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BAHIR DAR UNIVERSITY

BAHIR DAR INSTITUTE OF TECHNOLOGY (BiT)

SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

Dimensioning and Planning of Multi RAT Radio Network for Future Deployment in Bahir Dar City

By:

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Adviser

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A thesis submitted to the School of Electrical and Computer Engineering in partial Fulfillment of the Requirements for the Degree of Masters of Science in Communication Systems Engineering

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Declaration

I, the undersigned, declare that the thesis comprises my own work. In compliance with internationally accepted practices, I have fully acknowledged and refereed all materials used in this thesis work

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

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List of Acronyms

2G	Second Generation
3G	Third Generation
3GPP	3rd Generation Partnership Project
4G	Fourth Generation
AMC	Adaptive Modulation and Coding
AMR	Adaptive Multi Rate
AUC	Authentication Center
BCCH	Broadcast control channel
BH	Busy hour
BLER	Block error rate
BPSK	Binary phase shift keying modulation
BSC	Base Station Controller
BSIC	Base Station Identity Code
BSS	Base Station Subsystem
BTS	Base Transceiver Station
C/I	Carrier to Interference ratio
CP	Cyclic prefix
COST	European **Co**-operation in the Field of **S**cientific and **T**echnical research
CQI	Channel Quality Indicator
DCS	Digital Cellular System
DFT	Discrete Fourier Transform
DL	Down Link
DTX	Discontinuous Transmission
E_b/No	Energy per bit over Noise density
EDGE	Enhanced Data rates for GSM Evolution
EIRP	Effective Isotropic Radiated Power
eNB	Enhanced NodeB
EPC	Evolved Packet Core
EPS	Evolved Packet System
ETSI	European Telecommunications Standards Institute
EUTRA	Evolved UMTS Terrestrial Radio Access
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FFT	Fast Fourier Transform
FSK	Frequency shift keying
FSPL	Free space Path Loss
Gbps	Giga bits per Second

GGSN	Gateway GPRS Support Node
GoS	Grade of service
GPRS	Global packet radio service
GSM	Global System for Mobile Communication
HeNB	Home Enhanced NodeB
HLR	Home Location Register
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access (HSDPA + HSUPA)
HSUPA	High Speed Uplink Packet Access
ICI	Inter Carrier Interference
IDFT	Inverse Discrete Fourier Transform
IFFT	Inverse Fast Fourier Transform
IP	Internet Protocol
ISI	Inter Symbol Interference
ITU	International Telecommunications Union
KPI	Key Performance Indicator
LAC	Location Area Code
LTE	Long Term Evolution
MAC	Medium Access Control
Mbps	Megabits per Second
MCS	Modulation and Coding Scheme
MIMO	Multiple Input Multiple Output
MS	Mobile Station
MSC	Mobile Switching Center
OFDM	Orthogonal Frequency-Division Multiplexing
OFDMA	Orthogonal Frequency-Division Multiple Access
PAPR	Peak to Average Power Ratio
PBCH	Physical Broadcast Channel
PBH	Peak Busy Hour
PCH	Paging Channel
PCI	Physical Cell Identity
PDCH	Packet Data Channel
PDSCH	Physical Downlink Shared Channel
PDN	Packet Data Network
PHY	Physical Layer
PLMN	Public Land Mobile Network
PRB	Physical Resource Block
PS	Packet Switching
PSC	Pseudo random Scrambling Code
PSK	Phase shift keying

P-SCH	Primary Synchronization Channel
PSS	Primary Synchronization Signal
PSTN	Public Switched Telephone Network
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
RB	Resource Block RF Radio Frequency
RLB	Radio Link Budget
RLC	Radio Link Control
RNC	Radio Network Controller
RNP	Radio Network Planning
RRC	Radio Resource Control
RRM	Radio Resource Management
RS	Reference Signal
RSCP	Received signal code power
RSRP	Reference signal received power
RSSI	Received signal strength Indicator
RSRQ	Reference signal received quality
SDCCH	Stand-alone Dedicated Control Channel
SGSN	Serving GPRS support node
SC-FDMA	Single-Carrier Frequency-Division Multiple Access
SINR	Signal-to-Interference and Noise Ratio
SNR	Signal-to-Noise Ratio
SP	Smart phone
S-SCH	Secondary Synchronization Channel
SSS	Secondary Synchronization Signal
TCH	Traffic Channel
TDD	Time division duplex
TDMA	Time Division Multiple Access
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications System
UTRAN	UMTS Terrestrial Radio Access Network
VLR	Visitor Location Register
VoIP	Voice over Internet Protocol
WCDMA	Wideband code division multiple access
WiMAX	Worldwide Interoperability for Microwave Access

Abstract

Wireless communication networks enable customers to use communication services like telephony or Internet services at anytime and anywhere. A multitude of varying radio access technologies has been developed. Those access technologies have different characteristics: they differ in their radio coverage, their spectral efficiency, cell capacity, and peak data rate. For a network operator different radio access technologies may best be suited in different parts of the network, depending on the radio environment, the expected traffic pattern, and the anticipated services.

There are ongoing researches for various access technologies to be combined in a common network and to allow network convergence by the integration of multiple heterogeneous access technologies into a common network.

My thesis deals with the procedure of how to carry out the radio network planning for 2G, 3G and 4G systems. The general steps and methods for wireless radio network planning are first addressed. Then the issue of radio network planning for multi radio access technologies including GSM, UMTS & LTE is discussed with special focus on the coverage, capacity and frequency planning.

Most mobile subscribers in Ethiopia are using 2G handsets and it may be difficult to offload the 2G network traffic in to 3G or 4G in near future. Because this directly related with the people economy to buy 3G or 4G handsets, as well as the cost per Mbps to use 3G or 4G sim cards. However part of our community at this time are using smart phones supporting 3G or 4G network and for these customers need we considered 3G radio network planning. And LTE is designed for urban part of the city for data only usage by considering high data rate need for VIP customers. Hence the above concept justifies the necessities of both 2G, 3G and 4G networks.

2G network is excellent for coverage, DCS for capacity and UMTS & LTE mostly for data. Hence our planning considers that one base station may have different access technologies with different configuration scenarios, depending on the population of the subscribers and other parameters. The antenna usage also depending on the planned site scenarios: single, dual or triple band. Hence this thesis focuses on the main steps and procedures required for Multi RAT planning so that it will help ethio telecom for planning of telecom service provisioning for Bahr Dar city.

Keywords: 3GPP, GSM, UMTS, LTE, Coverage, Capacity, Frequency Planning

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Chapter One

1. Introduction

The radio access part of the wireless network is considered of essential importance as it is the direct physical radio connection between the mobile equipment and the core part of the network. In order to meet the requirements of the mobile services, the radio network must offer sufficient coverage and capacity.

The radio network planning process can be divided into different phases. At the beginning is the pre-planning phase. In this phase, the basic general properties of the future network are investigated, for example, what kind of mobile services will be offered by the network, what kind of requirements the different services impose on the network, the basic network configuration parameters and so on.

The second phase is the main phase. A site survey is done about the to-be-covered area, and the possible sites to set up the base stations are investigated. All the data related to the geographical properties and 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 this point. Based on the propagation model, the link budget is calculated, which will help to define the cell range and coverage threshold. There are some important parameters which greatly influence the link budget, for example, antenna gains, losses, receiver sensitivity, the fade margins etc. Based on the digital map and the link budget, computer simulations will evaluate the different possibilities to build up the radio network. The goal is to achieve as much coverage as possible with the optimal capacity. The coverage and the capacity planning are of essential importance in the whole radio network planning. The coverage planning determines the service range, and the capacity planning determines the number of to-be-used base stations and their respective capacities. In addition frequency is a scarce resource depending on the regulatory body's spectrum is available for operators (ethio telecom in Ethiopia) and hence proper frequency planning can minimize interference, PSC collisions and PCI conflict for multi RAT planning.

In the third phase, constant adjustment will be made to improve the network planning. Then the final radio plan is ready to be deployed in the area to be covered and served.

1.1. Background

Ethio telecom recent telecom expansion project (TEP) has a vision in deploying Multi RAT in Ethiopia and our government also signed contractual agreement with Huawei, ZTE and Ericsson to upgrade Addis Ababa cellular network to Multi Radio Access Technology (Multi RAT) and regional towns like Bahir Dar to 3G, which gives an easy and smooth transition to 4G network.

Up to October 2014, in Bahir Dar city there was 26 ZTE GSM base stations supports voice and EDGE data services, From November 2014 onwards 3G network is deployed by Huawei and currently there are 67 2G GSM and 71 3G WCDMA network infrastructures for an area of 200 sq.km..

However mobile customers are dissatisfied by the existing network quality of service (QoS). The main reason behind this is that, proper radio network planning in Ethiopia as a whole and Bahir Dar in particular, is not taken in to account during the radio access network planning phase of the existing network deployment.

Even though there is a responsible department for radio network planning in ethio telecom, the trend in this regard is not satisfactory. Ethio telecom has licensed Mentum Planet planning software for radio network planning, however; in practical speaking, ethio telecom's participation is limited on providing initial input about customers from the existing VLR. Vendor's are using a customized radio link budget software which doesn't show whether necessary system, transmitter and receiver parameters are considered or not per 3GPP standards. And when we see the result of the path loss compared with standards it is too small so that the area to be covered by a single base station is small which requires more sites per the entire area this may be vendor's strategy to sell more telecom equipment's for their clients.

Whoever did the planning in our country, the radio network planning problem is clearly seen by the congestion happened immediately after deployment in Addis Ababa, and customers are dissatisfied by the coverage, capacity and quality of service here in Bahir Dar city. Even after the planned network deployed, the regional project office is requested to choose areas to build additional new sites without conducting scientific planning procedures.

Hence this is the background information that motivates me to do proper Multi RAT radio network planning for Bahir Dar city.

1.2. Statement of the Problem

In recent years the government of Ethiopia made telecom infrastructures expansion projects throughout the country. And ethio telecom is the only service provider and responsible for every telecom services in Ethiopia. By this time the company has both fixed and radio access networks widely. One thing that has been clearly seen during the problem identification is that, the continuous demand on high data rate and multimedia services here in Bahir Dar is growing exponentially however; the service quality is far from being perfect. This is due to the coverage and capacity limitation in the existing network.

The problem being addressed in my study is regardless of the cellular network infrastructures built in Bahir Dar, the existing cellular network coverage and its capacity is limited to fulfill advanced customer service requirements. Hence the study will address the problem of Bahir Dar city cellular network on the basis of coverage, capacity and QoS. Hence proper Multi RAT radio network planning can solve the problem.

1.3. Objective of the Thesis

1.3.1. General Objective:

- Dimensioning and Planning of Multi RAT radio network for future deployment in Bahir Dar city

1.3.2. Specific Objectives

Particularly, the thesis focuses on

- Analyze the impact of increasing cellular users on the macro network.
- To obtain sufficient coverage and network capacity over the entire service area to ensure that high quality voice services and data services can be offered to the subscribers.
- Performing link budget calculation for Bahir Dar city.
- Defining mathematical model for coverage and capacity estimation of Multi RAT deployment, considering actual traffic demand information of all places of the city.
- Study of possible antenna usage scenarios for Multi RAT.
- Simulating the model with ATOLL planning software.
- To evaluate the performance of the planned network using computer simulation.

1.4. Literature Review

There have been several works done on the area of GSM, UMTS and LTE dimensioning and planning. Some of the recently published articles related to this work are reviewed as follows:

Yiming Sun, 2004 [34]: Radio Network Planning for 2G and 3G. He deals with the procedure of how to carry out the radio network planning for 2G and 3G systems. The general steps and methods for wireless radio network planning are first addressed. Then the issue of radio network planning is discussed with special focus on the 2G and 3G networks, as well as a comparison between 2G and 3G radio network planning processes which is summarized at the end.

Reshma Begum Shaik, T.Krishna Chaitanya, 2012 [10]: Simulation of GSM Mobile Networks Planning Using ATOLL Planning Tool, International Journal of Engineering and Innovative Technology (IJEIT). They showed that planning of GSM networks with ATOLL.

Anteneh Temesgen, 2015 [31]: WCDMA Radio Network Dimensioning and Planning for the case of Bahir Dar City. He covers WCDMA radio coverage and capacity dimensioning and planning. He took demographic data for capacity estimation and he considered cell load and calculated throughput in detail for capacity dimensioning.

A. Benjamin Paul & Sk.M. Subani, 2012 [18]: Code Planning of 3G UMTS Mobile Networks using ATOLL Planning Tool", International Journal of Engineering Research & Technology (IJERT). This paper involves on simulation exercise on planning of 3G UMTS network with the help of Atoll planning software tool. It involves planning of coverage, quality & capacity of UMTS Network which uses WCDMA in radio interface between 3G base station and the User equipment. It also involves planning of scrambling codes for 3G WCDMA Network.

Abdul Basit, Syed, 2009 [26]: Dimensioning of LTE Network Description of Models and Tool, Coverage and Capacity Estimation of 3GPP Long Term Evolution radio interface. This thesis covers coverage and capacity estimation in radio network dimensioning. Radio link budget is used to investigate coverage planning. He used excel based dimensioning vendor tool which is designed for the usage of vendor. This can't assure weather the important parameters are considered.

Basanta Shrestha, 2010 [7]: In this thesis an attempt to provide analysis of LTE system performance from radio network planning aspects has been made. Determination of simulation results has been obtained and the effect of change in number of transmitting antennas special focus on MIMO techniques has been shown in detail.

Liang Zhang, 2010 [27]: Network Capacity, Coverage Estimation and Frequency Planning of 3GPP Long Term Evolution, Linköping University Master Thesis. In this thesis, the capacity of the LTE network is depicted with the indicators of average transmission data rate, peak transmission data rate and the subscriber's numbers supported by the system. The coverage of the LTE system is also calculated on the base of base station parameters and different propagation models. The theoretical work of this thesis was implemented in WRAP software and by using WRAP‟s capacity calculation and evaluation tools, estimation and optimization of an LTE network was performed.

Bethelhem Seifu, 2012 [30]: LTE Radio Network Planning: Modeling Approaches for the Case of Addis Ababa. This thesis covers coverage and capacity dimensioning and RAN nominal planning of LTE networks. She used Matlab 2008b as a simulation environment for analysis. The planning didn't use the digital map of the area and she specifies as a limitation about the number of user in that area are not known and here is the main drawback of her thesis.

Marwa Elbagir Mohammed & Khalid Hamid Bilal, 2012 [29]: LTE Radio Planning Using Atoll Radio Planning and Optimization Software", International Journal of Science and Research (IJSR). They carried out coverage and capacity estimation in radio network dimensioning. Radio link budget is investigated for coverage planning.

Bekele Mulu, 2013 [31]: Dimensioning and Planning of LTE Radio Network for Future Deployment in Bahir Dar City. It covers LTE radio coverage and capacity dimensioning and planning, however the simulation results showed that it was not done based on the calculated cell radius and he did not use computational zone for his planning area. In addition he has not covered PCI planning.

There are also technical literature and periodic reviews that deal heavily with future coexistence of 2G, 3G and 4G. Especially Wireless World research Coexistence of GSM, HSPA/WCDMA and LTE, 4G Americas and 3GPP standards are the literatures that helps me in planning multi RAT planning and this thesis supports multi-service environment, and it has not been reported in literatures before.

1.5. Methodology

The concept of Multi RAT Planning leads to a smooth evolution to all IP 4G network and the introduction of intelligence towards the creation of smart infrastructures beyond the 2020, 5G wireless world, thus this thesis is entirely based on books on this area, different IEEE articles and journals, previous studies on this subject specifically on radio network planning of each radio access technologies.

On the process of performing Multi RAT radio network planning, I started the work with preliminary study on radio network planning of GSM, UMTS and LTE one by one. Data collections regarding the existing Bahir Dar GSM cellular network voice traffic demand and long term telecom forecast will be specified.

After that, data analysis will be done to identify the limitations of the existing infrastructure. Based on that, theoretical dimensioning processes on the basis of coverage extension and capacity improvement will be carried out for the whole city and also frequency planning will be taken in to account.

Generally the following points will be included in the methodology.

Site Survey: Making survey to collect data by using existing cellular network and identify and collect the customers current need and what he/she complain in service of voice, data and multimedia services in addition to existing network service problems.

System design: it includes studying problems of network and putting down system flow. By analyzing the mathematical modeling techniques and design a system that can co-plan GSM/UMTS/LTE as a multi RAT environment. And identify all necessary inputs for simulation including Bahir Dar digital map.

Simulation*:* it involves implementing system flow using ATOLL simulation software.

Analysis and Interpretation of the results: It involves conclusion of Multi RAT deployment scenarios and overall performance improvements will be analyzed based on the results.

1.6. Scope of the Thesis

This thesis work focuses on the essentials of coverage analysis, capacity evaluation and spectrum usage in dimensioning Multi RAT networks. It addresses in detail the coverage prediction and capacity evaluation, and frequency planning of Multi RAT radio network taking into account the actual morphology and topography details of Bahir Dar city for future deployment. It does not address the core network dimensioning and the end-to-end service aspects such as IP backhaul and microwave transmission.

1.7. Thesis Outline

This thesis report consists of five chapters. Chapter 1 introduces some background information, followed by statement of the problem, objectives of the thesis, some literature reviews relevant for this work, and the methodology**.** Chapter 2 deals with general overview of radio access technologies. This includes basics of GSM/UMTS/LTE technologies and their features related to network dimensioning. Chapter 3 explains the main thesis body: Multi RAT radio network planning. This chapter covers the radio link budget calculation, coverage dimensioning, propagation model selection and the method to calculate the number of sites based on the coverage. It describes also the capacity planning for GSM/UMTS/LTE Network elaborating the methods used and factors impacting the capacity planning process. And it explains the frequency planning for GSM/UMTS/LTE Network with particular attention on GSM 900MHz, DCS-LTE 1800MHz and WCDMA 2100MHz frequency band allocation, besides WCDMA PSC planning and LTE PCI planning. Cell throughput calculation, traffic demand estimation and air and access network dimensioning are derived in this chapter. Chapter 4 relates to the radio network planning tool. It explains the structure and functionalities of the software and discusses the prediction and performance results of the designed network. Chapter 5 concludes the thesis with summary of the entire thesis work and possibilities of future research.

Chapter Two

2. Radio Access Technologies Overview

The radio access technologies we took in to consideration for our radio network planning in this thesis are GSM, UMTS and LTE.

2.1. GSM

Global System for Mobile (GSM) is by far the most successful and widely used 2G system. Originally designed as a pan-European standard, it was quickly adopted all over the world. The basic GSM uses the 900MHz 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 new frequency band was the lack of capacity in the 900 MHz band.

2.1.1. GSM Network Architecture

The GSM network architecture as defined in the GSM specifications can be grouped into four main areas: Mobile station (MS), Base-Station Subsystem (BSS), Network and Switching Subsystem (NSS) and Operation and Support Subsystem (OSS)

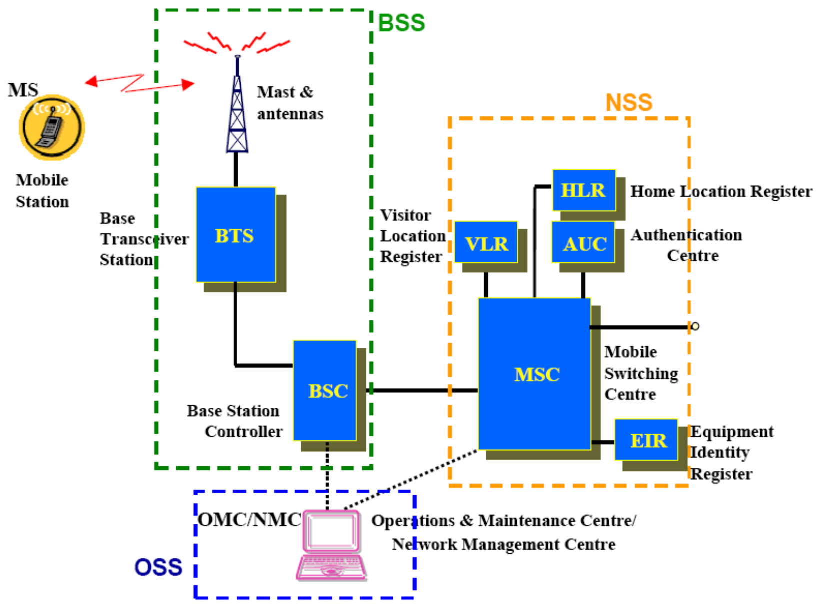

Figure 2.1: GSM Network Architecture

2.1.2. FDMA and TDMA Radio Spectrums

The radio spectrum is a scarce resource. Its usage must be carefully controlled. Mobile cellular systems use various techniques to allow multiple users to access the same radio spectrum at the same time.

An FDMA system divides the spectrum available into several frequency channels. Each user is allocated two channels, one for uplink and another for downlink communication. This allocation is exclusive; no other user is allocated the same channels at the same time.

In a TDMA system the entire available bandwidth is used by one user, but only for short periods at a time. The frequency channel is divided into timeslots, and these are periodically allocated to the same user so that other users can use other time slots. Separate time slots are needed for the uplink and the downlink. GSM is based on TDMA technology. In GSM, each frequency channel is divided into several time slots (eight per radio frame), and each user is allocated one (or more) slot(s). In a TDMA system, the used system band width is usually divided into smaller frequency channels. A slot is equal to one timeslot on one frequency.

2.1.3. GSM Channels

There are two types of channels in the air interface: physical channels and logical channels.
The physical channel is all the time slots of the BTS. There are again divided in to two types; half-rate (HR) and full-rate (FR).

Logical channel: refers to the specific type of information that is carried by the physical channel. Logical channels can also be divided into two types; traffic channels and control channels. From our thesis perspective TCH and BCCH channels are most important.

Basic Channel Structure

The GSM standard is based on a multi-carrier, time-division multiple access and frequency division duplex, MC/TDMA/FDD. The carrier spacing is 200 kHz, i.e, for 124 and 374 radio frequency channels in the 900 and 1800 MHz bands respectively, there is a guard band of 200 kHz at each end of the sub-bands. Each TDMA frame is subdivided 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.

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2.2. UMTS

WCDMA is the air interface chosen for the UMTS (universal mobile telecommunications system). It is quite different from the air interface used in GSM networks. 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.

Also, as only one frequency is used, frequency planning is therefore not such a tedious task as it is in the GSM networks. Packet data scheduling is load based as compared to timeslot based as in the GSM network, thus making the system more efficient. The algorithms that are used for Radio Resource Management (RRM) functionality are more advanced as compared to GSM networks.

By definition the bandwidth of WCDMA system is 5MHz, and this 5MHz is the nominal bandwidth of all 3G WCDMA.

2.2.1. UMTS Network Architecture

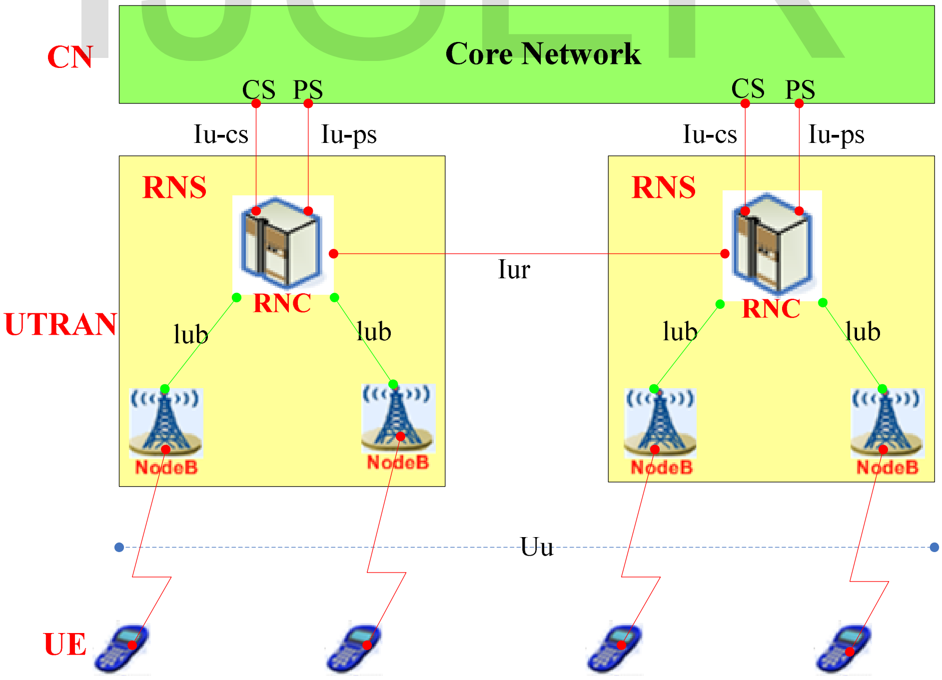

Figure 2.2: UMTS Network Architecture

The UMTS network architecture is shown in **figure 2.2**; the core network handles call control and mobility management functionalities while the UTRAN manages the radio packet transmission and resource management.

User Equipment (UE): is the name given to what was previous termed the mobile, or cell phone. The new name was chosen because the considerably greater functionality that the UE could have. It could also be anything between a mobile phone used for talking to a data terminal attached to a computer with no voice capability.

Node B: The Node B converts the data flow between the Iub and Uu interfaces, the main function of the Node B is to perform the air interface (channel coding and interleaving, rate adaptation, spreading, etc.). It also performs some basic radio resource management operations such as the inner loop power control.

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.

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

UTRAN: it consists of one or more RNSs (radio network subsystems), which in turn consist of base stations Node B's and RNCs (radio network controllers). The RNS performs all of the radio resources and air interface management functionalities.

CN (core network): it 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 [11,12,13].

Uu Interface: This is the WCDMA radio interface, it is the interface through which the UE accesses the fixed part of the system, and is therefore probably the most important open interface in UMTS.

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

2.2.2. UMTS Operation Modes and Multiple Access

UMTS may work in two different modes, the TDD and the FDD ones [3GPP00e] [3GPP00f], which means that channels in the UL and DL will be managed in two different ways:

In the FDD mode, two pairs of frequency bands are used at the same time, one for UL and the other for DL. This mode uses Wideband Code Division Multiple Access (WCDMA), the carried services being characterized by their symmetric traffic, like voice. This mode will be the most used, being deployed 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 asymmetric traffic, like Internet one. It will be used mainly in pico-cells (indoor) or in hot-spot areas.

The wide bandwidth of WCDMA gives an inherent performance gain over previous cellular systems, since it reduces the fading of the radio signal. In addition, WCDMA uses coherent demodulation in UL, a feature that was not previously 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 [14].

2.2.3. Power Control

Efficient power control is very important for WCDMA network performance. It is needed to minimize the interference in the system, and given the nature of the DS-CDMA (all signals are transmitted using the same frequency at the same time), a good power control algorithm is essential. Power control is needed both in the uplink and in the downlink, although for different reasons. In the uplink direction, all signals should arrive at the base station's receiver with the same signal power.

The mobile stations cannot transmit using fixed power levels, because the cells would be dominated by users closest to the base station and far away users couldn't get their signals heard in the base station. The phenomenon is called the near-far effect, this problem calls for uplink power control. The mobile stations far away from the base station should transmit with considerably higher power than mobiles close to the base station. The situation is different in the downlink direction. The downlink signals transmitted by one base station are orthogonal.

Signals that are mutually orthogonal do not interfere with each other, possible power level, which maintains the required signal quality. A mobile station close to the base station would not suffer if the signals it receives have been sent using too much power. But other users, especially those in other cells, could receive this signal as non-orthogonal noise, and therefore unnecessary high power levels should be avoided [10,11,12].

2.2.4. Spread Spectrum

Wideband Code Division Multiple Access (WCDMA) allows many subscribers to use the same 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.

