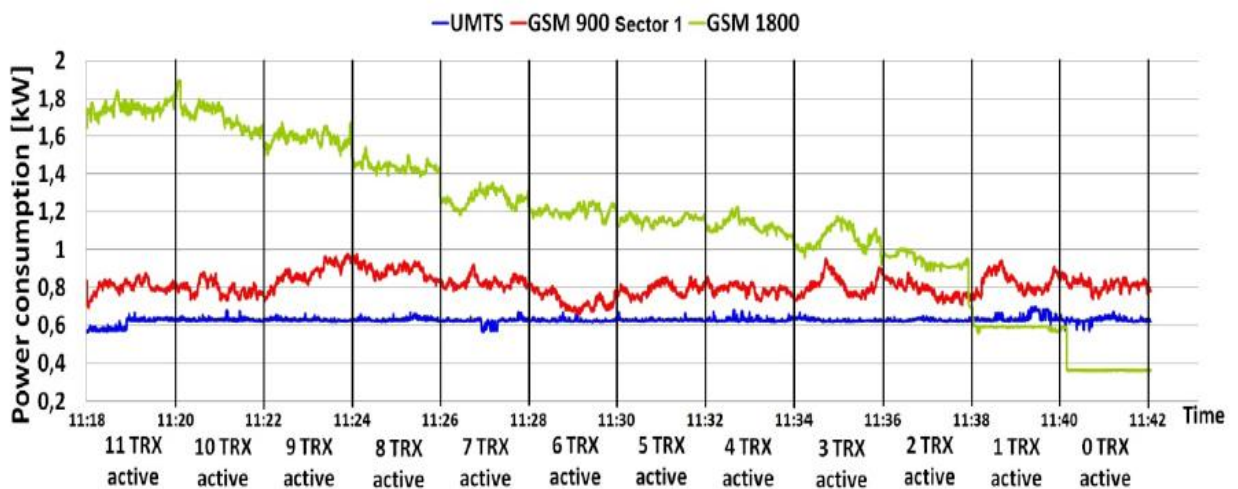


Figure 24: Power consumption of BSs during deactivation of TRXs in GSM1800 BS [46]

5.3.4.3 Base Station Power Consumption Specifications, the power rating for each RRU

The base station considered for the measurement D6/4/6 and G4/6/8 are located around British Embassy, near to Megenagna, which has a very high traffic, so that the power consumption expected to be very high. In the thesis document, the power measured is the sum of all the three sectors having a total of 18TRX for DCS and 18TRX for GSM 900 respectively.

From the 3900 Series Base Station Power Consumption Specifications of Huawei Technologies Co. Ltd, the power rating is taken for each RRU from the operating manual as for RRU3929 is around 1455W and for RRU3936 is around 1020W of smaller site configuration than ours.

Module type	Cabinet type	Frequency Band (MHz)	Working mode	Configuration	Output Power per GSM Carrier (W)	Output Power per UMTS Carrier (W)	Output Power per LTE FDD Carrier (W)	Typical Power Consumption (W)	Maximum Power Consumption (W)
RRU3929	DBS3900 (Ver.D) (-48 V DC)	1800	GO	S4/4/4	20	/	/	805	1110
RRU3929	DBS3900 (Ver.D) (-48 V DC)	1800	GO	S6/6/6	20	/	/	935	1425
RRU3929	DBS3900 (Ver.D) (-48 V DC)	900	GO	S1/1/1	20	/	/	510	510
RRU3929	DBS3900 (Ver.D) (-48 V DC)	900	GO	S2/2/2	20	/	/	580	680
RRU3929	DBS3900 (Ver.D) (-48 V DC)	900	GO	S3/3/3	20	/	/	655	855
RRU3929	DBS3900 (Ver.D) (-48 V DC)	900	GO	S4/4/4	20	/	/	690	1110
RRU3929	DBS3900 (Ver.D) (-48 V DC)	900	GO	S6/6/6	20	/	/	955	1455
RRU3929	DBS3900 (Ver.D) (-48 V DC)	900	UO	3x1	/	20	/	510	590
RRU3929	DBS3900 (Ver.D) (-48 V DC)	900	UO	3x2	/	20	/	605	740
RRU3929	DBS3900 (Ver.D) (-48 V DC)	900	UO	3x3	/	20	/	760	955
RRU3929	DBS3900 (Ver.D) (-48 V DC)	900	UO	3x4	/	20	/	945	1220
RRU3929	DBS3900 (Ver.D) (-48 V DC)	1800	UO	3x1	/	20	/	525	600
RRU3929	DBS3900 (Ver.D) (-48 V DC)	1800	UO	3x2	/	20	/	625	765
RRU3929	DBS3900 (Ver.D) (-48 V DC)	1800	UO	3x3	/	20	/	810	1010
RRU3929	DBS3900 (Ver.D) (-48 V DC)	1800	UO	3x4	/	20	/	990	1265
RRU3929	DBS3900 (Ver.D) (-48 V DC)	900	LO	3x10 MHz, 1 carrier	/	/	2x20	710	860
RRU3929	DBS3900 (Ver.D) (-48 V DC)	900	LO	3x10 MHz, 2 carriers	/	/	2x20	905	1170

Module type	Cabinet type	Frequency Band (MHz)	Working mode	Configuration	Output Power per GSM Carrier (W)	Output Power per UMTS Carrier (W)	Output Power per LTE FDD Carrier (W)	Typical Power Consumption (W)	Maximum Power Consumption (W)
RRU3936	DBS3900 (Ver.D) (-48 V DC)	1900	GO	S1/1/1	20	/	/	530	530
RRU3936	DBS3900 (Ver.D) (-48 V DC)	1900	GO	S2/2/2	20	/	/	590	695
RRU3936	DBS3900 (Ver.D) (-48 V DC)	1900	GO	S3/3/3	20	/	/	660	865
RRU3936	DBS3900 (Ver.D) (-48 V DC)	1900	GO	S4/4/4	20	/	/	725	1020
RRU3936	DBS3900 (Ver.D) (-48 V DC)	1800	GO	S1/1/1	20	/	/	530	530
RRU3936	DBS3900 (Ver.D) (-48 V DC)	1800	GO	S2/2/2	20	/	/	590	695
RRU3936	DBS3900 (Ver.D) (-48 V DC)	1800	GO	S3/3/3	20	/	/	660	865
RRU3936	DBS3900 (Ver.D) (-48 V DC)	1800	GO	S4/4/4	20	/	/	725	1020
RRU3936	DBS3900 (Ver.D) (-48 V DC)	900	GO	S1/1/1	20	/	/	475	475
RRU3936	DBS3900 (Ver.D) (-48 V DC)	900	GO	S2/2/2	20	/	/	540	635
RRU3936	DBS3900 (Ver.D) (-48 V DC)	900	GO	S3/3/3	20	/	/	610	805
RRU3936	DBS3900 (Ver.D) (-48 V DC)	900	GO	S4/4/4	20	/	/	655	965
RRU3936	DBS3900 (Ver.D) (-48 V DC)	850	GO	S1/1/1	20	/	/	480	480
RRU3936	DBS3900 (Ver.D) (-48 V DC)	850	GO	S2/2/2	20	/	/	555	655
RRU3936	DBS3900 (Ver.D) (-48 V DC)	850	GO	S3/3/3	20	/	/	635	835
RRU3936	DBS3900 (Ver.D) (-48 V DC)	850	GO	S4/4/4	20	/	/	680	1000
RRU3936	DBS3900 (Ver.D) (-48 V DC)	1900	UO	3x1	/	20	/	500	565
RRU3936	DBS3900 (Ver.D) (-48 V DC)	1900	UO	3x2	/	20	/	600	740

Figure 26: Power rating of different RRU

5.4 Power Consumption Model

The power consumption of base stations consists of two parts. The first part describes the static power consumption - a power figure that consumed already in an empty BSs and dynamic power consumption which changes with traffic load. Depending on the load situation, a dynamic power

consumption part adds to the static. In this study, only dynamic power consumption with respect to the traffic load has been considered.

As per previous observations, there is a linear relationship between the power consumption and traffic load at a base station. We therefore, use linear regression technique to develop a linear BS power consumption model based on our measurement results. A power consumption model is developed based on the power consumption and the traffic load generated by BSs.

5.4.1 Linear Regression

Based upon the measured traffic load and corresponding BS power consumption, now the objective is to develop a power consumption model as per carried traffic generated. The developed model must express power consumption of each BS as a function of real time traffic load given by the following equation:

$$P = \beta_1 f_1(T) + \dots + \beta_p f_p(T) + \mathcal{E} \quad (5.7)$$

$$\begin{bmatrix} P_1 \\ P_2 \\ \cdot \\ \cdot \\ P_p \end{bmatrix} = \begin{bmatrix} 1 & T_1 \\ 1 & T_2 \\ \cdot & \cdot \\ \cdot & \cdot \\ 1 & T_p \end{bmatrix} \begin{bmatrix} \beta_0 \\ \beta_1 \\ \cdot \\ \cdot \\ \beta_p \end{bmatrix} + \begin{bmatrix} \mathcal{E}_1 \\ \mathcal{E}_2 \\ \cdot \\ \cdot \\ \mathcal{E}_p \end{bmatrix} \mathcal{E} \quad (5.8)$$

According to equation: (5.7), response P - Power Consumption is modelled as a linear combination of function of independent variable T - traffic load and a random error \mathcal{E} . In this expression $f_j(T)$ ($j=1$ to p) are the terms for the model, while β_j ($j=1$ to p) represents the weight correspond to $f_j(T)$. It is assumed that the model has up to p -different terms and corresponding coefficients. Uncontrolled factors and experimental errors are modelled in above equation by \mathcal{E} and assumed to be uncorrelated and distributed with zero mean and constant variance.

