



ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

**Long Term Evolution (LTE) Radio Network Dimensioning:
Case of Addis Ababa City**

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A Thesis Submitted to the School of Electrical and Computer Engineering of Addis
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Abstract

With increasing demand for wireless services, the capacity of 2G and 3G networks is reaching saturation point. To deal with the shortage of mobile network resources, 3GPP has proposed Long Term Evolution (LTE) technology. But radio network planning is a challenge especially radio network planning for a densely populated city adds to certain level of complexity in the overall work in terms of proper resource management and capacity as well as coverage requirement fulfillment.

Ethio Telecom introduced LTE technology for Addis Ababa city to achieve the goal of Growth and Transformation Plan (GTP) of the country in 2015. The current LTE infrastructure consists of 329 sites from which 222 sites covered the dense urban area and the rest cover the hotspots of urban area to provide service for 400,000 subscribers. There is no doubt that the deployed LTE as pilot will be expanded to cover the whole of Addis Ababa city and to other city to align with the evaluation of technology.

In this paper, a detailed LTE radio network planning procedure has been elaborately presented which concentrates on nominal and detailed planning considering possible network implementation in the most populated city of Addis Ababa with area of 460 km². The possible parameters for link budget, capacity, frequency and coverage were collected from marketing department, standards and existing network for the purpose of theoretical analysis and simulations.

The propagation modeling is done using COST231-Model with inclusion of additional parameters obtained from the real environment i.e. terrain model which improves the coverage estimation. The simulation was performed using ATOLL program to evaluate the traffic demand throughput and to estimate the signal strength per pixel to ensure the coverage and capacity of the target area.

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List of Acronyms

2G	2 nd Generation
3G	3 rd Generation
4G	4 th Generation
3GPP	3rd Generation Partnership Project
ADSL	Asymmetric digital subscriber line
AFP	Automatic Frequency Planning
AMC	Adaptive Modulation and Coding
AMPS	Advanced Mobile Phone System
AS	Access Stratum
BH	Busy Hour
BLER	Block Error Rate
CDMA	Code Division Multiple Access
CP	Cyclic Prefix
CRBT	Call Ring Back Tone
DL	Downlink
DL-SCH	Downlink Shared Channel
DTM	Digital Terrain Map
EDGE	Enhanced Data Rates for GSM Evolution
EIRP	Effective Isotropic Radiated Power
eNB	Enhanced NodeB (interchangeably used as base-station)
EPC	Evolved Packet Core
EUTRA	Evolved UMTS Terrestrial Radio Access
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
FDD	Frequency Division Duplex

FDMA	Frequency Division Multiple Access
FTP	File Transfer Protocol
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
GTP	Growth and Transformation Plan
HARQ	Hybrid Automatic Repeat reQuest
HSPDA	High-Speed Downlink Packet Access
ICI	Inter Carrier Interference
ICIC	Inter-Cell Interference Coordination
IMT	International Mobile Telecommunication
ISI	Inter Symbol Interference
LTE	Long Term Evolution
MAC	Media Access Control
MBMS	Multimedia Broadcast Multicast Services
MIMO	Multiple Input Multiple Output
MME	Mobile Management Entity
MTCH	Multicast Traffic Channel
NAS	Non Access Stratum
NGN	Next Generation Network
NNOC	National Network Operation Center
OFDM	Orthogonal Frequency-Division Multiplexing
OFDMA	Orthogonal Frequency-Division Multiple Access
PAPR	Peak Average Power Ratio
PAPR	Peak-to-average Power Ratio
PAPR	Peak to Average Power Ratio

PDN	Packet Data Network
PMIs	Pre-coding Matrix Indicators
PRB	Physical Resource Block
P-SCH	Primary Synchronize
QAM	Quadrature Amplitude Modulation
QoS	Quality of Services
RF	Radio Frequency
RLC	Radio Link Control
RLC	Radio Link Control
SC-FDMA	Single-Carrier Frequency-Division Multiple Access
SINR	Signal to Interference and Noise Ratio
S-SCH ID	Secondary Synchronize
TDD	Time Division Duplex
TMA	Tower mounted Amplifier
TTI	Transmission Time Interval
UE	User Equipment
UL	Uplink
UL-SCH	Uplink Shared Channel
UMTS	Universal Mobile Telecommunications System
VoIP	Voice over Internet Protocol
VSAT	Very Small Aperture Terminal
WCDMA	Wideband Code Division Multiple Access
WIMAX	Worldwide Interoperability for Microwave Access

1. Introduction

Ethio Telecom is a government owned Telecom Company born from the ambition of the Ethiopian government to provide a world-class telecom services for the country and serve the Ethiopian citizen by being a customer centric company. The mobile communication services were introduced in the year 2000 using second-generation (2G) Global System for Mobile Communications (GSM) standard and network equipment were supplied by Ericsson and Nokia-Siemens and initial deployment done for the city of Addis Ababa and by 2005, the network was expanded to cover tourist destinations across the country.

In 2007, as part of the *Ethiopia Millennium Project*, the next generation network (NGN) was launched to expand and upgrade Ethiopia's network, which also includes the associated rollout of mobile coverage in *rural areas* and was deployed by ZTE Company. The NGN project introduces new technology, system application and services such as third generation (3G) WCDMA and CDMA 2000 mobile network infrastructures (3G available in Addis Ababa), call center, billing system and value added services (CRBT, GPRS, NNOC and short code services). As a result of these expansions, the number of mobile subscribers has exponentially increased and the prevailing data indicates over 20 million subscribers.

With increasing demand for wireless services, the capacity of 2G and 3G networks is reaching saturation point. To deal with the shortage of mobile network resources, 3GPP has proposed Long Term Evolution (LTE), and this is now developing from theory into practice [1] and Ethio Telecom introduced this technology for Addis Ababa to achieve the goal of Growth and Transformation Plan (GTP) of the country [2]. With powerful service bearing capability, efficient resource utilization, low network construction and operation costs, and flexible network deployment, LTE has won favor from leading operators around the world.

With 3GPP freezing Release 8 in 2008, LTE standards are now in a mature state. LTE systems adopt advanced radio link technologies in the air interface, including orthogonal frequency-division Multiplexing (OFDM), multiple-input multiple-output (MIMO), adaptive modulation and coding (AMC), and Hybrid Automatic Repeat reQuest (HARQ) [3,4,5]. From the perspective of LTE network design, these technologies and algorithms improve network performance but increase system complexity as well.

1.1 Problem Statement

Ethio Telecom invested millions of dollars to introduce different technologies and services at different times. Telecommunication *sub-sector development* part of the Growth and Transformation Plan (GTP) of Ethiopia launched in 2010, among other things, demands embracing the latest information technologies of project increases the capacity of mobile subscribers to 59 million while it enables the telecom utility to offer the state of the art 4G mobile technology services in the capital Addis Ababa.

But the company did not meet the required service quality level starting from 2G and this mainly related to the planning problem of the radio network. The problems corresponding to radio network planning (capacity and coverage) are:-

- Network busy
- Mute while in communication
- Cross talk
- Un able to connect
- Network coverage
- Blocking of signal due to building

The current trend of data users of Ethio Telecom increase from time to time and the problem related to the fixed line data (ADSL, VSAT,..) such as power problem, cable cut and theft direct the company to focus on the mobile technology to provide the data services and due to the above reason the customer complain is one pain for Ethio Telecom. To address the issue and to provide quality of data service coverage and capacity dimensioning should be properly done for LTE.

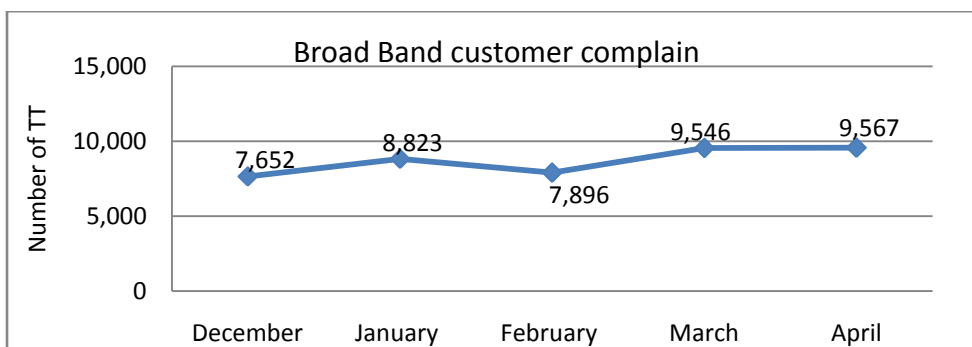


Figure 1-1 Number of customer complain for broad band service (Ethio Telecom, 2015)

1.2 Objectives

General Objectives

The general objective of this work is to come up with the detailed radio network planning guideline with respect to Addis Ababa city. With this mission ahead, in this paper a step by step method was followed starting from gathering preplanning information such as marketing requirement which go up to coverage and capacity analysis. Prior to that, a brief description of radio network planning methodology has been given.

Specific Objectives

- Explain LTE features relevant for the dimensioning
- Define the model and methods for LTE capacity and coverage estimation
- Explain the process of wireless network dimensioning
- Describe the link budget and propagation model for the LTE system
- Define system parameter and network parameters
- Design the radio network based on capacity, coverage and quality requirements
- Detailed planning and analysis using industry leading tool ATOLL

1.3 Scope

The capacity and coverage will be based on simulation of the proposed techniques using ATOLL tools and for this thesis, only the radio network dimensioning for LTE technology based on Addis Ababa area will be studied.

1.4 Literature Review

Factors to be considered to design the cellular network and the procedure are discussed and explained in detail for 2G and 3G [6]. Different steps of the dimensioning process are listed and explained and methods and models for coverage and capacity planning are developed for dimensioning of LTE radio access networks [7] and special emphasis is laid on radio link budget along with detailed coverage and capacity and the tool used for planning were Excel.

The LTE Radio network planning involves the coverage estimation, capacity evaluation and frequency planning using COST 231 W/I propagation model with selected area of Addis Ababa, 53 km² areas around National Hotel was done using MATLAB simulation [8].

Traditionally, the design objective is to determine the number and location of the radio access sites in order to satisfy certain coverage and capacity requirements with minimum deployment cost [9].

An analysis of practical coverage scenario in an urban area (i.e. Kolkata) in terms of received signal levels, total noise, interference, throughput, and quality factor for downlink signal level is shown in [10]. In [11] a detailed LTE radio network dimensioning procedure i.e. capacity and coverage analysis has been performed in order to prepare a radio planning guideline considering possible network operation in Dhaka city through link budget preparation along with link and system level simulations. For the densely populated city Dhaka, nominal and detailed radio planning stage has been covered in [12].

But the current work is different from [6-12], as it not only takes a different city for planning; but the operating frequency has also been taken as the currently available one in Addis Ababa i.e. 1800MHz. That makes the current analysis quite closer to the practical scenario.

For this thesis factors to be considered to design cellular network [6] will be fully considered and methods and models for coverage and capacity planning are considered for dimensioning of LTE radio access will be carried out using ATOLL radio network planning tool for radio network planning simulation.

1.5 Methodology

Radio Network Planning contains number of phases or procedures:

- Initial phase-which includes collection of pre-planning information and starting network dimensioning i.e. Link Budget preparation, coverage and capacity calculation by running simulations.
- Nominal and detailed planning- which includes selection and use of radio planning tool. This step involves propagation model tuning, defining thresholds from Link budget, creating detailed radio plan based on the thresholds, checking network capacity against more detailed traffic estimates, to meet all the above procedures, planning methodology is shown as follow in detail.

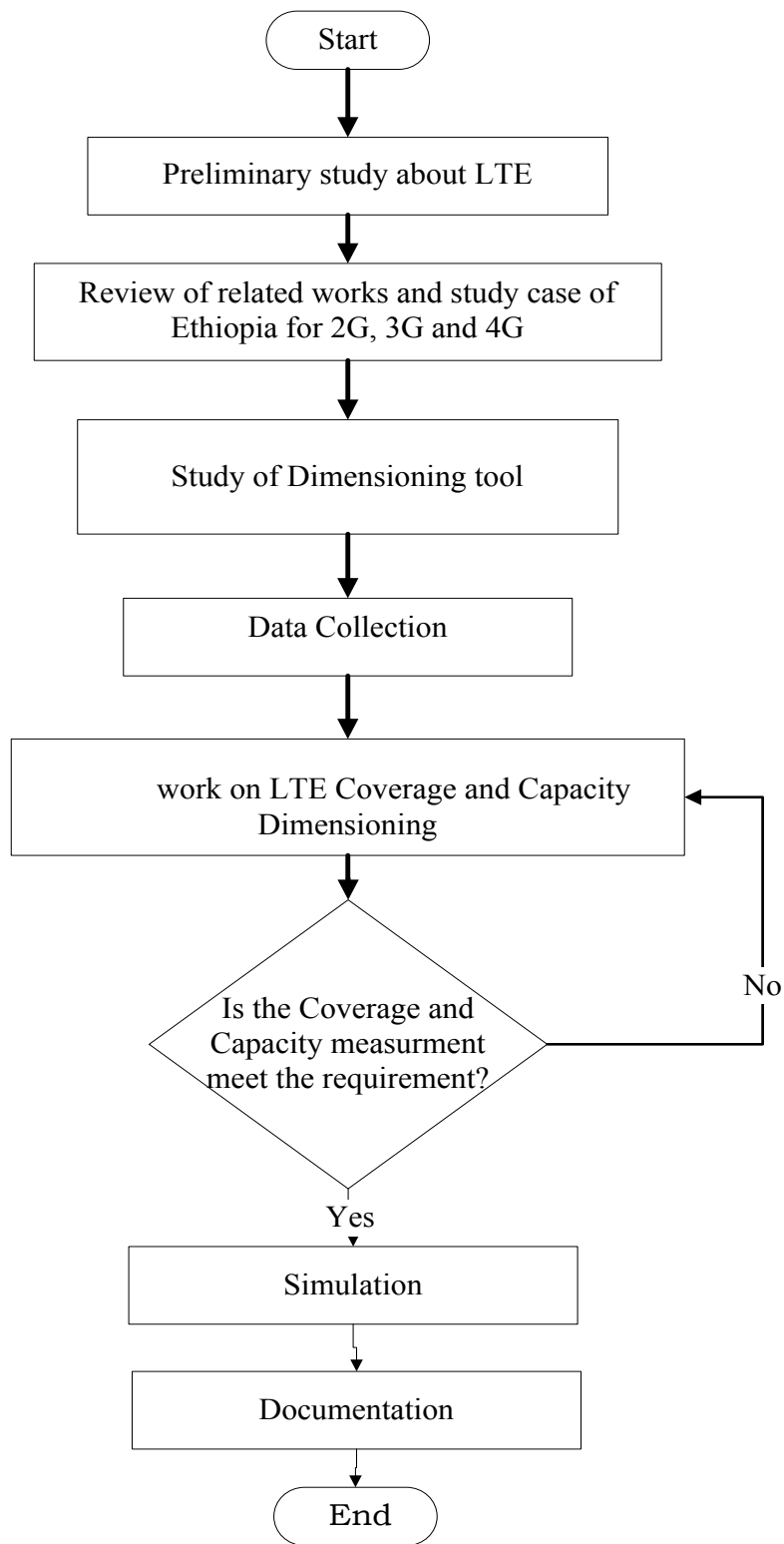


Figure 1-2 Project methodology and process

1.6 Thesis Layout

This thesis consists of six Sections. Section 1 defines the objective and approach and a short introduction is presented to the company where the thesis was made. Section 2 presents the theoretical fundamentals of LTE and it includes some of the key technologies in LTE which are related in this thesis and this gives background knowledge for further discussion. Section 3 describes the High Level Network Design Cycle of capacity and coverage planning in the LTE system in both downlink and uplink directions. Section 4 presents LTE network planning including coverage planning and capacity planning. Section 5 presents Simulation analysis and Result of the thesis and finally section 6 concludes with summary of the entire thesis and discusses possibilities of future research.

2. Technical Overview of Long Term Evolution of 3GPP (LTE)

2.1 Cellular Network Evolution

The first generation (1G) of the analog cellular networks was introduced as Advanced Mobile Phone System (AMPS) in early 1980s [13], which was based on Frequency Division Multiple Access (FDMA). In 1990s, the second generation (2G) of mobile phone system emerged, and it was based on Global System for Mobile Communications (GSM) in Europe and on Code Division Multiple Access (CDMA) in the USA. The 2G allowed limited data support compared to the second and a half generation (2.5G) networks that were extended from it. The 2.5G includes the General Packet Radio Service (GPRS), and it uses both circuit and packet switching; the former is used for voice, and the latter is used for data transmission. In fact, the high demand for data services and higher speeds led to the evolution of the third generation (3G) which also uses packet switching instead of circuit switching for data transmission, but can provide services with higher efficiency, better streaming services, and faster web browsing than 2.5G. During the recent years, 3G networks were overwhelmed by the amount of growth in services and applications such as media streaming [1, 13, 14]. Hence, the fourth generation (4G) was introduced and two competing standards were proposed: WiMAX and Long Term Evolution (LTE). It eliminated circuit switching and utilized packet switching efficiently over the Internet to provide users with better performance.

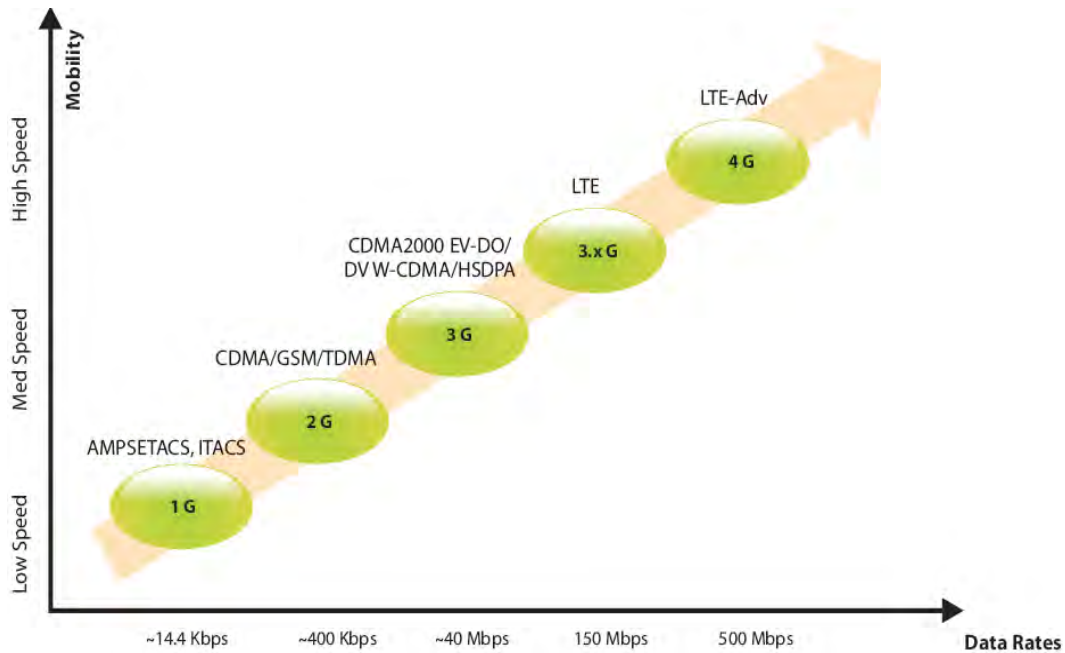


Figure 2-1 Evolution of 4G network based on data rates

LTE provides many benefits like high-speed data, bandwidth efficiency, latency, multimedia unicast and multimedia broadcast services to cellular networks [6] and can be summarized as:

- **Performance.** The 4G systems are intended to provide high quality video services providing data transfer speeds of about 100 Mbps.
- **Bandwidth.** The 4G technology offers transmission speeds of more than 20 Mbps and is capable of offering high bandwidth services within the reach of local area network (LAN) hotspots, installed in airports, homes and offices.
- **Interoperability.** The existence of multiple standards for 3G made it difficult to roam and interoperate across networks. There is therefore a need for a global standard providing global mobility and service portability so that the single-system vendors of proprietary equipment do not bind the customers.
- **Technology.** Rather than being an entirely new standard, 4G basically resembles a conglomeration of existing technologies and is a convergence of more than one technology.

2.2 3GPP Release Overview

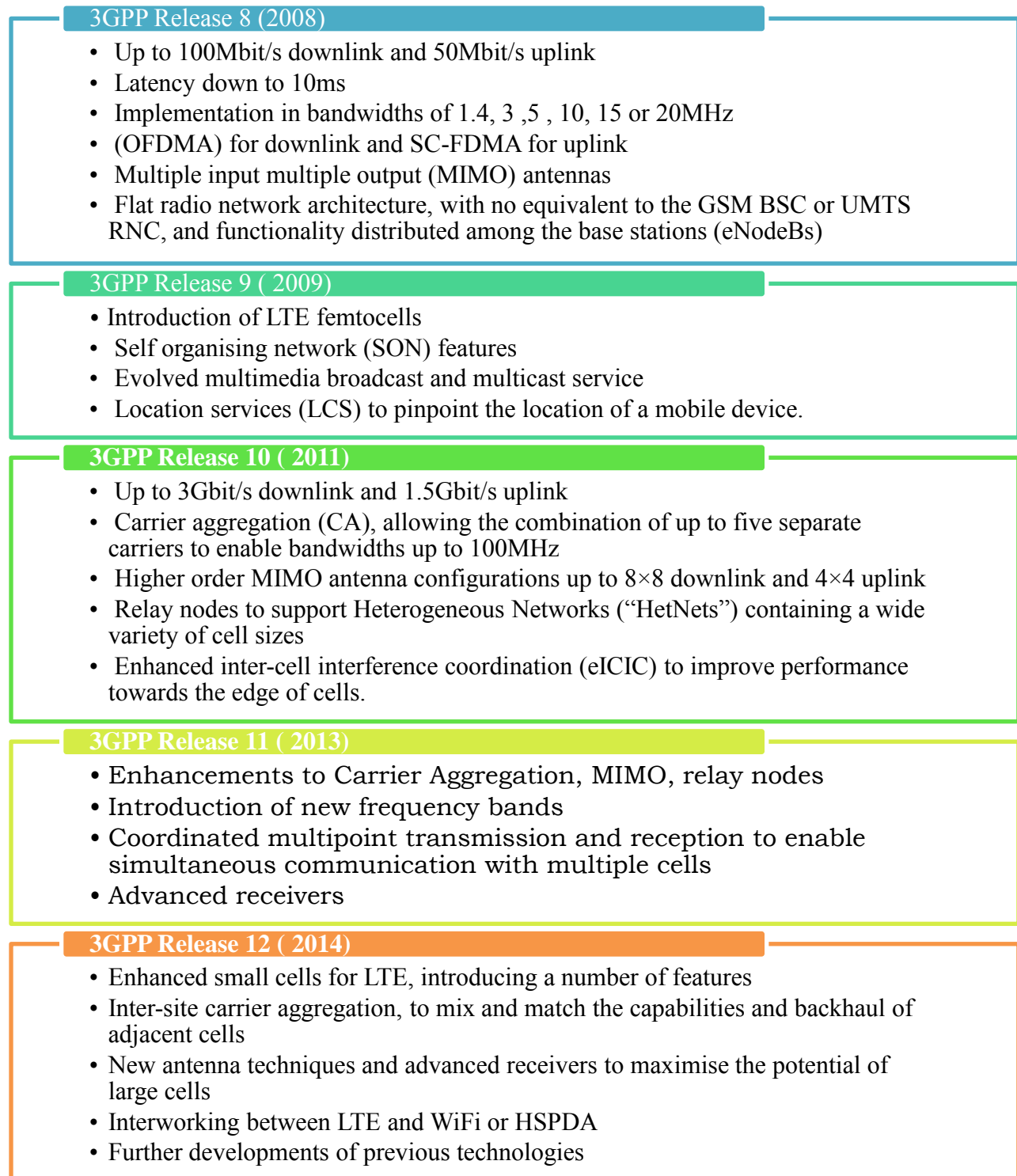


Figure 2-2 LTE 3gpp releases and features

2.3 LTE Technical Overview

LTE Architecture

LTE is the evolution of the radio access Universal Mobile Telecommunications System (UMTS) known as Evolved UTRAN (E-UTRAN), whereas the evolution of the non-radio part including the Evolved Packet Core (EPC) network is referred to as the System Architecture.

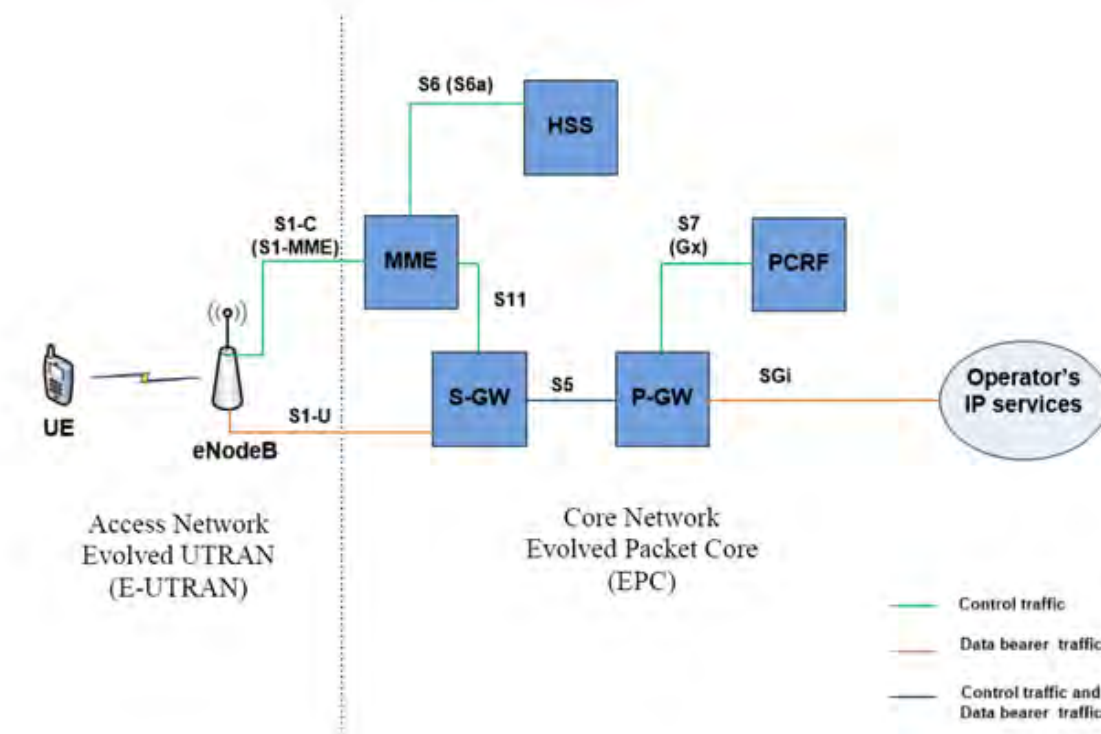


Figure 2-3 Typical architecture of LTE networks

The architecture of the core network is a little bit more complex as is it composed of different pieces of equipment. As shown in Figure 2-3, the EPC is composed of five main nodes which are as follows [15].

UE Categories

The UE categories stand for an abstract grouping of common UE radio access capabilities and are defined in 3GPP 36.306. In particular, the handset-type groups vary in maximum possible throughput (the maximum number of DL-SCH transport blocks bits received within a Time Transmission Interval (TTI)). Assuming a TTI of 1ms for category 1, the maximum possible throughput is 10296 bits/1ms which is approximately 10Mbps of physical layer DL throughput including the RLC/MAC header information so the payload throughput will be slightly less.

Category 5 mobiles are the only handsets that support 64 Quadrature Amplitude Modulation (QAM) on the UL.

UE category	Maximum number of UL-SCH transport block bits received within a TTI	Maximum number of bits of a DL-SCH transport block received within a TTI	Approximate maximum bit rate DL (Mbps)
Category 1	10296	10296	10
Category 2	51024	51024	50
Category 3	102048	75 376	75
Category 4	150752	75 376	75
Category 5	302752	151 376	150

Table 2-1 UE categories and DL capabilities (according to 3GPP 36.306)

Serving Gateway (S-GW):- It is the local mobility anchor that holds data when the UE are moving between eNodeBs during handover and deals with the user plane. S-GW is the connection between the radio part and the EPC. It is the hub on which all IP packets are transferred through; it transports the IP data traffic between UE and the external networks. Moreover, it keeps information about the bearers when the UE is idle and it works as a buffer for downlink data when the MME is initiating paging of the UE for bearers' reestablishment. S-GW has different administrative tasks in the network; it gathers data for charging such as the traffic on the link whether sent or received by a user. In addition, it works as mobility anchor for internetworking with other 3GPP technologies like UMTS and GPRS. Logically, this gateway is connected to the PDN gateway.