In WCDMA each user is assigned 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 after reception and recovers the original data. Spreading codes are divided into scrambling codes and channelization codes (CC). Each transmitter (cell in downlink) is assigned a different scrambling code and each data channel is assigned 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 must carry out 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 [14].

Spreading codes are also known as spreading sequences. There are two types of spreading codes in the UTRAN air interface: orthogonal codes and pseudorandom codes. Pseudorandom codes are also known as pseudo noise (PN) codes. Both kinds of codes are used together in the uplink and in the downlink. The same code is always used for both the spreading and dispreading of a signal. This is possible because the spreading process is actually an XOR operation with the data stream and the spreading code [17].

2.3. LTE

LTE, an abbreviation for Long Term Evolution, commonly marketed as 4G LTE, is a standard for wireless communication of high-speed data for mobile phones and data terminals. It is based on the GSM/EDGE and UMTS/HSPA network technologies, increasing the capacity and speed using a different radio interface together with core network improvements.

All LTE devices have to support Multiple Input Multiple Output (MIMO) transmissions, which allow the base station to transmit several data streams over the same carrier simultaneously. All interfaces between network nodes in LTE are now IP based, including the backhaul connection to the radio base stations.

2.3.1. LTE Network Architecture

LTE-Long Term Evolution of UMTS is one of the latest steps in an advancing series of mobile telecommunication systems. The standards body behind the paperwork is the 3rd Generation Partnership Project (3GPP). The standard development in 3GPP is grouped into two work items, where LTE targets the radio network evolution and System Architecture Evolution (SAE) targets the evolution of the packet core network. Common to both LTE and SAE is that only a packet switched will be specified. The result of these work items are the Evolved UTRAN (eUTRAN) and the Evolved Packet Core (EPC).

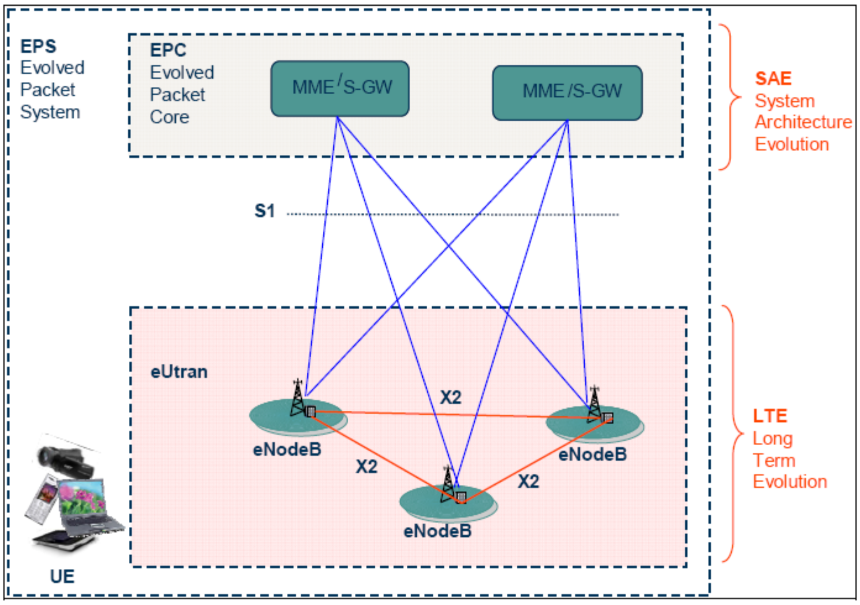

Figure 2.3: EPS Architecture

User Equipment (UE) Architecture

As in UMTS, the LTE mobile station is called User Equipment (UE). The UE categories stand for an abstract grouping of common UE radio access capabilities and are defined in 3GPP 36.306. The maximum possible bit rate ranges from 5Mbps (Cat. 1) to 75Mbps (Cat. 5).

Evolved-UTRAN (E-UTRAN) Architecture

The E-UTRAN handles the radio communications between the mobile and the evolved packet core and just has one component, the enhanced NodeB (eNB). Each eNB is a base station that controls the mobiles in one or more cells.

Evolved Packet Core (EPC) Architecture

Figure 2.3 shows the main components of the evolved packet core. One of the component, the home subscriber server (HSS), which is a central database that contains information about all the network operator's subscribers. This is one of the few components of LTE that has been carried forward from UMTS and GSM.

Evolved Packet System (EPS) Architecture

EPC + eUTRAN builds the Evolved Packet System (EPS). LTE/SAE is specified from Release 8. Note that LTE and SAE refer to the work items in 3GPP. The name of the actual Radio Access Network (RAN) is eUTRAN and the name of the Core Network (CN) is Enhanced Packet Core (EPC). The eUTRAN supports use of different MIMO (Multiple Input Multiple Output) multiple antenna configurations. This increases the data rates and spectrum efficiency. One of the objectives of radio access network E-UTRAN is to simplify and reduce the number of interfaces between different network elements. Interfaces between different network elements are S1 (eNodeB-EPC) and X2 (inter eNodeB) as shown in **figure 2.3**.

Mobility Management Entity (MME):

MME is the main control element in the EPC. It used to process signaling between the CN and the UE. The protocols running between the UE and the CN are called as the Non-Access Stratum (NAS) protocols.

The S-GW (Serving Gateway):

S-GW is responsible for IP packet transferring. Acts as a router, and forwards data between the base station and the packet data network (PDN) gateway.

2.3.2. LTE Physical Layer

The design of the LTE physical layer is heavily influenced by requirements for high peak transmission rate (100 Mbps DL or 50 Mbps UL), spectral efficiency, and multiple channel bandwidths (1.25-20 MHz). To fulfill these requirements, orthogonal frequency division multiplex (OFDM) was selected as the basis for the physical layer.

OFDMA and SC-FDMA

LTE has selected Orthogonal Frequency Division Multiple Access (OFDMA) in the downlink and Single-Carrier Frequency Division Multiple Access (SC-FDMA) in the uplink. For the downlink, OFDMA is unanimously considered as the most appropriate technique for achieving high spectral efficiency. For the uplink, the LTE of 3GPP employs SC-FDMA because of its low Peak-To-Average Power Ratio (PAPR) properties compared to OFDMA.

OFDMA is a multiple access scheme on the base of the Orthogonal Frequency-Division Multiplexing (OFDM) modulation technique. The OFDM signal can be generated by using the Fast Fourier Transform (FFT). In an OFDM system, the available spectrum is divided into multiple, mutually orthogonal subcarriers. Each of these subcarriers are independently modulated by a low rate data stream and can carry independent information streams. **Figure 2.4** shows how the OFDM technique is applied for a signal with 5 MHz bandwidth [27,28].

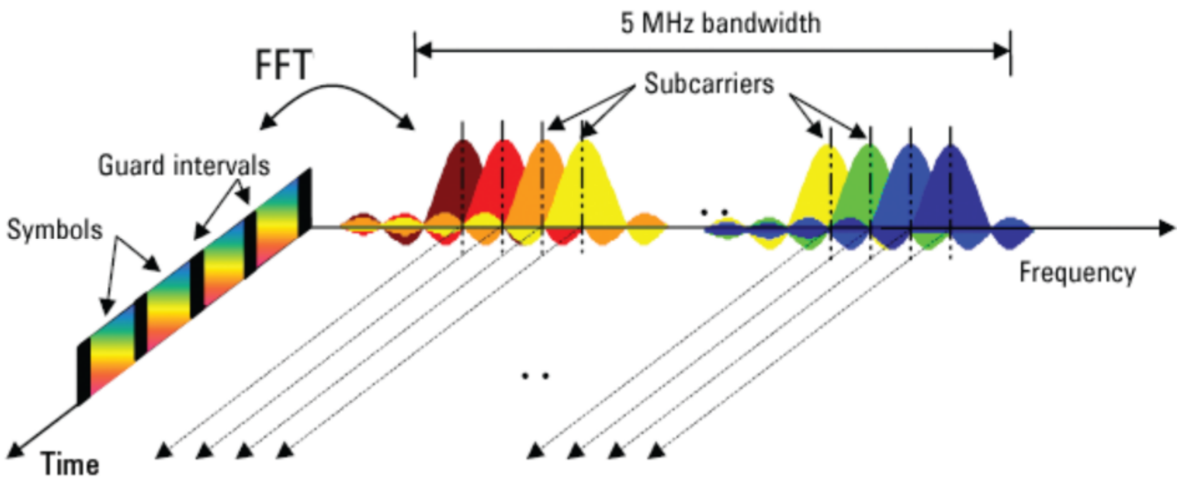

Figure 2.4: Frequency-time representation of an OFDM Signal

In the frequency domain, the 5 MHz bandwidth is divided into a high number of closely spaced orthogonal subcarriers. The subcarriers in LTE have a constant spacing of 15 kHz. In E-UTRA, the downlink modulation schemes can be QPSK, 16QAM and 64QAM. In the time domain, a guard interval is added to each symbol to combat inter OFDM symbol interference due to channel delay spread. In E-UTRA, the guard interval is a cyclic prefix (CP) which is inserted prior to each 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 them is equivalent to an Inverse Fourier Transform operation (IFFT). The reverse operation is applied to the OFDM symbol to retrieve the data stream which is equivalent to a Fast Fourier Transform operation (FFT).

There are many advantages to using OFDM in a mobile access system, namely:

1. Long symbol time and guard interval increases robustness to multipath and limits inter symbol interference.
2. Eliminates the need for intra-cell interference cancellation.
3. Allows flexible utilization of frequency spectrum.
4. Increases spectral efficiency due to orthogonality between sub-carriers.
5. Allows optimization of data rates for all users in a cell by transmitting on the best (i.e. non-faded) sub-carriers for each user.

The downlink physical layer of LTE is based on OFDMA. However, despite its many advantages, OFDMA has certain drawbacks such as high sensitivity to frequency offset (resulting from instability of electronics and Doppler spread due to mobility) and high peak-to-average power ratio (PAPR). PAPR occurs due to random constructive addition of sub-carriers and results in spectral spreading of the signal leading to adjacent channel interference. It is a problem that can be overcome with high compression point power amplifiers and amplifier linearization techniques. While these methods can be used on the base station, they become expensive on the User Equipment (UE). Hence, LTE uses Single Carrier FDMA (SC-FDMA) with cyclic prefix on the uplink, which reduces PAPR.

Adaptive Modulation and Coding (AMC)

In cellular communication systems, the quality of the signal received by a UE depends on the channel quality from the serving cell, the level of interference from other cells, and the noise level. To optimize system capacity and coverage for a given transmission power, the transmitter should try to match the information data rate for each user to the variations in the received signal. This is commonly referred to as link adaptation and is typically based on Adaptive Modulation and Coding (AMC). The AMC consists of the modulation Scheme and code rate.

Modulation Scheme: Low-order modulation (i.e. few data bits per modulated symbol, e.g. QPSK) is more robust and can tolerate higher levels of interference but provides a lower transmission bit rate. High-order modulation (i.e. more bits per modulated symbol, e.g. 64QAM) 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.

Code rate: For a given modulation, the code rate can be chosen depending on the radio link conditions: a lower code rate can be used in poor channel conditions and a higher code rate in the case of high SINR [27].

The type of modulation used in LTE depends on the radio environment. The UE estimates the quality in the downlink and signals it back to the eNodeB in the Channel Quality Indicator (CQI). The uplink reference signals that are embedded into the uplink transmission are used by the eNodeB to estimate the quality in the uplink. The eNodeB decides which modulation technique should be used based on the quality of the downlink and uplink radio environment. LTE supports the following modulation techniques in the downlink and uplink:

- 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
- Quadrature Phase Shift Keying (QPSK) which used 4 different quadrature's to send 2 bits per symbol [21, 22, and 31].

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In LTE and WiMAX, each subcarrier is modulated with a conventional modulation scheme depending on the channel condition. LTE uses QPSK, 16QAM, or 64QAM. The FFT sizes of 128, 256, 512, 1024 and 2048, corresponding to WiMAX and LTE channel bandwidth of 1.25, 2.5, 5, 10 and 20MHz are used. In time domain, guard intervals known as cyclic prefix (CP) are inserted between each of the symbols to prevent inter-symbol interference at the receiver caused by multi-path delay spread in the radio channel [21].

Spectrum Flexibility: FDD and TDD

Depending on regulatory aspects in different geographical areas, radio spectrum for mobile communication is available in different frequency bands in different bandwidths. Spectrum flexibility, which enables operation under all these conditions, is one of the key features of LTE radio access. Besides being able to operate in different frequency bands, LTE can be deployed with different bandwidths ranging from approximately 1.25MHz up to approximately 20MHz. Furthermore, LTE can operate in both paired and unpaired spectrum by providing a single radio-access technology that supports frequency-division duplex (FDD) as well as time division duplex (TDD) operation [26,27].

2.3.3. LTE FDD Frame Structure

In this section, we summarize the basic concepts of the LTE system that form the foundation for the LTE network planning. The LTE FDD frame structure is demonstrated in Figure 2.8 for normal cyclic prefix (CP). Each LTE FDD radio frame is $T_f = 307200 \times Ts = 10$ ms long and consists of 20 slots of length $T_{slot} = 15360 \times Ts = 0.5$ ms, numbered from 0 to 19. For LTE FDD, 10 sub-frames are available for downlink transmission and 10 for uplink transmissions in each 10 ms interval. UL and DL transmissions are separated in the frequency domain [21,26].

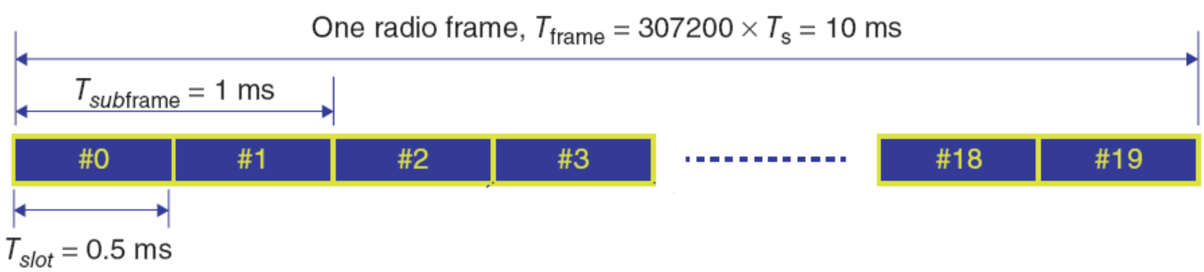

Figure 2.5: LTE FDD frame and slot structure

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Resource Blocks (RB)

A physical resource block (PRB) is used in LTE to describe the physical resource in the time/frequency grid. **Figure 2.6** illustrates the LTE time/frequency grid definitions. A PRB consists of 12 consecutive subcarriers and lasts for one slot, 0.5 ms. Each subcarrier is spaced by 15 kHz. The N_{RB}^{DL} parameter is used to define the number of RB (resource blocks) used in the downlink. This is dependent on the channel bandwidth. In contrast, N_{RB}^{UL} is used to identify the number of resource blocks in the uplink. Each resource block consists of N_{SC}^{RB} subcarriers, which for standard operation is set to 12 or a total of 180 kHz lasting in a 0.5ms slot.

The resource element (RE) is the smallest defined unit, which consists of one OFDM subcarrier during one OFDM symbol interval. Each RB consists of 12 × 7 = 84 REs in the case of normal CP and 72 REs for extended CP. The maximum RB is 100. The 100 RB corresponds to the transmission bandwidth while 20MHz is the channel bandwidth.

The number of subcarriers depends on the system BW (i.e., 1.4→72, 3→180, 5→300, 10→600, 15→900, 20→1200). Within the LTE carrier bandwidth of up to 20MHz there are some subcarriers that are faded and other that are not faded. Transmission is done using those frequencies that are not faded. The transmission can be scheduled by RB, each of which consists of 12 consecutive subcarriers, or 180 kHz, for the duration of one slot (0.5 ms) [21].

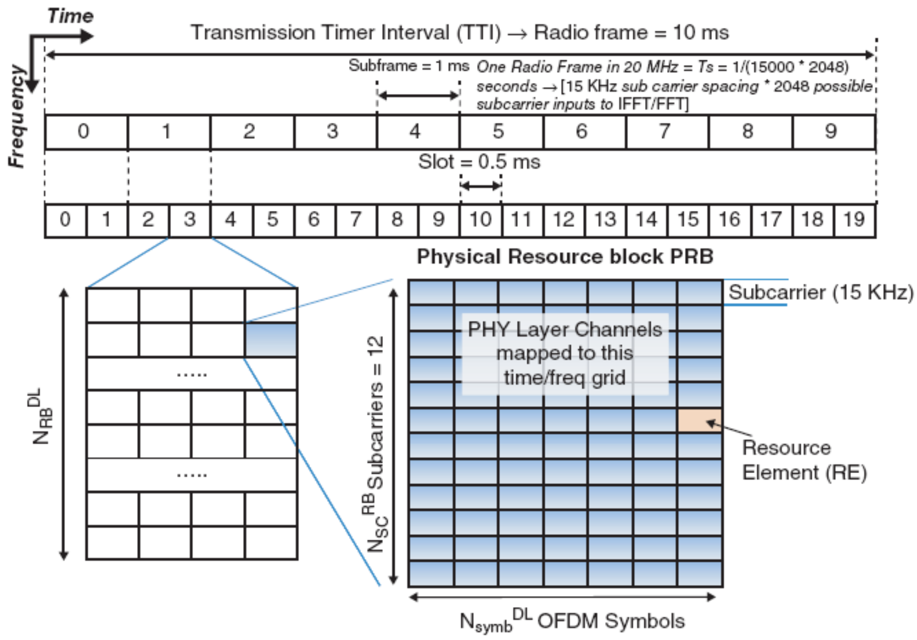

Figure 2.6: Physical resource block and resource element

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2.3.4. LTE MIMO Basics

Multiple Input Multiple Output (MIMO) systems form an essential part of LTE in order to achieve the ambitious requirements for throughput and spectral efficiency. MIMO refers to the use of multiple antennas at the transmitter and receiver side. There are two functionality modes of MIMO. Different gains can be achieved depending on which MIMO mode is used. Two methodologies are used to provide improvements in the signal to noise ratio and they are characterized by improving the reliability of the system with respect to the various forms of fading.

The Spatial Multiplexing mode: allows transmitting different streams of data simultaneously on the same resource blocks by exploiting the spatial dimension of the radio channel so that the data rate or capacity is increased.

Spatial Diversity mode: spatial diversity used in this narrower sense often refers to transmit and receive diversity, used to exploit diversity and increase the robustness of data transmission. Each transmit antenna transmits essentially the same stream of data, so the receiver gets replicas of the same signal. This increases the signal to noise ratio at the receiver side and thus the robustness of data transmission especially in fading scenarios [27].

Only the spatial multiplexing mode is concerned in this thesis while calculating the LTE capacity and data rate. Take a 4 x 4 antenna configuration (4 transmit antenna and 4 receiver antenna) as an instance, as **Figure 2.7** shows, where each receiver antenna may receive the data streams from all transmit antennas.

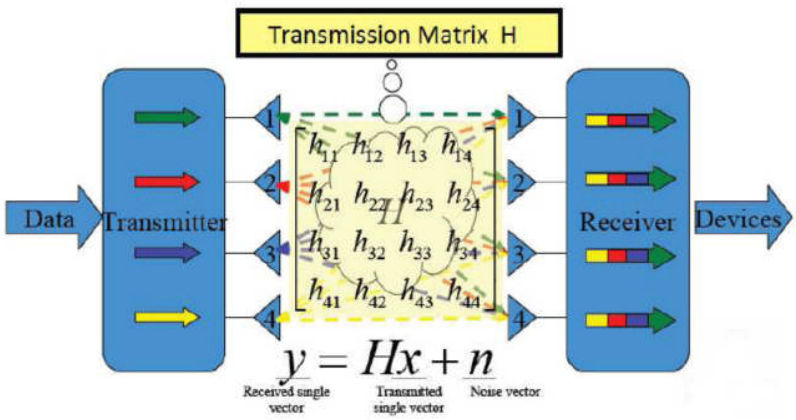

Figure 2.7: MIMO Transmission

The transmission relationship can be described with a Transmission Channel Matrix H. The coefficients h_{ij} stands for transmit antenna j to receive antenna i, thus describing all possible paths between transmitter and receiver sides.

Suppose receive vector is y, transmit vector is x, the noise vector is n and H is the transmission channel matrix. Then the MIMO transmission can be described with the formula:

$$y = Hx + n \tag{2.1}$$

In an M x N antenna configuration, the number of data streams which can be transmitted in parallel over the MIMO channel is given by the minimum value of M and N and is limited by the rank of the transmission matrix H. For example, a 4 x 4 MIMO system could be used to transmit four or fewer data streams.

In the spatial multiplexing mode, the data streams transmitted can belong to one single user (single user MIMO/SU-MIMO) or to different users (multi user MIMO/MU-MIMO). While SU-MIMO increases the data rate of one user, MU-MIMO allows increasing the overall capacity.

In Spatial Multiplexing mode the data rate (in the case of SU-MIMO) or capacity (in the case of MU-MIMO) is increased; see **Figure 2.8** [27,28,30].

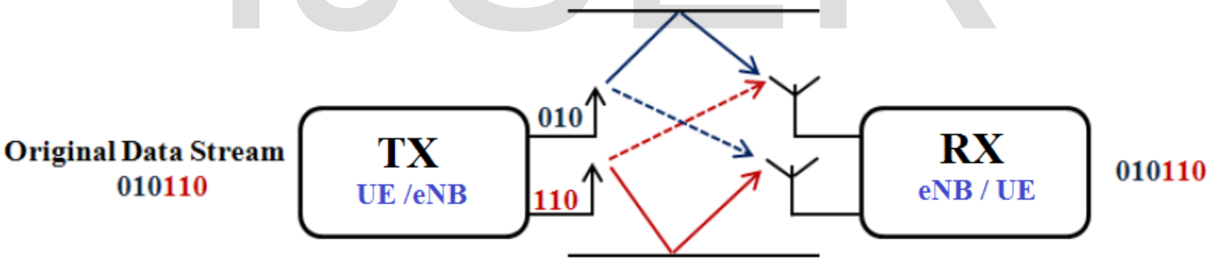

Figure 2.8: Spatial Multiplexing

Only the MU-MIMO is concerned in the thesis when calculating the system capacity. As the MIMO for the uplink is considered in 3GPP LTE advanced standards phase, the MIMO is not applied in Uplink in this thesis.

As a result of the use multiple antennas, MIMO wireless technology is able to considerably increase the capacity of a given channel while still obeying Shannon's law.

Physical Signals and channels

The LTE air interface consists of physical signals and physical channels, which are defined in 36.211. Physical signals are generated in Layer 1 and used for system synchronization, cell identification, and radio channel estimation. Physical channels carry data from higher layers including control, scheduling, and user payload.

Physical signals are summarized in **Table 2.1**. In the downlink, primary and secondary synchronization signals encode the cell identification, allowing the UE to identify and synchronize with the network. In both the downlink and the uplink there are reference signals (RS), known as pilot signals in other standards, which are used by the receiver to estimate the amplitude and phase flatness of the received signal. The flatness is a combination of errors in the transmitted signal and additional imperfections that are due to the radio channel.

Without the use of the RS, phase and amplitude shifts in the received signal would make demodulation unreliable, particularly at high modulation depths such as 16QAM or 64QAM. In these high modulation cases, even a small error in the received signal amplitude or phase can cause demodulation errors [28].

Table 2.1: LTE Physical Signals

Downlink Physical Signals	**Purpose**
Primary Synchronization Signal, PSS	Used for cell search and identification by the UE. Carries part of the cell ID (one of three orthogonal sequences)
Secondary Synchronization Signal, SSS	Used for cell search and identification by the UE. Carries the reminder of the cell ID (one of 168 binary sequences)
Reference Signal, RS	Used for downlink channel estimation. Exact sequence derived from cell ID (one of 3×168=504 pseudo random sequences)
Uplink Physical Signals	**Purpose**
Reference Signals (Demodulation and Sounding)	Used for Synchronization to the UE and for UL channel estimation

Reference Signals

To carry out coherent demodulation of different physical channels at both the downlink and uplink, the transmitters and receivers need to perform channel estimation. A straightforward way to enable channel estimation in LTE is to insert known reference symbols into the OFDM/SC-FDM time frequency grid. In the downlink direction, an example of reference symbols for 1 antenna transmission is illustrated in **Figure 2.9**.

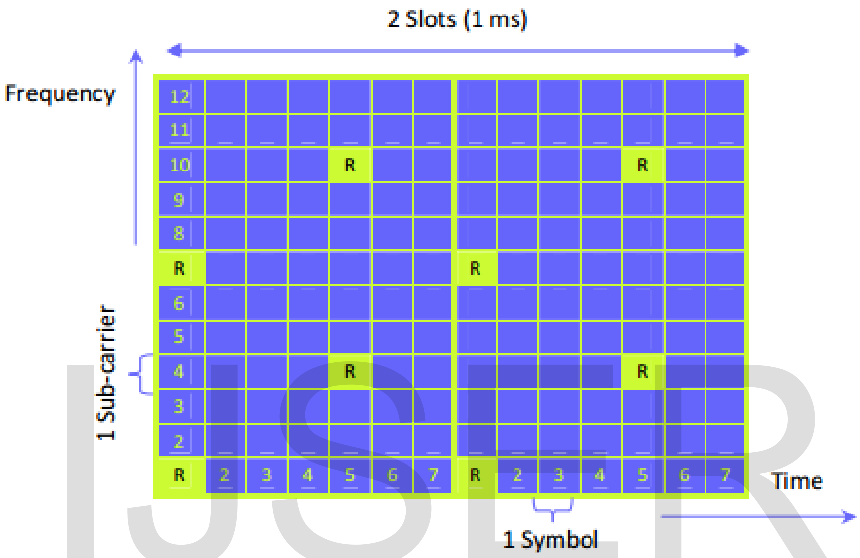

Figure 2.9: LTE downlink reference signals

The RS is similar to the "UMTS pilot" and it is used by the UE to predict the channel characteristics. As LTE is a MIMO based technology, it can have more than two transmit antennas and in order to avoid RSs from the same cell interfering with each other, different antennas will be transmitting RS at different times and frequencies.

Synchronization Signals

A UE wishing to access the LTE system follows a cell search procedure which includes a series of synchronization stages by which the UE determines time and frequency parameters that are necessary to demodulate DL signals, to transmit with correct timing and to acquire some critical system parameters. There are two cell search procedures in LTE: one for initial synchronization and another for detecting neighbor cells in preparation for handover. In both cases, the UE uses two special signals broadcast on each cell: primary synchronization sequence (PSS) and secondary synchronization sequence (SSS) [27, 28].

2.4. Propagation Models

Propagation models have been developed to be able to estimate the radio wave propagation as accurately as possible. Models have been created for different environments to predict the path loss between the transmitter and receiver.

2.4.1. Free Space Path loss Model (FSPL)

The basic electromagnetic wave propagation mechanisms are free space loss, reflection, diffraction and scattering. 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 [3,5,7,8]:

$$S = \frac{P_t G_t}{4\pi d^2} \tag{2.2}$$

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

$$A = \frac{\lambda^2 G_r}{4\pi} \tag{2.3}$$

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

$$S = \frac{P_r}{A} \tag{2.4}$$

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

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 \tag{2.5}$$

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:

$$L = \left(\frac{4\pi d}{\lambda}\right)^2 \tag{2.6}$$

And the free space loss converted in decibels

$$L_{dB} = 10\ log_{10}\left(\frac{4\pi d}{\lambda}\right)^2 \qquad (2.6a)$$

$$L_{dB} = 20\ log_{10}\left(\frac{4\pi d}{\lambda}\right) \qquad (2.6b)$$

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

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

$$L_{dB} = 20\ log_{10}(4\pi) + 20\ log_{10}(d) - 20\ log_{10}\left(\frac{0.3}{f}\right) \qquad (2.6d)$$

$$L_{dB} = 32.4 + 20\ log_{10}(f) + 20\ log_{10}(d) \qquad (2.6e)$$

Where f is the frequency in megahertz and d is the distance in kilometers.

