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SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

LTE RADIO NETWORK PLANNING:COVERAGE AND CAPACITY ESTIMATION FOR FUTURE IMPLEMENTATION IN JIMMA,ETHIOPIA

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DEDICATION

TO THE ALMIGHTY!

ABSTRACT

Radio network planning (RNP) has been a long-standing problem since the very starting commercialization of mobile communications,of which power coverage and capacity coverage are the two major objectives.RNP of a new Radio interface such as LTE needs new tools and competencies.The introduction of Multiple input multiple out put(MIMO)driven Orthogonal division multiple access(OFDM),and sophisticated scheduling techniques in Long Term Evolution(LTE) technology,makes network planning challenging.In this work,coverage and capacity estimation of LTE network was performed for future network deployment in Jimma,Ethiopia.In the case of coverage planning,Radio link budget together with important link level simulations was performed to determine path loss.A COST231-Hata macroscopic path loss model was used to determine the cell range per morphology.For capacity evaluation,throughput analysis,and important system level simulations was performed to know subscribers supported per cell.Cell edge throughput and spectral efficiency was determined as the measure of performance and effectiveness for capacity analysis.

Finally,coverage target number of sites,capacity target number of sites,and the final limiting site count was determined.

Key Words:long term evolution(LTE),Orthogonal frequency division multiple access(OFDM),Multiple input multiple output,COST231-Hata.

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Acronyms and Abbreviations

AMCS: Adaptive Modulation and coding Schemes

AST: Average Sector Throughput

BLER: Block Error Rate

CDMA: Code division Multiple access

CLSM: Closed loop Spatial Multiplexing

CN: Core Network

CP: Cyclic prefix

CQI: Channel Quality Indicator

CSFB : circuit Switched fallback

COST: Cooperative scientific

eNodeB: Evolved node Base transceiver station

EPC: Evolved packet core

E-UTRAN: Evolved UMTS Terrestrial Radio access network

GSM: Global system for mobile

3GPP: Third generation partnership project

4G: Fourth generation

3G: Third generation

HSDPA: High speed down link packet access

HSPA: High speed packet access

IEEE: Institute of Electrical and electronic engineers

ITU: International Telecommunication union

IMT: International Mobile Telecommunication

JiT: Jimma Institute of Technology

LTE: Long term evolution

LTE-A: Long term evolution advanced

MAPL: Maximum allowed Pathloss

Mbps: Mega bits per second

MIMO: Multiple input multiple output

OFDMA: Orthogonal frequency division multiple access

OBF: Overbooking factor

OLSM: Open loop Spatial multiplexing

PAPR: Peak-to-average power ratio

PUSCH: Physical Uplink shared channel

PDSCH: Physical downlink shared channel

PRB: Physical Resource Block

PMI: Pre-coding Matrix indicator

QOE: Quality of experience

QOS: Quality of Service

QAM: Quadrature Amplitude Modulation

QPSK: Quadrature Phase shift Keying

RNP: Radio Network Planning

RAN: Radio access network

RF: Radio frequency

RLB: Radio Network planning

SAE: System architecture evolution

SC-FDMA: Single carrier Frequency division multiple access

SINR: Signal to interference noise ratio

TTI: Transmission Time Interval

UMTS: Universal mobile telecommunication systems

UE: User Equipment

WCDMA: Wide band code division multiple access

1 INTRODUCTION

As internet goes to mobile for broadband services,the mobile data traffic already exceeds the voice traffic[1].According to Cisco visual networking index[2]:global mobile data traffic forecast update,for 2012-2017,*"the overall mobile data traffic is expected to grow to 11.2Exabyte/month by 2017,a 13-fold increase over 2012"*.Additionally,it is expected that there will be compound annual growth rate(CAGR) of 66% from 2012 to 2017 for mobile data traffic[2].This rate increase has been as a result of the tremendous effects of several connected devices that are becoming clustered in cloud of computing and the concept of the internet of things(IoT).Mobile data subscribers in Ethiopia grew from none in 2007 to 2.7% in 2013[3].Currently,the launching of 3G network will be expected to accelerate mobile data traffic in this country.

Therefore,we are living in the era of mobile data revolution,with the mass market expansion of smartphones,tablets,notebooks,and laptop computers.Users demand services and applications that go far beyond mere voice and telephony.The growth in multimedia intensive mobile services and applications such as Web browsing,social networking,and music and video streaming has become a driving force for development of the next generation of mobile wireless standards. As a result,new standards are being developed to provide the data rates,network capacity and coverage necessary to support worldwide delivery of these types of rich multimedia application.

LTE (Long Term Evolution) has been developed to respond to the requirements of this era,and to realize the goal of achieving global broadband mobile telecommunications.The goals and objectives of this evolved system include high data rates,improved system capacity and coverage,flexible bandwidth operations,significantly improved spectral efficiency,low latency,reduced operating costs,multi-antenna support,and seamless interworking with legacy Internet,and existing 3GPP mobile communication standard like GSM / UMTS.

