



Planning and Analysis of Energy Efficient Multi-RAT Networks: The case of Addis Ababa City

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On

Communication Engineering

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Abstract

Now a day's wireless communication is one of the most active areas of technology development. It enables customers to use communication services like telephony or internet services at anytime and anywhere. A multitude of varying radio access technologies has been developed in which they differ in their radio coverage, spectral efficiency, cell capacity, and peak data rate. For a network operator different radio access technology may best be suited in different parts of the network in terms of the radio environment, the expected traffic pattern, and the anticipated services. But cooperating of multiple radio access technologies by combining into a common network to allow network convergence and resource management is the main concern for the operator.

On the other hand, energy is a scarce resource and becoming a main concern due to the increasing demands on natural energy resources. Hence, implementation of energy efficient communication networks has become the main research concern currently. Therefore, avoiding of unnecessary energy consumptions by adopting sleep mode mechanisms is promising solution as BSs consume the highest proportion of energy expenditure in cellular networks. Sleep mode techniques aim to save energy by selectively turning off BSs during "off-peak" hours.

This thesis deals with the procedure of how to carry out the Multi-RAT RNP for 2G, 3G, and 4G networks and reduce power consumption of the planned network without compromising the expected service. All the required steps and methods of RNP for Multi-RATs including GSM, UMTS & LTE like dimensioning, site selection for BS location, and radio resource management strategies has been addressed. The RNP focuses specially on the coverage, capacity dimensioning and frequency planning. Finally, minimizing of BSs energy consumption by switching off selective BSs based on daily network traffic load is addressed. Hence, the main aim of this thesis is planning of energy efficient Multi-RAT network for a dense urban area and Addis Ababa city is used as a case study. The planning considers that one site may have different access technologies with different configuration scenarios, depending on the subscribers and other parameters due to the reason of GSM network is excellent for coverage and mostly used for voice service, and UMTS & LTE have less coverage and mostly used for data.

Keywords: *GSM, UMTS, LTE, Coverage, Capacity, Energy Efficiency*

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List of Acronyms

2G	Second Generation
3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
AMC	Adaptive Modulation and Coding
AuC	Authentication Center
BCCH	Broadcast Control Channel
BCH	Broadcast Channel
BSs	Base Stations
CCCH	Common Control Channel
CINR	Carrier to Interference plus Noise Ratio
CoMP	Coordinated Multipoint
CQI	Channel Quality Indicator
DCCH	Dedicated Control Channel
DCS	Digital Cellular System
DFE	Decision Feedback Equalizer
DFT	Discrete Fourier Transform
DL	Down Link
DL-SCH	Downlink Shared Channel
DTCH	Dedicated Traffic Channel
EIRP	Effective isotropic radiated power
eNodeB	Evolved Node B
EPC	Evolved Packet Core
EPS	Evolved Packet System
ETSI	European Telecommunications Standard Institute
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FSPL	Free Space Path Loss
GoS	Grade of Service
GPRS	Global Packet Radio Service

GREEN	Globally Resource- optimized & Energy-Efficient Networks
GSM	Global System for Mobile communication
HetNet Conf 4b	Heterogeneous Network Configuration 4b
HLR	Home Location Register
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSS	Home Subscriber Server
HSUPA	High Speed Uplink Packet Access
ICI	Inter Carrier Interference
IP	Internet Protocol
ISI	Inter Symbol Interference
ITU	International Telecommunications Union
LTE	Long Term Evolution
MAC	Medium Access Control
MAPL	Maximum Allowed Path Loss
MCCH	Multicast Control Channel
MCH	Multicast Channel
MCS	Modulation and Coding Scheme
MIMO	Multiple Input- Multiple Output
MLSE	Maximum Likelihood Sequence Estimation
MME	Mobility Management Entity
MS	Mobile Stations
MSC	Mobile Switching Centers
MTCH	Multicast Traffic Channel
NAS	Non-Access Stratum
NSN	Nokia Simense Network
OBF	Overbooking factor
OFDMA	Orthogonal Frequency Division Multiple Access
PAPR	Peak to Average Power Ratio
PBCH	Physical Broadcast Channel
PCCH	Paging Control Channel
PCFICH	Physical Control Format Indicator Channel
PCH	Paging Channel

PCRF	Policy and Charging Rules Function
PDCCH	Physical Downlink Control Channel
PDN	Packet Data Network
PDSCH	Physical Downlink Shared Channel
PMCH	Physical Multicast Channel
PRACH	Physical Random-Access Channel
PS	Packet Switching
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
QAM	Quadrature Amplitude Modulation
QoS	Quality of service
QPSK	Quadrature Phase Shift Keying
RAN	Radio Access Network
RAT	Radio Access Technology
RACH	Random Access Channel
RB	Resource Block
RLB	Radio Link Budget
RLC	Radio Link Control
RNP	Radio Network Planning
RRC	Radio Resource Control
RRHs	Remote Radio Heads
RRM	Radio Resource Management
RSCP	Received Signal Code Power
RSRP	Reference Signal Received Power
RSSI	Received Signal Strength Indicator
RSRQ	Reference Signal Received Quality
SC-FDMA	Single Carrier FDMA
SINR	Signal to Interference and Noise Ratio
SNR	Signal to Noise Ratio
TCH	Traffic Channel
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TMA	Tower-Mounted Amplifiers

UE	User Equipment
UL	Up Link
UMTS	Universal Mobile Telecommunications Systems
UTRAN	Universal Terrestrial Radio Access Network
VLR	Visitor Location Register
WCDMA	Wideband Code Division Multiple Access

1. Chapter One: Introduction

1.1. Overview

A cellular network is a radio network laid overland through cells. Each cell includes a fixed location transceiver which is known as the base station. Supporting a large number of users within a limited spectrum is the main concept behind cellular networks. The network can support more simultaneous users than would be possible without deploying the cellular system using the efficient utilization of the spectrum over the network coverage area. Cellular systems accommodate very large number of subscribers over a large geographic area within restricted frequency spectrum. Generally, a cellular system mainly consists of mobile stations (MS) or user equipment (UE), base stations (BS), and mobile switching centers (MSC) also known as the core network [1].

Radio Network planning is the most important part of the whole network design owing to its proximity to mobile users. The main aim of the radio network planning is to provide a cost-effective solution for the radio network in terms of coverage, capacity and quality. The radio access part of the wireless network is taken into account of essential importance in planning because it is the direct physical radio connection between the mobile equipment (ME) and the core part of the network. In order to fulfill the needs of the mobile services, the radio network should offer adequate coverage and capacity. Multiple radio access technologies (Multi-RAT) provides a cellular network to the users by incorporating GSM, UMTS, and LTE.

The radio network planning (RNP) process can be divided into different phases. Dimensioning is the initial phase of network planning. It provides the primary estimate of the network part count in addition of the capacity of those elements. The purpose of network dimensioning is to predict/estimate the desired number of radio BSs required to support a specified traffic load in a given area. Generally, dimensioning provides the first quick assessment of the probable wireless network configuration [2].

The second phase is the main phase. A site survey will address the about to-be-covered area, and the possible sites to set up the base stations will investigate. Once it supplemented all the data related to the geographical properties the estimated traffic volumes at different points of the area will be incorporated into a digital map, which consists of different pixels, each of which records all the information about the selected site locations. Based on the propagation model, the link

budget will be calculated, which will help to define the cell range and coverage threshold. Antenna gains, losses, receiver sensitivity, the fade margins are some important parameters which greatly influence the link budget. Computer simulations will evaluate the different possibilities to build up the radio network based on the digital map and the link budget results. The general objective (goal) is to achieve or attain as much coverage as possible with the optimal capacity. Here, coverage and the capacity planning are of essential importance in the whole radio network planning. The coverage planning determines the service range, and the capacity planning determines the number of to-be-used base stations and their respective capacities [3].

In the third phase, a constant adjustment will be made to ensure an optimal operation of the network. Finally, the radio plan is ready to be deployed in the area to be covered and served so that the performance of Multi-RAT network will proceed in terms of several parameters such as coverage signal level, overlapping zone, throughput, and so on.

In addition, energy efficiency in information and communications technology and in cellular mobile radio networks in particular, is a scarce resource and gaining importance not only with regard to the ecological assessment. Reducing the energy consumption of cellular systems has recently attracted the attention of network operators as energy costs make up a huge portion of today's operational expenditure [2]. Hence, GREEN is one of the major initiatives taken in the field of energy saving [4] because of its ability to enable for cellular growth while guarding against increased environmental impact. The goal is to reduce energy consumption, without compromising the offered Quality of Service (QoS), by deactivating the redundant BSs according to the native or local traffic profile and depending on the required area coverage and cell energy efficiency. Energy saving can also be achieved by adopting renewable energy resources or improving the design of certain hardware to make it more energy-efficient.

1.2. Statement of the problem

In recent years the continuous demand on high data rate and multimedia services here in Addis Ababa is growing exponentially, however; the service quality is far from being perfect in terms of coverage and capacity. This is due to the coverage and capacity limitation in the existing network of the city. In addition, currently power saving has become one of the biggest issues due to the increasing demand on natural energy resources. To provide quality of data service with reduction

of network reconfiguration costs, RNP should be done by considering power source management as on metric.

The problem which is going to address in this study is on the basis of the cellular network infrastructures built in Addis Ababa, the existing cellular network coverage and its capacity because of its limitation to fulfill advanced customer service requirements and also unnecessary energy consumptions due to traffic load variation. Hence the study will address the problem of Addis Ababa city cellular network on the basis of coverage, capacity, and QoS in addition to power consumption by planning proper energy efficient Multi-RAT network.

1.3. Objectives

1.3.1. General objective

The general objective of this thesis is planning and analyzing of energy efficient Multi-RAT network by taking Addis Ababa city as case study.

1.3.2. Specific objectives

The specific objectives to achieve the above general objective are:

- To assess basics of the three radio access technologies i.e. GSM, UMTS and LTE and also energy consumption in cellular networks.
- To perform link budget calculation, defining a mathematical model for coverage and capacity estimation of the three RAT network planning for Addis Ababa city.
- To model the network traffic, digital terrain model of the geographic structure, clutter heights, clutter classes, population and environmental traffic of Addis Ababa city.
- To study cell sleep technique and traffic load variations in cellular system based on daily hours.
- To simulate the planned network with the help of ATOLL network planning tool.
- To evaluate and discuss the performance of the planned network and saved energy based on the obtained simulation results.

1.4. Literature Review

A lot of researches have been made on RNP and Energy Efficiency of the radio access parts of the cellular system. Some of the recently published articles related to this work are reviewed as follows:

Energy cost minimization in heterogeneous cellular networks with hybrid energy supplies which is done by Bang Wang, Qiao Kong, and Qiang Yang [5]. They deal with energy cost minimization in the green heterogeneous cellular network with hybrid energy supplies. Energy cost minimization is discussed in both temporal optimization of resource allocation and spatial mobile traffic distribution. They present a solution by combining optimization of the temporal green energy allocation and spatial mobile traffic distribution by achieving spatial traffic balancing and temporal green energy balancing. As a result, the proposed algorithm is more effective in terms of significant cost reduction.

Yiming Sun [3] examines radio network planning for 2G and 3G. he deals with the procedure of how to carry out the RNP for 2G and 3G systems. The general steps and methods for wireless RNP are first addressed. Finally, the issue of RNP is discussed with special focus on the 2G and 3G networks, as well as a comparison between 2G and 3G RNP processes.

Tibebu Mekonnen [6] studies dimensioning and planning of Multi-RAT radio network by taking Bahir Dar City as case study. The thesis deals with the procedure of how to carry out the RNP for 2G, 3G and 4G systems for Bahir Dar city. He discussed RNP technologies including GSM, UMTS, and LTE with a special focus on the coverage, capacity and frequency planning for different clutter types.

A proactive approach for LTE RNP with green considerations which is developed by Wissam El-Beaino, Ahmad M. El-Hajj, and Zaher Dawy [7] presents a proactive green RNP algorithm that jointly optimizes BS locations and generates the BS on/off switching patterns based on the changing traffic conditions. This algorithm results in significant energy saving by reducing active BSs based on the daily traffic load variation.

Liang Zhang [8] introduced network capacity, coverage estimation and frequency planning of 3rd Generation Partnership Project (3GPP) LTE. He investigated the capacity and coverage of LTE based on average transmission data rate, peak transmission subscriber's numbers supported by the

system data rate and different propagation models. He also studied the frequency planning of LTE. The result addressed the interference limited coverage calculation, the traffic capacity calculation, and radio frequency assignment. Generally, the study gives macroscopic dimension and valuable estimation of the LTE system. Finally, the theoretical work of this thesis was implemented in WRAP software and by using WRAP's capacity calculation and evaluation tools.

Oliver Blume, Harald Eckhardt, Siegfried Klein, Edgar Kuehn at al. [9] discussed energy savings in mobile networks based on adaptation to traffic statistics: Deals with automatic switching off unnecessary cells, modifying the radio topology, and reduced the radiated power with methods such as bandwidth shrinking and cell micro-sleep. They use Self-Organizing Network (SON) for proper selection of the appropriate energy saving mechanism and automatic collaborative reconfiguration of cell parameters with the neighbor cells. As a result of the study introduction of micro-sleep and dynamic spectrum reduction are suitable for short-term mechanism due to its applicability at the local site, while switching of the entire sector is suited for long-term mechanism.

In addition, there are also technical and periodic papers and journals which concern on the future coexistence of 2G, 3G and 4G as well as energy efficient planning mechanisms. To the best of my knowledge, it can be generalized that the existing works did not consider both power saving and multi-service environment as part of the RNP. Hence, this thesis attempts to come up with an RNP approach that considers a power saving technique as well as a multi-service environment which carry out 2G, 3G and 4G systems.

1.5. Methodology

The methodology to be followed in order to achieve the objectives has different procedures. Generally, the overall block diagram of the methodology is as shown in the figure below.

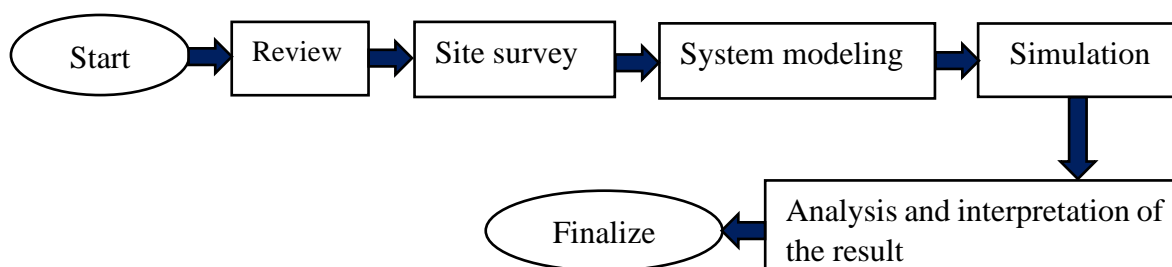


Figure 1.1: The overall block diagram of the methodology

Literature review: Includes books on this area, different IEEE articles and journals, previous studies on this subject specifically on radio network planning of each radio access technologies as well as energy reduction of cellular system.

Site Survey: Making survey to collect data by using an existing cellular network and identify and collect the customers current need and the problems occurred in the existing network service.

System modeling: Includes modeling of the selected study area network traffic, geographic digital terrain model, clutter heights, clutter classes, population, and environmental traffic then design a system which incorporates GSM, UMTS and LTE as a Multi-RAT network by considering uniformly distribution of subscribers. In addition to this, cell sleeping technique on cellular system and its impact on the network performance in terms of coverage, capacity and signal quality is discussed.

Simulation: ATOLL network planning tool is used for modeling. In the modeling and planning process, an actual data & scenario from Addis Ababa city will be used.

Analysis and Interpretation of the results: Include the conclusion and analysis of the planned network and overall performance improvements based on the results.

1.6. Scope of the study

This study focuses mainly on the essentials of coverage and capacity analysis of Multi-RAT networks and impact of cell sleep on the performance of planned network during low traffic load. It addresses energy consumption reduction of cellular network by taking one mechanism from Green network i.e. cell sleep mode technique in addition to detail coverage prediction and capacity evaluation of Multi-RAT radio network by taking into account the actual morphology and topography details. Additionally, it shows the performance variation of the planned network if some BSs are in their sleep mode when the network traffic experiences low load and compare the energy consumption of the network. It doesn't address detailed of Green network modelling and the process of how to sleep and wakeup the BSs based on the traffic load or what we call self-organization network as well as the variation of the signal strength due to on off time of the BSs, the core network dimensioning and the end-to-end service aspects such as IP backhaul and microwave transmission.

1.7. Thesis Organization

This thesis consists of six Chapters. In the first Chapter the statement of problem, literature reviews, objectives and approach with short introduction is presented. The second Chapter presents the theoretical fundamentals and basics of RAT's which includes GSM, UMTS and LTE in addition to their features related to dimensioning work. Chapter three covers fundamentals and basics of Green technology in addition to power consumption basics and energy saving techniques in cellular system. In the fourth Chapter the main part of the thesis which is Multi-RAT network with reduced power consumption is presented. This includes radio link budget, coverage and capacity planning, selection of propagation models and calculation of site numbers based on capacity and coverage planning for all RATs (GSM/UMTS/LTE). Additionally, a preliminary study on cell sleep technique and its impact in the network performance and QoS is presented in the fourth section. Chapter five presents Simulation result analysis and discussion of the of the planned network and finally Chapter six concludes with summary of the entire thesis and discusses possibilities of future research.

2. Chapter Two: Radio Access Technologies and Propagation Models

2.1 Introduction

In this section the general introduction and the overall architecture of radio access technologies are discussed. The intended technologies for network planning are GSM, UMTS and LTE.

2.2 Global System for Mobile (GSM)

GSM is an associate open, digital cellular technology used for transmitting mobile voice and data services. GSM is additionally spoken as 2G, as a result of it represents the second generation of this technology, and it it's definitely the foremost winning the most successful mobile communication system. It was specified by European Telecommunications Standards Institute (ETSI) and originally intended to be used only in Europe GSM, later on has evolved to be more or less the first truly global standard for mobile communication. The basic GSM network uses the 900MHz frequency band, but there are also several derivatives, of which the two most important are Digital Cellular System 1800 (DCS-1800; also known as GSM-1800) and PCS-1900 (GSM-1900). The prime reason for the adding of GSM 1800 frequency band was the dearth of capacity within the 900 MHz frequency band.

2.2.1 GSM architecture

GSM system comprises four subsystems named Mobile station (MS), Base Station Subsystem (BSS), Network and Switching Subsystem (NSS) and Operation and Support Subsystem (OSS).

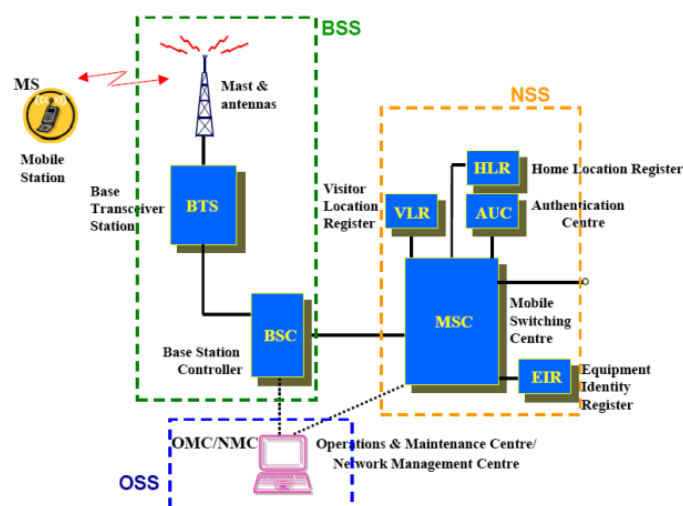


Figure 2.1: GSM Network architecture

2.2.2 Multiple access in GSM

The radio spectrum is a scarce resource. Therefore, the cellular systems use various mechanisms to allow multiple users accessing the same radio spectrum at the same time. FDMA and TDMA are the most common ones.

An FDMA system divides the available spectrum into several frequency channels. Each user is allocated 2 channels, one for uplink and another for downlink communication. This allocation is exclusive; no alternative user is allocated identical channels at the same time. Whereas in TDMA system the entire available bandwidth is shared by single user at a time only for short periods. The frequency channel is divided into timeslots so that it's allocated periodically and other users can use other time slots. Separate time slots are needed for the uplink and the downlink and also a slot is equal to one timeslot on one frequency. GSM is based on TDMA technology, each frequency channel is divided into several time slots and each user is allocated one (or more) slot(s).

2.2.3 GSM channels

In the air interface there are two types of channels named physical and logical channels. The physical channel is all the time slots of BTS and also, it's divided in two types: Half-rate (HR) and Full-rate (FR). A Logical channel refers to the particular kind of info that's carried by the physical channel and divided into two types; traffic channels and control channels.

The GSM standard is based on a multi-carrier, time-division multiple access and frequency division duplex. The carrier spacing is 200 kHz, i.e. for 124 radio frequency channels in the 900 and 374 radio frequency channels in the 1800 MHz bands, there is a guard band of 200 kHz at each end of the sub-bands. Each TDMA frame is divided into eight full slots. Each of these slots can be assigned to a FR traffic channel, two HR TCHs or one of the control channels.

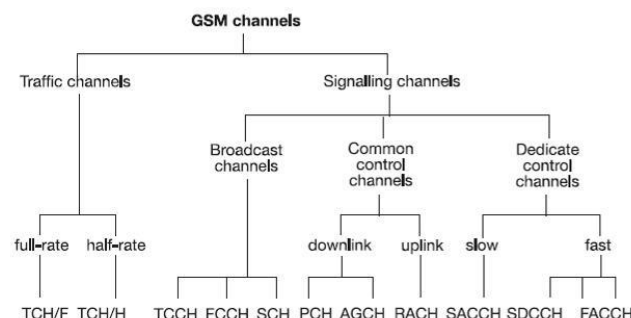


Figure 2.2: GSM channel

2.3 Universal Mobile Telecommunications System (UMTS)

The Universal Mobile Telecommunications System (UMTS) is the third generation (3G) mobile telecommunication system by using the Wide-band Code Division Multiple Access (WCDMA) air interface technology. It adopts a structure similar to the second generation (2G) mobile telecommunication system, including the Radio Access Network (RAN) and the Core Network (CN) [10]. The quality and delay requirement is much higher in UMTS networks as compared to GSM networks. The bit rates are higher which means that a larger bandwidth of 5MHz is required to support these higher bit rates. The possibility of offering subscriber variable bit rates and bandwidth on demand is an attractive feature in UMTS networks [6].

2.3.1 UMTS architecture

UMTS network architecture consists of three interacting domains: Core Network (CN), Universal Terrestrial Radio Access Network (UTRAN) and User Equipment (UE).

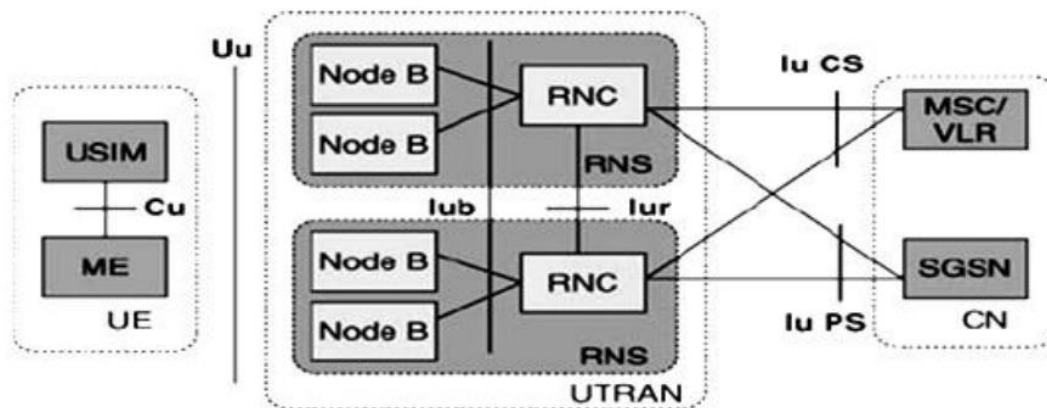


Figure 2.3: UMTS Network Architecture

User Equipment (UE): contains the mobile phone and the SIM (Subscriber Identity Module) card called Universal SIM (USIM). It has a specific data of subscribers that enables the authenticated entry of the subscriber into the network. UE exchanges data with network equipment through the Uu interface, and provides services like common voice, data, mobile multi-media and Internet application.

Uu interface: This is often the WCDMA radio interface, it's the interface through that the UE accesses the mounted (fixed) part of the system, and is thus most likely the foremost vital part

UMTS Terrestrial Radio Access Network (UTRAN): consists of one or more RNSs (radio network subsystems), which in turn consist of base stations Node B's and RNCs (radio network controllers).

Radio Network subsystem (RNS): is the equivalent of the previous Base Station Subsystem in GSM. It provides and manages the air interface for the general network.

Node B: the main function of the is to perform the air interface (channel coding and interleaving, rate adaptation, spreading, etc.) and converts the data flow between the Iub and Uu interfaces.

Radio Network controller (RNC): is the network element responsible for the control of the radio resources of UTRAN. It interfaces the CN (normally to one MSC and one SGSN) and also terminates the RRC (Radio Resource Control) protocol that defines the messages and procedures between the mobile and UTRAN. It logically corresponds to the GSM BSC.

Core network (CN): is used to process all voice calls and data connections within the UMTS system, and implements the function of external network switching and routing. Logically, the CN is divided into the CS (Circuit Switched) domain and the PS (Packet Switched) domain [11, 12].

IU interface: connects UTRAN to CN and is an open interface that divides the system into radio-specific UTRAN and CN which handles switching, routing and service control.

Iub interface: is an open normal interface connecting Node B and RNC. It allows RNC to connect to Node B from another equipment manufacturer.

Iur interface: is the interface connecting RNCs. It is specific to the UMTS system for mobility management of UEs in RAN.

Cu interface: The Cu interface is the electrical interface between the USIM card and UE, and it adopts the standard interface.

2.3.2 UMTS Operation Modes and Multiple Access

UMTS might work in two different modes i.e. TDD and FDD in other words the channels in the UL and DL will be managed in two different ways:

In FDD mode two pairs of frequency bands are used at the same time, one for UL and the other for DL. It uses WCDMA, the carried services being characterized by their symmetric traffic, like

voice. It will be used mainly in every kind of environment, particularly in macro and micro cells. In the TDD mode, both UL and DL use the same frequency, through a scheme of Time Division - Code Division Multiple Access (TD-CDMA) in unpaired bands, which will be advantageous to handle services with uneven traffic, like Internet one. It will be used primarily in pico-cells (indoor) or in hot-spot areas.

The wide BW of WCDMA provides an inherent performance gain over previous cellular systems, since it reduces the attenuation (fading) of the radio network. It uses coherent demodulation in UL, a feature that was not implemented in cellular CDMA systems.

WCDMA use BPSK (Binary phase-shift keying) and QPSK (Quadrature phase-shift keying) for data modulations in uplink and downlink respectively [13].

2.3.3 Spread spectrum

Wideband Code Division Multiple Access (WCDMA) permits several subscribers to use an identical frequency at the same time. In order to distinguish between the users, the information undergoes a process known as spreading that is, the information is multiplied by a channelization and scrambling code, hence WCDMA is referred to as a spread spectrum technology [6].

In WCDMA every user is appointed a unique code, which it uses to encode its information-bearing signal. The receiver, knowing the code sequences of the user, decodes a received signal once reception and recovers the first knowledge or information. scrambling codes (SC) and channelization codes (CC) are the two categories of spreading codes. Each transmitter (cell in downlink) is appointed completely different scrambling code and every information channel is appointed different CC code.

The bandwidth of the code signal is chosen to be much larger than the bandwidth of the information-bearing signal, hence, the encoding process spreads the spectrum of the signal. Therefore, a spread-spectrum technique should perform two criteria:

- The transmission bandwidth must be much larger than the information bandwidth;
- The bandwidth must be statistically independent of the information signal.

The flexibility supported by WCDMA is achieved with the use of Orthogonal Variable Spreading Factor (OVSF) codes for channelization of different users [13].

2.4 Long Term Evolution (LTE)

LTE network is developed by the 3GPP and also referred to as 4G wireless broadband technology. This LTE technology is used to enable fast mobile Internet connection. It is a path followed to achieve 4G speeds and a full IP technology used for the mobile broadband services for data transfer and voice calls. Wireless operators are more and more increasing their LTE networks to own advantage of additional extra efficiency, lower latency and additionally the power to manage ever-increasing traffic load. The core technologies have rapt from circuit-switching to the all-IP evolved packet core. Meanwhile, access has evolved from TDMA (Time Division Multiple Access) to OFDMA (Orthogonal Frequency Division Multiple Access) as the need for higher data speeds and volumes has increased [14]. All LTE devices got to support Multiple Input Multiple Output (MIMO) transmissions, which permit the BS to transmit multiple data streams over the identical carrier frequency simultaneously.

2.4.1 Network Architecture of LTE

3GPP identified in Release 8 that the architecture of LTE system is serving as a basis architecture network of 4G Network. The LTE architecture includes the radio access network or also called Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and Evolved Packet Core (EPC) network

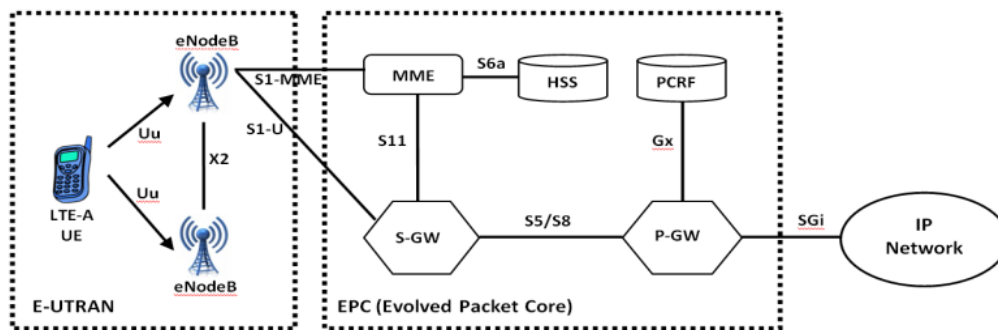


Figure 2.4: LTE Network Architecture [14]

The radio access network is used for wireless radio connection between the mobile phones and base stations of the mobile operator. Radio infrastructure is formed of the LTE mobile terminals which are Radio interface and E-UTRAN Node B (eNode B) nodes. Core Network is the brain of the system. It is formed of telephony switches that enable the different services for the mobile users [15, 14]. Core network devices connect the mobile devices within the mobile network. They

also connect the mobile network with the fixed telephony network and internet. The LTE core network or Evolved Packet Core (EPC) is formed from the Mobility Management Entity (MME), Serving Gateway (S-GW), Packet Data Network Gateway (P-GW), Home Subscriber Server (HSS) and Policy and Charging Rules Function (PCRF).

LTE mobile terminals: LTE mobile terminals are the mobile phones and alternative devices that support the LTE network. The LTE mobile station is also termed as User Equipment (UE).

eNodeB (eNB): eNB's are situated all over the network of the mobile operator. They connect the LTE mobile terminal via radio interface to the CN. The eNB's are distributed throughout the network's coverage area.

MME: MME is that the central control node within the EPC network. It is responsible for mobility and security signaling, tracking and paging of mobile terminals. It has a major role in registering UE in a network, handling mobility functions between UE and core network, and creating and keeping IP connectivity.

S-GW: transports the user traffic between the mobile terminals and external networks. It additionally interconnects the radio access network with the EPC network. It acts as a router [6, 16], and forwards data between the base station and the packet data network (PDN) gateway.

P-GW: PDN Gateway connects the EPC network to the external networks. It routes traffic to and from PDN networks. It is the highest-level mobility anchor in the system and is mainly in charge of assigning and distributing the IP addresses for the UE.

HSS: is the database of all mobile users that includes all subscriber data. It is responsible for authentication due to its ability to integrate the Authentication Center (AuC) which formulates security keys and authentication vectors. It is also responsible for call and session setup.

PCRF: is node responsible for real-time policy rules and charging in EPC network. It makes decisions on how to handle the services in terms of QoS, and provides information to the P-GW, and if applicable also to the S-GW, so that appropriate bearers and policing can be set up.