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

The attenuation of the radio wave signal power depends on the frequency band and terrain types between the transmitting and receiving antenna. When estimating the total path loss of the radio signal, the travelled path can be split into sections according to terrain types. As the propagation varies according to the area type, this has to be taken into account in the propagation model. The difference can be explained using the measured correction factor for each terrain type.

One more phenomenon of the mobile environment is the different fading types. Slow fading happens when the radio wave signal is diffracted due to buildings or other big obstacles in the signal path. The receiver, the mobile phone, is in a way in the shadow of these obstacles. Slow fading is log-normal fading and therefore modeled with a Gaussian distribution.

The previously mentioned multipath propagation causes short term fades, which can be relatively deep, in the received signal due to the summarized signal vectors, which are having different phases and amplitudes. This fading is known as fast fading or Rayleigh fading. As the second name implies, fast fading can be modeled using the Rayleigh distribution.

2.4.2. Okumura-HATA Model

The Okumura-Hata model is a well-known propagation model, which can be applied for a macro cell environment to predict median radio signal attenuation. Having one component the model uses free space loss. The Okumura-Hata model is an empirical model, which means that it is based on field measurements.

Okumura performed the field measurements in Tokyo and published results in graphical format. HATA applied the measurement results into equations. The model can be applied without correction factors for quasi-smooth terrain in an urban area but in case of other terrain types correction factors are needed. The weakness of the Okumura-Hata model is that it does not consider reflections and shadowing. The parameter restrictions for this model are [3, 5]:

- Frequency f: 150-1500 MHz, extension 1500-2000 MHz
- Distance between MS and BTS d: 1-20 km
- Transmitter antenna height H_b: 3-200 m
- Receiver antenna height H_m:1-10 m

The Okumura-Hata model for path loss prediction can by written as

$$L = A + B\ log_{10}(f) - 13.82\ log_{10}(H_b) - a(H_m) + [44.9 - 6.55\ log_{10}(H_b)]log_{10}(d) + L_{other} \quad (2.7)$$

Where

- f is the frequency (MHz),
- H_b is the base station antenna height (m),
- $a(H_m)$ is the mobile antenna correction factor,
- d is the distance between the BTS and MS (km) and
- L_{other} is an additional correction factor for area type correction.

The correction factor for the MS antenna height is represented as follows for a small or medium sized city:

$$a(H_m) = [1.1\, log_{10}(f) - 0.7]H_m - [1.56\, log_{10}(f) - 0.8] \qquad (2.7a)$$

And for a large city:

$$a(H_m) = \begin{cases} 8.29[log_{10}(1.54\, H_m)]^2 - 1.1 : & f \leq 200\ MHZ \\ 3.2[log_{10}(11.75\ \ H_m)^2 - 4.97 : & f \geq 400\ MHz \end{cases} \qquad (2.7b)$$

Where H is the MS antenna height:

$$1 \leq H_m \leq 10 \qquad (H_m\ in\ metres) \qquad (2.7c)$$

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

$$A = \begin{cases} 69.55, & f = 150 - 1500\ MHZ \\ 46.30, & f = 1500 - 2000\ MHz \end{cases}$$
$$B = \begin{cases} 26.16, & f = 150 - 1500\ MHZ \\ 33.90, & f = 1500 - 2000\ MHz \end{cases} \qquad (2.7d)$$

The Okumura-Hata model is valid for the frequency ranges 150-1500 MHz and 1500-2000 MHz. The range for the base station antenna height is from 30 to 200 meters, the mobile antenna height from1 to 10 meters and the cell range, i.e. the distance between the BTS and MS, from 1 to 20 km. With the additional correction factor (L_{other}) the Okumura-Hata model can be applied for all terrain types, meaning different morphological areas. The correction factors for each area are received as a result of model tuning including field measurements in the particular areas [1,2,3,5,7,8].

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2.4.3. COST-231 HATA Model

The HATA model is introduced as a mathematical expression to mitigate the best fit of the graphical data provided by the classical Okumura model. HATA model is used for the frequency range of 150 MHz to 1500 MHz to predict the median path loss for the distance d from transmitter to receiver antenna up to 20 km, and transmitter antenna height is considered 30 m to 200 m and receiver antenna height is 1 m to 10 m. To predict the path loss in the frequency range 1500 MHz to 2000 MHz COST 231 Hata model is initiated as an extension of HATA model. It is used to calculate path loss in three different environments like urban, suburban and rural (flat).

This model provides simple and easy ways to calculate the path loss. Although our working frequency range (2100 MHz) is outside of its measurement range, its simplicity and correction factors still allowed to predict the path loss in this higher frequency range. The basic path loss equation for this COST-231 Hata Model can be expressed as [11, 12, 13]:

$$PL = 46.3 + 33.9log_{10}(f) - 13.82log_{10}(h_b) - ah_m + [44.9 - 6.55log_{10}(h_b)]log_{10}(d) + c_m \quad (2.8)$$

Where: d is distance between transmitter and receiver antenna (km)

f is Frequency (MHz)

h_b is Transmitter antenna height (m)

The parameter c_m has different values for different environments like 0 dB for suburban and 3 dB for urban areas and the remaining parameter ah_m is defined in urban areas as [1]:

$$ah_m = 3.2[log_{10}(11.75\ h_r)]^2 - 4.79, \quad for\ f > 400\ MHz \quad (2.8a)$$

The value for ah_m in suburban and rural (flat) areas is given as [1]:

$$ah_m = [1.11\ log_{10}(f) - 0.7]h_r - [1.5\ log_{10}(f) - 0.8] \quad (2.8b)$$

Where: h_r is the receiver antenna height in meter.

2.4.4. COST-231 Walfisch-Ikegami Model

This model is a combination of J. Walfisch and F. Ikegami model. The COST 231 project further developed this model. Now it is known as a COST 231 Walfisch-Ikegami (W-I) model. This model is most suitable for flat suburban and urban areas that have uniform building height (see **Figure 2.10**). Among other models like the HATA model, COST 231 W-I model gives a more precise path loss. This is as a result of the additional parameters introduced which characterized the different environments. It distinguishes different terrain with different proposed parameters. The equation of the proposed model is expressed in [3,11,17,30,31]:

For LOS condition

$$PL_{LOS} = 42.6 + 20\,log_{10}(f) + 26\,log_{10}(d) \tag{2.9}$$

For N-LOS condition

$$PL_{NLOS} = \begin{cases} L_{FSL} + L_{rts} + L_{msd} & for\ urba\ and\ suburban \\ L_{FS} & if\quad L_{rts} + L_{msd} > 0 \end{cases} \tag{2.10}$$

Where:

$$L_{FSL} = free\ space\ loss$$

$$L_{rts} = roof\ top\ to\ street\ diffraction$$

$$L_{msd} = multi\ screen\ diffration\ loss$$

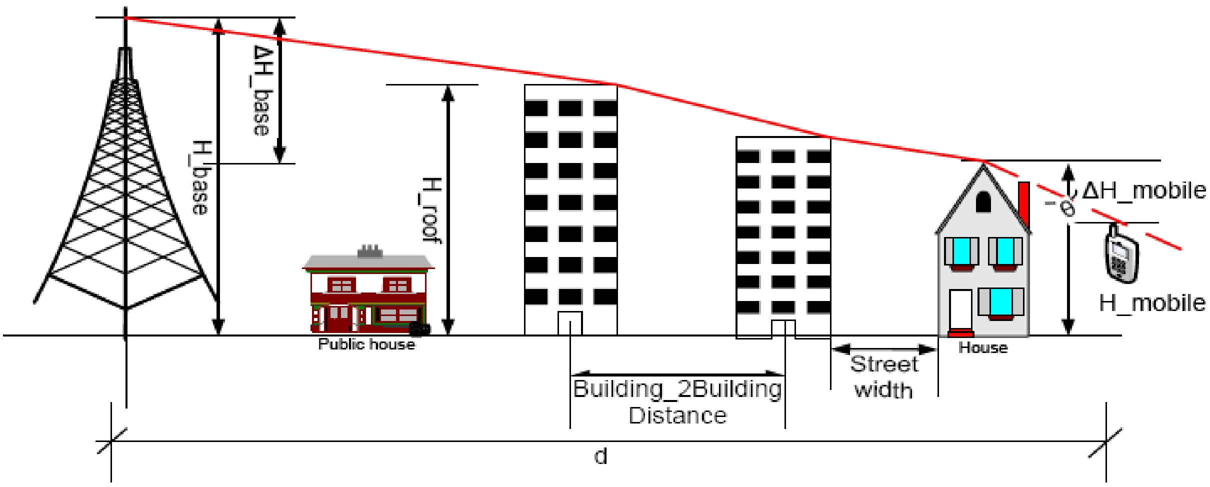

Figure 2.10: COST-231 W-I Model

Free space loss:

$$L_{FSL} = 32.4 + 20\ log_{10}(f) + 20\ log_{10}(d) \tag{2.11}$$

Roof top to street diffraction:

$$L_{rtsS} = \begin{cases} -16.9 - 10\log(w) + 10\log(f) + 20\log(H_{mobile}) + L_{ori} H_{roof} > H_{mobile} \\ L_{FS} \qquad\qquad if\quad L_{rts} + L_{msd} > 0 \end{cases} \tag{2.12}$$

$$L_{ori}(\phi) = \begin{cases} -10 + 0.354\phi: & for\ 0 = \phi < 350^0 \\ 2.5 + 0.075(\phi - 35): & for\ 35 = \phi < 55^0 \\ 4.0 - 0.114(\phi - 55): & for\ 55 = \phi < 90^0 \end{cases} \tag{213}$$

The multi-screen diffraction loss is caused by propagation from the BTS to the rooftop, which is closest to the MS:

$$\mathrm{L_{msd}} = L_{bsh} + K_a + K_d logd + K_f logf_c - 9logb \tag{2.14}$$

Where:

$$\mathrm{L_{bsh}} = \begin{cases} -18(1 + (h_{BTS} - h_{roof}): & h_{BTS} > h_{roof} \\ 0: & h_{BTS} < h_{roof} \end{cases} \tag{2.14a}$$

$$\mathrm{K_a} = \begin{cases} 54: & h_{BTS} > h_{roof} \\ 54 - 0.8(h_{BTS} - h_{roof}): & d \geq 0.5\ and\ h_{BTS} \leq h_{roof} \\ 54 - \frac{0.8(h_{BTS} - h_{roof})d}{0.5}: & d < 0.5\ and\ h_{BTS} \leq h_{roof} \end{cases} \tag{2.14b}$$

$$\mathrm{K_d} = \begin{cases} 8: & h_{BTS} > h_{roof} \\ 18 - 15\frac{(h_{BTS} - h_{roof})}{h_{BTS} - h_{MS}} & h_{BTS} < h_{roof} \end{cases} \tag{2.14c}$$

$$\mathrm{K_f} = \begin{cases} 0.7\left(\frac{f_c}{925} - 1\right): & medum\ size\ city \\ 1.5\left(\frac{f_c}{925} - 1\right): & Urban\ city \end{cases} \tag{2.14d}$$

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2.4.5. Comparison of Propagation Models

Figure 2.11 is a matlab simulation to compare and contrast among deterministic propagation models which is important to select proper propagation model for coverage planning. We compared free space, COST-231 HATA and Walfisch-Ikegami propagation model for UMTS, and Okumura-HATA and free space propagation model for GSM and LTE. By considering the worst case scenario we chose COST-231 HATA for UMTS and Okumura-HATA for GSM and LTE radio network planning that shown from the simulation result.

Here the selection is based on which propagation model reads maximum path loss at a certain calculated radius. And this is because to minimize signal degradation at the edge of the cell and to get better signal coverage.

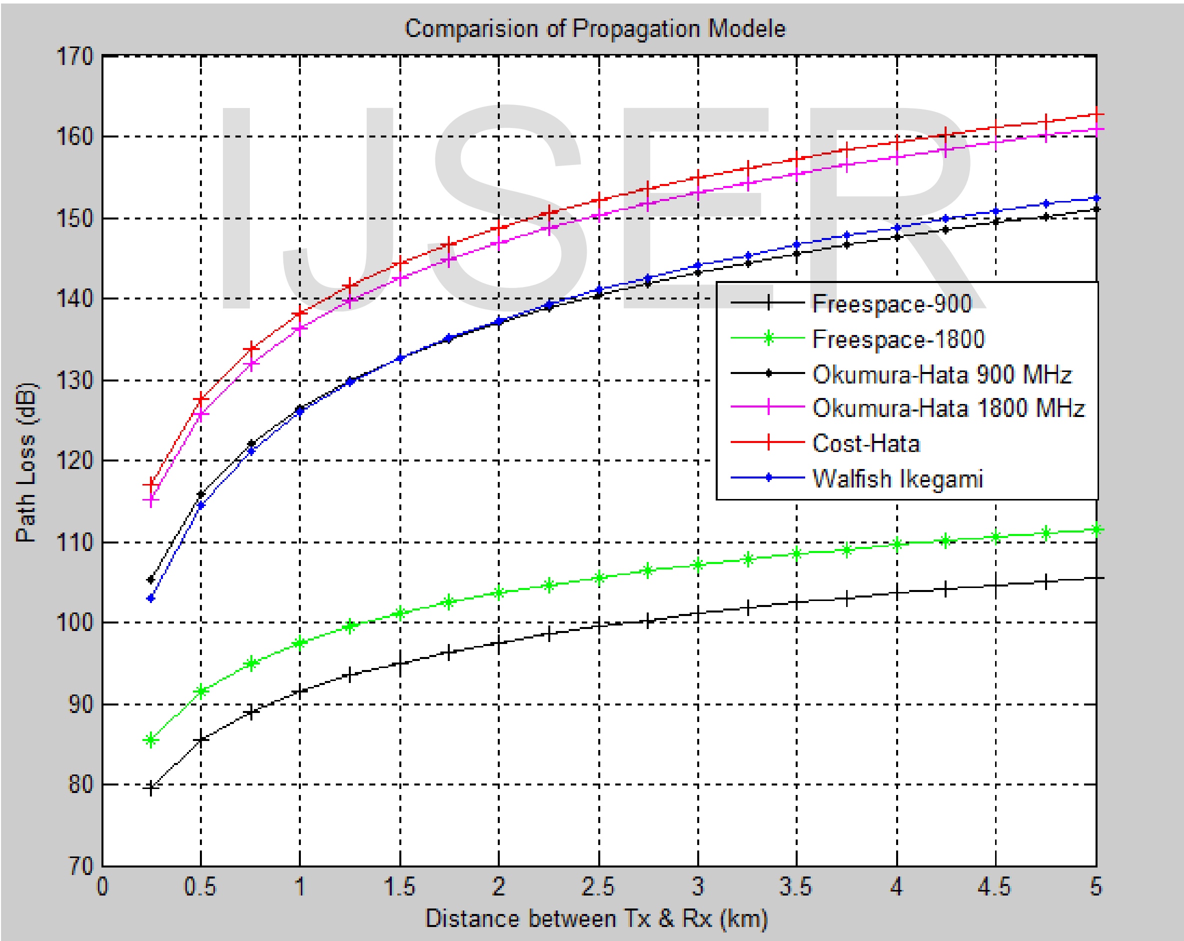

Figure 2.11: Measurements of path losses with distance

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Chapter Three

3. Multi RAT Radio Network Planning

The common vision on Multi RAT network architecture evolution and the introduction of intelligence towards the creation of smart infrastructures beyond the 2020, 5G wireless world. Next Generation Mobile Networks (NGMN) has a dedicated project related to "RAN Evolution" so as to give recommendations on future radio access network architectures.

Multi-RAT becomes a hot topic among major industrial partners. Multi-RAT operation is a key deployment now and in the coming years. An efficient and general control solution for 2G/3G/LTE operations is needed. The control plane optimization regarding Multi-RAT signaling overhead reduction, spectrum utilization and resources management is necessary and important for operators.

Single Radio Controller (SRC) for Multi-RAT operation

Similar to UMTS/GSM coordination are the management functions within multi cell in RNC and BSC. SRC as multi-RAT controller is responsible for coordinating GSM/UMTS/LTE (G/U/L) multi-RAT cell.

In Single RAN scenario, G/U/L cell is in a base station. RNC/BSC and the eNB mobility function are in one controller which is located within the SRC entity.

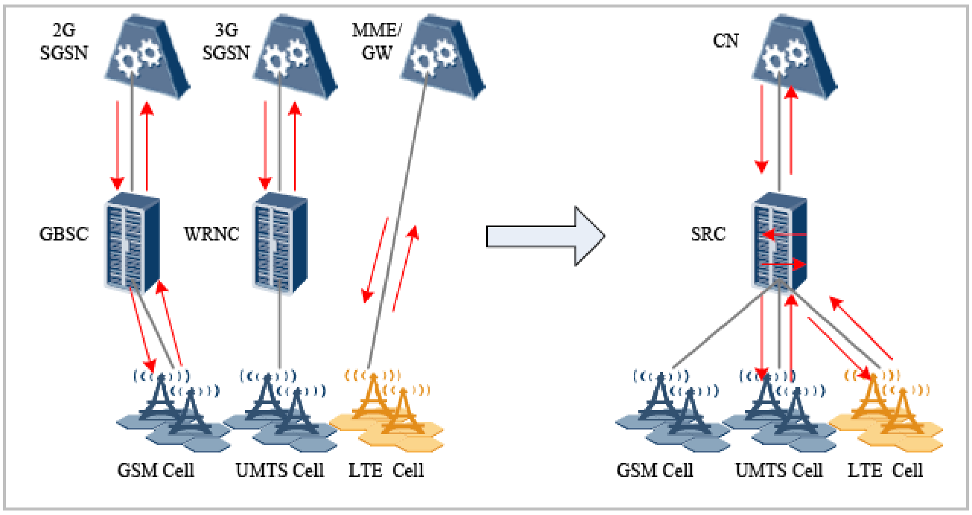

Figure 3.1: RAN Evolution

The RAN evolution on this regard is very important for operators that needs to build multi RAT, since it saves CAPEX. & 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 our scope on this thesis is to focus on the planning part of multi RAT networks.

Mobile Radio Network Planning

Network planning refers to the process of designing a network structure and determining network elements subject to various design requirements. Network planning is associated with network dimensioning and detailed planning.

With new wireless communication technologies and the increasing size of radio networks, the tasks of network planning and resource optimization are becoming more and more challenging. This is firstly because the radio resource is scarce these days due to the increasing number of subscribers and the 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.

By doing a proper Network Planning by keeping the future growth plan in mind we can reduce lots of problems that we may encounter in 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 [33,34,35].

The detailed part of radio network plan can be sub-divided into three sub-plans:

- Link budget calculation
- Coverage, capacity planning and spectrum efficiency
- Parameter planning

Link Budget Calculations

Link budget (LB) calculations give the loss in the signal strength on the path between the mobile station antenna and base station antenna. And radio link budget (RLB) analysis should be done for both uplink and downlink communications.

Coverage Planning

The objective of coverage planning phase in coverage limited network areas is to find a minimum amount of cell sites with optimum locations for producing the required coverage for the target area. The basic input information for coverage planning includes Coverage regions, coverage threshold values on per regions (outdoor, in-car, indoor), Antenna (tower height limitations), preferred antenna line system specifications, preferred base station specification & activities such as propagation modeling, field strength predictions and measurements are usually referred to as coverage planning.

Capacity Planning

The steps for calculating the network capacity are:

- Find the maximum no of carriers per cell that can be reached for the different regions based on the frequency reuse patterns and the available spectrum.
- Calculate the capacity of the given cell using blocking probability and the number of carriers.
- Finally the sum of all cell capacities gives the network capacity.

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. The frequency plans need to be fine-tuned based on drive test results and network management statistics.

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 [34].

The multi radio access technologies I took in to consideration for my radio network planning in this thesis are GSM, UMTS and LTE.

3.1. GSM Radio Network Planning

In GSM, the network is divided into a lot of cells, and usually a base station 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.

There is one important feature in GSM network planning: the coverage planning and capacity planning are independent. The coverage planning depends on the received signal strength, that is to say, the covered area is nearly only limited by the minimum signal strength at the cell range, while the later capacity planning depends mainly on the frequency allocation.

In GSM 900 system, there are 125 channels in both uplink and downlink, and these channels span the available bandwidth of GSM 900. The frequency is a scare resource in GSM system, and the frequency must be carefully planned to be reused. The frequency reuse factor is defined as the number of base stations that can be implemented between the current base station and the ones before the same frequency is reused. 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.

DCS also known as GSM-1800. The prime reason to use DCS 1800 frequency band was the lack of capacity in the 900-MHZ. The 1800-MHz band can solve capacity issue, and can be deployed in densely populated areas [1, 2, 35].

3.1.1 GSM Coverage Planning

Dimensioning is the main part of the preplanning phase. In addition to the dimensioning parameters the priority of the parameters also needs to be agreed. 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. In this thesis macro cells with three sector sites are considered. When performing tasks related to coverage during network planning, link budget is an important step [35].

Link Budget Calculations

The radio link budget aims to calculate the cell coverage area. When defining the cell coverage area, the aim is to balance the uplink and downlink powers. The links are calculated separately and are different from the transmission powers. The BTS transmission power is higher than the MS transmission power and therefore the reception of the BTS needs to have high sensitivity. One of the required parameters is radio wave propagation to estimate the propagation loss between the transmitter and the receiver.

The purpose of link budget is to analyze the power balance between downlink and uplink through the given system parameters and design parameters.

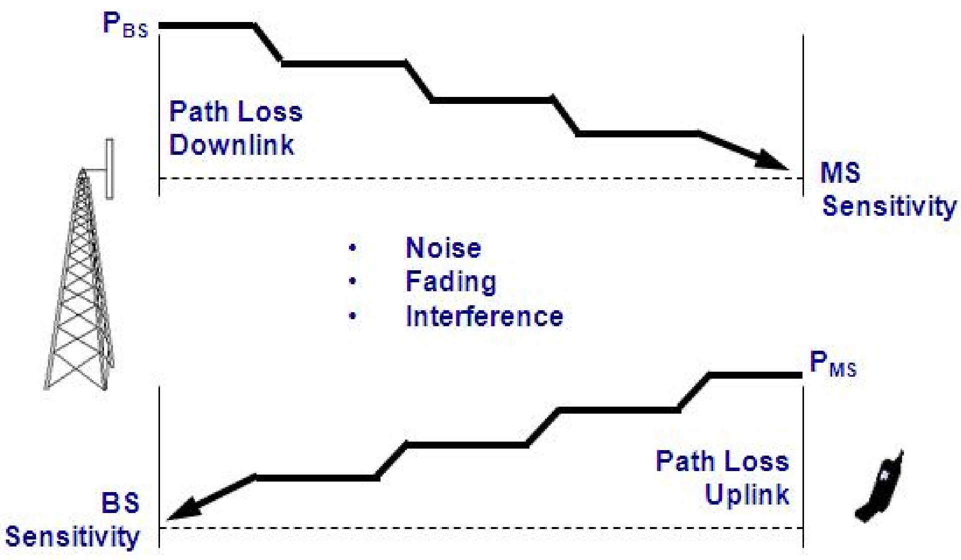

Figure 3.2: A simplified block diagram of link budget calculations

Analysis of link Budget Parameters

The formula of link budget is as follows:

$$Maximum\ allowable\ path\ loss\ (MAPL)$$

$$= TX\ EIRP + RX\ Gains - RX\ Losses\ - Receiver\ Sensitivity - Total\ margins \qquad (3.1)$$

$Where$

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

$$And\ Total\ margins = Slow\ fading\ margin\ + Fast\ fading\ margin + interference\ margin + building\ or\ vehicle\ penetration\ loss$$

The parameters for link budget can be classified into four types: system parameter, transmitter parameters, receiver parameters, and margin reservation.

System Parameters

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

2. **System bandwidth:** In a GSM system, the receiver bandwidth is 200 kHz (that is, 53dBHz)

3. **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: At MS side, according to GSM protocol, the max MS transmission power is 2W (33dBm). The MS transmission power is defined by the MS class in ETSI specifications. For MS class 4 (GSM 900) the maximum TX power is 2W and for class 1 (GSM 1800) 1W.

BTS TX power depends on the BTS type and vendor. The TX power is adjustable, which enables the link budget to be balanced [6].

Antenna gain: For MSs, electronically small antennas are always used. For GSM MSs, unipole antenna and planar inverted-F antennas (PIFA) are always used and the MS antenna has a lower gain, of the order of 0dBi. In the link budget calculations for the MS antenna the gain is generally 0dBi.

The BTS antenna gain can vary from 8dBi to 21dBi depending upon the type of antenna (Omni directional versus directional) being used. This gain can be increased by using various techniques, such as antenna diversity (both uplink and downlink) [1,2,6].

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. In the link budget of voice service, the value is 3dB. In the link budget of data service using data card, the value is 0dB.

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.

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

$$Spectral\ density = kT \quad (3.2)$$
$$= -174\text{dBm/Hz in room temperature (290K)}.$$

Where, k is Boltzmann constant, which equals 1.38 x 10^{-23}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.

$$N_i = kTB \quad (3.3)$$

Where, B is system 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: In link budget of mobile telecommunications, noise figure includes the noise figure of base station receiver and the noise figure of MS receiver. When signals pass a receiver, noise is added to the signal and thus the noise figure is a method to measure the noise addition.

When signals and noises are input to an ideal receiver with no noise, they are equally attenuated or amplified. Thus, the SNR is changed, that is, F = 1 or 0 dB. 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 base station receiver is 8 dB and 10dB for MS receiver.

Receiver Sensitivity: It refers to the minimum signal power which ensures that the receiver input can successfully discern and decode (or retain the required FER) signals, Receiver sensitivity refers to sensitivity of MS receiver and BS receiver. In telecommunications system, receiver sensitivity is given by:

$$Receiver\ sensitivity = noise\ spectral\ density\ (dBm/Hz)$$

$$+ bandwidth\ (dBHz) + noise\ figure\ (dB) + \frac{C}{I}(dB) \qquad (3.4)$$

Or receiver sensitivity (Si): is solved from the following equation, where the input noise power (N_i) is the product of three parameters: Boltzman constant (k); temperature (T_0) = 290K and bandwidth (B) = 200 kHz (53 dB):

$$F = \frac{S_i/N_i}{S_o/N_o} = \frac{S_i/(kT_oB)}{E_b/N_o} \qquad (3.5)$$

Where: $N_i = kT_oB$

$$S_i = \frac{E_b}{N_o} FkT_oB \qquad (3.5a)$$

BTS sensitivity: The sensitivity of the base stations specified on the ETSI (European telecommunication institute) 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.

$$S_i = \frac{E_b}{N_o} FkT_oB \tag{3.6}$$

$$= 8dB + 7dB + (290K \times 1.38 \times 10^{-23} J/K) + 53dB$$

$$= 8dB + 7dB - 174dBm + 53dBm$$

$$= -106dBm$$

MS sensitivity: This factor is dependent upon the receiver noise figure F and minimum level of E_b/N_o (i.e. output signal to noise ratio) needed. This is calculated by using the GSM specifications (ETSI GSM recommendation 05.05). The value for the noise is 10 dB and the minimum E_b/N_0 is 8 dB, as defined in the ETSI recommendation 03.30.