As we aimed to analyse the base station power consumption under the real traffic loads as a major contributing factor, hence the above model reduces to $f_1(T)=1$ and $f_2(T)=T$. and for 'n' independent observations (P_1, T_1) to (P_n, T_n), equation (5.9) represents a linear regression equation for our concern:

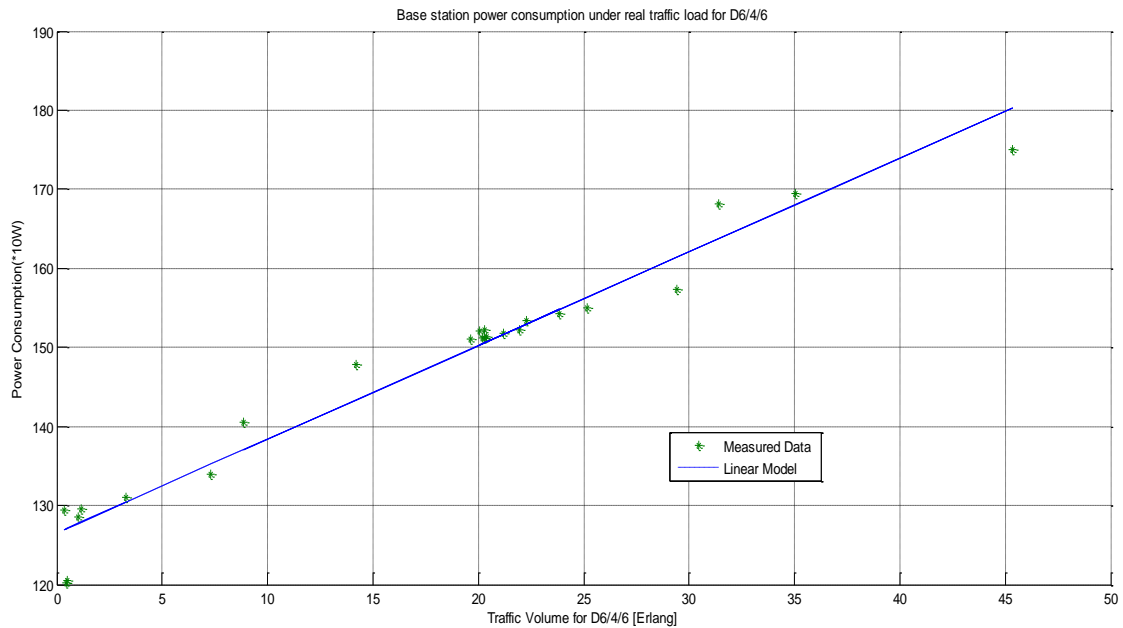
$$P = T\beta_1 + \beta_0 + \mathcal{E} \quad (5.9)$$

Where, ‘T’ represents telecommunication traffic in Erlang, while ‘P’ acts as corresponding measured power, in Watt. Whereas, the coefficients of the regression line, $\epsilon = \beta_0$ [Watt] represents the intercept and β_1 [W/Erl] represents the slope of line.

Calculations were performed in curve fitting toolbox in MATLAB version R2013a and determined a line of best fit for our measured values and determined the coefficients regression analysis under data function. In response to characterize a relationship, this study provides a sufficient knowledge between the traffic load and corresponding BS power consumption. This give rise to the linear relationship between traffic load (T) and corresponding power consumption (P) for GSM1800 as given by equation (5.10).

5.4.2 The linear regression method for High traffic cases

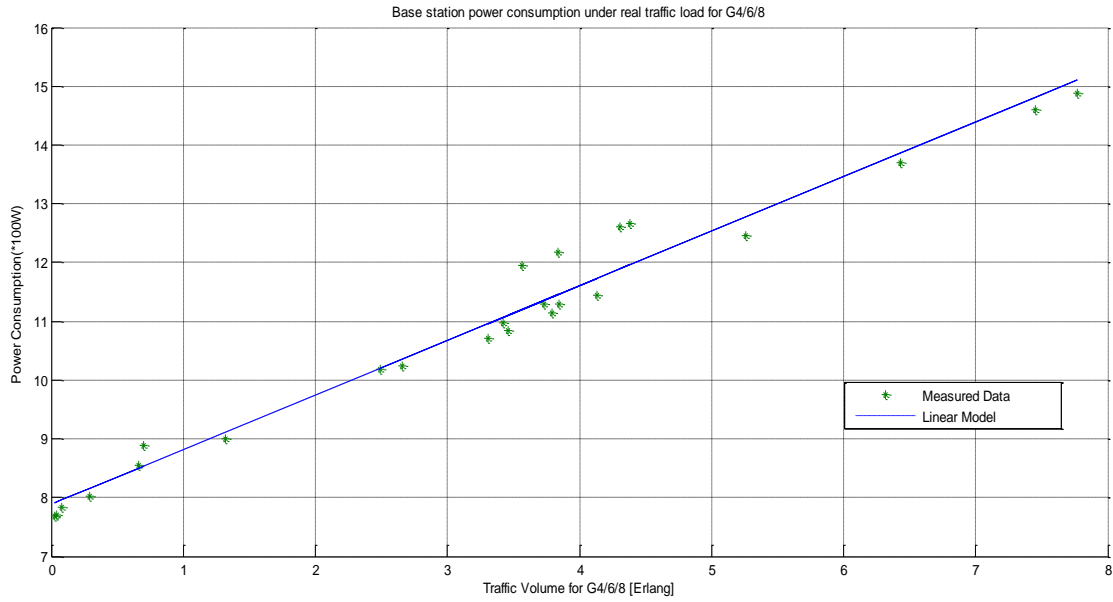
$$P = 11.85T + 1265.3 \quad (5.10)$$



Graph 5: Linear Regression result for D6/4/6

As well, the linear relationship between traffic load (T) and corresponding power consumption (P) for GSM900 under a specific traffic configuration is given by equation (5.11).