2.4.2 LTE Channels

LTE adopts a hierarchical channel structure in order to efficiently support various QoS classes of services. Channel types in LTE network are divided in to three categories. These channel types are

logical channels, transport channels and physical channels. Each channel type is associated with a service access point between different layers [17].

2.4.2.1 Logical Channels: What to Transmit

Logical channels are used by the Medium access control (MAC) to provide services to the Radio link control (RLC). Each logical channel is fixed based on the carried information type. In LTE, there are two categories of logical channels depending on the service they provide: logical control channels and logical traffic channels.

The logical control channels, which are used to transfer control plane information, include the following types [18]:

Broadcast Control Channel (BCCH): A downlink common channel accustomed broadcast system control data to the mobile terminals inside the cell, including DL system BW, antenna configuration, and reference signal power. Due to the large amount of information carried on the BCCH, it is mapped to two different transport channels: The Broadcast Channel (BCH) and the Downlink Shared Channel (DL-SCH).

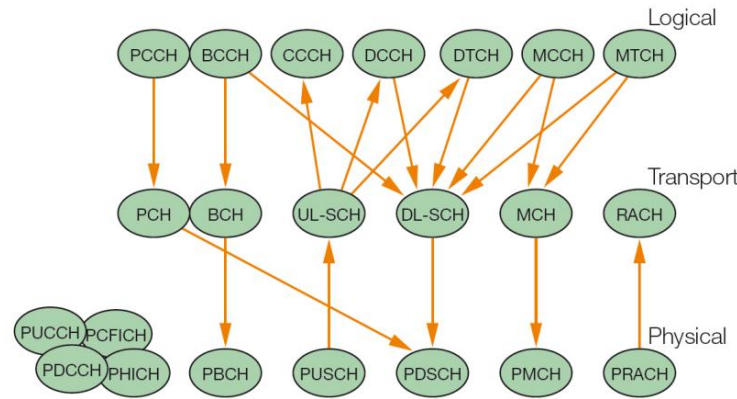


Figure 2.5: Logical to Transport Channel Mapping

Multicast Control Channel (MCCH): A point-to-multipoint downlink channel used for transmitting control data to UEs within the cell. It is only used by UEs that receive multicast/broadcast services.

Paging Control Channel (PCCH): A downlink channel that transfers paging data to registered UEs within the cell.

Common Control Channel (CCCH): A bi-directional channel for transmitting control information between the network and UEs when no Radio resource control (RRC) connection is available, implying the UE is not attached to the network like within the idle state.

Dedicated Control Channel (DCCH): A point-to-point, bi-directional channel that transmits dedicated control between a UE and the network. This channel is employed once the RRC connection is obtainable, that is, the UE is attached to the network.

The logical traffic channels, which uses to transfer user plane information, include:

Dedicated Traffic Channel (DTCH): A point-to-point, bi-directional channel used between a given UE and the network. It can exist in both uplink and downlink.

Multicast Traffic Channel (MTCH): A unidirectional, point-to-multipoint data channel that transmits traffic information from the network to UEs. It is associated with the multicast/broadcast service.

2.4.2.2 Transport Channels: How to Transmit

The transport channels are used to offer services to the MAC. A transport channel is actually characterized by how and with what characteristics data is transferred over the radio interface, that is, the channel coding scheme, the modulation scheme, and antenna mapping. Transport channels are classified in to uplink and downlink channels [18, 19]. The downlink transport channels are described below:

Downlink Shared Channel (DL-SCH): This channel will carry downlink signaling and traffic and may have to be broadcast in the entire cell, given the nature of the data in this channel. It will also support for both dynamic and semi-static resource allocation with the option to support for UE discontinuous reception (DRX) to enable UE power saving and error control is supported in this channel by means of Hybrid automatic repeat request (HARQ) and dynamic link adaptation by varying the modulation coding and transmit power. Spectral efficiency can also be increased due to the possibility of using beam forming antenna techniques. The channel also supports Multimedia Broadcast Multicast Service (MBMS) transmissions.

Broadcast Channel (BCH): A downlink channel related to the BCCH logical channel and is employed to broadcast system information over the entire coverage area of the cell. It has a fixed

and pre-defined transport format largely defined by the requirement to be broadcast in the entire coverage area of the cell since the information carried by this channel contains system information.

Multicast Channel (MCH): The channel is associated with the multicast services from the upper layers and as such there is a requirement to broadcast both control and user data over the entire coverage area of the cell. It conjointly supports the Single Frequency Network as semi-static resource allocation.

Paging Channel (PCH): Associated with the PCCH logical channel. It is mapped to dynamically assign physical resources, and is needed for broadcast over the whole cell coverage area. It is transmitted on the Physical Downlink Shared Channel (PDSCH), and supports UE discontinuous reception.

The uplink transport channels include:

Uplink Shared Channel (UL-SCH): carries common and dedicated signaling as well as dedicated traffic information. It supports the same features as the DL-SCH.

Random Access Channel (RACH): is a very specific transport channel and carries limited control information during the very earliest stages of connection establishment. This is a common UL channel so there's the chance of collisions during UE transmission.

2.4.2.3 Physical Channels: Actual Transmission

The design of the LTE physical layer is heavily influenced by needs of high peak transmission rate (100 Mbps DL or 50 Mbps UL), spectral efficiency, and multiple channel bandwidths (1.25-20 MHz). Each physical channel corresponds to a group of resource elements within the time-frequency grid that carry info from higher layers. The basic entities that build a physical channel are RE and RB. A RE is a single subcarrier over one OFDM symbol, and specifically this could carry one (or two with spatial multiplexing) modulated symbol(s). A resource block (RB) is a collection of RE and in the frequency domain this represents the littlest quanta of resources which will be allocated. Physical channels are classified in to UL and DL channels.

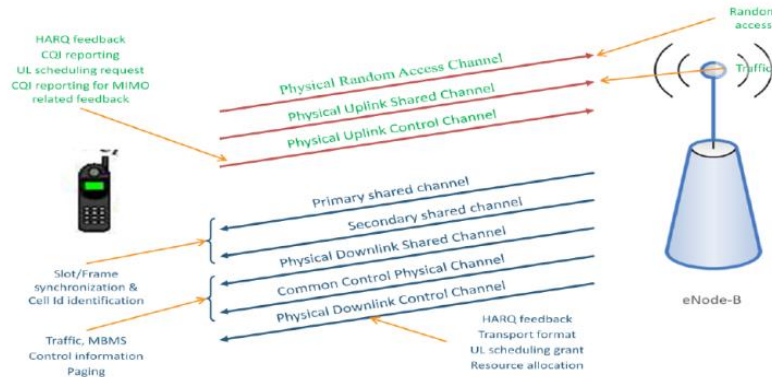


Figure 2.6: Uplink and downlink physical channels [20]

2.4.3 Multiple Access Technology

LTE employs Orthogonal Frequency Division Multiple Access (OFDMA) for DL data transmission and Single Carrier FDMA (SC-FDMA) for UL transmission. The OFDM signal is often generated by using the Fast Fourier Transform (FFT). The available spectrum in an OFDM system is divided into multiple, mutually orthogonal subcarriers. Each of those subcarriers are modulated independently by a low data rate stream and might carry freelance or independent data streams. The main reasons LTE chooses OFDM and SC-FDM as the basic transmission schemes includes [21]: robustness to the multipath fading channel, high spectral efficiency, low-complexity implementation, and the ability to provide versatile or flexible transmission bandwidths and support advanced features like frequency-selective scheduling, MIMO transmission, and interference coordination.

In the downlink, OFDM was selected as the air interface for LTE and also it is a specific form of multicarrier modulation (MCM). In general, MCM is a parallel transmission technique that divides a radio frequency channel into several, a lot of narrow-bandwidth subcarriers and transmits information at the same time on every subcarrier. OFDM is well suited for high data rate systems that operate in multipath environments as a result of its strength to delay spread. The cyclic extension allows an OFDM system to operate in multipath channels while not the necessity for a complex Decision Feedback Equalizer (DFE) or Maximum Likelihood Sequence Estimation (MLSE) equalizer. As such, it's simple to exploit frequency selectivity of the multipath channel with low complexity receivers. This allows frequency-selective scheduling, as well as frequency

diverse scheduling and frequency reuse deployments. Furthermore, due to its frequency domain nature, OFDM enables flexible bandwidth operation with low complexity [22].

OFDM was selected for the DL as a result of it can: Improve spectral efficiency, scale back Inter Symbol Interference (ISI) impact by multipath and supply higher protection against frequency selective fading. Despite its many blessings, OFDMA has some drawbacks like high sensitivity to frequency offset (resulting from instability of electronics and doppler spread as a result of mobility) and high peak-to-average power ratio (PAPR) which occurs due to random constructive addition of sub-carriers and results in spectral spreading of the signal leading to adjacent channel interference. High PAPR needs expensive or valuable and inefficient power amplifiers with high linearity requirements, that will increase the price of the terminal and drains the battery quicker. SC-OFDMA brings the benefit of low peak-to-average power ratio compared to OFDMA making it suitable for uplink transmission by user terminals [19, 23, 24].

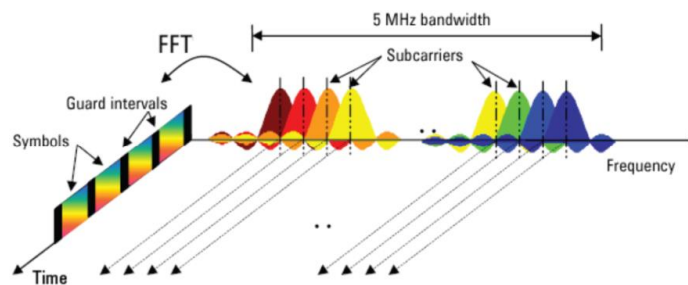


Figure 2.7: Frequency-time representation of an OFDM Signal [23]

In the frequency domain, the 5 MHz BW is divided into a high number of closely spaced orthogonal subcarriers. The subcarriers in LTE have a constant or continuing spacing of 15 kHz. In E-UTRA, the DL modulation schemes are often QPSK, 16QAM and 64QAM. In the time domain, a guard interval is added to every symbol to combat inter OFDM symbol interference because of channel delay spread. In E-UTRA, the guard interval is a cyclic prefix (CP) that is inserted before every OFDM symbol. A group of subcarriers is called a sub-channel.

Each of the 15 kHz LTE air interface subcarriers are ‘Orthogonal’ to each other giving rise to the name ‘Orthogonal Frequency Division Multiplexing’ (OFDM) which is employed in the downlink. The process of modulating data symbols and combining or mixing them is equivalent to an Inverse Fourier Transform operation (IFFT). The reverse operation is applied to the OFDM symbol to retrieve the information stream which is equivalent to a Fast Fourier Transform operation (FFT).

2.4.4 MIMO Technology

MIMO systems are one among the most important and major enabling technologies for LTE. They allow higher data rate transmission through the use of multiple antennas at the transmitter and receiver to provide simultaneous transmission of multiple parallel data streams over a single radio link. MIMO needs two or more transmitters and receivers.

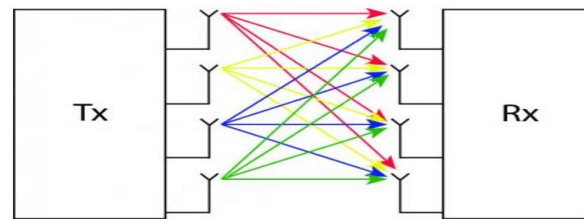


Figure 2.8: Simplified MIMO structure [24]

2.4.5 Adaptive Modulation and Coding (AMC) Schemes

In cellular communication systems, the standard of the signal received by a UE depends on the channel quality from the serving cell, the extent of interference from different cells, and the noise level. In LTE, Adaptive Modulation and Coding (AMC) is implemented on the UL and DL, where the modulation scheme and the coding scheme are changed automatically for best transmission performance according to channel conditions [6]. The AMC consists of the modulation Scheme and code rate.

Modulation Scheme: Low-order modulation is more robust and can tolerate higher levels of interference but provides a lower transmission bit rate. High-order modulation offers a higher bit rate but is more prone to errors due to its higher sensitivity to interference, noise and channel estimation errors; it is therefore useful only when the Signal to Interference and Noise Ratio (SINR) is sufficiently high.

The type of modulation employed in LTE depends on the radio environment. The UE estimates the quality or standard within the DL and signals it back to the eNodeB within the Channel Quality Indicator (CQI). The UL reference signals that are embedded into the UL transmission are employed by the eNodeB to predict the quality or strength in the UL. The eNodeB make a decision which modulation technique should be used based on the quality of the DL and UL radio environment.

Modulation techniques which supports by LTE in downlink and uplink are: 64 Quadrature Amplitude Modulation (64 QAM) which uses 64 different quadrature and amplitude combinations to carry 6 bits per symbol, 16 Quadrature Amplitude Modulation (16 QAM) which uses 16 different quadrature and amplitude combinations to carry 4 bits per symbol and Quadrature Phase Shift Keying (QPSK) which used 4 different quadrature's to send 2 bits per symbol [25, 26, 6].

Code rate: For a given modulation, the code rate are often chosen based on the radio link conditions: a lower code rate are often utilized in poor channel conditions and a higher code rate in the case of high SINR [8].

2.5 Propagation Models

In radio link budget calculation, the radio propagation model plays a key role. The coverage radius of a base station is obtained based on the maximum propagation loss allowance in the link budget. Therefore, Path loss models are important in the RF planning phase to be able to predict coverage and link budget among other important performance parameters. These models are based on the frequency band, type of deployment area (dense urban, urban, rural, suburban, etc.), and type of application [27].

Radio propagation models are classified into two types: outdoor and indoor propagation models. These two types of propagation models involve various factors. In an outdoor environment, landforms and obstructions on the propagation path, in addition to buildings and trees should be considered. Signals fade at varying rates in different environments. Propagation in free space gives the lowest fade rate. The fading of signals is larger than free space when radio waves propagate in open areas/suburban areas and fading rate is the largest in urban/dense urban areas. Indoor propagation model features low RF transmits power, a short coverage distance and complicated environmental changes [8, 28].

2.5.1 Free Space Path Loss Model

Free space loss describes the ideal situation, where the transmitter and receiver have line-of-sight and no obstacles are around to create reflection, diffraction or scattering. In this ideal case the attenuation of the radio wave signal is equivalent to the square of the distance from the transmitter. When the signal has been transmitted in the free space towards the receiver antenna, the power density S at the distance from the transmitter d can be written as [[1, 29]:

$$S = \frac{P_t G_t}{4\pi d^2} \quad (2.1)$$

Where P_t is the transmitted power and G_t is the gain of the transmitter antenna. The effective area A of the receiver antenna, which affects the received power, can be expressed as

$$A = \frac{\lambda^2 G_r}{4\pi} \quad (2.2)$$

Where λ is the wavelength and G_r is the gain of the receiver antenna. The received power density can also be written as:

$$S = \frac{P_r}{A} \quad (2.3)$$

Combining these equations, previous the format for the received power is:

$$P_r = P_t G_t P_r \left(\frac{\lambda}{4\pi d} \right)^2 \quad (2.4)$$

The free space path loss is the ratio of transmitted and received power. Here is the equation in simplified format, when the antenna gains are excluded:

$$L = \left(\frac{4\pi d}{\lambda} \right)^2 \quad (2.5)$$

And the free space loss converted in decibels

$$L_{dB} = 10 \log_{10} \left(\frac{4\pi d}{\lambda} \right)^2$$
$$L_{dB} = 20 \log_{10} \left(\frac{4\pi d}{\lambda} \right)$$

$$L_{dB} = 20 \log_{10}(4\pi) + 20 \log_{10}(d) - 20 \log_{10}(\lambda) \quad (2.6)$$

Substituting $\lambda = 0.3/f$ (in MHz) and rationalizing the equation produces the generic free space path loss formula:

$$L_{dB} = 20 \log_{10}(4\pi) + 20 \log_{10}(d) - 20 \log_{10} \left(0.3/f \right)$$

$$L_{dB} = 20 \log_{10}(f) + 20 \log_{10}(d) + 32.4 \quad (2.7)$$

Where f is the frequency in MHz and d is the distance in km's

In reality the radio wave propagation path is often a non-line-of-sight scenario with close obstacles like buildings and trees. Therefore, the applicability of the free space propagation loss is limited [1]. The received signal actually consists of several components, which have been travelling through different paths facing reflection, diffraction and scattering. This result is named as multipath and one component represents one propagation path. The different components, signal vectors, are summarized as one signal considering the vector phases and amplitudes.

2.5.2 Okumura Model

Okumura model is one of the most commonly used models. Almost all the propagation models are raised form of Okumura model. It can be used for frequencies up to 3000 MHz [27]. The model is ideal and typical for using in cities with several urban structures however not several tall obstruction structures. Okumura model was engineered into 3 modes which are urban, suburban and open areas. The model for urban areas was engineered first and used as the baseline for others. Clutter and terrain categories for open areas are; there are no tall trees or buildings in path, plot of land cleared for 200-400m [30]. The path loss in Okumura model is expressed as follows.

$$L_m(dB) = L_F(d) + A_{mu}(f, d) - G(h_t) - G(h_r) - G_{AREA} \quad (2.8)$$

Where,

$L_m = \text{median of the path loss}$

$L_F = \text{free space propagation pathloss}$

$A_{mu} = \text{median attenuation relative to free space}$

$G(h_t) = \text{BS antenna height gain factor}$

$$= 20 \log(h_t/200), 1000m > h_t > 30m$$

$G(h_r) = \text{MS antenna height gain factor}$

$$= 20 \log(h_t/3), 10m > h_t > 3m$$

$G_{AREA} = \text{gain due to type of environment given in suburban, urban or open areas}$

2.5.3 Okumura-Hata Model

The Okumura-Hata model is an empirical model, which suggests that it's supported field measurements. Okumura performed the field measurements in Japanese capital Tokyo and published results in graphical format. HATA applied the measurement results into equations. The model may be applied without correction factors for quasi smooth terrain (similar swish piece of ground) in an urban or populated geographical area however in case of other terrain types correction factors are required. The weakness of the Okumura-Hata model is that it doesn't think about reflections and shadowing.

The distance between transmitter and receiver can be around 100 km while the receiver height can be 1 m to 10 m [1]. Generally, this model can be applied to the following scenario [25, 19, 6]:

- Frequency range 150–1500 MHz, extension 1500-3000 MHz
- Terrain morphologies (DU, U, SU, and RU)
- Mobile antenna height from 1 to 10 m
- BTS antenna height from 30 to 200 m

The path loss in Okumura-Hata model can be calculated as:

$$L = A + B \log(f) - 13.82 \log(H_b) - a(H_m) + [44.9 - 6.55 \log(H_b)] \log(d) + L_{other} \quad (2.9)$$

Where, f if the frequency (MHz)

H_b = base station antenna height (m)

H_m = the MS antenna height (m)

$a(H_m)$ = the mobile antenna correction factor

d = the distance between the MS and BTS (km)

L_{other} = additional correction factor for area type correction with the of 3 for urban/dense urban area.

The function $a(H_m)$ for urban/dense urban area is defined as:

$$a(H_m) = 3.2(\log(11.75H_m))^2 - 4.79 \quad (2.10)$$

For suburban and rural area, the function is defined as:

$$a(H_m) = [1.1 \log(f) - 0.7]H_m - (1.58f - 0.8) \quad (2.11)$$

The parameters A and B are dependent on the frequency as follows:

$$A = \begin{cases} 69.55, & f = 150 - 1500 \text{ MHz} \\ 46.30, & f = 1500 - 2000 \text{ MHz} \end{cases}$$

$$B = \begin{cases} 26.16, & f = 150 - 1500 \text{ MHz} \\ 33.90, & f = 1500 - 2000 \text{ MHz} \end{cases}$$

2.5.4 Cost-231 Hata Model

Cost231-Hata Model is an extension of Hata's model and designed for use in the frequency range 1500 MHz to 2.0 GHz. Four parameters are used for estimation of the propagation loss. These are frequency f , distance d , base station antenna height H_{BS} and the height of the mobile antenna H_{mobile} . The model can be expressed by the following formula [23]:

$$Total = A - a(H_m) + C_m \quad (2.12)$$

Where,

$$A = 46.3 + 33.9 \times \log(f) - \log(H_{BS}) + [(44.9 - 6.55 \times \log(H_{BS}) \times \log(d))$$

f is the working frequency of the system in MHz

H_{BS} is height of the BS antenna in m

H_m is height of the mobile antenna in m

d is the distance between the terminal and BS in km

aH_m is the terminal gain function. This function is related to the antenna height and working frequency of the terminal and the environment.

$$aH_m = 3.2[\log(11.75)H_m]^2 - 4.79 \quad (2.13)$$

C_m depends on the terrain type. The value of C_m in the standard Cost231-Hata in large cities (U and DU) is 3 and in medium sized cities is 0 [31].

3. Chapter Three: Green Cellular Network Basics

3.1 Introduction

Traditionally, mobile communication networks have been designed for maximum throughput and maximum spectral efficiency while promising QoS to the user. With advent of new technologies like 4G LTE and above technologies, speed and efficiency were enhanced. Consequently, the growth rate of data traffic on mobile networks has been increasing and is expected to grow in the coming years. There have been several reasons for the growing awareness of energy-efficient wireless networks in the telecommunication community. Energy prices which imply electricity bills have become a significant cost factor for mobile operators. The radio access part (includes BS and antennas) of the cellular network is a major energy killer, which accounts from 50% up to 80% of the total energy [32]. Due to this reason improving the energy efficiency of base station key components, such as power amplifiers and air conditioners, is of great importance for mobile operators. The increase in energy consumption of mobile cellular networks has currently become a priority not solely attributable to increase within the value of energy on the part of mobile network operators but also because of its adverse effect on the environment due to global warming. In order to reduce energy consumption, GREEN solution has been suggested [32, 33] [34].

GREEN is one of the major initiatives taken in field of energy saving. GREEN radio has been a key enabler for cellular growth while guarding against increased environmental impact. There are various distinctive approaches to reduce energy consumptions in a mobile cellular network. These approaches include: Improving energy efficiency of hardware components, turning off components selectively, optimizing energy efficiency of the radio transmission process, planning and deploying heterogeneous cells and adopting renewable energy resources [4].

3.2 Energy use in Cellular Networks

Traditionally, the mobile terminals have been designed with energy efficiency in mind because of their battery limitations. Furthermore, within a single base station the Power amplifiers (PAs) are the dominating energy consumers [14]. Generally, the useful output power is only around 5% to 20% of the input power. Base stations are the key elements in energy consumption because they consume relatively high energy as shown in Figure 3.1.

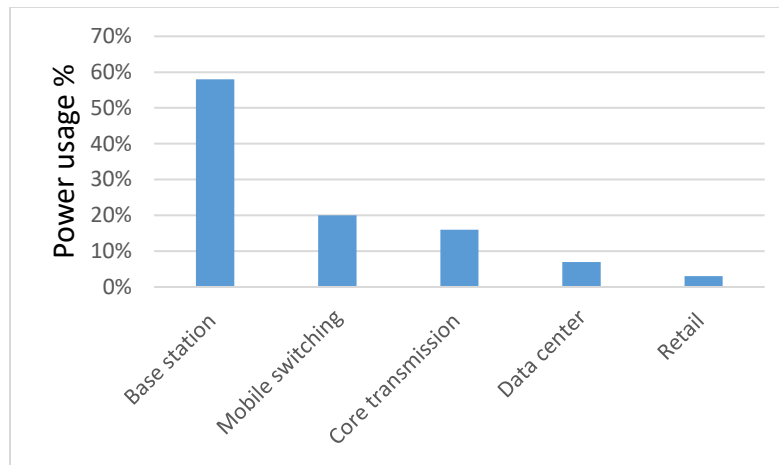


Figure 3.1: Power consumption of a typical wireless cellular network [34]

3.3 Energy Savings in Base Station

A typical cellular network consists of 3 main elements; a core network that takes care of switching, BSs providing radio frequency interface, and also the mobile terminals so as to create or make voice or data connections. As the number of BSs increases, it becomes crucial to deal with their energy consumption for a cellular network. In the next few subsections, different ways of energy consumption reduction will be discussed.

3.3.1 Minimizing BS Energy Consumption

The energy consumption of a typical BS can be minimized by improving the BS hardware design in addition to software and system features to balance between energy consumption and performance. In order to improve hardware design of a BS for energy consumption, energy efficiency of the power amplifier (PA) should be addressed. A PA dominates the energy consumption of a BS and its energy efficiency depends on the frequency band, modulation and operating environment [34].

Improvements in Power Amplifier

Modern BSs are really inefficient due to their need for PA linearity or we call it one-dimensionality and high peak-to-average power ratios (PAPR). The modulation schemes that are utilized in communication standards like WCDMA/HSPA and LTE are characterized by powerfully variable signal envelopes with PAPR that exceeds 10dB. To obtain high linearity of the PAs in order to maintain the quality of radio signals, PAs have to operate well below saturation, resulting in poor

power efficiency. The significant setback in increasing power efficiency with PAs is that they perform better at maximum output power in order to maintain the required signal quality. However, during the low traffic load conditions (e.g. night time), lot of energy is routinely wasted. Therefore, design of flexible PA architectures that would allow a better adaptation of the amplifier to the required output power has been addressed. In addition to this, more efficient modulation schemes have been investigated, because modulation also affects the PA efficiency [34].

3.3.2 Energy-Aware Cooperative BS Power Management

This is done either by allowing the cell area served by the BS to change size dynamically, or simply allowing a BS to sleep for a period of time depending on the traffic load experienced by the BS.

A. Cell Zooming

The cell area of a base station is defined as the coverage area in which a mobile user can receive control signals sent by a specific base station. In general, the size and capacity of a cell are usually fixed based on the estimation or prediction of peak traffic load done by network planners. However, traffic load in cellular networks can experience substantial spatial and temporal variations because of user mobility. Cell zooming, which adjusts the cell size according to traffic conditions, is a potential solution to this problem. Cell zooming has the potential to balance the traffic load and reduce the energy consumption [35, 36].

In cell zooming, the central cell can respectively “zoom in” or “zoom out” depending on the traffic loads. Cell size can be adjusted by: Increasing or decreasing the transmit power when traffic load is respectively low or high in the cell or physically adjusting the cell size by the mean of the antenna height and tilts adjustment.

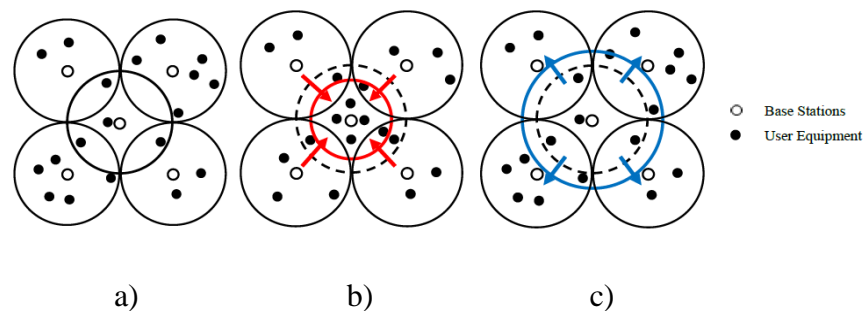


Figure 3.2: Cell zooming concepts a) Standard cell size b) Zoom in c) Zoom out [37]

Several advantages are achieved through implementing the cell zooming idea. First, load balancing is achieved by transferring traffic from high congested base stations to others experiencing low congestion. Also, cell zooming may be used for energy saving.

B. Sleep Mode

Sleep mode technique consists of turning off a BS experiencing low traffic load. However, this should be done while ensuring the same quality of service to MSs in the cell. In order for the sleep mode techniques to function, BSs usually need to cooperate with each other. A BS controller (BSC) or Radio Network Controller (RNC) facilitates exchange of traffic information between BSs. If certain BSs are selected to sleep, the sleeping BSs release their channel resources to active neighbors, while active BSs make use of obtained resources to cooperatively provide extensive coverage to the mobile users located in the service areas of nearby sleeping BSs [4].

The sleep mode concept is a variant of the classical cell zooming concept, where the central cell can be switched off (i.e. zoomed to zero) based on the traffic load conditions. At the stage of network planning, cell size and capacity are usually fixed based on the estimation of peak traffic load. During low traffic load, some BSs can be switched off, particularly at the idle hours during the night with relatively little impact on the network quality. When central cells are switched off, neighboring cells can zoom out to compensate the coverage or remain in standard mode and use the Cooperative BSs to transmit or receive the signal. The more cells we turn off, the more energy consumption we will save. On the other hand, there will be some coverage holes [42].

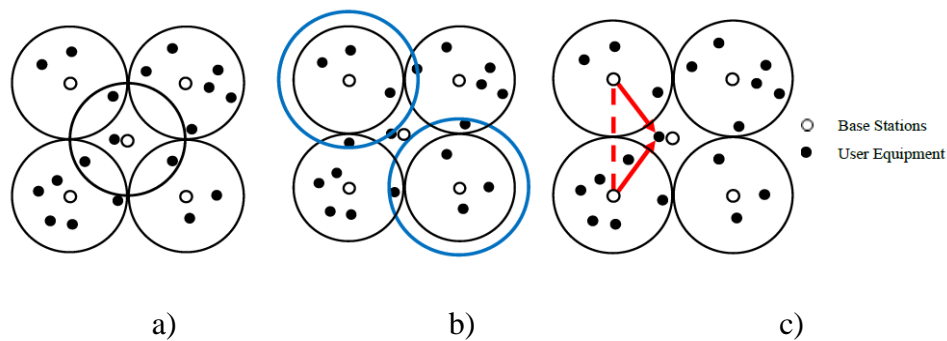


Figure 3.3: Sleep mode concepts a) Standard cell size b) Neighboring cells zoom out to compensate c) Neighboring cells remain in standard mode and use the CoMP [35]

3.3.3 Using Renewable Energy Resources

In several remote locations of the world, electrical grids are not available or are unreliable. Cellular network operators in these off-grid sites constantly consider on diesel power-driven generators to

run BSs that isn't only pricey, however conjointly generates CO₂ emissions. In such places, renewable energy resources such as sustainable biofuels, solar and wind energy seem to be more viable options to reduce the overall network expenditure. In most cases a hybrid solution combining of solar and wind is the most feasible for autonomous BTS site. For base station sites, the renewable energy could be used for several reasons like: long distance to electricity grid, unreliable grid and reduce amount of CO₂ emission. In the design of base station site to be powered by renewable energy the key factors to take in to account are the site and energy consumption of BTS. The size of solar cell and wind turbine has to be defined based on that load and the available solar and wind situation on the site location [34, 38].

3.3.4 Other Ways to Reduce BS Power Consumption

Since the energy consumption of the whole cellular network includes the summation of energy utilized by each BS, reducing the quantity of BSs incorporates a direct impact on energy consumption of a cellular network. However, efficient network design and finding an optimal balance between cell size and BS capacity can be very challenging. Features like 2-way and 4-way diversity, feeder less site, extended cell, low frequency band, 6-sector site and smart antenna can be used to minimize the number of BS sites.

Another way to improve power efficiency of a BS is to bring some architectural changes to the BS. Currently, the connection between the RF-transmitter and antenna is completed by long coaxial cables that add nearly 3dB to the losses in power transmission and thus, low power RF-cables should be used and RF-amplifier must to be near closer to the antenna. This will improve the efficiency and reliability of the BS [35, 34, 39, 40].

4. Chapter Four: Energy Efficient Multi-RAT Radio Network Planning

4.1. Introduction

The basic objective of planning Multi-RAT network architecture evolution and introduction of intelligence is towards the creation of smart infrastructures. Next Generation Mobile Networks (NGMN) has a dedicated project related to “RAN Evolution” so as to give recommendations on future radio access network architectures [6].

Due to the need of an efficient and general control solution for 2G/3G/4G operations, Multi-RAT becomes a hot topic among major industrial partners and is a key deployment now and in the coming years. For operator’s reduction of overhead signaling, resource management and spectrum utilization are the main and necessarily important parameters related to Multi-RAT network.

Generally, Multi-RAT planning is the planning of multiple layers as a single network, taking into account multi-technology coverage targets, traffic sharing and offloading between layers, as well as installation and implementation constraints (e.g. shared antennas).