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. In other words, the recommended values of MS sensitivity in GSM 900 and 1800 are -102 dBm and -100 dBm respectively [1,2,6].

$$S_i = \frac{E_b}{N_o} FkT_oW \tag{3.7}$$

$$= 9dB + 10dB + (290K \times 1.38 \times 10^{-23} J/K) + 53dB$$

$$= 9dB + 10dB - 174dBm + 53dBm$$

$$= -102dBm$$

Slow fading margin / Shadow fading margin: Shadow fade is also named 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 areas, the shadow fading standard deviation is about 8 – 10 dB. In suburban and rural areas, the value range is 6 – 8 dB.

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

Edge Coverage Probability: 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.

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 3.3**.

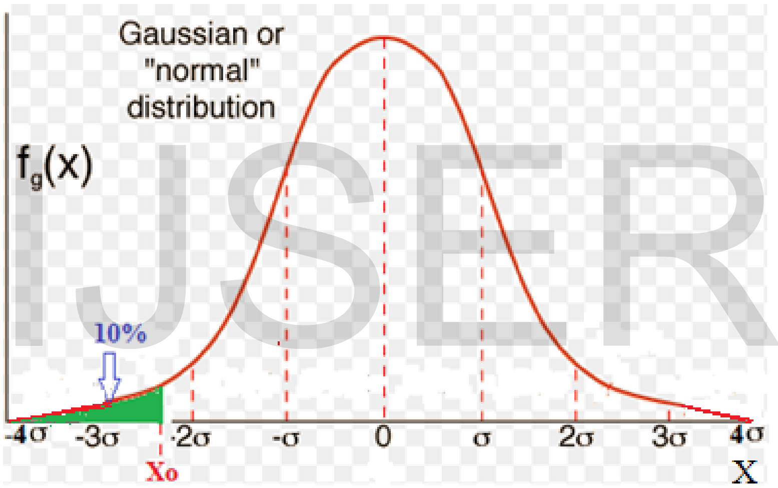

Figure 3.3: Lower tail of normal distribution curve

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

$$\mathcal{P}(r) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{(r-r_m)^2}{2\sigma^2}} \tag{3.8}$$

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. 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 [2,6].

The location probability can be expressed by an equation, which is upper tail probability of **Equation 3.8**. The location probability for upper tail probability can be expressed as follows:

$$\mathcal{P}_{x_0} = \frac{1}{\sqrt{2\pi\sigma}} \int_{-\infty}^{x_0} e^{-\frac{(r-r_m)^2}{2\sigma^2}} dr \tag{3.9}$$

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

$$\mathcal{P}_{x_0} = \frac{1}{\sqrt{2\pi\sigma}} \int_{x_o}^{\infty} e^{-\frac{(r-r_m)^2}{2\sigma^2}} dr \tag{3.10}$$

The location probability can be expressed as well as the lower tail in **Equation 3.10**, 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 [6].

The location probability, slow fading margin (x_o - r_m), maximum path loss and cell range are all connected. The cell range is dependent on the maximum allowed path loss 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 our 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]:

$$\mathcal{P}_{coverage} = \mathcal{P}_r(x < x_o) = \frac{1}{\sqrt{2\pi\sigma}} \int_{-\infty}^{x_0} e^{-\frac{(r-r_m)^2}{2\sigma^2}} dr \tag{3.11}$$

For outdoor environment, 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:

$$x_o - r_m \;=\; 1.29\sigma \;=\; 1.29 \times 8 \;=\; 10.32\; dB \tag{3.12}$$

Table 3.1: 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.

In our GSM network planning and design 10.32 dB margin is reserved to ensure a 90% edge coverage probability.

Area coverage probability: 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. The 90% edge coverage probability corresponds to 95% area coverage probability and shadow fading margin is 10.3dB

Fast fading margin (Rayleigh fading margin): Fast fading 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 produce 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 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. Based on the above link budget parameters the link budget for GSM 900MHz and 1800MHz are summarized in below tables.

Table 3.2: GSM 900 MHz Radio Link Budget General Information

	Scenario		Urban		Suburban		Formula
	Parameter	Unit	UL MS	DL BS	UL MS	DL BS	
Transmitting End	Tx power	W	2	10	2	10	
	Tx power	dBm	33.01	40	33.01	40	a
	Antenna Gain	dBi	0	18	0	18	b
	Cable loss + connector	dB	0	3	0	3	c
	Body Loss	dB	3	0	2	0	d
	EIRP	**dBm**	**30.01**	**55**	**31.01**	**55**	e = a+b-c-d
Receiving End	Antenna gain	dBi	18	0	18	0	f
	Cable loss + connector	dB	3	0	3	0	g
	Body Loss	dB	0	2	0	2	h
	Dual-Polarization Antenna Loss	dB	1	1	1	1	i
	Noise spectral Density, Ni	dBm/Hz	-174	-174	-174	-174	$j = kT$
	Noise Figure	dB	10	7	10	7	k
	Bandwidth (B)	dBHz	53	53	53	53	$l = \log_{10}B$
	C/I (E_b/N_O)	dB	9	8	9	8	m
	Receiver Sensitivity	**dBm**	**-102**	**-106**	**-102**	**-106**	n = j+k+l+m
Margin Reservation	Area Coverage Probability	%	95		95		
	Edge Coverage Probability	%	90		90		
	Slow Fading Standard Deviation	dB	8		7		
	Slow Fading Margin	dB	10.3	10.3	5.93		o
	Fast Fading Margin	dB	5	5	3		p
	Interference Margin	dB	3	3	1		q
	Indoor penetration Loss	dB	4.4	0	0		r
	Sum of Margins	**dB**	**22.7**	**18.3**	**9.93**		s = o+p+q+r
Max. Allowed Path Loss (MAPL)		**dB**	**123.31**	**139.7**	**137.08**	**158**	t = e+f-g-h-i-n-s
Cell Radius	Frequency Band	MHz	900				
	Propagation Model		Okumura-HATA				
	Cell Radius	km	0.817	2.386	2.011	7.897	$u = 10^{[(t-126.4)/35.21]}$
	Cell Radius Output	km	0.817		2.011		

Selected radius

Table 3.3: GSM 1800 (DCS) Radio Link Budget General Information

	Scenario		Urban		Suburban		Formula
	Parameter	Unit	UL MS	DL BS	UL MS	DL BS	
Transmitting End	Tx power	W	2	20	2	20	
	Tx power	dBm	33	43.01	33	43.01	a
	Antenna Gain	dBi	0	18	0	18	b
	Cable loss + connector	dB	0	2	0	2	c
	Body Loss	dB	3	0	3	0	d
	EIRP	**dBm**	**30**	**59.01**	**30**	**59.01**	e = a+b-c-d
Receiving End	Antenna gain	dBi	18	0	18	0	f
	Cable loss + connector	dB	2	0	2	0	g
	Body Loss	dB	2	3	0	3	h
	Dual-Polarization Antenna Loss	dB	1	0	1	0	i
	Noise spectral Density, Ni	dBm/Hz	-174	-174	-174	-174	j = *kT*
	Noise Figure	dB	5	7	10	7	k
	Bandwidth (B)	dBHz	53	53	53	53	$l = \log_{10}B$
	C/I (E_b/N_O)	dB	11	8	11	8	m
	Receiver Sensitivity	**dBm**	**-105**	**-106**	**-100**	**-106**	n = j+k+l+m
Margin Reservation	Area Coverage Probability	%	95		95		
	Edge Coverage Probability	%	90		90		
	Slow Fading Standard Deviation	dB	8		7		
	Slow Fading Margin	dB	10.3	10.3	5.93		o
	Fast Fading Margin	dB	2	5	1		p
	Interference Margin	dB	3	3	1		q
	Indoor penetration Loss	dB	0	0	0		r
	Sum of Margins	**dB**	**10.3**	**8**	**2**		s = o+p+q+r
Max. Allowed Path Loss (MAPL)		**dB**	**132.7**	**143.71**	**137.07**	**162**	t = e+f-g-h-i-n-s
Cell Radius	Frequency Band	MHz	1800				
	Propagation Model		Okumura-HATA				
	Cell Radius	km	0.789	1.621	1.050	5.366	$u = 10^{[(t-136.32)/35.21]}$
	Cell Radius Output	km	0.789		1.050		

Selected radius

As can be seen, there is an obvious difference in the results of the uplink and downlink power budget calculations, where the downlink path loss exceeds the uplink path loss.

This is an indication that the area covered by the base station antenna is more than the area covered by the mobile station antenna, thereby giving more coverage in the downlink direction.

Propagation Model Selection

Based on the simulation results of propagation model comparison in section 2.3.5, 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.

Cell Radius Calculation for GSM 900 MHz

From **equation (2.7)**, the Okumura-Hata model for path loss prediction is given by

$$PL = A + B\,log_{10}(f) - 13.82\,log_{10}(Hb) - a(Hm) + [44.9 - 6.55\,log_{10}(Hb)]log_{10}(d) + L_{other}$$

- $A = 69.55$
- $B = 26.16$
- $log_{10}(f) = log_{10}(900) = 2.954$
- $Blog_{10}(f) = 26.16 \times 2.954 = 77.276$
- $13.82\,log_{10}(H_b) = 13.82\,log_{10}(30) = 20.41$
- $a(H_m) = [1.1\,log_{10}(f) - 0.7]H_m - [1.56\,log_{10}(f) - 0.8]$
  $= [(1.1 * 2.954) - 0.7] * 1.5 - [(1.56 * 2.954) - 0.8] = 0.016$
- $[44.9 - 6.55\,log_{10}(Hb)]\,log10(d) = [44.9 - 6.55\,log_{10}(30)]\,log_{10}(d)$
  $= [44.9 - (6.55 * 1.48)]\,log_{10}(d)$
  $= 35.21\,log_{10}(d)$
- L_{other}

$$PL = A + B\,log_{10}(f) - 13.82\,log_{10}(Hb) - a(Hm) + [44.9 - 6.55\,log_{10}(Hb)]log_{10}(d) + L_{other}$$

$$= 69.55 + 77.276 - 20.41 - 0.016 + 35.21\,log_{10}(d)$$

$$PL = 126.4 + 35.21\,log_{10}(d)$$

$$d_{900MHz(km)} = 10^{[(PL-126.4)/35.21]} \quad (3.13)$$

Cell Radius Calculation for DCS 1800 MHz

$$PL = A + B\, log_{10}(f) - 13.82\, log_{10}(Hb) - a(Hm) + [44.9 - 6.55\, log_{10}(Hb)]\, log_{10}(d) + L_{other}$$

- $A = 46.30$
- $B = 33.90$
- $log_{10}(f) = log_{10}(1800) = 3.26$
- $Blog_{10}(f) = 26.16 \times 3.26 = 110.51$
- $13.82\, log_{10}(H_b) = 13.82\, log_{10}(30) = 20.45$
- $a(H_m) = [1.1\, log_{10}(f) - 0.7]H_m - [1.56\, log_{10}(f) - 0.8]$
  $= [(1.1 * 3.26) - 0.7] * 1.5 - [(1.56 * 3.26) - 0.8] = 0.04$
- $[44.9 - 6.55\, log_{10}(Hb)]\, log10(d) = [44.9 - 6.55\, log_{10}(30)]\, log_{10}(d)$
  $= [44.9 - (6.55 * 1.48)]\, log_{10}(d)$
  $= 35.21\, log_{10}(d)$
- L_{other}

$PL = 46.30 + 110.51 - 20.45 - 0.04 + 35.21\, log_{10}(d)$

$PL = 136.32 + 35.21\, log_{10}(d)$

$=> log_{10}(d) = (PL - 136.32) / 35.21$

$$d_{1800MHz(km)} = 10^{[(PL-136.32)/35.21]} \quad (3.14)$$

Determining the Number of BTS's

For this thesis work, tri-sector cells in a single base station are considered to provide precise coverage for the selected regions. The coverage area of the tri-sector base station is determined using the following formula [1, 2].

Site coverage area,

$$A = \frac{9\sqrt{3}}{8} d^2 = 1.95d^2 \quad (3.15)$$

Where A is maximum area covered by a single base station and

d is radius of single cell

We can now predict the coverage per base station using **equation (3.15)**. Thus the computed cell radius is 0.817 km for urban and 2 km for suburban.

Therefore the coverage area of a single site for urban and sub urban are 4.45 km^2 and 1.304 km^2 respectively, hence from the coverage perspective, we need 23 base stations for urban and 22 base station for suburban area. Totally 45 GSM 900MHz base stations are required for the entire 200 km^2 area of Bahir Dar city.

3.1.2 GSM Capacity Planning

GSM Subscriber Analysis and demand forecast

Population of Bahir Dar city: Bahir Dar city is structured in 9 "Kifle Ketemas" and the central statistical agency (CSA) conducted census per five year basis. We took the data from Bahir Dar city Municipality and CSA. Both CSA and Bahir Dar Municipality data include Tis abay, Zegie and Meshenti population as part of Bahir Dar city. And I figure out the population inside the city only. At this time all the "Kifle Ketemas" started exact registration about the city population by a section called "Wesagn Kunetoch" and this will help in providing better information for future population analysis.

Table 3.4 presents the CSA data and existing ethio telecom network users to define the demographics of Bahir Dar city. CSA conducted census in the year 2006/2007 and 2011/2012 and its result and the growth rate of population and current mobile network user are all shown. In this thesis we consider users in the age of 15 to 65 years old.

Table 3.4: Bahir Dar city CSA demographic & Mobile Network Subscriber data

Items	15-65 Age group	Notes
2006/2007 population	122,468	a, from CSA Data
2011/2012 population	190,220	b, from CSA Data
Population growth rate	0.64	c = a / b
2016/2017 population	312688	d = b + c x b
2015 current Mobile user	192,047	e , from ethio telecom current VLR user
Current market penetration	0.61	f = e / d
Expected 2021/2022 Mobile user	309,999	g = e + f x e

Area of Bahir Dar city: In this thesis work, Bahir Dar is assumed to have urban and suburban region and according to Bahir Dar Municipality office, the area of Bahir Dar City including satellite towns Zegie, Tis Abay, Hamusit and Zenzelima is 28,660 Hectare. But my thesis focusses on Bahir Dar city including Yibab and Zenzelima only, and these area is 20,000 Hectare.

Note that 1 Hectare = 10,000 square meters. So the area of Bahir Dar City including Yibab and Zenzelima is 200 square kilometers.

Table 3.5: Forecasted Subscribers for GSM

City	Current Subscribers	Forecasted Subscribers	Planned
Bahir Dar	192,047	309,999	316,356

GSM voice Traffic Intensity Calculation

Average traffic intensity offered (generated) by each individual user (in erlang).

$$A_v = H \times \lambda \qquad (3.16)$$

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

In this thesis design we used erlang B channel allocations for cells and 2% GOS (grade of service) for voice traffic modeling. GOS is a measure of the ability of a user to access the trunked system at the busiest hour. So we can use it as an input and calculate individual voice traffic intensity in erlang.

Currently ethio telecom use 20 milli erlang individual traffic intensity for main regional cities as a standard, Based on this in our thesis design, we assume a user makes on average two call per hour, and that a call lasts an average of 90 seconds per call and individual voice traffic intensity can be calculated using **equation (3.16)**.

$$A_v = {}^{2\ calls}/_{3600\ seconds} \times {}^{45\ seconds}/_{call}$$

$$A_v = 0.025\ erlang\ or\ 25\ milli\ erlang$$

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Configuration Dimension for Bahir Dar City

Based on the above inputs we have developed the below tables upon which the capacity dimensioning was carried on. Based on ErlangB table and subscriber analysis, the configuration can be listed as follows and **table 3.6** shows the number of supported subscribers per each configuration.

Table 3.6: GSM Configuration Result (Erlang & Subscriber per site)

Configuration	BCCH per cell	SDCCH per cell	Static PDCH /cell	Dynamic PDCH/cell	TCH/ sector	Erl/ user	Erl/ sector	Erl/ site	Subs/ Site
S111	1	1	2	2	4	0.025	1.092	3.276	131.04
S222	1	1	2	2	12	0.025	6.6	19.8	792
S333	1	2	2	2	19	0.025	12.3	36.9	1476
S444	1	2	3	3	26	0.025	18.4	55.2	2208
S555	1	3	3	3	33	0.025	24.6	73.8	2952
S666	1	3	3	3	41	0.025	31.9	95.7	3828
S777	1	3	4	3	48	0.025	38.4	115.2	4608
S888	1	4	4	3	55	0.025	44.9	134.7	5388
S999	1	4	4	3	63	0.025	52.48	157.44	6297.6
S101010	1	4	4	3	71	0.025	60.08	180.24	7209.6
S111111	1	4	4	3	79	0.025	67.73	203.19	8127.6
S121212	1	4	4	3	87	0.025	75.42	226.26	9050.4

Table 3.7: Final GSM Configurations

Final Configuration	No. of Sites	Final Subscriber No. Calculation
G333+D888	8	44,280
G444+D999	20	170,100
G555+D888	5	41,700
G555	12	44,280
Total	45	310,992

Out of 45 GSM 900MHz sites, we add GSM1800 MHz on the 20 urban sites and 13 sub-urban sites by considering the capacity requirement of our design.

3.1.3 GSM Frequency Planning

Frequency resource is scarce for the mobile communication, so how to maximize the spectrum utilization ratio is a great concern for many carriers, equipment providers, and scholars. And their research into this problem has accelerated the development of the communication technologies. The purpose to enhance the spectrum utilization ratio is to expand the network capacity based on the limited spectrum resource while ensuring the network quality. If not considering adding frequencies to the network, you can expand the capacity of a GSM network using the two methods. One is to increase the number of base stations in the network; the other is to use the frequency reuse technologies. This chapter mainly describes the GSM frequency reuse technologies, namely, frequency planning technologies.

To expand the network capacity, you must reuse the limited frequency resources. Though frequency reuse is beneficial for network expansion, it brings into another problem. That is, it deteriorates the conversation quality. The more aggressive the frequencies are reused, the greater the interference will arise in the network. Therefore, how to seek a balance between network capacity and conversation quality is a demanding task in frequency planning.

For the 4 x 3 frequency reuse pattern, the frequency utilization ratio is relatively low, but the higher carrier-to-interference ratio (C/I) can be obtained, so we can enjoy better conversation quality. Compared with the 4 x 3 frequency reuse pattern, the 1 x 3 frequency reuse pattern ensures a relatively high frequency utilization ratio, but the reuse distance is shorter, so interference is greater and the conversation quality is poorer. In this case, you should take some measures, such as the frequency hopping and DTX, against the interference.

The frequency planning is a key technology for GSM network, so the quality of the frequency planning will determine the network quality.

Frequency Division and C/I Requirement

Frequency Division: The GSM cellular system can be divided into GSM 900MHz system and DCS 1800MHz system in terms of the band to be used. The carrier spacing is 200 KHz.

GSM 900MHz

In GSM 900 there are two frequency bands, one for uplink (890.2-915 MHz) and the other for downlink (935.2-960 MHz). Both are at a distance of 20 MHz from each other.

Frequencies are expressed by channel numbers 1 to 124 (the so called ‘ARFCN’ = Absolute Radio Frequency Number). Channel numbers are used in messages instead of explicit frequencies. If the ARFCN = n is known the absolute frequency can be calculated by

- for the downlink: F(DL) = (935.2 + 0.2*(n-1) MHz,
- for the uplink: F(UL) = (890.2 + 0.2*(n-1) MHz

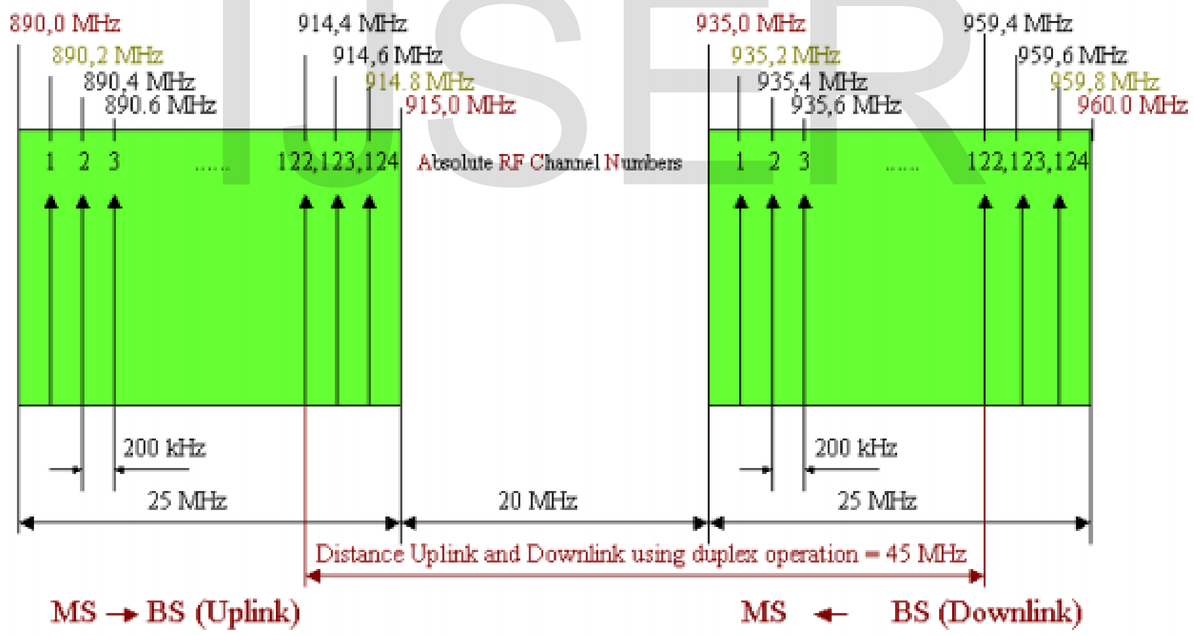

Figure 3.4: Frequency Spectrum of GSM 900 MHz

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DCS 1800MHz

In the Digital Communication System 1800 there are the frequencies uplink (1710-1785 MHz) and downlink (1805-1880 MHz). It has 374 channel numbers. The ARFCN is 512 - 885. The relationship between the frequency and the channel number (n) are listed in the following:

- for the downlink: F(DL) = (1805.2 + 0.2*(n-512) MHz,
- for the uplink: F(UL) = (1710.2 + 0.2*(n-512) MHz

Table 3.8: GSM Spectrum Information

System		GSM 900	GSM 1800
Frequencies:	Uplink	890 - 915 MHz	1710 -1785 MHz
	Downlink	935 - 960 MHz	1805 - 1880 MHz
Wavelength		~33cm	~17cm
Bandwidth		25 MHz	75 MHz
Duplex Distance		45MHz	95 MHz
Carrier Separation		200KHz	200 KHz
Radio Channels		125	375
Transmission Rate		270kbits/s	270kbits/s

Carrier to Interference ratio (C/I)

In the GSM system, frequency reuse will cause intra-frequency interference. The intra-frequency is related to both the reuse distance and the cell radius.

Frequency Division and C/I Requirement

Generally, the 4 x 3 frequency reuse pattern is used in GSM frequency planning. For the areas where the traffic is great, you can use other frequency reuse patterns, such as 3 x 3 and 1 x 3.

In the GSM system, the requirements on the C/I are listed in the following:

- For intra-frequency C/I, it must be equal to greater than 9 dB. In actual projecting, a margin of 3 dB is needed, namely, it is equal to or greater than 12 dB.
- For adjacent-frequency C/I, it must be equal to or greater than -9 dB. In actual projecting, a margin of 3 dB is needed, namely, it is equal to or greater than -6 dB.

The purpose the frequency planning is to reach a balance between the frequency utilization ratio and the network capacity. Based on the assurance of the network quality, you must take measures to maximize the network capacity.

In the GSM system, the 4 x 3 frequency reuse pattern is in basic use. Here "4" indicates 4 base stations, and "3" indicates the 3 cells under the control of each base station. Therefore, there are 12 sectors are available. And the 12 sectors makes up of a frequency reuse cluster, but the frequency in the same cluster cannot be reused.

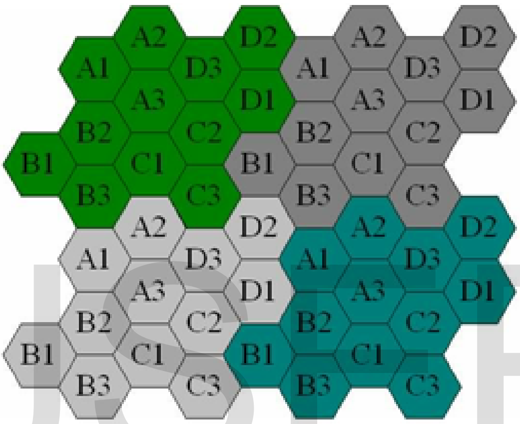

Figure 3.5: Normal 4 x 3 frequency reuse pattern

For the 4 x 3 frequency reuse pattern, the intra-frequency spacing is great, so it can meet GSM system's requirement on the intra-frequency interference protection ratio and adjacent frequency interference protection ratio. As a result, this frequency reuse pattern is good for the network quality and security. **Figure 3.5** shows the normal 4 x 3 frequency reuse pattern

Frequency Channel Allocation:

In GSM systems we divide the total allocated spectrum in to two sub-groups one for control information with traffic referred to as BCCH frequency and other only for traffic referred to as TCH (or non-BCCH) frequency.

Frequency Planning Details

For our thesis design, we took a spectrum of 12 MHz for 900MHz, for each UL and DL communication, for GSM 1800MHz we used 21.6 MHz for each UL and DL, besides 20 MHz for LTE 1800 MHz.

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By taking in to consideration our capacity planning in **tables 3.6 and 3.7**, we select 4x3 frequency reuse to be adopted for BCCH and TCH.

1) GSM900 Frequency Planning, totally 60 frequencies
    - BCCH: 4x3 frequency reuse, totally 12 channel
    - TCH: 4x3 frequency, totally 36 frequencies
    - SDCCH, static and dynamic PDCH: 4x3 frequency reuse, totally 64 channels.
    - Standby: 14 frequencies
    - The maximum configuration for continuous coverage is S555
2) GSM1800 Frequency Planning, totally 108 frequencies
    - BCCH: 4x3 frequency reuse, totally 12 channels
    - TCH: 4x3 frequency, totally 89 frequencies
    - SDCCH, static and dynamic PDCH: 4x3 frequency reuse, totally 363 channels.
    - Standby: 13 frequencies
    - The maximum configuration for continuous coverage is S999

As the name implies, 4 x 3 reuse divides the available frequency into 4 x 3 = 12 groups, which are tagged as A1, B1, C1, D1, A2, B2, C2, D2, A3, B3, C3, and D3, as shown in the following tables:

Assign A1, A2, and A3 as a group to three sectors of a base station. Assign B1, B2, and B3 as a group, C1, C2, and C3 as a group, and D1, D2, and D3 as a group to three sectors of an adjacent base station. Obviously, the following frequency reuse patterns are available:

Table 3.9: GSM 900 MHz Frequency Planning

Bandwidth	**Planned Sector Frequencies**											
	A1	B1	C1	D1	A2	B2	C2	D2	A3	B3	C3	D3
	60	61	62	63	62	65	66	67	68	69	70	71
	72	73	74	75	76	77	78	79	80	81	82	83
12MHz	84	85	86	87	88	89	90	91	92	93	94	95
	96	97	98	99	100	101	102	103	104	105	106	107
	108	109	110	111	112	113	114	115	116	117	118	119

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Table 3.10: DCS 1800 MHz Frequency Planning

Bandwidth	Planned Sector Frequencies											
	A1	B1	C1	D1	A2	B2	C2	D2	A3	B3	C3	D3
21.6MHz	767	768	769	770	771	772	773	774	775	776	777	778
	779	780	781	782	783	784	785	786	787	788	789	790
	791	792	793	794	795	896	797	798	799	800	801	802
	803	804	805	806	807	808	809	110	811	812	113	814
	815	816	817	818	819	920	821	822	823	824	825	826
	827	828	829	830	831	832	833	834	835	836	837	838
	839	840	841	842	843	844	845	846	847	848	849	850
	851	852	853	854	855	856	857	858	859	860	861	862
	863	864	865	866	867	868	869	870	871	872	873	874

Hence the frequency assignment per site per sector for both GSM 900 MHz and 1800 MHz are listed in **tables 3.11 and 3.12** below.