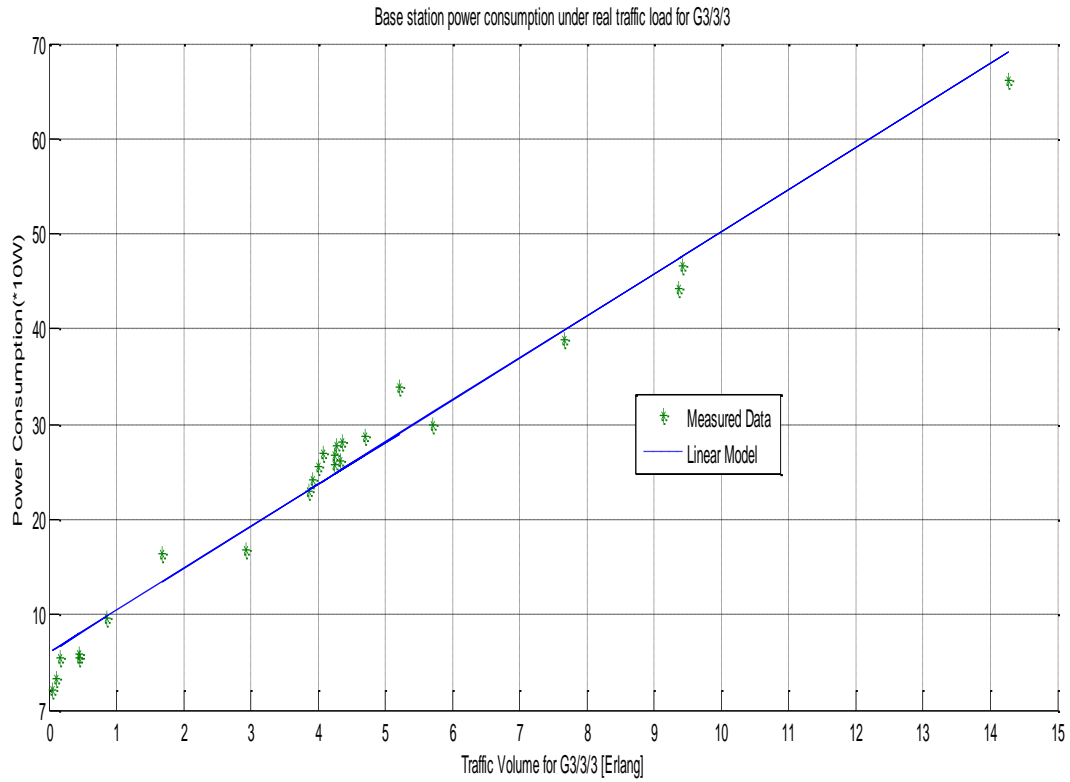
$$P = 92.9T + 789.0 \quad (5.11)$$



Graph 6: Linear Regression result for G4/6/8

5.4.3 The linear regression method for Low traffic cases

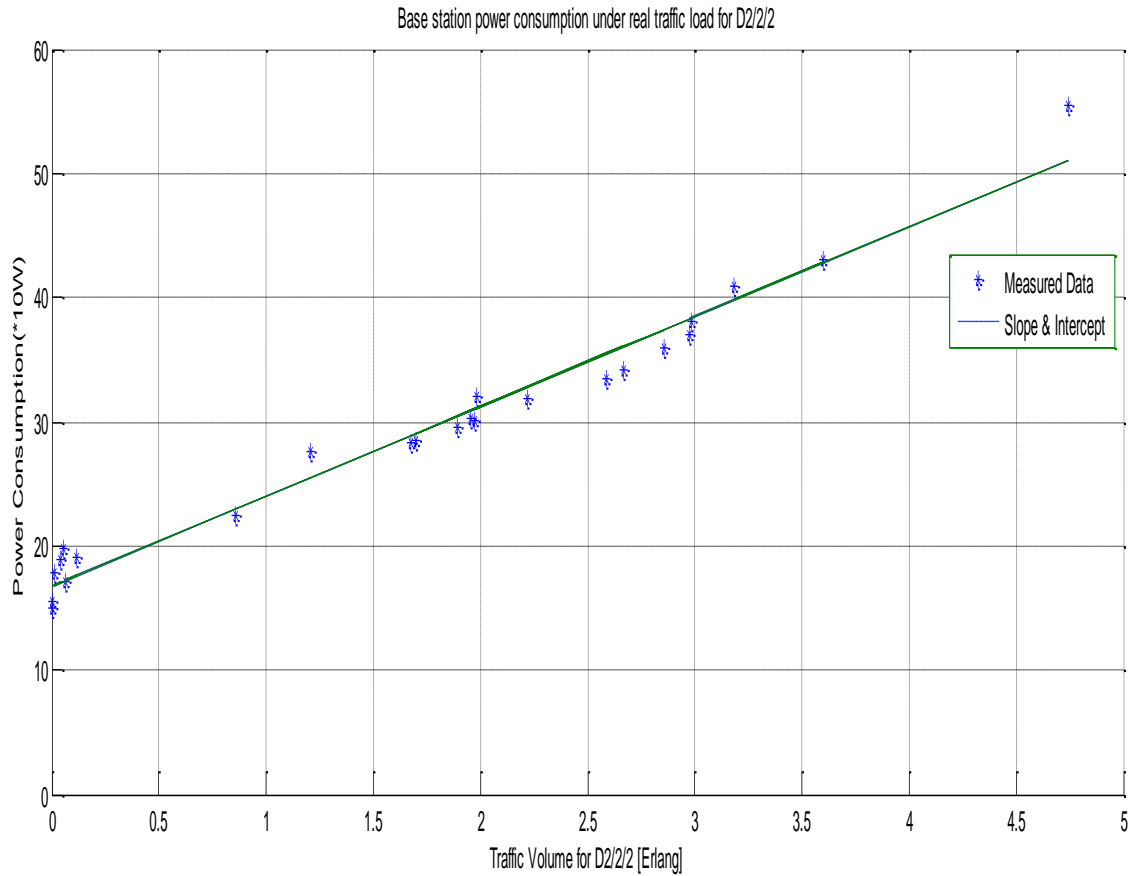
For GSM900 low traffic with a configuration of G3/3/3



Graph 7: Linear Regression result for G3/3/3

$$P = 44.15T + 60.31 \quad (5.12)$$

For GSM1800 low traffic with a configuration of D2/2/2



Graph 8: Linear Regression result for D2/2/2

$$P = 72.4T + 167.7 \quad (5.13)$$

5.5 Power Consumption Model Analysis

Therefore, active site power consumption also varies according to changes in the traffic intensity. Additionally, we develop for each of the analysed BSs, a linear power consumption model. The proposed model with a significant percentage of confidence follows the results obtained through precise on-site measurements. It is also noted that the power level required goes hand in hand with

increased traffic load, which is justified by the linear regression line in the above graphs. As per the above equations, when the traffic load is very low, the proposed linear models ensure some fixed amount of power consumption. If we consider a null effect of low traffic demand (since, the weight of dependent variable is too small), the intercept value still ensures some residual power consumption. It means during no traffic; certain amount of power consumption is always taken by BSs.

Therefore, linear power consumption model can be accepted as a model for precise expression of the interdependence between instantaneous base station power consumption and traffic load. This interdependence is important for our future studies focused on improving the energy efficiency of already installed BSs

Now, it is urgent to shift towards energy efficient wireless communication with all possible measures in order to serve traffic on demand more dynamically. Hence, by knowing the traffic variations, for instance using a prediction technique, radio resources can be adapted to the effective requests in order to save energy, which is unexploited as a fixed amount of power consumption. Please note also that, each linear model corresponds to the specific BS technology and BSs of different technologies, manufacturers, production years or configurations, which might have different linear models.

6. Optimization and Result Analysis

6.1 Traffic Adaptive Power Consumption

Recent developments have focused on reducing the power consumption of Base Stations during low-traffic periods. Typical energy saving solutions are relying on Operation and Maintenance (O&M) supervision systems to predefine time periods naturally five to six hours per night during which the unnecessary radio resources of the Base Station are shut down or switched off in order to reduce the energy consumption during this ideal time, based on user's characteristics. Even though such solutions save a significant amount energy consumption, but in turn the solution significantly degrades the Quality of Service (QoS): in case of unexpected telecom traffic rise. In this case, the system needs continues monitoring of the telecom network, in which case the radio resources will only be available after system synchronization with the different interface with a delay of 2 to 3 minutes typically. In addition, some energy saving solutions are requiring hardware updates making them difficult and inefficient to implement by the network operators which are not willing to plan a full retrofit of their equipment installed base.

Even though there are different energy saving techniques as presented in section four, for this thesis TRX power amplifier intelligent shutdown on the timeslot level is selected as energy reduction mechanism. This energy saving mechanism is selected due to two reasons; the first is easy implementation without any hardware upgrade in the existing system as this energy saving options are there in the base station controller and it only needs license upgrading. The second reason is it just saves energy during night & day with zero impact on the QoS.

Based on the linear relationship obtained in section five, power consumption of a BS consists of two parts, namely the static power consumption and the dynamic power consumption. The static power consumption is a power figure that is spent independently by the load status of the BS. On the other hand, the dynamic power consumption is strictly related to the traffic managed instantaneously by the BS. At full load the BS's radio units dominate the site's power consumption, which is completely reasonable (and to be expected), but at near zero load still significant amount

of a static power is consumed by the base station. This static power consumption is mainly due to the following reasons:

- ✓ The biasing circuit in the base stations and continuous broadcast signalling radiated by an idle time slot.
- ✓ Power consumed by the digital intermediate frequency (IF) circuit for the whole carrier.
- ✓ Digital-to-Analog/Analog-to-Digital (DA/AD) circuit.
- ✓ Low-power RF signal circuit for the receiver parts.
- ✓ Due to transport and processing units in the RRU.
- ✓ DC/AC and AC/DC conversion components.

So, studying the components of the RRU in terms of power consumption will give us a hint for power consumption optimization points of the radio system.

An evolution of the heterogeneous network deployment is the coordinated multi-point (CoMP) transmission technology. CoMP divides the traditional base station in two part: the baseband unit (BBU) and the remote radio unit (RRU). The BBU is connected to the RRU via optical fibre and can be placed in a different part with respect to the RRUs it is managing. So, by considering CoMP, the optimal RRU placement can be derived in order to minimize the average transmission power.

6.2 Logical Structure of the RRU

The RRU, which features a modular design, consists of the interface module, transceiver (TRX), Power Amplifier (PA), filter, Low Noise Amplifier (LNA), extended interface, and power module.

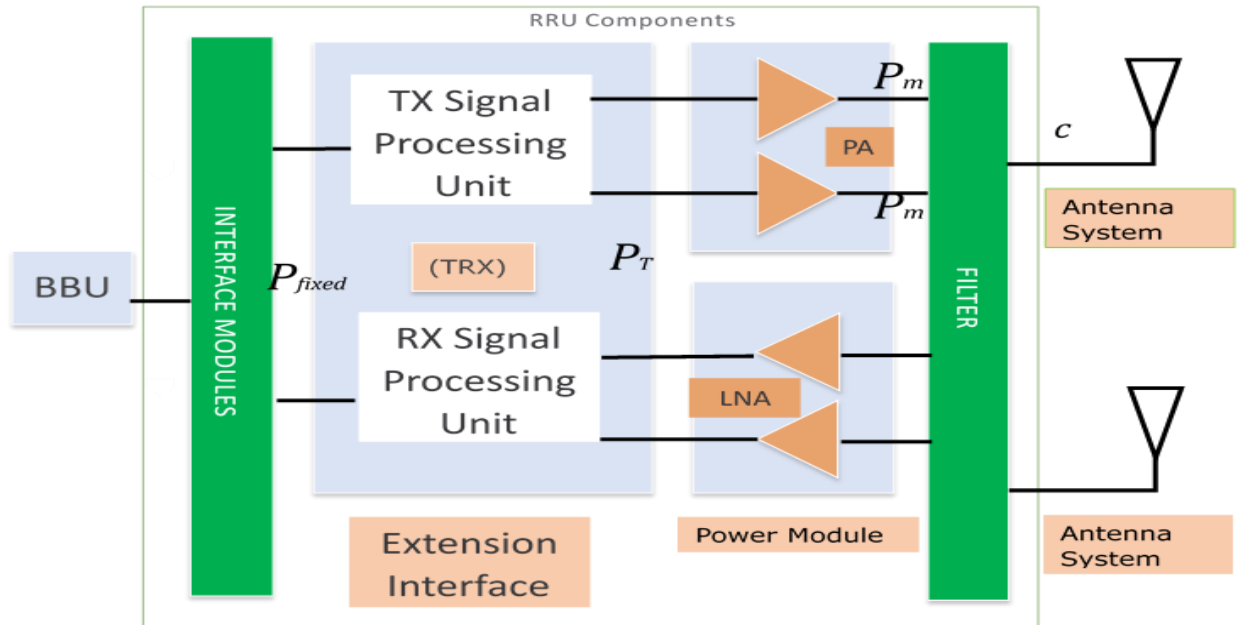


Figure 23: RRU Components

6.2.1 Interface Module

The interface module performs the following functions:

- Receives the downlink baseband data from the BBU.
- Transmits the uplink baseband data to the BBU.
- Forwards data from the cascaded RRUs.