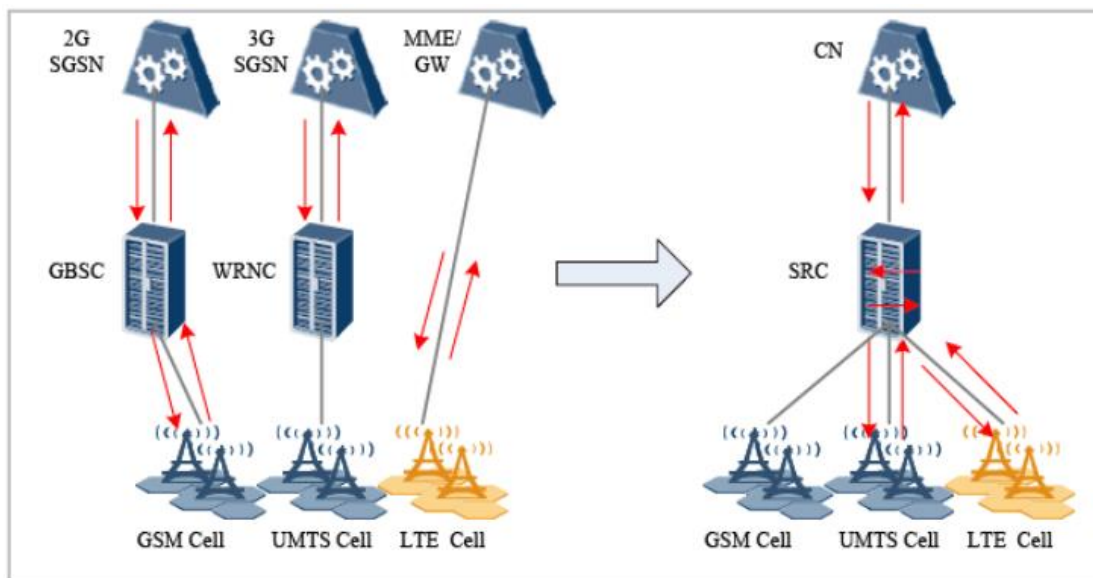


Figure 4.1: RAN evolution [41]

Single Radio Controller (SRC) is Multi-RAT controller which is responsible for coordinating GSM/UMTS/LTE (G/U/L) Multi-RAT cell as a single network. The RAN evolution on this regard is very important for operators that needs to build Multi-RAT, since it saves Capital Expenditure (CAPEX) & Operational Expenditure (OPEX) of the operators. Besides it can avoid unnecessary

resource usage by different controllers for signaling, handover and the like which can be controlled by a single controller. The technological advancement on the basis of RAN evolution is a matter of vendors to manufacture RAN equipment's based on ITU & 3GPP standards, and this thesis is focused on the planning part of Multi-RAT networks.

4.2. Radio Network Planning Criteria

Network coming up with may be a difficult method consisting of many phases. The final target for the network coming up with method is to outline the network style, that is then engineered as a cellular network. The basic requirements for the cellular network are to meet coverage and quality targets. Coverage targets firstly mean the geographic area in which the network is covering with an agreed location probability. The requirements also specify signal strength values that need to be met inside different area types. The quality targets are related to factors such as success of the call, call drop ratio, which should not exceed the agreed value and the success ratio for the call setup and for handovers. With new wireless communication technologies and therefore the increasing size of radio networks, the tasks of network planning and resource optimization are becoming more and more challenging. This is because of the scarcity of radio resources currently due to the increasing number of subscribers and many different types of networks operating within the limited frequency spectrum. Secondly, deploying and operating a large network is expensive and therefore requires careful network dimensioning to ensure high resource utilization [3].

By doing a proper Network Planning and keeping the longer-term growth plan in mind we are able to cut or reduce lots of problems that we have a tendency to could encounter within the future and also reduce substantially the cost of optimization. On the other hand, a poorly planned network not only leads to many network problems, it also increases the optimization costs and still may not ensure the desired quality. A good plan should address the following issues: provision of required capacity, optimum usage of the available frequency spectrum, minimum number of sites, provision for easy and smooth expansion of the network in future & provision of adequate coverage of the given area, for a minimum specified level of interference [3, 42, 43]. Generally, the detailed part of radio network planning covers link budget calculation, coverage planning, capacity planning, frequency planning, and parameter planning

- a) **Link budget calculation:** Gives the loss in the signal strength on the path between the mobile station antenna and BS antenna and should be done for both UL and DL communications [31].
- b) **Coverage Planning:** Its objective is to find a minimum amount of cell sites with optimum locations for producing the required coverage for the target area. Coverage regions, coverage threshold values on per regions (outdoor, in-car, indoor), antenna (tower height limitations), most well-linked antenna line system specifications, preferred BS specification & activities such as propagation modeling, field strength predictions and measurements are the basic input data for coverage planning section.
- c) **Capacity planning:** is a very important process in the network rollout as it defines the number of BS/NB's/eNB's required and their respective capacities. The number of transceivers required is derived from capacity planning as it is directly associated with the frequency re-use factor. BS antenna height is another factor because if the antenna height is too high then the signal has to travel a greater distance, so the probability that the signal causes interference becomes greater. Generally, there are three essential parameters required for capacity planning: Estimated traffic, Average antenna height, and Frequency usage.
- d) **Frequency Planning:** After site selection, assignment of the frequency channel for each cell is done in a manner that causes minimal interference and maintains the desired quality. Frequency allocation is based on the cell-to-cell channel to interference (C/I) ratio.
- e) **Parameter Planning:** There is a parameter set for each cell that is used for network launch and expansion. This set may include cell service area definitions, channel configurations, handover and power control, adjacency definitions, and network specific parameters [43].

In this radio network planning GSM, UMTS and LTE are the multiple radio access technologies which are taken in to account for planning as Multi-RAT network and the system model is shown below.

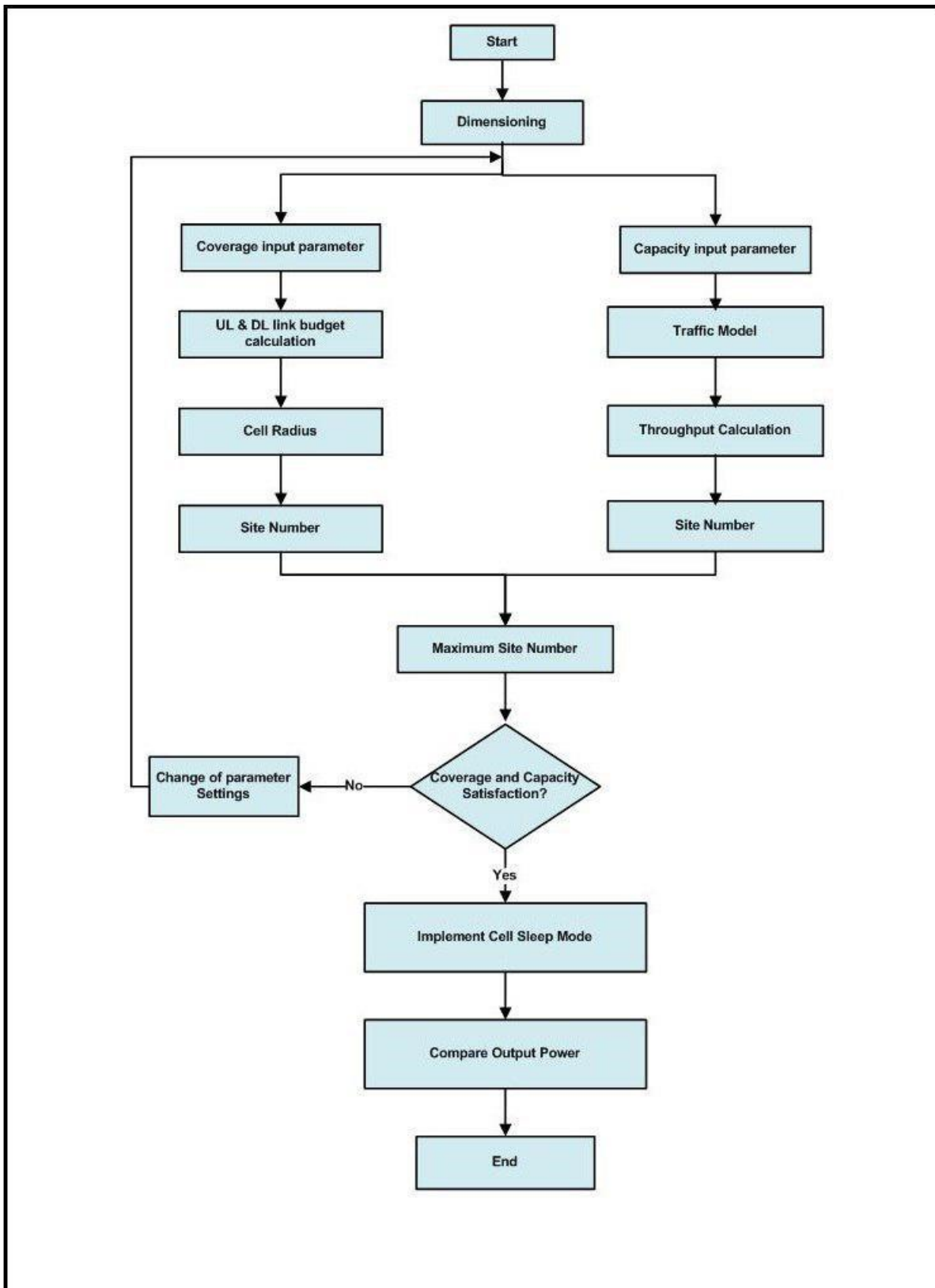


Figure 4.2: System model of Multi-RAT network planning

4.3. Site Survey and Selection

The purpose of site survey is to identify the different environmental factors that directly or indirectly affect the radio network planning process and as well to list out them as planning parameters. In this thesis, Addis Ababa city is considered as the area of planning with size of 413.612 km² [19]. For capacity analysis the subscriber number should be specified by considering future expansion and also uniform distribution of those subscribers with dense urban clutter.

In 2015 the total population number of Addis Ababa was assumed approaching 3,048,631 based on [19] with annual growth of 0.86 as [44]. After five years which is in 2020 total population of Addis Ababa is estimated to be approach 5,670,454 based on the annual growth. According to [19] 36.5% of the total population are mobile users and therefore 2,068,060 subscribers are assumed by considering future expansion.

4.4. GSM Radio Network Planning

In GSM, the network is divided into a lot of cells, and usually a BS is planted in the center of each cell. For the sake of easy analysis, the cells are represented as neighboring hexagons, while in reality they can be of any kind of forms and overlap with each other. The size of each cell, when fixed, will usually stay stable. In GSM network planning: the coverage planning and capacity planning are independent which is the coverage planning depends on the received signal strength, while the capacity planning depends mainly on the frequency allocation [3].

In GSM 900 system, there are 125 channels in both UL and DL, and these channels span the available bandwidth of GSM 900. Since, the frequency is a scare resource in GSM system, then frequency must be carefully planned to be reused. The frequency reuse factor is defined as the number of BSs that can be implemented between the current BSs and the ones before the same frequency is reused. As stated at the beginning of the chapter the antenna height can also influence the reuse factor, since the higher the antenna is, the greater the possibility that the signal causes more interference.

Frequency planning is done by setting an adequate cost function to maximize the capacity of the network while minimizing the number of frequency sub-bands used. There is also GSM 1800 which is called digital cellular system (DCS). The prime reason to use DCS 1800 frequency band

was the lack of capacity in the 900 MHz and can give solution on the issue of capacity, and used to be deployed in most densely populated areas or large cities [3, 31, 44].

4.4.1. GSM Coverage Planning

As discussed in the first chapter dimensioning is the primary part of the planning phase. The priority of the parameters also needed to be agreed besides the dimensioning parameters. The radio network dimensioning parameters have an impact on each other and therefore it is important to decide the emphasis in order to get an optimal dimensioning result within the agreed parameter ranges [3, 44].

In this thesis macro cells with three sector sites which actually characterized by an outdoor antenna are considered. When performing tasks related to coverage during network planning, link budget calculation is an important step as mentioned above.

The main aim of radio link budget (RLB) is determining the cell coverage area by calculating UL and DL path losses and then to balance the UL and DL powers. The links are calculated separately and are different from the transmission powers. The Base Transceiver Station (BTS) transmission power is higher than the MS transmission power and therefore the reception of the BTS needs to have high sensitivity. To estimate the propagation loss between the transmitter and the receiver radio wave propagation is the basic and required parameter.

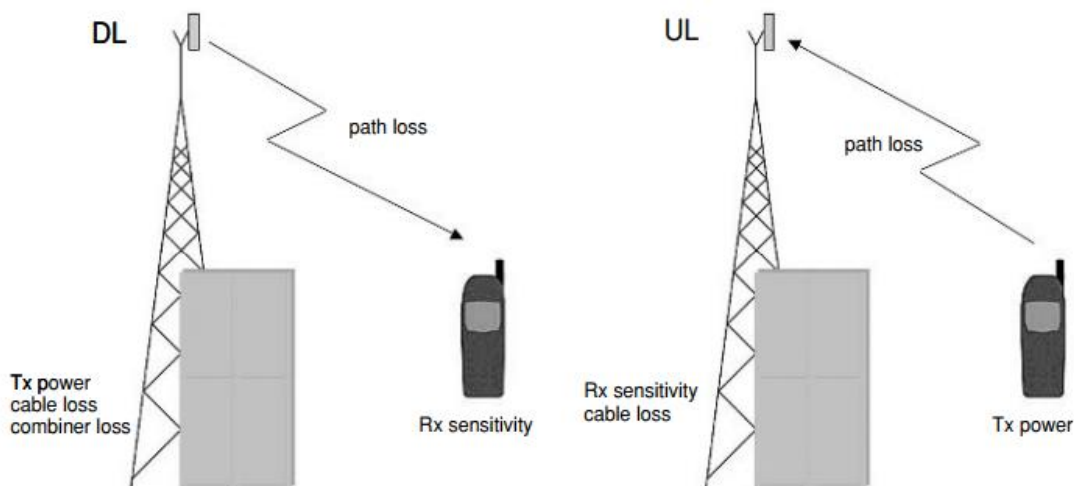


Figure 4.3: Block diagram of link budget calculations

The GSM link budget parameters are classified into four types; these are system parameter, transmitter parameters, receiver parameters, and margin reservation. Hence, the formula of link budget is described as follows:

$$MAPL = TX\ EIRP + RX\ Gains - RX\ Losses - Receiver\ Sensitivity - Total\ margins \quad (4.1)$$

Where, $TX\ EIRP = TX\ power + TX\ antenna\ gain - body\ loss$

$$Total\ margins = slow\ fading\ margin + fast\ fading\ margin + interference\ margin \\ + building\ or\ vehicle\ penetration\ loss$$

System parameters

Carrier frequency: Carrier frequency affects the transmission loss and radio waves of different frequencies have different propagation models and different losses.

System bandwidth: In a GSM system, the receiver bandwidth is 200 kHz or 53dBHz

Data rate: The full rate of GSM voice service is 9.6 Kbit/s and the corresponding half rate is 4.8 Kbit/s.

Transmitter Parameters

Transmitter power: The MS transmission power is defined by the MS class in European Telecommunications Standards Institute (ETSI) specifications. For MS class 4 (GSM 900) the maximum TX power is 2W (33 dBm) and for class 1 (GSM 1800) 1W (30 dBm). BS TX power depends on the BS type and vendor. The TX power is adjustable, which enables the link budget to be balanced [44] but for this work it's assumed to be 20 W (43 dBm).

Antenna gain: For MS, electronically small uni-pole antenna and planar inverted-F antennas (PIFA) are always used and has a lower gain, of the order of 0dBi. The BS antenna gain can vary from 8dBi to 21dBi depending upon the type of antenna being used (Omni directional versus directional) and can be increased by using various techniques, such as antenna diversity [31, 44].

Body Loss: Body loss refers to the loss produced by the signal blockage and absorption when hand-held mobile phones are near to the human body. It's always taken 3dB and 0dB for the case of voice service and data service using data card respectively [6].

Cable loss: Cable attenuation figures are usually quoted in loss (dB) per 100 m, obviously a longer cable gives a higher loss and because of this the shortest possible route for the cable should be used.

Connector losses: are usually gives a loss of around 0.1 dB, but depending on the cable installations there can be several in one antenna line.

Receiver parameter

Noise spectral density: Spectral density of thermal noise is calculated as:

$$\text{Spectral density} = kT = -174 \frac{\text{dBm}}{\text{Hz}} \text{ in room temperature (290k)} \quad (4.2)$$

Where, k is Boltzmann constant, which equals $1.38 \times 10^{-23} \text{ J/k}$ and T is absolute temperature (290k)

Noise power: Noise power N_i , also called thermal noise is produced by the thermal movement of electrons.

$$N_i = kTB \quad (4.3)$$

Where, B is bandwidth

C/I required by TCH: Carrier-to-Interference ratio C/I is the SNR requirement on the air interface. In narrowband system, C/I is the requirement of receiver base band demodulation performance. The target value varies depending on the propagation environment, mobility speed, and coding rate. According to the GSM protocol, C/I should be greater than or equal to 9dB [6].

Noise figure: is a method to measure the noise added when a signal is pass through BS or/and MS receiver. In the case of ideal receiver nose figure is $F = 1$ or 0dB. In actual situations, a receiver has noise and the output noise power is greater than signal power. Thus, the SNR is worse and $F > 1$. As defined in GSM protocol, the noise figure of a BS receiver is 8 dB and 10dB for MS receiver.

Receiver sensitivity: is a measure of how well the receiver performs and is defined as the power of the weakest signal the receiver can detect. In telecom system, receiver sensitivity is given by:

$$\begin{aligned} \text{Receiver sensitivity} &= \text{noise spectral density} \left(\frac{\text{dBm}}{\text{Hz}} \right) + \text{bandwidth}(\text{dBHz}) + \\ &\text{noise figure (dB)} + \frac{C}{I}(\text{dB}) \end{aligned} \quad (4.4)$$

Or **receiver sensitivity (Si)**: is solved from the following equation [44], where the input noise power (Ni) is the product of three parameters: Boltzmann constant (k); temperature (T0) = 290K and bandwidth (B) = 200 kHz (53 dB):

$$F = \frac{S_i/N_i}{S_0/N_0} = \frac{S_i(kT_0B)}{E_0/N_0} \quad , \quad N_i = kT_0B \quad (4.5)$$

$$\text{Where, } S_i = \frac{E_b}{N_0} FkT_0B \quad (4.6)$$

BS sensitivity: The sensitivity of the base stations specified on the ETSI GSM recommendation 05.05 and the recommended value is -106 dBm. This is a general recommendation, however when doing link budget calculations, the value given by the manufacturer (or measured value) should be used. Based on ETSI recommendation 03.30 the value of energy per bit over noise density (E_b/N_0) is 7dB and using the Equation (4.6) the receiver sensitivity can be calculated as:

$$\begin{aligned} S_i &= \frac{E_b}{N_0} FkT_0B = 8\text{dB} + 7\text{dB} + (290\text{K} \times 1.38 \times 10^{-23} \text{ J/K}) + 53\text{dB} \\ &= 8\text{dB} + 7\text{dB} - 174\text{dBm} + 53\text{dBm} = -106\text{dBm} \end{aligned}$$

MS sensitivity: is also specified in the ETSI recommendation 05.05, where the receiver sensitivity value for MS class 4 the recommended value is -102dBm. The MS sensitivity can also be calculated using the information of receiver noise F and minimum E_b/N_0 equation (4.6). The minimum value of E_b/N_0 is 9 dB, as defined in the ETSI recommendation 03.30. Therefore, the receiver sensitivity of MS can be calculated as:

$$\begin{aligned} S_i &= \frac{E_b}{N_0} FkT_0B = 9\text{dB} + 10\text{dB} + (290\text{K} \times 1.38 \times 10^{-23} \text{ J/K}) + 53\text{dB} \\ &= 9\text{dB} + 10\text{dB} - 174\text{dBm} + 53\text{dBm} = -102\text{dBm} \end{aligned}$$

The value of MS sensitivity given in these specifications is according to the class of mobile being used. For MS class 4, which means GSM 900, the recommended value is -102 dBm. Correspondingly for class 1, GSM 1800, the value is -100 dBm [6, 31, 44].

Interference degradation margin: describes the loss due to frequency reuse. Therefore, the frequency reuse rate corresponds to the degradation margin value. The suggested value for the interference degradation margin in an average suburban and rural area is 3dB according to the ETSI recommendation 03.30. In the case of high frequency reuse in urban and dense urban areas the degradation margin can have a value of 4-5dB.

Margin reservation

Slow fading margin / Shadow fading margin: also named as slow attenuation. It follows a lognormal distribution in the calculation of radio coverage. To reach the specified coverage probability, during network planning, certain power margin must be reserved for BS or MS receivers to reduce the attenuation effect. Shadow fading standard deviation is related to electromagnetic wave propagation environment. In urban and dense urban areas, the shadow fading standard deviation is about 8 to 10 dB, in suburban and rural areas, the value range is 6 to 8 dB [6, 45, 46].

Coverage Probability: Coverage probability refers to the probability that the quality of communication between terminals in radio coverage edge (or inside coverage) and the BS meet the requirement. Coverage probability can also be classified into area coverage probability and edge coverage probability.

- a) **Area coverage probability:** is the percentage of area of the location where receiving signal strength is greater than receiving threshold to the total area in a round region with radius R.
- b) **Edge Coverage Probability:** is used to evaluate the reliability of communication links in shadow fading environment. Edge coverage probability is an index determining the coverage quality.

The 90% edge coverage probability corresponds to 95% area coverage probability and shadow fading margin is 10.3dB [6]. To determine the location probability a distribution for the received signal has to be defined. The slow fading variations in the average received signal level are normally distributed, which is presented in Figure 4.4.

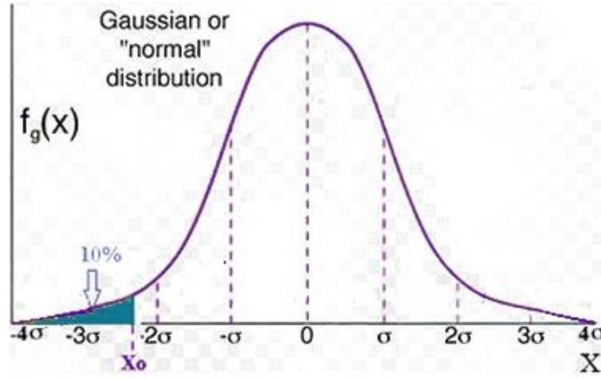


Figure 4.4: Lower tail of normal distribution curve

In radio propagation, for a given distance, the path loss changes quickly and can be regarded as a random variable in lognormal distribution. To improve cell coverage, fade margin should be considered in link budget. The distribution function for slow fading is:

$$\mathcal{P}(r) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(r-r_m)^2}{2\sigma^2}} \quad (4.7)$$

Where r is the random variable and r_m the mean value for it, and σ is the standard deviation, which is measured in dB and the standard deviation σ depends on the area type and is normally 5-10dB. The slow fading is described by the normal random variable r [44].

The location probability can be expressed by an equation, which is upper tail probability of Equation 4.7. The location probability for upper tail probability can be expressed as follows:

$$\mathcal{P}_{x_0} = \frac{1}{\sqrt{2\pi}\sigma} \int_{-\infty}^{x_0} e^{-\frac{(r-r_m)^2}{2\sigma^2}} dr \quad (4.8)$$

The probability \mathcal{P}_{x_0} gives the location probability at a certain point when the random variable r exceeds some threshold x_0 :

$$\mathcal{P}_{x_0} = \frac{1}{\sqrt{2\pi}\sigma} \int_{x_0}^{\infty} e^{-\frac{(r-r_m)^2}{2\sigma^2}} dr \quad (4.9)$$

The location probability can be expressed as well as the lower tail in Equation 4.9, and therefore the probability can be calculated below a certain margin. The planning target for the location probability is normally 90-95% over the whole cell area [45, 46].

The location probability, slow fading margin ($x_0 - r_m$), maximum path loss and cell range are all connected. The maximum allowed path loss affects the cell radius and therefore improvement in the location probability causes a decrease in the cell range. The normal random variable is the most important type of continuous random variable. It has played a significant role in the study of random phenomena in nature. Many naturally occurring random phenomena are approximately normal (Gaussian). The following part explains the edge coverage probability design target which is 90%.

Suppose the propagation loss random variable is r , then r is Gauss distribution in db. Let the average be r_m , standard deviation be σ , and the corresponding probability distribution function be \mathcal{P} . Set a loss threshold x_0 . When the propagation loss exceeds the threshold, signals fails to meet the demodulation requirement of expected services. Then, at the cell edge, satisfying 90% edge coverage probability can be translated into [6]:

$$\mathcal{P}_{coverage} = \mathcal{P}_r(x < x_0) = \frac{1}{\sqrt{2\pi}\sigma} \int_{-\infty}^{x_0} e^{-\frac{(r-r_m)^2}{2\sigma^2}} dr \quad (4.10)$$

For outdoor environment [6], the standard deviation of propagation loss random variable is always 8 dB Then, the slow fading margin of 90% edge coverage probability is as follows:

$$x_0 - r_m = 1.29\sigma = 1.29 \times 8 = 10.32 \quad (4.11)$$

Table 4.1: Common edge coverage probability and shadow fading margin

Edge coverage Probability (%)	70	75	80	85	90	95	98
Shadow fading margin (dB)	0.53σ	0.68σ	0.85σ	1.04σ	1.29σ	1.65σ	2.06σ

Note: σ is the standard deviation of slow fading. The value is 6, 8, or 10.

Therefore, in the GSM network planning and design 10.32 dB margin is reserved to ensure a 90% edge coverage probability.

Fast fading margin (Rayleigh fading margin): is a type of multipath wave interference generated because the propagation is reflected by scattering objects (mainly buildings) or natural obstacles

(mainly forest) around the MS (within 50-100 wave length). Fast fading always produces standing wave field.

Interference margin: In a GSM system, the internal interference can be co-channel interference or adjacent channel interference. The interference degradation margin describes the loss due to frequency reuse. The suggested value for the interference degradation margin in an average urban/dense urban and suburban area is 3 dB according to the ETSI recommendation 03.30.

Penetration loss: Building loss is associated with building style and structure, for example, concrete structure, brick structure, window size, and style.

Propagation Model Selection

For GSM 900MHz and GSM 1800MHz Okumura-Hata propagation model is selected, because it reads the maximum path loss at the calculated cell radius. This is done by considering the worst-case scenario for better radio network planning. For link budget calculation 900MHz frequency band is used because it gives 30 up to 40 percent better coverage than 1800MHz frequency band. Therefore, based on the above link budget parameters and path loss calculations in the appendix the link budget for 900MHz is summarized in Table 4.2.

Table 4.2: GSM 900 MHz Radio Link Budget calculation

	Scenario		Dense urban		Formula
	Parameter	Unit	UL	DL	
			MS	BS	
System parameter	Carrier frequency	MHz	900/1800		
	System band width	kHz	200		
	Data rate	kbps	9.6 or 4.6		
Transmitting parameter	Tx power	W	2	20	
	Tx power	dBm	33	43	a
	Antenna Gain	dB _i	0	17	b
	Cable loss + connector	dB	0	3	c
	Body Loss	dB	3	0	d
	EIRP	dBm	30	61	e = a+b-c-d

Receiving parameter	Antenna gain	dBi	18	0	f
	Cable loss + connector	dB	2	0	g
	Body Loss	dB	2	3	h
	Dual-Polarization Antenna Loss	dB	1	0	i
	Noise spectral Density, Ni	dBm/Hz	-174	-174	$j = kT$
	Noise Figure, F	dB	10	8	K
	Bandwidth (B)	dBHz	53	53	$l = \log_{10} B$
	C/I (Eb/No)	dB	9	7	m
	Receiver Sensitivity	dBm	-102	-106	$n = j+K+l+m$
Margin Reservation parameter	Area Coverage Probability	%	95	95	o
	Edge Coverage Probability	%	90	90	
	Slow Fading Standard Deviation	dB	8	7	
	Slow Fading Margin	dB	10.3	10.3	
	Fast Fading Margin	dB	2	5	
	Interference Margin	dB	3	3	
	Indoor penetration Loss	dB	0	0	
	Sum of Margins	dB	15.3	25.3	
Maximum Allowed Path Loss (MAPL)		dB	132.7	144.7	$u = e+f-g-h-i-n-t$
Cell Radius	Frequency Band	MHz	900		$v = 10^{[(u-129.32)/35.22]}$
	Propagation Model	Okumura-HATA			
	Cell Radius	km	0.6598	1.446	
	Selected Cell Radius	km	0.659		

As can be seen, there is an obvious difference in the results of the UL and DL power budget calculations, where the DL path loss exceeds the UL path loss. This is an indication that the area covered by the BS antenna is more than the area covered by the mobile station antenna, thereby giving more coverage in the DL direction.

Determining the required number of BS's

A tri-sector cells in a single BS are considered to provide precise coverage for the selected regions. The coverage area of the tri-sector BS is determined using the following formula [19, 44].

$$A = \frac{9\sqrt{3}}{8}R^2 = 1.95R^2 \quad (4.12)$$

Where, A is maximum area covered by a single BS and

R is radius of single cell.

We can now predict the coverage per BS using above equation. Thus, the computed cell radius is 0.66 km² for dense urban. Consequently, the coverage area of a single site would be 0.8494 km².

Then, we can calculate the required number of BS using the equation [19]:

$$\text{Required number of sites} = \frac{\text{Area to be covered}}{\text{site coverage area}} \quad (4.13)$$

The city of Addis Ababa which is area to be covered is 413.612 km² [19]. Therefore, a totally of 487 GSM 1800MHz BS's are required for the entire area of Addis Ababa city by considering uniform distribution of subscribers with dense urban area.

4.4.2. GSM Capacity Planning

Capacity dimensioning is a very important process in the network rollout as it defines the number of BS required and their respective capacities. There are three essential parameters required for capacity planning: estimated traffic, average antenna height and frequency usage.

Traffic estimation or modeling relays on theoretical estimates or assumptions, and on studies of existing networks. Traffic within the network depends on the user communication rate and user movement within the network. The user communication rate means that what quantity traffic is generated by the subscriber and for how long. The estimated traffic in the network is given in terms of '*Erlangs*'. One Erlang (*1 Erl*) is defined as the amount of traffic generated by the user when he/she uses one traffic channel for one hour (this one hour is usually the busy hour of the network).

In this thesis it is assumed an average of two call per hour and the call lasts an average of 90 seconds per call and individual voice traffic intensity is calculated as:

$$A_u = H \times \lambda \quad \text{in Erlang} \quad (4.14)$$

Where: H is average holding time i.e. average duration of a call or time for which UE requires service and λ is average arrival rate i.e. average number of UEs requesting service which is called call request/time.

Another term that's oftentimes utilized in network planning is '*Blocking*'. Blocking describes the situation when a user is trying to make a call and is not able to reach a dialed subscriber owing to

lack of resources. The actual traffic flowing in the network can be calculated by using tables that use the maximum traffic at a BS and the blocking rate. Commonly used Erlang tables are Erlang B and Erlang C. Erlang B assumes that if calls can't go through then they get dropped (i.e. no queuing possible). Erlang C considers that if a call does not get through then it will wait in a queue.

The frequency re-use factor is defined as the number of BS that can be implemented before the frequency can be re-used. The minimum frequency re-use factor calculation is based on the C/I ratio. As soon as the C/I ratio decreases, the signal strength starts deteriorating, thereby reducing the frequency re-use factor [31].

Another issue to stay in mind is that the BS's antenna height. If the antenna height is simply too high the signal should travel a bigger distance, therefore the likelihood that the signal causes interference becomes bigger. The antenna height may influence the reuse factor as the antenna height increases the chance that the signal causes additional interference will also increase [3]. Besides using Erlang B channel allocations for cells, the following assumptions has been made in the planning process.