Table 3.11: Final frequency per site for 900MHz

BCCH	40, 41, 41, 43, 44, 45, 46, 47, 48, 49, 50, 51
A	60, 72, 84, 96, 108, 62, 76, 88, 100, 112, 68, 80, 92, 104, 116
B	61, 73, 85, 97, 109, 65, 77, 89, 101, 113, 69, 81, 93, 105, 117
C	62, 74, 86, 98, 110, 66, 78, 90, 102, 114, 70, 82, 94, 106, 118
D	63, 75, 87, 99, 111, 67, 79, 91, 103, 115, 71, 83, 95, 107, 119

Table 3.12: Final frequency per site for 1800MHz

BCCH	740, 741, 742, 743, 744, 745, 746, 747,748, 749, 750,751
A	767, 779, 791, 803, 815, 827, 839, 851, 863, 771, 783, 795, 807, 819, 831, 843, 855, 867, 775, 787, 799, 811, 823, 835, 847, 859, 871
B	768, 780, 792, 804, 816, 828, 840, 852, 864, 772, 784, 896, 808, 920, 832, 844, 856, 868, 776, 788, 800, 812, 824, 836, 848, 860, 872
C	769, 781, 793, 805, 817, 829, 841, 853, 865, 773, 785, 797, 809, 821, 833, 845, 857, 869, 777, 789, 801, 113, 825, 837, 849, 861, 873
D	770, 782, 794, 806, 818, 830, 842, 854, 866, 774, 786, 798, 110, 822, 834, 846, 858, 870, 778, 790, 802, 814, 826, 838, 850, 862, 874

3.2. WCDMA Radio Network Planning

The main procedures of UMTS are very similar to that of GSM, and the coverage and capacity planning play also important roles in the whole radio network planning. They are both strongly related, and the coverage is a function of the capacity. Since UMTS is interference limited, a big number of users will reduce the power availability at the base station to combat interference, and therefore reduce the cell site in what is called the cell breathing effect. Here we will emphasize on the different points in which UMTS planning distinguishes itself from GSM planning.

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. UMTS uses WCDMA as its multiplex access method, which determines that the interference plays an essential role in the coverage planning and capacity planning.

The cell size in UMTS is not fixed. When the interference arises, the SIR deteriorates, which makes the mobile equipment at the old cell fringe hard to communicate with the base station. So the cell size shrinks. The resulting swinging of the cell size in UMTS due to the changing interference is called "cell breathing". The network upper capacity limit can also be easily reached when too much interference leads to the limit of the power at the base station through the mechanism of power control loop. So in UMTS the coverage planning and capacity planning cannot be independently made like in GSM, they are closely correlated. The higher the coverage, the lower is the capacity, and vice versa [11, 12, 13].

Adaptive Multi-rate (AMR)

Unlike in GSM, where speech codes are fixed - e.g. FR or HR and their channel protection is also fixed rate, in WCDMA radio networks the process of 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.

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 BTS are involved.

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 DCH. This process is known as link adaptation. Thus, by using AMR, speech, coverage and quality performance can be improved [14, 15].

3.2.1 WCDMA Coverage Planning

The main aim of this WCDMA radio network planning in the case of Bahir Dar city is to perform a cost effective result for the radio network deployment in terms of; coverage area, capacity and QoS such as estimating the optimum number of base stations and its location, determining the type of the antenna, the receiver or transmitter power and the characteristics of the propagation environment. The radio network planning process and design criteria vary from place to place depending up on the dominating factor, which could be capacity or coverage. WCDMA radio network planning includes dimensioning, detail coverage and capacity planning, frequency and scrambling code planning.

The link budgets here are intended to form an input to the radio network planning process belonging to UMTS FDD macro cells for Bahir Dar city. The link budgets are used to define path loss thresholds, which form an input to the radio network planning tool when evaluating radio bearer coverage across a geographic area of interest.

This section presents the approach used for the link budget analysis and discusses the various system, transmitter and receiver parameters.

Chip and information rates: The system chip rate is 3.84 Mchips/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 HSPA.

The processing gain is defined by the equation:

$$\text{Processing Gain} = 10 \times \log\left(\frac{\text{Chip Rate}}{\text{Bit Rate}}\right) \tag{3.17}$$

UE velocity: is an important parameter as it impacts the uplink and downlink E_b/N_o requirements. The E_b/N_o 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_o value is now affected by the interleaving performance [11,16,37].

Transmit power: The Node B transmitter power represents the maximum transmit power that can be assigned to a single connection.

The maximum UE transmit power for voice terminals is specified as 21dBm while for data terminals (> 64kbps) the maximum power is 40dBm.

Note the data terminal may have positive antenna gain and somebody loss but is assumed to have a net gain of 0dB [37].

EIRP: The EIRP represents the effective isotropic radiated power from the transmitter antenna. In the case of the uplink it is computed from the equation:

$$EIRP_{UL} = UE\ Transmitter\ Power + UE\ Antenna\ Gain - UE\ Body\ Loss$$

For the downlink it is computed from the equation:

$$EIRP_{DL} = NodeB\ Transmitter\ Power + NodeB\ Antenna\ Gain - Cable\ loss - Connector\ Loss \qquad (3.18)$$

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

Spectral density of thermal noise is kT. It is -174dBm/Hz in room temperature (300K).

$$N = kT$$

$$= 1.38\,x\,10^{-23} \times 290{,}000 = 4.002\,x\,10^{-23}$$

$$N_{dB} = 10\,log_{10}(4.002\,x\,10^{-23}) = -174\ dBm/Hz$$

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

$$B_{dB}\ per\ Chip\ rate_{dB} = 10\,log_{10}(3.84 \times 10^{6}) = 65.84$$

Thermal noise power: the thermal noise density is computed from the equation:

$$\text{Thermal Noise Power} = \text{Boltzman's Constant} \times \text{Temperature} \times \text{Bandwidth}$$

$$N_i = kTB \quad (3.19)$$

Where, k is Boltzmann constant, which equals 1.38 x 10^{-23}J/K, T is absolute temperature (T_o=290K), and B is system bandwidth.

$$N_{i\ chiprat/s} = 1.38\ x\ 10^{-23} \times 290{,}000 \times\ 3.84\ \times 10^{6}$$

$$= 1.54 \times 10^{-11}$$

$$N_{i(dB)} = 10\ log_{10}(kT_oB\ )$$

$$= N_{dB} + B_{dB}$$

$$= -108.16\ dBm$$

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

$$Receiver\ Noise\ Power = Thermal\ Noise\ Power + Noise\ Figure$$

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 bandwidth [1].

Receiver thermal sensitivity - The receiver thermal sensitivity is computed according to the equation:

$$Receiver\ thermal\ sensitivity\ = \ Effective\ noise\ power + Required\ {}^{E_b}/_{N_o} - Processing\ Gain \quad (3.20)$$

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 base stations, soft handoff results in a reduction of the required slow fading margin. In addition, soft handoff provides gain against fast fading by reducing the required E_b/N_o. Typical values for soft handoff gain are around 2-4dB [37].

Loading Effect

Interference from neighboring cells has an impact on the cell's performance. This is also known as cell loading, and the parameter to describe this is the loading factor. Owing to this loading, degradation in the link budget takes place, also known as interference degradation. If the loading factor is α, then the interference degradation margin can be calculated as:

$$L = 10log_{10}(1-\alpha) \tag{3.21}$$

Theoretically, the parameter α may vary from zero to 100%, but practically it is in the range 40-50% [12,13,37].

Loading Factor and interference margin

The coverage and capacity of CDMA systems are closely related due to the use of the same frequency and sharing of power. As the cell load increases, more interference is generated in the system resulting in a reduced coverage area. The increase and reduction in coverage area as a result of the loading is known as cell breathing/shrinking and must be taken into account when dimensioning the system.

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

$$Interference\ margin = 10 \times log\left(\frac{1}{1-load\ factor}\right) \tag{3.22}$$

Based on this equation, for a cell load of 50%, the interference margin is 3dB.

As coverage is generally uplink limited, the assumed uplink 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.

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

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 require appropriate headroom in the UE transmission power. In the current link budget, 2-3 dB is used [19,37].

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 and circuit switched 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 uplink and downlink.

Uplink and downlink load factors are assumed based upon the traffic density expectation. The transmit EIRP and receiver sensitivities are calculated as are the net gains and losses of the radio link. Finally the maximum allowed path loss is computed for both the uplink and downlink. The uplink is generally the limiting link in terms of radio bearer coverage. Nevertheless the downlink is checked to verify this assumption.

Table 3.13: 3G Link Budget Formula

	Parameter	Units	Formula
System Parameters	Environment		Pedestrian / Vehicular
	Mobile Velocity		3kmph / 120kmph
	Service		Service Type
	Information bit rate	kbps	a
	Chip rate	Mchip/s	b
Transmitter Characteris	Max. mobile transmission power	dBm	c
	UE Antenna gain	dBi	d
	UE Body loss	dB	e
	EIRP	**dBm**	f = c + d - e
Receiver Characteristics	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	$l = k + 10\times\log_{10}(3840000)$
	Receiver noise figure	dB	m
	Receiver noise power	dBm	n = l + m
	Processing gain	dB	$o = 10\times\log_{10}(3840/a)$
	Required E_b/N_o	dB	p
	Receiver Sensitivity	**dBm**	q = p - o + n
	Mean Noise Rise/ Device Noise	dB	r
	Loading factor		$s = 1-[10^{(-r/10)}]$
Margin Reservation	Coverage area reliability	%	
	Standard deviation	dB	
	Log-normal fading margin/Shadow Fading Margin	dB	t
	Fast fading margin/Power control headroom	dB	u
	Interference margin	dB	v
	Indoor Penetration Loss	dB	w
MAPL & Cell Radius	**Max. Allowable Outdoor Path Loss**	**dB**	x = f+g+h-i-j-q-x-t-u-v
	Frequency Band	MHz	
	Propagation Model		
	UE/NodeB Antenna Height	m	
	Outdoor Coverage Cell Radius	km	$y = 10^{[(x-136.32)/35.21]}$
	Cell Radius Output	km	
	Max. Allowable Indoor Path Loss	**dB**	z = x - w
	Indoor Coverage Cell Radius	km	$z_1 = 10^{[(z-136.32)/35.21]}$
	Cell Radius Output	km	

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Table 3.14: R99 and HSPA Radio Link Budget General Information (12.2kbps & 64kbps LB)

Parameters	Units	UL UE	DL NodeB	UL UE	DL NodeB
Service		Speech	Speech	LCD64	LCD64
Information bit rate	kbps	12.2	12.2	64	64
Chip rate	Mchip/s	3.84	3.84	3.84	3.84
Max. UE transmission power	dBm	21	25	25	25
TX Antenna gain	dBi	0	18	0	18
Cable, Body and connector loss	dB	2	2	2	2
EIRP	**dBm**	**19**	**41**	**23**	**41**
RX Antenna gain	dB	18	0	18	0
Soft handover gain	dB	4	3	3	3
Cable, Body and connector loss	dB	2	3	2	2
Thermal Noise Spectral Density	dBm/Hz	-174	-174	-174	-174
Thermal Noise Power	dBm/Hz	-108.16	-108.16	-108.16	-108.16
Receiver noise figure	dB	7	5	3	3
Receiver noise power	dBm	-101.16	-103.16	-105.16	-105.16
Processing gain	dB	24.98	24.98	17.78	17.78
Required E_b/N_o	dB	3	3	3	3
Receiver Sensitivity	**dBm**	**-123.14**	**-125.14**	**-119.94**	**-119.94**
Mean Noise Rise/ Device Noise	dB	3	3	3	3
Loading factor		0.50	0.50	0.50	0.50
Coverage area reliability	%	95	95	95	95
Standard deviation	dB	10	10	10	10
Shadow Fading Margin	dB	4	4	4	3
Fast Fading Margin	dB	3	3	3	3
Interference margin	dB	3	3	3	2
Indoor Penetration Loss	dB	8	10	8	8
Max. Allowable Outdoor Path Loss	**dB**	**152.14**	**156.14**	**151.94**	**153.94**
Frequency Band	MHz	1950	2140	1950	2140
Propagation Model		Cost 231 - HATA		Cost 231 - HATA	
UE/NodeB Antenna Height	m	1.5	30	1.5	30
Outdoor Coverage Cell Radius	km	2.504	3.253	2.472	2.817
Cell Radius Output	km	2.504		2.472	
Max. Allowable Indoor Path Loss	**dB**	**144.14**	**146.14**	**143.94**	**145.94**
Indoor Coverage Cell Radius	km	1.585	1.653	1.565	1.632
Cell Radius Output	km	1.585		1.565	

(128kbps, 384kbps, HSUPA & HSDPA LB continued)

Parameters	Units	UL UE	DL NodeB	UL UE	DL NodeB	UL UE	DL NodeB
Service		LCD128	LCD128	LCD384	LCD384	**HSUPA**	**HSDPA**
Information bit rate	kbps	128	128	384	384	600	800
Chip rate	Mchip/s	3.84	3.84	3.84	3.84	3.84	3.84
Max. NodeB TX power	dBm	24	25	24	25	30	40
TX Antenna gain	dBi	0	18	0	18	0	18
TX losses	dB	0	0	0	0	0	0
EIRP	**dBm**	**24**	**43**	**24**	**43**	**30**	**58**
RX Antenna gain	dB	18	0	18	0	18	0
Soft handover gain	dB	4	4	3	3	3	2
RX losses	dB	2	0	2	0	2	0
Noise Spectral Density	dBm/Hz	-174	-174	-174	-174	-174	-174
Thermal Noise Power	dBm/Hz	-108.16	-108.16	-108.16	-108.16	-108.16	-108.16
Receiver noise figure	dB	3	3	3	3	3	3
Receiver noise power	dBm	-105.16	-105.16	-105.16	-105.16	-105.16	-105.16
Processing gain	dB	14.77	14.77	10	10	8.0618	6.81241
Required E_b/N_o	dB	4	4	3	4	4	4
Receiver Sensitivity	**dBm**	**-115.93**	**-115.93**	**-112.16**	**-111.16**	**-109.22**	**-107.97**
Device Noise	dB	3	3	3	3	3	3
Loading factor		0.50	0.50	0.50	0.50	0.50	0.50
Coverage area reliability	%	95	95	95	95	95	95
Standard deviation	dB	10	10	10	10	10	10
Shadow Fading Margin	dB	4	4	3	2	2.65	3
Fast Fading Margin	dB	2	2	2	2	2	3
Interference margin	dB	2	2	2	2	2	4
Indoor Penetration Loss	dB	8	9	5	6	8	13.5
Max. Allowable Outdoor Path Loss	**dB**	**151.93**	**154.93**	**148.16**	**151.16**	**151.57**	**157.97**
Frequency Band	MHz	1950	2140	1950	2140	1950	
Propagation Model		Cost 231 - HATA		Cost 231 - HATA		Cost 231 - HATA	
Antenna Height	m	1.5	30	1.5	30	1.5	30
Outdoor Cell Radius	km	2.470	3.006	1.930	2.349	2.413	3.617
Cell Radius Output	km	2.470		1.930		2.413	
Max. Allowable Indoor Path Loss	**dB**	**143.93**	**145.93**	**143.16**	**145.16**	**143.57**	**144.47**
Indoor Cell Radius	km	1.564	1.631	1.487	1.551	1.430	1.482
Cell Radius Output	km	1.564		1.487		1.430	

Selected Radius

Propagation Model Selection

Based on the simulation result of propagation model comparison in for UMTS 2100 MHz COST-231 HATA propagation model is selected by comparing with Welfisch Ikagami, because it reads the maximum path loss at the calculated cell radius, so COST-231 HATA propagation model is selected by considering the worst case scenario for better radio network planning.

Cell Radius Calculation for UMTS 2100 MHz

From **equation (2.8)**, the COST-231 HATA model for path loss prediction is given by:

$$PL_{dBm} = 46.3 + 33.9log_{10}(f) - 13.82log_{10}(h_b) - ah_m$$

$$+ [44.9 - 6.55log_{10}(h_b)]log_{10}(d) + c_m$$

- $A = 46.3$
- $33.9\ log_{10}(f) = 33.9\ log_{10}(2100) = 33.9 * 3.32 = 112.55$
- $13.82\ log_{10}(h_b) = 13.82\ log_{10}(30) = 13.82 * 1.48 = 20.45$
- $ah_m = [1.11\ log_{10}(f) - 0.7]h_r - [1.5\ log_{10}(f) - 0.8]$
  $= [(1.11 * 3.32) - 0.7] * 1.5 - [(1.5 * 3.32) - 0.8] = 0.3$
- $[44.9 - 6.55\ log_{10}(h_b)]\ log_{10}(d) = [44.9 - 6.55\ log_{10}(30)]\ log_{10}(d)$
  $= 35.21\ log_{10}(d)$
- $c_m = 0\ , for\ suburban$

$$PL_{dBm} = 46.3 + 112.55 - 20.45 - 0.3 + 35.21\ log_{10}(d) + 0$$

$$log_{10}(d) = (PL - 138.1) / 35.21$$

$$d = 10^{[(PL-138.1)/35.21]} \qquad (3.23)$$

Determining Number of NodeB sites

Using **equation (3.23)**, NodeB cell radius is 1.43 km. Therefore, the coverage area of one NodeB would be, $1.95(1.43km)^2 = 4km^2$ using **equation (3.15)**. Hence, from the dimensioning perspective, 50 NodeB's are enough to provide 3G services throughout the entire 200 km^2 area of Bahir Dar.

3.2.2 WCDMA Capacity Planning

Individual voice traffic intensity for UMTS is similar with GSM, and based on **equation (3.16)**

$$A_v = {}^{2\ calls}/_{3600\ seconds} \times {}^{45\ seconds}/_{call}$$

$$A_v = 0.025\ erlang\ or\ 25\ milli\ erlang$$

UMTS Traffic Model

For UMTS, 25mErl for voice, 6GB per month per user for dongle (load heavy user); 1GB per month per for Smart phone user and 100MB for mobile user, and we used the following assumptions as our design requirement.

- % of daily traffic at busy hour is 7.5% and down link ratio 70%
- Active users is assumed to be 70%
- From the total data users the average load heavy user are assumed to be 25%, smart phone user 75% and all users considered to use100% of the assumed handset data.
- This traffic per user includes normal traffic, signaling traffic and additional soft handover traffic.

Table 3.15: UMTS Traffic Model

Type	**Load heavy User**	**Smart phone**	**Handset**	
			Data user	**Voice user**
Monthly user allowance	6 GB/Month	1GB/month	100MB/Month	0.025 erl

The table shows traffic usage in GB/Month/User for UMTS. Since the calculated individual voice traffic intensity is in erlang, first it should be converted to kbps, and then calculate the total supported throughput.

$$Volume\ per\ user\ @BH\ (kbps) = Erlang\ per\ User\ @BH \times Activity\ Factor \times\ Service\ rate \qquad (3.24)$$

Where, Activity Factor, v for voice (AMR12.2) is 0.67, video phone (CS 64) is 1 and for PS services is 0.9. And Bearer or Services bit rate (R_i), for voice is 12.2kbps.

$$Volume\ per\ user\ @\ BH\ (kbps) = \ 0.025 \times 0.67 \times 12.2 = 0.204$$

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In order to calculate the load of one connection of different services, we should convert the above traffic model to the following format:

$$Throughput\ \ @BH/user\ (kbps) = \frac{Monthly\ user\ allowance \times \frac{8bits}{byte} \times BH \times v}{30\ days \times 3600\ seconds} \qquad (3.25)$$

Load heavy user:

$$Throughput\ \ @BH/user\ (kbps) = \frac{6{,}000{,}000 \times \frac{8bits}{byte} \times 0.075 \times 0.9}{30\ days \times 3600\ seconds} \qquad (3.25a)$$

$$= 30$$

Load Smart phone user:

$$Throughput\ \ @BH/user\ (kbps) = \frac{1{,}000{,}000 \times \frac{8bits}{byte} \times 0.075 \times 0.9}{30\ days \times 3600\ seconds} \qquad (3.25b)$$

$$= 5$$

Handset user:

$$Throughput\ \ @BH/user\ (kbps) = \frac{100{,}000 \times \frac{8bits}{byte} \times 0.075 \times 0.9}{30\ days \times 3600\ seconds} \qquad (3.25c)$$

$$= 0.5$$

Load heavy and smart phone average user average throughput @ BH (kbps):

$$Average\ \text{user average throughput @ BH (kbps)} = (0.25 \times 30) + (0.75 \times 5) \qquad (3.25d)$$

$$= 11.25$$

Average user average throughput @ BH (kbps):

$$Average\ \text{user average throughput @ BH (kbps)} = 11.25 + 0.5 + 0.204 \qquad (3.25e)$$

$$= 11.954$$

HSDPA and HSUPA user per carrier calculation

Based on orange telecom lab test, the HSDPA and HSUPA average throughput per cell can be obtained as follows. According to orange telecom laboratory test, the HSDPA average throughput per cell is 3.6Mbps, and HSUPA average throughput per cell is 1.9Mbps.

In this thesis we consider that 70% user is active user, so we can calculate the subscribers supported per cell in the following table.

Table 3.16: UMTS Cell Load Dimension Result for Bahir Dar City

Bear	Cell Load	Traffic per subs	Active Subs/Cell	Total Subs/Cell
HSDPA+Voice	3.6 Mbps	8.386 kbps	429	612
HSUPA+Voice	1.9 Mbps	3.586 kbps	529	755

Therefore for FDD mode one cell will support 958 subscribers for DL and UL communication, finally the required number of cells for Bahir Dar city is calculated as follows.

$$Required\ no.of\ cells\ (carriers) = \frac{Total\ Population}{Total\ No.of\ active\ user/cell} \quad (3.26)$$

$$Required\ no.of\ cells\ (carriers) = \frac{309.999}{958} = 324$$

Where, from **Table 3.4**, Bahir Dar City WCDMA network subscribers for the next 5 years forecasted as 309,999.

Configuration Dimension for Bahir Dar City

To avoid WCDMA cell breathing effect coverage and capacity must be inter related. Based on coverage and capacity planning analysis, the final NodeB sites configuration is planned in the following table:

Table 3.17: Final UMTS Configurations

City	UMTS Final Configuration	No. of NodeB's	No. of Carriers
Bahir Dar	U111	9	27
	U222	24	144
	U333	17	153
Total		50	324

3.2.3 UMTS Frequency Spectrum Overview - FDD

Table 3.18: UTRA FDD Operation Bands

Band Number	Name	Uplink (MHz)	Downlink (MHz)	Remarks
I	UMTS2100	1920 - 1980	2110 - 2170	IMT-2000 / UMTS Core band
II	UMTS1900	1850 - 1910	1930 - 1990	GSM1900 band
III	UMTS1800	1710 - 1785	1805 - 1880	GSM1800 band
IV	UMTS1700	1710 - 1755	2110 - 2155	Pairing with the core band
V	UMTS850	824 - 849	869 - 894	For the USA
VI	UMTS800	830 - 840	875 - 885	For Japan
VII	UMTS2600	2500 - 2570	2620 - 2690	IMT-2000 extension band
VIII	UMTS900	880 - 915	925 - 960	GSM900 band
IX	UMTS1700	1749.9 - 1784.9	1844.9 - 1879.9	Japanese version of UMTS1700
X	Extended UMTS1700	1710 - 1770	2110 - 2170	

Frequency band: 2100MHZ

Common Name: IMT (international mobile Telecommunication)

Downlink, Uplink and Downlink Frequencies and its duplexes distance is as follows:

- Downlink Frequency: 1920 – 1980 MHz
- Uplink Frequency: 2110 – 2170 MHz
- Duplex Spacing: 190 MHz
- Carrier spacing: 5 MHz
- Band width 60 MHz
- No. of carrier frequencies = 60 MHz / 5 MHz =12, and each has 5 MHz band width.

UMTS ARFCN is integer value and its UL and DL channels for main bands (2100MHZ) are:

UARFCN UL channel number 9612 – 9888 and UARFCN DL channel number 10562 – 10838.

UTRA Absolute Radio Frequency Channel Number (UARFCN)

0 MHZ ≤ f_(CenterUplink/Dowlink) ≤ 3276.6 MHZ With

UARFCN = 5 × f_(CenterUplink/Dowlink) [MHZ]

Center frequency range (MHz): $f_{center}UL$ = 1922.4 – 1977.6 and $f_{center}UL$ = 2112.4 – 2167.6

3.2.4 WCDMA PSC Planning

Planning Principles

There are totally 512 PSCs. They are divided by 64 groups, so each group has 8 PSCs. The scrambling code planning aims to guarantee that the two cells interfering with each other and using the same frequency do not use the same PSC.

Fundamental principle for scrambling code planning

Allocate a proper scrambling code to each cell to improve the utilization of scrambling code resources in the whole network and meet the expansion and maintenance requirements in the process of network development.

Downlink scrambling code planning is a process of distributing 512 groups of primary scrambling codes to various sectors. Several rules need to be followed during scrambling code planning.

Reserve sufficient distances for geographical isolation of frequency reuse BSs during the reuse of the same scrambling code.

The isolation distance required for scrambling code reuse is irrelevant to the radio environment, and it is used to ensure that the identical scrambling code signal will not be received at the same place and thus to prevent scrambling code confusion. The longer the scrambling code reuse distance, the smaller the scrambling code confusion probability, but the scrambling codes may be insufficient for distribution. On the contrary, the shorter the scrambling code reuse distance, the greater the scrambling code confusion probability, but the scrambling codes are sufficient for distribution. The same scrambling code shall not be distributed to the primary cell and the adjacent cell of one of the primary cell's adjacent cells.

Scrambling Code Allocation

All 512 scramble codes can be tabulated as follows. Neighboring sites are grouped into hexagons or clusters, and each hexagon is assigned a Color Group. This strategy is based on splitting the scrambling codes into eight different Color Groups

BiT Bahir Dar Institute of Technology
ባሕር ዳር ቴክኖሎጂ ኢንስቲትዩት
Bahir Dar University
ባሕር ዳር ዩንቨርሲቲ

Table 3.19: Grouping and Allocation of scrambling codes

Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Group 7		Group 8	
Site 1	0	Site 8	1	Site 15	2	Site 22	3	Site 29	4	Site 36	5	Site 43	6	Site 50	7
	8		9		10		11		12		13		14		15
	16		17		18		19		20		21		22		23
Site 2	24	Site 9	25	Site 16	26	Site 23	27	Site 30	28	Site 37	29	Site 44	30		31
	32		33		34		35		36		37		38		39
	40		41		42		43		44		45		46		47
Site 3	48	Site 10	49	Site 17	50	Site 24	51	Site 31	52	Site 38	53	Site 45	54		55
	56		57		58		59		60		61		62		63
	64		65		66		67		68		69		70		71
Site 4	72	Site 11	73	Site 18	74	Site 25	75	Site 32	76	Site 39	77	Site 56	78		79
	80		81		82		83		84		85		86		87
	88		89		90		91		92		93		94		95
Site 5	96	Site 12	97	Site 19	98	Site 26	99	Site 33	100	Site 40	101	Site 47	102		103
	104		105		106		107		108		109		110		111
	112		113		114		115		116		117		118		119
Site 6	120	Site 13	121	Site 20	122	Site 27	123	Site 34	124	Site 41	125	Site 48	126		127
	128		129		130		131		132		133		134		135
	136		137		138		139		140		141		142		143
Site 7	144	Site 14	145	Site 21	146	Site 28	147	Site 35	148	Site 42	149	Site 49	150		151
	152		153		154		155		156		157		158		159
	160		161		162		163		164		165		166		167
⋮															
	432		433		434		435		436		437		438		439
	440		441		442		443		444		445		446		447
	448		449		450		451		452		453		454		455
	456		457		458		459		460		461		462		463
	464		465		466		467		468		469		470		471
	472		473		474		475		476		477		478		479
	480		481		482		483		484		485		486		487
	488		489		490		491		492		493		494		495
	496		497		498		499		500		501		502		503
	504		505		506		507		508		509		510		511

For our UMTS frequency planning we used the first 50 PSC's highlighted in yellow color, since we calculated the total NodeB's as 50.