6.2.2 Transceiver (TRX)

The TRX with old version of the Huawei's remote radio unit (such as RRU3804, RRU3801E, or RRU3806) provides two RX channels and only one TX channel for RF signals. But, the latest versions TRX which are installed in Ethiopia (Such as RRU3805, RRU3808, RRU3908, RRU3828, RRU3928, RRU3936 or RRU3929 type) provides two RX channels and two TX channels for RF signals.

The TRX in the RRU performs the following functions at the RX channels:

- Down-converts the received signals to Intermediate Frequency (IF) signals.
- Amplifies the IF signals.
- Performs Analog-to-Digital Conversion (DAC).
- Performs digital down-conversion.

- Performs matched filtering.
- Performs Digital Automatic Gain Control (DAGC).

The TRX in the RRU performs the following functions at the TX channels:

- Shapes and filters downlink spread spectrum signals.
- Performs Digital-to-Analog Conversion (DAC).
- Up-converts IF signals to the TX band.

6.2.3 Power Amplifier (PA)

The PA adopts the Digital Pre-Distortion (DPD) and Advanced-Doherty (A-Doherty) technologies to amplify the low-power RF signals from the TRX.

6.2.4 Filter

The duplex filter multiplexes one RX and one TX signals over RF channels so that they can share one antenna channel. In addition, it filters RX and TX signals.

6.2.5 Low Noise Amplifier (LNA)

The LNA amplifies the signals received from the antenna system.

6.2.6 Power Module

The power module supplies power to other modules of the remote radio units.

6.3 Detailed Optimization Framework

Moreover, an optimization framework is introduced to find the optimum network configuration able to minimize the global power consumption for a given number of simultaneous active users.

In this work, we developed a generic framework for measurement and modelling of the power consumption at a base station and once the required power consumption versus traffic load variations are obtained the best energy saving solution among the available options in the base station and base station controller will be applied in the mobile network as an energy saving resolution.

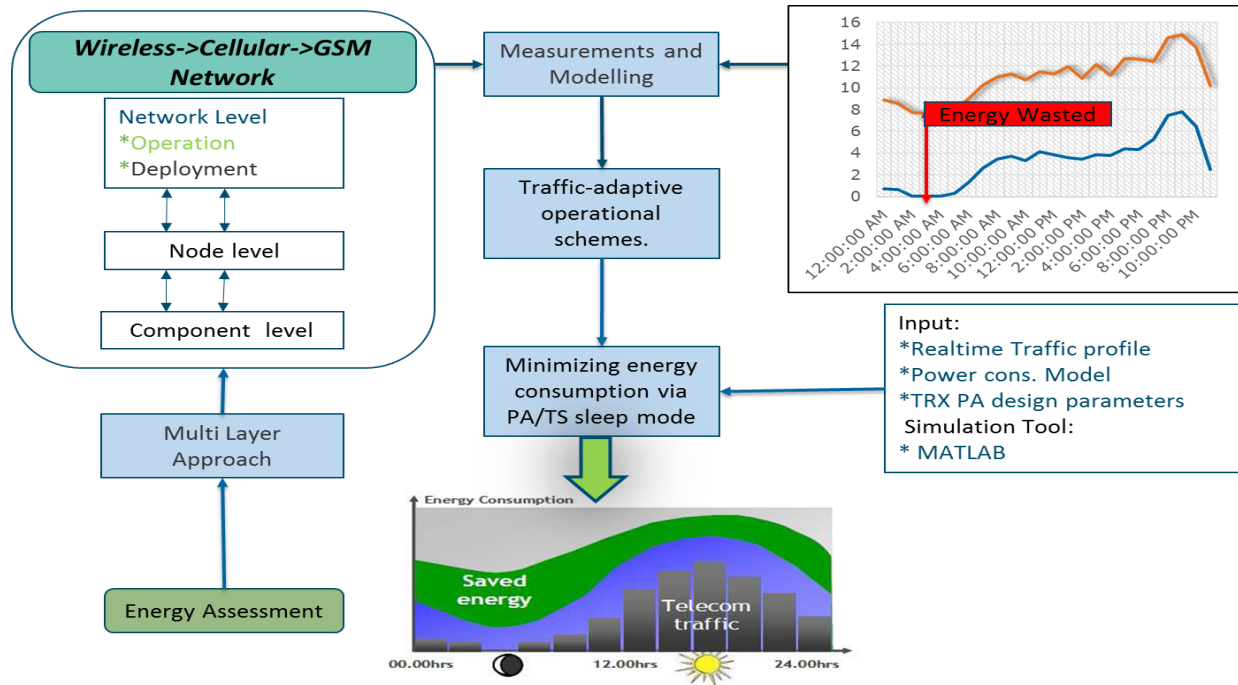


Figure 24: System frame work

6.4 Framework for Applying Energy Reduction

- ✚ We consider a cell with a set of available resources and activate resources based on the cell traffic load or it means resources are activated based on the instantaneous number of users in the cell. When a resource is not needed to ensure the target QoS, it is switched off to reduce global energy consumption of the base station as a whole.
- ✚ Based on queuing theory modelling, drive the performance of the proposed schemes, in terms of energy efficiency and quality of service (QoS).
- ✚ Apply the analysis on realistic network.
- ✚ Demonstrate obtained energy savings based on throughput figures of a typical working days for a specific high and low traffic cell.

6.4.1 Energy Saving

Consider a cell with a pool of R resources (TRX), If the load of resource $r \in [1 R]$, the power consumption of a base station becomes:

$$P_{BS} = P_{Static} + \sum_{r=1}^R [P_{TRX} + T_r(P_{max}/c)] \quad (6.1)$$

$$P_{RRU} = P_{cst} + \sum_{r=1}^R [T_r(P_{max}/c)] \quad (6.2)$$

Where;

C is the DC to RF conversion factor.

P_{max} is the radio frequency output power of the power amplifier.

P_{TRX} is the fixed power consumption of the radio module (transceiver).

P_{cst} is a constant power consumption due to transport and processing units in the RRU.

P_{static} is a fixed power consumption due to transport and processing units in the base station.

From the result obtained in Chapter Five, the constant or fixed power consumption part which is due to transport and processing units in the remote radio unit is very high, which is 40-60% of its peak. So that, the proposed energy saving schemes shall reflect minimizing the fixed energy consumption, which has no any direct relationship with the carried traffic.

Finding the good trade-off between the power consumed and resource utilization of a network is a good parameter for energy optimization schemes. Hence, the capacity/channel required to accommodate the given traffic shall be first calculated and compared with the designed system for a given load predictions and blocking probabilities by using Poisson distribution or Erlang B formula.

6.4.2 Poisson Distribution or Erlang B

Assume that there are a finite number of channels available in the trunking pool. The Erlang B formula (also known as the blocked calls cleared formula) determines the probability that a call is blocked and is a measure of the Grade of Service (GOS) for a trunked system which provides **no** queuing for blocked calls.

For a real-time energy saving schemes, Ethio-telecom's traffic forecast techniques, Holt-Winter forecast (HWF) model have to be used for cellular networks. The network dimensioning is done by approximating the traffic volume with a given distribution function. Following this strategy, the user's arrival is modelled according to a Poisson process while the breaking time is exponentially distributed.

$$\Pr(\text{blocking}) = \frac{\frac{A^C}{C!}}{\sum_{k=0}^C \frac{A^k}{K!}} = GOS \quad (6.3)$$

Where:

- P_r probability of call failure (“2% blocking assumed for Ethio-telecom network”).
- A offered traffic in Erlangs (number of simultaneous calls).
- C number of channels (No. of voice calls directed to TCHF).

Using the above formula, the resources that are needed in order to ensure the target QoS is obtained; so that it will be easy to calculate the underutilized resources in the base stations.

6.4.3 Considered Assumptions

- 2% Target Blocking Probability is considered for Ethio-telecom network, which is obtained from their engineering office.
- Only voice calls will be directed to GSM (TCHF) base station, while data traffic (Static PDCH) will be carried by 3G or LTE systems.
- Activate resources only when they are needed to satisfy user demand and QoS requirement.

6.4.4 BS Designed Parameters

The configuration parameters or the low-level design (LLD) for base stations with site ID No. *112110* and *112223* of GSM900MHz and GSM1800MHz technologies have been examined for the analysis,

Table 2: Designed parameters

Cell Name	S3655: Number of configured TRXs in a cell	CR3000: Number of Initially Configured Channels (SDCCH)	CR3001: Number of Initially Configured Channels (Static PDCH)	CR3007: Number of Initially Configured Channels (TCHF)	Designed Traffic in Erlang @2% of GoS
112110_CAAZ.AA-D1	6	32	6	37	28.25357565
112110_CAAZ.AA-D2	4	24	4	24	16.63057649
112110_CAAZ.AA-D3	6	32	6	37	28.25357565
112110_CAAZ.AA-G1	4	24	4	24	16.63057649
112110_CAAZ.AA-G2	6	32	6	37	28.25357565
112110_CAAZ.AA-G3	8	64	12	43	33.76042501
112223_NAAZ.AA-D1	2	16	3	10	5.08400463
112223_NAAZ.AA-D2	2	8	2	12	6.614718301
112223_NAAZ.AA-D3	2	8	2	12	6.614718301
112223_NAAZ.AA-G1	3	24	4	16	9.828449178
112223_NAAZ.AA-G2	3	24	4	16	9.828449178
112223_NAAZ.AA-G3	3	24	4	16	9.828449178

From the designed parameters, the base station with the site ID No. 112110 designed to provide a voice service for GSM900MHz of 78.64Erlang and for GSM1800MHz of 73.13Erlang with 202 voice traffic channels. The base station with the site ID No. 112223 designed to provide a voice service for GSM900MHz of 29.48Erlang and for GSM1800MHz of 18.31Erlang with 82 voice traffic channels.