Packet Data Network (PDN) Gateway (P-GW): It is the interconnection point between the EPC and the external IP networks and it is mainly in charge of assigning and distributing the IP addresses for the UE, besides enforcing the QoS and flow based charging that is based on PCRF rules. The PDN gateway has the responsibility to distribute and sort out the IP packets in the downstream into different QoS based channels and bearers based on the Traffic Flow Templates (TFTs). It also has the ability to work as a mobility anchor for internetworking with non 3GPP

technologies like High Rate Packet Data (HRPD) (aka 1xEV-DO) and WiFi. P-GW is considered the default gateway as well; it performs packet filtering and lawful interception which includes analyzing the signaling data in addition to the network management information.

Mobility Management Entity (MME): It is the control node that is responsible for the signaling between the UE and the core network. It deals with the control plane, and it is considered the termination point of the Non Access Stratum (NAS) which plays a key role in initiating and maintaining the EPS bearers. It has a major role in registering UE in a network, handling mobility functions between UE and core network, and creating and keeping IP connectivity. NAS is carried over LTE-Uu which is the air interface between UE and eNB and the S1-MME interfaces between the eNB and the MME. On the other hand, Access Stratum (AS) protocols are those that run between eNodeBs and UE. In conclusion, NAS functions between a core network and the user equipment; whereas, AS functions between the radio network and the user equipment. There are two classifications for the main functions supported by the MME: (15) bearer management and (16) connection management. The former is handled by the session management layer in the NAS protocol and is related to the establishing, maintaining and releasing bearers; but the latter is handled by the connection or mobility management layer in the NAS protocol and is related to establishing connection between the network and the UE along with providing security. In fact, the MME is responsible for [16]: (15) distributing the paging messages to the eNBs, (16) security, (17) mobility control for users in idle state, control of bearers, and protecting NAS signaling integrity and ciphering.

Home Subscriber Server (HSS): It holds dynamic information to keep track of the MME identities to which users are connected. HSS also includes data for the user's System Architecture Evolution (SAE) subscription such as the QoS profile and any roaming access restrictions. Moreover, it has the Packet Data Network (PDNs) information that allows users to connect to the PDN such as Internet, IM. It also plays a role in authentication and security due to its ability to integrate the Authentication Center (AuC) which formulates security keys and authentication vectors.

Policy Control and Charging Rules Function (PCRF): One of its tasks is to control the Policy Control and Charging Enforcement Function (PCEF) functionalities that are flow-based and residing in the P-GW. The QoS authorization, which is consisting of the QoS Class Identifiers

(QCI) and bit rates, defines the PCEF treatment for certain data flows in harmony and agreement with the user's subscription profile.

As shown in Figure 2.3, the names of the interfaces are standardized [18]. The S1-U interface connects the eNB and the S-GW for user plane traffic (i.e. bearers' tunneling, inter-eNB handover), also the S1-C (currently referred to as S1-MME) connects the eNB with the MME for control processes and signaling messages between the eNB and the MME. S11 connects the MME to the S-GW, S6 (currently referred to as S6a) connects the MME and the HSS, and S5 connects the S-GW to the P-GW. In addition to that, the S7 (currently referred to as Gx) connects the P-GW (PCEF) to the PCRF, and the S-Gi is the interface between the P-GW and the packet data network such as Internet or IMS (IP Multimedia Subsystem).

The architecture of the access network is pretty simple as it is composed of a single type of node called enhanced NodeB (eNodeB or eNB). These advanced base stations are used to connect the User Equipment (UE) to the network. The E-UTRAN is considered a flat architecture because it has no centralized controllers. As shown in Figure 2.4, the E-UTRAN architecture consists of a network of eNodeBs that are interconnected with each other by X2 interfaces that allow communication between the different eNBs and connected to the EPC by S1 interfaces; S1-U user plane interface used between the eNB and the S-GW and S1-C (S1-MME) interface which allows communication between the eNB and the MME.

All the following active UE radio functions are run by the E-UTRAN [13] [14]: (13) IP packet header compression; (14) Security and data encryption; (15) Connecting to the EPC which includes.

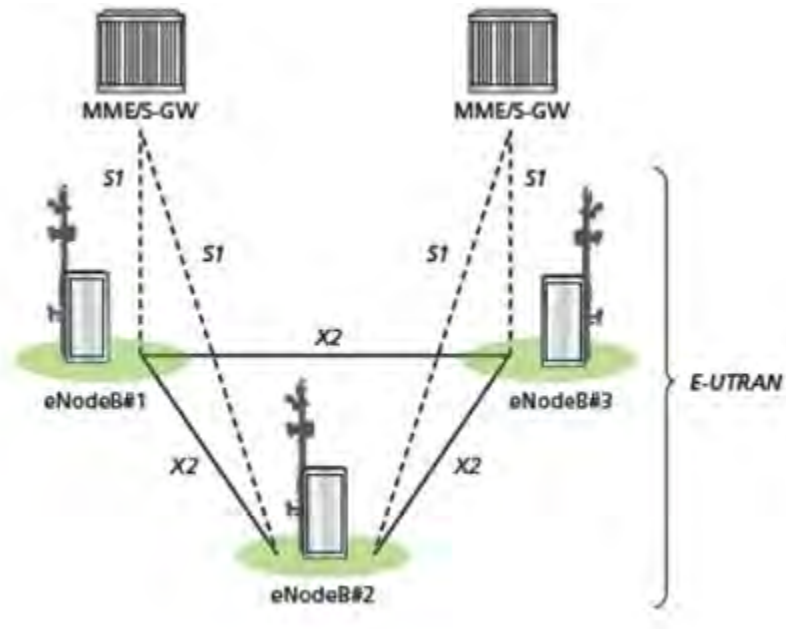


Figure 2-4 LTE access network

The eNB is connected to the core network on the S1 interface. The S1 interface allows the eNB to communicate with the Mobility Management Entity (MME) via the S1-MME interface and the Serving Gateway (SGW) via the S1 interface. The interfaces support a many to many relationship between eNB and SGW/MME.

The eNB are also networked together using the X2 interface. The X2 interface is based on the same set of protocols as the S1 and is primarily in place to allow user plane tunneling of packets during handover to minimize packet loss.

2.4 LTE Channels and Channel Mapping

Information, both signaling and user, is transmitted through the protocol stack and over air using channels. There are 3 basic types of channel defined, Logical, Transport and Physical channels. Each channel is defined by a set of functions or attributes which determines the handling of the data over the radio interface [4].

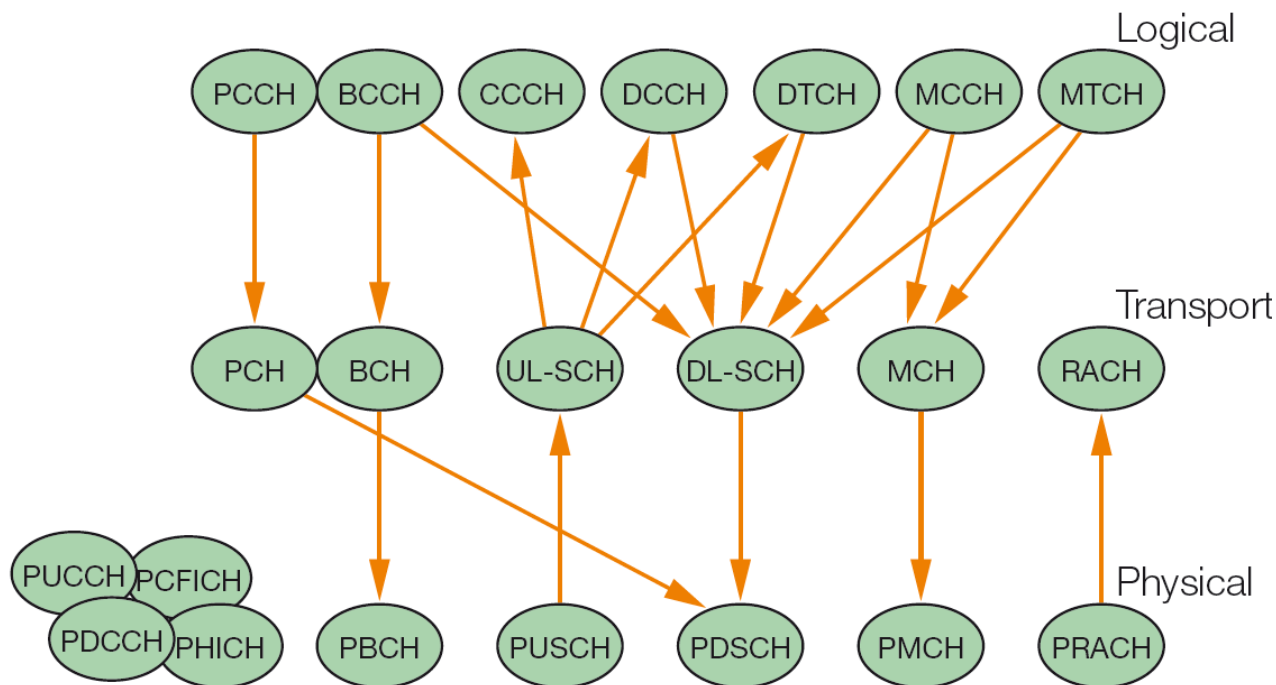


Figure 2-5 Logical to Transport Channel Mapping

Logical Channels

Logical Channels exist between the Packet Data Convergence Protocol (PDCP) layer and MAC, they are principally defined by the type of information that they carry. There are two types of logical channel: control channels and traffic channels. Control channels are used for transfer of control plane information only. The control channels offered by MAC are [19]:

Broadcast Control Channel (BCCH): A downlink channel for broadcasting system control information. Information broadcast on this channel is shared by all the users in the cell, the information broadcast relates to the Operator identity, cell configuration, access information etc.

Paging Control Channel (PCCH): A downlink channel that transfers paging information. This channel is used when the network does not know the location cell of the UE.

Common Control Channel (CCCH): Channel for transmitting control information between UEs and network. This channel is used for UEs having no RRC connection with the network. It would be used during the earliest phases of communication establishment.

Multicast Control Channel (MCCH): A point-to-multipoint downlink channel used for transmitting MBMS control information from the network to the UE, for one or several MTCHs. This channel is only used by UEs that receive MBMS.

Dedicated Control Channel (DCCH): A point-to-point bi-directional channel that transmits dedicated control information between a UE and the network. UEs having an RRC connection

will exchange RRC and NAS signaling, it should be noted that application level signaling (SIP messages from the IMS) is not handled by the DCCH.

Traffic channels are used for the transfer of user plane information only. The traffic channels offered by MAC are:

Dedicated Traffic Channel (DTCH): A Dedicated Traffic Channel (DTCH) is a point-to-point channel, dedicated to one UE, for the transfer of user information. The DTCH will also carry signaling from the application layers, this may be SIP and RTSP signaling if the EPC supports IMS (IP Multimedia Subsystem).

Multicast Traffic Channel (MTCH): A point-to-multipoint downlink channel for transmitting traffic data from the network to the UE. This channel is only used by UEs that receive MBMS.

Transport Channels

Transport Channels exist between the MAC layer and the Physical Layer and are define the manner in which the data will be transferred, i.e. the type of channel coding, whether the data is protected from errors, size of data packets, etc. The attributes of data transfer applied to the data in the transport channel is otherwise known as the transport format.

Transport channels are classified in to uplink and downlink channels and are described below [19].

Broadcast Channel (BCH): The BCH has a fixed and pre-defined transport format largely defined by the requirement to be broadcast in the entire coverage area of the cell since the information carried by this channel contains system information.

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

Paging Channel (PCH): This channel is associated with the PCCH and will carry paging message to UEs not currently connected to the network. The PCH supports discontinuous reception (DRX) to enable UE power saving where the sleep cycle is indicated by the network to the UE. The PCH may also have to be broadcast in the entire coverage area of the cell. The PCH

is also mapped to physical resources which can be used dynamically also for traffic/other control channels.

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

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

Random Access Channel (RACH): The RACH is a very specific transport channel and carries limited control information during the very earliest stages of connection establishment. This a common uplink channel therefore there is the risk of collisions during UE transmission.

Physical Channels

Physical Channels [19] are the actual implementation of the transport channels in the physical layer. They only exist in the physical layer and depend on the physical layer characteristics, i.e. channel bandwidth, FFT size, etc.

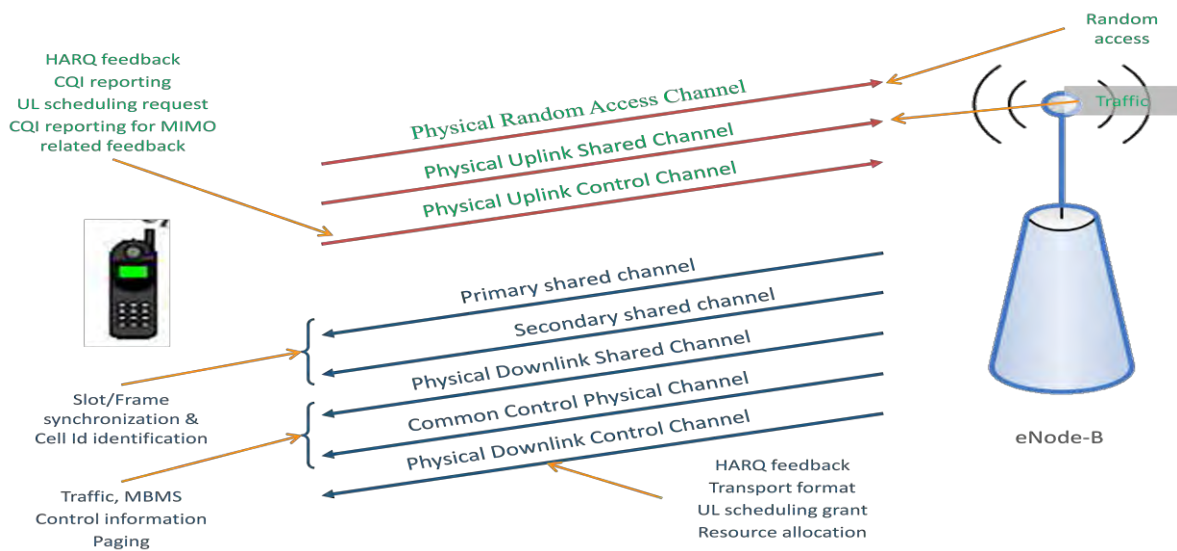


Figure 2-6 Uplink and downlink physical channels

Physical Broadcast Channel (PBCH): The system information is transmitted cyclically within BCH transport block and mapped to four sub frames over a 40 ms interval. There is minimal synchronization from the UE perspective since the 40 ms timing is blindly detected i.e. there is no explicit signaling indicating 40 ms timing. Each sub frame is assumed to be self-decodable

i.e. the BCH can be decoded from a single reception, assuming sufficiently good channel conditions.

Physical Control Format Indicator Channel (PCFICH): This channel informs the UE about the number of OFDM symbols used for the PDCCHs and is transmitted in every sub frame.

Physical Downlink Control Channel (PDCCH): This channel informs the UE about the resource allocation of PCH and DL-SCH, and Hybrid ARQ information related to DL-SCH and also carries the uplink scheduling grant.

Physical Hybrid ARQ Indicator Channel (PHICH): Carries Hybrid ARQ ACK/NAKs in response to uplink transmissions.

Physical Downlink Shared Channel (PDSCH): Carries the DL-SCH and PCH.

Physical Multicast Channel (PMCH): Carries the MCH, Multicast and Broadcast information

Physical Uplink Control Channel (PUCCH): This channel carries uplink control information such as Hybrid ARQ ACK/NAKs in response to downlink transmission, carries Scheduling Request (SR) and, CQI reports.

Physical Uplink Shared Channel (PUSCH): Carries the UL-SCH, user data and application level signaling.

Physical Random Access Channel (PRACH): Carries the random access preamble sent by the UE to initiate and RRC connection.

2.5 LTE Physical Layer

OFDM uses a large number of narrow sub-carriers for multi-carrier transmission. The basic LTE downlink physical resource can be seen as a time-frequency grid, as illustrated below. A Resource Block corresponds to twelve OFDM sub-carriers during one 0.5 ms slot. The smallest unit that can be allocated by the scheduler is two consecutive Resource Blocks i.e. 12 subcarrier per 1ms [19, 20, 21].

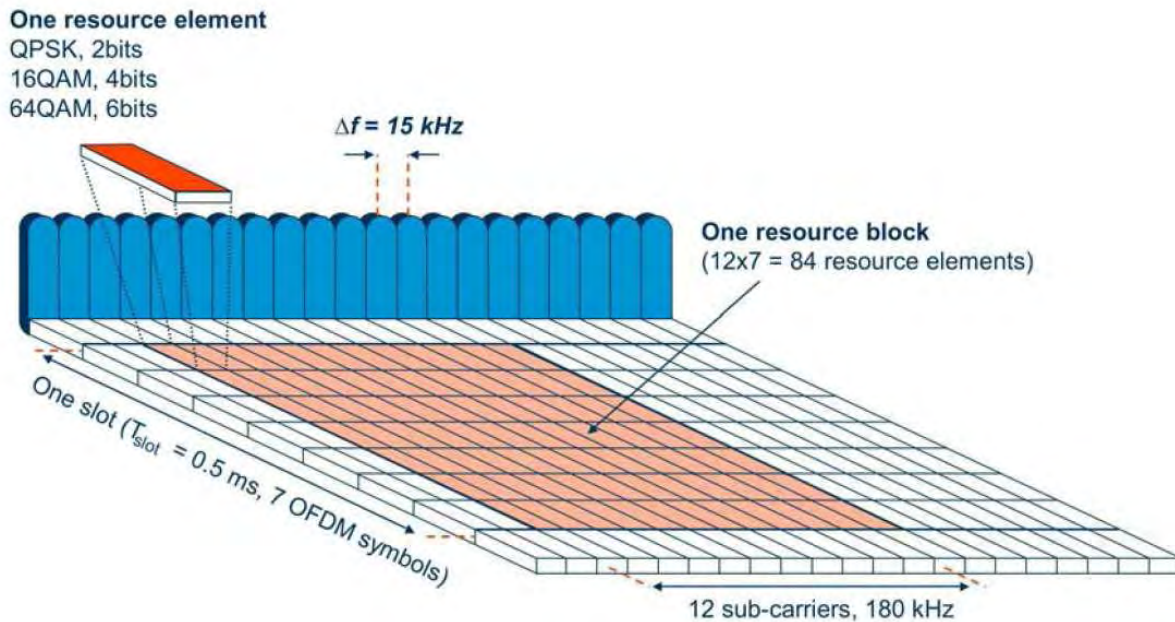


Figure 2-7 LTE downlink physical resource based on OFDM [20]

In the frequency domain, LTE have a constant spacing of $Df = 15 \text{ kHz}$. To each OFDM symbol, a cyclic prefix (CP) is appended as guard time. In addition, the OFDM symbol duration time is $1/Df + \text{cyclic prefix (CP)}$. One resource element carries QPSK, 16QAM or 64QAM with number of different bits. The OFDM symbols are grouped into resource blocks. A resource block is the smallest unit of bandwidth assigned by the base station scheduler. The resource blocks have a total size of 180 kHz with 12 subcarriers in the frequency domain and 0.5 ms with 7 OFDM symbols with the normal CP in the time domain. Each 1 ms Transmission Time Interval (TTI) consists of two slots. Each user is allocated a number of resource blocks in the time–frequency grid. The more resource blocks a user gets, and the higher the modulation used in the resource elements are, the higher the bit-rate becomes.

Channel bandwidth [MHZ]	1.4	3	5	10	15	20
Number of resource blocks	6	15	25	50	75	100

Table 2-2 Number of resource blocks for different LTE bandwidths (FDD and TDD) [18]

Hence, the building block of LTE is a physical resource block (PRB) and all of the allocation of physical resource blocks (PRBs) is handled by a scheduling function at the 3GPP base station (eNodeB). In summary:

- One frame is 10ms and it consists of 10 sub-frames
- One sub frame is 1ms and contains 2 slots
- One slot is 0.5ms in time domain and each 0.5ms assignment can contain N resource blocks [$6 < N < 110$] depending on the bandwidth allocation and resource availability.
- One resource block is 0.5ms and contains 12 subcarriers for each OFDM symbol in frequency domain.
- There are 7 symbols (normal cyclic prefix) per time slot in the time domain or 6 symbols in long cyclic prefix.

Sampling frequency varies under different bandwidth configuration in LTE and the table below summarizes the possible combinations [19].

Transmission BW [MHZ]	1.4	3	5	10	15	20
Sub-frame duration	1.0ms					
Sub-carrier spacing	15MHZ					
Sampling frequency (MHZ)	1.92	3.84	7.68	15.36	23.04	30.72
FFT size	128	256	512	1024	1536	2048
Number of occupied sub-carrier	72	180	300	600	900	1200
CP length (μ s)	Normal	4.69*6, 5.21*1				
	extended	16.6				

Table 2-3 Sampling frequency for different LTE bandwidths (FDD and TDD) [19]

2.6 Multicarrier Technology

LTE employs Orthogonal Frequency Division Multiple Access (OFDMA) for downlink data transmission and Single Carrier FDMA (SC-FDMA) for uplink transmission.

OFDM subdivides the bandwidth available for signal transmission into a multitude of narrowband subcarriers, arranged to be mutually orthogonal, which either individually or in

groups can carry independent information streams. In OFDMA, this subdivision of the available bandwidth is exploited in sharing the subcarriers among multiple users [15].

This resulting flexibility can be used in various ways:

- Different spectrum bandwidths can be utilized without changing the fundamental system parameters or equipment design.
- Transmission resources of variable bandwidth can be allocated to different users and scheduled freely in the frequency domain.
- Fractional frequencies re-use and interference coordination between cells is facilitated.

OFDM is a scheme that offers good resistance to multipath and is now widely recognized as the method of choice for mitigating multipath for broadband wireless. It can be straight forwardly extended to a multi-access scheme called OFDMA, where each user is assigned a different set of subcarriers.

OFDM was selected for the downlink because it can:

1) Improved spectral efficiency

OFDM increases spectral efficiency by incorporating multiple carriers in the same frequency space as a single carrier.

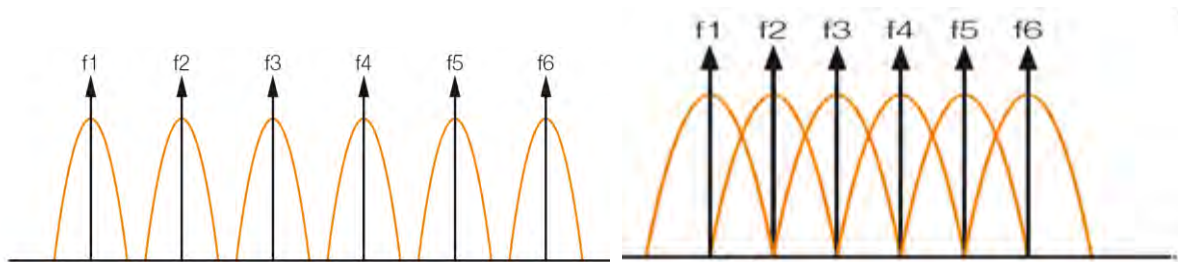


Figure 2-8 Traditionally Spaced FDM Channels versus Orthogonally Spaced FDM Channels (sub carriers)

2) Reduce ISI effect by multipath

Improvement of frequency spectral efficiency requires the reduction of Inter symbol interference (ISI). This is achieved by tighter frequency roll off and alignment of nulls and peaks between different frequencies.

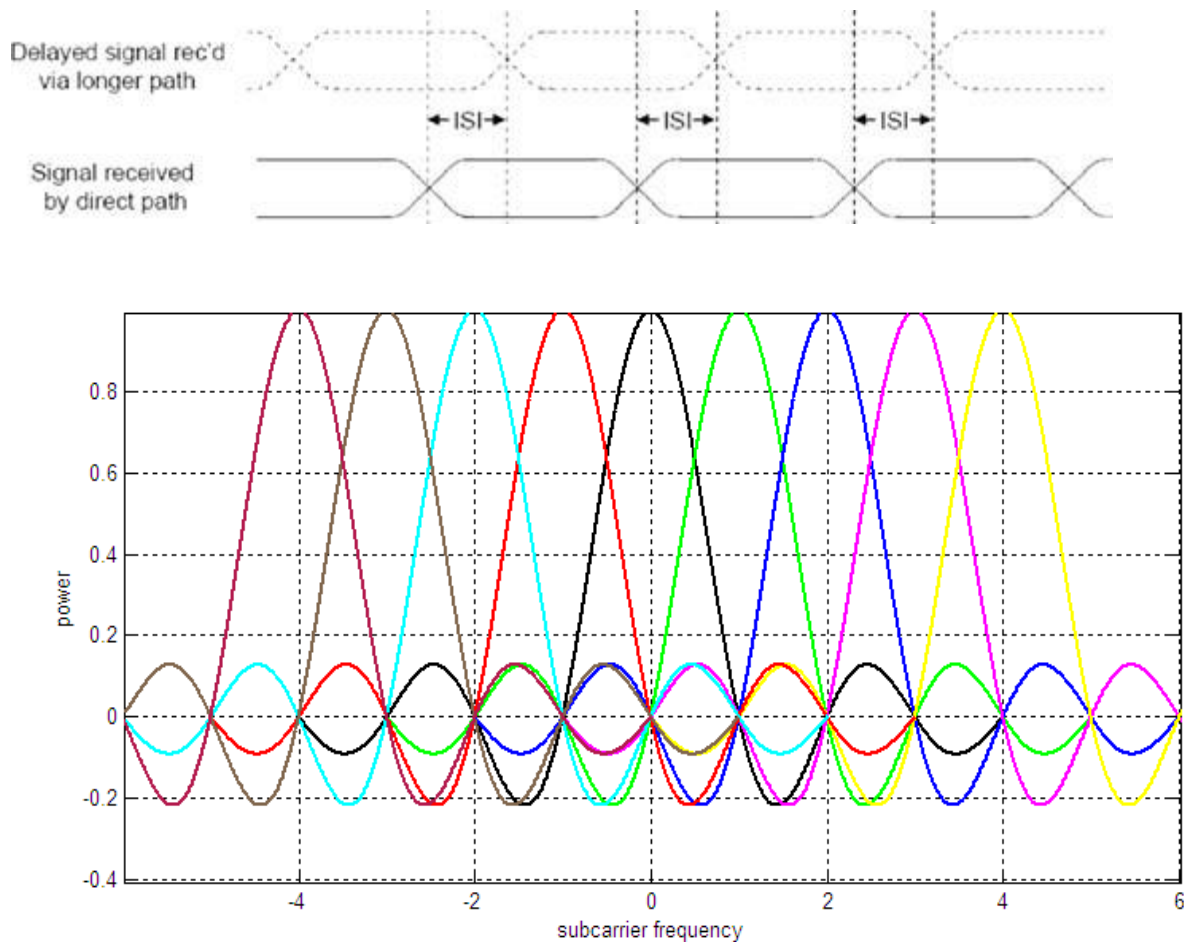


Figure 2-9 Orthogonality of subcarrier reduce ISI

3) Provide better Protection against frequency selective fading

Smaller subcarrier and resource block bandwidth increase robustness against frequency related fading.

With this smaller carrier bandwidth, the frequency coherence bandwidth is much smaller than 3G systems while correlation factor is much higher. As a result, it will also be much easier to implement scheduling algorithm based on Frequency Selective Scheduling to improve system throughput in the manner shown below.

3GPP has chosen SC-FDMA for the uplink. Not surprisingly, power consumption is a key consideration for UE terminals. The high Peak to Average Power Ratio (PARP) and related loss of efficiency associated with OFDMA are major concerns. As a result, an alternative to OFDM was sought for use in the LTE uplink.

SC-FDMA is well suited to the LTE uplink requirements because the data transmitted is consecutive and reduce PAPR. The basic transmitter and receiver architecture is very similar or

nearly identical to OFDMA, and it offers the same degree of multipath protection. Most important though is that the underlying waveform is essentially single-carrier, and therefore the PAPR is lower.

The figure opposite compares the OFDMA and SC-FDMA structures. For clarity this example uses only four (M) sub-carriers over two symbol periods with the payload data represented by quadrature phase shift keying (QPSK) modulation.

Data symbols in the time domain are converted to the frequency domain using a discrete Fourier transform (DFT) and then in the frequency domain they are mapped to the desired location in the overall channel bandwidth before being converted back to the time domain using an inverse FFT (IFFT). Finally, the CP is inserted. Because SC-FDMA uses this technique, it is sometimes called discrete Fourier transform spread OFDM or (DFT-SO-OFDM) [22, 19].

The most obvious difference between the two schemes is that OFDMA transmits the four QPSK data symbols in parallel, one per sub-carrier, while SC-FDMA transmits the four QPSK data symbols in series at four times the rate, with each data symbol occupying $M \times 15$ kHz bandwidth.