Table 4.3: Capacity planning input parameters and assumptions

Parameter	Value
GoS	2%
Average calls per hour	2
Average call duration	90 seconds
Pages per cell	2
Available frequency channel	125
Frequency re-use pattern	4x3 = 12 sector
SMS ratio	0.1

Now the individual voice traffic intensity can be calculated as:

$$A_u = 45 \text{ seconds/call} \times 2 \text{ calls/hour}(3600 \text{ sec}) = 0.025 \text{ Erlang} = 25\text{mErl}$$

The following steps are used for GSM capacity panning:

Step 1: calculate frequency per cell

$$\text{frequency per cell} = \frac{\text{Available frequency channel}}{\text{frequency reuse factor}} = \frac{125}{12} = 10 \quad (4.15)$$

Step 2: calculate traffic channel per cell

As discussed in previous chapter GSM is TDMA based and contains 8 time slots. Out of the time slots 2 are for control channel and then traffic channel per cell can be calculated as:

$$\begin{aligned} TCH \text{ per cell} &= \text{number of time slots} \times \text{frequency per cell} - \text{control channel} \quad (4.16) \\ &= 8 \times 10 - 2 = 78 TCH \end{aligned}$$

Step 3: calculate number of subscribers per cell

First voice traffic intensity per cell is calculated and therefore from Erlang B table, 78 TCH with GOS 2% implies 66.77 Erlangs per cell and using this value number of subscribers per cell can be calculated as:

$$\begin{aligned} \# \text{ of sub/cell} &= \frac{\text{voice traffic intensity per cell}}{\text{Individual voice traffic intensity}} \quad (4.17) \\ &= \frac{66.77}{0.025} = 2671 \end{aligned}$$

Step 4: calculate required number of cells

As we discuss in the beginning of the chapter 2,068,060 subscribers are considered and the number of cells needed can be calculated as:

$$\begin{aligned} \# \text{ of cells required} &= \frac{\text{Total \# of subscribers}}{\text{subscribers per cell}} \quad (4.18) \\ &= \frac{2,068,060}{2671} = 775 \text{ cells} \end{aligned}$$

Step 5: calculate number of BS required

As discussed in the coverage planning session three sector cells in a single site is used in this thesis. Therefore, the required number of sites can be calculated as:

$$\text{required \# of sites} = \frac{\text{Number of cells}}{\text{sector size}} = \frac{775}{3} = 259 \text{ BS's} \quad (4.19)$$

Therefore, based on capacity planning a total of GSM 900MHz 259 BS's are needed to provide the intended capacity.

Finally, to get the required QoS we have to choose the maximum number of BS's from the coverage and capacity planning perspectives.

Table 4.4: Selected number of GSM sites for Addis Ababa city

Dimensioning	# of BS's calculated	Best selection
Coverage	487	487
Capacity	259	

4.5. UMTS Radio Network Planning

The main procedures of UMTS are very similar to that of GSM, and the coverage and capacity planning play additionally vital roles within the whole radio network designing. The main difference from GSM is that both are strongly related, and the coverage is a function of the capacity. Since UMTS is interference restricted, an enormous range of users can scale back the power availability at the BS to combat interference, and thus scale back the cell range in what is called the cell breathing effect. In UMTS, the frequency reuse factor is 1, and in each cell the whole bandwidth is used. So, there is no frequency assignment in UMTS [3, 6]. It uses WCDMA as its multiplex access method, which determines that the interference plays an essential role in the coverage and capacity planning.

The cell size in UMTS is not fixed. When the interference arises, the C/I deteriorate, which makes the UE at the old cell fringe hard to communicate with the BS. So, the cell size shrinks. The resulting swinging of the cell size in UMTS because of the dynamical interference is termed as “*cell breathing*”. Therefore, in UMTS the coverage and capacity planning can't made independently like in GSM, they are closely correlated. The higher the coverage, the lower is that the capacity, and the other way around [11, 12].

Unlike in GSM, where speech codes are fixed e.g. Full Reference (FR) or Half Reference (HR) and their channel protection is also fixed rate, in WCDMA radio networks the process of Adaptive Multi-Rate (AMR) is used to make it possible to adapt speech and channel coding rates according to the quality of the radio channel. This improves the error protection and channel quality [31].

The codec basically has one single integrated speech codec with eight source rates. This is controlled by the radio resource management functions of the RAN. These eight source rates are 12.2, 10.20, 7.95, 7.40, 6.70, 5.90, 5.15 and 4.75 kbps. The process of AMR selection is based on the channel quality measurements for which both the UE and BS are involved [31].

Once it is confirmed that the quality of a signal is bad, the number of speech codec bits is reduced, thereby increasing the number of bits that can be used for error detection. The speech frames in the AMR coder are of 20 ms, so if the sampling rate is 8000/s, 160 samples are processed. Thus, the bit rate can be changed at each of these 160 samples through in-band signaling or through dedicated channel (DCH). This process is known as link adaptation. Thus, by using AMR, speech, coverage and quality performance can be improved [13, 47].

4.5.1. UMTS Coverage Planning

The link budget is performed as part of coverage dimensioning process to acquire the maximum allowable path loss based on the given planning scenes. And the acquired maximum path loss will be further used to calculate the maximum cell radius based on the radio propagation model. In all these processes the final target is to estimate the number of required BS or NodeB to cover the target coverage area [48].

Using the minimum cell radius, the area covered by the single NB can be calculated through the hexagonal cellular layout. And as a final step, the number of NB required for the target coverage area is estimated based on the coverage area of a single NB.

Link budget parameters

Based on the signal propagation path from the transmitting end to receiving end, there are two paths, UL path, and a DL path. UMTS system could be UL or DL limited based on the system loading. In a lightly loaded system, the UE transmit power sets a coverage limitation, therefore, it is UL limited. In a heavily loaded system, the BS or NodeB transmit power limits the number of user equipment it can serve, therefore it is DL limited. Therefore, initially typical UMTS network is UL limiting or the UL is limiting link in terms of radio bearer coverage and later on a loaded network becomes DL limiting [48].

The link budget calculation involves various link parameters associated with gains, losses and design margins of the particular signal transmission path. As in [49] the major link parameters are discussed below.

System parameter

Chip and information rates: The system chip rate is 3.84 Mcps/s whereas the information rate depends upon the service. For speech the information rate is 12.2 kbps while for data services it can be 64kbps, 128kbps, 384 kbps or High-Speed Packet Access (HSPA). The processing gain is defined by the equation:

$$\text{Processing Gain} = 10 \log \frac{\text{chip rate}}{\text{bite rate}} \quad (4.20)$$

UE velocity: is an important parameter as it impacts the UL and DL E_b/N_0 requirements. The E_b/N_0 figures are based upon propagation models assuming 120 km/h and 3 km/h for vehicular and pedestrian environments, respectively. These two UE velocities are used in the link budget as they were deemed to provide the most challenging cases for planning. At 3 km/h the UE suffers significantly from fast fading and therefore power control is required to track this fading environment. At 120 km/h, power control is unable to track the fast fading, and therefore the E_b/N_0 value is now affected by the interleaving performance [11, 50, 51].

Transmitter parameters

UE maximum transmitting power (dBm): The maximum transmits power of the mobile station is set by the UE power class. On any given network there exists different mobile equipment from different power class. But usually voice-centric UE is class 3 or 4 and data-centric UE is class 3. Therefore, in the link budget calculation, the transmit power parameter for the UL path is specified as 21dBm for voice terminal while for data terminal it is specified as 24dBm and also 40dBm for data terminals in which (>64kbps) [52]. However, the data terminal may have positive antenna gain and some body loss but is assumed to have a net gain of 0dB.

NodeB's transmitting power (dBm): The common pilot channel (CPICH) is used by the NodeB to provide a reference to all mobile stations and aid the channel estimation at the terminals. For this reason, the CPICH channel is used to define the maximum possible coverage of a particular

cell [53, 25]. In this thesis the value for transmitting power of the NodeB is taken as 43dBm which is the typical CPICH power configuration of a cell [11, 44, 10].

Required E_b/N_o : E_b/N_o is the ratio of the received bit energy to the thermal noise. E_b is received energy per bit multiplied by the bit rate. N_o is the noise power density divided by BW [31]. For the UL link budget calculation, the E_b/N_o value assumption reflect the performance of the NodeB receiver and the value may vary from one vendor to the other. Accordingly, the E_b/N_o figures used for this link budget calculation are taken from Huawei company product documentation [19, 50].

Table 4.5: Required E_b/N_o Values

Information rate	Downlink	Uplink
CS 12.2kbps	7.5	4.2
CS 64kbps	5.2	2.7
PS 64kbps	4.8	1.6
PS 128kbps	4.5	1.1
PS 384kbps	4.3	0.6

Body loss (dBm): Body loss occurs at the UE side and its value depends on usage habit of the user. In the link budget calculation, the default value of body loss is 3dB for speech service and 0dB for data services because data services are mainly read and watched and the UE is far away from the human body [53].

Antenna gains (dBi): Antenna gain is one of the important attributes of antenna characteristic that is used in the link budget calculation. Normally the antenna gain for the UE is taken as 0dBi whereas for the NodeB antenna the value is chosen based on the type of antenna selected for each propagation scenario. For this particular case or thesis, the BS antenna selected for all propagation scenarios has an 18dBi gain [26].

EIRP: represents the effective isotropic radiated power from the transmitter antenna and for the UL and DL, it is computed as:

$$EIRP_{UL} = UE \text{ Transmitter Power} + UE \text{ Antenna Gain} - UE \text{ Body Loss} \quad (4.21)$$

$$EIRP_{DL} = \text{NodeB Transmitter Power} + \text{NodeB Antenna Gain} - \text{Cable Loss} - \text{Connector Loss} \quad (4.22)$$

Receiver parameters

The noise figures: Noise figure is an index used to evaluate whether noise performance of the amplifier is good or not. It is expressed by Noise Figures (N) and defined as the ratio of input Signal-to-Noise ratio (SNR) and output Signal-to-Noise ratio (SNR) of an amplifier.

Thermal noise spectral density: The thermal noise density is computed from the equation:

$$N = KT = -174\text{dBm/Hz}$$

Thermal noise power (N_i): The thermal noise density/power is computed from the equation:

$$N_i = KT_0B$$

Where, k is Boltzmann constant, which equals $1.38 \times 10^{-23}\text{J/K}$, T_0 is absolute temperature ($T_0 = 290\text{K}$), and B is system bandwidth

$$\text{Bandwidth per chip rate} = 3.84\text{Mchip/s} = 3.84 \times 10^6\text{chip/s}$$

$$B_{dB} \text{ per chip rate} = 10 \log(3.84 \times 10^6) = 65.84$$

$$N_{i \text{ chiprate/s}} = 1.38 \times 10^{-23} \times 290,000 \times 3.84 \times 10^6 = 1.54 \times 10^{-11}$$

$$\begin{aligned} N_{i(dB)} &= 10 \log(KT_0B) \\ &= -108.12 \text{ dBm} \end{aligned}$$

Receiver noise power / Total effective noise power: The total effective noise at the receiver is computed from the sum of the thermal noise power and the receiver noise figure.

$$\text{Receiver Noise Power} = \text{Thermal Noise Power} + \text{Noise Figure}$$

Receiver sensitivity: measures how well the receiver performs and is defined as the power of the weakest signal the receiver can detect. The receiver sensitivity is computed using the equation:

$$\text{Receiver Sensitivity} = \text{Receiver Noise power} + \frac{E_b}{N_0} - \text{Processing Gain} \quad (4.23)$$

Other Margins and Gains

Loading Factor: The coverage and capacity of UMTS systems are closely related because of the employment of constant frequency and sharing of power. As the cell load increases, additional interference is generated within the system leading to reduced coverage area. The increase and

reduction in coverage area as a result of the loading is termed as cell breathing/shrinking and should be taken under consideration when dimensioning the system.

Interference margin: The link budget includes an interference margin that is based upon the load factor and is given by the following equation:

$$Interference\ margin = 10\log\left(\frac{1}{1-load\ factor}\right) \quad (4.24)$$

As coverage is generally UL limited, the assumed UL loading will impact the cell ranges and site density. It should also be noted that a percentage of the noise rise within a cell would be due to interference from adjacent cells.

$$Load\ factor = 1 - [10^{-(noise\ rise/10)}] \quad (4.25)$$

The value of load factor may vary from zero to 100%. But practically it is in the range 40-50% [12, 11, 52]. Hence, the load factor is the ratio of actual load to the pole capacity and based on the above equation, for a cell load of 50%, the interference margin is 3dB.

Slow fading / log-normal fading margin: Slow fading or shadowing is the variation in the local mean of the received signal that is caused by terrain irregularity and is typically lognormally distributed. In this design thesis, the standard deviation of shadowing is taken as 10 dB in a dense urban propagation environment [6].

Fast fading margin / Power control headroom: Fast fading refers to the attenuation of the signals due to multipath reflections and diffractions. The short-term average of fast fading can typically be represented by a Rayleigh distribution. In slow moving environments, the UE's closed-loop fast power control can effectively compensate for fast fading. This would need applicable headroom within the UE transmission power. Based on [50, 52] in thesis link budget calculation, 2-3 dB is used for all propagation scenarios.

Soft Handover Gain: The soft handover phenomenon gives an additional gain against the fast fading that takes place in the network. The soft handover phenomenon can give a better signal quality for connection between UE & NodeB. Depending upon the degree of slow fading correlation between BS, soft handover results in a reduction of the required slow fading margin. In addition, soft handover provides gain against fast fading by reducing the required E_b/N_0 . Typical

values for soft handover gain are 4dB, 3dB, and 2dB for dense urban, urban and suburban scenario respectively [52].

Penetration loss: The in-building penetration losses are assumed to be dependent upon the building construction. In all the propagation environment a mean penetration loss is assumed to provide good indoor coverage for the outdoor macro cells. The value 20dB is assumed for dense urban scenario [54].

Cable and Connector Losses: Cable and connector losses in the link budget attribute to the losses in RF jumper cable that connects Remote Radio Unit (RRUs) of the BS to the antenna system. RF jumpers transmit signals between a BS and an antenna system. The RF jumper comes with a standard length of 2 m, 3m, 4 m, 6 m, and 10 m. For this design thesis 3m, standard length is selected and accordingly, a cable loss of 0.5 dB is considered [54].

Link Budget Calculations

The fundamental principle remains the same as described in GSM link budget. However, in WCDMA radio networks the link budget calculations need to be done individually for voice and various data rates (e.g. 64 kbps, 128 kbps, 384 kbps & HSPA) for a certain load (50% in this thesis) and for different applications.

This section presents the link budget templates for each radio bearer i.e. 12.2kbps speech, 64kbps data, 128kbps data, 384kbps data and HSPA. The data service link budgets are presented for Low Delay Constrained Data (LCD) services. It is assumed that the Unconstrained Delay Data (UDD) services have identical link budgets i.e. there is no difference between the packet switched (PS) and circuit switched (CS) radio bearer link budgets.

Maximum Allowed Path Loss (MAPL)

The Maximum Allowed Path Loss (MAPL) for each service and in every environment can be computed for UL and DL load factors and are assumed based upon the traffic density expectation. The transmitter EIRP and receiver sensitivities are calculated as the net gains and losses of the radio link. Finally, the maximum allowed path loss is computed for both the UL and DL. The UL is generally the limiting link in terms of radio bearer coverage. Nevertheless, the DL is checked to verify this assumption.

Selection of propagation model

For UMTS 2100 MHz COST- 231 HATA propagation model is selected because it reads the maximum path loss at the calculated cell radius and given frequency range. Therefore, by taking the worst-case scenario and using the above parameters and path loss calculations the link budget for UMTS 2100MHz is summarized in Table 4.6 and 4.7.

Table 4.6: Link Budget Formula for UMTS

	Parameter	Unit	Formula
System parameter	Environment		Pedestrian/vehicular
	Mobile velocity		3km/h / 120km/h
	Service		Service type
	Information bit rate	kbps	A
	Chip rate	Mchip/s	B
Transmitter parameter	Max. mobile transmission power	dBm	C
	UE antenna gain	dB	D
	UE body loss	dB	E
	EIRP	dBm	$F = C + D - E$
Receiver parameter	NodeB antenna gain	dB	G
	Soft handover gain	dB	H
	NodeB cable and connector loss	dB	I
	NodeB body loss	dB	J
	Thermal noise spectral density	dBm/Hz	$K = kT$
	Thermal noise power	dBm/Hz	$L = K + 10 \times \log B$
	Receiver noise figure	dB	M
	Receiver noise power	dBm	$N = L + M$
	Processing gain	dB	$O = 10 \times \log B/A$
	Required E_b/N_0	dB	P
	Receiver sensitivity	dBm	$Q = P - O + N$
	Mean noise rise/device noise	dB	R

	Loading factor		$N = 1 - [10^{-R/10}]$
Margin reservation	Coverage area reliability	%	T U V W
	Standard deviation	dB	
	Log-normal fading margin/shadow fading margin	dB	
	Fast fading margin/power control headroom	dB	
	Interference margin	dB	
	Indoor penetration loss	dB	
MAPL and cell radius	Max. allowable outdoor path loss	dB	$X = F + G + H - I - J - Q - R - T - U - V$ $Y = 10^{[(X-141.1)/35.22]}$ $Z = X - W$ $\gamma = 10^{[(Z-141.1)/35.22]}$
	Frequency band	MHz	
	Propagation model		
	UE/NodeB antenna height	m	
	Outdoor coverage cell radius	km	
	Cell radius output	km	
	Max. allowable indoor path loss	dB	
	Indoor coverage cell radius	km	
	Cell radius output	km	

Table 4.7: UMTS 2100MHz Radio Link Budget calculation for different services

	Unit	UL	UL	UL	UL	UL
Service		Speech	CS64K	PS128	PS384	HSUPA
Information bit rate	kbps	12.2	64	128	384	600
Chip rate	Mchip/s	3.84	3.84	3.84	3.84	3.84
Max. transmission power	dBm	21	24	24	24	30
UE antenna gain	dBi	0	0	0	0	0
Cable, connector and body loss	dB	3	0	0	0	0
EIRP	dBm	18	24	24	24	30
RX antenna gain	dB	18	18	18	18	18
Soft handover gain	dB	4	4	4	3	3

Cable, connector and body loss	dB	2	2	2	2	2
Thermal noise spectral density	dBm/Hz	-174	-174	-174	-174	-174
Thermal noise power	dBm/Hz	-108.12	-108.12	-108.16	-108.16	-108.16
Receiver noise figure	dB	2.1	2.1	2.1	2.1	2.1
Receiver noise power	dBm	-106.02	-106.02	-106.02	-106.02	-106.02
Processing gain	dB	24.98	17.78	14.77	10	8.062
Required E_b/N_0	dB	4.2	2.7	1.6	1.1	0.6
Receiver sensitivity	dBm	-116.03	-121.14	-119.19	-114.92	-113.48
Mean noise rise/device noise	dB	3	3	3	3	3
Loading factor		0.50	0.50	0.50	0.50	0.50
Coverage area reliability	%	95	95	95	95	95
Standard deviation	dB	10	10	10	10	10
Shadow fading margin	dB	10	10	10	10	10
Fast fading margin	dB	3	3	2	2	2
Interference margin	dB	3	3	3	3	3
Indoor penetration loss	dB	20	20	20	20	20
MAPL (Outdoor)	dB	153.03	146.14	145.19	139.92	144.48
Frequency band	MHz	2100				
Propagation model		Cost 231-HATA				
UE/NodeB antenna height	m	1.5	1.5	1.5	1.5	1.5
Outdoor coverage cell radius	km	1.36	1.39	1.31	0.926	1.25
MAPL (Indoor)	dB	133.03	126.14	125.19	119.92	124.48
Indoor coverage cell radius	km	0.59	0.376	0.353	0.250	0.337

As it shown on the table PS384 data has the smallest coverage which is 0.25km whereas AMR 12.2 (voice service) have the larger coverage than PS384 which is (0.59km). In this regard the limiting service is PS384 but it is more conservative to ensure continues voice coverage in this design. Hence, the site density is calculated based on the cell radius for voice service.

Therefore, the cell radius becomes 0.59 km, and the coverage area of a single NodeB would be $1.95(0.59)^2 = 0.67879 \text{ km}^2$. More over from the perspective of dimensioning and the area of study, a total of 610 NodeB's are enough to provide 3G services for the entire Addis Ababa city.

4.5.2. UMTS Capacity Planning

The purpose of capacity dimensioning is to estimate the approximate BS number needed from the capacity perspective. Similar to the link budget, the capacity estimation should be performed from the UL and DL based on the traffic model and service traffic demand. After the estimation of the cell size and sites count from the coverage prediction, the capacity estimation is carried out to verify whether the given sites count can carry the estimated user's capacity. Therefore, let's start from the individual voice traffic intensity for UMTS which is similar to GSM.

$$A_v = 45 \text{ seconds}/\text{call} \times 2 \text{ calls}/\text{hour} = 0.025 \text{ Erl} = 25 \text{ mErl}$$

UMTS Traffic Model

In this thesis 25mErl for voice, 10GB per month per user for dongle (heavy load user), 1GB per month per user for smart phone is used for UMTS [10], and the following assumptions are used.

- ✓ Percentage of daily traffic at busy hour is 10%, DL ratio 70% and UL ratio 30%
- ✓ Active users are assumed to be 70%
- ✓ From the total data user's, the average load heavy user is assumed to be 35%, smart phone user 65% and all users considered to use 100% of the assumed handset data.
- ✓ This traffic per user includes normal traffic, signaling traffic and additional soft handover traffic.

Table 4.8: Inputs for UMTS Traffic Model

Type	HSPA+		Hand set
	Dongle	Smart phone	Voice user
Traffic Usage in Month/User	10 GB	1 GB	0.025 Erl
Distribution percentage	35 %	65 %	

By taking the above traffic model inputs the capacity calculation is done as follows:

Calculate the data volume per month per user using the equation;

$$\begin{aligned}
 \text{Data volume/month/user} &= \sum(\text{Traffic usage in month/user} \times \\
 &\text{subscribers distribution \%}) \quad (4.26) \\
 &= 10GB \times 35\% + 1GB \times 65\% = 4.15GB
 \end{aligned}$$

Calculate HSPA throughput per user as:

$$\text{HSPA per day per user} = \frac{\text{Data volume/month/user} \times 8 \times 1024 \times 1024}{30 \times 24 \times 3600} = 13.43 \text{ kbps} \quad (4.27)$$

Since the busy hour ratio is 10 %, HSPA/day/user @BH throughput value becomes

$$\text{HSPA per day per user}_{BH} = 13.43 \text{ kbps} \times 0.1 = 1.343 \text{ kbps}$$

Calculate HSPA throughput per day per user @BH per active user by using the assumption of active user ratio which is 70 %

$$\text{HSPA per day per user @BH per active user} = 1.343 \times 0.7 = 0.940 \text{ kbps}$$

Since the calculated individual voice traffic intensity is in Erlang, it should be converted to kbps and calculate the total supported throughput

$$\text{Volume per user @BH} = \text{Erl per user@BH} \times 3600 \times AF \times \text{service rate} \quad (4.28)$$

Where, AF = Activity Factor with the value of 0.67, 1 and 0.9 for AMR12.2, CS64 and PS service respectively. The value of service rate is also 12.2kbps and 64kbps for AMR12.2 and CS64 respectively.

$$\text{Volume per user @BH} = 0.025 \times 3600 \times 1 \times 64 = 5.76 \text{ kbps}$$

Therefore, we can calculate HSPA throughput per user for DL and UL using the assumption 70 % DL ratio and 30 % UL ratio as:

$$\begin{aligned}
 \text{HSUPA throughput/user} \\
 &= \text{Volume per user @BH} + \text{HSPA/day/user @BH/active user} \times 0.3 \\
 &= 5.76 + 0.94 \times 0.3 = 6.042 \text{ kbps} \quad (4.29)
 \end{aligned}$$

HSDPA throughput/user

$$\begin{aligned}
 &= \text{Volume per user @BH} + \text{HSPA/day/user @BH/active user} \times 0.7 \\
 &= 5.76 + 0.94 \times 0.7 = 6.418 \text{ kbps}
 \end{aligned}$$

Estimate of radio capacity of one cell:

According to orange telecom laboratory test, the HSDPA average throughput per cell is 3.6Mbps, and HSUPA average throughput per cell is 1.9Mbps. Therefore, the supported subscribers per cell results as follow:

Table 4.9: UMTS cell load dimension result

Service	Cell load	Traffic/subs	Active subs/cell
HSUPA + Voice	1.9 Mbps	6.042 Kbps	315
HSDPA + Voice	3.6 Mbps	6.418 Kbps	561

Therefore, one cellular cell would support 876 subscribers for both DL and UL FDD mode communication. Finally, the required number of cells becomes:

$$\begin{aligned}
 \text{Required \# of cells} &= \frac{\text{Total subscriber \# of the selected area}}{\text{Total \# of active subscriber per cell}} && (4.30) \\
 &= \frac{2,068,060}{876} = 2361 \text{ cells}
 \end{aligned}$$

Since, three sector cells in a single site is used in this thesis a total of 787 UMTS NodeB’s are needed to give the required capacity for the entire Addis Ababa city. Therefore, from the coverage and capacity planning perspective we have to select the maximum number of sites for better QoS.

Table 4.10: Selected number of UMTS sites for Addis Ababa city

Dimensioning	# of NB’s calculated	Best selection
Coverage	610	787 NodeB’s
Capacity	787	

4.6. LTE Radio Network Planning

LTE Coverage planning consists of evaluation of UL and DL radio link budgets. The maximum path loss is calculated based on the required SINR level at the receiver, taking into account the

extent of the interference caused by traffic. The radius of the cell is determined by considering minimum of the maximum path losses in UL and DL directions and using a propagation model appropriate to the deployment area. Radio link budget is that the most outstanding element of coverage planning exercise as usual.

Capacity planning gives an estimate of the resources needed for supporting a specified offered traffic with a certain level of QoS (e.g. throughput or blocking probability). Theoretical capacity of the network is limited by the number of eNB installed in the network. Cell capacity in LTE is impacted by several factors, which includes interference level, packet scheduler implementation and supported modulation and coding schemes.

Link Budget offers the maximum allowed path loss and therefore the maximum vary of the cell, whereas coverage planning takes into account the interference by providing a suitable model. LTE conjointly exhibits soft capacity like 3G systems. Therefore, the rise in interference and noise by increasing the number of users can decrease the cell coverage forcing the cell radius to become smaller. In LTE, the most indicator of capacity is SINR distribution within the cell [25, 23, 17, 49].

4.6.1. Factors Affecting the LTE planning

LTE is design to support a single channel reuse pattern without resorting to tricks like spread spectrum. When considering capacity planning, or general system planning, the followings are some of the factors that should be taken in to account [19, 55].

Frequency Band: The chosen spectrum can have huge impact on the planning process since the nominal radius of the LTE radio cell is depends on the frequency of operation. Generally speaking, the lower the frequency, the larger the radio cell, the better the building penetration, the less sensitive to atmospheric issues the system becomes.

Allocated Spectrum and Channel Bandwidth: The bands are regulated in terms of the allowed operational BW. This is driven for the most part by the number of accessible spectrums in every of the bands. Some of the bands do not allow the use of the narrow channels, while others prohibit the use of the larger bandwidths. The amount of allocated spectrum can affect the overall network capacity and also the individual sector capacity.

LTE Channel Parameters: Once the individual channel bandwidths are known, it is possible to work out what the likely capacity of the channel will be. This is less straight forward in LTE for many reasons, not least of which is the nature of the OFDM technique employed on the radio interface.

Maximum Bit Rate per Channel: Based on a simple Nyquist calculation and an assumption of the overall efficiency (80%) of the radio, Table 4.11 shows the maximum data rates that could be expected from the various channel bandwidths. However, the actual cell capacity in LTE might vary due to issues of serving cell load and adjacent cell load and additionally the interference coordination feature of LTE.

Table 11: Maximum Uplink Capacity per Radio Channel

Modulation coding	Pick bit rate per sub carrier /BW combination					
		72/1.4 MHz	180/3.0 MHz	300/5.0 MHz	600/10 MHz	1200/20 MHz
QPSK ½	Single stream	0.9	2.2	3.6	7.2	14.4
16QAM ½	Single stream	1.7	4.3	7.2	14.4	28.8
16QAM ¾	Single stream	2.6	6.5	10.8	21.6	43.2
64QAM ¾	Single stream	3.9	9.7	16.2	32.4	64.8
64QAM 4/4	Single stream	5.2	13.0	21.6	43.2	86.4
64QAM ¾	2 x 2 MIMO	7.8	19.4	32.4	64.8	129.6
64QAM 4/4	2 x 2 MIMO	10.4	25.9	43.2	86.4	172.8

Equipment Performance: System performance will be affected by many factors related to the equipment used in the network. The fundamental aspects of the link budget swear entirely on the performance of the instrument. In many cases the vendor spec sheet will provide the majority of the information required to perform basic link budgets. This may be enough throughout the initial planning section of coming up with to determine a baseline for capacity and performance. Once the fundamental performance parameters have been functional and certain levels of performance have been determined, it is then possible to include the more complex features of the equipment to determine the additional gains possible. For example, MIMO, beamforming antennas, trafficker specific algorithms for interference management.

Population Demographic: The market research administration throughout the planning period can make use of the area classifications mentioned on top of and conjointly the population demographics. Analysis of typical demographic information can enable the planner to work out doubtless range of subscribers in a very given location at totally different times of the day.

Data Throughput: Data rates available to mobile subscriber have been increasing steadily over the last few years and will continue to do so, promoted by the additional capability of LTE. However, the capacity of the radio sector is not unlimited and careful throughput must be applied to the type of service sold to the subscriber. Of course, the best way to manage the traffic load in the network is to support different service levels and manage the flow data using QoS mechanisms.

4.6.2. Dimensioning of LTE Network

Dimensioning is the initial phase of network planning as we discussed at the beginning. It provides the primary estimate of the network part and their capacity. The purpose of dimensioning is to estimate the needed number of radio BS's required to support a specified traffic load in a specific area with specific service to the cell edge users as we know.

4.6.2.1. LTE network dimensioning inputs

LTE dimensioning inputs are generally divided into 3 categories: Traffic, coverage and capacity inputs. Traffic related inputs include average cell throughput, number of subscribers and demand traffic for each user in busy hour. These parameters are the client needs to produce a particular level of service. These inputs directly translate into QoS parameters. Besides this, cell edge coverage probability is used in the dimensioning tool to determine the cell radius and thus the site.

Radio link budget is of central importance to coverage planning in LTE. Its inputs include transmitter power, transmitter and receiver antenna systems, configuration antennas used, conventional system gains and losses, cell loading that effect the value of interference margin and propagation models. LTE can operate in conventional frequency bands of 900, 1800 and 2100MHz as well as extended band of 2600MHz. Additionally, channel types (Pedestrian, Vehicular) and geographical information is needed to start the coverage dimensioning exercise. Geographical input information consists of area type information (Dense urban, Urban, Suburban, Rural, etc....) and its related parameters (penetration loss, shadowing margin, etc....) and sizes of each area type to be covered. Furthermore, needed coverage likelihood plays a significant role in determination

of cell radius. Even a minor modification in coverage likelihood causes an outsized variation in cell radius.

Capacity dimensioning inputs provide the requirements, to be met by LTE network dimensioning exercise. Capacity planning input gives the number of subscribers in the system, their demanded services and subscriber usage level in the busy hour. Available spectrum and channel BW employed by the LTE system are vital for LTE capacity planning. Traffic analysis and data rate to support available services (voice, Data) are used to determine the number of subscribers supported by a single cell and eventually the cell radius based on capacity evaluation.

4.6.2.2. LTE network dimensioning outputs

LTE dimension outputs are used to estimate the feasibility and cost of the network. These outputs are further employed in detailed part of network planning. The main output of LTE dimensioning is the size of the cell. Two values of cell radii are determined, one from coverage evaluation and second from capacity evaluation. The minimum of the two numbers is taken as the final output. Cell radius is then used to calculate the required number of eNB's. Assuming a hexagonal cell shape, number of sites can be determined by victimization easy pure mathematics. Capacities of eNBs are obtained from capacity evaluation, along with the number of subscribers supported by each cell. The input and output parameters of the LTE dimensioning tool is shown in Figure below.

4.6.3. LTE Coverage Planning

For LTE systems, the main goal of coverage planning is to estimate the coverage distance of an eNB with parameter settings based on actual cell edge coverage requirements in order to meet network size requirements. The first steps for the initial planning of a cellular network are the selection of an adequate propagation model for the frequency range and type of region considered [23].

LTE Link Budget

Coverage planning consists of analysis of DL and UL radio link budgets. The maximum path loss is calculated based on service throughput defined by the cell edge user that required SINR level at the receiver. The radius of the cell is determined by considering minimum of the maximum path

losses in UL and DL values and using a propagation model appropriate to the deployment area. Radio Link Budget is that the most main component of coverage planning.

The Link budget considers many factors, such as building penetration loss, feeder loss, antenna gain, and the interference margin of radio links to calculate all gains and losses that affect the final cell coverage.