LTE is developed by 3GPP (Third generation partnership project)[4] based on ITU IMT-2000 project recommendations[5],and it inherits a lot from its predecessors (UMTS-HSPA).However,to meet a 4G standard,and to keep competitive with non

3GPP standards like mobile WiMax,LTE standard need to make a radical departure from WCDMA based transmission technology employed in 3G standards.In terms of their underlying transmission technology LTE completely deviate from the past,and introduce orthogonal frequency division multiple access (OFDMA) in the DL and single carrier frequency division multiple access (SC-FDMA) in the UL.LTE brings two fundamental changes to the 3G-UMTS architecture:a novel approach physical layer to the Radio access part called Evolved Universal Terrestrial Radio Access Network(E-UTRAN) and reforming the core network(CN),and yields Evolved Packet Core (EPC).

It is not the intension of this study to discuss details of LTE technology in this document.Rather,the study only aims to underline important concepts in LTE physical layer which might be important for network planning based on 3GPP technical specification on its release 8.

The field of Radio network planning (RNP) is essential in order to efficiently deploy cellular networks that can meet the increasing demand for high data rates and enhanced quality of service (QoS).RNP depends on several inputs that include the geographical area to be covered;estimated traffic load,base station configurations (antenna patterns and transmit power capabilities),path loss models,and frequency reuse patterns.The main output of the RNP process is the locations and configurations of base stations (eNodeBs)t hat are needed to meet the network coverage and capacity requirements.

Cell planning has been a long-standing problem since the very starting commercialization of mobile communications,of which power coverage and capacity coverage are two major objectives.The introduction of MIMO driven OFDM,and sophisticated scheduling techniques in LTE makes RNP challenging.This study aims to estimate coverage and capacity of LTE network,considering possible future network deployment in Jimma,Ethiopia.

1.1 Problem Statement

The mobile data demand in Ethiopia has grown at a phenomenal rate in recent years.Customers demand services and applications that go far beyond mere voice and telephony.Legacy cellular systems,like GSM-UMTS technology are however designed for voice optimized performance,and are relatively expensive to operate.This trend will expected to push the operators to invest on a new data optimized packet network like LTE.But,network planning of a new radio interface such as LTE requires a different set of competencies and new tools that should be designed to solve the challenges of mobile broadband.MIMO driven OFDM is a new concept in 3GPP mobile technology,and it makes the RNP challenging.

Whenever new cellular technology is considered to be deployed in a certain area with the aid of extensive RF measuring devices,hundreds of its RF parameters go through tuning process with a view to find out optimum value,and this phase is time consuming as well as very costly.But,if extensive simulations can be run before commercial deployment,this tuning phase can be facilitated in numerous ways.Cost can also be greatly minimized.This method is greatly important for immature network operator,like ethiotelecom. For the same reason,along with the fact that in LTE-RNP just like its predecessors,initial stage planning is normally guided by industries and vendors at their own interest;they are not likely to disclose their findings for the academic research.This makes the issue of RNP hidden for academic research.

For intervention of the above problem,and to perform RNP exercise,selection of a certain site is quite essential,in this view,Jimma city was chosen.

1.1.1 General Objective:

The fundamental goal of this study is preparing a guideline for radio network planners for coverage and capacity estimation of a 4G-LTE network,considering possible future network deployment in Jimma,Ethiopia.

1.1.2 Specific Objectives

Under the general objective,the study have the following specific objectives.

1. Computing Radio link budget,and path loss estimation for each terrain environment
2. Determining cell range and cell area for each morphology,thereby predicting the signal coverage.

3. Determining number of sites for coverage and capacity requirement
4. Determining the final site count.

1.2 Scope and Limitation of the Study

1.2.1 Scope of the Study

Radio network planning is a very complicated task under taken by experienced vendors and network deploying organizations.But,currently it got a massive attention from the current academic research arena.It have a number of phases from Pre-planning to deployment and optimization.But,due to the complex nature of the research subject,this study was delimited to pre-planning and nominal planning phases.As shown in Fig (1.1) interface dimensioning and backhaul dimensioning are not included in this study.