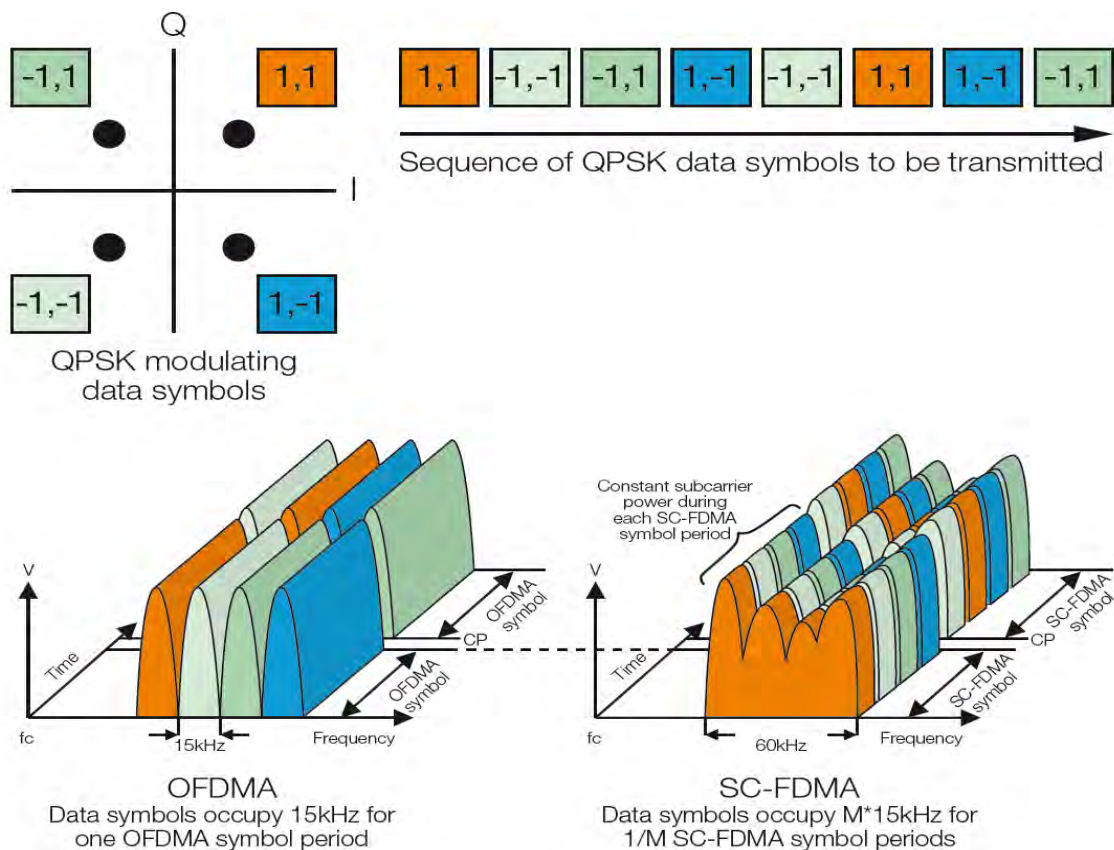


Figure 2-10 Comparison of how OFDMA and SC-FDMA transmit a sequence of QPSK data symbols

SC-FDMA signal generation begins with a special pre-coding process. The diagram opposite shows the first steps which create a time-domain waveform of the QPSK data sub-symbols. Using the four color-coded QPSK data symbols from the previous diagram, the process creates one SC-FDMA symbol in the time domain by computing the trajectory traced by moving from one QPSK data symbol to the next. This is done at M times the rate of the SC-FDMA symbol such that one SC-FDMA symbol contains M consecutive QPSK data symbols. Once an IQ representation of one SC-FDMA symbol has been created in the time domain, the next step is to represent that symbol in the frequency domain using a DFT.

To complete SC-FDMA signal generation, the process follows the same steps as for OFDMA. Performing an IDFT converts the frequency-shifted signal to the time domain and inserting the CP provides the fundamental robustness of OFDMA against multipath. The diagram opposite shows the stages in common with OFDM.

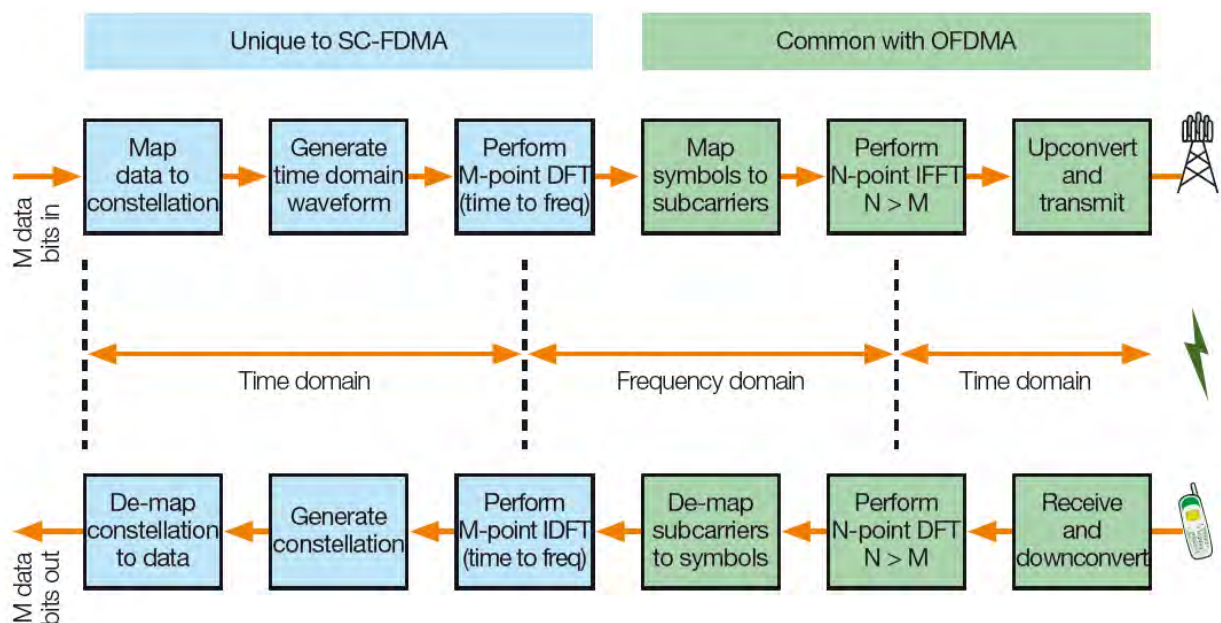


Figure 2-11 The SC-FDMA Block Diagram

Cyclic Prefix/Guard Time

The multi-path environment through which the radio signals propagate creates temporal distortions in the data carried by the radio channel. The differing propagation durations of each of the multi-path components create inter-symbol interference (ISI). Inter-symbol interference in OFDM systems cannot be tolerated since it reduces the orthogonality between the sub-carriers

and increases the BER and reduces the performance of the channel. All of the information important to the FFT (Fast Fourier Transform) is contained within the symbol time. Therefore it is critical that there is no distortion during this period.

Since the ISI cannot be eliminated from the channel, the information must be protected from its effect. The solution in OFDM systems is to extend the length of each symbol by a factor equivalent to the likely delay spread in the channel. This extension to the symbol is known as the cyclic prefix (CP) or guard time.

The CP, which appears at the beginning of each symbol, is actually a copy of the last part of that symbol. The inclusion of the guard period eliminates the effects of multi-path ISI at the expense of throughput, since the CP carries no actual information and is discarded at the receiver once the RF signal has been successfully digitized [19].

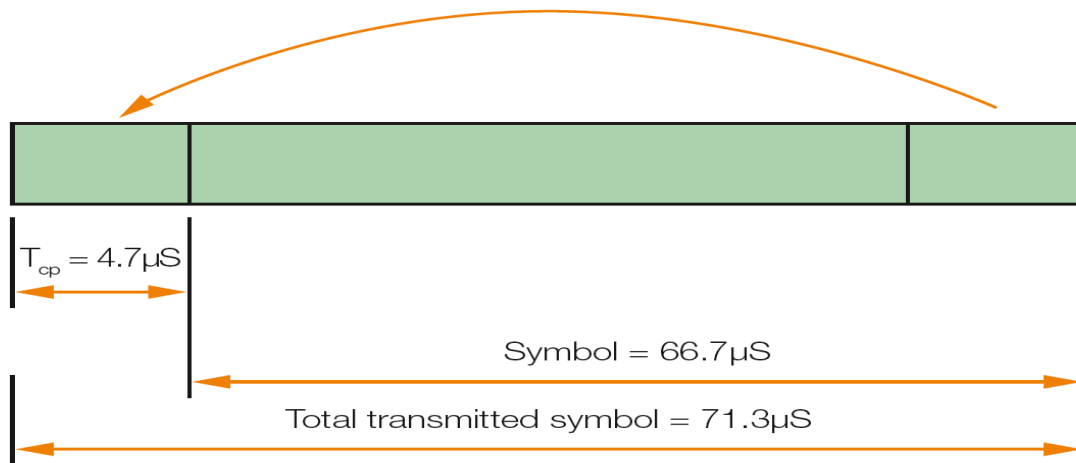


Figure 2-12 Symbol allocated for guard time

2.7 MIMO Technology

Due to the rapid development of wireless communications, customers have ever increasing requirements for system capacity and spectral efficiency. Various solutions to this problem, such as expanding the system bandwidth and increasing the modulation order, have emerged.

However, expanding the system bandwidth only increases system capacity without effectively increasing the spectral efficiency and increasing the modulation order increases the spectral efficiency only to a limited extent because the modulation order can hardly be doubled.

Multiple-input multiple-output (MIMO) was developed to provide more than double spectral efficiency [21]. As an extension of single-input single-output (SISO), MIMO uses multiple

antennas at the transmitter and/or receiver in combination with several signal processing techniques.

Generally speaking, single-input multiple-output (SIMO), multiple-input single-output (MISO), and beam forming are all categorized under MIMO.

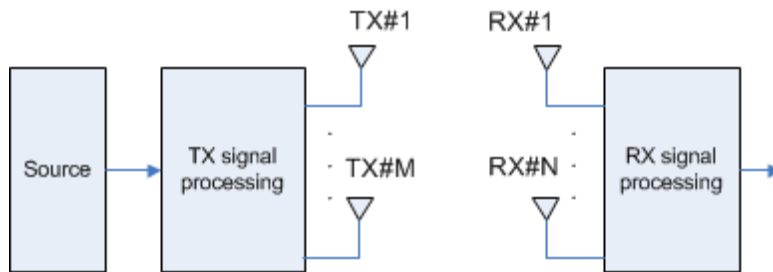


Figure 2-13 types of MIMO

Theoretically, channel capacity scales linearly with the minimum of the number of transmit and receive antennas deployed. By adopting specific signal processing techniques, MIMO improves radio link reliability and signal quality, which further helps increase system capacity, coverage, and user rate, and ultimately improve user experience and in addition MIMO also brings power gains, multiplexing gains, and diversity gains.

LTE systems use various MIMO techniques in both the uplink and downlink to increase spectral efficiency.

Downlink MIMO Techniques

Open-Loop MIMO and Closed-Loop MIMO: MIMO techniques are classified into open-loop MIMO and closed-loop MIMO based on whether UEs are required to report pre-coding matrix indicators (PMIs) for eNodeB downlink data transmission. Open-loop MIMO does not require UEs to report PMIs while closed-loop MIMO requires UEs to report PMIs.

Transmit Diversity and Spatial Multiplexing: In the downlink, MIMO techniques are classified into transmit diversity and spatial multiplexing based on the number of independent data streams transmitted over multiple antennas using the same time-frequency resource. When transmit diversity is adopted; only one data stream can be transmitted at each time. When spatial multiplexing is adopted, one or more data streams can be transmitted at each time.

When open-loop MIMO, closed-loop MIMO, transmits diversity, and spatial multiplexing is combined, MIMO techniques in the downlink are further classified into four categories: open

loop transmit diversity, closed-loop transmit diversity, open-loop spatial multiplexing, and closed-loop spatial multiplexing.

SU-MIMO and MU-MIMO: classified into single-user MIMO (SU-MIMO) and multi-user MIMO (MU-MIMO) based on the number of UEs related to the data streams transmitted using the same time-frequency resource. When SU-MIMO is adopted, data streams are transmitted to or received from only one UE. When MU-MIMO is adopted, data streams are transmitted to or received from multiple UEs.

Uplink MIMO Techniques

In the uplink, the UE compliant with 3GPP Release 8 or 9 uses only one transmit antenna and the eNodeB uses multiple receive antennas. Therefore, only receive diversity is used.

3. High Level Network Design Cycle

Network design is a complex and time consuming affair with many steps and processes. However from a high level it could be considered that there are 4 main steps in the planning cycle [18, 23].

The process begins with information gathering and objective setting. Information gathered at this stage will include both marketing and technical data. The marketing information is important so that realistic objectives can be set. Technical data will include information about the technology to be used, spectrum related data and possibly equipment performance data from a vendor.

Information gathered during this first phase is used to test the objectives and determine the viability of the business case. Since there are no major investments at this stage it is also a good time to analyse the risks involved using known information. The assumptions and objectives can be tested iteratively until some initial design is decided.

The second phase used the outputs of phase one to determine the best location for the base sites and to determine the back haul requirements. Issues of co-location and new site builds would be addressed at this stage.

Once all the site locations have been determined the initial assumptions regarding coverage will need to be validated. This is possible through the use of software RF planning tools. Some design optimizations can be determined during this stage. Choice of software tools and models will have to be made; this is often a matter of scale and budget.

Phase 4 is the build out of the system. Some starting point must be determined, possibly from the demographic information from the marketing team or from site availability. At some point during this stage drive tests should be carried out to confirm the accuracy of the software planning models used in stage three and if necessary some redesign and optimizations can be made. The use of additional software tools to plan the deployment may be used at this stage.

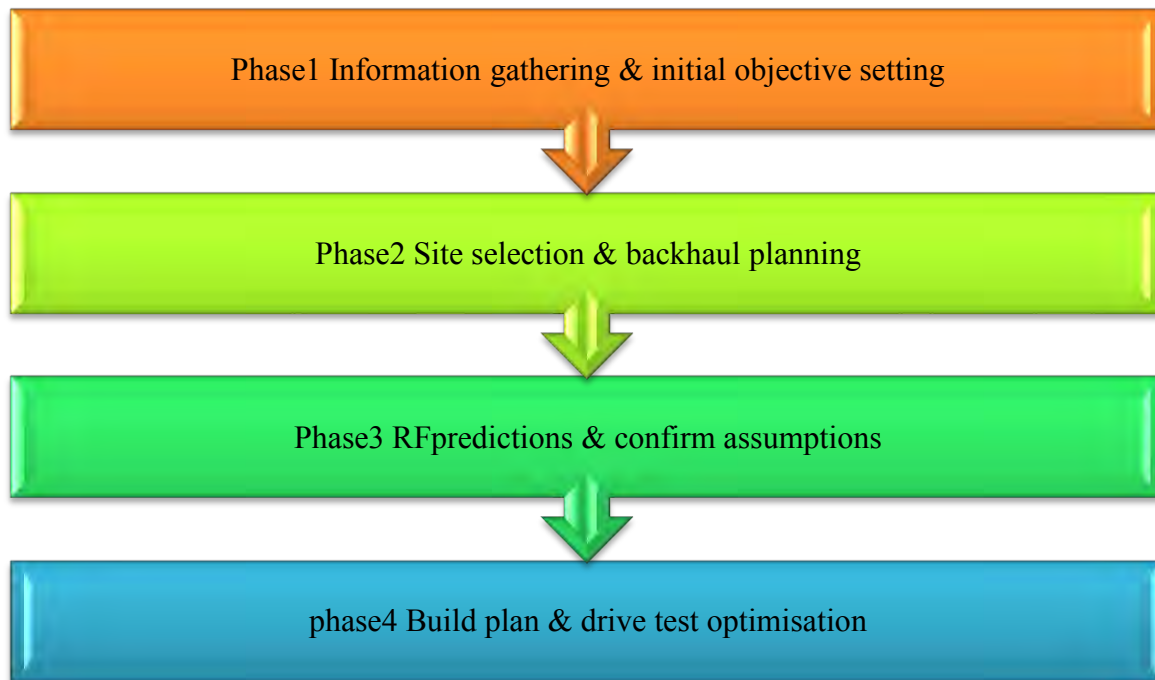


Figure 3-1 High Level Design Life Cycles

Phase 1 Detailed Procedure

As stated above phase 1 is the information gathering and objective setting stage. The more information that can be gathered and tested at this stage, the better the understanding of the design and the behavior of the system when variables are included. Some of the additional steps that need to be considered in the early stages of planning are:

- Gather relevant technical and marketing information
- Set primary objectives based in some initial assumptions, type of service, coverage, capacity etc
- Draft initial plan based on objectives and other assumptions, equipment selection, technology selection
- Determine the number of base station required, through simple modeling techniques to fulfill the initial objectives
- Test the performance of the initial design based on market assumption variability
- Test the business case based on market variability and equipment performance

- Iterate the results and make necessary changes to basic plan

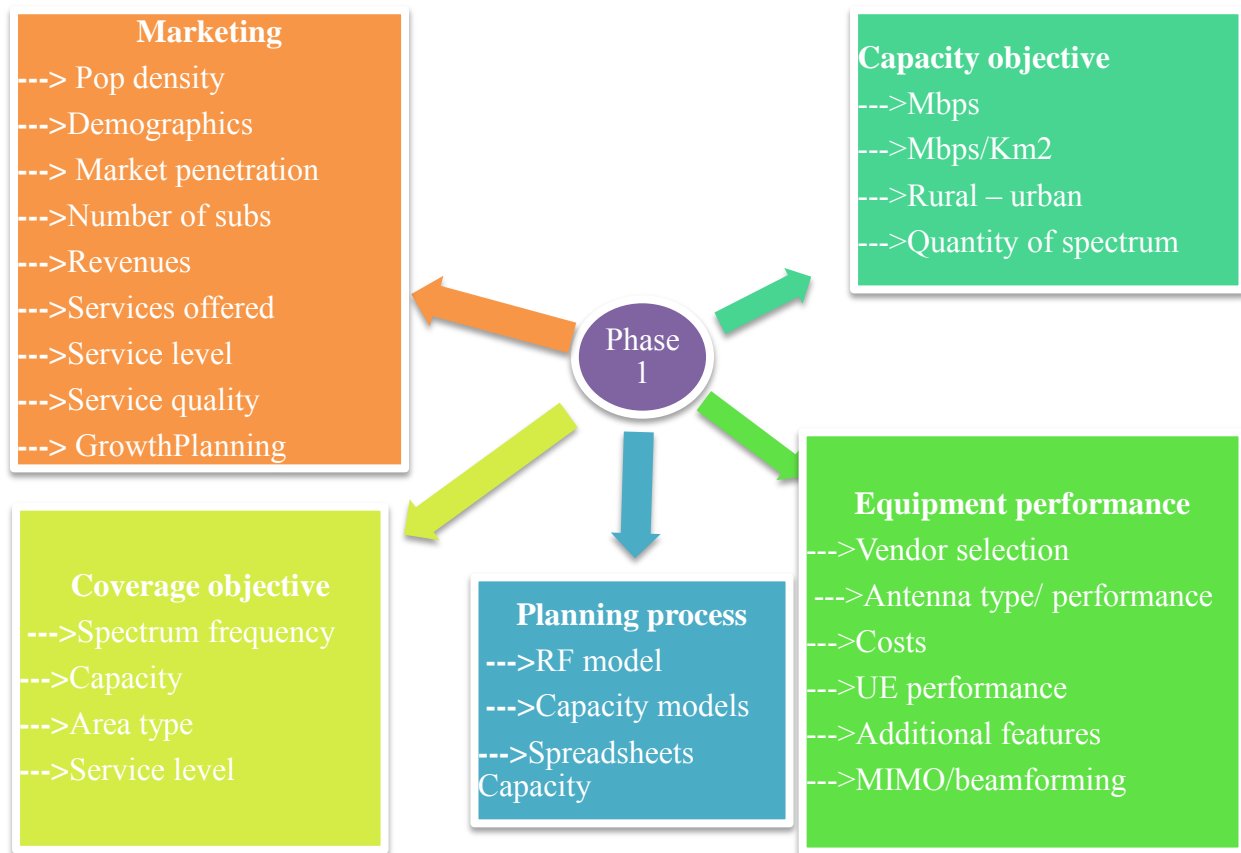


Figure 3-2 Phase 1 Information Required

Phase 2 Detailed Procedures

The output of phase 1 is, amongst others, is the number of base stations required to meet the objectives; however the location of the base stations is yet to be determined. Phase 2 is about site selection and confirming the assumptions from the first stage holds true against the real location of sites.

Many operators will have existing sites on which they may co-locate the new LTE equipment; however one of the implications of mobile broadband is the number of new sites that may have to be deployed depending on the spectrum used. This will involved detailed site planning and acquisition to be carried out.

In addition the backhaul requirements for both the co-located sites and new sites will have to be calculated and planned:

- Introduce real site location including existing and new sites

- Test system performance using real location against initial objectives
- Begin site acquisition process
- Determine the optimal build out plan
- Investigate and plan backhaul requirements

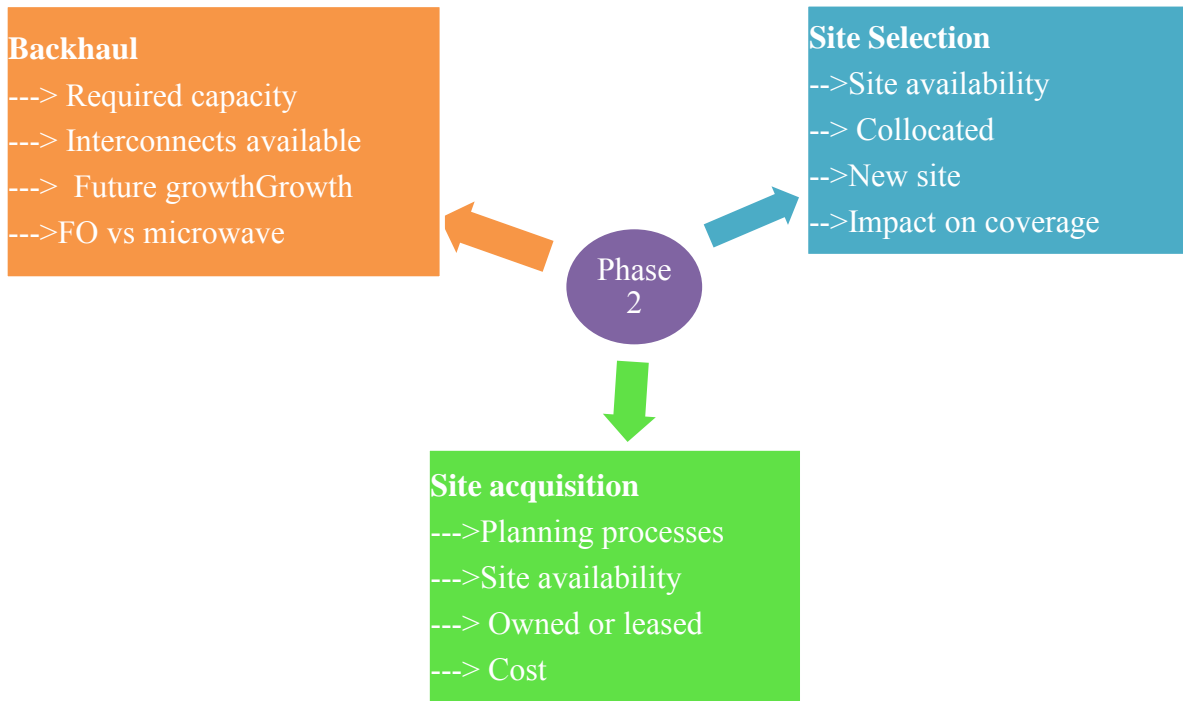


Figure 3-3 Phase 2 Information Required

Phase 3 Detailed Procedures

Once the site locations have been established, software tools scan is used to confirm the coverage and capacity assumptions made in the first stage. Changes can be made to the initial design at this stage as well the selection of ideal locations for new sites. It is important at this stage to develop a build out plan that will quickly establish the required coverage and capacity in the least amount of time with the least amount of cost, there are software tools available that can develop this plan.

- Use software tools to confirm initial assumptions for coverage and capacity
- Make changes to site planning
- Optimize the build plan
- Begin the build

Phase 4 Detailed procedures

Before a major build is undertaken the accuracy of the software tools must be determined, therefore it is not uncommon to run drive test against a test site, this can be used to confirm the coverage predicted by the RF tools and if the site is fully functional some estimate of cell capacity can also be determined. Any major discrepancy between the RF prediction and the actual measurements can be used to tune the prediction models. Tuning of the software models is important in order to reduce the amount of retro planning and site building further in to the build process.

- Drive test to confirm the software planning models used
- Optimize radio plan if necessary

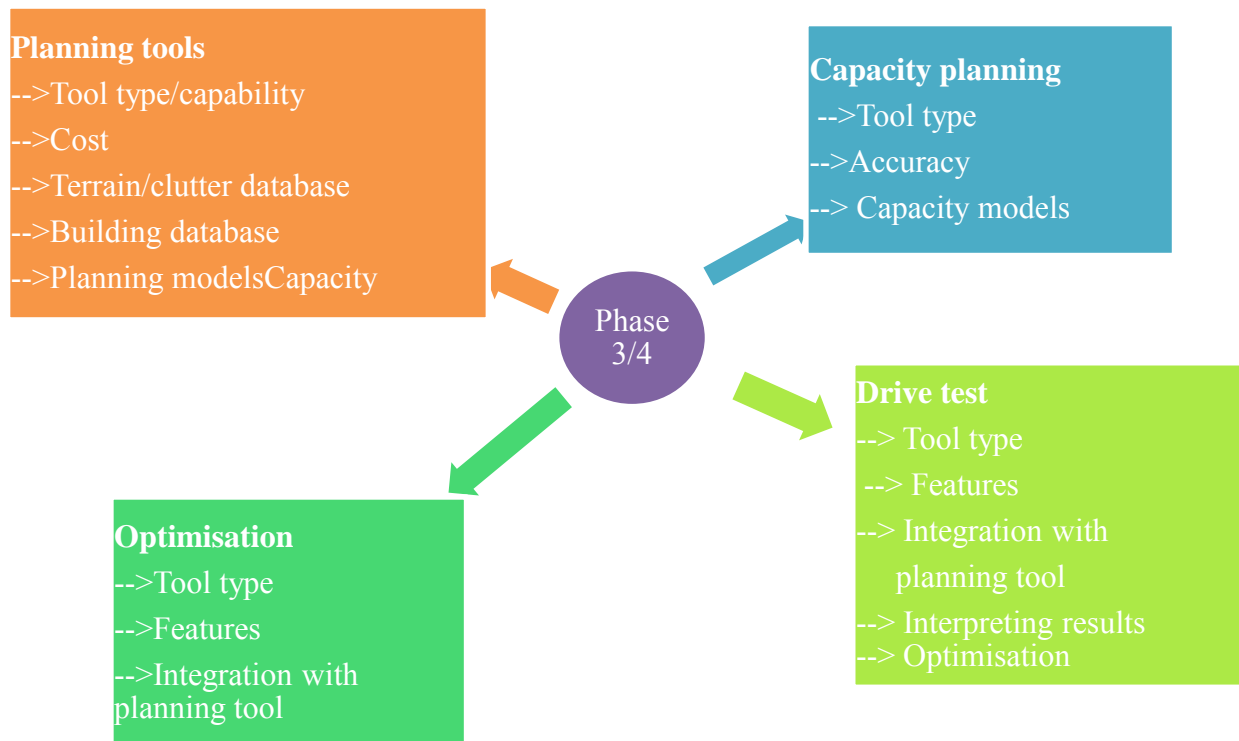


Figure 3-4 Phase 3-4 Information Required

4. Coverage and Capacity Dimensioning

The target of the LTE access network dimensioning is to estimate the required site density and site configurations for the area of interest. Initial LTE access network planning activities include radio link budget and coverage analysis, cell capacity estimation, estimation of the amount of eNB. This section focuses on the issues related to LTE dimensioning i.e. calculation of the sites number based on the coverage and the capacity [19, 21].

LTE dimensioning process starts with the Radio Link Budget Calculations, used to determine the maximum path loss. The result of this step depends upon the propagation models used. The estimated cell size, obtained in this step, leads to the maximum allowed size of the cells. This parameter is used to calculate the number of cells in the area of interest. Thus, a rough estimate of the required number of ends is obtained. Capacity calculations follow the above process for coverage estimation. If the coverage estimates for the given configuration, fulfills the capacity requirements, then there is no addition to the previous plan. On the other hand, suitable number of cell sites is added to achieve the capacity targets.

4.1 Factors Affecting the LTE planning

Whilst LTE technology is new and complex some of the basic rules of system planning do not change. Much of the complexity of LTE is designed to make the best use of the available spectrum, better spectral efficiency, in other words. Achieving better efficiency means that higher data rates can be achieved in systems that are spectrum limited. Indeed LTE is design to support a single channel reuse pattern without resorting to tricks like spread spectrum [19].

When considering capacity planning, or general system planning, the followings are some of the factors that should be taken in to account [19, 23].

a) Frequency Band

There are many frequency bands potentially available for the deployment of LTE; the bands listed opposite have been identified through work done by the ITU and the 3GPP. The bands are part of the IMT spectrum and many are in use already with cellular technologies like GSM, UMTS, LTE and WiMAX.