Besides, BSC snapshots for both base stations has taken from the operator to check the availability of the said underutilized resources.

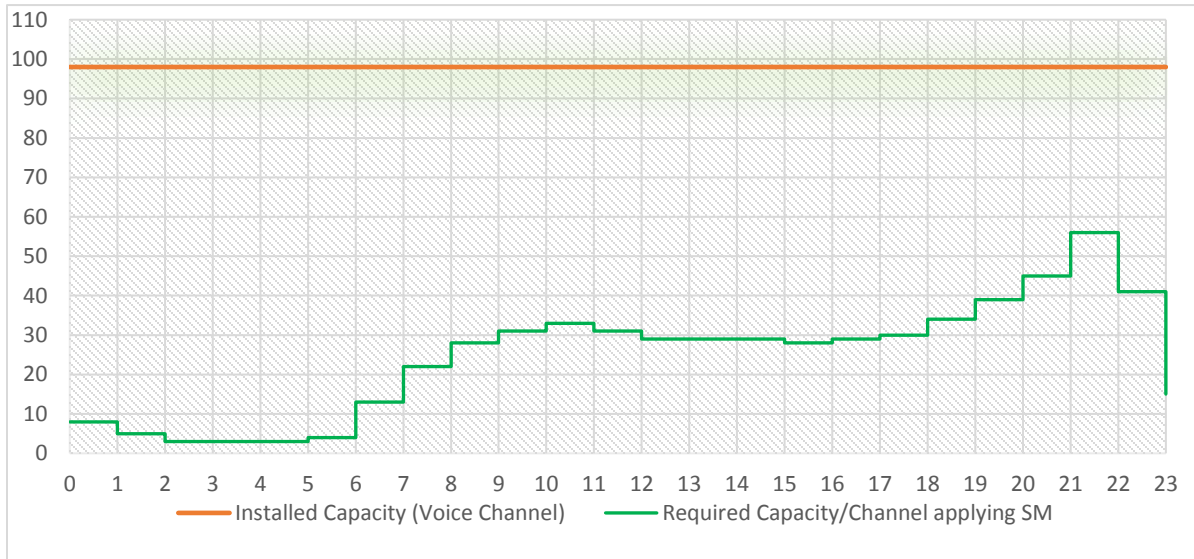
Site: 112110_DG_WL_GUL_BSCRNC1		Cell: All		TRX No.: All						
Site Name	Cell Name	TRX No.	Channel 0	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7
L_BSCRNC1.HW.YKNG	BSCRNC1.HW.YKNGA1	0	Main BCCH ○	SDCCH/8 ●●●●○○○○	TCH/F ○	PDTC ○	PDTC ○	PDTC ○	PDTC ○	PDTC ○
L_BSCRNC1.HW.YKNG	BSCRNC1.HW.YKNGA1	1	TCH/H ○	TCH/F ○	TCH/H ○	TCH/H ○	TCH/H ○	TCH/F ○	SDCCH/8 ○○○○○○○○	SDCCH/8 ○○○○○○○○
L_BSCRNC1.HW.YKNG	BSCRNC1.HW.YKNGA1	2	TCH/H ○	TCH/F ●	TCH/H ○	TCH/F ●	TCH/H ○	TCH/F ●	TCH/F ○	TCH/F ●
L_BSCRNC1.HW.YKNG	BSCRNC1.HW.YKNGA1	3	TCH/F ●	TCH/H ○	TCH/F ○	TCH/F ○	TCH/H ○	TCH/H ○	TCH/H ○	TCH/H ○
L_BSCRNC1.HW.YKNG	BSCRNC1.HW.YKNGA1	4	TCH/H ○	TCH/F ○	TCH/F ○	TCH/H ○	TCH/F ○	TCH/F ○	TCH/H ○	TCH/H ○
L_BSCRNC1.HW.YKNG	BSCRNC1.HW.YKNGA1	5	TCH/H ○	TCH/F ○	TCH/F ○	TCH/H ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/H ○
L_BSCRNC1.HW.YKNG	BSCRNC1.HW.YKNGA1	6	Main BCCH ○	SDCCH/8 ●●○○○○○○●	TCH/F ○	PDTC ○	PDTC ○	PDTC ○	PDTC ○	PDTC ○
L_BSCRNC1.HW.YKNG	BSCRNC1.HW.YKNGA1	7	PDTC ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	SDCCH/8 ○○○○○○○○	SDCCH/8 ○○○○○○○○
L_BSCRNC1.HW.YKNG	BSCRNC1.HW.YKNGA1	8	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○
L_BSCRNC1.HW.YKNG	BSCRNC1.HW.YKNGA1	12	Main BCCH ○	SDCCH/8 ○○○○○○○○●	TCH/F ○	TCH/F ○	TCH/F ○	PDTC ○	PDTC ○	PDTC ○
L_BSCRNC1.HW.YKNG	BSCRNC1.HW.YKNGA1	13	TCH/H ○	TCH/H ○	TCH/H ○	TCH/H ○	TCH/F ○	TCH/F ○	SDCCH/8 ○○○○○○○○	SDCCH/8 ○○○○○○○○
L_BSCRNC1.HW.YKNG	BSCRNC1.HW.YKNGA1	15	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○
L_BSCRNC1.HW.YKNG	BSCRNC1.HW.YKNGA1	18	Main BCCH ○	SDCCH/8 ●○○○○○○○○	TCH/F ○	TCH/F ○	PDTC ○	PDTC ○	PDTC ○	PDTC ○
L_BSCRNC1.HW.YKNG	BSCRNC1.HW.YKNGA1	19	PDTC ○	PDTC ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	SDCCH/8 ○○○○○○○○	SDCCH/8 ○○○○○○○○
L_BSCRNC1.HW.YKNG	BSCRNC1.HW.YKNGA1	20	SDCCH/8 ○○○○○○○○	TCH/H ○	TCH/H ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/H ○
L_BSCRNC1.HW.YKNG	BSCRNC1.HW.YKNGA1	21	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	PDTC ○	TCH/F ○	TCH/F ○
L_BSCRNC1.HW.YKNG	BSCRNC1.HW.YKNGA1	22	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/H ○	TCH/F ○	TCH/F ○
L_BSCRNC1.HW.YKNG	BSCRNC1.HW.YKNGA1	26	Main BCCH ○	SDCCH/8 ●○○○○○○○○	TCH/F ○	TCH/F ○	PDTC ○	PDTC ○	PDTC ○	PDTC ○
L_BSCRNC1.HW.YKNG	BSCRNC1.HW.YKNGA1	27	PDTC ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	SDCCH/8 ○○○○○○○○	SDCCH/8 ○○○○○○○○
L_BSCRNC1.HW.YKNG	BSCRNC1.HW.YKNGA1	29	TCH/H ○	TCH/F ○	TCH/F ○	TCH/H ○	TCH/H ○	TCH/F ○	TCH/F ○	TCH/F ○
L_BSCRNC1.HW.YKNG	BSCRNC1.HW.YKNGA1	34	Main BCCH ○	SDCCH/8 ○○○○○○○○	TCH/F ○	PDTC ○	PDTC ○	PDTC ○	PDTC ○	PDTC ○
L_BSCRNC1.HW.YKNG	BSCRNC1.HW.YKNGA1	35	PDTC ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	SDCCH/8 ○○○○○○○○	SDCCH/8 ○○○○○○○○
L_BSCRNC1.HW.YKNG	BSCRNC1.HW.YKNGA1	36	SDCCH/8 ○○○○○○○○	TCH/H ○	TCH/H ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○