3.3. LTE Radio Network Planning

LTE Coverage planning consists of evaluation of downlink and uplink 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 minimum of the maximum path losses in UL and DL directions is converted into cell radius, by using a propagation model appropriate to the deployment area. Radio Link Budget is the most prominent component of coverage planning exercise.

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 base stations-eNodeB 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 (Coverage Planning) gives the maximum allowed path loss and the maximum range of the cell, whereas coverage Planning takes into account the interference by providing a suitable model. LTE also exhibits soft capacity like its predecessor 3G systems.

Therefore, the increase in interference and noise by increasing the number of users will decrease the cell coverage forcing the cell radius to become smaller. In LTE, the main indicator of capacity is SINR distribution in the cell [21, 27, 28].

3.3.1 LTE Coverage Planning

LTE Link Budget and Coverage Analysis

The aim of the link budget is to identify the maximum allowable path loss (MAPL) between the transmitter and receiver for the UL and DL. Therefore, the cell radius can be calculated for different terrain morphologies (i.e., dense urban, urban, suburban, and rural) based on the appropriate propagation model. The minimum SINR requirements in both the UL and DL are achieved with the MAPL and maximum transmit power.

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. The cell radius of an eNB can be obtained according to the MAPL under a tuned propagation model.

The cell radius can be used to estimate the total number of sites that needed to provide the RF coverage that meets the predefined coverage objectives.

LTE Link budget Parameters

eNB Output Power

This is one of the main factors that impact the link budget. In the link budget illustrated in **Table 3.20**, we considered 46 dBm output power per each branch of the MIMO 4×4 which means 4×40 watts.

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 gain and beam width depends on the clutter type and coverage requirement.

A typical LTE 1800MHz antenna with two dual polarized antennas (four antenna ports) that can accommodate LTE 1800MHz and GSM 1800 or LTE 1800MHz with 4RX diversity or MIMO 4 × 4 is considered.

Equivalent Isotropic Radiated Power (EIRP)

The EIRP indicates the power that would be radiated by the theoretical isotropic antenna to achieve the peak power density observed in the direction of maximum antenna gain. The power radiated by a directional antenna is transposed into the radiated power of an isotropic antenna by consideration of antenna gain and power at the antenna input. The EIRP in the DL is calculated

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 be 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 PCIs

Interference Margin

The interference margin is encountered in the link budget due the possibility of noise rise according to the load level. LTE has no intra-cell interference due to OFDM subcarriers' orthogonality.

LTE 1800 MHz Link budget Calculation

From **equation 3.6**, the Okumura-Hata model for path loss prediction is given by:

$$PL = A + B\,log_{10}(f) - 13.82\,log_{10}(Hb) - a(Hm) + [44.9 - 6.55\,log_{10}(Hb)]\,log_{10}(d) + L_{other}$$

And for f = 1800MHz, the cell radius is simplified in **equation 3.25** as:

$$d = 10^{[(PL-136.32)/35.21]}$$

Table 3.20 provides typical link budgets for an LTE system at 1800MHz band (i.e., 3GPP band 3) with 20MHz channel Band width. Okumura-Hata model is used to estimate the path loss of this LTE Planning design. The cell radius for each clutter is determined based on the smallest cell radius from the UL and DL.

Table 3.20: LTE 1800MHz Radio Link Budget General Information

	Morphology	**Units**	**Urban**		**Formulas**
	Data Channel type		PUSCH	PDSCH	
Transmitting End	Duplex mode		FDD	FDD	
	TX Power	dBm	23	46	a
	Allocated RB		3	19	b
	RB to distribute Power		3	100	c
	Subcarrier to distribute Power		36	1200	$d = 12 \times c$
	Subcarrier Power	dBm	7.44	15.21	$e = a - 10 \times \log_{10} d$
	TX Antenna Gain	dBi	0	18	f
	TX Cable loss	dB	0	0.5	g
	TX Body Loss	dB	0	0	h
	EIRP	dBm	7.44	32.71	$i = e+f-g-h$
Receiving End	RX Antenna gain	dBi	18	0	j
	RX Cable + connector loss	dB	3	0	k
	RX Body Loss	dB	0	2	l
	Noise Spectral Density, Ni	dBm/Hz	-174	-174	$m = kT$
	Bandwidth	dBHz	41.76	41.76	$n = 10 \times \log_{10}(15000)$
	Noise Power per subcarrier	dBm/Hz	-132.24	-132.24	$o = kTB$
	Noise Figure	dB	6.2	7	p
	SINR	dB	-4.19	-5.37	q
	Receiver Sensitivity	dBm	-130.23	-130.61	$r = o+p+q$
Margins	Area Coverage Probability	%	95		
	Edge Coverage Probability	%	90		
	Slow Fading Standard Deviation	dB	8		
	Slow Fading Margin	dB	10.3	10.3	s
	Interference Margin	dB	2	3	t
	Indoor Penetration Loss	dB	3	5	u
	Sum of Margins	dB	15.3	18.3	$v = s+t+u$
Maximum Allowed Path Loss, MAPL		dB	137.37	143.02	$w = i+j-k-l-r-v$
Cell Radius	Frequency Band	MHz	1800		
	Propagation Model	Okumura-Hata			
	Cell Radius	km	1.071	1.550	$x = 10^{[(u-136.32)/35.21]}$
	Cell Radius Output	km	1.071		

Determining the Number of eNodeB

For this thesis work, tri-sector cells in a single eNodeB are considered to provide precise coverage for the selected 30 km^2 Bahir Dar urban city. The coverage area of one eNodeB, of a tri-sector is determined by **equation (3.15)**. And from LTE link budget calculation cell radius is 1.071 km. Therefore, the coverage area of one eNodeB site will be 2.236 km^2

Hence, from the coverage dimensioning perspective, we need 19 eNodeB sites to provide LTE service throughout the entire 30 km^2 area of Bahir Dar urban area.

3.3.2 LTE Capacity Planning

The following steps are procedures for LTE Capacity Planning.

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

Capacity dimensioning and Planning Analysis

The daily traffic can be estimated as a percentage of the busy hour traffic. In this thesis design we assume the busy hour traffic is 7.5% of the daily traffic. Three types of service packages are provided, golden service package, silver service package, and bronze service package, each service has its own quality, the month service package, the DL and UL peak data rates, and the package percentage, all of these characteristics are shown in **table 3.21**.

The traffic ratio of the UL and DL in terms of the total traffic is chosen to be 20% for UL and 80% for DL. The number of subscribers must be specified in order to continue the analysis, the subscriber's number for Bahir Dar city urban clatter is considered to be 230,591.

Table 3.21: LTE Users Category

Package Type	Month service package (GB)	Package Percentage
Gold	20	10%
Silver	15	40%
Bronze	10	50%

Firstly the total average throughput per subscriber must be calculated in order to calculate the average throughput per site.

$$\begin{matrix} Avg.throughput \\ per\ sub\ @\ BH \end{matrix}_{DL+UL}(Kbps) = \frac{Monthly\ service\ package \times\ 8bit/byte \times\ BH\ ratio}{no.of\ days \times time\ in\ second} \quad (3.27)$$

- Gold customer Average throughput (DL + UL):

$$Avg.throughput\ per\ sub\ in\ BH_{DL+UL}\ (Kbps) = \frac{20 \times 10^9 \times \frac{8bit}{byte} \times 7.5\%}{30 \times 3600\ second} = 111.11$$

- Silver customer Average throughput (DL + UL):

$$Avg.throughput\ per\ sub\ in\ BH_{DL+UL}\ (Kbps) = \frac{15 \times 10^9 \times \frac{8bit}{byte} \times 7.5\%}{30 \times 3600\ second} = 83.33$$

- Bronze customer Average throughput (DL + UL):

$$Avg.throughput\ per\ sub\ in\ BH_{DL+UL}\ (Kbps) = \frac{10 \times 10^9 \times \frac{8bit}{byte} \times 7.5\%}{30 \times 3600\ second} = 55.55$$

Table 3.22: Total Average Throughput per subscriber at BH

Package Type	Average Throughput @BH per user (kbps), DL+UL
Gold	111.11
Silver	83.3
Bronze	55.55

$$Total\ avg.throughput\ per\ sub.@\ BH(kbps)$$
$$= \sum (Avg.throughput\ per\ sub\ @BH_{DL+UL} \times\ packet\ \ percentage) \quad (3.28)$$

$$= 111.11 \times 10\% + 83.33 \times 40\% + 55.55 \times 50\% = 72.21$$

Table 3.23: Average Throughput per subscriber for UL & DL

Total Average Throughput per sub (kbps), DL+UL	Channel Type	Traffic ratio	Total Average Throughput per sub (kbps)
72.21	UL	20%	14.442
	DL	80%	57.768

The peak average throughput per sector and per site for both UL and DL can be calculated as follows.

To calculate the peak capacity throughput per sector, first we consider a 2×20 MHz LTE system with 4×4 MIMO configuration, 64QAM and code rate 1:

We first calculate the number of resource elements (RE) in a sub-frame (a sub-frame is 1 msec).

$$One\ sub\ frame\ =\ 12\ Subcarriers\ x\ 7\ OFDMA\ Symbols$$

$$x\ 100\ Resource\ Blocks\ x\ 2\ slots \quad (3.29)$$

$$=\ 16{,}800\ RE$$

Then we calculate the data rate for 64 QAM with coding rate 1.

$$Peak\ throughput\ =\ 6\ bits\ per\ 64QAM\ symbol\ x\ 16{,}800\ REs\ symbol$$

$$=\ 100800\ bits$$

$$Peak\ throughput\ in\ a\ sub\ frame\ =\ 100{,}800/1\ msec$$

$$=\ 100.8\ Mbps.$$

Peak Throughput per sector calculation for DL communication:

Peak throughput for 4 ×4 MIMO configuration

$$Peak\ throughput\ 4\times 4MIMO\ configuration\ DL\ =\ 4x\ 100.8Mbps\ =\ 403.2\ Mbps$$

$$=\ 403.2\ Mbps$$

We now we have to subtract the overhead related to control signaling as follows:

- Pilot overhead (4 TX antennas) = 14.29%
- Common channel overhead (adequate to serve 1 UE/sub frame) = 10%
- CP overhead = 6.66%
- Guard band overhead = 10%

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The total DL overhead for the 20 MHz channel is 14.29% + 10% + 6.66%+ 10% = 40.95%.

$$ThePeak\ throughput_{DL} = 0.59\ x\ 403.2\ Mbps$$

$$= 237.89\ Mbps$$

Peak Throughput per sector for UL communication calculation:

1 TX antenna (no MIMO), 64 QAM code rate 1 (Note that typical UEs can support only 16QAM), and we now have to subtract the overhead related to control signaling as follows:

- Pilot overhead = 14.3%
- Random access overhead = 0.625%
- CP overhead = 6.66%
- Guard band overhead = 10%

The total UL overhead for the 20 MHz channel is 14.3% + 0.625% + 6.66%+ 10% = 31.585%.

The peak data rate UL $= 0.684x\ 100.8Mbps = 68.947\ Mbps$

Peak Throughput per site calculation for DL & UL:

$$Total\ throughput\ per\ site_{DL} = 3 \times DL\ data\ rate\ per\ sector$$

$$= 3 \times 237.89Mbps = 713.67Mbps$$

$$Total\ throughput\ per\ site_{UL} = 3 \times UL\ data\ rate\ per\ sector$$

$$= 3 \times 68.947\ Mbps = 206.841Mbps$$

Table 3.24: Total Average Throughput per site

	DL	UL
Total throughput per site (Mbps)	713.67	206.841

Now, the maximum subscriber's number per site is calculated for UL and DL and the lowest is chosen.

Total number of subscriber per site:

$$\text{Max. no. of subscriber per site} = \frac{Total\ Average\ throughput\ per\ site}{Total\ average\ throughput\ per\ subscriber}$$

$$Max.no.of\ subscriber\ per\ site_{DL} = \frac{713.67Mbps}{57.768kbps}$$

$$= 12{,}354$$

$$Max.no.of\ subscriber\ per\ site_{UL} = \frac{206.841Mbps}{14.442kbps}$$

$$= 14{,}322$$

Total number of sites calculation for DL and UL

$$Total\ no.of\ sites_{DL} = \frac{Total\ subscriber\ no.for\ the\ required\ area}{Max.no.of\ subscriber\ per\ site}$$

$$= \frac{230{,}591}{12{,}354} = 19$$

$$Total\ no.of\ sites_{UL} = \frac{Total\ subscriber\ no.for\ the\ required\ area}{Max.no.of\ subscriber\ per\ site_{UL}}$$

$$= \frac{230{,}591}{14322} = 17$$

The required sites number for a specific Bahir Dar city urban area should be chosen to be the maximum number of sites obtained from coverage and capacity planning calculations to satisfy the traffic requirements of both coverage and capacity. According to the results obtained from the coverage and capacity planning analysis, we can take 19 sites that we get from the maximum capacity dimensioning for adequate radio network planning.

3.3.3 LTE Frequency Spectrum Overview - FDD

3GPP Release 8 & 9 (3GPP TS36.104-860 Table 3.25 E-UTRA frequency bands) has clearly defined LTE as a system that can operate in various frequency bands in order to suit the need of different operators in the world.

Table 3.25: 3GPP LTE E-UTRA supported bands for FDD

EUTRA operating band	UL operating band BS receive UE transmit $F_{UL\_low} – F_{UL\_high}$	DL operating band BS transmit UE receive $F_{DL\_low} – F_{DL\_high}$	Duplex mode
1	1920MHz–1980MHz	2110MHz–2170MHz	FDD
2	1850MHz–1910MHz	1930MHz–1990MHz	FDD
3	1710MHz–1785MHz	1805MHz–1880MHz	FDD
4	1710MHz–1755MHz	2110MHz–2155MHz	FDD
5	824MHz–849MHz	869MHz–894MHz	FDD
6	830MHz–840MHz	875MHz–885MHz	FDD
7	2500MHz–2570MHz	2620MHz–2690MHz	FDD
8	880MHz–915MHz	925MHz–960MHz	FDD
9	1749.9MHz–1784.9MHz	1844.9MHz–1879.9MHz	FDD
10	1710MHz–1770MHz	2110MHz–2170MHz	FDD
11	1427.9MHz–1447.9MHz	1475.9MHz–1495.9MHz	FDD
12	699MHz–716MHz	729MHz–746MHz	FDD
13	777MHz–787MHz	746MHz–756MHz	FDD
14	788MHz–798MHz	758MHz–768MHz	FDD
15	Reserved	Reserved	FDD
16	Reserved	Reserved	FDD
17	704MHz–716MHz	734MHz–746MHz	FDD
18	815MHz–830MHz	860MHz–875MHz	FDD
19	830MHz–845MHz	875MHz–890MHz	FDD
20	832MHz–862MHz	791MHz–821MHz	FDD
21	1447.9MHz–1462.9MHz	1495.9MHz–1510.9MHz	FDD
22	3410MHz–3490MHz	3510MHz–3590MHz	FDD
23	2000MHz–2020MHz	2180MHz–2200MHz	FDD
24	1626.5MHz–1600.5MHz	1525MHz–1559MHz	FDD
25	1850MHz–1915MHz	1930MHz–1995MHz	FDD
26	814MHz–849MHz	859MHz–894MHz	FDD
27	807MHz–824MHz	852MHz–869MHz	FDD
28	703MHz–748MHz	758MHz–803MHz	FDD
29	NA	717MHz–728MHz	FDD
30	2305MHz–2315MHz	2350MHz–2360MHz	FDD
31	452.5MHz–457.5MHz	462.5MHz–467.5MHz	FDD

The most popular commercial LTE bands are 2.6GHz (Band 7), AWS (Band 4) and 700MHz (Band 12) while momentum is being built up also for 1800MHz (Band 3) as well as Public Safety spectrum (Band 14) According to 3GPP TS 36.104 V9.4.0 (2010-06), In our thesis design we select 1800MHz for LTE band to use dual band antenna with DCS 1800MHz.

The selection of appropriate spectrum depends on many factors, such as the regulatory policy, spectrum fees, existing technologies, and so on.

LTE in 1800MHz

This is the most promising LTE band as it can be used for nationwide coverage and for dense urban, urban, and suburban convergence.

The main advantages of this band for LTE deployment are:

- Coverage area is about 2x larger than LTE 2.6 GHz with better indoor penetration.
- 35% improvement in cell edge throughput compared to LTE 2.6 GHz.
- Reduction of extra sites results in quick delivery of the LTE to market.
- Reuse of existing GSM1800 coverage polygons and possibility to share antenna system of GSM1800.
- Possibility of nationwide coverage using this band.
- Availability of LTE terminals in this band. Even some major smartphone manufacturers have supported this band before the 2.6 GHz band.

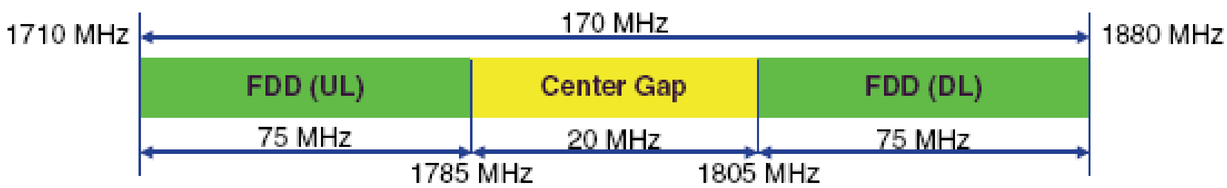

Figure 3.6: Band 1800MHz arrangement

Guard Band Requirement

One of the important aspects when introducing the LTE system on top of existing systems like 2G or 3G is the guard band requirement. More specifically, when LTE is collocated with other technologies in the same site where nearby antennas or sharing scenarios are adopted then a guard band needs to be maintained to avoid interference between collocated systems.

In the case of LTE with GSM collocated in the same band, that is, 1800 MHz, then a single carrier of GSM 200 kHz is enough to avoid interference between the two systems.

Based on the simulation results in 3GPP Report 36.942, it can be concluded that 300 kHz offset from the LTE channel edge (separation between the nearest GSM carrier center frequency and LTE channel edge) is sufficient for the protection of GSM UL/DL against interferences from LTE (i.e., 200 kHz guard band edge-to-edge between the LTE1800 FDD (frequency division duplex) and GSM1800) [27, 28].

3.3.4 LTE PCI Planning

Frequency scan and cell Identification

When the LTE device powers on, it needs to perform an LTE attach procedure to connect to the EPC. The EPS attach procedure takes place after the UE accesses a suitable cell from the surrounding LTE eNBs deployed in a network.

In order for the UE to identify the cell and synchronize with the radio frame timing, the eNB sends synchronization signals (SCH) over the center 72 sub-carriers.

The SCH is comprised of the PSS (primary synchronization signal) and the SSS (secondary synchronization signal). Together they enable the UE to identify the physical cell identity (PCI) and then synchronize any further transmissions. There are 504 unique PCIs, divided into 168 cell identity groups, each containing three cell identities (sectors). Once a PCI is identified and both slot and frame synchronization is done through the PSS and SSS, the UE acquires the strongest cell measured during this cell search stage, known as the acquisition Stage.

During the eNB planning and deployment, the PCI planning of cells in adjacent clusters is an important topic to avoid any mismatch given the limited number of PCI. A mismatch in the PCI within two nearby cells can typically lead to system acquisition failures, low throughput or eventually call drops [21].

PCI Introduction

In LTE, 504 physical cell IDs are available, numbered from 0 to 503. Physical cell IDs are grouped into 168 unique cell ID groups (called S-SCH IDs), with each group containing 3 unique identities (called P-SCH IDs). An S-SCH ID is thus uniquely defined by a number in the range of 0 to 167, and a P-SCH ID is defined by a number in the range of 0 to 2. Each cell's reference signals transmit a pseudo-random sequence corresponding to the physical cell ID of the cell.

The S-SCH and P-SCH are transmitted over the center six frequency blocks independent of the channel bandwidths used by cells. Mobiles synchronize their transmission and reception frequency and time by listening first to the P-SCH. Once know the P-SCH ID of the cell, listen to the S-SCH of the cell in order to know the S-SCH ID. The combination of these two IDs gives the physical cell ID and the associated pseudo-random sequence that is transmitted over the downlink reference signals [21].

Once the physical cell ID and the associated pseudo-random sequence are known to the mobile, the cell is recognized by the mobile based on the received reference signals. Channel quality measurements are also made on the reference signals. Because the cell search and selection depend on the physical cell IDs of the cells, these must be intelligently allocated to cells in order to avoid unnecessary problems in cell recognition and selection.

There are 504 unique physical-layer cell identities (PCIs). The PCI are grouped into 168 unique physical-layer cell-identity groups (sometimes referred as SSS IDs), each group containing three unique identities (sometimes called PSS IDs). The grouping is formed to have each PCI as part of one and only one PCI group. A PCI is defined as

$$N_{ID}^{cell} = 3N_{ID}^{(1)} + N_{ID}^{(2)} \qquad (3.35)$$

which is uniquely identified by a number $N_{ID}^{(1)}$ in the range of 0–167, representing the PCI group, and a number $N_{ID}^{(2)}$ in the range of 0–2, representing the physical-layer identity within the PCI group.

Therefore, an SSS ID is identified by a number from 0 to 167, and a PSS ID is identified by a number from 0 to 2. A cell ID is the combination of one P-SCH (primary synchronization channel) and the group ID supported by the S-SCH (secondary synchronization channel) [38].

To summarize,

- PSS: Three possible sequences called physical-layer identities (0 - 2)
- SSS: 168 different sequences called PCI groups (0 - 167) with 3 physical layer identities per group
- PCI: 168 × 3 = 504 PCI [21].

PCI Planning Guidelines

PCI assignment

- Avoid PCI collision and confusion by allocating different PCIs to neighbor cells and thus avoid problems in cell search and selection.
- Use different PSS at neighbor cells.
- Assign different PSS ID at neighbor cells.
- The PCI planning can be conducted manually considering the above guidelines or automatically using planning tools.

Summary of PCI planning recommendation

- The distance between cells with the same PCI should be maximized to prevent any UE from receiving the same PCI from two different cells.
- Cells belonging to the same eNodeB should have PCI from the same group.
- We should not consume all PCI resources from day one and we should have reserved buffer for future expansion to avoid full PCI re-planning.
- If the same frequency is being used by two adjacent countries, then PCI coordination needs to be considered on the border, similar to overshooting coordination. If the same frequency is used in the neighbor countries, then PCI planning needs to be considered although it belongs to different PLMNs (public land mobile networks) [21].

Table 3.26: PSS, SSS & Physical cell ID Table

SSS ID	PSS ID			SSS ID	PSS ID				SSS ID	PSS ID		
	0	1	2		0	1	2			0	1	2
0	0	1	2	28	84	85	86		140	420	421	422
1	3	4	5	29	87	88	89		141	423	424	425
2	6	7	8	30	90	91	92		142	426	427	428
3	9	10	11	31	93	94	95		143	429	430	431
4	12	13	14	32	96	97	98		144	432	433	434
5	15	16	17	33	99	100	101		145	435	436	437
6	18	19	20	34	102	103	104		146	438	439	440
7	21	22	23	35	105	106	107		147	441	442	443
8	24	25	26	36	108	109	110		148	444	445	446
9	27	28	29	37	111	112	113		149	447	448	449
10	30	31	32	38	114	115	116		150	450	451	452
11	33	34	35	39	117	118	119		151	453	454	455
12	36	37	38	40	120	121	122		152	456	457	458
13	39	40	41	41	123	124	125		153	459	460	461
14	42	43	44	42	126	127	128	…	154	462	463	464
15	45	46	47	43	129	130	131		155	465	466	467
16	48	49	50	44	132	133	134		156	468	469	470
17	51	52	53	45	135	136	137		157	471	472	473
18	54	55	56	46	138	139	140		158	474	475	476
19	57	58	59	47	141	142	143		159	477	478	479
20	60	61	62	48	144	145	146		160	480	481	482
21	63	64	65	49	147	148	149		161	483	484	485
22	66	67	68	50	150	151	152		162	486	487	488
23	69	70	71	51	153	154	155		163	489	490	491
24	72	73	74	52	156	157	158		164	492	493	494
25	75	76	77	53	159	160	161		165	495	496	497
26	78	79	80	54	162	163	164		166	498	499	500
27	81	82	83	55	165	166	167		167	501	502	503

As mentioned before we did LTE planning for urban clutter of Bahir Dar city and we calculated the number of eNodeB's as 19, and thus we used the first 19 PCI's highlighted in yellow color above for our simulation.

Chapter Four

4. Simulation Results and Analysis

In this part we shall discuss the simulation results of GSM, UMTS and LTE coverage and capacity planning using Atoll simulation software based on the analytical results obtained from coverage and capacity estimation. This multi RAT radio network planning simulation is intended to carry out the maximum calculated path loss between the transmitter and receiver, the appropriate propagation modeling, signal level, antenna height and others for coverage prediction, UL and DL throughput for capacity evaluation, and after multi RAT coverage and capacity site count and modeling to determine the maximum site layout within the computation zone.

Designing Multi RAT Network using Atoll

The Atoll 3GPP multi-RAT simulator is basically composed of individual system level simulators for different RATs (HSPA and LTE) in conjunction with a central control unit (CCU). The individual RAT simulators are able to carry out system level simulations with multiple cells/UEs deployments almost in real-time, and their results are well calibrated at 3GPP standardization evaluations.

In this thesis, simulation is used to investigate the RAN nominal planning of G/U/L networks as it is done using Atoll simulation environment 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 as one input digital map data (which are often based on paper maps, satellite photos,…). These digital map data should contain information about, the land usage, about the height of obstacles and they should also contain so called vector data.

A digital map is an electronic database containing geographical information.

The smallest unit on such a map is called a pixel. The typical edge-length of such a pixel is ranging from several meters to several hundred meters. A digital map is often subdivided into several blocks consisting of many pixels. The different layers of information in one block always use the same resolution, whereas different blocks can have different resolutions.

Each pixel should contain information about: Land usage (Clutter information), Height data, Vector data (like rivers, streets…).

Digital Map

The most important basic preparatory requirement for an RNP tool is a geographical map of the planning area. The map is needed in coverage (link loss) predictions and subsequently the link loss data are utilized in the detailed calculation phase and for analysis purposes.

For network planning purposes, a digital map should include at least topographic data (terrain height), morphographic data (terrain type, clutter type) and building location and height data, in the form of raster maps.

In addition, it is important to include data for building locations in digital maps. If available, road information (raster or vector) can also be used in certain operations, such as traffic modeling and coverage predictions. A raster unit (map resolution) is usually in the range of 1 up to 200 m.