It is not expected for a UE to support all of the bands shown here, but is highly likely that UE will support a subset of the bands depending on the intended area of deployment, allowing national and international roaming as cost effectively as possible.

The chosen spectrum will have a very large impact on the planning process since the nominal radius of the LTE radio cell is dependent on the frequency of operation. Generally speaking the lower the frequency the larger the radio cell, the better the building penetration, the less sensitive to atmospheric issues the system becomes. This is of great interest to operators since the cost of deploying LTE networks is likely to be very high, lower frequency allocations can save many millions of dollars in CAPEX, i.e. there will be less eNBs to buy.

Band Number	Uplink (MHz)	Downlink (MHz)	Band Gap (MHz)	Duplex Separation (MHz)	UMTS Usage	LTE Usage
1	1920-1980	2110-2170	130	190	Y	Y
2	1850-1910	1930-1990	20	80	Y	Y
3	1710-1785	1805-1880	20	95	Y	Y
4	1710-1755	2110-2155	355	400	Y	Y
5	824-849	869-894	20	45	Y	Y
6	830-840	875-885	35	45	Y	Y
7	2500-2570	2620-2690	50	120	Y	Y
8	880-915	925-960	10	45	Y	Y
9	1749.9-1784.9	1844.9-1879.9	60	95	Y	Y
10	1710-1770	2110-2170	340	400	Y	Y
11	1427.9-1452.9	1475.9-1500.9	23	48	Y	Y
12	698-716	728-746	12	30	Y	Y
13	777-787	746-756	21	31	Y	Y
14	788-798	758-768	20	30	Y	Y
17	704-716	734-746	18	30	N	Y

Table 4-1 Frequency Bands

b) Allocated Spectrum and Channel Bandwidth

The bands are regulated in terms of the allowed operating bandwidth. This is driven largely by the amount of available spectrum in each of the bands. Some of the bands do not allow the use of the narrow channels, whilst others prohibit the use of the larger bandwidths.

The amount of allocated spectrum will impact the overall network capacity and the individual sector capacity. As with many aspects of system planning more is better.

In some cases the operator may have the flexibility to choose the channel bandwidth depending on the total amount of spectrum they have.

LTE band	Downlink bandwidth	Channel bandwidth (MHz)					
		1.4	3	5	10	15	20
1	60	–	–	12	6	4	3
2	60	42	20	12	6	4	3
3	75	53	23	15	7	5	3
4	45	32	15	9	4	3	2
5	25	17	8	5	2	–	–
6	10	–	–	2	1	X	X
7	70	–	–	14	7	4	3
8	35	25	11	7	3	–	–
9	35	–	–	7	3	2	1
10	60	–	–	12	6	4	3
11	25	–	–	5	2	1	1
12	18	12	6	3	1	–	X
13	10	7	3	2	1	X	X
...
17	12	–	4	2	1	X	X
...
40	100	–	–	–	10	6	5

Table 4-2 Available Capacity and Channel Bandwidths for LTE

c) LTE Channel Parameters

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

The table opposite shows the main attributes of the various channel bandwidths. It can be seen that the entire channel is not occupied due to the FFT sampling of the channel, this will yield a lower than expected capacity using the Nyquist and Shannon assumptions.

Channel Bandwidth (MHz)	1.4	3	5	10	15	20
Number of Resource Blocks (NRB)	6	15	25	50	75	100
Number of Occupied Subcarriers	72	180	300	600	900	1200
IDFT(Tx)/DFT(Rx) Size	128	256	512	1024	1536	2048
Sample Rate (MHz)	1.92	3.84	7.68	15.36	23.04	30.72
Samples per Slot	960	1920	3840	7680	11520	15360

Table 4-3 LTE Channel Parameters

d) Maximum Bit Rate per Channel

Based on a simple Nyquist calculation and an assumption of the overall efficiency (80%) of the radio, table 4.4 shows the maximum data rates that could be expected from the various channel bandwidths.

However the actual cell capacity in LTE may vary due to considerations of serving cell load and adjacent cell load and also the interference coordination feature of LTE.

Modulation coding		Peak bit rate per sub-carrier/bandwidth combination				
		72/1.4 MHz	180/3.0 MHz	300/5.0 MHz	600/10 MHz	1200/20 MHz
QPSK 1/2	Single stream	0.9	2.2	3.6	7.2	14.4
16QAM 1/2	Single stream	1.7	4.3	7.2	14.4	28.8
16QAM 3/4	Single stream	2.6	6.5	10.8	21.6	43.2
64QAM 3/4	Single stream	3.9	9.7	16.2	32.4	64.8

64QAM 4/4	Single stream	5.2	13.0	21.6	43.2	86.4
64QAM 3/4	2 x 2 MIMO	7.8	19.4	32.4	64.8	129.6
64QAM 4/4	2 x 2 MIMO	10.4	25.9	43.2	86.4	172.8

Table 4-4 Maximum Uplink Capacity per Radio Channel

e) Equipment Performance

System performance will be affected by many factor related to the equipment used in the network. The fundamental aspects of the link budget rely entirely on the performance of the equipment. In many case the vendor spec sheet will provide the majority of the information required to perform basic ink budgets. This may be enough during the initial phase of planning to establish a baseline for capacity and performance. Once the basic performance parameters have been worked out and certain levels of performance have been determined, it is then possible to include the more complex features of the equipment to determine the additional gains possible. For example MIMO, beamforming antennas, vendor specific algorithms for interference management.

f) Population Demographic

The marketing research carried out during the planning period will make use of the area classifications mentioned above and also the population demographics. Analysis of typical demographic data will allow the planner to determine the likely number of subscribers in a given location at different times of the day.

Population and population distribution are particularly important as this will give a base level for planning the capacity and coverage of the system. Other factors such as age, ethnicity, and employment status will help the marketing researchers to determine the likely number of subscribers that can be captured.

g) Marketing Inputs

It is of critical importance that the planning process is carried out with input from the marketing department. Based on the demographic statistics the marketing researchers will be able to provide data regarding the total number of subscriber and the area over which they will be distributed, these are of course factors to be considered when designing the system.

The service type, acceptable contention ratio and population penetration are most important for capacity planning.

h) Data Throughput

Data rates available to mobile subscriber have been increasing steadily over the last few years and will continue to do so, promoted by the additional capability of LTE. However the capacity of the radio sector is not unlimited and careful thought must be applied to the type of service sold to the subscriber.

Of course the best way to manage the traffic load in the network is to support different service levels and manage the flow data using QoS mechanisms.

4.2 Coverage Planning

Coverage analysis gives an estimation of the resources needed to provide service in the deployment area with the given system parameters i.e. it estimates the number of eNodeB required to cover the specified area with good signal strength. The link budget calculations estimate the maximum allowed signal attenuation, called path loss, between the mobile and the base station antenna. The maximum path loss allows the maximum cell range to be estimated with a suitable propagation model. The cell range gives the number of base station sites required to cover the target geographical area. The link budget calculation can also be used to compare the relative coverage of the different systems.

Various factors must be considered during LTE system coverage planning and setting of these parameters will affect coverage radius and the quantity of base stations. Coverage and design requirement must be analyzed in choosing parameters within the following parameter groups such as propagation related, equipment related, LTE specific and system reliability [19].

Network coverage depend mainly on natural factors such as geographical aspect, propagation conditions, and on human factors such as the landscape (urban, suburban, rural), subscriber behavior etc.

Three main mechanisms that impact the signal propagation are depicted:

- Reflection. It occurs when the electromagnetic wave strikes against a smooth surface, whose dimensions are large compared with the signal wavelength.
- Diffraction. It occurs when the electromagnetic wave strikes a surface whose dimensions are larger than the signal wavelength, new secondary waves are generated. This

phenomenon is often called shadowing, because the diffracted field can reach the receiver even when shadowed by an impenetrable obstruction i.e. no line of sight.

- Scattering. It happens when a radio wave strikes against a rough surface whose dimensions are equal to or smaller than the signal wavelength.

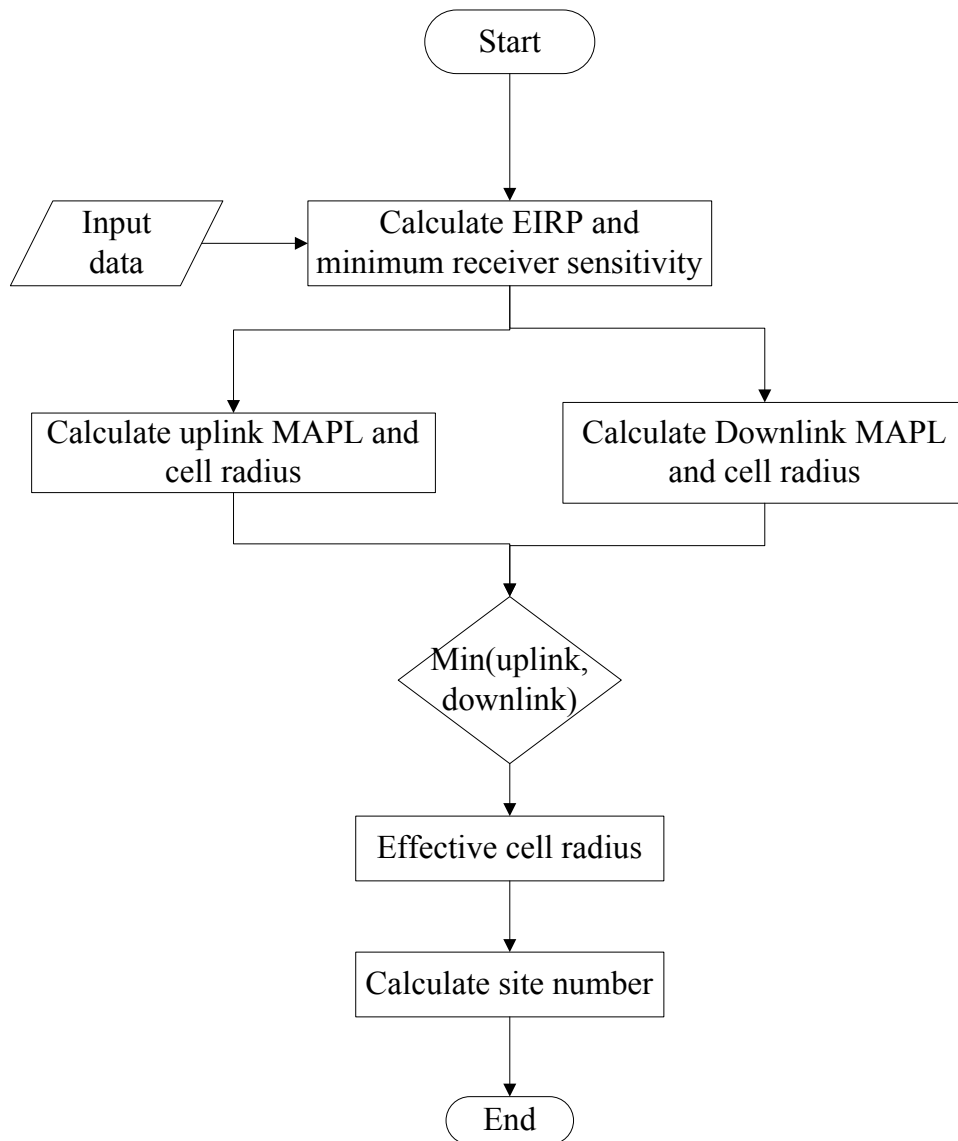


Figure 4-1 Radio network coverage planning flow

4.2.1 Link Budget

One of the main aims of calculating a link budget is to determine the maximum path loss allowed across the radio link for a given performance objective. The link loss will be due in part to the performance of the transmitter and receiver components as well as the impact of the environment through which the signal will propagate [17, 19, 20].

There are two main purposes for establishing the RF link budget for LTE designs:

- To establish the system design assumptions for all the gains and losses along the RF path between the base station and the subscriber device e.g. vehicle loss, building loss, ambient noise, transmit powers, receive sensitivities, antenna gains.
- To establish an estimate for maximum allowable path loss. This maximum allowable path loss number is used in conjunction with the propagation model to estimate site coverage, which ultimately determines the number of sites required for adequate system RF signal coverage and hence the system cost.

EIRP: Stands for effective isotropic radiated power; the term is used to express how much transmitted power is radiated in the desired direction. It takes into account the losses in transmission cables and connectors and includes the gain of the transmitter antenna as:

$$EIRP = P_{Tx} + G_{Tx} - \sum Total\ T_x\ losses \dots \dots \dots (4.1)$$

Where the P_{Rx} is the received power (dBm), G_{Tx} is the transmitter antenna gain (dBi) and L_{Tx} is the cable and other losses on the transmitter side (dB), respectively.

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

$$N = KBT \dots \dots \dots (4.2)$$

Where

- K indicates the Boltzmann constant (1.38×10^{-23} J/K).
- T indicates absolute temperature at a value of 290K
- B indicates channel bandwidth which is 20MHz

The receiver sensitivity: indicates the minimum signal strength required to enable decoding by the eNodeB or UE receiver if there is no interference and formulated as:

$$\text{Receiver Sensitivity} = \text{Noise figure} + \text{SINR} + \text{Thermal Noise} \dots \dots \dots (4.3)$$

Where

- SINR indicates the Signal to interference noise ratio
- Noise figure is the ratio of the SINR at the input end to the SINR at the output end of the receiver and used to measure the performance of a receiver.

Minimum signal reception strength: It used to formulate the receiver side losses and margin such as body loss, cable loss and marginal gain to receiver sensitivity and calculated as:

$$\text{Minimum Signal Reception Strength} = RS + IM + L_R - RA_G \dots \dots \dots (4.4)$$

Where

- RS is receiver sensitivity
- IM is interference Marginal
- L_R is receiver body loss + Cable loss
- RA_G is receiver antenna gain

Maximum allowable path loss (MAPL): It allows the maximum cell range to be estimated with suitable propagation models which provide number of base station sites required to cover the target geographical area. The maximum allowable path loss expressed as:

$$\text{MAPL} = \text{EIRP} - \text{Minimum Signal Reception Strength} - \text{Penetration loss} \\ - \text{shadow fading margin} \dots \dots \dots (4.5)$$

Typical losses and gains

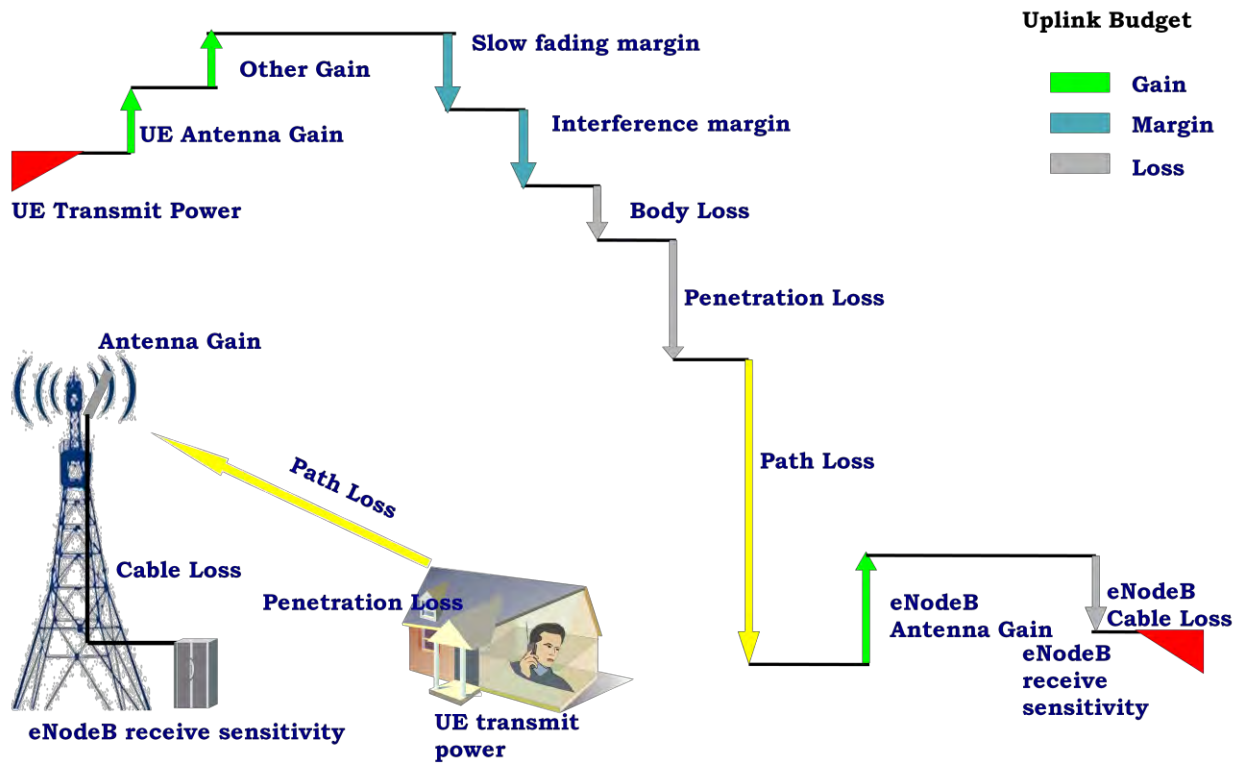


Figure 4-2 typical losses for uplink

Penetration loss: Penetration loss indicates the fading of radio signals from an indoor terminal to a base station due to obstruction by a building.

Body loss: Body loss indicates the loss generated due to signal blocking and absorption when a terminal antenna is close to the body.

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

Transmitter Power: It includes the base station affecting downlink budget and terminal sides which affects the uplink budget.

Antenna Gain: indicates the degree to which an antenna transmits input power in concentration and can be increase by reduce the lobe width of the radiation at the vertical plan and maintain the Omni-directional radiation performance at the horizontal plane.

The relationship between antenna gain, horizontal beamwidth, and vertical beamwidth is as follows:

$$G(dBi) = 10 * \log\left(\frac{3200}{A * B}\right) \dots \dots \dots (4.6)$$

Where, A and B indicate the horizontal beamwidth and vertical beamwidth and G indicates antenna gain.

Beamwidth

The beamwidth is also called the half power beamwidth, including horizontal beamwidth and vertical beamwidth. The horizontal beamwidth and vertical beamwidth is the beamwidth between two points where the power is lower 50% (3dB) than the maximum radiation power. The common horizontal beamwidth of eNodeB antennas includes 360°, 90°, 65°, 60°, and 33°. The common vertical beamwidth of eNodeB antennas includes 6.5°, 7°, 10°, 13°, and 16°.

Interference Margin

Interference margin accounts for the increase in the terminal noise level caused by the interference from other users and it indicates the degradation of system receive performance caused by internal interference in the system due to system traffic. In fact, due to the frequency division nature of LTE, there is also a close correlation between actual traffic load and interference margin experienced by the network.

Slow Fading Margin

Shadow fading indicates the fading brought by obstruction due to a building or a natural feature. Shadow fading changes slowly, and is thus called “slow fading”. Statistics repeatedly show that the median levels of received signals follow log-normal distribution with the time and location at a certain distance. Fading caused by location mainly from obstruction far exceeds fading caused by time. Therefore, the major concern for shadow fading is those caused by location changes.

To minimize the effect of shadow fading and ensure a certain edge coverage probability, certain allowances must be made. This is called the “slow fading margin”, or the “shadow fading margin”. Figure below shows the relationship between the slow fading margin and cell edge probability.

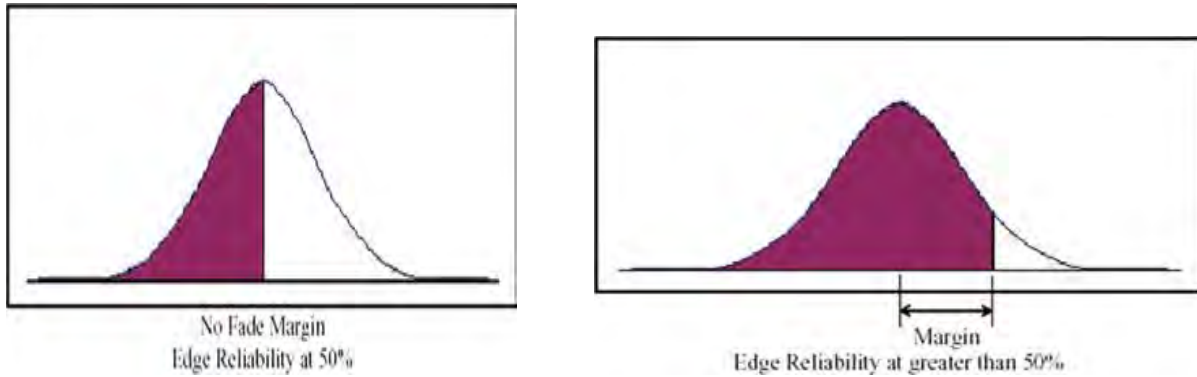


Figure 4-3 Impact of the slow fading margin on system reliability

The difference found in the slow fading is reflected by the standard deviation of slow fading. The standard deviation of slow fading shows the distribution of the radio signal strength at different test points at similar distances from the transmitter. This spread of values approximate to the standard deviation of the signal strength at different test points from similar distances. The standard deviation of slow fading varies with the geological form. In plain areas, such as rural areas and open areas, the standard deviation of slow fading is lower than that in suburban and urban areas. Standard deviations requirement in Dense Urban area with highly integrated building layout and deeper indoor coverage requirement is even higher than typical urban environment.

The slow fading margin can be obtained based on the cell edge coverage probability and standard deviation of slow fading and formulated as:

$$\sigma = 1 - Q\left(\frac{\text{Slow fading margin}}{\beta}\right) \dots \dots \dots (4.7)$$

The slow fading margin can be obtained through the following formula:

$$\text{Slow fading margin} = 1 - Q^{-1}(1 - \beta) * \sigma \dots \dots \dots (4.8)$$

Where

- σ is standard deviation of slow fading
- β is the Edge Coverage Probability

4.2.2 Propagation Model

The radio propagation model plays a key role in the link budget. The coverage radius of a base station is obtained based on the maximum propagation loss allowance in the link budget. Radio propagation models are classified into outdoor and indoor propagation models. These two types of propagation models involve different factors. In an outdoor environment, landforms and obstructions on the propagation path, such as buildings and trees, must be considered. Signals fade at varying rates in different environments. Propagation in free space gives the lowest fade rate. The fading of signals is larger than free space when radio waves propagate in open areas/suburban areas and fading rate is the largest in urban/dense urban areas. Indoor propagation model features low RF transmits power, a short coverage distance and complicated environmental changes [21, 10].

a) Free Space Model

Free space indicates an ideal, even, and isotropic medium of space. When electromagnetic waves are transmitted in this medium, no reflection, refraction, scattering, or absorption occurs. Propagation losses are caused only by the energy spread of electromagnetic waves. Satellite communication and microwave line-of-sight (LOS) communication are typical examples of free space propagation. In certain conditions, the antennae of the base station and terminal can be mounted at any height. In this case, LOS communication between the base station and the terminal is implemented. If a clear line of sight (CLOS) exists between the transmit antenna and receive antenna, then path loss complies with the free space model. The propagation losses in the free space model are as follows:

$$PL = 32.4 + 20 \log(d) + 20 \log(f) \dots \dots \dots (4.9)$$

Where, d indicates the distance between the terminal and the base station. The unit is km. f indicates the carrier frequency. The unit is MHz. The preceding formula does not consider the impact of ground reflection, and thus often underestimates propagation loss. This model is applicable to the scenario when the antennas of the base station and terminal are mounted at considerable height and CLOS exists between the base station and the terminal.

The selection of a suitable radio propagation model for LTE is of great importance.

b) Okumura Model

Okumura model is one of the most commonly used models. Almost all the propagation models are enhanced form of Okumura model. It can be used for frequencies up to 3000 MHz [20].

The distance between transmitter and receiver can be around 100 km while the receiver height can be 3 m to 10 m. The path loss in Okumura model can be calculated as:

$$PL(dB) = L_f + A_{m'n}(f, d)h - G(h_c) - G(h_r) - G_{AREA} \dots \dots \dots (4.10)$$

Here L_f is the free space path loss and it is calculated by the following expression:

$$L_f = -20 \log \left(\frac{\lambda}{4\pi d_o} \right) \dots \dots \dots (4.11)$$

While $G(h_b)$ and $G(h_r)$ are the BS antenna gain factor and receiver gain factors respectively. Their formulas are as follows:

$$G(h_b) = 20 \log \left(\frac{h_b}{200} \right) \dots \dots \dots (4.12)$$

$$G(h_r) = 10 \log \left(\frac{h_{br}}{3} \right) \dots \dots \dots (4.13)$$

Where h_b and h_r are the heights of base station and receiver receptively. $A_{m,n}(f,d)$ is called as median attenuation factor. Different curves for median attenuation factor are used depending on the frequency and the distance between the transmitter and receiver.

c) Cost-231Hata Propagation Model

COST-231 Hata model is expressed as follow and can be used up to 2000 MHz frequency.

$$PL(dB) = 46.3 + 33.9 * \log(f) - 13.82 * \log(h_b) - \alpha(h_r) - [44.9 - 6.55 \log * (h_b)] \log(d) + c \dots \dots \dots (4.14)$$

Here, f represents the frequency in MHz, d denotes the distance between the transmitter & receiver, h_b & h_r the correction factors for base station height and receiver height respectively.

The parameter c is zero for suburban & rural environments while it has a value of 3 for urban area. The function $\alpha(h_r)$ for urban area is defined as:

$$\alpha(h_r) = 3.2 (\log(11.75h_r))^2 h - 4.97 \dots \dots \dots (4.15)$$

For rural & suburban areas, its is as follows:

$$\alpha(h_r) = (1.1 \log(f)) - 0.7h_r - (1.58f - 0.8) \dots \dots \dots (4.16)$$

d) Erceg-Greenstein

The Erceg-Greenstein empirical propagation model was developed for multi-site broadband fixed wireless applications. The group that created the Erceg-Greenstein model found that the Hata-Okumura models were not suitable for lower base station antenna heights, and hilly or moderate-to-heavy wooded terrain. This group created a model to account for lower base station antenna heights in environments with flat to hilly terrain and light to moderate or heavy tree densities. Further the Erceg-Greenstein model is targeted more towards a suburban environment.

$$L(dB) = A + 10\gamma \log(d/d_o) + X_f + X_h \dots \dots \dots (4.17)$$

Where

$$A = 20 \log \left(\frac{4\pi d_o}{\lambda} \right)$$

$$\gamma = a - bh_b + c/h_b$$

$$X_f = 6 \log \left(\frac{f_{MHz}}{2000} \right)$$

$$X_h = -10.8 \log \left(\frac{h_m}{2} \right) \text{ for Terrain Types A and B}$$

$$X_h = -20.8 \log \left(h_m / 2 \right) \text{ for Terrain Types C}$$

e) Standard Propagation Model (SPM)

The standard propagation model is a model deduced from the Hata formula particularly suitable for predication in the 150MHz~3500MHz band over long distance (1Km<d<20Km) and is very adapted to GSM900/1800, UMTS, CDMA2000, WiMAX and LTE technologies. This model uses the terrain profile, diffraction mechanisms (calculated in several ways) and take into account clutter classes and effective antenna heights in order to calculate path loss.