Figure 25: BSC Snapshots for 112110

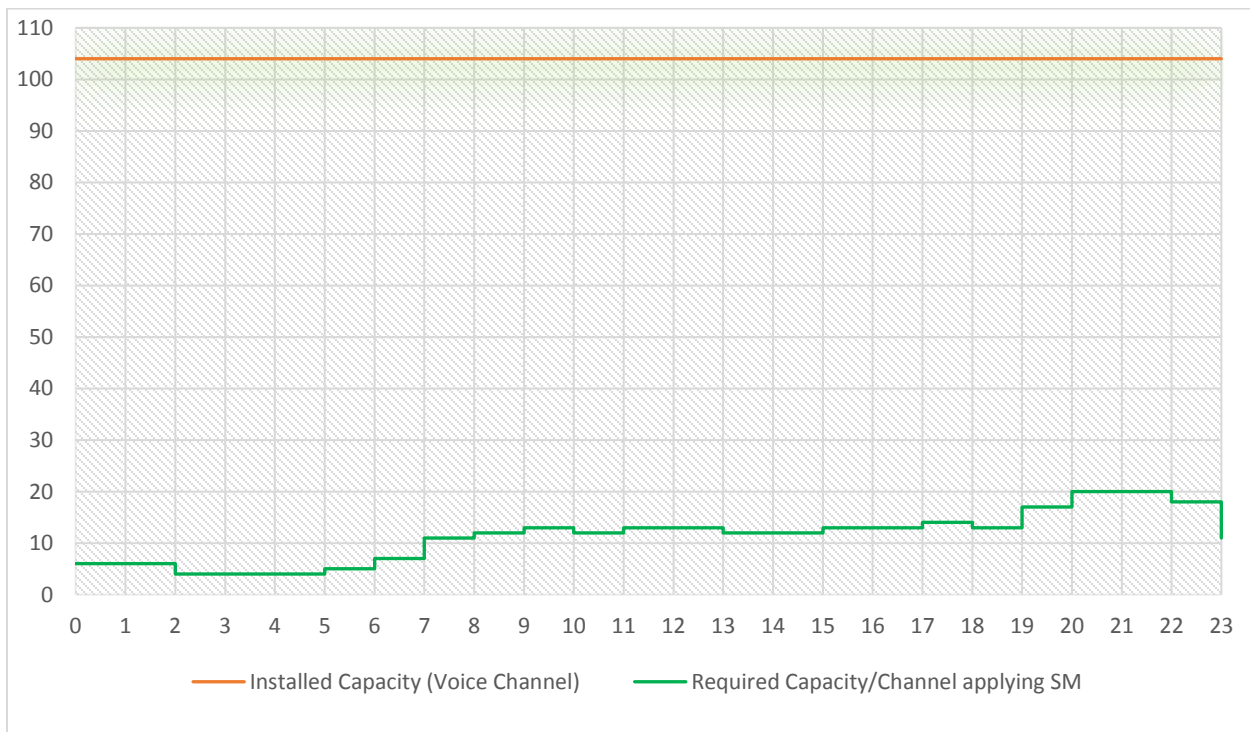
Site Name	Cell Name	TRX No.	Channel 0	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7
J_BSCRNC1.HW.SLTA	BSCRNC1.HW.SLTA	0	Main BCCH ○	SDCCH/8 ○○○●○○○○	TCH/F ○	TCH/F ○	TCH/F ●	TCH/F ○	PDTC ○	PDTC ○
J_BSCRNC1.HW.SLTA	BSCRNC1.HW.SLTA	1	SDCCH/8 ○○○○○○○○	TCH/F ○	TCH/F ○	TCH/F ○	PDTC ○	PDTC ○	TCH/F ○	TCH/F ○
J_BSCRNC1.HW.SLTA	BSCRNC1.HW.SLTA	2	SDCCH/8 ○○○○○○○○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ●	TCH/F ○	TCH/F ○	TCH/H ○○
J_BSCRNC1.HW.SLTA	BSCRNC1.HW.SLTA	3	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/H ○○	TCH/F ○	TCH/F ○
J_BSCRNC1.HW.SLTA	BSCRNC1.HW.SLTA	4	Main BCCH ○	SDCCH/8 ○○○○○○○○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	PDTC ○	PDTC ○
J_BSCRNC1.HW.SLTA	BSCRNC1.HW.SLTA	5	SDCCH/8 ○○○●●○○○	SDCCH/8 ○○○○○○○○	TCH/F ○	PDTC ●	PDTC ○	PDTC ○	TCH/F ○	TCH/F ○
J_BSCRNC1.HW.SLTA	BSCRNC1.HW.SLTA	6	SDCCH/8 ○○○○○○○●	SDCCH/8 ○○○○○○○○	TCH/F ○	TCH/F ●	TCH/F ○	TCH/H ○○	TCH/F ○	TCH/F ●
J_BSCRNC1.HW.SLTA	BSCRNC1.HW.SLTA	7	SDCCH/8 ○○○○○○○○	SDCCH/8 ○○○○○○○○	TCH/F ●	TCH/F ○	TCH/F ●	TCH/F ●	TCH/F ●	TCH/F ●
J_BSCRNC1.HW.SLTA	BSCRNC1.HW.SLTA	8	Main BCCH ○	SDCCH/8 ○○○○○○○○	TCH/F ○	TCH/F ○	TCH/F ○	PDTC ○	PDTC ○	PDTC ○
J_BSCRNC1.HW.SLTA	BSCRNC1.HW.SLTA	9	TCH/F ○	TCH/H ○○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○
J_BSCRNC1.HW.SLTA	BSCRNC1.HW.SLTA	10	SDCCH/8 ○○○○○○○○	TCH/F ○	TCH/F ○	TCH/H ○○	TCH/H ○○	TCH/F ●	TCH/F ○	TCH/F ○
J_BSCRNC1.HW.SLTA	BSCRNC1.HW.SLTA	12	Main BCCH ○	SDCCH/8 ●○○○○○○○	TCH/F ○	TCH/F ○	TCH/F ○	PDTC ○	PDTC ○	PDTC ○
J_BSCRNC1.HW.SLTA	BSCRNC1.HW.SLTA	13	SDCCH/8 ○○○○○○○○	TCH/H ○○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○	TCH/F ○
J_BSCRNC1.HW.SLTA	BSCRNC1.HW.SLTA	14	Main BCCH ○	SDCCH/8 ○○○○○○○○	PDTC ○	PDTC ○	PDTC ○	PDTC ○	TCH/F ○	TCH/F ○
J_BSCRNC1.HW.SLTA	BSCRNC1.HW.SLTA	16	Main BCCH ○	SDCCH/8 ○○○○○○○○	TCH/H ○○	TCH/F ○	TCH/F ○	TCH/F ○	PDTC ○	PDTC ○

Figure 26: BSC Snapshots for 112223

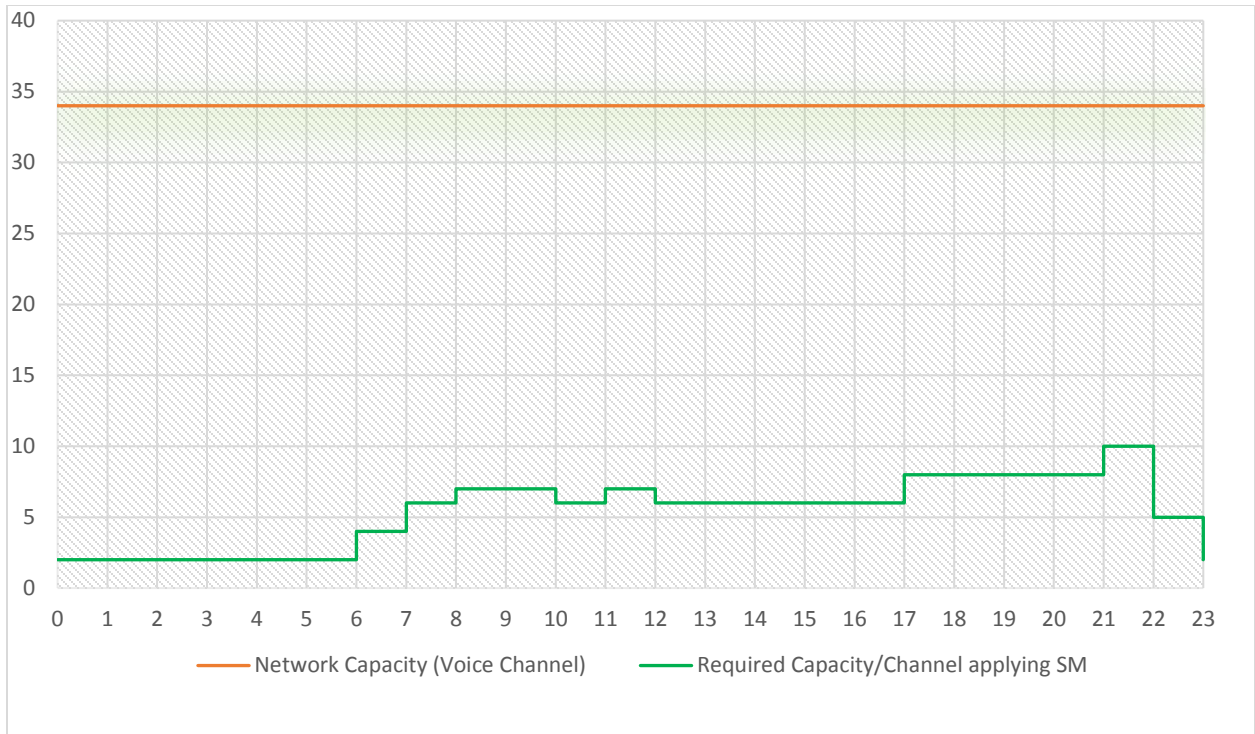
Based on the Erlang B formula, the required capacity for specific traffic load and installed network capacity are calculated for each base station considered in the thesis as follows;