LTE Link budget Parameters

Effective Isotropic Radiated Power (EIRP): is used to express how much transmitted power is radiated in the desired direction. It takes into account the losses in transmission cables and connectors and includes the gain of the transmitter antenna as:

$$EIRP = P_{Tx} + G_{Tx} - \sum Total\ transmission\ losses \quad (4.31)$$

Where, P_{Tx} is the transmitter power (dBm) and G_{Tx} is the transmitter antenna gain (dBi)

eNB Output Power: This is one of the main factors that impact the link budget. In the link budget, 46 dBm output power per each branch of the MIMO 2×2 which means 2×40 watt is considered.

UE Maximum Total Transmitter Power: refers to the UE transmit power which depends on the power class of the UE. Currently only one power class is defined in 3GPP TS 36.101; class 3 with maximum transmitter power of 23dBm.

eNB Antenna Gain: The antenna gain is proportional to the antenna size, LTE band, and beam width of the antenna patterns (horizontal and vertical). A large antenna with narrow beam width provides a high gain while a short antenna with wider beam width provides less gain. The selection of antenna gains and beam width depends on the clutter type and coverage requirement. The low gain antenna (15–17dBi) can be used in dense urban and urban clutters while a high gain antenna (18–20dBi) can be used in rural areas and highways to extend the RF coverage [23, 28, 55].

UE Antenna Gain: Based on the specifications of 3GPP, UE(s) are assumed to have an integral antenna only with a gain of 0 dBi for each antenna port(s) [23].

Signal to interference noise ratio (SINR): SINR is the ratio of the average received modulated carrier power to the sum of the average co-channel interference power and the noise power from other sources. The UE is able to identify new intra-frequency cells and perform the reference signal received power (RSRP) and the reference signal received quality (RSRQ) measurements of identified intra-frequency cells without an explicit intra-frequency neighbor list containing Physical Cell Identity (PCI). SINR values are obtained from the system level simulation result and it depends on the receiver design. Thus, SINR is a vendor specific parameter.

Noise Figure: It is a key factor to measure the receiver performance. It is defined as the ratio of the input SINR at the input end to the output SINR at the output end of the receiver. The noise figure depends on the bandwidth and the eNB capability. A typical value for the noise figure is between 6 to 8 dB [26].

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

$$N = kBT \quad (4.32)$$

Where,

- ✓ k is Boltzman constant = $1.38 \times 10^{-23} \text{ J/K}$
- ✓ B is bandwidth of the channel = 20MHz
- ✓ T is absolute temperature at 290k

Receiver sensitivity: The eNB receiver sensitivity is the signal level/threshold at which the RF signal can be detected with a certain quality.

$$\text{Receiver sensitivity} = \text{Noise figure} + \text{SINR} + \text{Thermal Noise} \quad (4.33)$$

Maximum Path Loss (L_{MAX}): Maximum allowable attenuation of the radio wave traversing the air interface excludes clutter data (e.g. penetration losses propagation data) is expressed as:

$$L_{MAX} = P_{Tx} + G_{Tx} - L_{Tx} - SR + G_{Rx} - L_{Rx} + G_{div} \quad (4.34)$$

Where, L_{MAX} is the maximum DL/UL loss (dB), P_{Tx} is the transmitter power (dBm), G_{Tx}/G_{Rx} is the transmitting/receiving antenna gain (dBi), L_{Tx}/L_{Rx} is the transmitter/receiver loss (dB), SR is the receiver sensitivity (dBm) and G_{div} is the diversity gain (dB).

Penetration loss: Is the fading of radio signals from an indoor terminal to a base station due to obstruction by a building and vice versa. It depends on the type of the clutter and the nature of the buildings in the target coverage area.

Table 4.12: Penetration losses and Standard deviation of slow fading based on clutter type [49].

Clutter type	Penetration loss range (dB)	Standard deviation of slow fading (dB)
Dense urban	19 – 25	10

Body loss: Is the loss generated due to signal blocking and absorption when a terminal antenna is close to the body of the user. It depends on the position of the terminal and the user [25]. For this thesis 3dB for voice and 0dB for data body loss is considered.

Feeder Loss: Is the signal loss caused by various devices that are located on the path of the antenna to the receiver. Any device using an external antenna for service provision at either the eNB side or terminal side must consider feeder loss.

Interference Margin: Accounts for the rise of noise level in the terminal caused by the interference from neighboring users. It indicates the degradation of system receive performance caused by internal interference in the system due to system traffic. In fact, because of the frequency division nature of LTE, there's conjointly a detailed correlation between actual traffic load and interference margin practiced by the network i.e. there is no intra-cell interference due to OFDM subscriber's orthogonality. In this thesis typical value for interference margin is 3-8dBm [28].

Slow/shadow Fading Margin: Is the fading that is brought by obstruction of a building or natural feature. Shadow fading changes slowly, and is thus called "slow fading". Fading caused by location primarily from obstruction way exceeds attenuation caused by time. Therefore, the foremost concern for shadow fading is those caused by location changes. To minimize the impact of shadow fading and guarantee a precise edge coverage likelihood, certain allowances must be made. This is referred to as "slow fading margin", or the "shadow fading margin".

Maximum allowable path loss (MAPL): Allows the maximum cell range to be estimated with suitable propagation models which provide number of base station sites required to cover the target

geographical area. Propagation data is included in the calculation such as penetration loss, fading margin, gain against shadowing, then considering the interference margin and the body loss, the maximum allowable path loss is given by:

$$L(MAPL) = L_{MAX} - BL - IM + Penetration\ loss - shadow\ fading\ Margin \quad (4.35)$$

Where, BL is the body loss and IM is interference margin. Maximum Allowed Path Loss (MAPL) has different values for dense urban, urban and suburban (UL & DL).

Cell Edge User Throughput: It is the minimum net single UE target throughput requirement to be achieved at the cell edge. It determines the service that can be provided at the cell edge; accordingly, it can limit the minimum Modulation and Coding Scheme (MCS) to be used. This parameter usually provided by the network operator based on the required services at cell edge. A typical value for UL can be 512 kbps to 1 Mbps where as in the DL it can be 1 Mbps up to 4 Mbps.

Selection of propagation model

COST231-Hata model has the maximum path loss as compared to the other models. Therefore, the worst-case scenario must be chosen for a better radio coverage and COST231-Hata model is selected in the calculation of the cell radius. Therefore, based on the above parameters and path loss calculations in the appendix the link budget calculation for LTE 1800MHz is summarized in Table 4.13.

Table 4.13: LTE 1800MHz UL and DL Radio Link Budget

	Scenario		Dense urban		Formula
	Parameter	Unit	UL	DL	
	Data channel type		PUSCH	PDSCH	
System	Duplex mode		FDD	FDD	A B C
	System bandwidth	MHz	20	20	
	Cell edge rate	kbps	128	512	
Transmitting end	Tx power	dBm	23	46	
	Allocated RB		3	19	
	RB to distribute power		3	100	

	Subcarriers to distribute power		36	1200	D=12*C
	Subcarrier power	dBm	7.44	15.21	E=A-10*log ₁₀ (D)
	Tx antenna gain	dBi	0	17	G
	Tx cable loss	dB	0	0.5	H
	Tx body loss	dB	0	0	I
	EIRP per subcarrier	dBm	7.44	31.71	J=E+G-H-I
Receiving End	SINR	dB	-4.19	-5.37	K
	Rx noise figure	dB	6	8	L
	Receiver sensitivity	dBm	-134.13	-130.61	M=K+L-174+10*log₁₀(15000)
	Rx antenna gain	dBi	17	0	N
	Rx cable loss	dB	0.5	0	O
	Rx body loss	dB	0	0	P
	Target load (%)	%	75	90	
	Interference margin	dB	3	4	Q
	Minimum signal reception strength	dBm	-149.74	-127.89	R=M-N+O+P+Q
Path loss and cell radius	Indoor penetration loss	dB	20	20	S
	Standard deviation of shadow fading	dB	11.7	11.7	
	Area coverage probability	%	95	95	
	Shadow/slow fading margin	dB	9.43	9.43	T
	Maximum allowable path loss	dB	126.6	128.74	U=J-R-S-T
	eNodeB/UE antenna height	m	1.5	30	
	Frequency Band	MHz	1800		
	Propagation Model	Cost231-HATA			
	Cell Radius	km	0.47	0.55	
	Cell Radius Output	km	0.47		V = 10^[(U-137.95)/35.23]

Therefore, the cell radius becomes 0.47 km, Thus the coverage area of a single eNB would be $1.95(0.47)^2 = 0.431 \text{ km}^2$. More over from the perspective of dimensioning, a total of 960 eNB's are enough to provide LTE services for the entire Addis Ababa city.

4.6.4. LTE Capacity Planning

Theoretical capacity of the network is limited by the number of eNBs installed in the network. In LTE, the main indicator of capacity is the SINR distribution in the cell. The SINR distribution may be directly mapped to the system capacity (data rate). Unlike thermal noise which may be overcome by increasing SINR, co-channel interference can't be countered by merely increasing the carrier power of a transmitter. This is because an increase in carrier transmission power will also increase the interference to the neighboring co-channel cells. Another type of interference in LTE networks is adjacent channel interference which results from imperfect receiver filters and allow nearby frequencies to interfere with the used frequency channel.

The subscriber density and subscriber traffic profile are the main requirements for capacity dimensioning. The dimensioning method finds the maximum capacity that the target cell can sustain momentarily, given the system load in the surrounding cells. It is improbable that all cells in a system are fully loaded at the same time, as observed in real networks of different technologies [23, 25]. Available spectrum and channel BW utilized by the LTE system also are vital for LTE capacity planning.

Generally, the following steps are procedures for LTE Capacity Planning.

- ✓ *Traffic model analysis*: Specific customer requirements
- ✓ *Throughput per subscriber*: can be calculated by using traffic model and assumptions
- ✓ *Network throughput per site*: determined as three times of the sector throughput at BH.
- ✓ *Number of subscribers per site*: can be calculated as throughput per site / throughput per user.
- ✓ *Number of sites*: Equals to total number of users / number of users per site

The daily traffic can be estimated as a percentage of the busy hour traffic in order to guarantee low delays and reasonably good data rates. In this thesis design 10% of the daily traffic is assumed as the busy hour traffic. Generally, the main purpose of traffic model is to describe the average subscriber behavior during the most loaded day period (Busy Hour) and the capacity of site should be based on busy hour as the traffic is not equally distributed during 24 hours [19].

Three category of service packages are provided, golden service package, silver service package, and bronze service package. Every service has its own quality, the month service package, the DL and UL peak data rates, and the package percentage. Generally, the traffic model of the above types of service based on the current usage of Ethio-Telecom data usage are listed in table below [19].

Table 4.14: Traffic model and assumption of input parameters for capacity dimensioning

Types of customer	Traffic Usage in GB/Month/User	Busy hour convergence ratio	Usage ratio of the services (%)	Traffic ratio	
				DL (%)	UL (%)
Golden	20	14.4	70	80	20
Silver	15	14.4	20	80	20
Bronze	10	14.4	10	80	20

Therefore, the average throughput per subscriber based on traffic usage in the month (GB) is calculated using:

$$\Omega(Kbps) = \left(\frac{\text{monthly service package} \times 8 \text{ bit} \times \text{BH ratio}}{30 \text{ days} \times 24 \times 60 \times 60} \right) \quad (4.36)$$

$$\Omega(Kbps) = \rho \times \alpha \times \left(\frac{8 \text{ bit}}{30 \text{ days} \times 86,400} \right) \times K \quad (4.37)$$

Where,

$\Omega(Kbps)$ is average throughput per user in BH (UL + DL)

ρ is the Traffic Usage in *month/user*

α is traffic ratio of BH to the traffic of the whole day

K is BH convergence ratio

$$\text{Golden: } \Omega(Kbps) = 20 \times 10^9 \times 0.1 \times \left(\frac{8 \text{ bit}}{30 \text{ day} \times 86,400} \right) \times 14.4 = 66.66$$

$$\text{Silver: } \Omega(Kbps) = 15 \times 10^9 \times 0.1 \times \left(\frac{8 \text{ bit}}{30 \text{ day} \times 86,400} \right) \times 14.4 = 50$$

$$\text{Bronze: } \Omega(Kbps) = 10 \times 10^9 \times 0.1 \times \left(\frac{8 \text{ bit}}{30 \text{ day} \times 86,400} \right) \times 14.4 = 33.3$$

Then, the total average throughput per subscriber in busy hour is given by:

$$\begin{aligned}\phi(\text{kbps}) &= \sum[\Omega(\text{Kbps}) \times \text{usage ratio of the servicpackages}] & (4.38) \\ &= 66.66 \times 0.7 + 50 \times 0.2 + 33.3 \times 0.1 = 59.992 \approx 60 \text{ kbps}\end{aligned}$$

Where, $\phi(\text{kbps})$ is the total average throughput/sub in BH (UL+DL)

Finally based on the traffic of services, the total average throughput per subscriber for uplink and downlink is written as:

$$\Gamma(\text{kbps}) = \phi(\text{kbps}) \times \text{UL traffic ratio} = 60 \times 0.2 = 12 \text{ kbps} \quad (4.39)$$

$$\eta(\text{kbps}) = \phi(\text{kbps}) \times \text{DL traffic ratio} = 60 \times 0.8 = 48 \text{ kbps} \quad (4.40)$$

where, $\Gamma(\text{kbps})$ is the average throughput for uplink

$\eta(\text{kbps})$ is the average throughput for downlink

The peak capacity throughput per sector is calculated by considering a 20 MHz LTE system with 2x2 MIMO. As per 3GPP release 10, LTE support QPSK, 16QAM and 64QAM modulations for downlink and QPSK and 16QAM for uplink. Each Modulation has its bits carrying capacity per symbol. One QPSK symbol can carry 2bits, one 16QAM symbol can carry 4bits and 64 QAM symbol can carry 6 bits.

As LTE uses OFDMA for the downlink, the basic substructure in time is a subframe of 1 ms duration. A subframe is in turn divided into two slots, and each slot is 7 symbols long. The basic data structure in LTE is a Resource Block (RB). A resource block consists of twelve (12) subcarriers (15 kHz wide each) and with a length of 1 slot. A resource element (RE) is one subcarrier wide in frequency and one symbol long in time.

Hence, first calculate the number of Resource Elements (RE) in a sub-frame.

- 1RB = 12 sub-carriers
- 1 Sub-frame=1ms
- 1time slot=7 OFDM symbols when normal cyclic prefix (CP) length is used

Therefore, number of RE in one sub-frame is calculated as:

$$\text{One sub frame} = 12 \text{ subscribers} \times 7 \text{ OFDM symbols} \times 100 \text{ RB} \times 2 \text{ slots} = 16,800 \text{ RE}$$

Generally, the input parameters to calculate peak and average throughput per site for uplink and downlink are listed below:

Table 4.15: Input parameters for UL and DL peak and average throughput per site

Description	Unit	Value	Assigned	Remark
Used BW	MHz	20	A	
Assumed 10% of BW used for guard	MHz	2	B	10% of A
Effective BW	MHz	18	C	A-B
BW of one subscriber	KHz	15	D	
Total subscriber		1200	E	C/D
Symbols per 1ms for RB		16800	F	$12 \times 7 \times 2 \times 100$
Symbols per 1ms for RB	Mbps	16.8	G	F/1000
MIMO effect	$2T \times 2R$ for downlink			
Bits capacity per symbol	Bit	2	H	QPSK
		4	I	16QAM
		6	J	64QAM

Based on the frame structure and coding rate the peak throughput per site is given by:

$$\delta(Mbps) = data \frac{RE}{sec} \times bits \text{ per } RE \times MIMO \text{ effect} \times coding \text{ rate} \quad (4.41)$$

Where, $\delta(Mbps)$ is the peak throughput per site per modulation, $data \frac{RE}{sec}$ is the data in resource element per second and coding rate indicates the volume coding rate of the channel code. For example, the volume coding rate of QPSK_{1/2} is 1/2, and the volume coding rate of 16QAM_{3/4} is 3/4.

Table 4.16: Input parameters for average throughput per site manipulation

Modulation	Data rate	MIMO effect	Data resource/sec (Mbps)	Code rate
QPSK	2	2	16.8	0.3
16QAM	4	2	16.8	0.38
64QAM	6	2	16.8	0.45

For QPSK:

$$\delta(Mbps) = 2 \times 2 \times 16.8 \times 0.3 = 20.16$$

For 16 QAM:

$$\delta(Mbps) = 4 \times 2 \times 16.8 \times 0.38 = 51.072$$

For 64 QAM:

$$\delta(Mbps) = 6 \times 2 \times 16.8 \times 0.45 = 90.72$$

The total peak throughput per site is therefore:

$$\delta(Mbps)_{Tot} = \delta(Mbps)_{QPSK} + \delta(Mbps)_{16QAM} + \delta(Mbps)_{64QAM} \quad (4.42)$$

$$\delta(Mbps) = 20.16 + 51.072 + 90.72 = 161.952 \approx 162$$

Then, the average throughput per site for uplink and downlink can be calculated as:

$$\lambda(Mbps) = \sum [\delta(Mbps)_{Tot} \times \text{traffic ratio of UL}] = 162 \times 0.2 = 32.4$$

$$\mu(Mbps) = \sum [\delta(Mbps)_{Tot} \times \text{traffic ratio of DL}] = 162 \times 0.8 = 129.6$$

Where, $\lambda(Mbps)$ and $\mu(Mbps)$ represents the average throughput per site of uplink and downlink respectively.

Therefor using the above results, we can calculate the maximum subscriber number per site for both uplink and downlink as:

$$\text{Max \# of sub per site} = \frac{\text{Avg.throughput per site}}{\text{Avg.throughput per sub}} \quad (4.43)$$

$$\text{Max \# of sub per site}_{UL} = \frac{\lambda(Mbps)}{\Gamma(kbps)} = 2,700$$

$$\text{Max \# of sub per site}_{DL} = \frac{\mu(Mbps)}{\eta(kbps)} = 2,700$$

Calculation number of sites for DL and UL

$$\text{Total site \#} = \frac{\text{Total sub of the area to be covered}}{\text{Max \# of sub per site}} \quad (4.44)$$

$$\text{Max \# of sub per site}_{UL} = \frac{2,068,060}{2,700} = 766 \text{ eNodB's}$$

$$\text{Max \# of sub per site}_{DL} = \frac{2,068,060}{2,700} = 766 \text{ eNodB's}$$

From the coverage and capacity dimensioning perspective we have to select the maximum number of sites.

Table 4.17: Selected number of LTE sites for Addis Ababa city

Dimensioning	# of eNB's calculated	Best selection
Coverage	960	960 eNodeB's
Capacity	766	

Therefore, from the GSM, UMTS and LTE planning perspectives a total of 2,234 BSs/NB's/eNB's (487+787+960), which is greater than the existing number of BSs i.e. 1,711 BSs are needed to give the required coverage and QoS for the entire Addis Ababa city. From this we can observe that 523 extra RATs are added to the existing number of BSs. In the case of Multi-RAT, a total of 960 sites are required which is greater than the existing number (i.e. 745 sites).

Table 4.18: Total required number of Multi-RAT sites

Technology Type	Planned number of sites	Technology Type	Existing number of sites
GSM-UMTS-LTE	487	GSM-UMTS-LTE	329
UMTS-LTE	300	GSM-UMTS	308
LTE only	173	UMTS only	105
		GSM only	3
Total	960		745

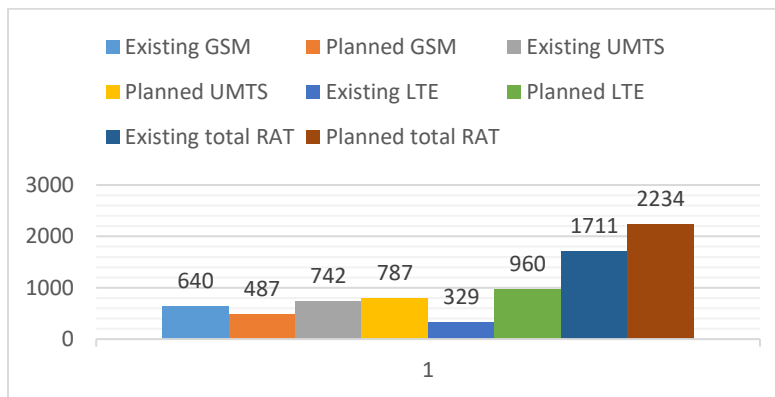


Figure 4.5: Comparison of single RAT site numbers with the existing ones

4.7. Cell Sleep Mode

As discussed in the previous chapter cell sleep mode technique consists turning off a BSs experiencing low traffic load. However, this should be done while ensuring the same quality of service to mobile users in the cell by the stations that remain active and this is the main challenge [4, 9]. A BS controller (BSC) facilitates exchange of traffic information between BSs. This challenge occurs because at least a basic capacity over the whole coverage area of the cell or sector that is being switched-off should maintain. Unnecessary energy consumptions, for example, air conditioning under-loaded BSs, can be avoided by adopting such sleep mode mechanisms.

The sleep mode technique is based on current architecture, it has the advantage of being easier to test and implement as no replacement of hardware is required, very helpful in the sense that it targets and causes a reduction in the most energy consuming component, the BS and the performance can be evaluated by computer simulation. In the other direction, implementing sleep mode introduces some drawbacks in the total throughput of the system. Some of these drawbacks include the duration of activation and deactivation of resources. This activation time normally blocks new arrived mobile users or handovers. As a result, some upgrade has to be done in order to reduce the activation time consequently reducing the blocking of mobile users and thus achieving the required quality of service. A second known threat of sleep mode is the ping-pong effect resulting in unnecessary on/off oscillations. This occurs when resources are activated or deactivated several times, leading to a large signaling overhead [36].

Considering the facts mentioned above, the application of sleep modes of BS decreases the energy consumption. BSs can be switched off when and where they are not necessary [56]. Furthermore, interference between cells is also reduced since the radio emission is interrupted during sleep modes. Generally, there are three requirements when BS sleep mode is applying:

1. Minimized the consumed energy.
2. Guarantee the availability of wireless access over the service area.
3. Minimize the perceived degradation of user experience.

Usually, the power consumption model of a BS consists of two parts [57]: The first part describes the static power consumption, a power figure which is consumed already in an empty base station. The second part is dynamic power consumption, which is depending on the load situation.

$$P_{BS} = P_{sta} + P_{dyn} \quad (4.45)$$

where, P_{sta} is the static power consumption and indicates the power consumed when a BS is idle or does not communicate with any UEs. It includes power consumption by the power amplifier, power supply, feeder, signal processing and air conditioning. P_{dyn} indicates the dynamic power consumption, which mainly determined by the power used for data transmission and depends on the associated traffic load.

Based on [4] low traffic is experienced in the interval time from 01:00 to 08:00 or in our local time from 7 am to 2 am morning as shown in the Figure 4.7. Therefore, the basic idea here is, sleep mode is activated by switching off some BS's experiencing low traffic load in these intervals of time and minimize the power consumption. After 8 am the traffic is increased rapidly and reach in the peak traffic load at 11 am and therefore the BS's which turned off before should release and remains permanently active in order to give the required coverage and capacity. In this case when some BS's are turned off, the sleeping sites release their channel resources to active neighbors, while active BS's make use of obtained resources to cooperatively provide extensive coverage to the mobile users located in the service areas of nearby sleeping BSs.

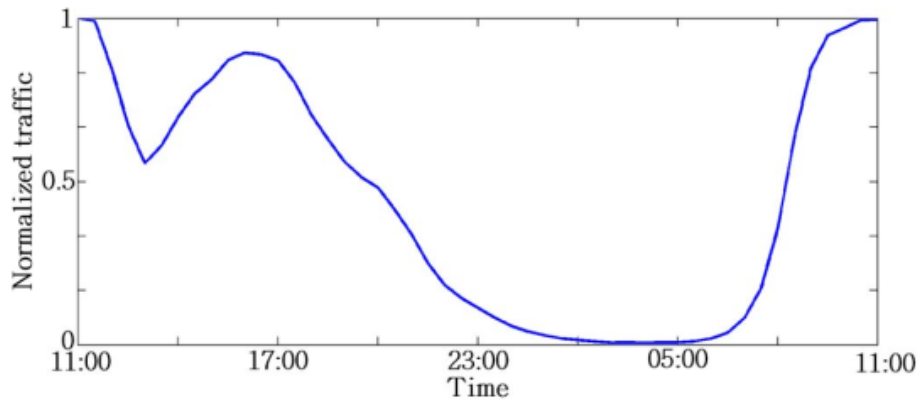


Figure 4.6: Daily traffic pattern of cellular system [4]

In this case, LTE network is selected for implementing cell sleep mode and by switch off 50% and then 75% of LTE eNB's the performance of the network is evaluated in terms of some parameters such as SINR and coupling loss. Then measure and discuss the overall performance of the network as well as the power consumption before and after sleep mode.

The first task to be done here is developing a typical heterogeneous based network topology and UE distributions using MATLAB and this is as preliminary study to show up the impact of cell sleep mode on the performance of the network. These follow 3GPP specifications that are widely used in simulations which are used for evaluating different performance metrics. In modeling of the heterogeneous network, Het-Net Conf 4b network topology has been chosen to consider a hotspot scenario. The performances of the Het-Net network have been evaluated by using coupling loss and SINR based on daily traffics. These output results are used for the purpose of justification of simulation results obtained with actual data.

4.7.1. Generation of the hexagonal eNBs topology

Structure of eNBs with 3 cells/sectors per eNB has been generated. Its fields include location in x-y plane, vertices of the hexagon containing an eNB, the three cells/sectors within the hexagon containing an eNB. The following steps have been followed in generation of the hexagonal eNB.

Generation of vertices:

The vertices for $0 \leq k \leq 5$ has been generated in the following manner

$$L(k + 2,1) = D * \text{Cos} \left(\frac{\pi}{6} + K * \frac{\pi}{3} \right) \quad (4.46)$$

$$L(k + 2,2) = D * \text{Sin} \left(\frac{\pi}{6} + K * \frac{\pi}{3} \right)$$

Where L is the location of eNB in x-y plane, D is the inter site distance, k is the number of vertices and the center of the cell is at the origin (0, 0).

Generation of the vertices for the center hexagon:

The Coordinates of the vertices of the hexagon containing an eNB for $0 \leq i \leq 5$ has been generated using:

$$C(1, i + 1,1) = b * \text{Cos} \left(i * \frac{\pi}{3} \right) \quad (4.47)$$

$$C(1, i + 1,2) = b * \text{Sin} \left(i * \frac{\pi}{3} \right)$$

Where C is coordinates of the vertices of the hexagon containing an eNB & $b = \frac{D}{\sqrt{3}}$

Generation of the sector boundary points for the center hexagon:

Assuming the three sectors within the hexagon containing an eNB are A, B & C, the coordinates of the three sectors within the hexagon containing an eNB has been generated in the following manner:

For Sector B and C boundary

$$S(1,1,1) = 0$$

$$S(1,1,2) = -a \quad (4.48)$$

For Sector A and B boundary

$$S(1,2,1) = -3 \times \frac{b}{4}$$

$$S(1,2,2) = \frac{a}{2} \quad (4.49)$$

For Sector C and A boundary

$$S(1,3,1) = 3 \times \frac{b}{4}$$

$$S(1,3,2) = \frac{a}{2} \quad (4.50)$$

Where $a = \frac{D}{2}$

Generation of the vertices and sector boundary points for the other hexagons:

The vertices and sector boundary points for the remaining hexagons have been generated as follows:

Generation of the vertices of the center hexagon for the remaining hexagons for $2 \leq k \leq n$

$$C(K, n, 1) = C(1, n, 1) + L(k, 1)$$

$$C(K, n, 2) = C(1, n, 2) + L(k, 2) \quad (4.51)$$

Where n is number of eNBs

Generation of the sector boundary points for the center hexagon of the remaining hexagons for $1 \leq j \leq 3$

$$S(K, j, 1) = S(1, j, 1) + L(k, 1)$$

$$S(K, j, 2) = S(1, j, 2) + L(k, 1) \quad (4.52)$$

4.7.2. Generation of the small cells or remote radio heads (RRHs)

The small cells or remote radio heads (RRHs) in each cell/sector as per a uniform distribution with a minimum distance constraint from the base station in the cell/sector and other small cells has been generated. The generated topology shows the sector, in which the given RRH is located, the location of the RRH amongst associated sectors & finally the location of the RRH in the x-y plane.

4.7.3. Calculation of the Angle and antenna gain

The sector of the hexagon where the point falls given a point with coordinates 'p' and a hexagon with center 'c' has been calculated as follows:

$$\phi = \text{atan2}(e, f) \quad (4.53)$$

Where,

$$e = p(2) - c(2)$$

$$f = p(1) - c(1)$$

ϕ is the azimuth angle of the point with respect to the hexagon center. For a given range value of ϕ ($\phi \geq \frac{\pi}{6}$ & $\phi \leq 5 \times \frac{\pi}{6}$) the sector in which the point falls is 1.

The combined gains of the horizontal (azimuth) sectorized and the vertical (elevation) antennas for a given UE to all base cells/sectors have been calculated.

The horizontal antenna pattern used for each BS sectors is specified as

$$A(\theta) = -\min \left[12 \left(\frac{\theta}{\theta_{3dB}} \right)^2, A_m \right] \quad (4.54)$$

Where, $A(\theta)$ is the relative antenna gain (dB) in the direction θ , $-180^\circ \leq \theta \leq 180^\circ$,

θ_{3dB} is 3 dB beam width &

A_m is the maximum attenuation

The vertical antenna pattern used for each BS sectors is specified as

$$A_e(\phi) = -\min \left[12 \left(\frac{\phi - \phi_{tilt}}{\phi_{3dB}} \right)^2, A_m \right] \quad (4.55)$$

Where, $A_e(\phi)$ is the relative antenna gain (dB) in the elevation direction ϕ , $-90^\circ \leq \phi \leq 90^\circ$,

ϕ_{3dB} is the elevation 3 dB value.

The combined Antenna gain (dB) is calculated as:

$$A(\theta, \phi) = -\min \left[- (A(\theta) + A_e(\phi)), A_m \right] \quad (4.56)$$

4.7.4. Generation of UEs and the large-scale channel between UEs and eNBs

The UEs based on a clustered distribution over each cell/sector and a minimum distance constraint from the base station and the small cells in that cell/sector have been generated. A certain fraction of the UEs are clustered around the small cells.

The large-scale channel between UEs and base stations for the Het-Net conf 4b topology has been generated. The path loss, shadow fading and sectorized antenna gains have been generated. They are based on parameters specified in "Guidelines for evaluation of radio interface technologies for IMT-Advanced" and 3GPP specifications. A certain percentage of UEs are assumed to be indoors.

The first simulation metric for the modeled system is the Coupling Loss (or the Link gain) and is calculated as:

$$P_{Rx} - P_{Tx} = AG - P_L - SF \quad (4.57)$$

Where, P_{Rx} and P_{Tx} are receiving and transmitting powers, P_L and SF are the path loss and shadow fading and also AG denotes the directional antenna gain that constitutes a sector. The path loss and shadow fading vary with carrier frequency as discussed in the planning session, whether the UE is indoor or outdoor and whether the UE link is LoS or NLoS. The links of most interest are the coupling loss between the base station.

The second simulation metric for the modeled system is SINR (Geometry) in which an indication of the overall performance of the cellular network.

$$SINR = \frac{Signal}{Interference+Noise} \quad (4.58)$$

The noise is constant while the interference is an aggregate of all interfering base stations apart from the serving base station.

Finally, the power consumption will be reduced while some BS's are turned off when low traffic load is experienced. During these times the total power consumption will calculate by adding transmitting power of the remaining active sites.

5. Chapter Five: Results and Discussions

5.1. Introduction

In this chapter, the system model developed in Chapter 4 will be used for simulation using Atoll network planning tool software as well as MATLAB & the results obtained from simulation will be discussed.

Overview of ATOLL

ATOLL is a 64-bit multi-technology wireless network design and optimization platform. It is scalable, flexible, and supports wireless operators throughout the network life cycle, from initial design to densification and optimization. Atoll's integration and automation features help operators smoothly automate planning and optimization processes through flexible scripting and service-oriented architecture (SOA) based mechanisms. Atoll supports a wide range of implementation scenarios, from standalone to enterprise wide server-based configurations using distributed and multi-threaded computing. It offers a series of coverage predictions which are based on the predicted signal level from the best server and the predicted signal levels from other cells (interference) at each pixel, i.e., carrier-to-interference-and-noise ratio, or $C/(I+N)$.