The model may be used for any technology; it is based on the following formula:

$$L_{SPM} = K_1 + K_2 \log(d) + K_3 \log(H_{Txeff}) + K_4 \text{Diffraction loss} \\ + K_5 \log(d) \log(H_{Txeff}) + K_6 H_{Rxeff} + K_{clutter} f(\text{clutter}) \dots \dots \dots (4.18)$$

Where:

- K1 is Constant offset (dB)
- K2 is Distance attenuation constant.
- d Distance between the receiver and the transmitter (m)
- K3 and K4 are Correction coefficient of height of mobile station antenna and K4 has to be a positive number
- HTxeff Effective height of the transmitter antenna(m)
- Diffraction loss Losses due to diffraction over an obstructed path(dB)
- K5 Multiplying factor for log(d)log(HTxeff)
- K6 Multiplying factor for HRxeff
- HRxeff Mobile antenna height (m)
- KClutter Multiplying factor for f(clutter)
- f(clutter) Average of weighted losses due to clutter

From the last section we get the cell radii a result of link budget calculation and propagation model. After determining the cell radius, sites number and sites coverage areas are calculated based on site configuration by the equations below:

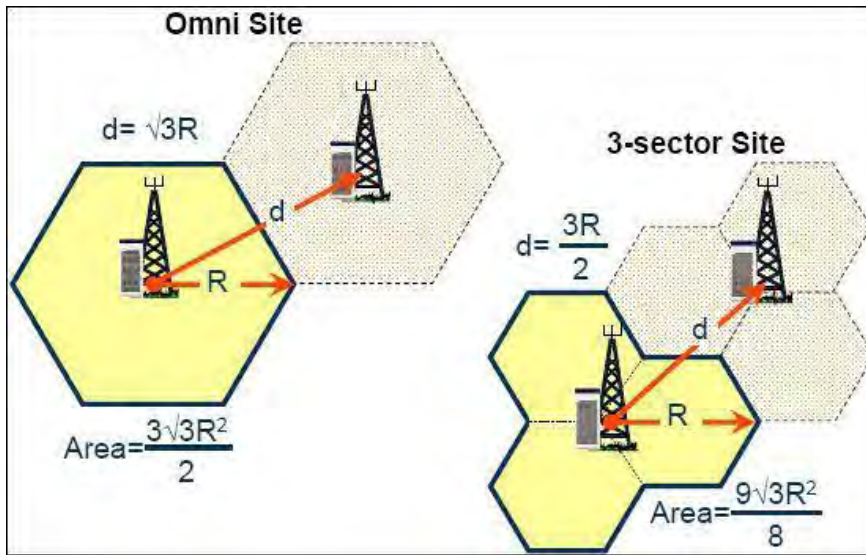


Figure 4-4 site configuration and coverage area calculation

$$\text{Site Coverage area} = \frac{9}{8} \times \sqrt{3} \times R^2 \text{ (3scetor site) } \dots \dots \dots (4.19)$$

$$\text{Site Coverage area} = \frac{3}{2} \times \sqrt{3} \times R^2 \text{ (3scetor site) } \dots \dots \dots (4.20)$$

$$\text{Required sites number} = \frac{\text{Area to be covered}}{\text{Site covered area}} \dots \dots \dots (4.21)$$

4.3 Capacity Planning

Interference is the major limiting factor in the performance of LTE networks. It has been recognized as the major bottleneck in network capacity and is often responsible for poor performance. The cells that use the same frequency are called co-channel cells, and the interference from users with the same channel in the other co-channel cells is called co-channel interference [11, 22].

Unlike thermal noise which can be overcome by increasing the signal-to-noise ratio (SNR), co-channel interference cannot be countered by simply increasing the carrier power of a transmitter. This is because an increase in carrier transmission power will increase the interference to neighboring co-channel cells. To reduce co-channel interference, co-channel cells must be

physically separated sufficiently by a distance, called the reuse distance. For a network with a limited number of frequency channels, a large reuse distance can guarantee a high QoS for the system, but the capacity will be decreased.

Another type of interference in LTE networks is adjacent channel interference. Adjacent channel interference results from imperfect receiver filters which allow nearby frequencies to interfere with the used frequency channel. Adjacent channel interference can be minimized through careful filtering and channel assignment.

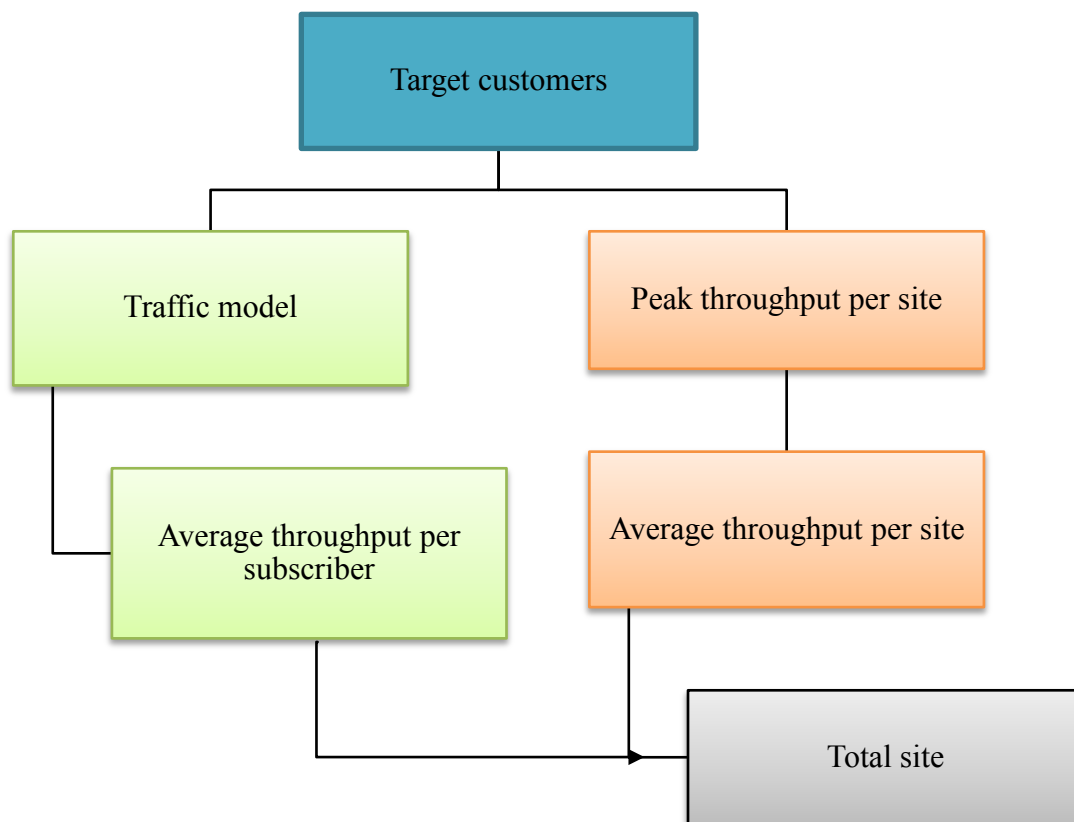


Figure 4-5 overview of capacity planning

4.3.1 Traffic Model Approach for Capacity Dimensioning

The traffic volume based approach estimates the maximum traffic volume in megabytes that can be carried by LTE site considering all the above factors.

Side the factors, network dimensioning in the busy hour needs to be reserved in order to guarantee low delays and reasonably good data rates. The traffic model defines an application services such as VoIP, Video, Streaming, Web browsing & FTP provided by network based on the service providers. The main purpose of traffic model is to describe the average subscriber behavior during the most loaded day period (the Busy Hour) and the capacity of site should be based on busy hour as the traffic is not equality distributed during 24 hour [24].

The average throughput per subscriber based on traffic usage in the month ρ (Gigabytes) is calculated using:

$$\Omega(Kbps) = \rho * \alpha * \left(\frac{8bit * 10^6}{30 day * 24 * 60 * 60} \right) * K \dots \dots \dots (4.22)$$

Where

- $\Omega(Kbps)$ is average throughput per subscriber in busy hour (UL + DL)
- α is traffic ratio of busy hour to the traffic of the whole day
- K is Busy hour convergence ratio = $\frac{1}{\text{Traffic ratio of busy hour to whole day}}$
- ρ is the Traffic Usage in $\frac{\text{Mont h}}{\text{User}}$

After manipulating the average throughput per subscriber for each service type defined by operator, the total average throughput per subscriber in busy hour is given by:

$$\Phi (Kbps) = \sum (\Omega(Kbps) * Usage ratio of the services) \dots \dots \dots (4.23)$$

Where

- $\Phi (Kbps)$ is the total throughput per subscriber in busy hour (UL + DL)
- Usage ratio of each service/package to the total services/package.
- Finally based on the traffic of services, the average throughput per subscriber for uplink and downlink written as:

$$\Gamma (Kbps) = \Phi (Kbps) * UL traffic ratio \dots \dots \dots (4.24)$$

$$\eta (Kbps) = \Phi (Kbps) * DL traffic ratio \dots \dots \dots (4.25)$$

Where

- Γ (Kbps) is the average throughput for uplink
- η (Kbps) is the average throughput for downlink

OFDM uses a large number of narrow sub-carriers for multi-carrier transmission. The basic LTE downlink physical resource can be seen as a time-frequency grid.

As per 3GPP release 10, LTE support modulation QPSK, 16QAM and 64QAM for downlink and QPSK and 16QAM for uplink. Each of Modulation has its bits carrying capacity per symbol. One QPSK symbol can carry 2bits, one 16QAM symbol can carry 4bits and 64 QAM symbol can carry 6 bits as shown in **figure 2.7**.

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

$$\delta \text{ (Mbps)} = \left(\text{data RE/sec} * \text{bits per RE} * \text{MIMO effect} * \text{coding rate} \right) \dots \dots \dots (4.26)$$

Where:

- δ (Mbps) is the peak throughput per site per modulation
- The data RE/s is the data in resource element per second
- Coding rate indicates the volume coding rate of the channel code. For example, the volume coding rate of QPSK1/2 is 1/2, and the volume coding rate of 16QAM3/4 is 3/4.

The average throughput per site for uplink and downlink formulated as:

$$\lambda \text{ (Mbps)} = \sum (\delta \text{ (Mbps)} * \text{Traffic ratio of UL}) \dots \dots \dots (4.27)$$

$$\mu \text{ (Mbps)} = \sum (\delta \text{ (Mbps)} * \text{Traffic ratio of DL}) \dots \dots \dots (4.28)$$

Where

- λ (Mbps) is the average throughput per site for uplink
- μ (Mbps) is the average throughput per site for downlink

The number maximum subscriber number per site is calculated for both uplink and downlink from eqs. 4.25 to 4.28 as follow:

$$\text{Max Sub No. per site (UL)} = \frac{\lambda(\text{Mbps})}{\Gamma(\text{Kbps})} \dots\dots\dots (4.29)$$

$$\text{Max Sub No. per site (DL)} = \frac{\mu(\text{Mbps})}{\eta(\text{Kbps})} \dots\dots\dots (4.30)$$

Finally the total site based on the capacity required, taking the minimum number of subscriber from uplink and downlink or from equation 4.29 and equation 4.30 is calculated as:

$$\text{Total site number} = \frac{\text{Total sub. of the area}}{\text{Max. Sub. per site}} \dots\dots\dots (4.31)$$

5. Simulation and Result Analysis

Simulation is a practical and scientific approach to analyze a complex system. In this project, simulation is used to investigate the RAN nominal planning of LTE networks as it is done using ATOLL simulation environment.

The LTE radio network planning simulation is intended to carry out the link budget calculation, propagation modeling using the terrain model, coverage estimation and capacity evaluation.

5.1 Site Survey

The process of site survey is to identify the different environmental factors that directly or indirectly affect the radio network planning process and as well to list out them as planning parameters. The city of Addis Ababa is located in the central of country on longitude line of $38^{\circ}44'24''\text{E}$ and at latitude line of $9^{\circ}1'48''\text{N}$, with population of 3,048,631 with annual growth 3.8% [25] with area of Addis Ababa is 461.009 km^2 with different population density.

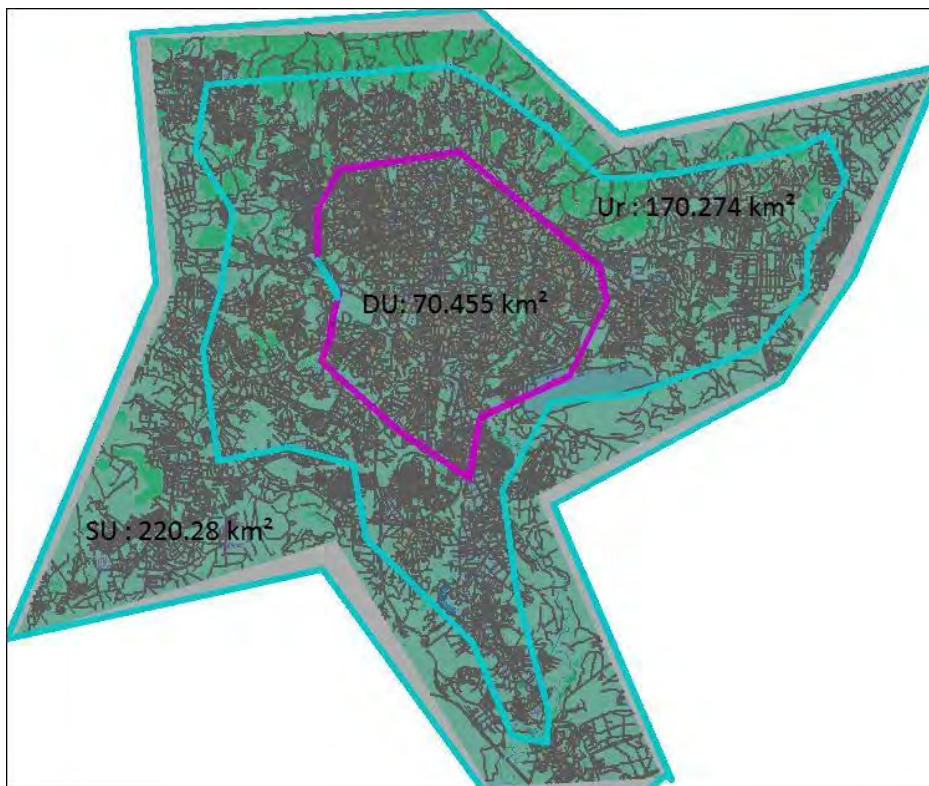


Figure 5-1 Addis Ababa city map (digital map)

The number of subscribers must be specified in order to continue the analysis, the subscribers' number for Dens Urban is considered to be 400,000, for Urban 350,000, and for Sub Urban 300,000, so that the total number of subscribers is 1,050,000 by considering feature expansion.

5.2 Coverage and Capacity Dimensioning

After collecting the planning parameters about the area of planning which was mainly given by [14, 16, 17, 19, 22] for all dimensioning result i.e. link budget, coverage and capacity done accordingly.

5.2.1 Coverage Planning Analysis

Coverage planning is performed with a link budget calculation and propagation model as mentioned in chapter 4. The propagation model is very important for calculating cell range and there are many of them with different properties but we choose COST231-Hata model because it can be applied in Addis Ababa and can be used for frequency band that we aim to work on.

Steps for coverage dimensioning and results:

- **Step 1:** Calculate the Max Allowed Path Loss (MAPL) for DL and UL (*Using Equation 4.5*).
- **Step 2:** Calculate the DL and UL cell radiuses by the propagation model equation and the MAPL (*Using Equation 4.14*).

Link budget for Uplink			
Morphology	Dense urban	Urban	Sub –urban
Duplex mode	FDM		
Channel bandwidth (MHz)	20		
Carrier frequency(MHz)	1800		
MIMO scheme	1/2		
Tx = UE			
Maximum total T_r power (dB)	23	23	23
Resource to distribute power	4	4	4
Subcarriers to Distribute Power	48	48	48
Tx Antenna Gain (dBi)	0	0	0
Tx Cable Loss (dB)	0	0	0

Tx Body loss (dB)	0	0	0
EIRP per Subcarrier (dBm)	6.19	6.19	6.19
Rx-eNB			
eNB Noise Figure (dB)	2.5	2.5	2.5
SINR (dB)	-2.52	0.47	1.49
Receiver Sensitivity (dBm)	-132.26	-129.27	-128.25
Rx Antenna Gain (dBi)	18	18	18
Rx Cable Loss (dB)	- 0.5	- 0.5	- 0.5
Interference Margin (dB)	- 0.87	- 1.97	- 2.34
Min Signal Reception Strength (dBm)	-148.89	-144.8	-143.41
Penetration Loss (dB)	19	15	11
Std.of Shadow Fading (dB)	11.7	9.4	7.2
Shadow Fading (dB)	9.48	8	2.8
Path loss	126.6	127.99	135.8
Propagation Model	Cost231-hata		
eNodeB Antenna Height (m)	25	30	30
UE Antenna Height (m)	1.5	1.5	1.5
Frequency (MHz)	1800	1800	1800
Cell Radius (km)	0.425	0.586	0.975

Table 5-1 Link budget and cell radius result for uplink

Link budget for downlink			
Morphology	Dense urban	Urban	Sub –urban
Duplex mode	FDM		
Channel bandwidth (MHz)	20		
Carrier frequency(MHz)	1800		
MIMO scheme	2TX2R		
Tx = eNodB			
Maximum total T_r power (dB)	46	46	46

Resource to distribute power	100	100	100
Subcarriers to Distribute Power	1200	1200	1200
Tx Antenna Gain (dBi)	18	18	18
Tx Cable Loss (dB)	0.5	0.5	0.5
EIRP per Subcarrier (dBm)	32.71	32.71	32.71
Rx-UE			
eNB Noise Figure (dB)	7	7	7
SINR (dB)	-3.39	-1.84	1.46
Receiver Sensitivity (dBm)	-128.3	-127.08	-123.78
Rx Antenna Gain (dBi)	0	0	0
Interference Margin (dB)	-5.41	-5.99	-6.80
Min Signal Reception Strength (dBm)	-122.89	-121.09	-116.98
Penetration Loss (dB)	19	15	11
Std.of Shadow Fading (dB)	11.7	9.4	7.2
Shadow Fading (dB)	9.48	8	2.8
Path loss	127.12	130.8	135.89
Propagation Model	Cost231-hata		
eNodeB Antenna Height (m)	25	30	30
UE Antenna Height (m)	1.5	1.5	1.5
Frequency (MHz)	1800	1800	1800
Cell Radius (km)	0.44	0.705	0.980

Table 5-2 Link budget and cell radius result for downlink

- **Step 3:** Calculate the site coverage area and the required sites number (*Using Equation 4.19, 4.20, 4.21*).

Morphology	Area (km ²)	Radius (km)	Site coverage area (km ²)	Required site
Dense urban	70.455	0.425	0.352	200

Urban	170.274	0.586	0.669	255
Sub-urban	220.28	0.975	1.8523	119
Total site				574

Table 5-3 Result of site coverage area and required site for each area

5.2.2 Capacity Planning Analysis

Capacity planning inputs gives the number of subscribers in the system, their demanded services and subscriber usage level in the busy hour. Available spectrum and channel bandwidth used by the LTE system are also very important for LTE capacity planning. The traffic model of table 5.4 is based on the current usage of Ethio Telecom data usage. Generally the input parameters and the output result summarized as follow:

Types of customer	Traffic Usage in GB/Month/User	Busy hour convergence raio	Usage ratio of the services	Traffic ratio	
				DL	UL
Type 1	20	14.4	70%	80%	20%
Type 2	15	14.4	20%	80%	20%
Type 3	10	14.4	10%	80%	20%

Table 5-4 Traffic model and assumption of input parameters for capacity dimensioning

Using the input of table 5.4 and traffic model equation described in chapter 4, the following the required result was obtained through the following steps:

- **Step1:** Obtain the average throughput per subscriber for uplink and downlink (*Using equation 4.22, 4.23, 4.24, 4.25 and input parameter of table 5.2.4*)

Types of customer	Average throughput /user in BH (Kbps)(DL+UL)
Type 1	88.89
Type 2	66.67
Type 3	44.44
Downlink and uplink throughput per subscriber	
Total avg. throughput per sub in BH (Kbps)	80

DL: Avg. throughput per subscriber (Kbps)	64
UL: Avg. throughput per subscriber (Kbps)	16

Table 5-5 Uplink and downlink average throughput per subscriber result

- **Step2:** calculate average throughput per site for uplink and downlink (*Using equation 4.26, 4.27, 4.28*)

Description	Value	Assigned	Remark
Used bandwidth (MHz)	20	a	-
Assumed 10% of bandwidth used for guard (CP) (MHz)	2	b	10% *a
Effective bandwidth (MHz)	18	c	a-b
Bandwidth of one subscriber (KHz)	15	d	-
Total subcarrier	1200	e	c/d
Symbols per 1ms for resource block	16800		12*7*2
Symbols per 1ms for resource block (Mbps)	16.8		16800/1000
MIMO	2Tx2R for downlink		
Bits capacity per symbol (bit)	2		QPSK
	4		16QAM
	6		64QAM
Coding rate	0.667		QPSK
	0.793		16QAM
	0.8		64QAM

Table 5-6 Input parameters for average throughput per site manipulation

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

Total Peak Throughput per site (Mbps)	162
Average throughput per site for downlink (Mbps)	129.6
Average throughput per site for uplink (Mbps)	32.4

Table 5-7 Average throughput per site for uplink and downlink result

- Step2: Obtain the total number of site using *eqs. 4.28 to 4.30*
 - Downlink: maximum number of subscriber =**2025 sub/site**
 - Uplink: maximum number of subscriber =**2025 sub/site**
 - Total sites number for dense urban =**198 site**
 - Total sites number for urban = **173 site**
 - Total sites number for sub urban= **148 site**

5.2.3 Site count

In the LTE network dimension the required sites number for a specific area should be chosen to be the maximum number of sites obtained from coverage and capacity dimensioning calculations to satisfy the demand traffic requirements; see **figure 5.2.1**

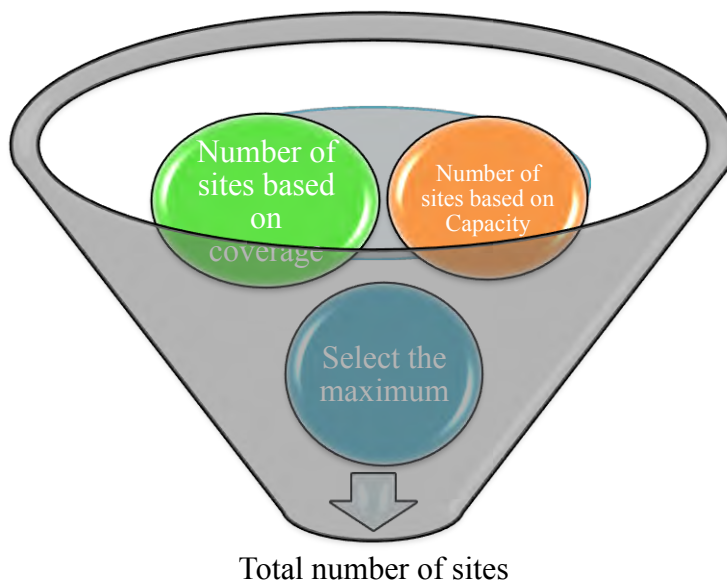


Figure 5-2 selections between coverage and capacity site result

Hence comparing the number of sites from capacity and coverage planning and choosing the maximum we obtain the maximum site to satisfy both coverage and capacity.

Morphology	Required Sites Number
Dense Urban	200
Urban	255
Sub Urban	148
Total site	603

Table 5-8 required number of sites for dense urban, urban and sub urban of Addis Ababa

5.3 ATOLL Overview

ATOLL is a multi-technology wireless network design and optimization platform that supports wireless operators throughout the network lifecycle, from initial design to densification and optimization.

ATOLL's integration and automation features help operators smoothly automate planning and optimization processes through flexible scripting and SOA-based mechanisms. ATOLL supports a wide range of implementation scenarios, from standalone to enterprise-wide server-based configurations and ATOLL has become the industry standard for radio network planning and optimization.

Before running the predictions, it is important to create the zones. Below is a description of these zones based on the ATOLL User Manual.

Filtering Zone: The filtering zone is a graphical filter that restricts the objects displayed on the map and on the Data tab of the Explorer window to the objects inside the filtering zone. It also restricts which objects are used in calculations such as coverage predictions, etc.

Computation Zone: The computation zone is used to define which base stations are to be taken into consideration in calculations and the area where ATOLL calculates path loss matrices, coverage studies, etc.

Focus Zone: With the focus zone, you can select the areas of coverage predictions or other calculations on which you want to generate reports and results.

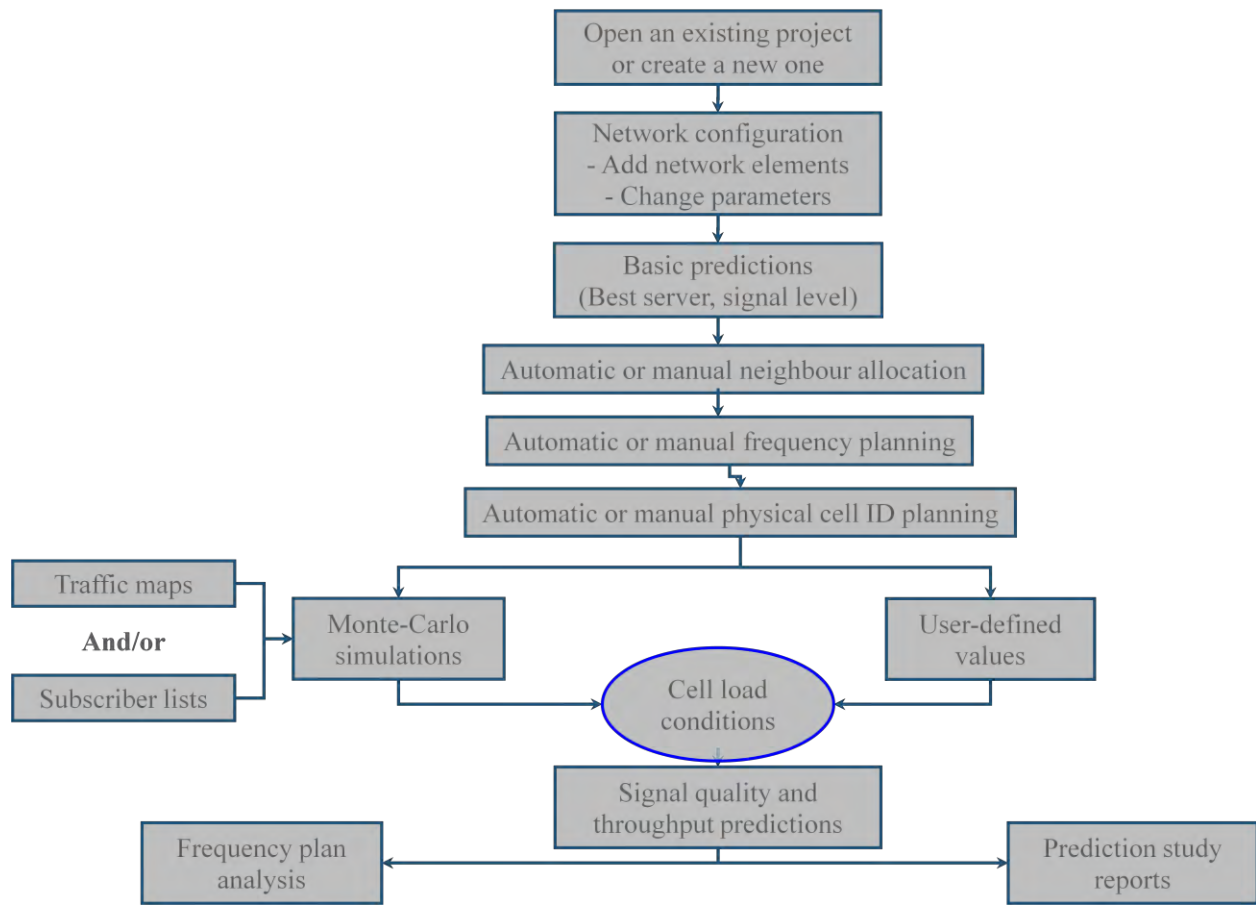


Figure 5-3 LTE workflow of for ATOLL

5.3.1 ATOLL Setting and Engineering Parameters Data

This section discusses some important LTE dimensioning inputs used in the development of methods and models for LTE dimensioning using ATOLL tool. LTE dimension inputs can be broadly divided into three categories: Traffic, coverage and capacity-related inputs. Traffic related inputs include average cell throughput, number of subscribers and demand traffic for each user in BH. These parameters are the customer requirements to provide a certain level of service to its users. These inputs directly translate into (QoS) parameters. Besides cell edge performance criterion is used in the dimensioning tool to determine the cell radius and thus the site counts.

A. Create the Project

- Go to File -> New -> From a Document Template.
- In the Project Templates, Choose LTE.
- Go to File -> Save As -> and save the project.

B. Setup the Coordinate System and Units

This defines the coordinate system and units that will be used in the project.

Go to document → properties. In the coordinates tab, choose the coordinates in Projection and Display.

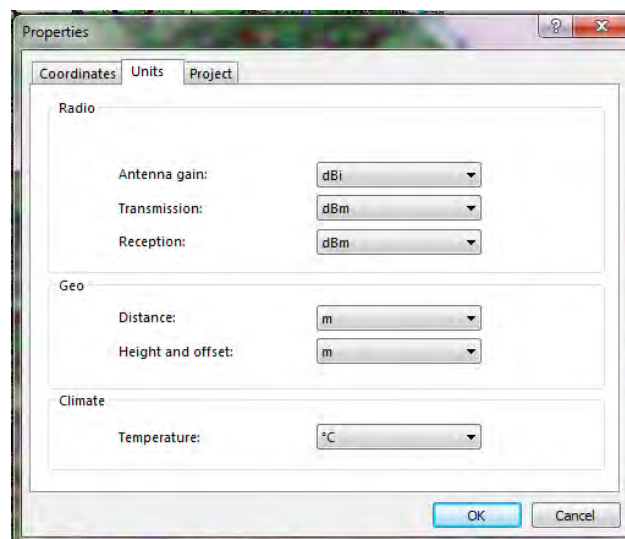


Figure 5-4 setting coordinates, units and project on

C. Geographical Data

The geographical data is a digital map includes information of main airport, main road, secondary road, street, railway and water.