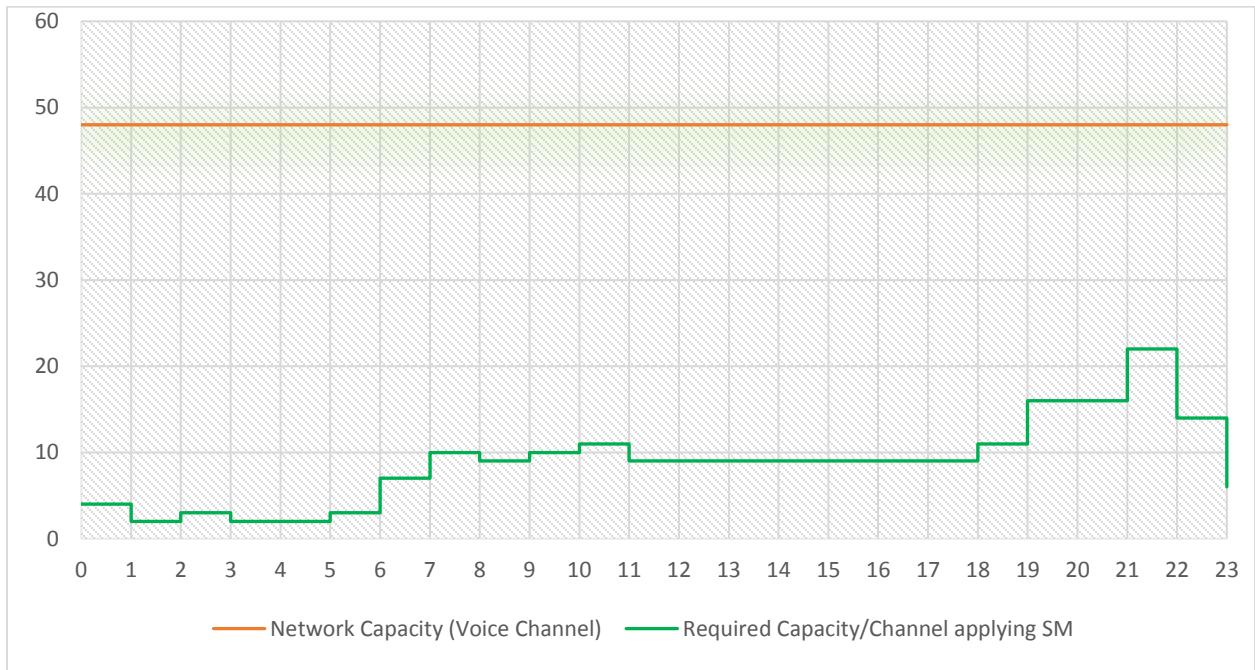
Graph 9: D646 Network Capacity



Graph 10: G468 Network Capacity



Graph 11: D222 Network Capacity



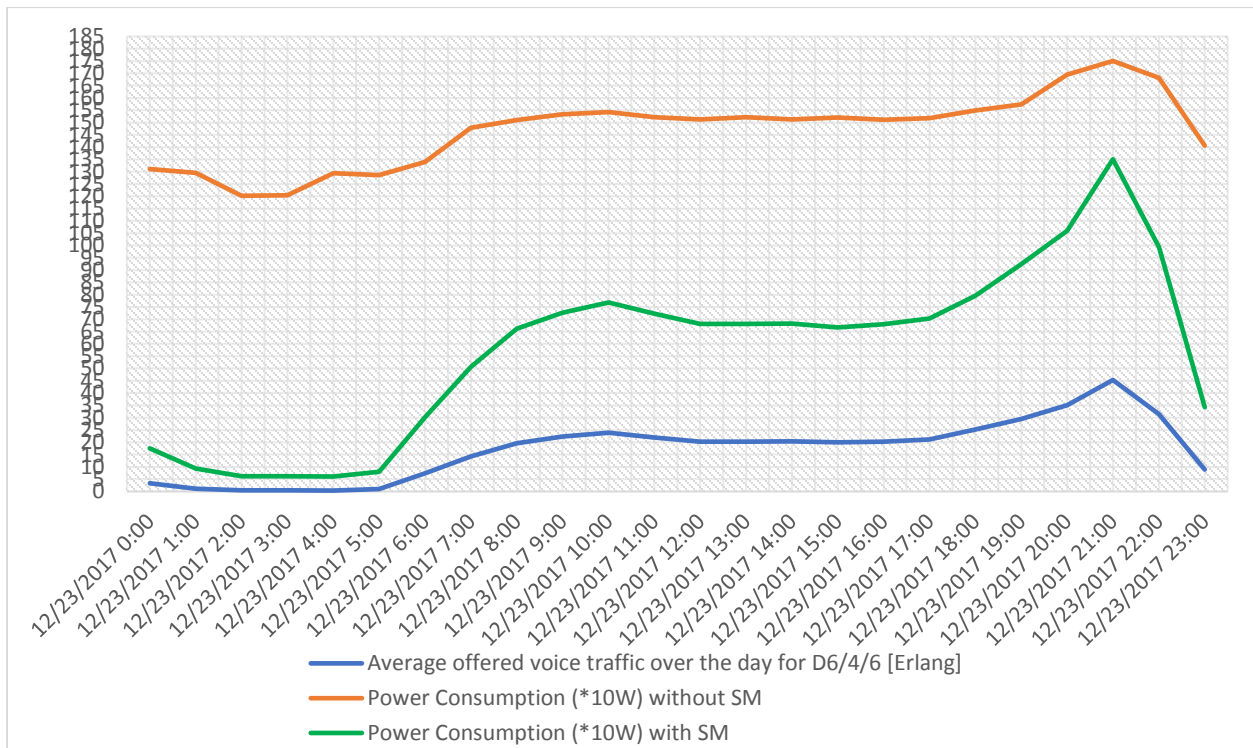
Graph 12: G333 Network Capacity

6.5 Numerical Results

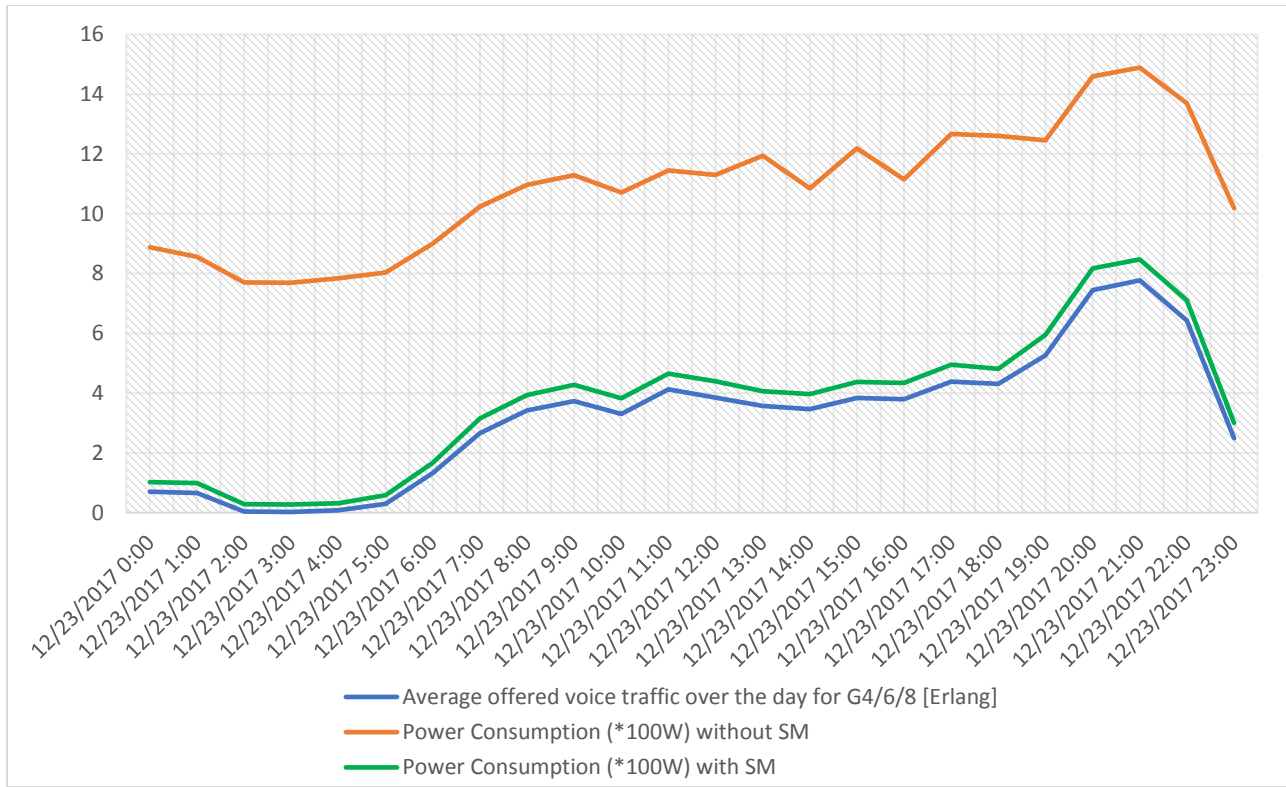
To illustrate the gains introduced by implementing a sleep mode in the base station, we consider the voice traffic of a typical days where the power measurement was conducted. The following considerations were taken for optimization;

- The power reduction is made on the fixed power consumption from obtained power consumption model previously.
- (TS0 & TS1) in the 1st carrier is used as broadcast and synchronization channels, the remaining channels (TS2 & TS7) in the 1st carrier are used for traffic.
- Time slots in the other carriers are all used for traffic.