In this thesis the atoll simulation environment is used to investigate the RAN nominal planning of G/U/L networks. The Multi-RAT radio network planning simulation is intended to carry out the link budget calculation, propagation modeling using the terrain model, coverage estimation and capacity evaluation. The cell planning tools require digital map as one input which contains information about, the land usage, about the height of obstacles and they should also contain so called vector data.

On the other hand, the simulation results of the hexagonal grid layout with the eNBs at the center and the location of the UEs for Heterogeneous Network Configurations is shown for different traffic durations. Next, depending on the daily traffic, Sleep mode has been activated to study its effect on coupling loss & SINR. The simulation results of above considered cases are obtained by using MATLAB.

5.2. Setting simulation parameters in Atoll

In this section, dimensioning inputs used in the development of methods and models for GSM, UMTS and LTE dimensioning using ATOLL tool has been discussed.

Digital Map: is a geographical map of the planned area. It is the most basic and initially required tool for RNP. In coverage (link loss) predictions and subsequently the link loss data are utilized in the detailed calculation phase and for analysis purposes. The digital map with topographic data, morpho graphic data and building location and height data, in the form of raster maps is the minimum requirement. The digital map of Addis Ababa city is shown in Figure 5.1

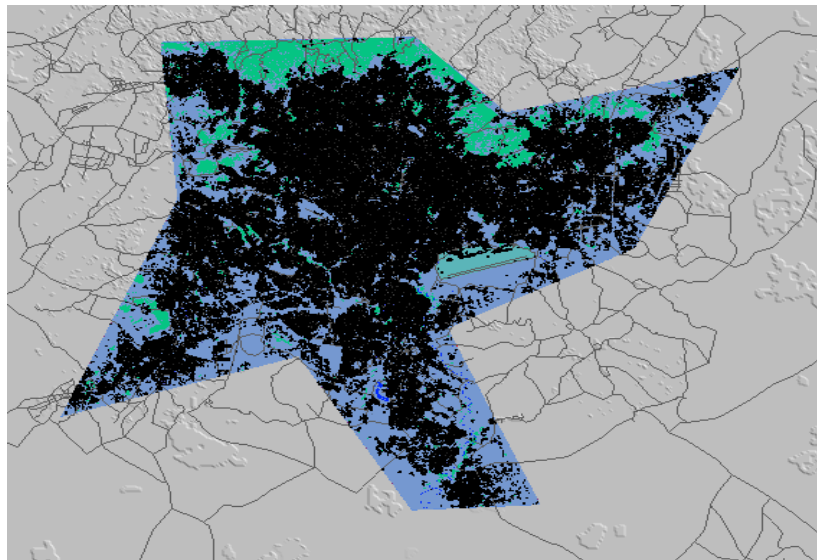


Figure 5.1: Digital map of Addis Ababa

Computational Zone: is a special zone where the intended calculations being carries out. It defines the area where the coverage prediction results will be displayed. Therefore, it allows to restrict the coverage prediction result to the part of the network aimed to work on. Unless Atoll makes its calculations for the entire extent of the geographical data available.

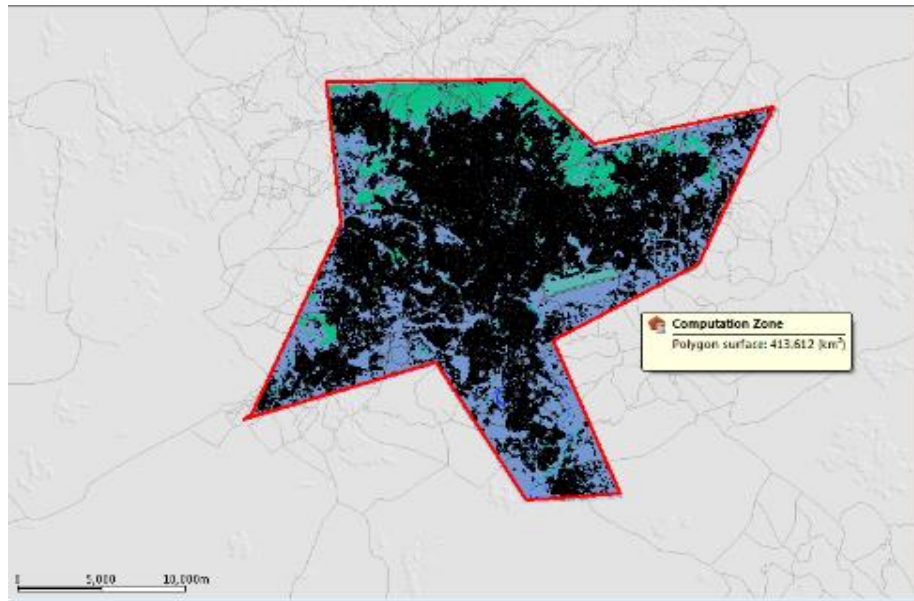


Figure 5.2: Computational zone of the case study

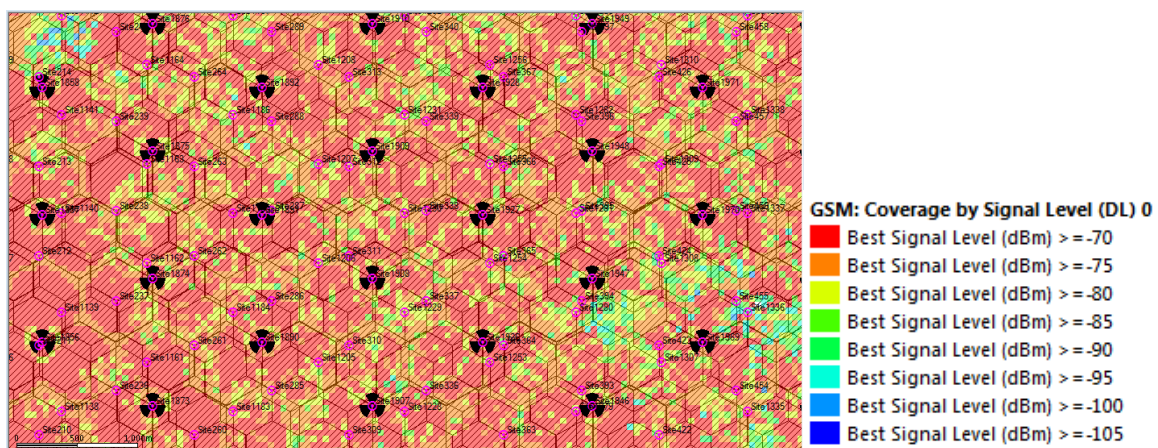
5.3. Analysis and Interpretation of Simulation Results

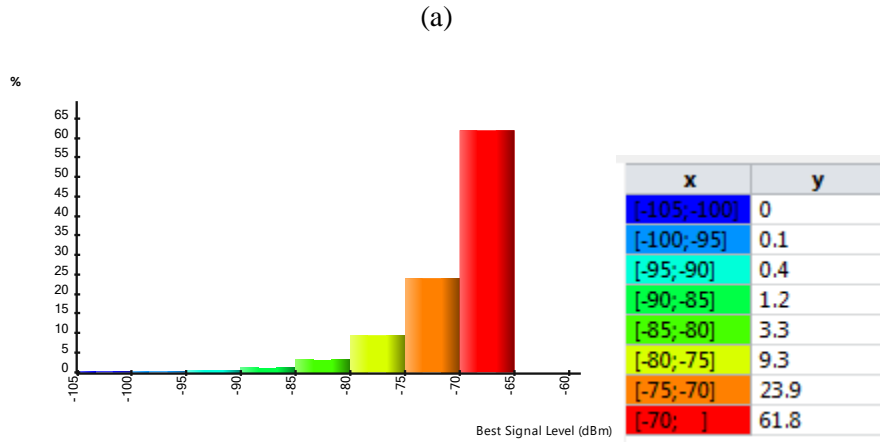
In this section manipulating of the performance and coverage predictions have been performed using parameters like Signal level, Overlapping Zones and Carrier to Interference plus Noise Ratio (CINR).

5.3.1. Performance Evaluation of GSM Network

a. Coverage Prediction by Signal level

The prediction by signal level shown in Figure 5.3 tells the prediction of the best signal strength at each pixel within the computation zone. The signal prediction result has an acceptable coverage from the simulation result below.





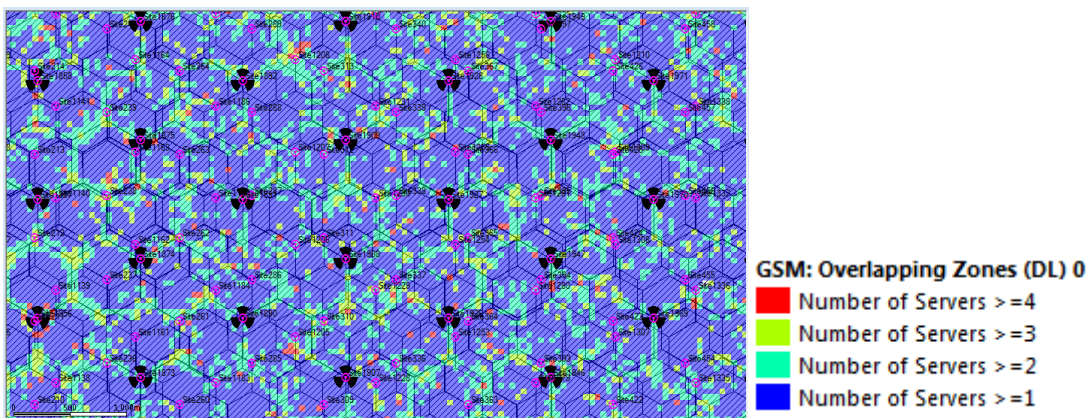
(b)

Figure 5.3: a) GSM Coverage Prediction by Signal level b) Histogram

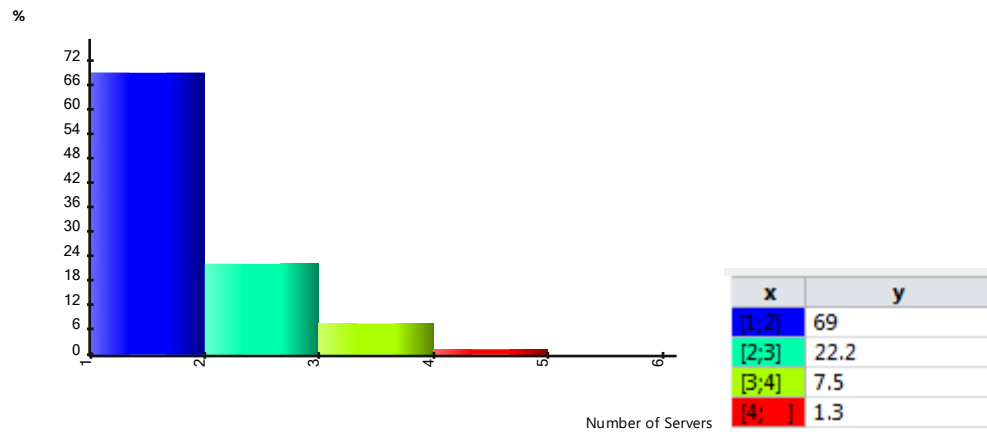
The statistical result shown in Figure 5.3 (b) is that more areas within the computation area (99.9%) is covered by strong signal level with in the range from -65 to -90dBm. The remaining area is also covered by acceptable signal level comparing with the designed receiver sensitivity signal level -106dBm in the dimensioning session.

b. Coverage Prediction on Overlapping Zones

The Figure 5.4 composed of pixels that are covered by the signal of at least two transmitters. The coverage is calculated for the cell with the highest power for a transmitter with more than one cell.



(a)



(b)

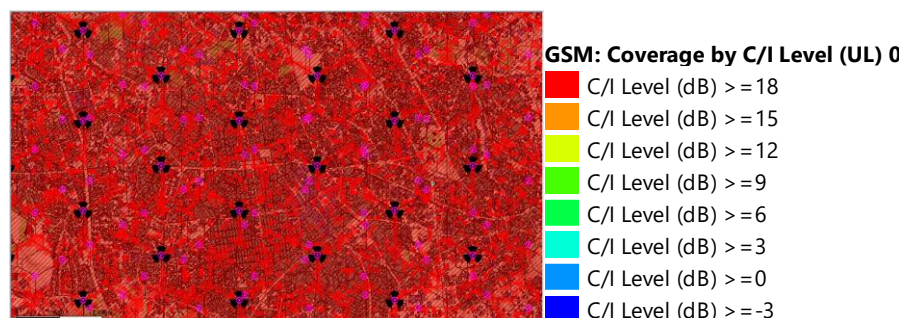
Figure 5.4: a) GSM Overlapping zone of transmitter b) Histogram

The result from the histogram shows that 69% of the subscribers are served by single cell without hand off. The remaining would serve with 22.2%, 7.5%, and 1.3% by 2, 3, and 4 cells respectively and we can see that 100% of the region is covered by at least one cell.

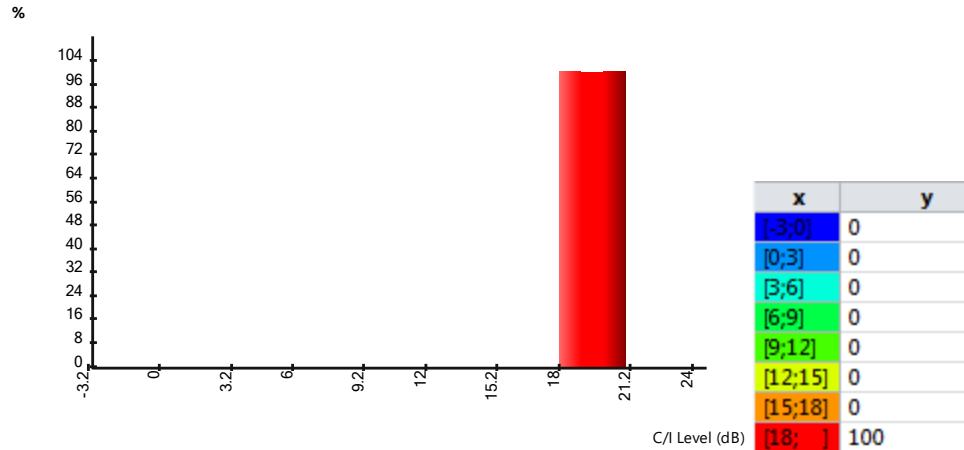
c. Coverage prediction by C(I+N)

The Carrier to Interference plus Noise Ratio (CINR) is the ratio of the signal carrier best servings for the intervention seemed at all other sites/sectors, plus all the noise. If a signal goes below the level of noise, it cannot be decoded and no useful information can be recovered from it.

Then, depending on the prediction definition, it calculates the interference from other cells, and finally calculates the $C/(I + N)$. If $C/(I + N)$ is higher than the $C/(I + N)$ threshold the pixel is colored.



(a)



(b)

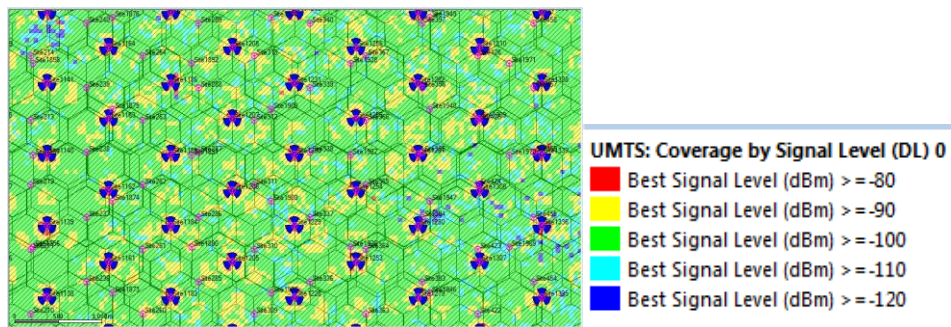
Figure 5.5: a) GSM Coverage by C/ (I+N) Level and b) Histogram

The histogram result shows comparison of coverage percentage area versus $C/(I + N)$ level value and 100% of the areas within the computation zone are covered by $C/(I + N)$ value of greater than 18dB which satisfies the standard value.

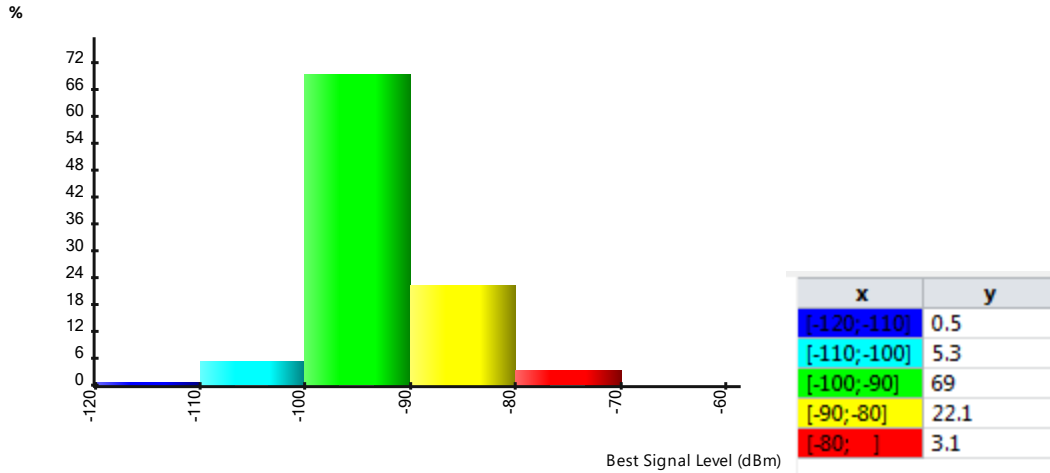
5.3.2. Performance Evaluation of UMTS Network

a. Coverage Prediction by Signal level

The result in Figure 5.6 shows that prediction of the best signal strength at each edge with in the designed dense urban computational zone is covered by an acceptable signal strength.



(a)



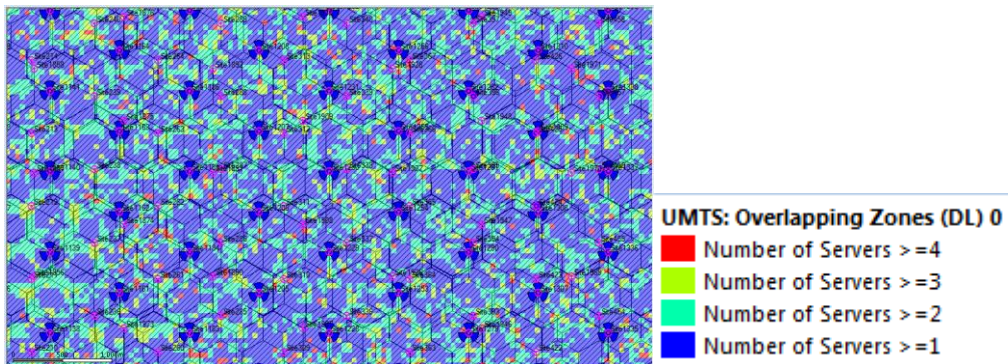
(b)

Figure 5.6: a) UMTS Coverage prediction by Signal level b) Histogram

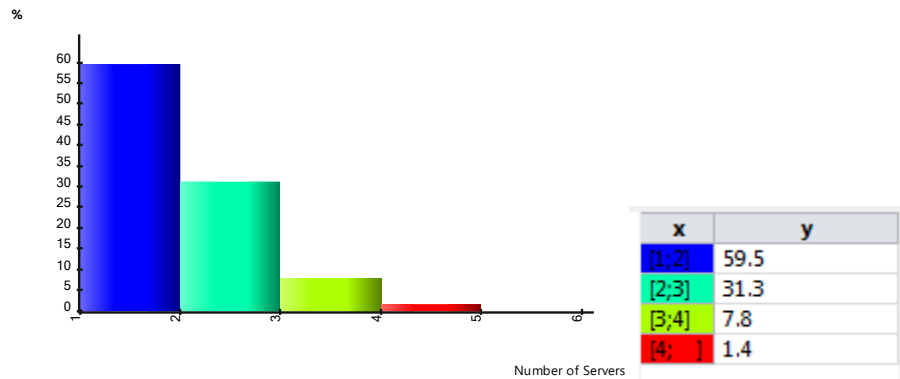
As we seen from the histogram, most of the target area (99.5%) within the computational zone is covered by -110 to -70dBm which is better signal strength than the received sensitivity signal value and the remaining zone is covered with acceptable signal strength which is above -126.8 dBm from dimensioning session.

b. Coverage Prediction on Overlapping Zones

Coverage prediction on overlapping zones as it is shown on Figure 5.7, they are composed of pixels that are covered by the signal of at least two transmitters. For a transmitter with more than one cell, the coverage is calculated for the cell with the highest power.



(a)



(b)

Figure 5.7: a) UMTS Overlapping zone of transmitter b) Histogram

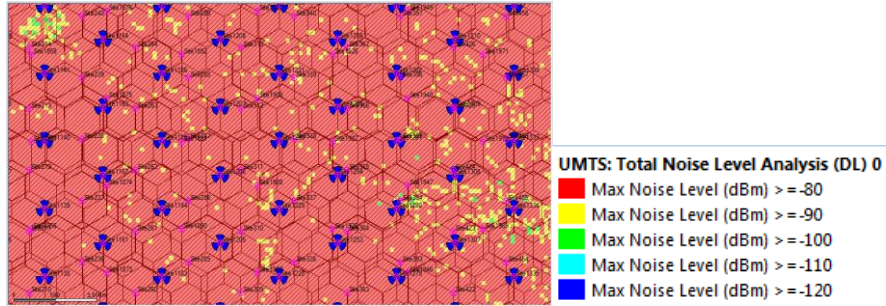
The result from the histogram shows that 59.5% of the subscribers are served by single cell without hand off. The rest would serve with 31.3%, 7.8%, and 1.4% by 2, 3, and 4 cells respectively and we can see that 100% of the region is covered by at least one cell.

c. Coverage Prediction by Total Noise Level Analysis or signal quality

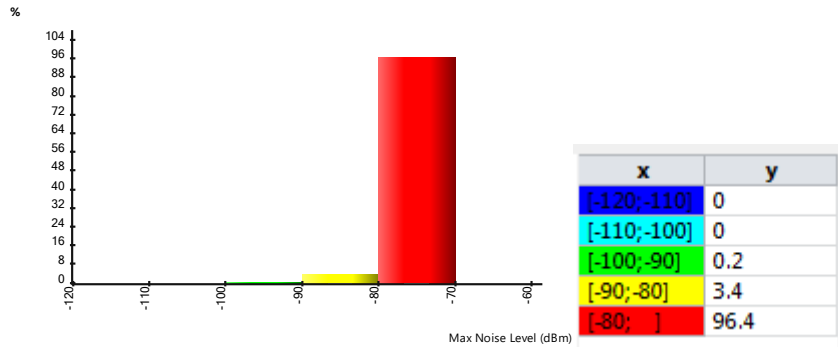
Coverage prediction by carrier-to-interference-and-noise ratio or $C/(I + N)$ is used to analyze the signal quality. These predictions are based on the predicted signal level from the best server and the predicted signal levels from other cells (interference) at each pixel.

ATOLL calculates the serving transmitter for each pixel based on the downlink reference signal level. The serving transmitter is determined according to the received reference signal level from the cell with the highest power. If more than one cell covers the pixel, the one with the lowest order is selected as the serving (reference) cell. Then, depending on the prediction definition, it calculates the interference from other cells, and finally calculates the $C/(I + N)$. The pixel is colored if the $C/(I + N)$ is higher than $C/(I + N)$ threshold.

The carrier to interference plus noise ($C/(I + N)$) is the ratio of the signal carrier best servings for the intervention seemed at all other sites/sectors, plus all the noise. If a signal goes below the level of noise, it cannot be decoded and no useful information can be recovered from it.



(a)



(b)

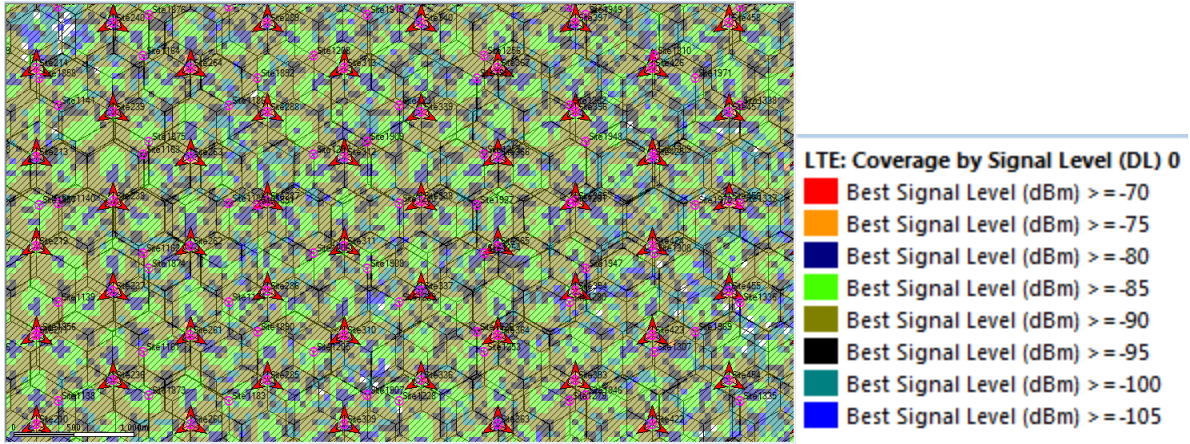
Figure 5.8: a) UMTS Total Noise Level Analysis b) Histogram

Figures 5.8 shows that 99.8% of the area has a maximum noise level of -70 to -90 dBm ranges which is 10^{-10} to 10^{-12} watt. The remaining area which is 0.2% has a noise level of -90 to -100 dBm which is 10^{-12} to 10^{-13} watt. When we compare with the transmitted power i.e. 43dBm (20W) mentioned in the dimensioning section, the level of noise in the targeted area is much lower than the transmitted power and therefore satisfies the standard value.

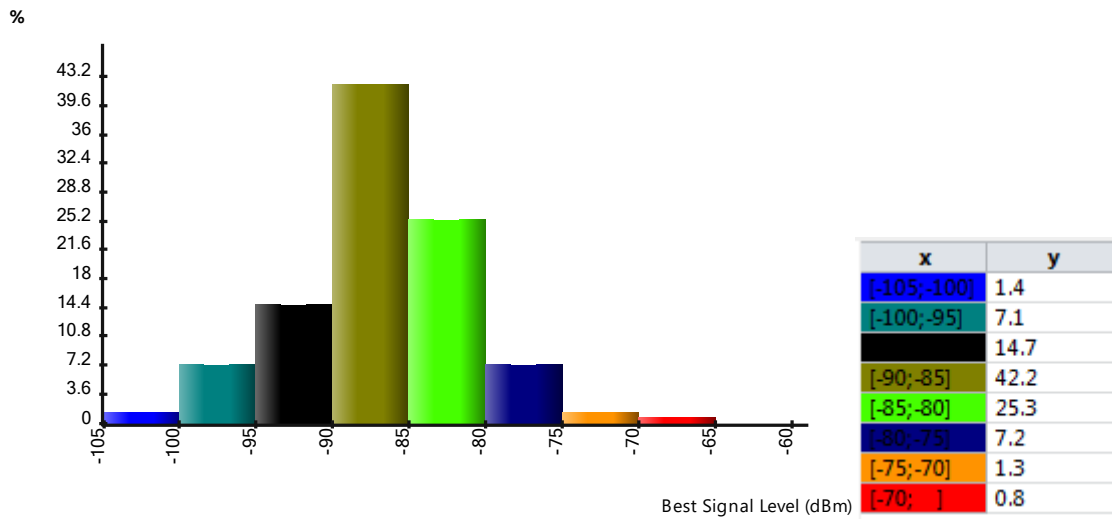
5.3.3. Performance Evaluation of LTE Network

a. Coverage prediction by signal level

As shown from Figure 5.9 the simulation signal level values are greater than the designed receiver sensitivity which is -134.13 dBm. This shows all the customers with in the selected coverage can sense the signal from the sites, which means any customer can be served by being in every places of the considered area.



(a)



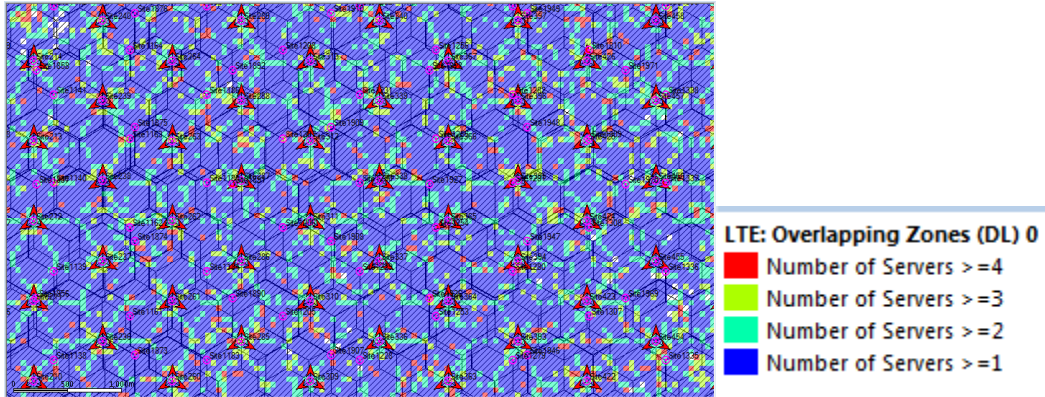
(b)

Figure 5.9: a) Coverage prediction by signal level b) Histogram

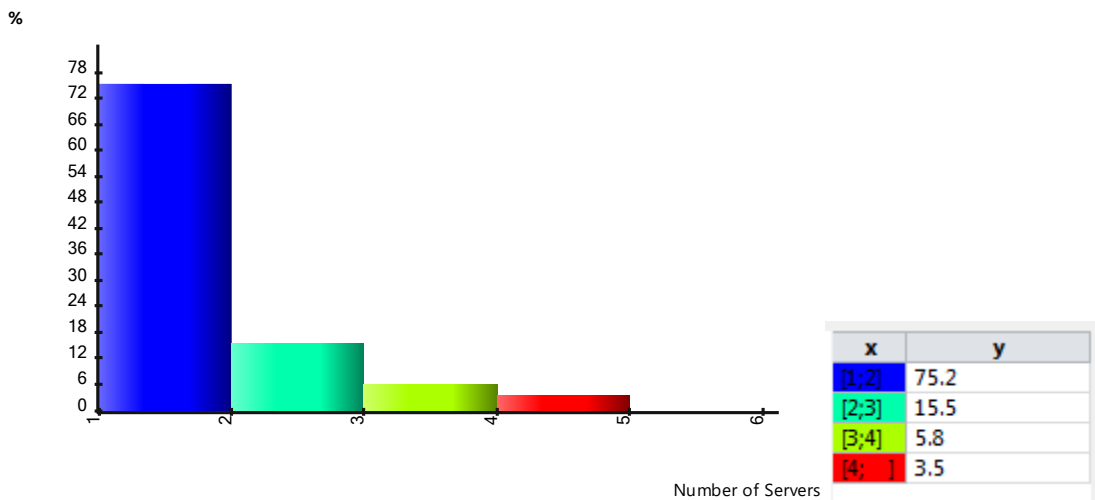
Figure 5.9 (b) shows the 98.6% of users with in the target area would serve with signal strength between -95 dBm and -65 dBm which is strong signal level and the remaining (i.e. 1.4%) customers get signal strength between -105dBm and -100dBm which is greater than the receiver sensitivity. Therefore, all subscribers can serve with excellent signal level which is above -134.13dBm.

b. Coverage prediction by overlapping zone

As it is described in both technologies overlapping zone measures the number of servers in which customers can be served while they are moving in the selected computational zone.