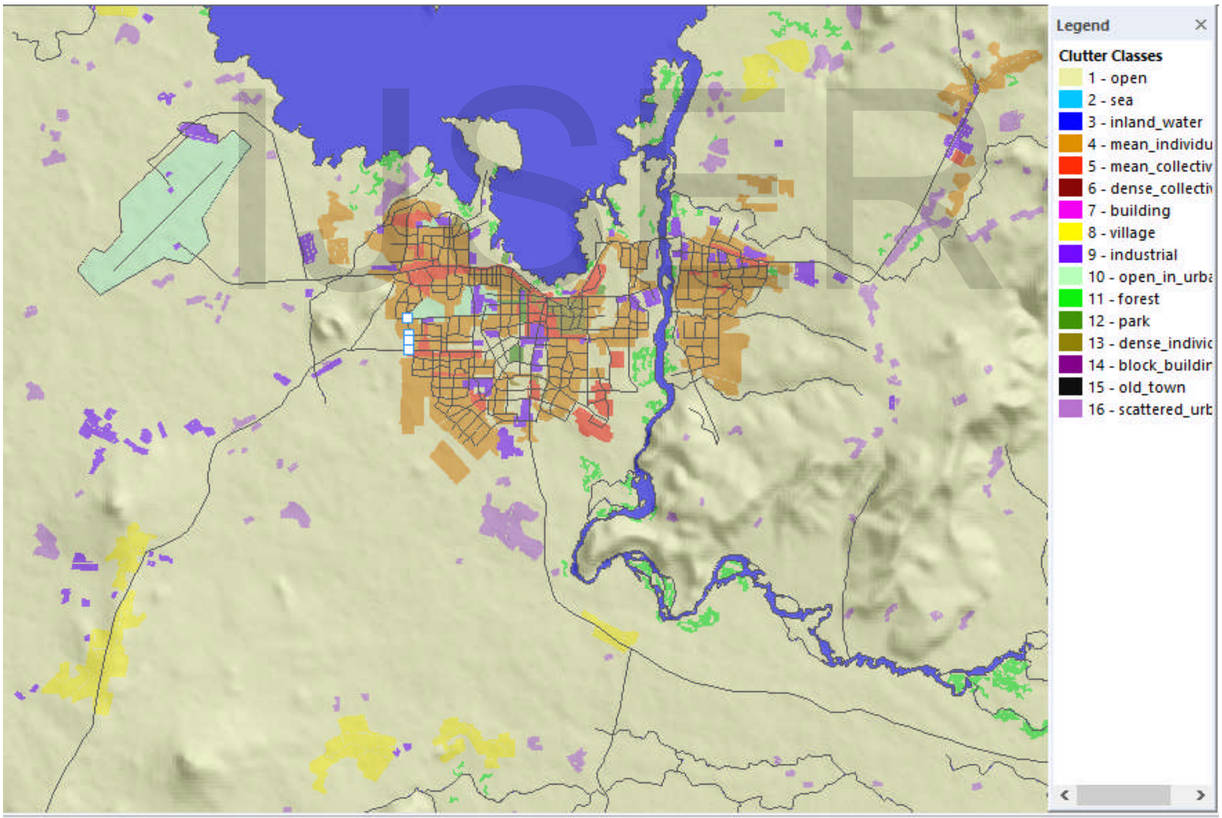

Figure 4.1: Clutter Classes of Bahir Dar City

Computational Zone

The computation zone is used to define the area where Atoll carries out calculations. When we create a computation zone, Atoll carries out the calculation for all base stations that are active. Area is an important input for coverage and capacity dimensioning and planning, hence the computation zone defines the area in which the coverage prediction results will be displayed.

Thus the computation zone that shows in **figure 4.2** allows us to restrict our coverage prediction result to the part of the network we are currently working on. If there is no defined computation zone, Atoll makes its calculations on all base stations that are active and filtered and for the entire extent of the geographical data available.

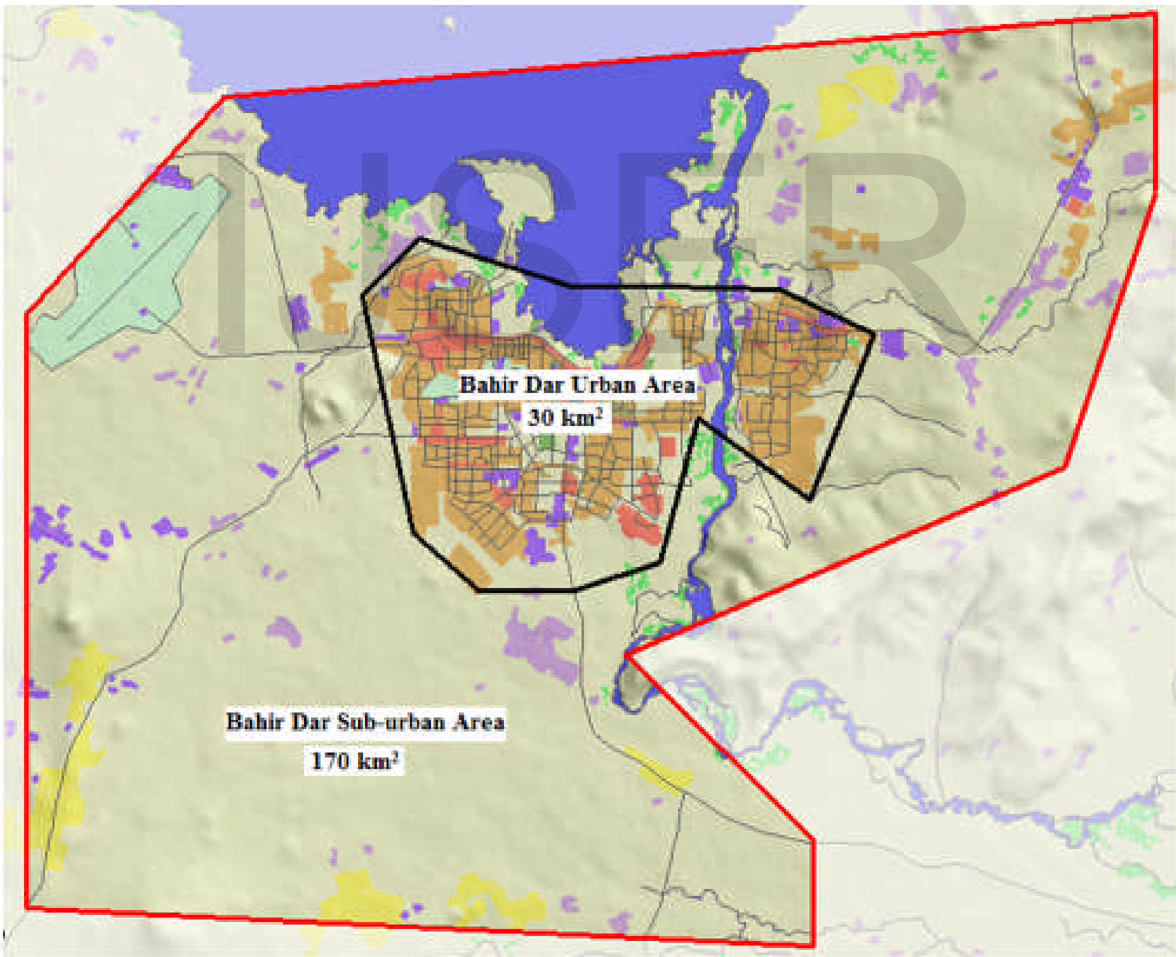

Figure 4.2: Bahir Dar city urban and suburban computational zone

Site Layout

After importing the maps into the Atoll program we started by selecting the Area of planning which was chosen according to the distribution of population. Atoll includes integrated single RAN - multiple RAT network design capabilities for both 3GPP (GSM/UMTS/LTE) and 3GPP2 (CDMA/LTE) technology streams. It provides operators and vendors with a powerful framework for designing and optimizing current and future integrated multi-technology networks. Atoll supports the latest technology advances such as HetNets and small cells.

We are created Multi RAT base stations based on the calculated coverage and capacity site count by considering different dimensioning parameters shown in chapter three.

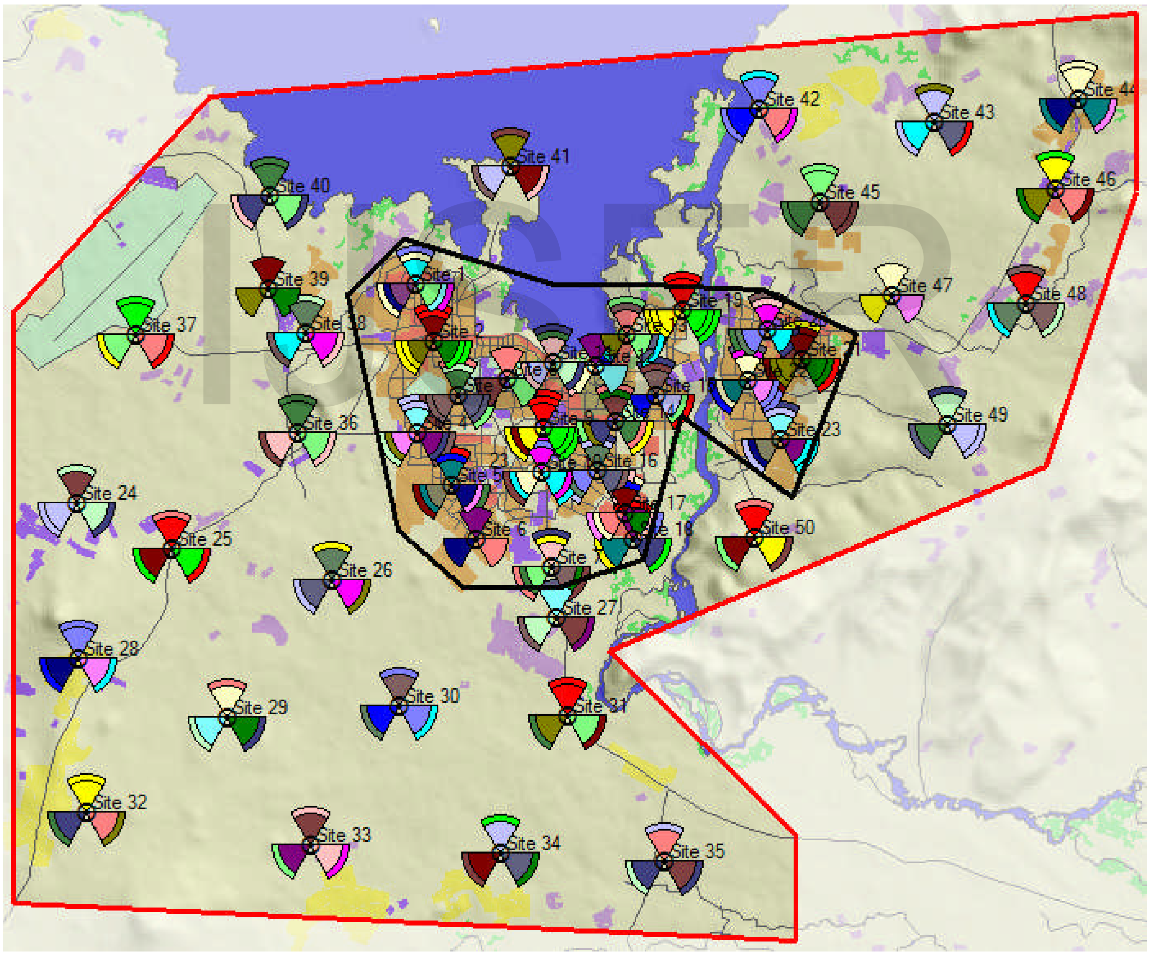

Figure 4.3: Maximum Multi RAT Sites Layout

The multi RAT sites within the computation zone has different transmitter colors and it shows the number of designed multi radio access technologies that will be deployed in the future, and each technology is marked by different transmitter as shown in **figure 4.3** above.

Analysis and Interpretation of Simulation Results

4.1. Performance Evaluation of Planned GSM Network

a) GSM Coverage Prediction by Signal level

A coverage prediction by signal level that shows in **figure 4.4** tells us the prediction of the best signal strength at each pixel within the computation zone. This signal prediction result have acceptable coverage as we observe from the simulation result below.

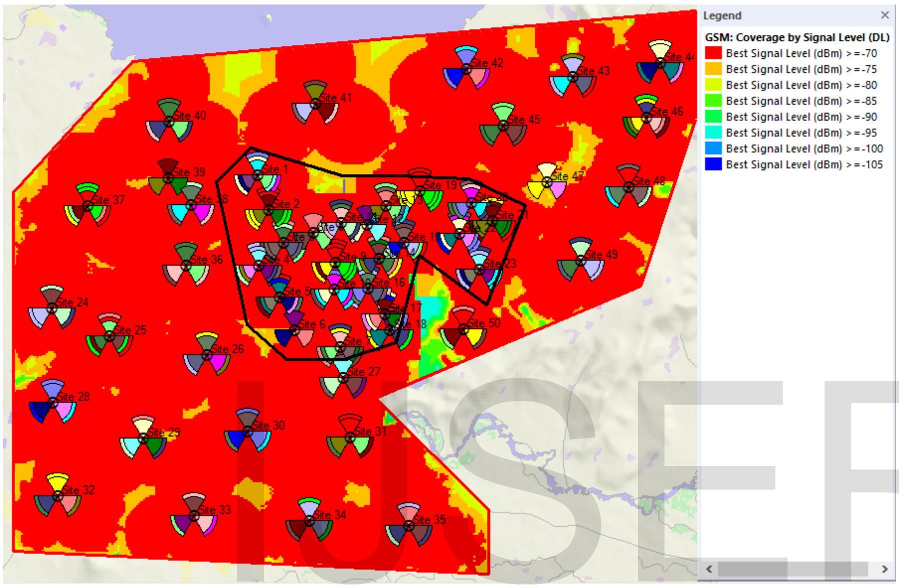

Figure 4.4: GSM Coverage Prediction by Signal level

b) GSM Coverage area with Signal level

The histogram statistical result shows comparison of coverage area versus best signal strength value. The statistical result shown in **figure 4.5** is that more areas within the computation area are covered by strong signal level and its signal values are ranges from 70- 80 dBm and also other areas are covered by acceptable signal level when we compare our design receiver sensitivity signal level -105 dBm.

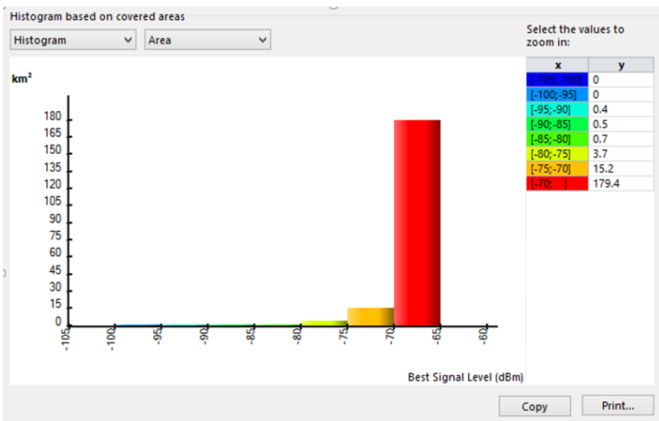

Figure 4.5: GSM Coverage area with Signal level

c) GSM Coverage Prediction using Point Analysis

The predicted signal level from different transmitters is reported in the reception view in the form of a bar chart as shown below in **figure 4.6**. Here Site 1 sector 1, supports the highest signal level -59.83 dBm acts as a serving sector and Site 2 sector 3 is the least candidate as a neighbor list, and each bar is displayed by the color of the transmitter it represents.

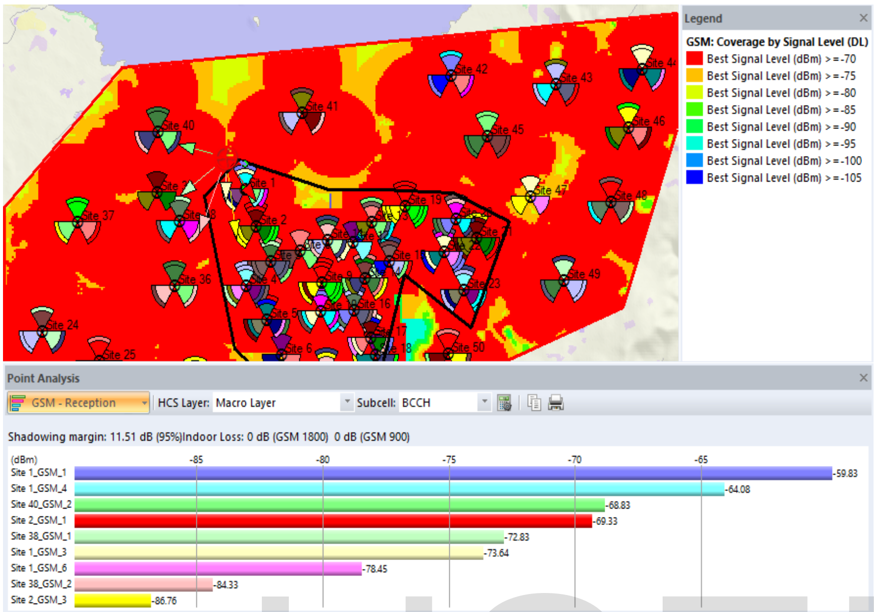

Figure 4.6: GSM Signal reception level

d) GSM Interference level Measurement

Figure 4.7 shows the signal level of the transmitter, site 19 sector 1which is -69.58 dBm and is indicated by a red bar. The black bar indicates the total interference experienced by the receiver -57.01 dBm. The interferers are responsible for the total interference: the co-channel interference and adjacent channel interference.

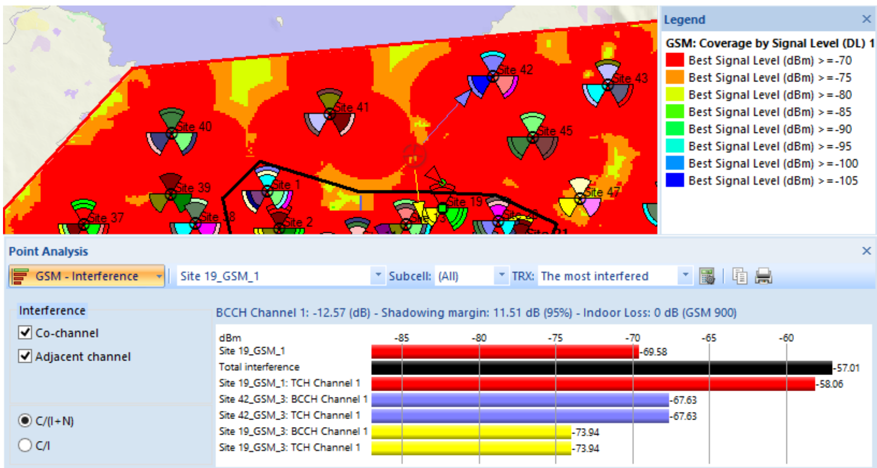

Figure 4.7: GSM interference level measurement

e) GSM Path loss with Distance

Atoll is a tool for the design and simulation of wireless systems. It predicts the performance of a radio link by using information from the designed network and a digital map of the area. During the simulation, it checks the line of sight and calculates the path loss.

The simulation result in **figure 4.8** below justifies that at our designed cell radius we can get an acceptable signal level which is better than our receiver sensitivity signal level, it implies the signal can fully serve a user at this particular point. And the link budget is shown in **figure 4.9.**

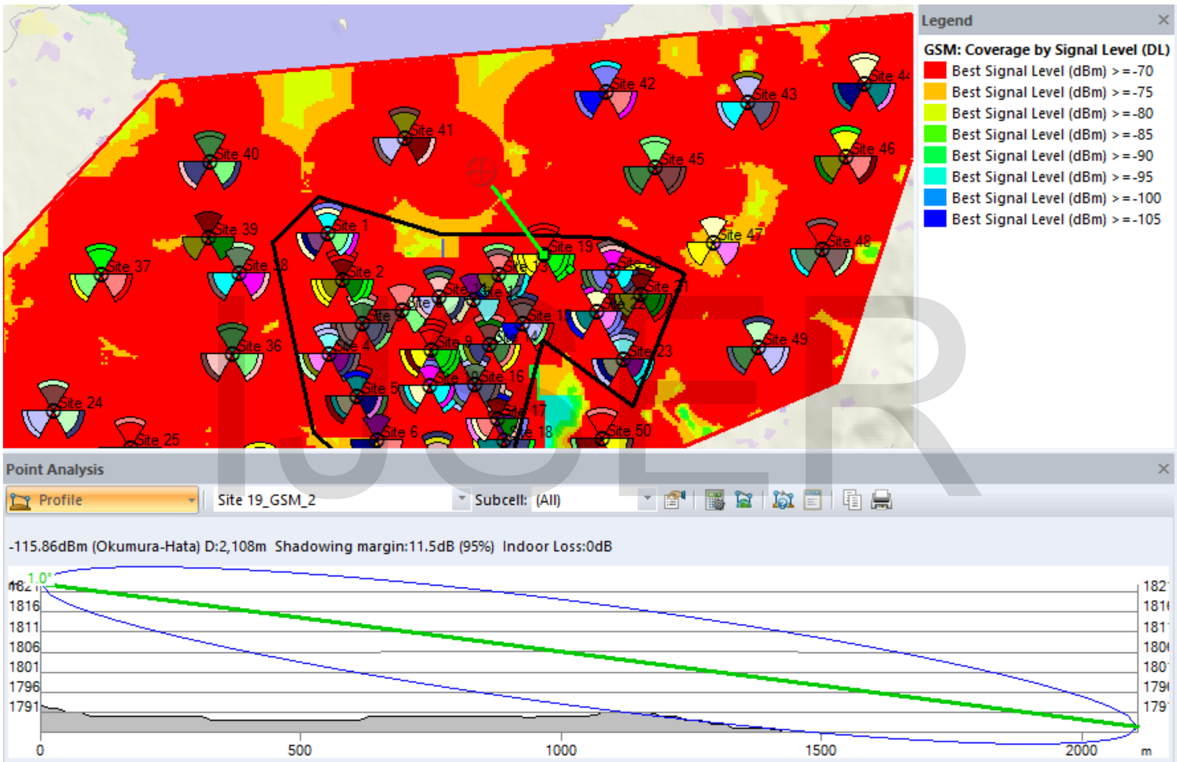

Figure 4.8: GSM Path loss with Distance

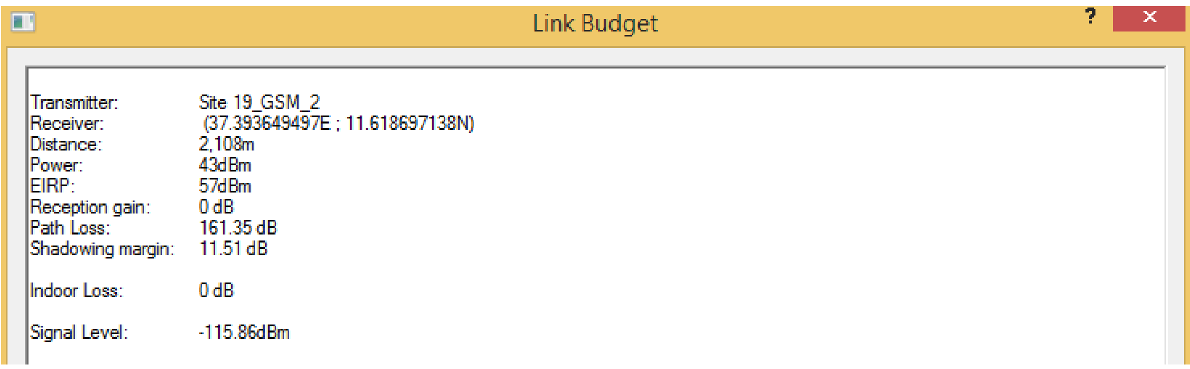

Figure 4.9: GSM Link Budget

4.2. Performance Evaluation of Planned UMTS Network

a) UMTS Coverage Prediction by Signal level

UMTS coverage prediction by signal level shown in **figure 4.10** shows the prediction of the best signal strength at each pixel within the computation zone. This signal prediction simulation result are acceptable, value when we see result in its legend.

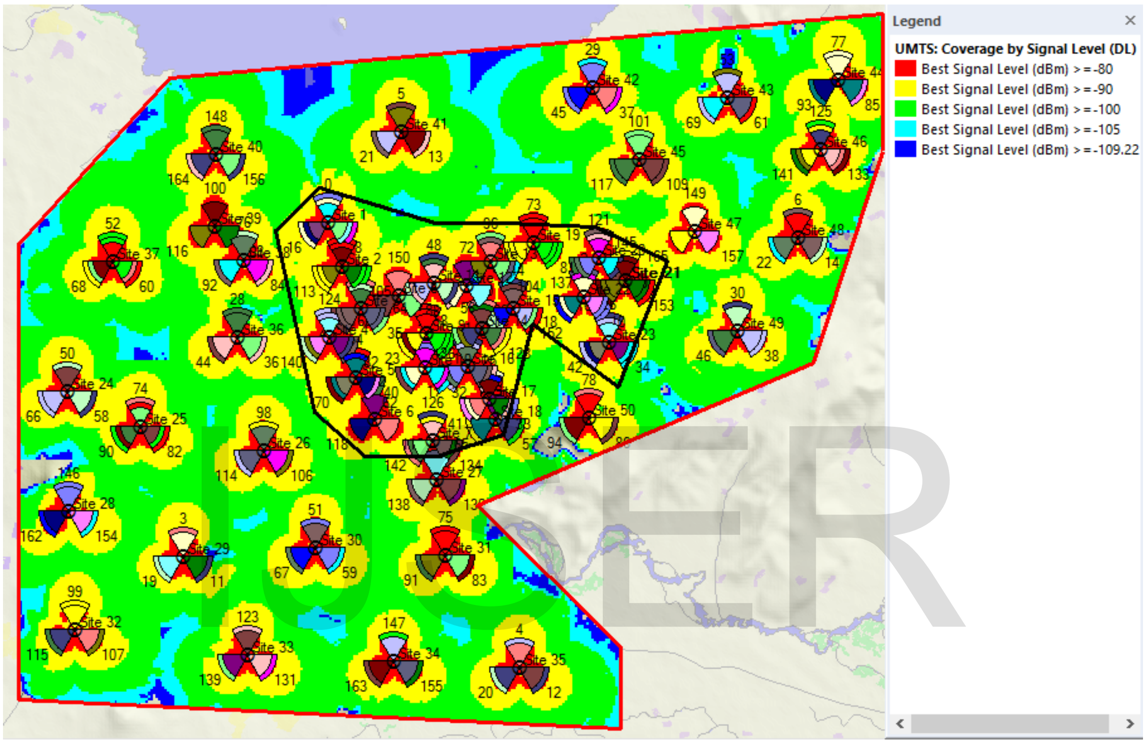

Figure 4.10: UMTS Coverage Prediction by Signal level

b) UMTS Coverage area with Signal level

The CDF statistical result shows comparison of coverage area versus best signal strength value, and its statistical result shown in **figure 4.11**. It shows that most areas within the computation zone are covered by strong signal level and its signal values ranges from 69.8 to 79.2 dBm, and also the rest areas are covered by acceptable signal value when we see our design receiver sensitivity signal level -109.22dBm

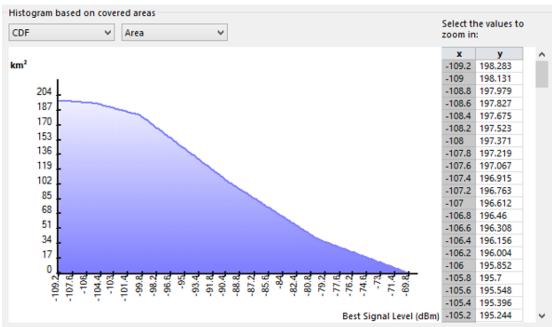

Figure 4.11: UMTS Coverage area with Signal level

c) UMTS Coverage Prediction using Point Analysis

The predicted signal level from different transmitters is reported in the reception view in the form of a bar chart as shown below in **figure 4.12**.