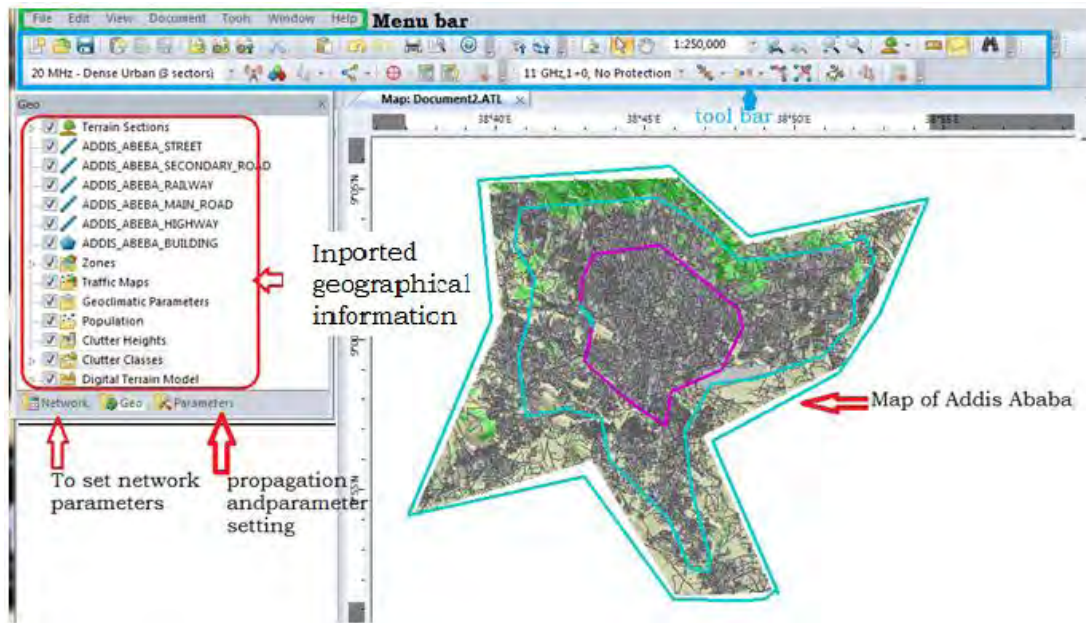


Figure 5-5 digital maps of Addis Ababa and ATOLL GUI

The different geographic data types play different roles in the ATOLL document:

- Geographic data used in propagation calculation:
 - ✓ Digital terrain model: describes the elevation of the ground over sea level
 - ✓ Clutter classes: geo data file describes land cover or land use
 - ✓ Clutter heights: describe the altitude of clutter over the DTM with one altitude defined per pixel
- Geographic data used in dimensioning:
 - ✓ Traffic maps: contain information on capacity and service use per geographic area
- Geographic data used in statistics:
 - ✓ Population maps: contain information on population density or on the total number of inhabitants
 - ✓ Custom maps

D. Enter the Clutter Height Information

Clutter height maps describe the altitude of clutter over the DTM. Clutter height files allow for a higher degree of accuracy because they allow more than one height per clutter class. In a clutter height file, a height is given for each point on the map. If you define clutter height as a property of clutter classes, the height is given as an average per clutter class. ATOLL uses its clutter height information for calculations using propagation models.

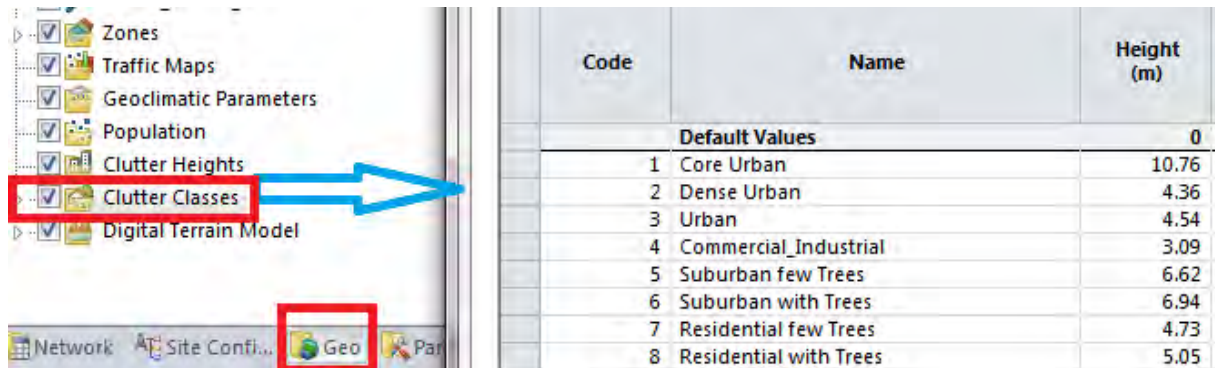


Figure 5-6 configuring clutter classes

E. Setup the Propagation Model

The Cost231-Hata propagation model can use an environment formula appropriate to each clutter class when calculating. So for this project the cost231-hata model is used as propagation model.

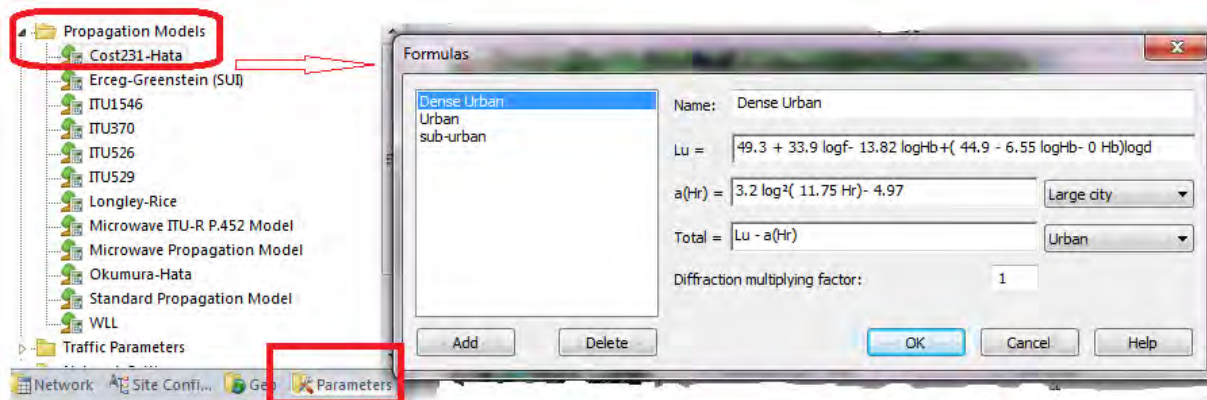


Figure 5-7 configuring propagation models

F. Create the Antennas to be used

The antenna is the part of the radio network equipment link that transmits electromagnetic energy from transmission lines into the air and receives transmitted electromagnetic energy from the air to be then sent on transmission lines.

The main characteristics of the microwave antenna are the following:

Frequency Band: The frequency band that this antenna will be used with.

Horizontal: The ratio of power received in the cross-polar section to the power received in the co-polar section, for the horizontal polarization.

Vertical: The ratio of power received in the cross-polar section to the power received in the co-polar section, for the vertical polarization.

Directivity: In practical terms, directivity is defined as:

- The ability to send the transmitted power in only the desired direction
- The ability to reject undesired signals coming from other directions.

Gain: The gain is the amount of power radiated in a given direction using only the RF power at the input terminals of the antenna.

Radiation pattern: The radiation pattern is a diagram showing the direction of the radiated power. The portion of the pattern where the maximum gain occurs is often referred to as the main lobe of the pattern

G. Setup the Frequency Bands

The LTE frequency bandwidth is 20MHz with frequency 1800 MHz will be selected in band number 3 because it satisfies the selected frequency. This frequency is used for GSM planning too, distinguishing with frequency point.

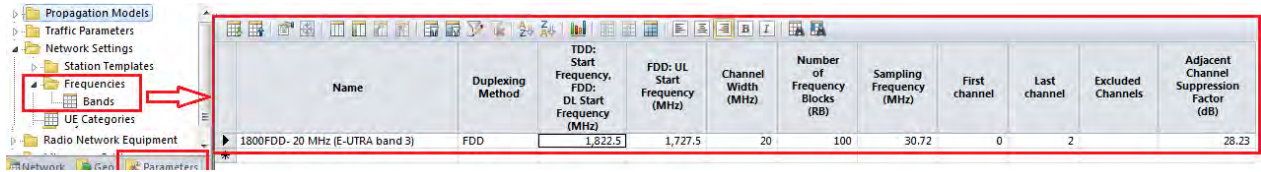


Figure 5-8 setting frequency bands

H. Create the LTE Bearers

Radio bearers are used by the network for carrying information. A "bearer" refers to a combination of MCS, i.e., modulation and coding schemes.

Radio Bearer Index	Name	Modulation	Channel Coding Rate	Bearer Efficiency (bits/symbol)
1	QPSK 1/12	QPSK	0.0761719	0.1523
2	QPSK 1/9	QPSK	0.117188	0.2344
3	QPSK 1/6	QPSK	0.188477	0.377
4	QPSK 1/3	QPSK	0.300781	0.6016
5	QPSK 1/2	QPSK	0.438477	0.877
6	QPSK 3/5	QPSK	0.587891	1.1758
7	16QAM 1/3	16QAM	0.369141	1.4766
8	16QAM 1/2	16QAM	0.478516	1.9141
9	16QAM 3/5	16QAM	0.601563	2.4063
10	64QAM 1/2	64QAM	0.455078	2.7305
11	64QAM 1/2	64QAM	0.553711	3.3223
12	64QAM 3/5	64QAM	0.650391	3.9023
13	64QAM 3/4	64QAM	0.753906	4.5234
14	64QAM 5/6	64QAM	0.852539	5.1152
15	64QAM 11/12	64QAM	0.925781	5.5547

Figure 5-9 setting LTE bearer

I. Create the TMA Equipment

Tower-mounted amplifier: Tower-mounted amplifiers (TMAs) also referred to as masthead amplifiers are used to reduce the composite noise figure of the base station. TMAs are connected between the antenna and the feeder cable.

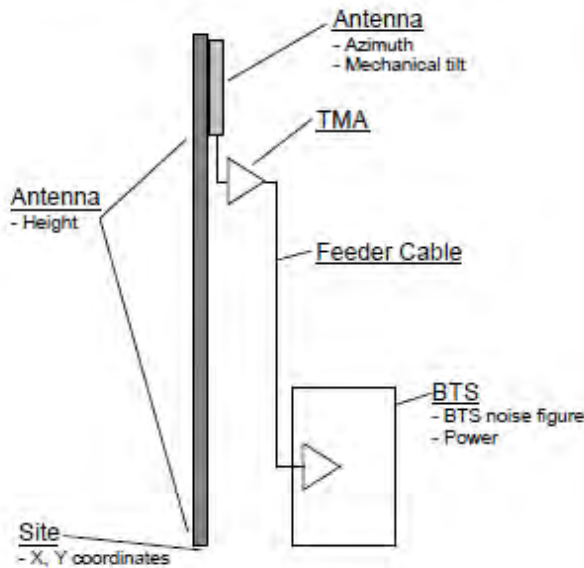


Figure 5-10 TMA equipment

J. Create the Feeder Equipment

Feeder cables connect the TMA to the antenna. Feeder loss indicates the signal loss caused by various devices that are located on the path of the antenna to the receiver. Any device using an external antenna for service provision at either the base station side or terminal side must consider feeder loss.

K. Create the Sites

Sites in ATOLL are just geographic point on the map and do not contain details about the antenna or transmitter. Once the coordinate of the site entered the Altitude i.e. geographic point where the site will be located, will be automatically populated base on the digital terrain model.

Name	Longitude	Latitude	Altitude (m)	Comments	Pylon Height (m)	Support Type
Site1	38°43'37.21"E	9°2'1.01"N	[2,462]		50	<Undefin
Site10	38°46'31.4"E	8°58'50.71"N	[2,315]		50	<Undefin
Site100	38°46'22.8"E	8°57'17.75"N	[2,223]		50	<Undefin
Site101	38°43'18.3"E	9°0'10.55"N	[2,344]		50	<Undefin
Site102	38°41'30.26"E	8°59'27.49"N	[2,358]		50	<Undefin
Site103	38°44'40.73"E	9°3'31.2"N	[2,569]		50	<Undefin
Site104	38°44'21.08"E	8°57'12.49"N	[2,225]		50	<Undefin
Site105	38°44'7.99"E	8°59'20.88"N	[2,307]		50	<Undefin
Site106	38°42'1.97"E	8°57'47.29"N	[2,288]		50	<Undefin
Site107	38°45'19.55"E	8°57'41.41"N	[2,255]		50	<Undefin
Site108	38°42'48.89"E	9°4'18.08"N	[2,642]		50	<Undefin
Site109	38°48'57.35"E	8°59'20.47"N	[2,308]		50	<Undefin
Site11	38°46'11.15"E	8°59'14.34"N	[2,312]		50	<Undefin
Site110	38°44'0.27"E	8°57'38.33"N	[2,226]		50	<Undefin
Site111	38°41'35.11"E	8°57'55.0"N	[2,311]		50	<Undefin

Figure 5-11 creating sites

L. Create the Transmitters

In ATOLL, a transmitter is defined as the antenna and any other additional equipment, such as the TMA, feeder cables, etc. The character of transmitter includes: antenna, antenna height, azimuth, mechanical and electrical down tilt, etc.

Mechanical DownTilt (°)	Additional Electrical DownTilt (°)	Smart Antenna Equipment	Transmission losses (dB)	Reception losses (dB)	Noise figure (dB)	Transmitter Equipment	TMA Equipment
0	0	Conventional Beamforming Smart Ante	4.42	4.31	2.5	eNode-B Equipment	TMA Equipment
0	0	Conventional Beamforming Smart Ante	4.42	4.31	2.5	eNode-B Equipment	TMA Equipment
0	0	Conventional Beamforming Smart Ante	4.42	4.31	2.5	eNode-B Equipment	TMA Equipment
0	0	Conventional Beamforming Smart Ante	5.01	4.79	2.5	eNode-B Equipment	TMA Equipment
0	0	Conventional Beamforming Smart Ante	5.01	4.79	2.5	eNode-B Equipment	TMA Equipment
0	0	Conventional Beamforming Smart Ante	5.01	4.79	2.5	eNode-B Equipment	TMA Equipment
0	0	Conventional Beamforming Smart Ante	3.64	3.68	2.5	eNode-B Equipment	TMA Equipment
0	0	Conventional Beamforming Smart Ante	3.64	3.68	2.5	eNode-B Equipment	TMA Equipment
0	0	Conventional Beamforming Smart Ante	3.64	3.68	2.5	eNode-B Equipment	TMA Equipment
0	0	Conventional Beamforming Smart Ante	4.07	4.03	2.5	eNode-B Equipment	TMA Equipment

Figure 5-12 creating transmitters

The **azimuth** is the angle formed between reference directions (North) and a line from the observer to a point of interest projected on the same plane as the reference direction.

M. Create the Cells Table

A cell or a sector refers to the characteristics of an RF channel on a transmitter which has the character of frequency band, transmitted power, traffic load, etc.

Transmitter	Active	Layer (0 = lowest priority)	Frequency Band	Channel Number
Site175_1	<input checked="" type="checkbox"/>	0	1800FDD-20 MHz (E-UTRA band 3)	0
Site1_1	<input checked="" type="checkbox"/>	0	1800FDD-20 MHz (E-UTRA band 3)	0
Site1_2	<input checked="" type="checkbox"/>	0	1800FDD-20 MHz (E-UTRA band 3)	0
Site1_3	<input checked="" type="checkbox"/>	0	1800FDD-20 MHz (E-UTRA band 3)	0
Site10_1	<input checked="" type="checkbox"/>	0	1800FDD-20 MHz (E-UTRA band 3)	0
Site10_2	<input checked="" type="checkbox"/>	0	1800FDD-20 MHz (E-UTRA band 3)	0
Site10_3	<input checked="" type="checkbox"/>	0	1800FDD-20 MHz (E-UTRA band 3)	0
Site100_1	<input checked="" type="checkbox"/>	0	1800FDD-20 MHz (E-UTRA band 3)	0
Site100_2	<input checked="" type="checkbox"/>	0	1800FDD-20 MHz (E-UTRA band 3)	0
Site100_3	<input checked="" type="checkbox"/>	0	1800FDD-20 MHz (E-UTRA band 3)	0

Figure 5-13 creating cells

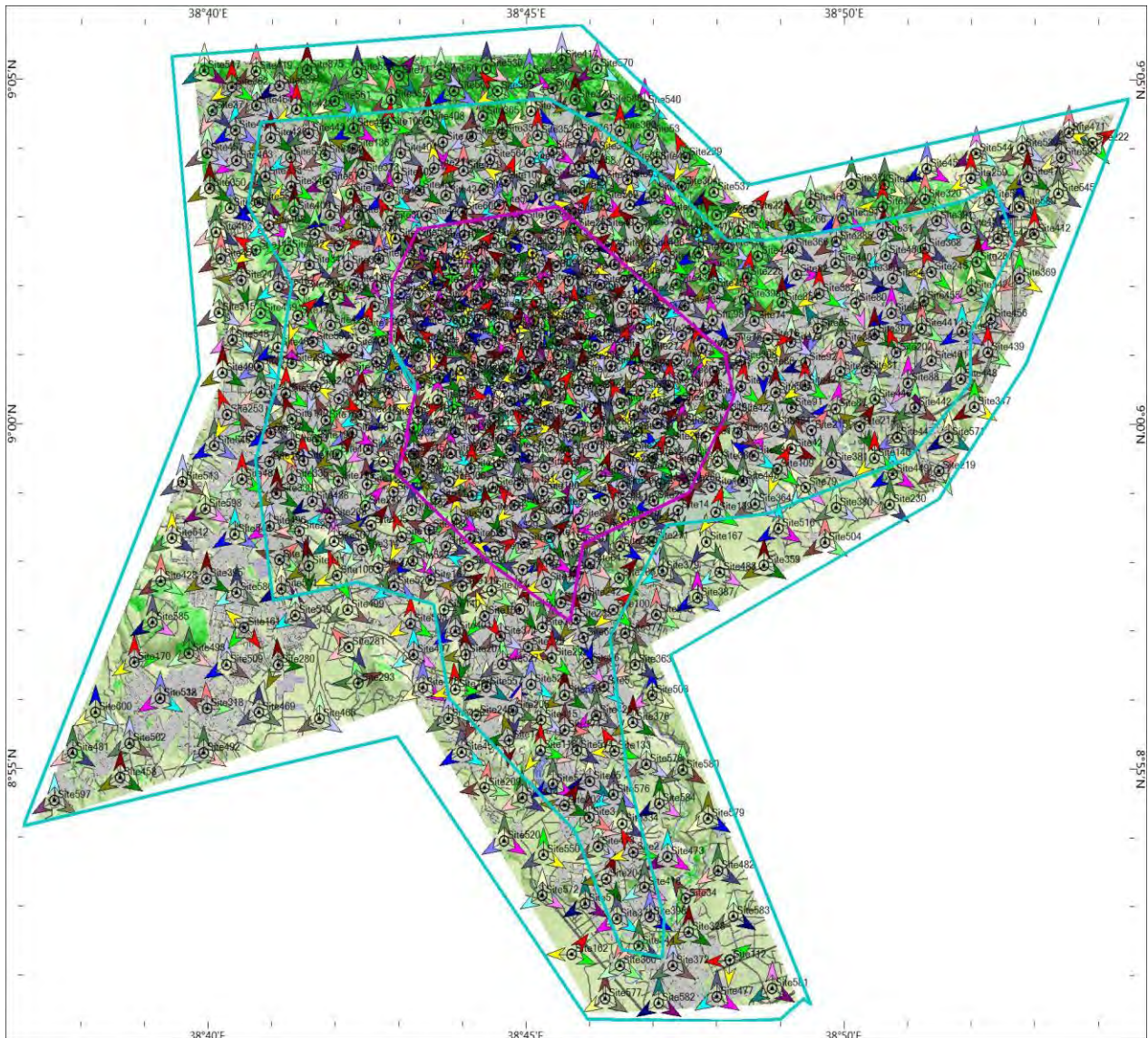


Figure 5-14 displayed radio network equipment

N. Setting Traffic Parameter

Traffic forecast should be done by analyzing the offered Busy Hour traffic per subscriber for different services in each area. The main purpose of traffic model is to describe the average subscriber behavior during the most loaded day period (the Busy Hour). This includes:

- Services: such as VoIP, Video, streaming, Web browsing & FTP.
- Mobility types
- Terminals
- User profile

➤ Environments

Inter-cell interference coordination (ICIC)

The LTE system uses the Orthogonal Frequency Division Multiple Access (OFDMA) technology in the downlink (DL) and the Single Carrier - Frequency Division Multiple Access (SC-FDMA) technology in the uplink (UL). OFDMA and SC-FDMA have a common characteristic. All physical resource blocks (PRBs) occupied by user equipment (UEs) in a cell are mutually orthogonal in the frequency domain; therefore, intra-cell interference is very low.

However, inter-cell interference is relatively high because the frequency reuse factor is 1, in which case every cell can provide services over the entire system band. For cell edge users (CEUs), the impact of the inter-cell interference is especially severe. Therefore, to increase the CEU throughput, inter-cell interference must be mitigated.

Inter-Cell Interference Coordination (ICIC) is a technology that collaborates with power control and media access control (MAC) scheduling technologies to mitigate inter-cell interference. ICIC divides the entire system band into three frequency bands and uses different frequency bands at the edge of neighboring cells. CEUs, which cause high interference or may be sensitive to interference, are preferentially scheduled in the cell edge bands to mitigate inter-cell interference. The interference mitigation enhances the network coverage and improves the CEU throughput.

Automatic neighboring planning

Neighbor cells are adjacent to each other in general. That is, sector A takes sector B as its neighbor cell and sector B also takes sector A as its neighbor cell. In some scenarios such as high-speed coverage, it is necessary to set unidirectional neighbor cells. For example, to implement handover from sector A to sector B but not from sector B to sector A, add sector A to the blacklist of sector B.

Neighbors can be set for each cell manually, or you can let **ATOLL** automatically allocate neighbors, based on the parameters set. When allocating neighbors, the cell that we allocating neighbors are referred to as the *reference cell*. The cells that fulfill the requirements to be neighbors are referred to as *possible neighbors*. When allocating neighbors to all active and filtered transmitters, ATOLL allocates neighbors only to the cells within the focus zone and

considers as possible neighbors all the active and filtered cells whose propagation zone intersects a rectangle containing.

Automatic Frequency Planning:

The role of an Automatic Frequency Planning (AFP) tool is to assign frequencies (channels) to cells of a network such that the overall network performance is optimized. In other words, the interference within the network is reduced as much as possible. Co-channel interference is the main reason for overall network quality degradation in LTE. In order to improve network performance, the LTE AFP tries to minimize co- and adjacent channel interference as much as possible while respecting any constraints input to it. The main constraints are the resources available for allocation, i.e., the number of frequencies with which the AFP can work, and the relationships to take into account, i.e., interference matrices, neighbors, and distance between transmitters.

The AFP is based on a cost function which represents the interference level in the network. The aim of the AFP is to minimize the cost. The best, or optimum, frequency plan is the one which corresponds to the lowest cost.

The following describes the automatic allocation method for carrier frequencies in LTE networks, which takes into account interference matrices, neighbor relations, and distance between transmitters.

Automatic physical cell ID Planning

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.

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.

5.3.2 Simulation and Result

Coverage predictions have been performed by: transmitter, signal level, downlink throughput and Channel to Interference plus Noise Ratio (CINR). Corresponding coverage prediction results have been shown with respective coverage prediction properties.

Coverage by Signal Level: - A signal level coverage prediction displays the signal of the best server for each pixel of the area studied. For a transmitter with more than one cell, the signal level is calculated for the cell with the highest power. As show on **figure 5.3.2-1** more than 95% of the target area/Addis Ababa city area is covered by strong signal i.e. -90 dBm.

Coverage Prediction by Transmitter: - A coverage prediction by transmitter allows predicting coverage zones by transmitter at each pixel. You can base the coverage on the signal level, path loss, or total losses within a defined range. For this project the coverage of transmitter based on the signal level is simulated in **figure 5.3.2-2**. For a transmitter with more than one cell, the coverage is calculated for the cell with the highest power.

Coverage Prediction on Overlapping Zones: - Overlapping zones as shown on **figure 5.3.2-3** are composed of pixels that are, for a defined condition, covered by the signal of at least two transmitters. You can base a coverage prediction on overlapping zones on the signal level, path loss, or total losses within a defined range. For a transmitter with more than one cell, the coverage is calculated for the cell with the highest power.

Analyzing the Signal Quality (Coverage by $C/(I+N)$ Level (DL) or (UL))

In LTE, the capacity and the effective service coverage areas of cells are influenced by network loads. As the network load increases, the area where a cell provides service decreases. For this reason, network loads must be defined in order to calculate these coverage predictions.

ATOLL offers a series of coverage predictions which are based on the predicted signal level from the best server and the predicted signal levels from other cells (interference) at each pixel, i.e., carrier-to-interference-and-noise ratio, or $C/(I+N)$.

In this section, these coverage predictions will be calculated using downlink traffic loads and the uplink noise rise values defined at the cell level. Before making a prediction, the downlink traffic loads and the uplink noise rise, and the parameters that define the services and users are defined. Downlink and uplink coverage predictions by $C/(I+N)$ level predict the interference levels and signal-to-interference levels in the part of the network being studied.

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

Coverage prediction by $C/(I+N)$ level calculates the co-channel interference as well as the adjacent channel interference, which is reduced by the adjacent channel suppression factor defined in the Frequency Bands table.

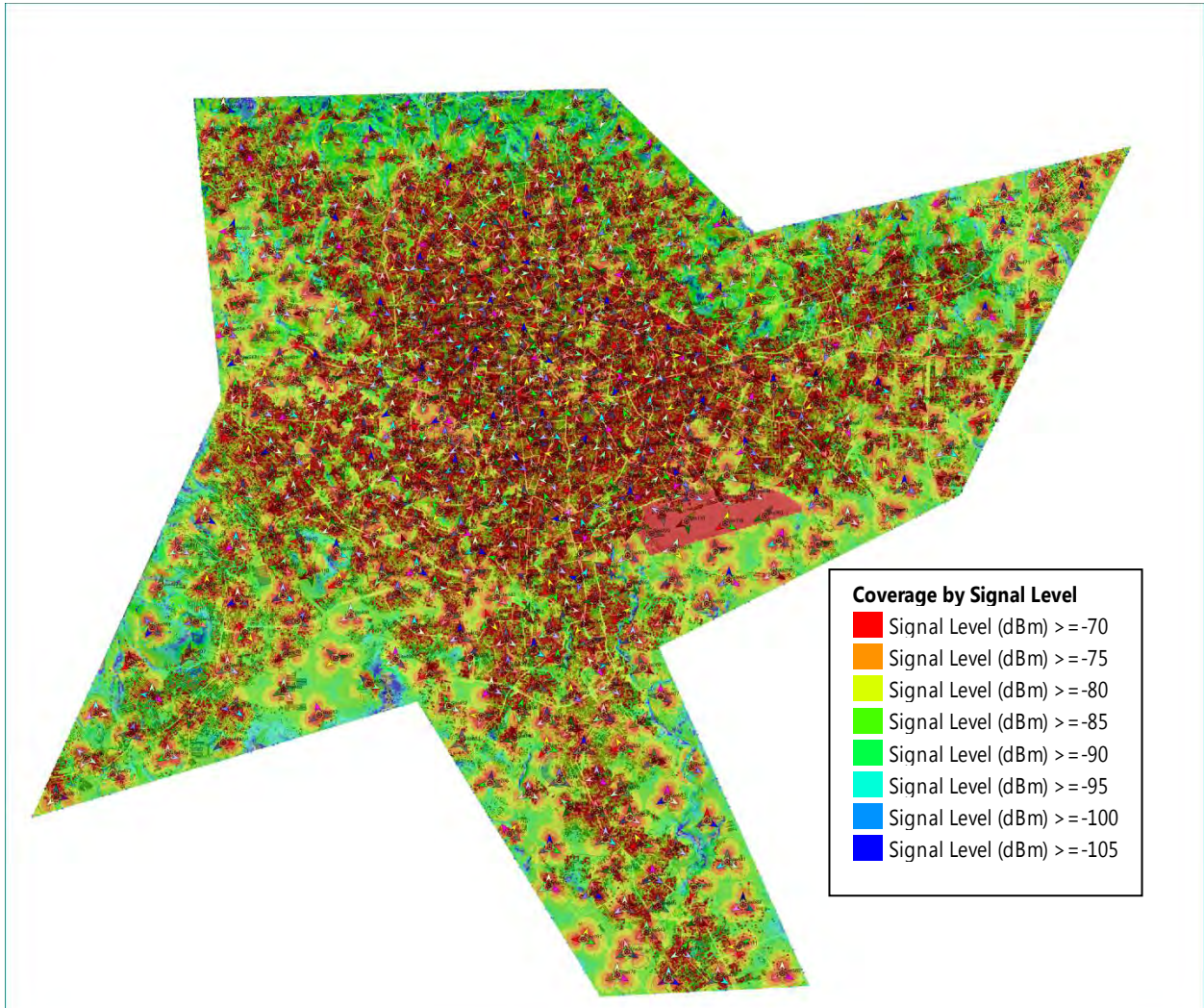
The carrier to interference plus noise (CINR) is the ratio of the signal carrier best servings for the intervention seemed at all other sites/sectors, plus all the noise. If a signal goes below the level of noise, it cannot be decoded and no useful information can be recovered from it. A good signal is important for high data rate communications as **figure 5.3.3-4**.