(a)



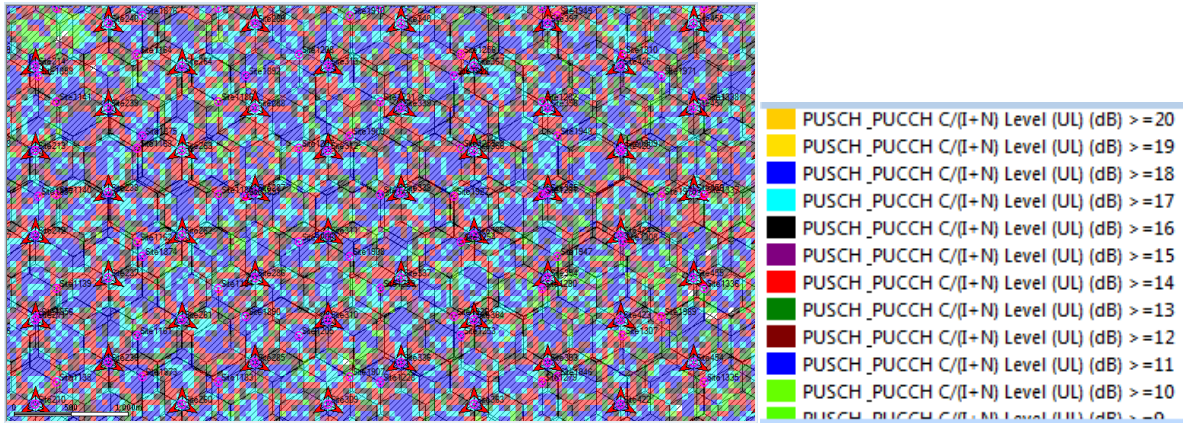
(b)

Figure 5.10: a) Coverage prediction by overlapping zone b) Histogram

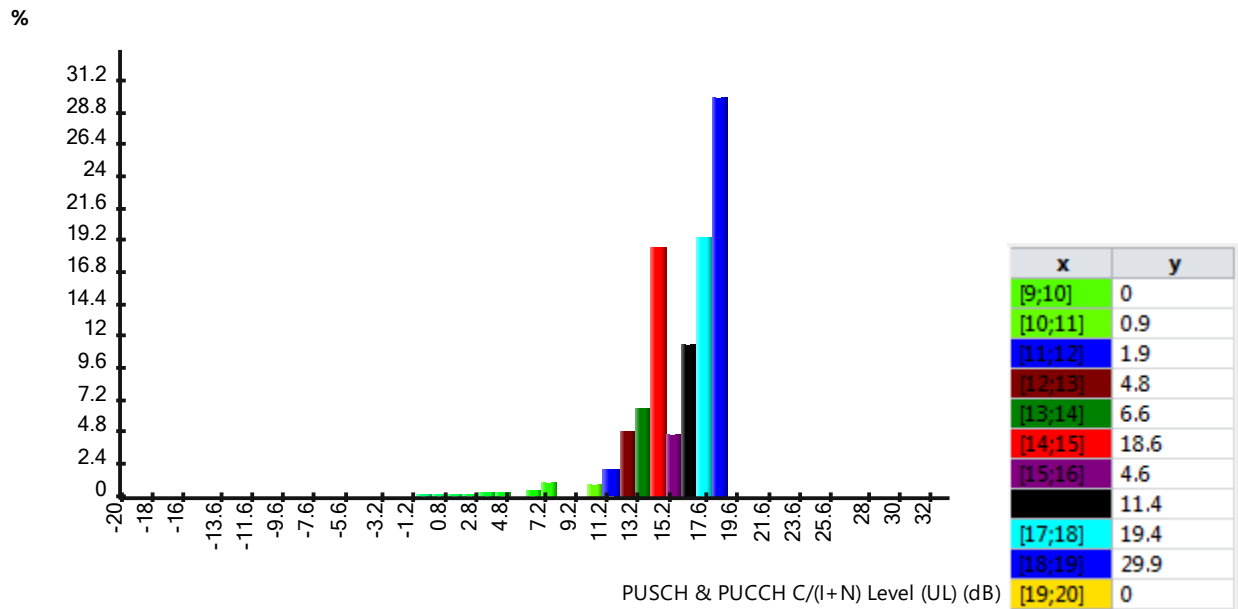
As it is shown in the Figure 5.10 (b) 75.2% of the registered customers are served by single server, 15.5% of them are served by 2 servers, 5.8% are served by 3 servers and 3.5 are served by 4 servers. Therefore, the target area is served by at least one server.

c. Coverage prediction based on C/(I+N)

Carrier to interference noise ratio is the ration of the received carrier signal to the received noise and interference from co-channel and neighbor cells. It is expected to get CINR between 13-20dB to be called good signal and above 20dB to provide excellent service to the costumers. If it is below 13dB it means the received signal is to small comparing to the unwanted received signal.



(a)

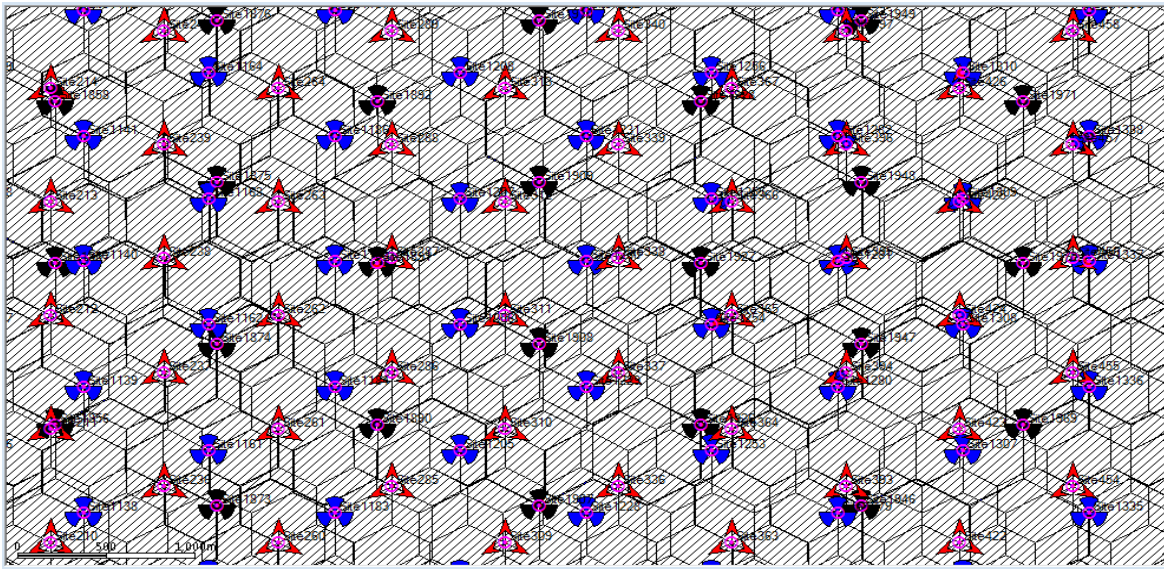


(b)

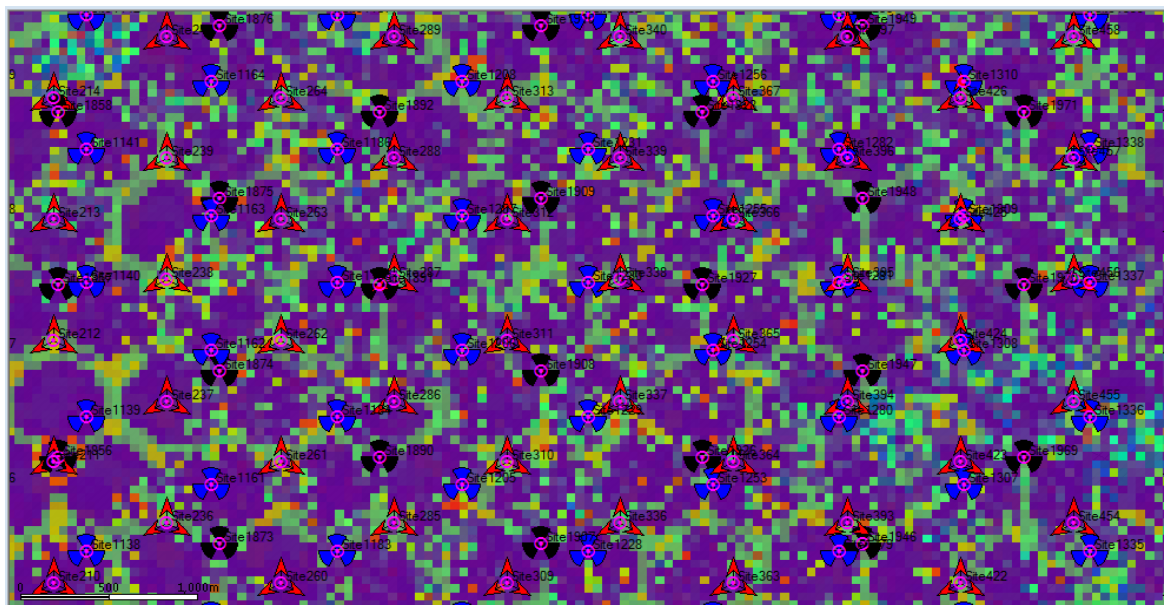
Figure 5.11: (a) Coverage analysis with C/ (I + N) (b) Histogram

The histogram result shows the relationship between coverage percentage area and C/(I+N) value. As it is shown in the Figure, 95.3% of the coverage percentage has CINR in between 13.2dB and 19dB which satisfies the standard value.

5.3.4. The Overall Multi-RAT Network



(a)



(b)

Figure 5.12: The Multi-RAT network (a) without prediction (b)with prediction

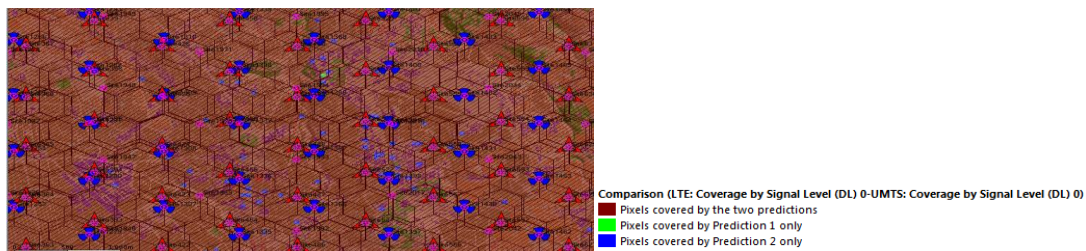
As shown in Figure 5.12 all of the three networks site and transmitters are described which covers the targeted area. LTE, UMTS and GSM transmitters are represented with red, blue and black colors respectively. From the above figure we can see that, the computational zone is covered by all of the networks with the standard value as designed in the dimensioning section.

5.4. Comparison of Multi-RAT Networks

In this section comparison of the three networks in terms of signal level, overlapping zone and carrier to interference noise ratio will be discussed.

5.4.1. Comparison of LTE and UMTS

✚ In terms of signal level



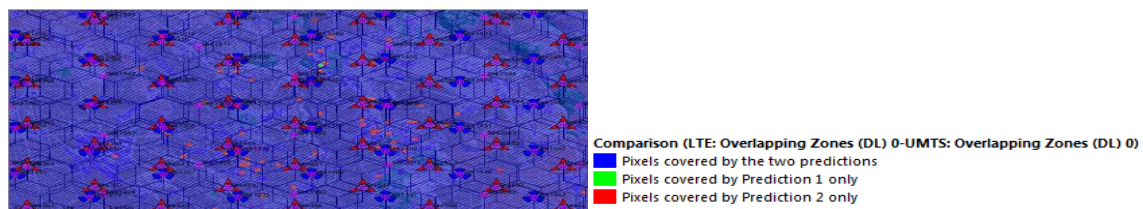
Name	% Computation Zone
Comparison (LTE: Coverage by Signal Level (DL) 0-UMTS: Coverage by Signal Level (DL) 0)	100
Pixels covered by the two predictions	99,6
Pixels covered by Prediction 1 only	0
Pixels covered by Prediction 2 only	0,4

Figure 5.13: Coverage comparison result of LTE and UMTS by signal level

The result in the above Figure 5.13 shows that 99.6 % of the computational zone is covered by both networks i.e. LTE and UMTS. The remaining area which is 0.4 % is covered by UMTS network only. Therefore, 100 % of the targeted area is covered by at least one network.

✚ In terms of overlapping zone

The result in Figure 5.14 shows that 99.6 % of the targeted area is covered by both networks i.e. LTE and UMTS. The remaining area which is 0.4 % is covered by UMTS network only. Therefore, 100 % of the computational zone is covered by at least one network.

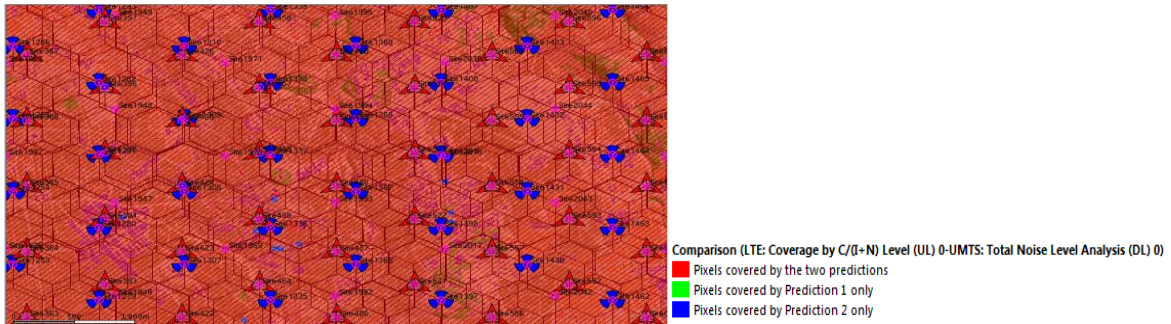


Name	% Computation Zone
Comparison (LTE: Overlapping Zones (DL) 0-UMTS: Overlapping Zones (DL) 0)	100
Pixels covered by the two predictions	99,6
Pixels covered by Prediction 1 only	0
Pixels covered by Prediction 2 only	0,4

Figure 5.14: Coverage comparison result of LTE and UMTS by overlapping zone

In terms of C/(I+N)

The result in Figure 5.15 shows that 99.9 % of the computational zone is covered by both networks i.e. LTE and UMTS. The remaining area which is 0.1 % is covered by UMTS network only. Therefore, 100 % of the targeted area is covered by at least one network.

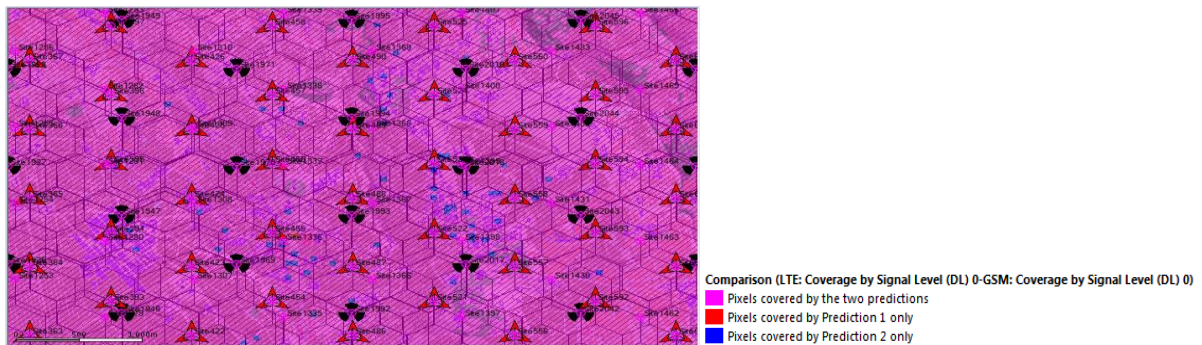


Name	% Computation Zone
Comparison (LTE: Coverage by C/(I+N) Level (UL) 0-UMTS: Total Noise Level Analysis (DL) 0)	100
Pixels covered by the two predictions	99.9
Pixels covered by Prediction 2 only	0.1

Figure 5.15: Coverage comparison result of LTE and UMTS by total noise level analysis

5.4.2. Comparison of LTE and GSM

In terms of signal level

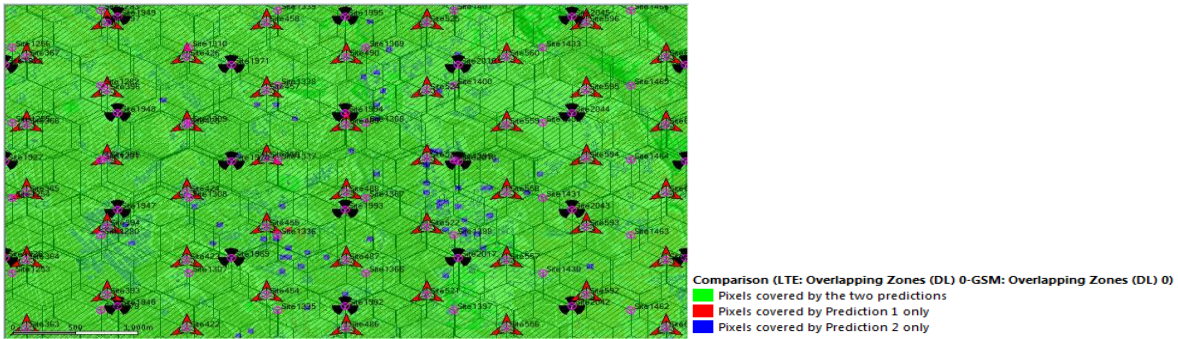


Name	% Computation Zone
Comparison (LTE: Coverage by Signal Level (DL) 0-GSM: Coverage by Signal Level (DL) 0)	100
Pixels covered by the two predictions	99.6
Pixels covered by Prediction 1 only	0
Pixels covered by Prediction 2 only	0.4

Figure 5.16: Coverage comparison result of LTE and GSM by signal level

The result in the above Figure 5.16 shows that 99.6 % of the computational zone is covered by both networks i.e. LTE and GSM. The remaining area which is 0.4 % is covered by GSM network only. Therefore, 100 % of the targeted area is covered by at least one network.

In terms of overlapping zone



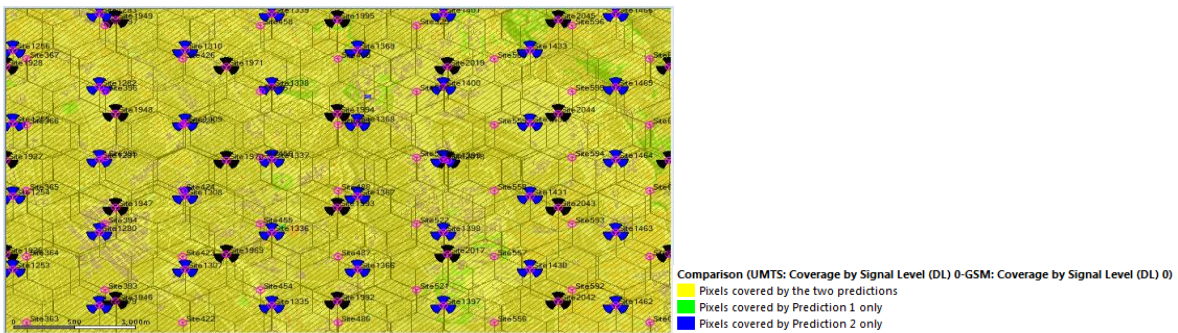
Name	% Computation Zone
Comparison (LTE: Overlapping Zones (DL) 0-GSM: Overlapping Zones (DL) 0)	100
Pixels covered by the two predictions	99.6
Pixels covered by Prediction 1 only	0
Pixels covered by Prediction 2 only	0.4

Figure 5.17: Coverage comparison result of LTE and GSM by overlapping zone

The result in the above Figure 5.17 shows that 99.6 % of the computational zone is covered by both networks i.e. LTE and GSM in terms of overlapping zone prediction. The remaining area which is 0.4 % is covered by GSM network only. Therefore, the conclusion is 100 % of the targeted area is covered by at least one network.

5.4.3. Comparison of UMTS and GSM

In terms of signal level



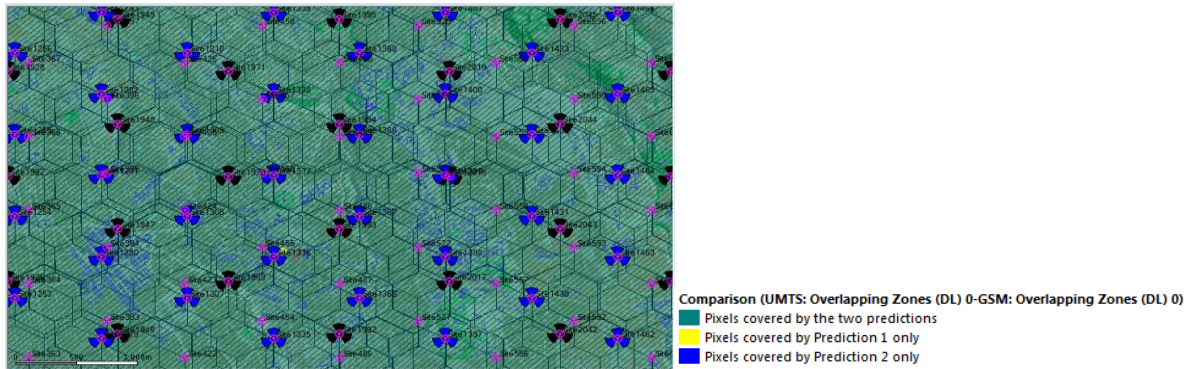
Name	% Computation Zone
Comparison (UMTS: Coverage by Signal Level (DL) 0-GSM: Coverage by Signal Level (DL) 0)	100
Pixels covered by the two predictions	100
Pixels covered by Prediction 1 only	0
Pixels covered by Prediction 2 only	0

Figure 5.18: Coverage comparison result of UMTS and GSM by signal level

As we seen in the result value of Figure 5.18, 100% of the computational zone or target area is covered by both networks (UMTS and GSM). This result shows us if one of the networks fails the other will cover the area and guarantee the service.

✚ In terms of overlapping zone

The result in Figure 5.19 shows that 100% of the computational zone is covered by both networks i.e. UMTS and GSM in terms of overlapping zone prediction.



Name	% Computation Zone
Comparison (UMTS: Overlapping Zones (DL) 0-GSM: Overlapping Zones (DL) 0)	100
Pixels covered by the two predictions	100
Pixels covered by Prediction 1 only	0
Pixels covered by Prediction 2 only	0

Figure 5.19: Coverage comparison result of UMTS and GSM by overlapping zone

Generally, the results in Figure 5.12 – Figure 5.19 shows that 100% of the target area or computational zone is served by at least one of the three radio access technologies.

5.5. Network layout Model of 4b Topology

The hexagonal grid layout with the eNBs at the center and also the location of the UEs for Heterogeneous Network Configurations 4b based on daily traffic is plotted in Figures 5.20 (a), (b) & (c). The simulation parameters taken for each case are shown in Table 5.1 and Table 5.2.

Table 5.1: General Parameters used for simulation [58, 59]

Field Name	Value	Description
UEHeight (m)	1.5	Height of the UE
BSHeight (m)	30	Height of the base station

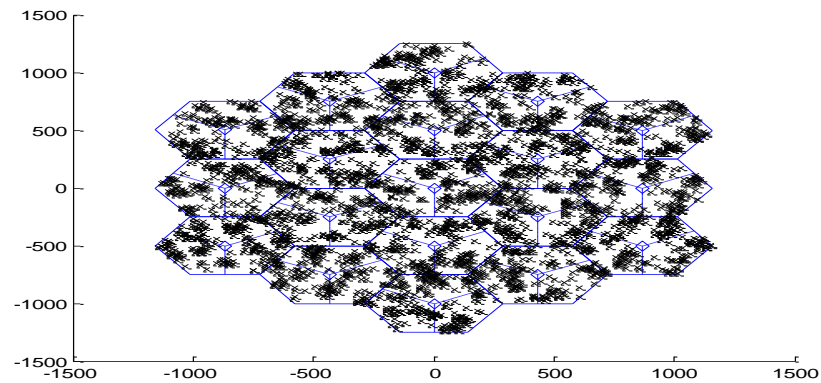
InterSiteDist (m)	500	Distance between centers of two adjacent eNB hexagons
HandOverMargin (dB)	1	Handover margin
UENoiseFigure (dB)	7	UE noise figure
BandWidth (MHz)	20	System bandwidth
theta tilt (degrees)	102	Tilt of the Elevation antenna response
theta_3db (dB)	10	Half Power Beam width of the elevation antenna
phi_3db (dB)	70	Half Power Beam width of the azimuth antenna
SLL_h (dB)	25	Side lobe level suppression of azimuth antenna
SLL_v (dB)	20	Side lobe level suppression of elevation antenna
SLL (dB)	25	Side lobe level suppression of combined antenna
MinDistMacroUE(m)	35	Minimum distance between a macro base station and a UE
UEVel (km/h)	3	Velocity of the UE
Center Frequency (GHz)	2	Center frequency
TX Power (dBm)	46	Transmit power of the macro cell
BSAntennaGain (dB)	17	Maximum gain of the macro combined antenna
NumUEperCell	60	Number of UEs per cell
IndoorUEProb	0.8	Probability that a given UE is located indoors

Table 5.2: Small Cell Related Parameters used for simulation [58, 59]

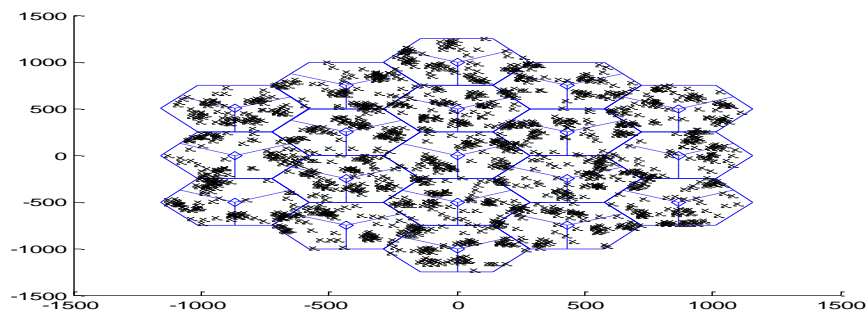
Field Name	Value	Description
RRHHeight (m)	10	Height of the small cell
MinDistMacroRRH (m)	75	Minimum distance between a small cell and the macro
MinDistRRH (m)	40	Minimum distance between two small cells
MinDistRRHUE (m)	10	Minimum distance between a small cell and a UE
RRHAntenna Gain (dB)	5	Maximum gain of the combined antenna of the small cell
TxPower RRH (dBm)	30	Transmit power of the small cell
NumRRHper Macro	4	Number of small cells per sector
Rho	2/3	Fraction of UEs clustered around small cells
RRHRadius (m)	40	Radius of clustered UE locations

The impact of introducing cell sleeping on the coupling loss and received SINR is investigated for heterogeneous network Conf 4b. As discussed in the above chapters low traffic period is considered during 1a.m to 8a.m. In this interval of time, sleep mode is activated by switching 75% of the cells which means 3 out of 4 cells can be switched off and 1 out of 4 cells remain permanently

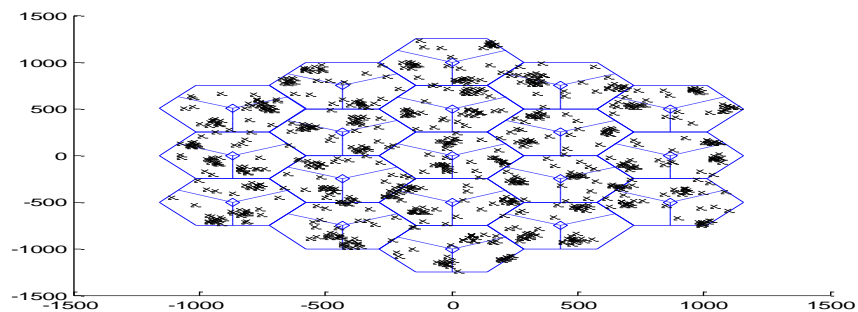
active in order to give coverage. From 8a.m-11a.m traffic period increases progressively. In this interval of time, sleep mode is activated by switching 50% of the cells which means 2 out of 4 cells can be switched off and the 2 cells remain permanently active in order to give coverage. After 11a.m traffic period reaches to peak. In this interval of time, all cells remain permanently active.



(a)



(b)



(c)

Figure 5.20: Hexagonal network layouts for (a) standard mode (peak hour) (b) 50% sleep mode (c) 75% sleep mode

5.6. Impact of cell sleeping on coupling loss and SINR

Figure 5.21 shows comparison of coupling loss of Het-Net conf 4b with and without activation of sleep mode. For example, in case of peak hour traffic $p(y \leq 0.3) = -94.96\text{dB}$ which means 30% or less that of the users have a coupling loss of -94.96dB . For 50% Sleep mode $p(y \leq 0.3) = -98.03\text{dB}$ means 30% or less those of the users have coupling loss of -98.03dB . For 75% of sleep mode $p(y \leq 0.3) = -100.1\text{dB}$ means 30% or less those of the users have coupling loss of -100.1dB . Generally, the result indicates that activation of sleep mode minimizes the coupling loss.

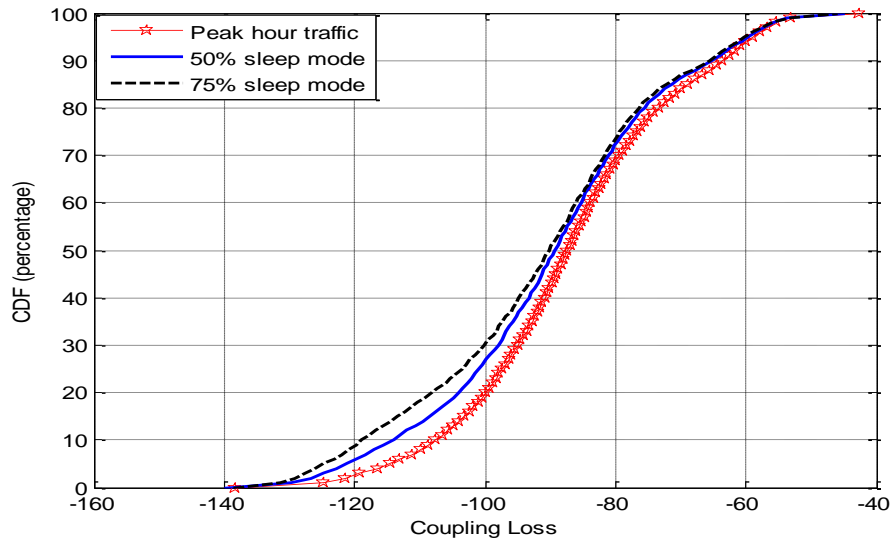


Figure 5.21: Impact of cell sleep mode on coupling loss

On the other hand, Figure 5.22 shows comparison of Het-Net conf 4b with and without activation of sleep mode on SINR. For example, in case of peak hour traffic $p(y \leq 0.3) = 2.951\text{dB}$ which means 30% or less that of the users have SINR of 2.951dB . For 50% sleep mode $p(y \leq 0.3) = 3.71\text{dB}$ means 30% or less that of the users have SINR of 3.71dB . For 75% of sleep mode $p(y \leq 0.3) = 4.283\text{dB}$ means 30% or less that of the users have SINR of 4.283dB . Generally, the result indicates that activation of sleep mode increases the received SINR.