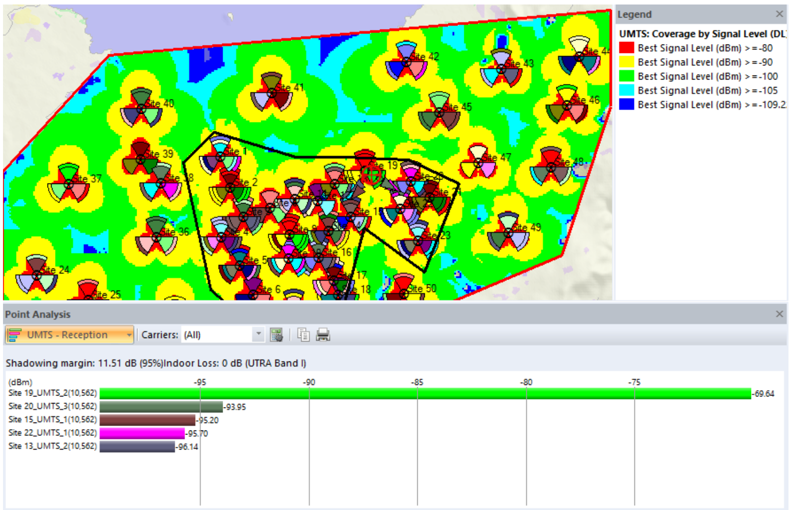

Figure 4.12: UMTS Signal reception level

d) UMTS Active Set Signal reception analysis

The active set analysis view of the point analysis window gives us information on the pilot quality (C/I) which is the main parameter used to define the mobile active set, the connection status, and the active set of the UE. When we see the simulation results below, a particular user at a point inside the computation area can get 3G services (R99, HSUPA & HSDPA) with good quality.

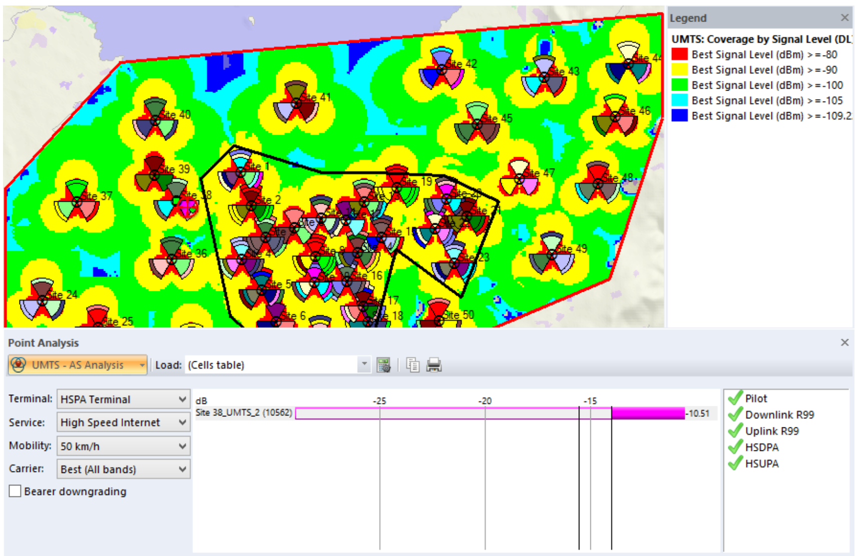

Figure 4.13: UMTS Active Set Signal reception level

e) UMTS Path loss with Distance

Figure 4.14 shows the profile view of the point analysis between a reference transmitter and receiver. The simulation results justifies that, at our designed cell radius 1.43 km, a user can receive an acceptable signal. And the link budget for this instant is shown in **figure 4.15.**

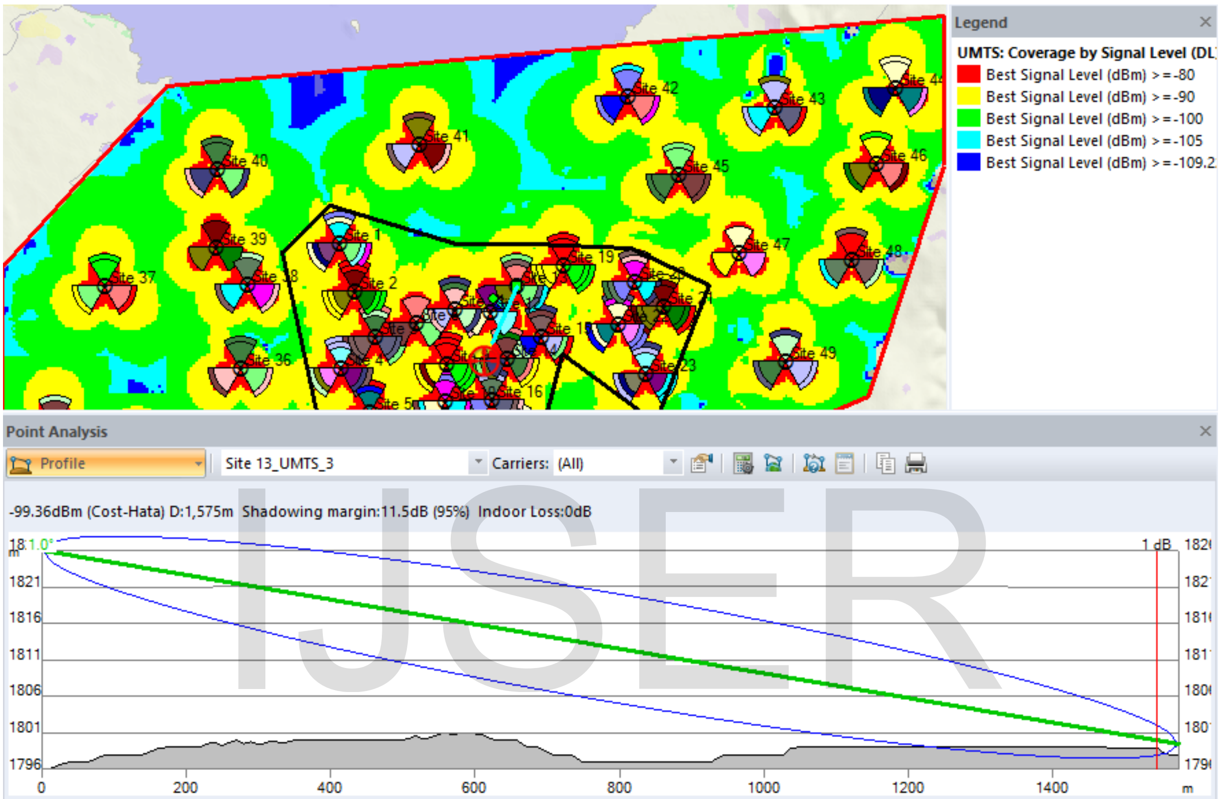

Figure 4.14: UMTS Path loss with Distance

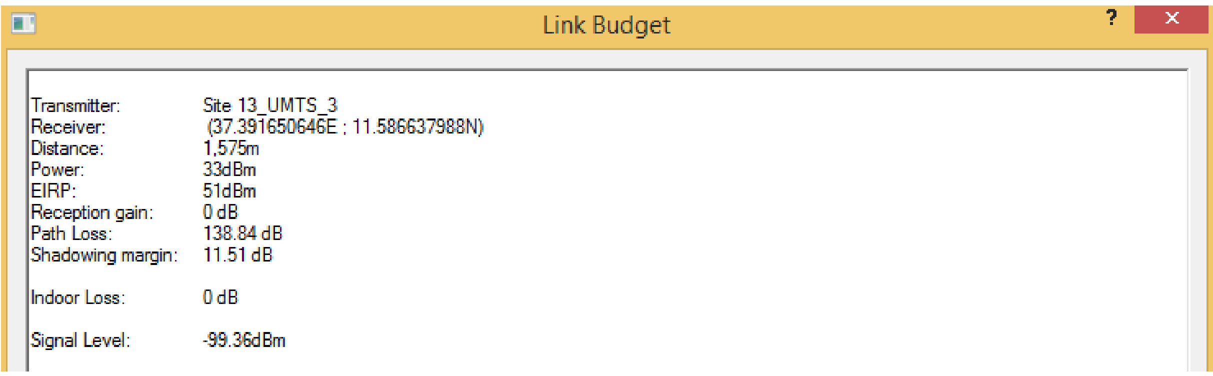

Figure 4.15: UMTS Link Budget

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4.3. Performance Evaluation of Planned LTE Network

a) LTE Coverage Prediction by Signal level

A coverage prediction by signal level that shown in **figure 4.16** tells us the prediction of the best signal strength at each edge within the designed urban computation zone. The simulation signal level values are greater than our design receiver sensitivity signal value.

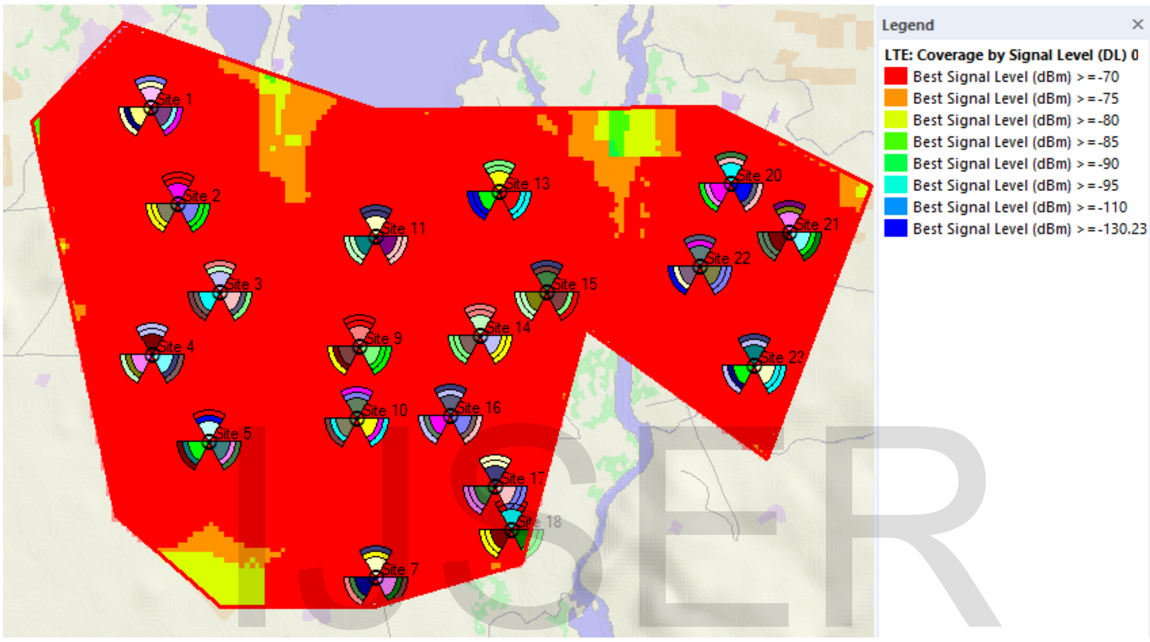

Figure 4.16: LTE Coverage Prediction by Signal level

b) LTE Coverage area with Signal level

The histogram statistical result shows comparison of coverage area versus best signal strength value, as shown in **figure 4.17. A**lmost 27.975 km^2 area within the computation zone are covered by -70 dBm strong signal level and the rest 2.025km^2 areas are covered by 70 to 90 dBm signal value which is better signal strength than our calculated receiver sensitivity signal value.

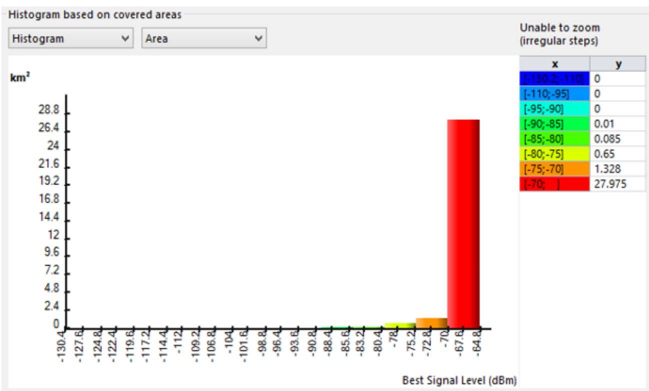

Figure 4.17: LTE Coverage area with Signal level

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c) LTE Coverage Prediction using Point Analysis

The predicted signal level from different transmitters is reported in the reception view in the form of a bar chart as shown below **figure 4.18**. Here Site 13 sector 3, supports the highest signal level -52.57 dBm, which is a serving sector and Site 15 sector 1, is the least candidate as a neighbor list.

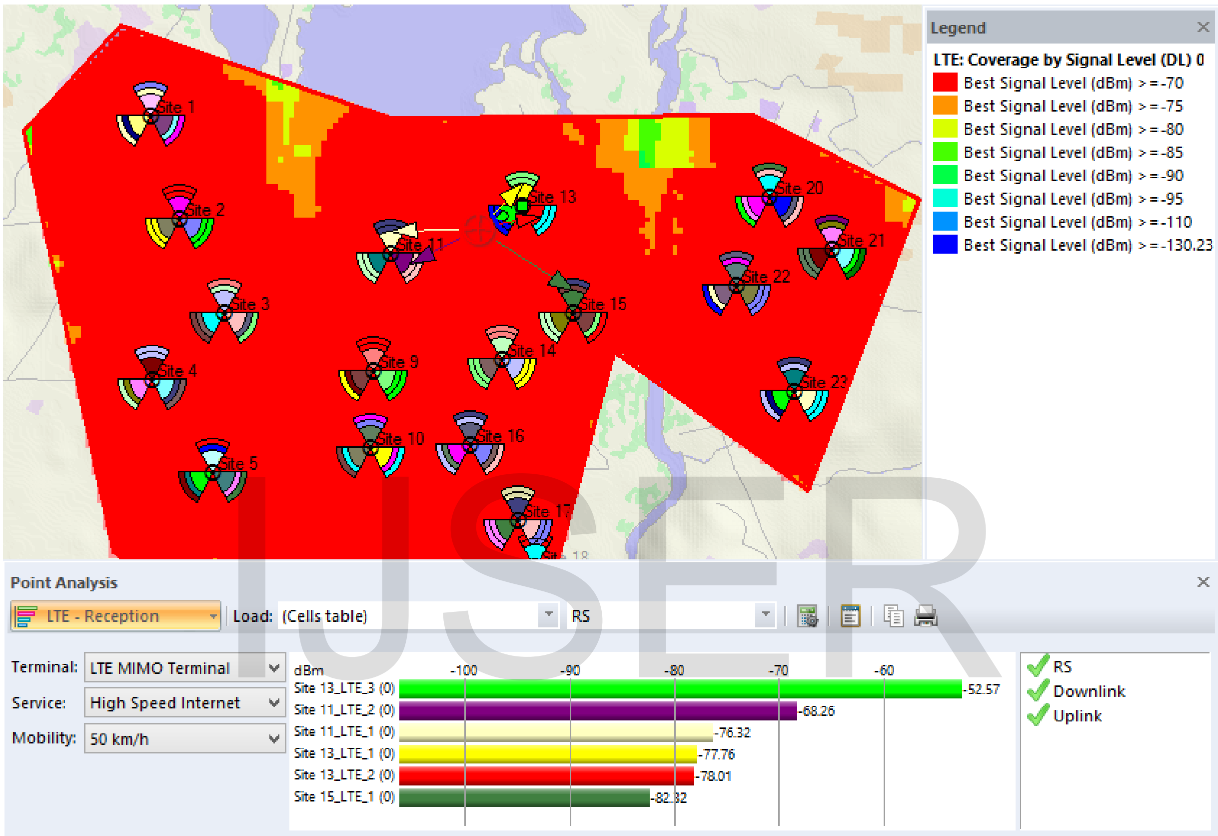

Figure 4.18: LTE Signal reception level

d) LTE Path loss with Distance

Figure 4.19 shows LTE profile view of point analysis between a reference transmitter and receiver. The simulation signals level of the received signal from the selected Site 2 LTE sector 2, transmitter is greater than our designed receiver sensitivity signal within 1.071 km designed cell radius. **Figure 4.20** shows the link budget results of the profile simulation by considering the acceptable displayed parameters when to compare in our designed parameter results.

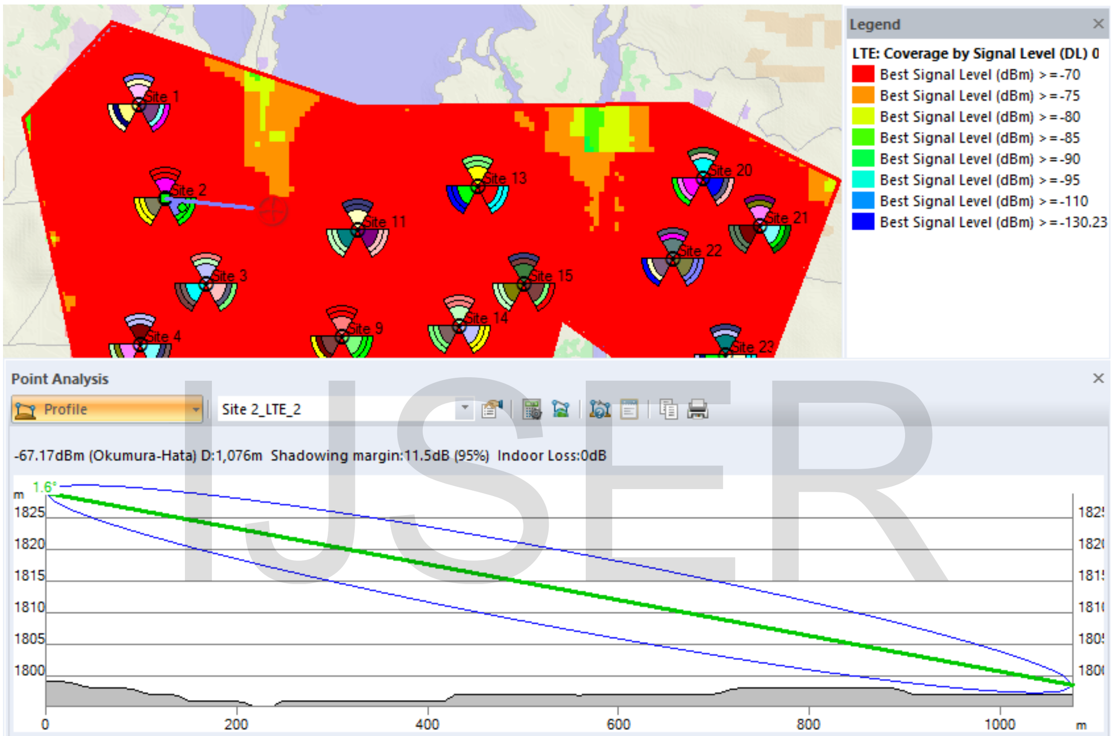

Figure 4.19: LTE Path loss with Distance

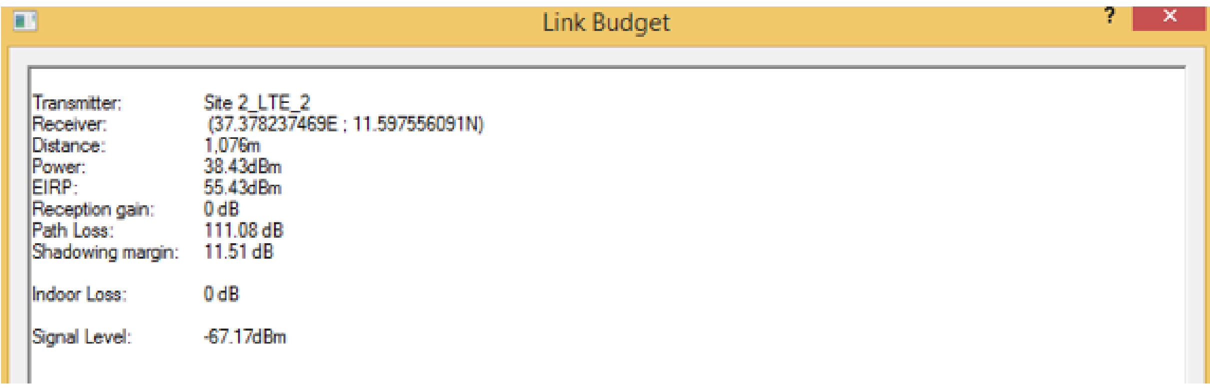

Figure 4.20: LTE Link budget

e) LTE Coverage area with Throughput

Downlink and uplink throughput coverage predictions calculate and display the channel throughputs and cell capacities based on C/(I+N) and bearer calculations for each pixel. These coverage predictions can also display aggregate cell throughputs.

The simulation result determines the total number of symbols in the downlink and the uplink sub frames from the input parameter tables. Then, Atoll determines the bearer at each pixel and multiplies the bearer efficiency by the number of symbols in the frame to determine the peak MAC channel throughputs. The cell capacity is equal to channel throughput when the maximum traffic load is set to 100%, and is equal to a throughput limited by the maximum allowed traffic loads otherwise. Cell capacities are, therefore, channel throughputs scaled down to respect the maximum traffic load limits.

The per-user throughput in DL and UL is calculated by dividing the DL and UL cell capacity by the number of DL and UL users of the serving cell respectively, but in uplink, the per-user throughput is smaller than the DL per-user throughput. Finally the simulation result shows the DL individual user throughputs within the urban area is acceptable as shown in **figure 4.21**.

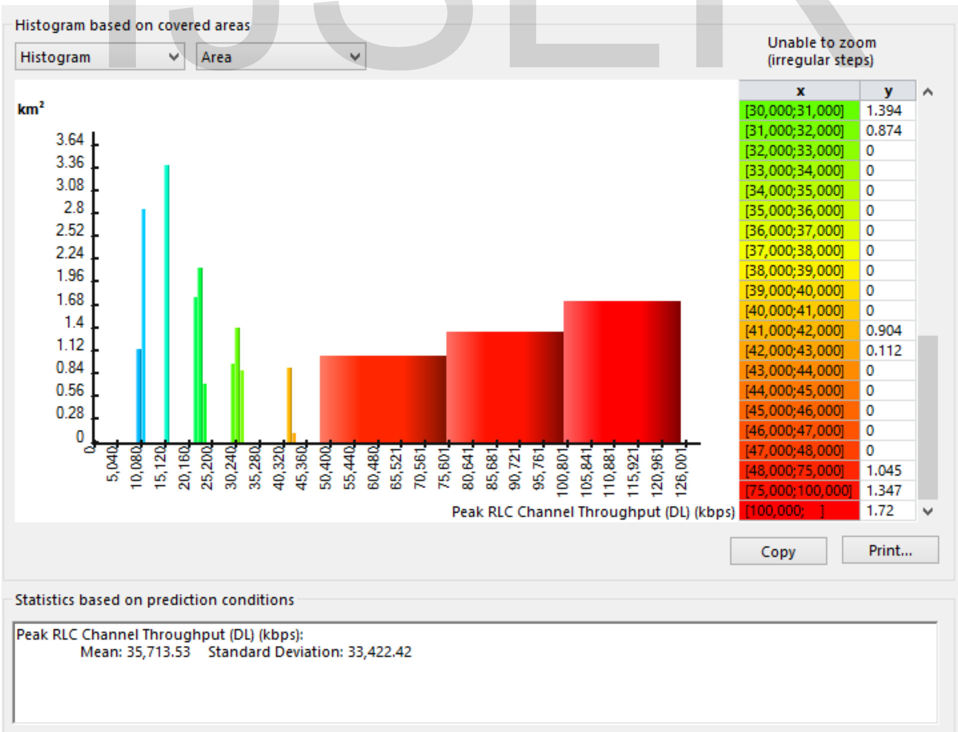

Figure 4.21: LTE Coverage area vs Throughput

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Chapter Five

5. Conclusions and Recommendations for Future Work

Conclusions

Network RF planning is the foundation of a mobile communication network, especially the wireless part of a mobile communication network and is of vital importance to network quality, so we must make a good planning at earlier stage, which is helpful for network expansion and service update in the future. The main motivation for this work was to generate tools and methods to be able to support multi-service radio network dimensioning and planning for multi radio access technology. Furthermore, understanding of the relevance of the radio network planning phase to the overall network performance was of interest.

The output of this planning process by using radio network prediction and simulation can verify and adjust the coverage and capacity planning results. The dimensioning output such as cell radius of sites and required number of sites are some of the main important factors for our final simulation results. The simulation output includes coverage prediction area with best signal level, signal reception level, detail parameter measurement, path loss measurement for a user at a point, throughput and quality per each radio access technology that verify the planned multi RAT radio network can handle the cellular traffic of Bahir Dar city for the next five and more years, since we used the real Bahir Dar digital map for working area of our inputs in Atoll.

In this thesis the result of our capacity and coverage dimensioning shows that, 50 WCDMA NodeB's are enough to cover the urban and sub-urban clutters of Bahir Dar city. From these 23 sites are planned for the urban 30 sq. km area and 27 sites are designed for the rest suburban 270 sq.km clutter. Besides 45 GSM BTS's are co-located with 45 WCDMA NodeB's. Specifically speaking 23 GSM BTS's are co-site with 23 WCDMA NodeB's in the urban area and 22 GSM BTS's are co-site with 22 WCDMA NodeB's in the suburban area, Thus 2 UMTS only NodeB's are found in urban clutter and 3 UMTS only NodeB's are found in sub-urban clutter. LTE is designed for data only services in the urban clutter only and it is co-located with 19 GSM-UMTS sites in the urban clutter.

Hence the overall output of our Multi RAT simulation results, fulfill nominal radio network dimensioning and planning design requirement of this thesis.

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Recommendations for Future Work

3GPP technologies have evolved from GSM-EDGE, to UMTS-HSPA-HSPA+, to LTE and soon LTE-Advanced, in order to provide increased capacity and user experience. But even with these technology evolutions, the exponential rate of growth in wireless data usage puts further pressure to continue driving innovations into the 3GPP family of technologies.

With the multiple new technologies, LTE is well positioned to meet the requirements of next generation mobile network from both the users and the operators. LTE is well checked to provide greatly improved user experience, delivery of new revenue generating mobile services and will remain a strong advantage to other wireless technologies in the next decade. It will also enable the operators to offer higher performance, mass-market mobile broadcast services, through a combination of high bit-rates and system throughput with low latency in both uplink and downlink directions.

Our designed Multi RAT network is based on 3GPP standard it gives easy and smooth transition towards LTE-advanced and future technologies and thus it can reduce the CAPEX of the operator. In our case as the city is grown faster even the planned Multi RAT network may suffer to give high data rates for indoor users at some point since the network is designed using macro base stations. Hence deployment of 3G and LTE femtocells known as home evolved node base station (HeNB) in dead-zone areas of the city can satisfy customer indoor needs since studies on wireless usage show that more than 50% of all voice calls and more than 70% of data traffic originates indoors. This solution is especially attractive for those homes where the signal from the macro cell cannot penetrate the home due to difficult radio propagation conditions. Thus, in situations like these, the user equipment would use the femtocell base station instead of a macro cell base station thereby achieving a superior connection.

Reducing load on the existing macro network by offloading traffic to femtocells also helps to improve performance of the macro cell users at the same time reducing the capital and operating expenditure of the operator. Hence indoor planning using LTE femtocell is an interesting area of future research work for Bahir Dar city.

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