Coverage by Throughput DL: - 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. ATOLL calculates the peak MAC channel throughputs from the information provided in the frame configurations and in the terminal and mobility properties for the terminal and mobility selected in the coverage prediction. 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.

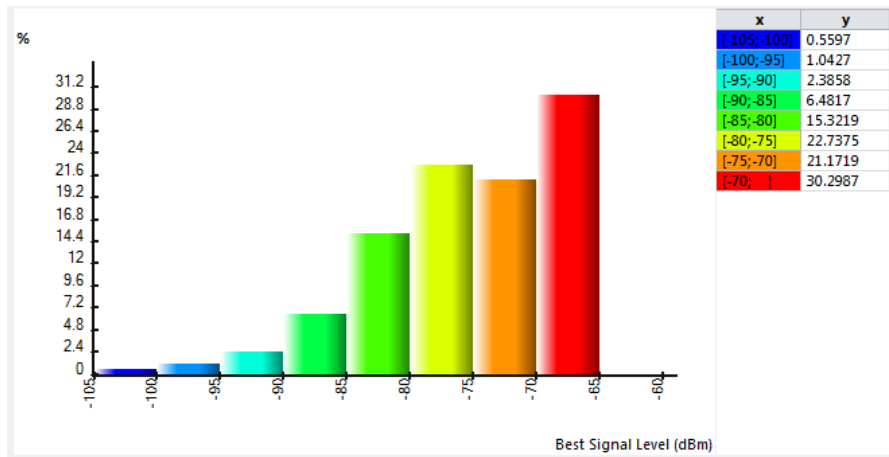
The effective MAC throughputs are the peak MAC throughputs reduced by retransmission due to errors, or the Block Error Rate (BLER). ATOLL uses the block error rate graphs of the reception equipment defined in the selected terminal for downlink or the reception equipment of the cell of the serving transmitter for uplink.

The application throughput is the effective MAC throughput reduced by the overheads of the different layers between the MAC and the Application layers.

The cell capacity display types let to calculate and display the throughputs available on each pixel of the coverage area taking into account the maximum traffic load limits set for each cell. In other words, 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 on **figure 5.3.2-5**.



a)



b)

Figure 5-15 (a) Coverage prediction by Signal level (b) Histogram

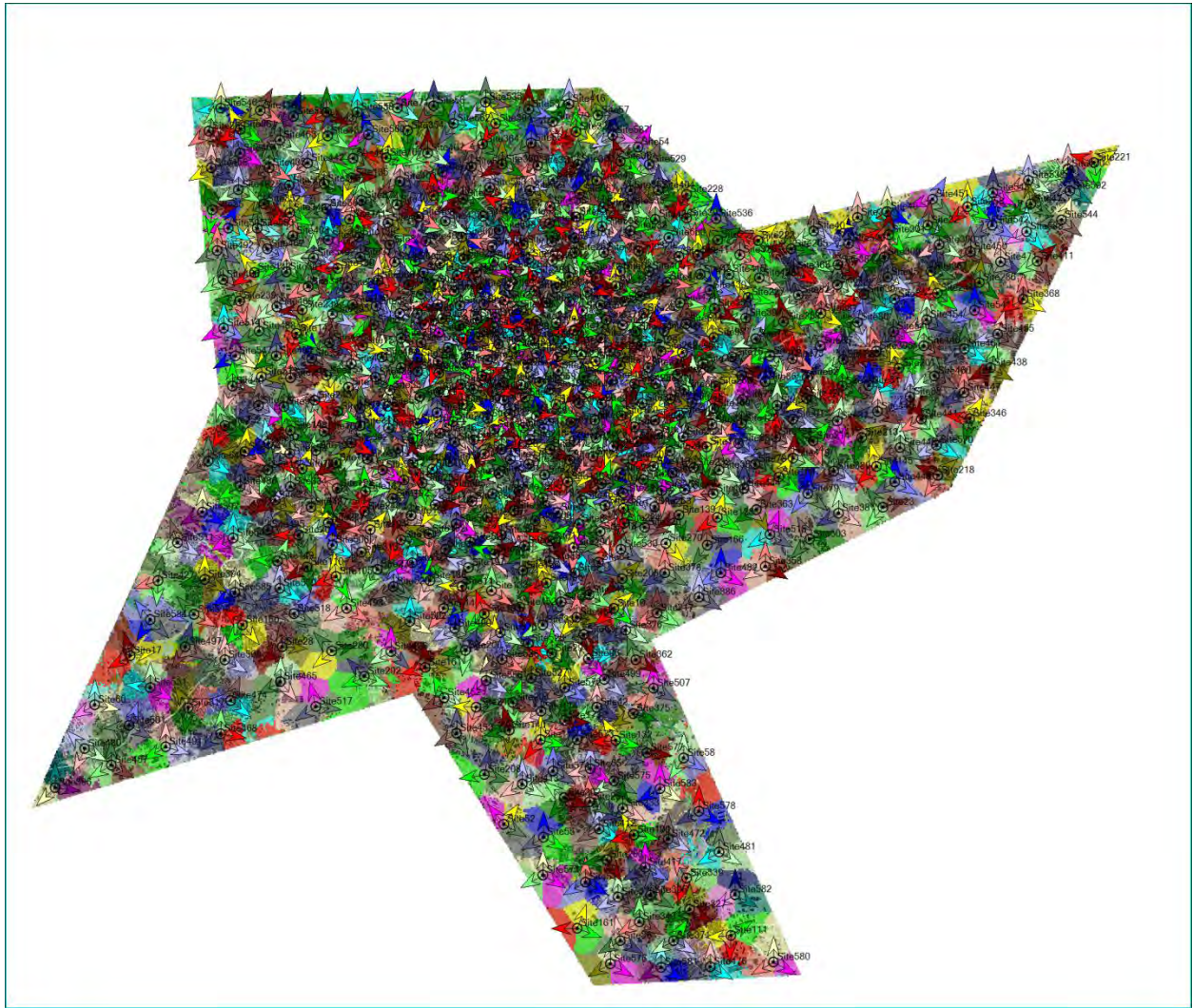
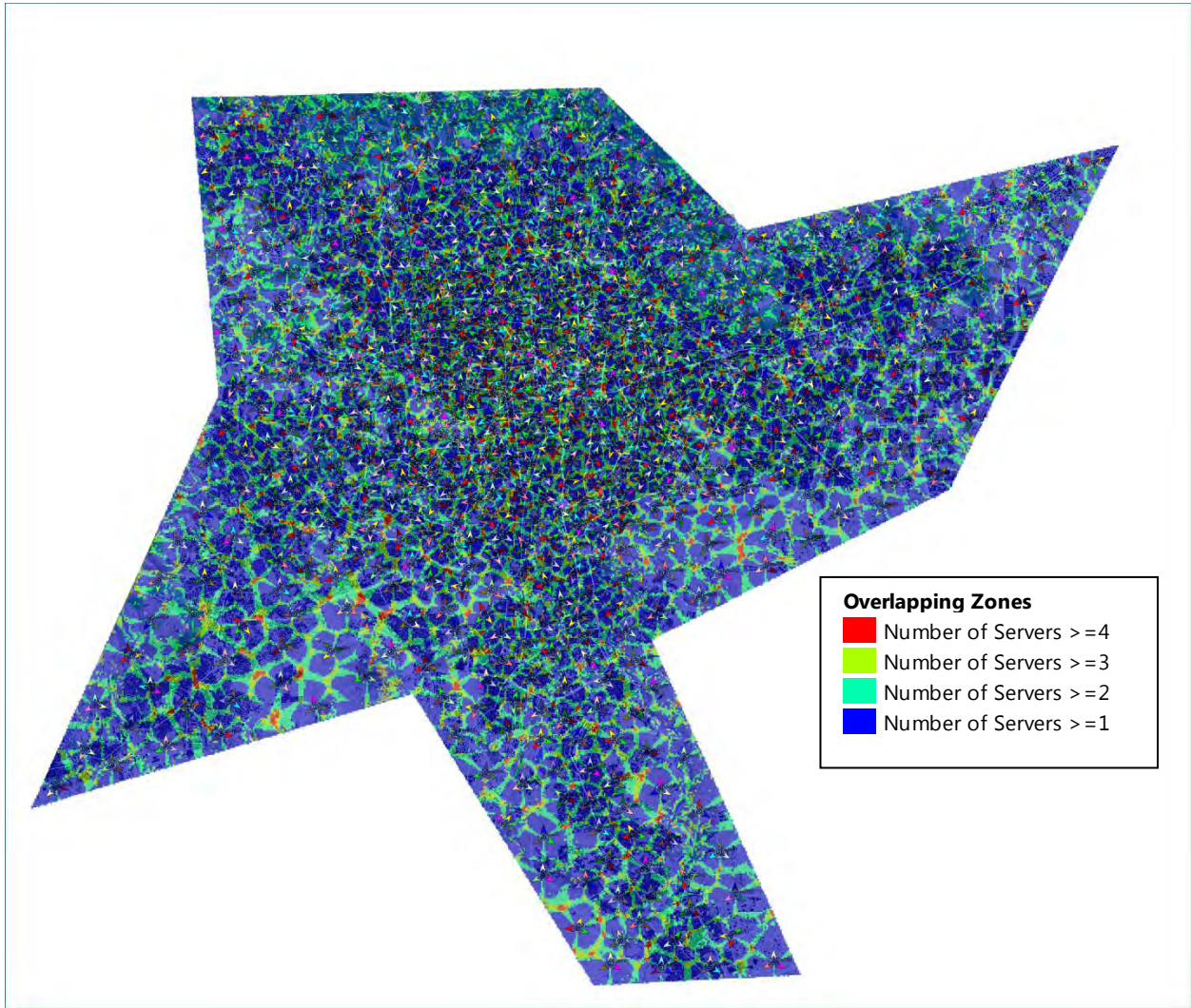
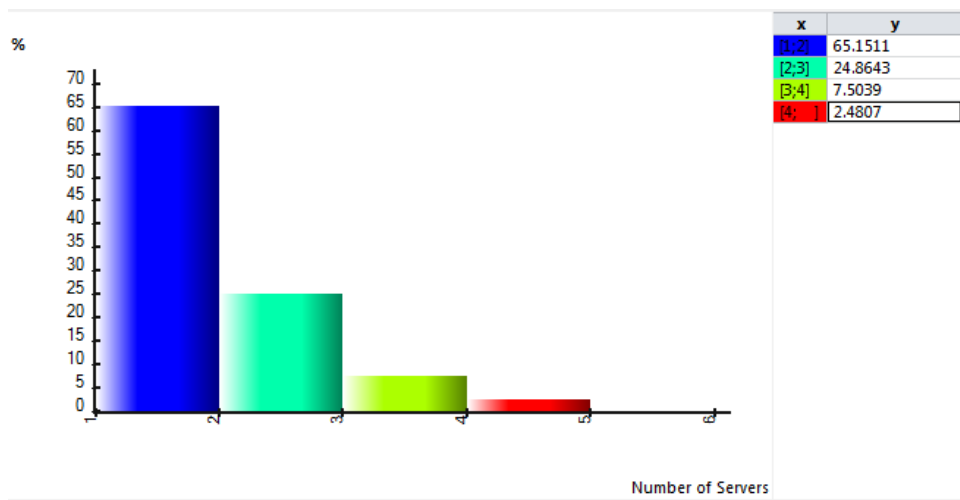


Figure 5-16 Coverage predictions by transmitter

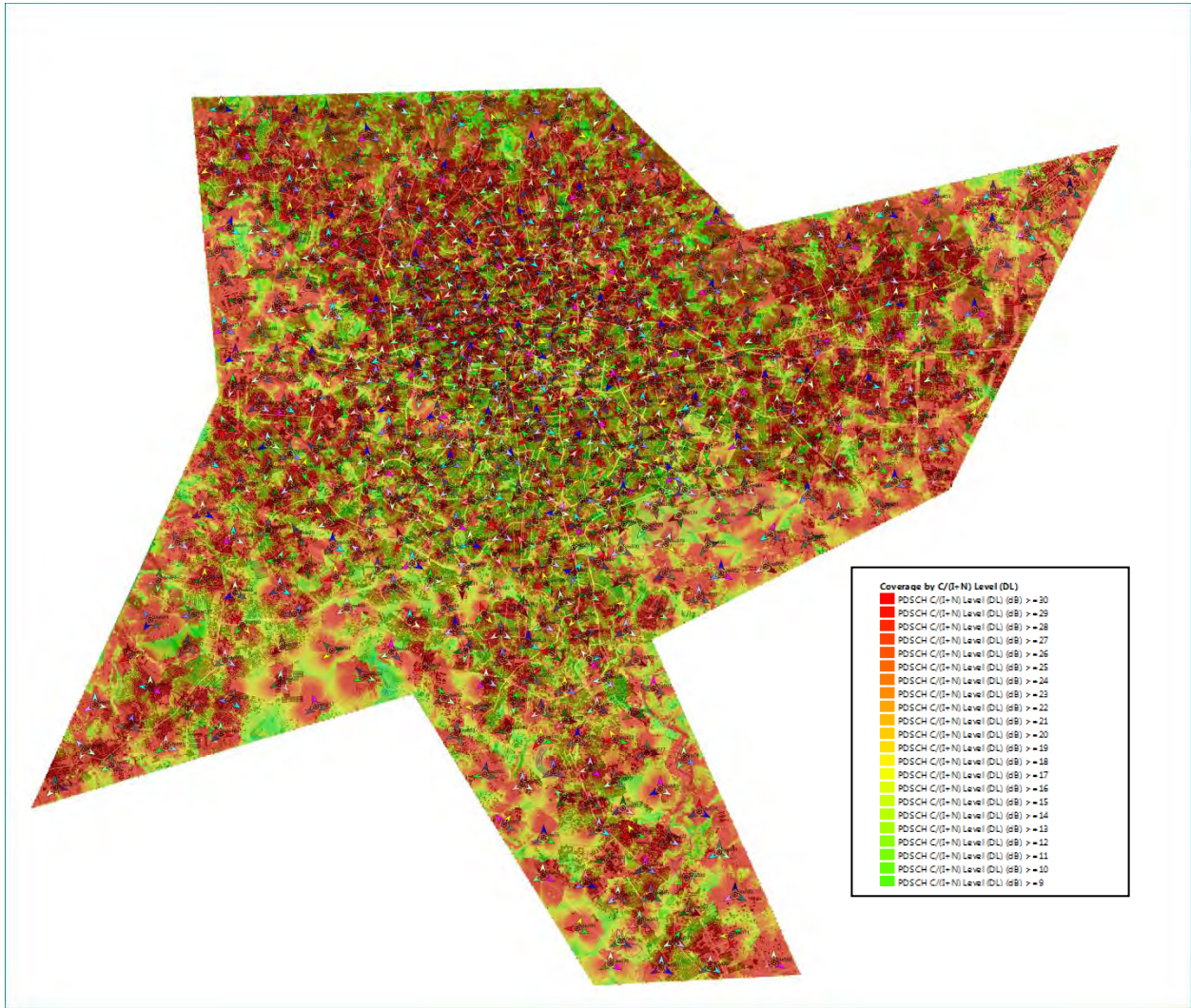


a)

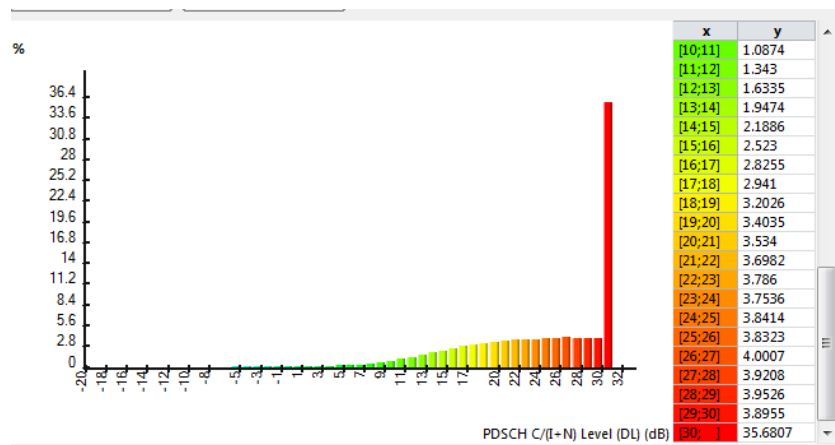


b)

Figure 5-17 (a) overlapping zone of transmitter (b) Histogram

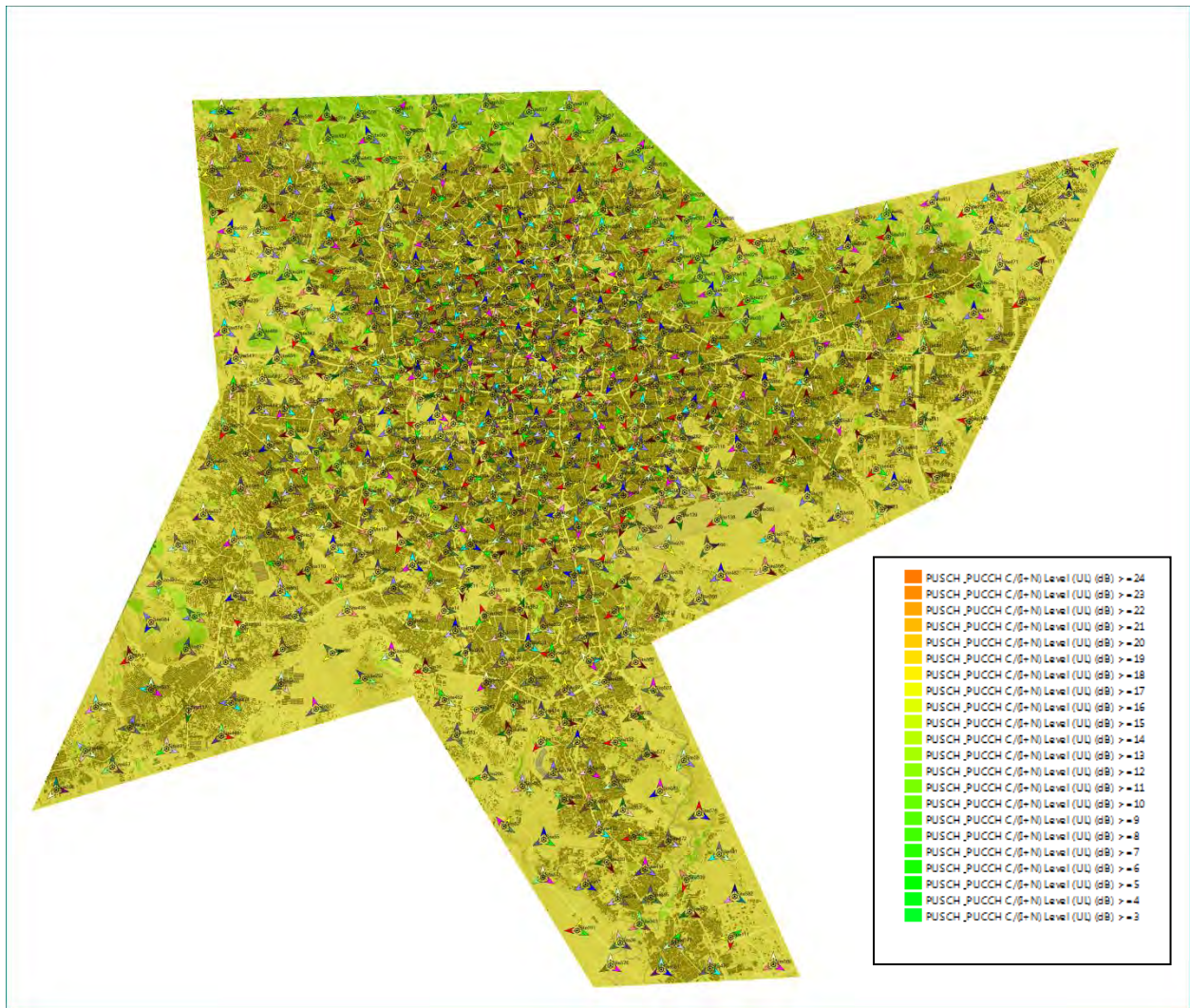


a)

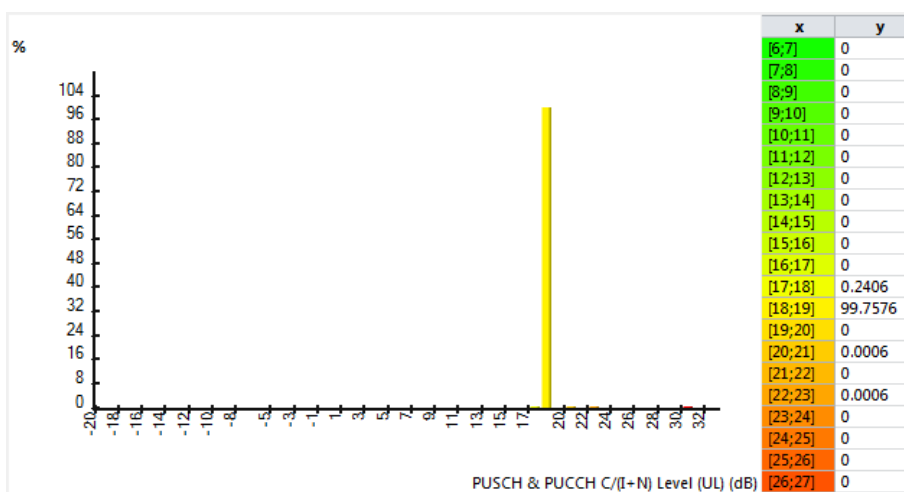


b)

Figure 5-18 (a) Coverage by C/ (I+N) Level (DL) and (b) Histogram

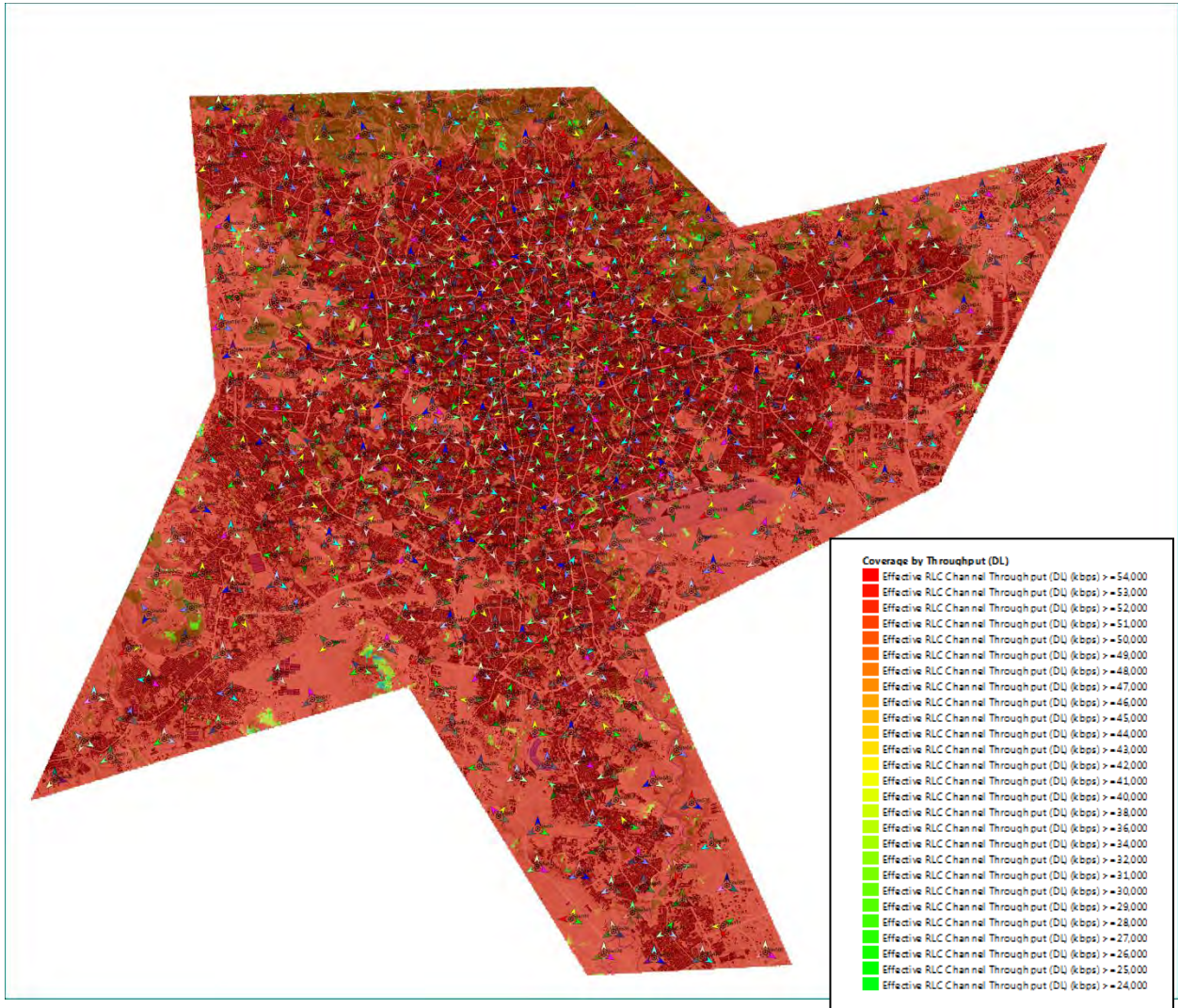


a)

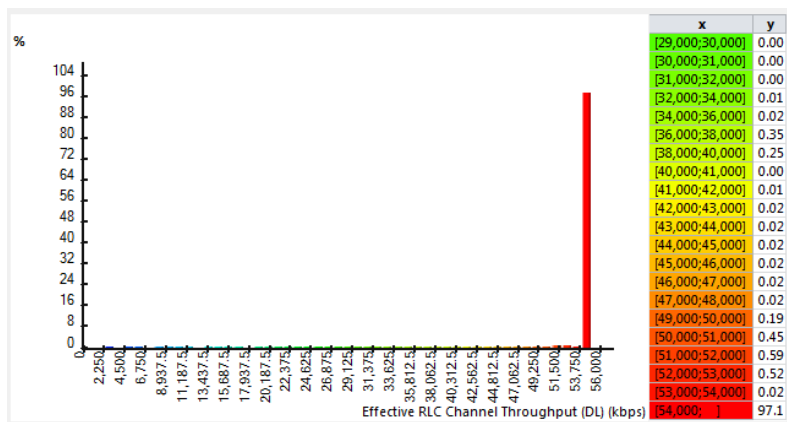


b)

Figure 5-19 (a) Coverage by C/ (I+N) Level (UL) and (b) Histogram

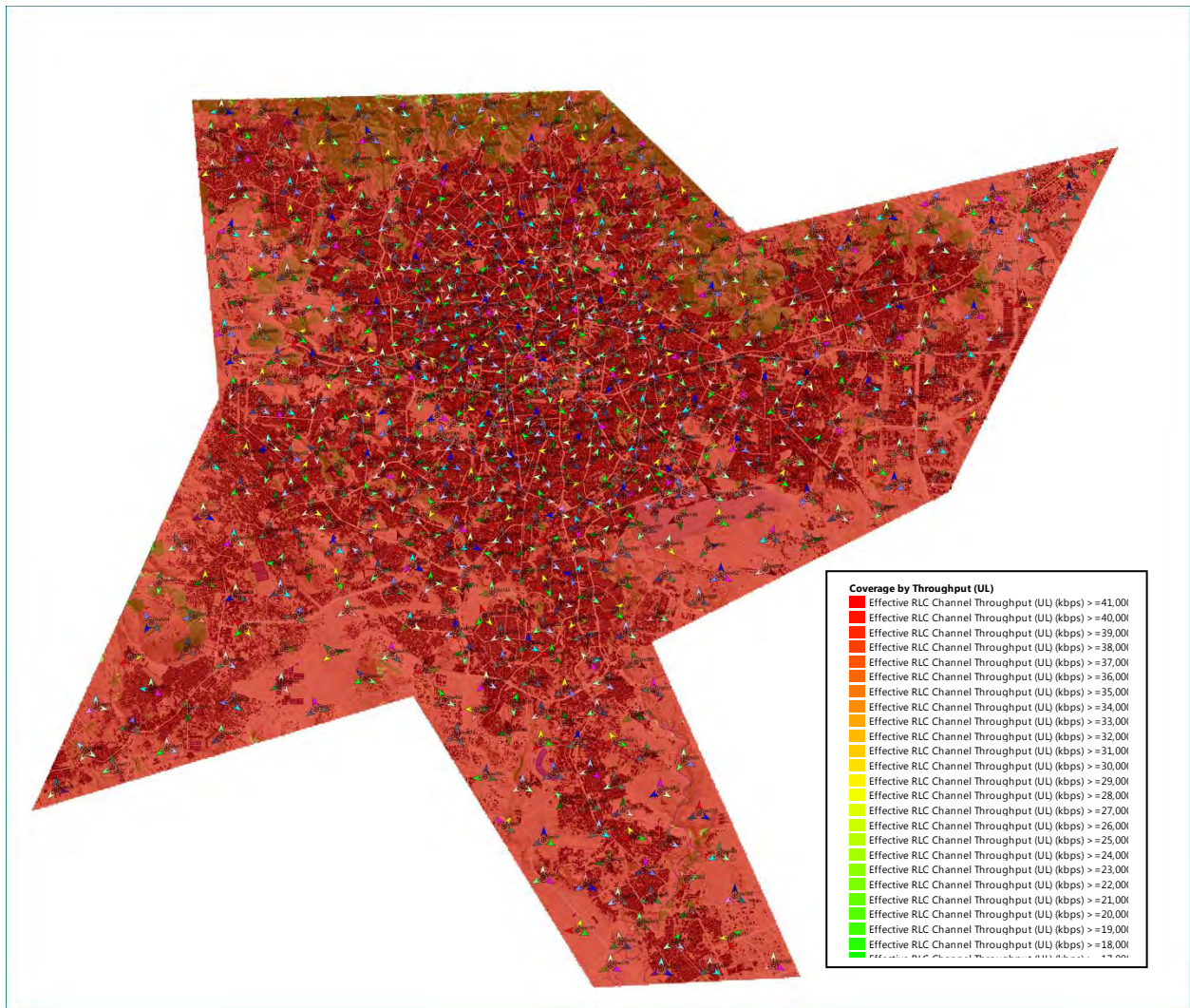


a)



b)

Figure 5.19 (a) coverage by throughput (DL) and (b) Histogram



a)

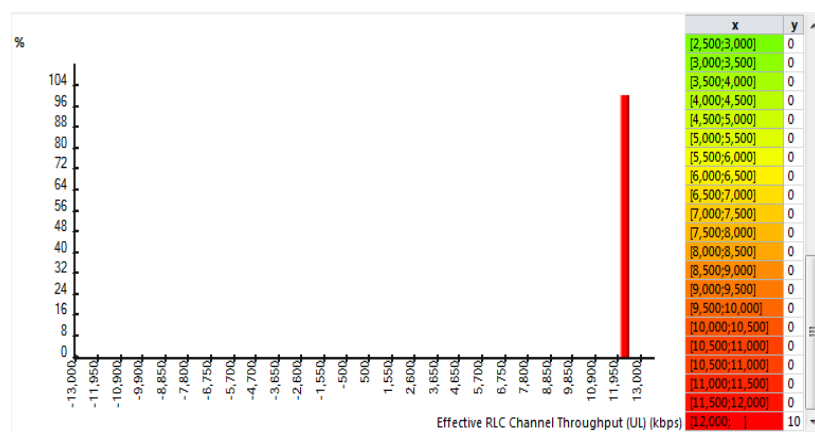


Figure 5-20 (a) coverage by throughput (UL) and (b) Histogram

Monte Carlo Simulation

Monte Carlo simulation is a computerized mathematical technique that allows people to account for risk in quantitative analysis and decision making. The technique is used by professionals in such widely disparate fields as finance, project management, energy, manufacturing, engineering, research and development, insurance, oil & gas, transportation, and the environment.