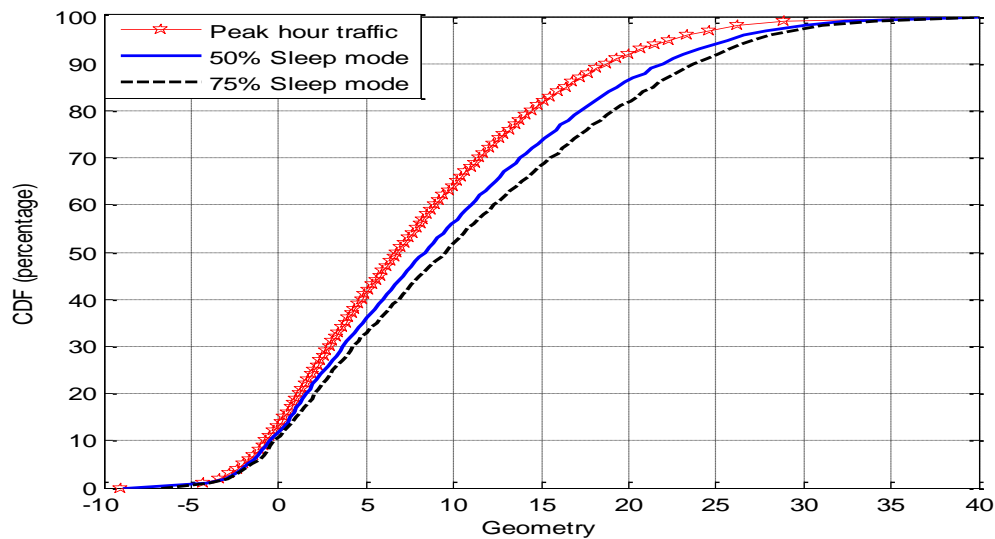


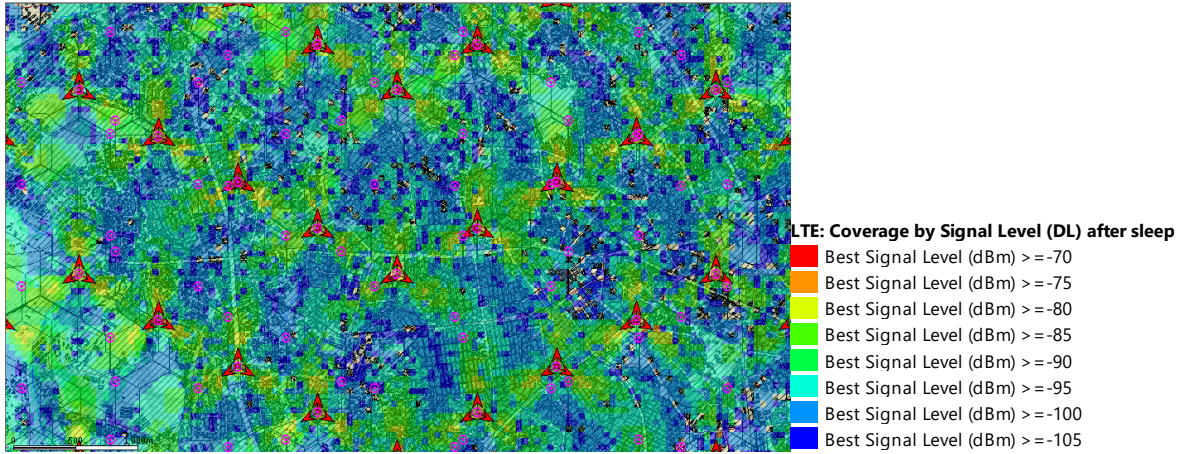
Figure 5.22: Impact of cell sleep mode on SINR

5.7. Performance analysis LTE network at sleep mode condition

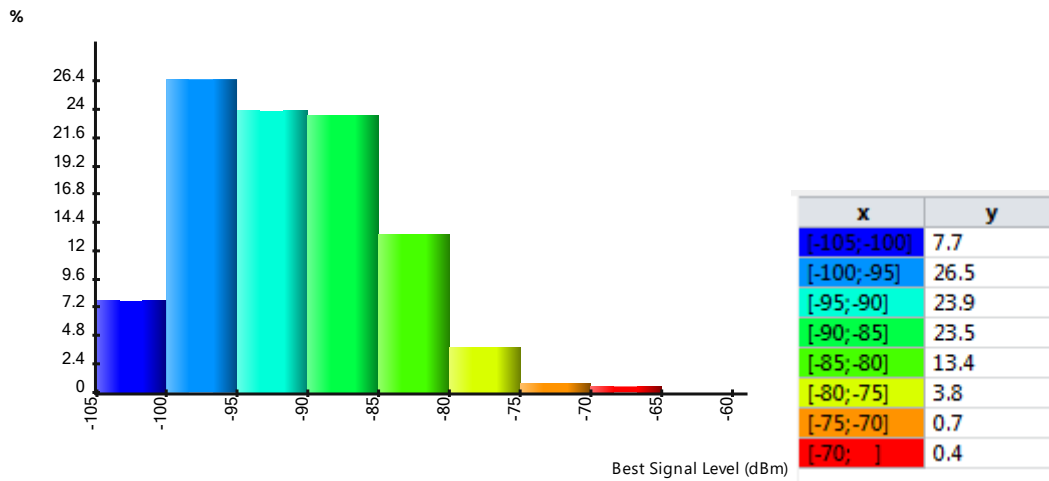
In the previous section performance of the planned Multi-RAT network in terms of Coverage Prediction by Signal level, Overlapping Zones and C/ (I+N) Level has been shown with the help of simulation results. In this section cell sleeping technique has been introduced to the modeled network (LTE network), discuss the overall performance and compare with the previous one. As discussed in section 4.7, the traffic periods considered are according to [4] which is low traffic period is considered during 1a.m-8a.m. In this interval of time, sleep mode is activated by switching off 50% of the LTE sites. In this case the number of LTE sites is reduced to 480 sites (deactivate all even number LTE sites).

Coverage Prediction by Signal level

Figure 5.23 shows signal level with 50% activation of sleep mode and comparing with Figure 5.9, it is observed that activation of sleep mode minimizes the strength of the signal level of coverage percentage area.



(a)



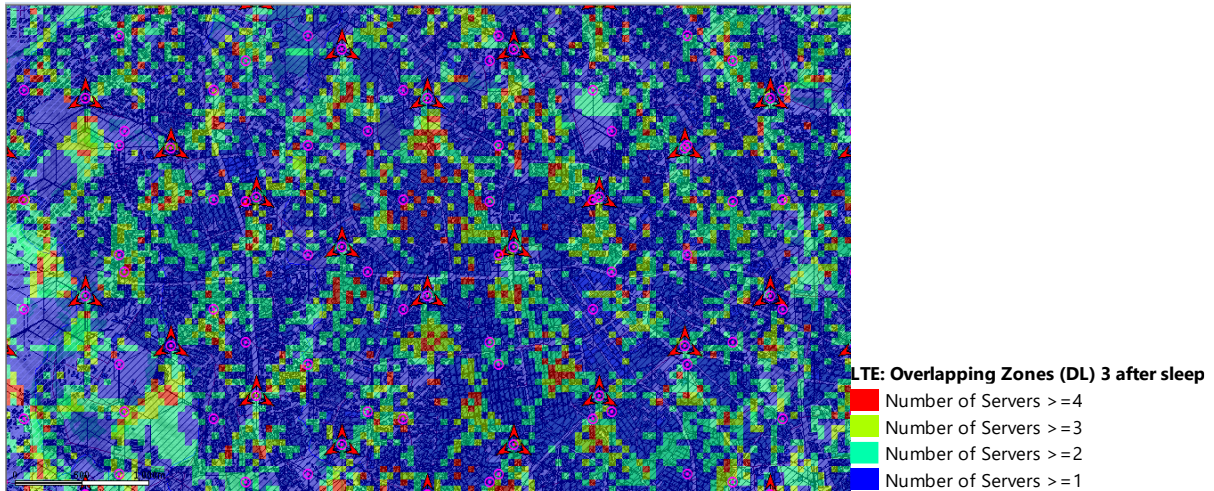
(b)

Figure 5.23: With 50% sleep mode a) Coverage prediction by Signal level b) Histogram

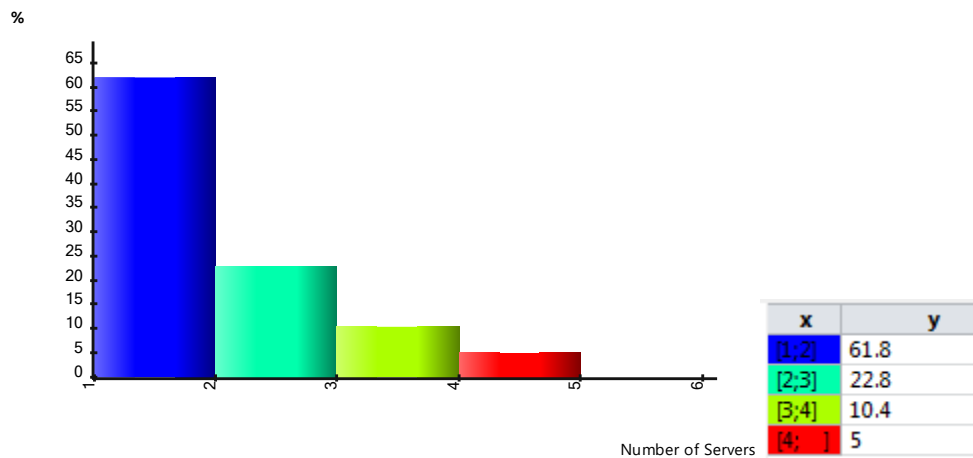
The histogram statistical result shows comparison of coverage percentage area versus best signal strength value, as shown in Figure 5.23 (b). Comparing the results of Figure 5.23 with Figure 5.9, it can be observed that the strength of signal level of coverage percentage area is minimized. For example, before sleep mode 98.7% of customers with in the area will be served with signal strength greater than -95dBm but after sleep mode 92.2% of the customers get signal strength of greater than -95dBm which is better signal strength than receiver sensitivity signal value calculated in the dimensioning process.

✚ Coverage prediction by overlapping zones

Figure 5.24 shows coverage prediction on overlapping with 50% activation of sleep mode and it is observed that even with activation of sleep mode the computational zone or target area is covered with at least one transmitter.



(a)

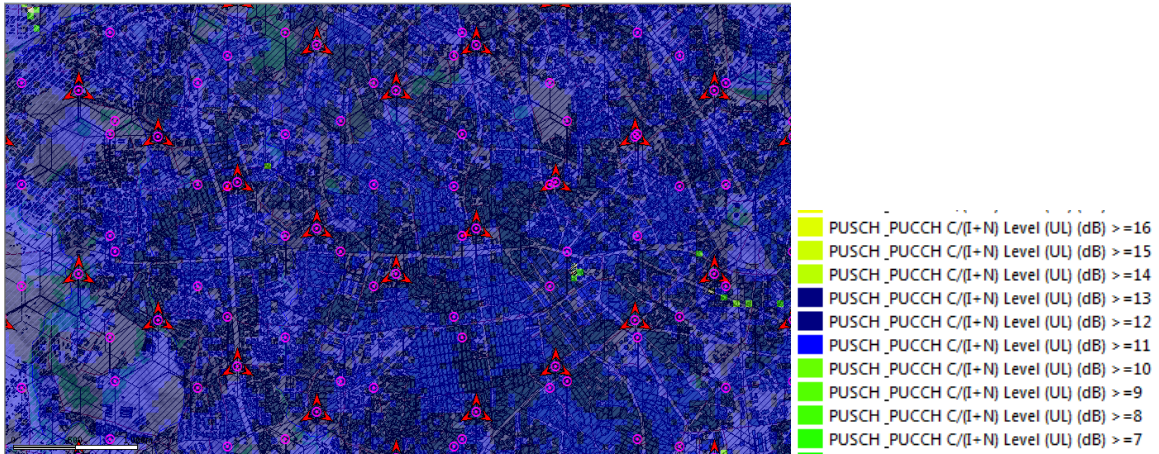


(b)

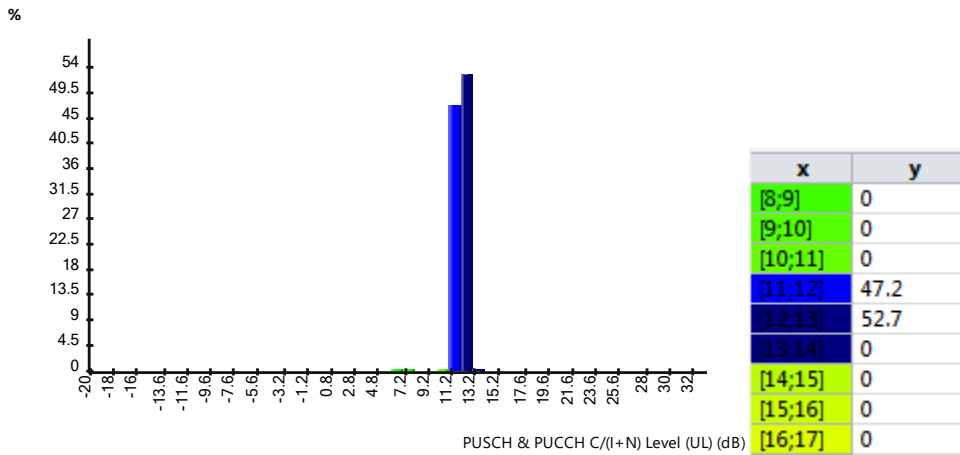
Figure 5.24: With 50% sleep mode a) Coverage prediction on overlapping zones b) Histogram

✚ Coverage prediction based on C/(I+N)

Figure 5.25 shows coverage prediction by $C/(I + N)$ Level with 50% activation of sleep mode. It is observed that with activation of sleep mode even though the target area's $C/(I + N)$ level is minimized, it is satisfying the standard value. The histogram result shows comparison of coverage percentage area versus $C/(I + N)$ Level value when 50% of the cells are switched off.



(a)



(b)

Figure 5.25: With 50% sleep mode a) Coverage prediction by C/ (I+N) Level b) Histogram

Comparing the results of Figure 5.25 with Figure 5.11, it can be observed that the $C/(I + N)$ level of coverage percentage area is minimized. For example, in peak hour traffic 96% of the coverage percentage has CINR in between 13.2dB and 19.6dB but after 50% of the sites are switched off, 99.9% of the coverage percentage has CINR in between 11.2dBm and 13.2dBm which is reduced value but it satisfies the standard value.

5.8. Comparison of power consumption before and after sleep mode

Transmitted Power consumption of the base station is calculated for peak hour traffic which means before cell sleep mode and for low traffic load which means after applying cell sleep mode.

Transmitted Power of macro cell for GSM1800, UMTS and LTE is 43 dBm (20 watt), 43 dBm (20 watt) and 46 dBm (40 watt) respectively. A comparison of total transmitted power between the two cases is shown in Table 5.3.

Table 5.3: Comparison of transmitted power for peak hour traffic and sleep mode

Mode	Active eNBs or BSs	Total consumed power
Peak hour traffic	LTE+UMTS+GSM	40,461 W
Sleep mode	50% of LTE+UMTS+GSM	21,261 W

As shown in Table 5.3 transmitted power of the base stations can be minimized by 19,200 W or 47.5 % by activating 50 % of LTE sites to their sleep mode based on daily traffic loads.

6. Chapter Six: Conclusion and Recommendation

6.1. Conclusion

In cellular system network RF planning is the basic foundation of a mobile communication network. Hence, making a good planning at earlier stage will be a basic requirement for network expansion and service update in the future. In addition to this energy usage in cellular system is other issue over all the world due to high power consumption. Therefore, this study was done to develop Multi-Rat network or tools and methods to be able to support multi-service radio network dimensioning and planning for multi radio access technology besides techniques which help to reduce energy consumption of cellular without compromising QoS for Addis Ababa city with the area of 413.612 km^2 by considering dense urban clutter. The performance of the planned network and results was modeled and analyzed using ATOLL network planning tool and MATLAB software. Best signal level, overlapping zone and C(I+N) per each RAT are the selected performance measuring parameters of the planned network and also coupling loss and SINR for measuring the impact of energy reduction on the network performance.

From the coverage and capacity planning perspective of the Multi-RAT network 960 LTE eNB's, 787 UMTS NB's and 487 GSM BTS's are obtained for Addis Ababa city. Since one Multi-Rat site contains three radio access technologies, out of 960 LTE eNB's and 787 UMTS NB's the 487 can be shared or cohabited with GSM BTS's. In addition to this 300 of LTE eNB's can be shared with the remaining 300 UMTS NB's and finally the remaining 173 LTE eNB's are located alone. Therefore, a total of 960 sites are needed to cover the whole city.

In the case of energy efficiency, the result indicates that activation of sleep mode minimizes the coupling loss but the SINR value will be increased as shown in the preliminary study results. In this work sleep mode was activated by switching off 50% of LTE eNB's as a case study during 1a.m up to 8a.m period and the transmitting power can be minimized by 47.5% during that period. When sleep mode is activated, the performance of network is reduced in terms of coverage prediction by signal strength, overlapping zones and C/ (I+N) comparing with performance of peak hour traffic. But the network performance still satisfies the standard requirements while saving large amount of transmitting power.

Generally, the investigations performed in this thesis work has shown that the performance of the planned energy efficient Multi-Rat network satisfies the desired minimum standard requirements even if sleep mode is activating during low traffic period and can save huge power consumption of the cellular network.

6.2. Recommendation

There are several issues that can be addressed as a future work for this work. Some of the related future works include:

- ✓ This study focused on the network planning of the radio access technologies by mainly concentrated on coverage and capacity. One can further study the various features of these technologies as well as the core network and microwave part.
- ✓ In this work only energy saving technique was considered as part of the RNP. This can be extended by considering energy harvesting techniques as part of the RNP
- ✓ The analysis in this thesis was by manually switching off the base stations during low traffic periods. Another future work that can be addressed is applying self-organization technique in which the base station switch's on and off by itself based on daily traffics.
- ✓ Beyond switching of individual cell modifying of the radio topology to different radio configurations by comparing their capacity and radiated power. In this manner the when there is a low traffic load the network is reconfigured to a topology with lower capacity and radiated power.

Bibliography

- [1] T. S. Rappaport, *Wireless Communications Principles and Practice*, 2nd ed ed., Prentice Hall Communications Engineering and Emerging Technologies Series, 2001.
- [2] R. L. Nils Anders Stefan Gustafsson, "System and Method for Radio Network Planning with HSDPA Analysis". United States Patent US 8,209,038 B2, 26 June 2012.
- [3] Y. Sun, "Radio Network Planning for 2G and 3G," Munich University of Technology , 2004.
- [4] Y. Z. M. Z. a. E. K.-N. Y. Jingjin Wu, "Energy-Efficient Base-Stations Sleep-Mode Techniques in Green Cellular Networks: A Survey," *IEEE Communication Surveys and Tutorials*, vol. 17, no. 2, pp. 803-826, 2015.
- [5] Q. BangWang, "Energy Cost Minimization in Heterogeneous Cellular Networks with Hybrid Energy Supplies," 29 August 2016.
- [6] T. Mekonnen, "Dimensioning and Planning of Multi RAT Radio Network for Future Deployment in Bahir Dar City," *International Journal of Scientific & Engineering Research*, 2016.
- [7] A. M. E.-H. a. Z. D. Wissam El-Beaino, "A Proactive Approach for LTE Radio Network Planning With Green Considerations," in *19th International Conference on Telecommunications*, Beirut, 2012.
- [8] L. Zhang, " Network Capacity, Coverage Estimation and Frequency Planning of 3GPP Long Term Evolution," 2010.
- [9] H. E. S. K. E. K. a. e. Oliver Blume, "Energy savings in mobile networks based on adaptation to traffic statistics," *Bell Labs Technical Journal* , vol. 15, no. 2, pp. 77 - 94, 2010.
- [10] L. Mitikie, "UMTS Coverage and Capacity Planning for the case of Bole Sub City in Addis Ababa," Addis Ababa, April, 2016 .
- [11] J. Laiho, "RADIO NETWORK PLANNING AND OPTIMISATION FOR WCDMA," Helsinki University of Technology Radio Laboratory Publications, July, 2002.
- [12] J. Korhonen, *Introduction to 3G Mobile Communications*, Boston.London: ARTECH HOUSE, 2003.
- [13] A. J. N. Serrador, "Optimisation of Cell Radius in UMTS-FDD Networks," December 2002.
- [14] R. S. Rakesh Kumar Singh, "4G LTE Cellular Technology: Network Architecture and Mobile Standards," *International Journal of Emerging Research in Management &Technology*, vol. 5, no. 12, December 2016.
- [15] N. A. M. O. Magri Hicham, "4G System: Network Architecture and Performance," *IJIRAE*, vol. 2, no. 4, April, 2015.

- [16] R. Nossenson, "Long-term Evolution Network Architecture," *2009 IEEE International Conference on Microwaves, Communications, Antennas and Electronics Systems*, 2009.
- [17] C. C. C. L. Christopher Cox: Director, *An Introduction to LTE, LTE-Advanced, SAE And 4G Mobile Communications*, UK: A John Wiley & Sons, Ltd, 2012.
- [18] A. a. e. Ghosh, "Fundamental of LTE," *Pearson Education*, 2010.
- [19] Z. Gurmu, "Long Term Evolution (LTE) Radio Network Dimensioning: Case of Addis Ababa City," June, 2015 .
- [20] T. H. K. a. E. A, "Utran Long Term Evolution in 3GPP," *2006 IEEE 17th International Symposium on Personal, Indoor and Mobile Radio communications*, 2006.
- [21] D. H. Zarrinkoub, *Understanding LTE with Matlab from Mathematical Modeling to Simulation and Prototyping*, 1st ed, John Wiley & Sons, 2014.
- [22] w. paper:, "LTE: The Future of Mobile Broadband Technology," Verizon Wireless, 2009.
- [23] A. S. A. K. H. w. H. a. a. e. Abdullah Abdulwahab Mohammed Ghaleb, "LTE Network Planning and Optimization," Taiz University Faculty of Engineering and IT Communication Department, 2014.
- [24] T. D. Assefa, "QoS Performance of LTE Networks with Network Coding," M.S.thesis, Norwegian University of Science and Technology, June 2015.
- [25] M. A. E.-s. M. R. S. Ayman Elnashar, *Design, Deployment & Performance of 4G LTE Networks: A Practical Approach*, John Wiley & Sons, Ltd, 2014.
- [26] N. A. A. Abd-Elhamid M. Taha and Hossam S. Hassanein, *LTE, LTE- Advanced, and WiMAX: towards IMT-advanced networks, TOWARDS IMT-ADVANCED NETWORKS*, A John Wiley & Sons, Ltd, 2002.
- [27] H. K. M. T. S. R. U. Noman Shabbir, "Comparison of Radio Propagation Models for Long Term Evolution (LTE) Network," *International Journal of Next-Generation Networks (IJNGN) Vol.3, No.3,,* vol. 3, pp. 27-41, 07 September September, 2011.
- [28] Z. I. S. H. a. S. F. M. M. Ahamed, "LTE network coverage prediction for multi-traffic users in an urban area," in *IEEE International Conference on Electro/Information Technology (EIT 2013)*, Rapid City, SD, USA, 17 October 2013.
- [29] M. S. a. A. Q. M. A. Hes-Shafi, "Analysis of Propagation Models for WiMAX at 3.5 GHz," Blekinge Institute of Technology, Master's thesis of Science in Electrical Engineering, Karlskrona, Sweden, September 2009.
- [30] Y. Singh, "Comparison of Okumura, Hata and COST-231 Models on the Basis of Path Loss and Signal Strength," *International Journal of Computer Applications (0975 – 8887)* , vol. 11, pp. 37-41, December 2012.

- [31] A. R. Mishra, "Fundamentals of Cellular Network Planning and Optimization 2G/2.5G/3G... Evolution to 4G," John Wiley & Sons Ltd, 2004.
- [32] R. R. P. B. V. a. R. D. Srudhi Lakshmi V., "Green Radio Technology for Energy Saving in Mobile Towers," *International Journal of Information and Electronics Engineering*, vol. 3, no. 1, pp. 39-43, Vol. 3, No. 1, January 2013.
- [33] M. A. Deepa Palani, "ENERGY EFFICIENT SOLUTIONS FOR GREEN CELLULAR NETWORKS – A SURVEY," *International Journal of Electronics and Communication Engineering and Technology (IJCET)*, vol. 9, no. 5, pp. 1-16, September-October 2018.
- [34] H. B. a. V. K. B. Ziaul Hasan, "Green Cellular Networks: A Survey, Some Research Issues and Challenges," *IEEE*, vol. 3, 24 Sep, 2011.
- [35] S. K. A. Landou, "OPTIMIZATION OF 4G CELLULAR NETWORKS FOR THE REDUCTION OF ENERGY CONSUMPTION," Masters Dissertation, UNIVERSITY OF BRASILIA Faculty of Technology, Brasilia, August 2015.
- [36] S. A.-N. L. B. a. F. S. Michel Nahas, "Reducing Energy Consumption in Cellular Networks by Adjusting Transmitted Power of Base Stations," School of Engineering, Lebanese International University (LIU), Lebanon .
- [37] Y. W. J. G. a. Z. Y. Zhisheng Niu, "Cell Zooming for Cost-Efficient Green Cellular Networks," *IEEE Communications Magazine*, pp. 74-79, November 2010.
- [38] J.Louhi, "Energy Efficiency of Modern Cellular Base Stations," in *INTELEC 07 - 29th International Telecommunications Energy Conference*, Rome, Italy, 2007.
- [39] O. P. A. W. N. A. S. R. I. Y. Hani'ah Mahmudah, "Performance Analysis of Cell Zooming Based Centralized Algorithm for Energy Efficient in Surabaya," *EMITTER International Journal of Engineering Technology* , vol. 4, no. 2, pp. 324-343, December 2016.
- [40] C. H. O. a. S. M. Shelly Salim, "Are Heterogeneous Cellular Networks Superior to Homogeneous Ones?," *International Federation for Information Processing, South Korea*, pp. 61-68, 2012.
- [41] L. Y. C. Q. L. P. D. A. G. Pingping Xing, "Multi-RAT network Architecture," *Wireless World, WGC – Communication Architectures and Technologies*, November 2013.
- [42] J. J. Tushar Saxena, "Review on 2G, 3G and 4G Radio Network Planning," *International Journal of Engineering, Business and Enterprise Applications (IJEBA)*, pp. 84-89, 2013.
- [43] J. S. J. RichaBudhiraja, "Mobile Radio Network Planning: A Survey," *International Association of Scientific Innovation and Research (IASIR)*, pp. 308-311, 2013.
- [44] "Population of 2019.com," 2019. [Online]. Available: <https://populationof2019.com/population-of-addis-ababa-2019.html>. [Accessed 04 February 2019].

- [45] A. R. Mishra, ADVANCED CELLULAR NETWORK PLANNING AND OPTIMISATION 2G/2.5G/3G. . . EVOLUTION TO 4G, John Wiley & Sons Ltd, 2007.
- [46] Z. University, "GSM Basic Radio parameters".
- [47] "Digital cellular telecommunications system (Phase 2+): Radio transmission and reception (GSM 05.05)," European Telecommunications Standards Institute (ETSI), March 1996.
- [48] S. B. Mahato, "Performance Evaluation of Six-Sectored Configuration in Hexagonal WCDMA (UMTS) Cellular Network Layout," Master of Science Thesis, LAPPEENRANTA UNIVERSITY OF TECHNOLOGY, DEPARTMENT OF INFORMATION TECHNOLOGY, October, 2006.
- [49] S. A. Benjamin Paul, "Code Planning of 3G UMTS Mobile Networks Using ATOLL Planning Tool," *International Journal of Engineering Research & Technology (IJERT)*, vol. 1, no. 5, pp. 1-5, July - 2012.
- [50] S. Abdul Basit, "Dimensioning of LTE Network Description of Models and Tool, Coverage and Capacity Estimation of 3GPP Long Term Evolution radio interface," Masters Thesis submitted in partial fulfillment of the requirements for the Degree of Masters of Science in Technology, February, 2009.
- [51] I. Siomina, "Radio Network Planning and Resource Optimization: Mathematical Models and Algorithms for UMTS, WLANs, and Ad Hoc Networks," Linköping Studies in Science and Technology, Dissertations No. 1116, Sweden, 2007.
- [52] M. Eheduru, "Indoor Radio Measurement and Planning for UMTS/HSPDA with Antennas," University of Wisconsin Milwaukee UWM Digital Commons, Theses and Dissertations, May 2013.
- [53] K. H. Jamal Khalab, "UTRAN Macro Link Budget," H3G CONFIDENTIAL, 2001.
- [54] K. H. B. Marwa Elbagir Mohammed¹, "LTE Radio Planning Using Atoll Radio Planning and Optimization Software," *International Journal of Science and Research (IJSR)*, vol. 3, no. 10, October 2014.
- [55] M. M. A. F. Martins, "3G Radio Network Planning for a Mobile Network Operator," Masters Thesis in Electrical and Computer Engineering, December 2014.
- [56] Huawei, "Long Term Evolution (LTE) Radio Access Network Planning Guide," Huawei Technology, Co, Ltd, 2008.
- [57] C. ZHANG, "Energy Efficient Cellular System Design with QoS Assurance," Stockholm, Sweden , October 2014.
- [58] E. W. M. W. J. G. M. Z. Jingjin Wu, Writer, *Performance Analysis of Green Cellular Networks with Selective Base-Station Sleeping*. [Performance]. Department of Electronic Engineering, City University of Hong Kong, 83 Tat Chee Avenue, Kowloon, Hong Kong, 2017.

- [59] ITU-R, "Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications-Advanced (IMT-Advanced)," Electronic Publisher, Geneva , 2018.
- [60] T. Report, "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Further advancements for E-UTRA physical layer aspects (Release 9)," 3GPP TR 36.814 , 2017.

Appendix

1. Okumura Hata path loss calculation

The general formula for Okumura-Hata model is:

$$L = A + B \log(f) - 13.82 \log(H_b) - a(H_m) + [44.9 - 6.55 \log(H_b)] \log(d) + L_{other}$$

Where, $L_{other} = 3$, $H_b = 30$ & $H_m = 1.5$

For GSM 900 MHz

For frequencies 150-1500MHz the value of: $A = 69.55$ & $B = 26.16$

$$a(H_m) = 3.2(\log(11.75H_m))^2 - 4.79 \quad \text{for dense urban areas}$$

$$= 3.2(\log(11.75 \times 1.5))^2 - 4.79 = 0.105$$

$$B \log(f) = 33.9 \log(900) = 77.28$$

$$13.82 \log(H_b) = 13.82 \log(30) = 20.41$$

$$6.55 \log(H_b) = 6.55 \log(30) = 9.68$$

Therefore,

$$L = 69.55 + 77.28 - 20.41 - 0.105 + [44.9 - 9.68] \log(d) + 3$$

$$L = 129.32 + 35.22 \log(d)$$

$$\log(d) = \frac{L-129.32}{35.22}$$

$$d = 10^{[(L-129.32)/35.22]}$$

For GSM 1800 MHz

For frequencies 1500-2000MHz the value of: $A = 46.3$ & $B = 33.9$

$$a(H_m) = 3.2(\log(11.75H_m))^2 - 4.79 \quad \text{for dense urban areas}$$

$$= 3.2(\log(11.75 \times 1.5))^2 - 4.79 = 0.105$$

$$B \log(f) = 33.9 \log(1800) = 110.35$$

$$13.82 \log(H_b) = 13.82 \log(30) = 20.41$$

$$6.55 \log(H_b) = 6.55 \log(30) = 9.68$$

Therefore,

$$L = 46.3 + 110.35 - 20.41 - 0.105 + [44.9 - 9.68] \log(d) + 3$$

$$L = 139.14 + 35.22 \log(d)$$

$$\log(d) = \frac{L-139.14}{35.22}$$

$$d = 10^{[(L-139.14)/35.22]}$$

2. Cost-231 Hata Model

The general formula for Cost-231 Hata model is:

$$PL_{dBm} = A + 33.9 \log f - 13.82 \log(h_b) - ah_m + [44.9 - 6.55 \log(h_b)] \log(d) + c_m$$

Where, $A = 46.3$, $h_b = 30$, $h_m = 1.5$ & $c_m = 3$, for dense urban area

For 2100 MHz frequency band:

$$33.9 \log f = 33.9 \log 2100 = 33.9 \times 3.32 = 112.55$$

$$13.82 \log(h_b) = 13.82 \log 30 = 13.82 \times 1.48 = 20.45$$

$$ah_m = 3.2[\log(11.75)h_m]^2 - 4.79 = 3.45$$

$$[44.9 - 6.55 \log(h_b)] \log(d) = [44.9 - 6.55 \log 30] \log d = 35.21 \log d$$

Therefore, $PL_{dBm} = 46.3 + 112.55 - 20.45 - 3.45 + 35.21 \log d + 3$

$$\log d = (PL - 141.1)/35.21$$

$$d = 10^{(PL-141.1)/35.21}$$

For 1800 frequency band:

$$33.9 \log f = 33.9 \log 1800 = 33.9 \times 3.32 = 110.35$$

$$13.82 \log(h_b) = 13.82 \log 30 = 13.82 \times 1.48 = 20.45$$

$$ah_m = 3.2[\log(11.75)h_m]^2 - 4.79 = 3.45$$

$$[44.9 - 6.55 \log(h_b)] \log(d) = [44.9 - 6.55 \log 30] \log d = 35.21 \log d$$

Therefore, $PL_{dBm} = 46.3 + 110.35 - 20.45 - 3.45 + 35.21 \log d + 3$

$$\log d = (PL - 137.953)/35.21$$

$$d = 10^{(PL-137.953)/35.21}$$