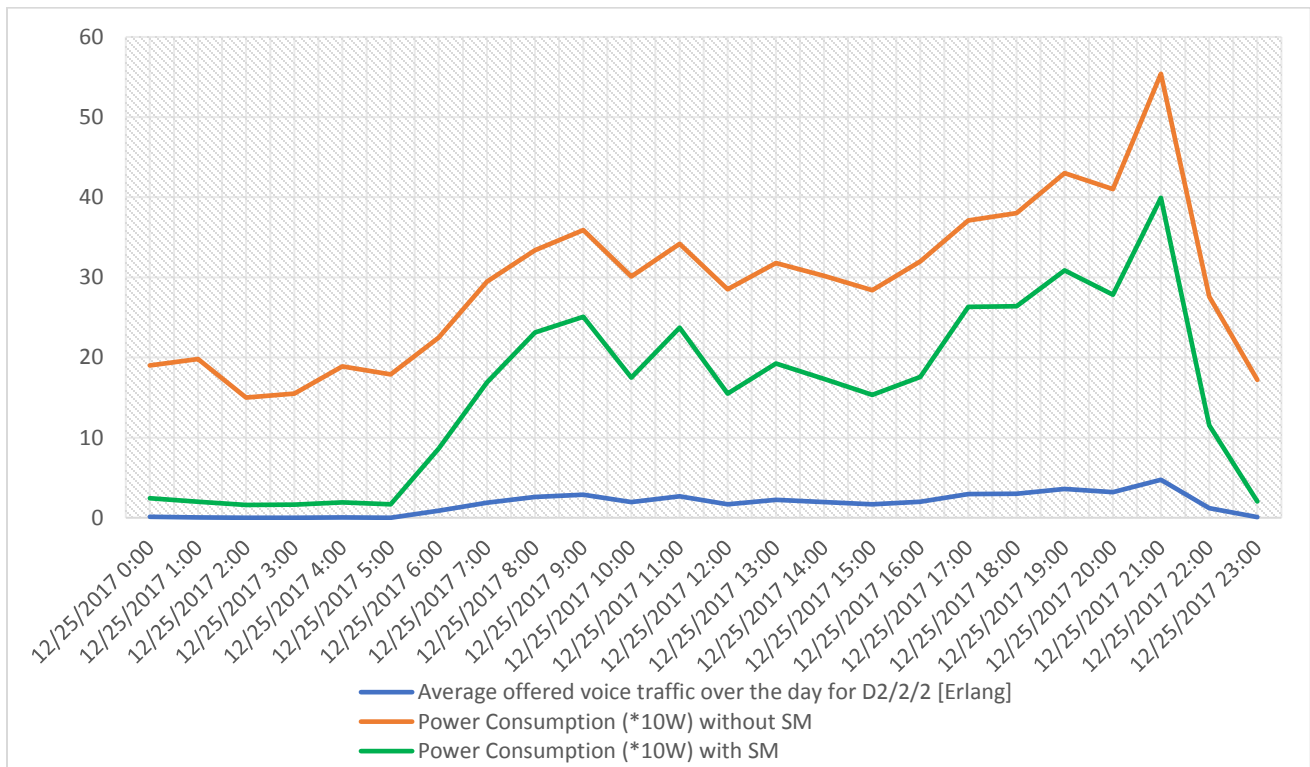
Here are some numerical results in which the energy consumption savings are illustrated.



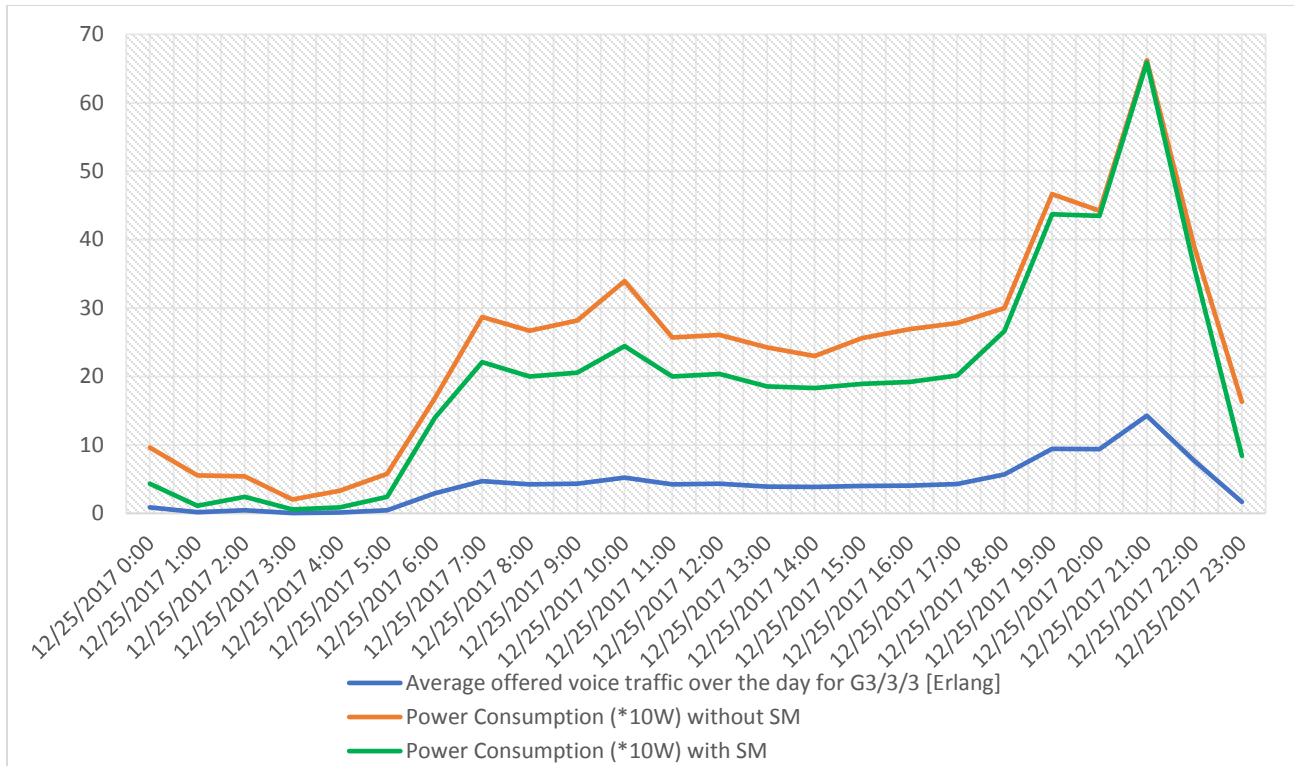
Graph 13: Energy consumption with & without sleep mode for D6/4/6



Graph 14: Energy consumption with & without sleep mode for G4/6/8



Graph 15: Energy consumption with & without sleep mode for D2/2/2



Graph 16: Energy consumption with & without sleep mode for G3/3/3

Among the power saving features in a base station and base station controller, TRX power amplifier intelligent shutdown on the timeslot level which enables switching on and switching off power amplifiers (PA) of the GSM TRX modules according to traffic conditions; saves energy during night & day with zero impact on the QoS, as the assumption of 2% GOS. The Field measurements and obtained power consumption model have confirmed time averaged savings of up to 25% of the total base station power consumption for macro base station and 10% energy saving for micro base station.

With a software upgrade for Ericson equipment's and to all Alcatel-Lucent GSM Base Stations deployed and a firmware upgrade /license/ for all type of configurations for Huawei and ZTE equipment, Ethio-telecom can implement it more quickly resulting an immediate carbon footprint and operating expenses reductions. As a result, this is a very efficient solution to minimize the power consumption in all type of markets, emerging and mature.

This power saving mode is very efficient because it can be applied at precise time increments and the system can anticipate how many time slots need to be active to process the anticipated traffic:

the reaction is immediate. Since this application works dynamically at the time slot level, there is no time delay when the radio resources would be in restart/warm-up mode, while traffic would be high. As a result, there is no impact on the QoS, and it enables power consumption savings not only during low traffic hours (typically, at night) but also during the rest of the day when there is still significant traffic but a few time slots may remain idle.

7. Conclusions and Future Works

7.1 Conclusions

The main goal of this research was to develop a model for the power consumption of BSs as per the carried traffic in a real time base station. So that, the impact of traffic on the BS power consumption is monitored. The traffic and power consumption data of two BSs were collected for two working and weekend days for 24 hours on hourly basis. For each BS, the linear model has been developed using a linear regression technique. So that, for every BS, the power consumption is found to be varied proportionally with the traffic loads showing a high correlation between the variables, which means traffic loads could be a prominent source that the consumption of power heavily lies upon regardless of all other random constraints. Hence, the proposed model presents a significant result and can be accepted as a model for precise expression for BS power consumption under real traffic loads. The result can be further taken for prediction of the power usage of a base station from its annual traffic forecast data of the planning department.

From the proposed traffic versus power consumption model, we have found that the static part of the power consumption is very large; in order to optimize this fixed amount of power a TRX power amplifier intelligent shutdown on the timeslot level algorithm is selected as a reduction technique. The main goal of the considered algorithm is the adaption of the number of active carriers to the daily traffic profile. By considering that, during the day, the number of active carriers can be kept constant and equal to the needed carriers at the peak hour, a significant energy saving is afforded. Actually, considering a very low traffic window, as in the night-time, just one carrier is effectively required to guarantee the access to the service. In a similar way, during the other windows of non-peak hours, the algorithm works by simply activating the needed resources. The field measurements confirmed that Ethio-telecom could save up to 25% average energy for macro & up to 10% energy gain for micro BSs by switching ON/OFF a resource or a timeslot from BSC.

In addition to the measured gain due to dynamic resource management, putting the timeslots dedicated for voice service will also enhance the air conditioner and the base band-processing unit to reduce their service burden, which allow them to reduce a significant amount of energy.

7.2 Future Works

As future works, it is recommended to do the following studies on base stations power consumption and practical base stations power saving features cases:

1. For a better reliability and class of the data, it is recommended to conduct a site measurement using a *Three-phase power analyzer*, for longer time on more base stations in terms of user's behavior, configuration and geography.
2. This thesis assumed that only voice calls would be directed to GSM (TCHF) base station, while data traffic (Static PDCH) supposed to be carried by 3G or LTE systems. However, it is also recommended to conduct a power consumption versus data traffic correlation in 3G and LTE.
3. In order to serve traffic on demand more dynamically, Ethio-telecom shall use readymade (which are available in the system) energy saving techniques in the system on the base station that are under operation without preserving user's QoS.
4. Set a new standard for different core and access network components to minimize power consumption and monitor for their effectiveness.

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