Monte Carlo simulation furnishes the decision-maker with a range of possible outcomes and the probabilities they will occur for any choice of action. It shows the extreme possibilities the outcomes of going for broke and for the most conservative decision along with all possible consequences for Middle-of-the-road decisions.

Simulations require traffic data, such as traffic maps i.e. raster, vector, or live traffic data and subscriber lists. ATOLL generates a user distribution for each simulation using a Monte Carlo algorithm. This user distribution is based on the traffic data input and is weighted by a Poisson distribution.

Each mobile generated during the simulations is assigned a service, a mobility type, and a terminal according to the user profile assigned to it. A transmission status is determined according to the activity probabilities. The geographical location of each mobile is determined randomly for the mobiles generated based on the traffic data from traffic maps. The mobiles generated based on the traffic data from subscriber lists are located on the subscriber locations.

Create Traffic Maps

There are several ways to create traffic maps in ATOLL. Here, we will discuss Map per density of users. Three steps are needed to create this map.

- a) Run Coverage by Transmitter Prediction: this is already done in the above simulation.
- b) Create a Traffic Map per sector

In the Geo tab of the ATOLL, right click Traffic and select New. Traffic map per sector chosen and click Create

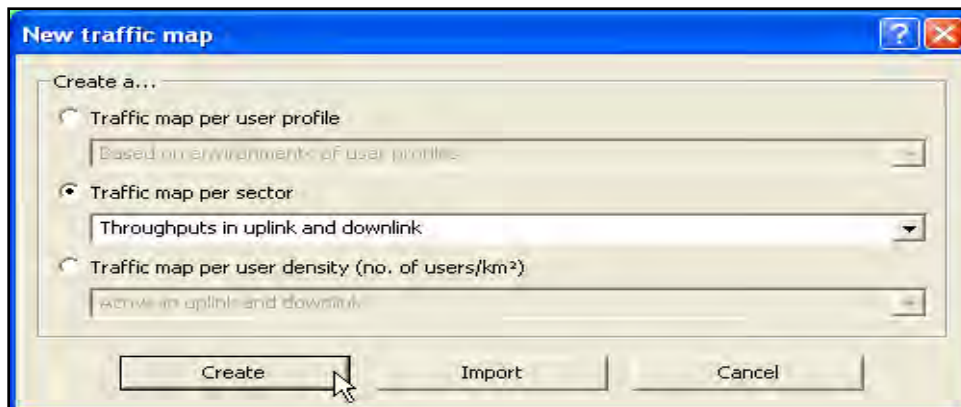


Figure 5-21 creating traffic map per sector

In the next pop up window, the Coverage by Transmitter created in the previous step is chosen.

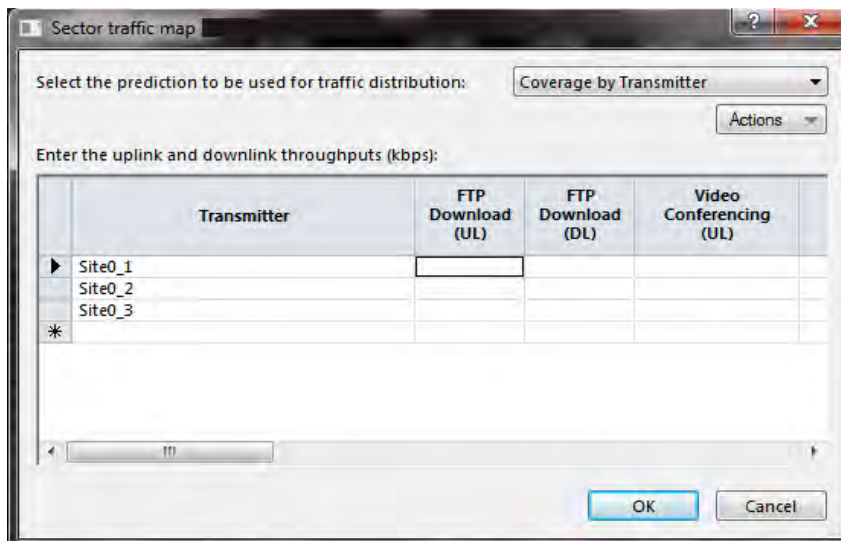


Figure 5-22 setting traffic map relation with coverage by transmitter

The transmitters and downlink and up link throughputs for different services are configured based on the requirement as shown below:

Transmitter	FTP Download (UL) (kbps)	FTP Download (DL) (kbps)	Video Conferencing (UL) (kbps)	Video Conferencing (DL) (kbps)	VoIP (UL) (kbps)	VoIP (DL) (kbps)	Web Browsing (UL) (kbps)	Web Browsing (DL) (kbps)	Real Time Gaming (UL) (kbps)	Real Time Gaming (DL) (kbps)	Streaming Media (UL) (kbps)	Streaming Media (DL) (kbps)	IMS Signaling (UL) (kbps)	IMS Signaling (DL) (kbps)	Email (UL) (kbps)	Email (DL) (kbps)	P2P shar (U) (kb)
Site0_3	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site0_2	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site0_1	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site1_3	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site1_2	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site1_1	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site10_3	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site10_2	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site10_1	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site100_3	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site100_2	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site100_1	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site101_3	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site101_2	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site101_1	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site102_3	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site102_2	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site102_1	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site103_3	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site103_2	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site103_1	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site104_3	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site104_2	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site104_1	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site105_3	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site105_2	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site105_1	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site106_3	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site106_2	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site106_1	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site107_3	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site107_2	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site107_1	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	
Site108_3	128	1,024	62.528	125.056	62.528	62.528	62.528	250.112	31.264	125.056	31.264	125.056	15.632	15.632	140.689	750	

Figure 5-23 setting throughput per cell for each service

In the property window the Weights of the different Clutter class and the traffic distribution configured as:

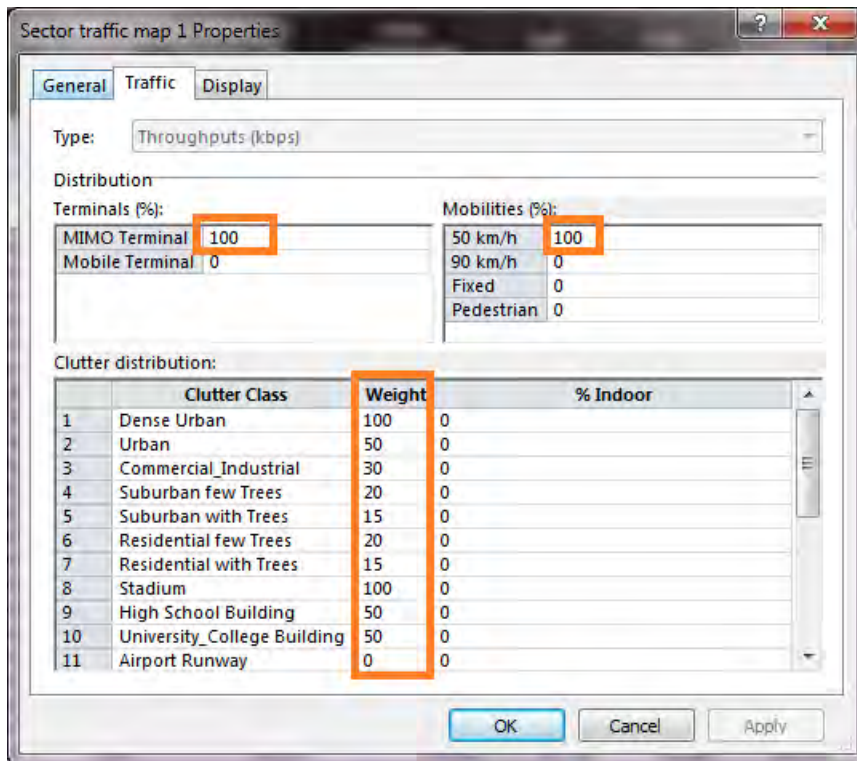


Figure 5-24 setting clutter weights

Right click the Traffic folder and select Export Cumulated Traffic:

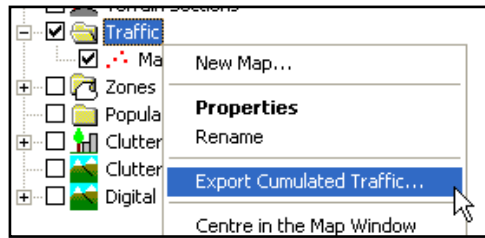


Figure 5-25 export cumulated traffic

Save the traffic map file as *.bil. Click Save.

c) Create a Traffic Map per density of users

Right click Traffic and select New. Choose traffic map per user density and then click Import:

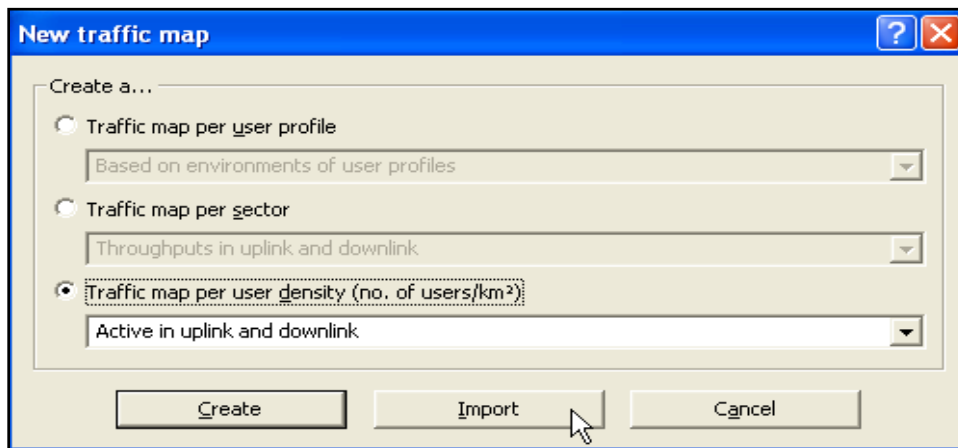


Figure 5-26 Create a Traffic Map per density of users

Select the *.bil that was created in the previous step

Now, we have the traffic map that you can use for the Monte Carlo Simulations.

Run Monte Carlos Simulations

In the network tap, right click on the simulation to create traffic randomly and run the simulation.

The created traffic shows as follow.

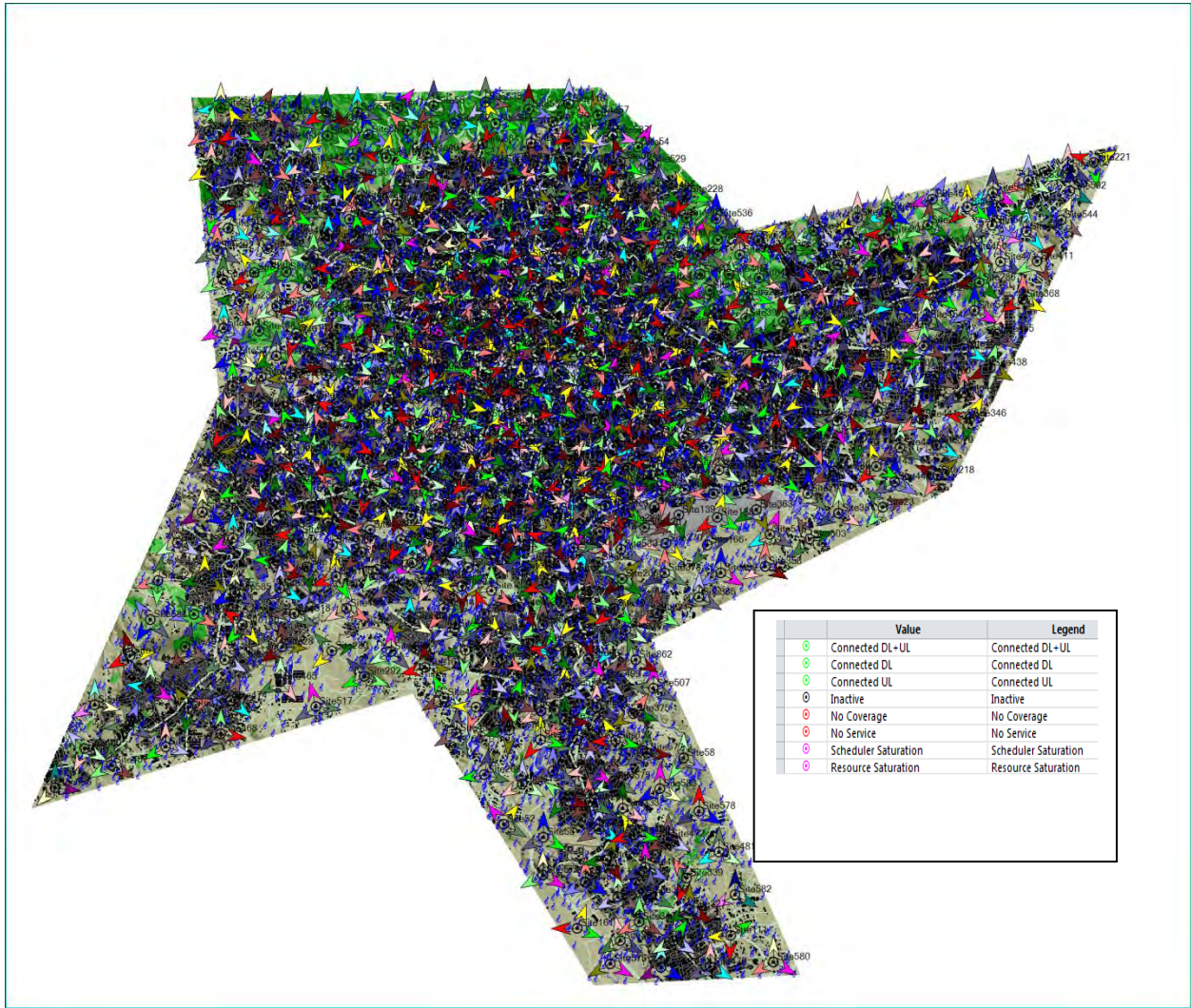


Figure 5-27 Monte Carlos Simulations

The results are displayed base on Connection Status of the subscribers and the parameters displayed after simulation includes:

- **Connected UL:** If a subscribers active in UL with allocated resources in UL.
- **Connected DL:** If a subscribers active in DL with allocated resources in DL.
- **Connected UL+DL:** If a subscriber active in UL+DL with allocated resources in UL+DL.
- **No Service:** If the subscriber/mobile does not have any best serving cell, if the mobile is not located in the service area of its best server, or if the mobile is not able to access a bearer in the direction of its activity, i.e., UL, DL, or UL+DL.

- **Scheduler Saturation:** If the mobile is not in the list of mobiles selected for scheduling
- **Resource Saturation:** If all the cell resources are used up before allocation to the mobile

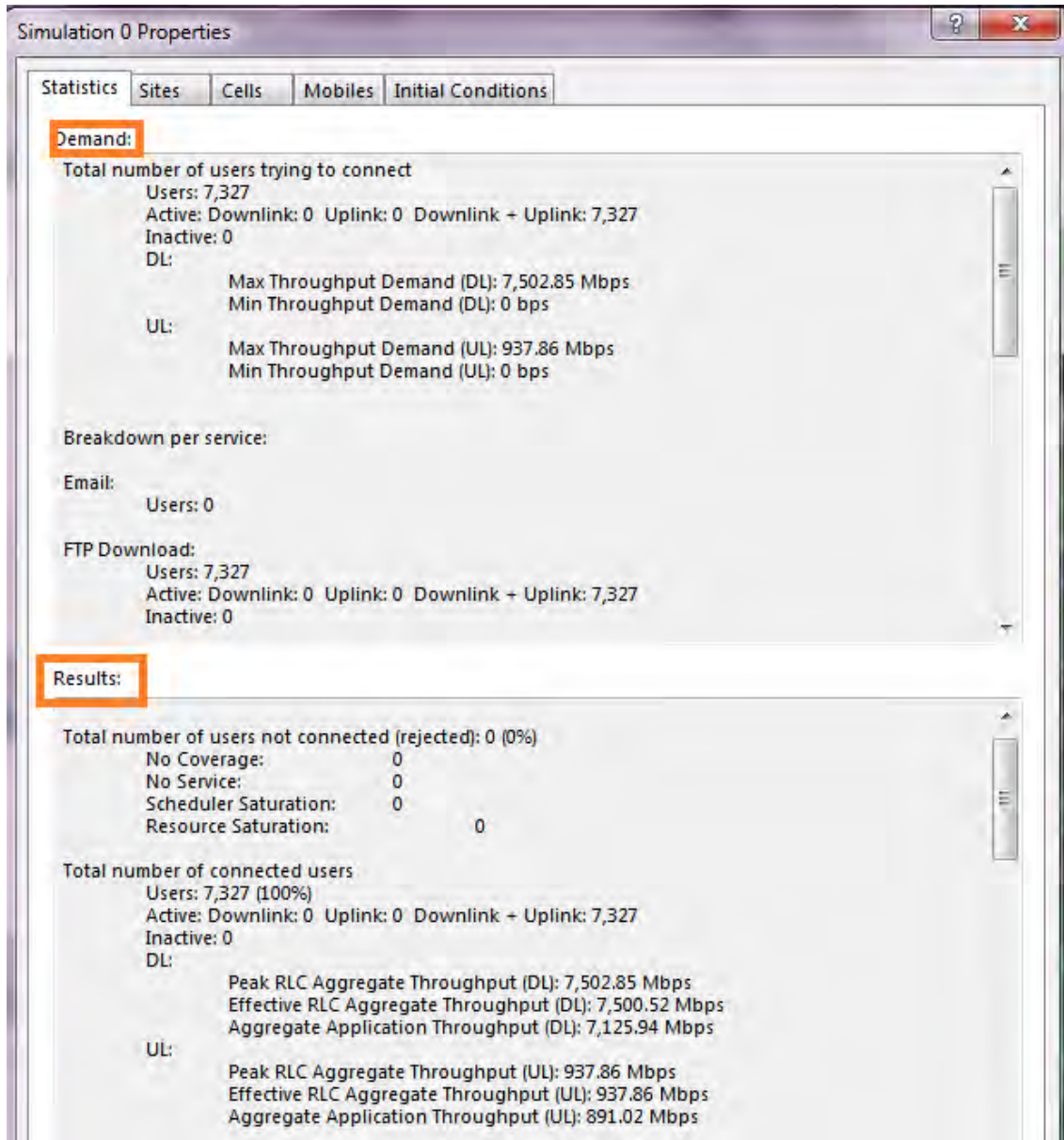


Figure 5-28 coverage prediction result using Monte Carlos Simulations

In the Statistics tab, you will see how many users were connected and how many were not able to get service. Hence based on the demand, all users (100%) are connected to get service. From result, we can assure that the coverage of the Addis Ababa city covered with 603 sites without any hole.

The Cells tab will show the results for each Cell such as Traffic Load (DL), Traffic Load (UL), and UL Noise Rise of each cell.

Transmitter	Name	Traffic Load (DL) (%)	Traffic Load (UL) (%)	UL Noise Rise (dB)	ICIC UL Noise Rise (dB)	MU-MIMO Capacity Gain (UL)
Site0_3	Site0_3 (0)	3.23	0.7	0.07	0	1
Site0_2	Site0_2 (0)	3.1	0.7	0.06	0	1
Site0_1	Site0_1 (0)	3.1	0.7	0.1	0	1
Site1_3	Site1_3 (0)	1.53	0.35	0.04	0	1
Site1_2	Site1_2 (0)	3.06	0.7	0	0	1
Site1_1	Site1_1 (0)	2.32	0.52	0.03	0	1
Site10_3	Site10_3 (0)	2.3	0.52	0.01	0	1
Site10_2	Site10_2 (0)	1.53	0.35	0.01	0	1
Site10_1	Site10_1 (0)	3.12	0.7	0	0	1
Site100_3	Site100_3 (0)	1.54	0.35	0.03	0	1
Site100_2	Site100_2 (0)	2.3	0.52	0	0	1
Site100_1	Site100_1 (0)	2.3	0.52	0.02	0	1
Site101_3	Site101_3 (0)	2.31	0.52	0.01	0	1
Site101_2	Site101_2 (0)	3.75	0.88	0.05	0	1
Site101_1	Site101_1 (0)	2.31	0.52	0.03	0	1
Site102_3	Site102_3 (0)	3.21	0.7	0.07	0	1
Site102_2	Site102_2 (0)	0	0	0.03	0	1
Site102_1	Site102_1 (0)	2.34	0.52	0.04	0	1
Site103_3	Site103_3 (0)	8.45	1.93	0	0	1
Site103_2	Site103_2 (0)	4.6	1.05	0.07	0	1
Site103_1	Site103_1 (0)	0	0	0	0	1
Site104_3	Site104_3 (0)	1.55	0.35	0.07	0	1
Site104_2	Site104_2 (0)	2.32	0.52	0.04	0	1
Site104_1	Site104_1 (0)	3.08	0.7	0.02	0	1
Site105_3	Site105_3 (0)	3.83	0.88	0.01	0	1
Site105_2	Site105_2 (0)	0.76	0.17	0.06	0	1

Figure 5-29 Cell loads result using Monte Carlos Simulations

6. Conclusion and Recommendation

6.1 Conclusions

The ultimate objectives of the present study of LTE radio network planning guidelines are to introduce the relevant LTE features, to define the basic models for radio propagation planning, to estimate coverage and network element count for Addis Ababa city which minimize the level of planning challenge. This study is useful for optimizing the recently launched LTE networks in dense urban and hot spot area of Addis Ababa city and spreading the coverage all over the city. Here obtained results of coverage and capacity analysis (200,255 and 148 sites for dense urban, urban and sub-urban respectively) have been used in nominal and detailed radio planning stage using ATOLL and taking Addis Ababa digital map as input.

From the simulation we can conclude as:

- More than 95% of the area covered by optimum signal strength i.e. greater than -90dBm (Figure 5.3.2-1).
- More than 65% of the area covered by single cells (Figure 5.3.2-3).
- Interference levels and signal-to-interference levels a challenge for radio network planning. $C/(I+N)$ level calculates the co-channel interference as well as the adjacent channel interference. From the analysis the carrier to interference plus noise ratio for both uplink and downlink are greater than 18dB for more than 96% of target area (figure 6-4 and Figure 6-5).
- From the capacity perspective, the maximum throughput that we're expecting is 130Mbps and 32Mbps per site for downlink and uplink respectively. This ensured by 99.71% of the target area covered with more than expected value (Figure 6-6 and Figure 6-7).
- With Monte Carlo simulation, the random generated traffic of 7,327 connected 100% successfully without any signal and connection problems which guarantee us there is no coverage problem within the target area (Figure 6-14 and Figure 6-15).

The current deployed LTE infrastructure consist of 329 sites from which 222 sites covered the dense urban area and the rest cover the hot spot of urban area to provide service for a total 242,623 and 157,377 subscribers respectively. Based on the analysis 200 sites can cover the dense urban with the optimization of number of customer to 400,000 which reduce the number of

infrastructure and cost by improving the quality of network. Generally, based on analysis, the Addis Ababa city can be covered by **603** sites (200, 255 and 148 sites for dense urban, urban and sub-urban respectively) which is lower than the number of GSM and WCDMA (more than 700 sites) sites to cover the same area with better signal strength.

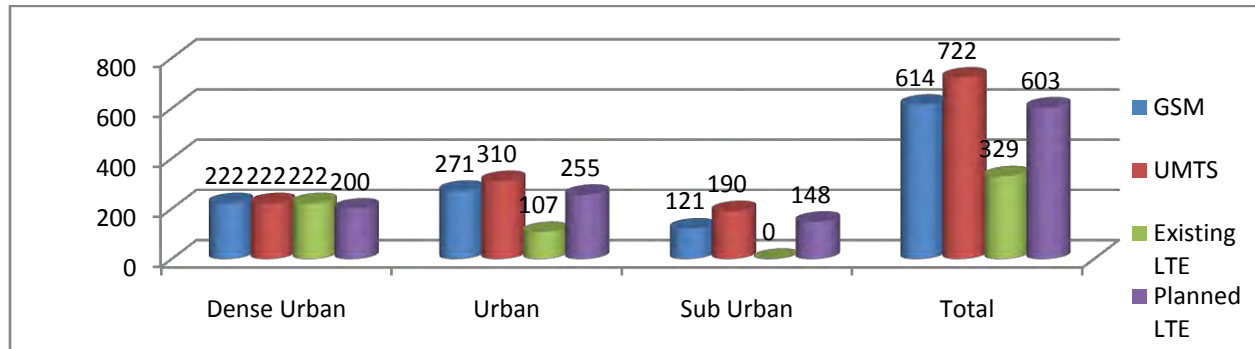


Figure 6-1 Comparison of the planned number of Sites with existing plan (2015)

6.2 Recommendations

The planning and implementing of LTE has to be done first by performing in-depth assessment of the existing cellular network. After that, new planning of the LTE network has to be done with proper optimization of the current topology and the expected quality using the standard parameters. It has to be planned to efficiently minimize both the initial investment cost and as well as operational cost to the deployment of the optimized LTE radio network dimensioning, but this needs to conduct study on cost analysis to compare the planned radio network with existing one.

The Ethio Telecom IP backhaul network is designed to widen the coverage scope of the transport network based on the GSM, UMTS, LTE and other networks transmission capacity. The network has been planned to provide connectivity for these sites as per the RNP output. Hence it is highly recommended to design the microwave part using ATOLL tool by considering the radio network planning as input.

Radio Network Dimensioning alone does not bring customer satisfaction i.e. it needs to provide the service with affordable price based on the network traffic analysis and dynamic tariff. So study on this and other value added services (VAS) is recommended to manage the available resource and generate extra money in addition to customer satisfaction.

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