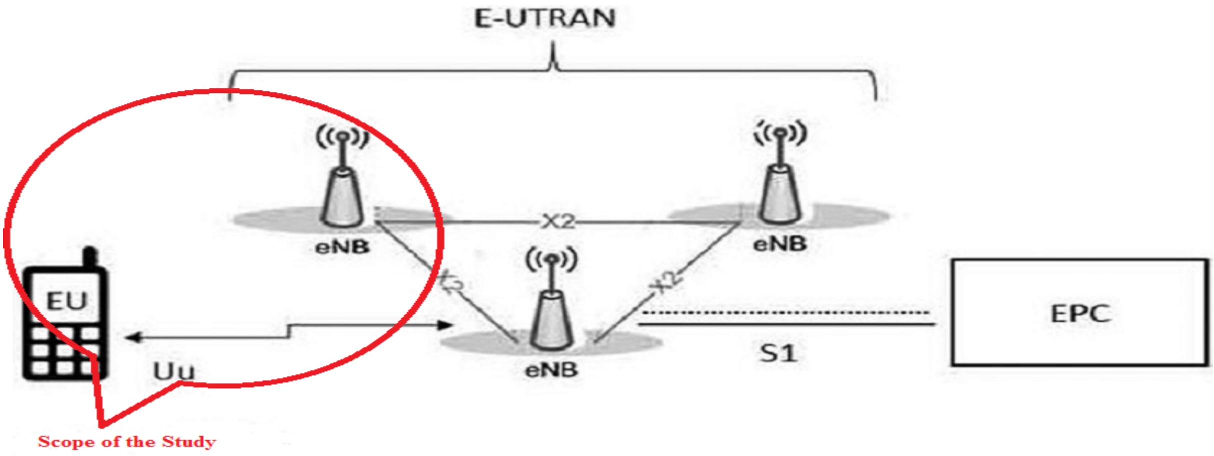


Figure 1.1: Scope of the study

1.2.2 Limitation of the study

Currently,there are a number of publications on LTE technology,but there is a shortage of simulators,and network planning tools on this technology.Technology specific simulators and tools are mainly developed by network operators and vendors,and are typically not intended for commercial distribution.On the other hand,the study area have no digital map during the formulation of this thesis,and Radio network planning data and tools are mostly available with vendors.But,Vendor's document and their planning tools are not easily accessible for academic research.

1.3 Methodology

Under this section,the Research methodology to define the systematic and scientific procedures used to arrive at the result,and findings expected from this study will be addressed.In terms of methodology used,this thesis can be categorized in to two main parts:the literature review,and the implementation through simulation,and analytical calculation.The literature study is mainly based on 3GPP technical specifications,books,conference proceedings,and technical white papers.For simplicity,the work flow of methodology in literature review is as shown in Fig (1.2)

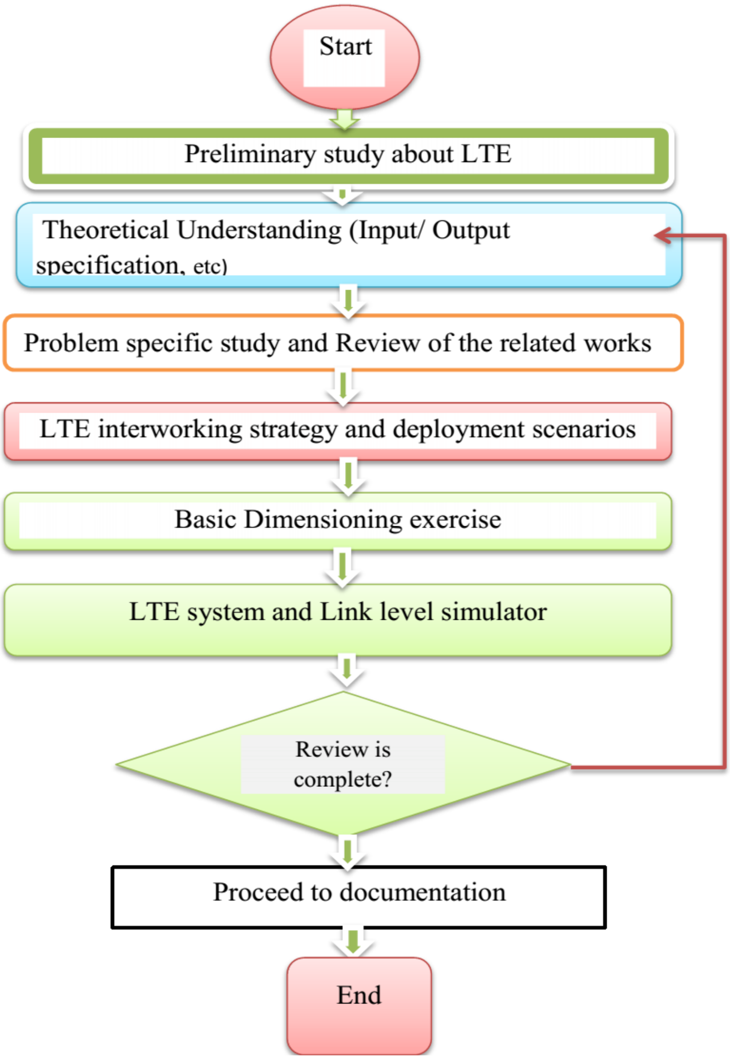


Figure 1.2: Flow chart of Literature Review

For literature gap analysis,IEEE publications,and journals related to LTE-RNP were reviewed.The main research subjects such as:Coverage planning,and capacity planning were defined at a high level of abstract in the literature study part,and later be implemented through simulation.

The implementation part is Jimma city specific LTE-RNP (chapter 7) based on simulations,and analytical calculations.The simulators used in this study was Vienna institute of telecommunications system and link level simulators[6]& [7].There are two goals here:capacity based site count and coverage based site count.Figure (1.3) shows the basic method for LTE dimensioning exercise and work flows.

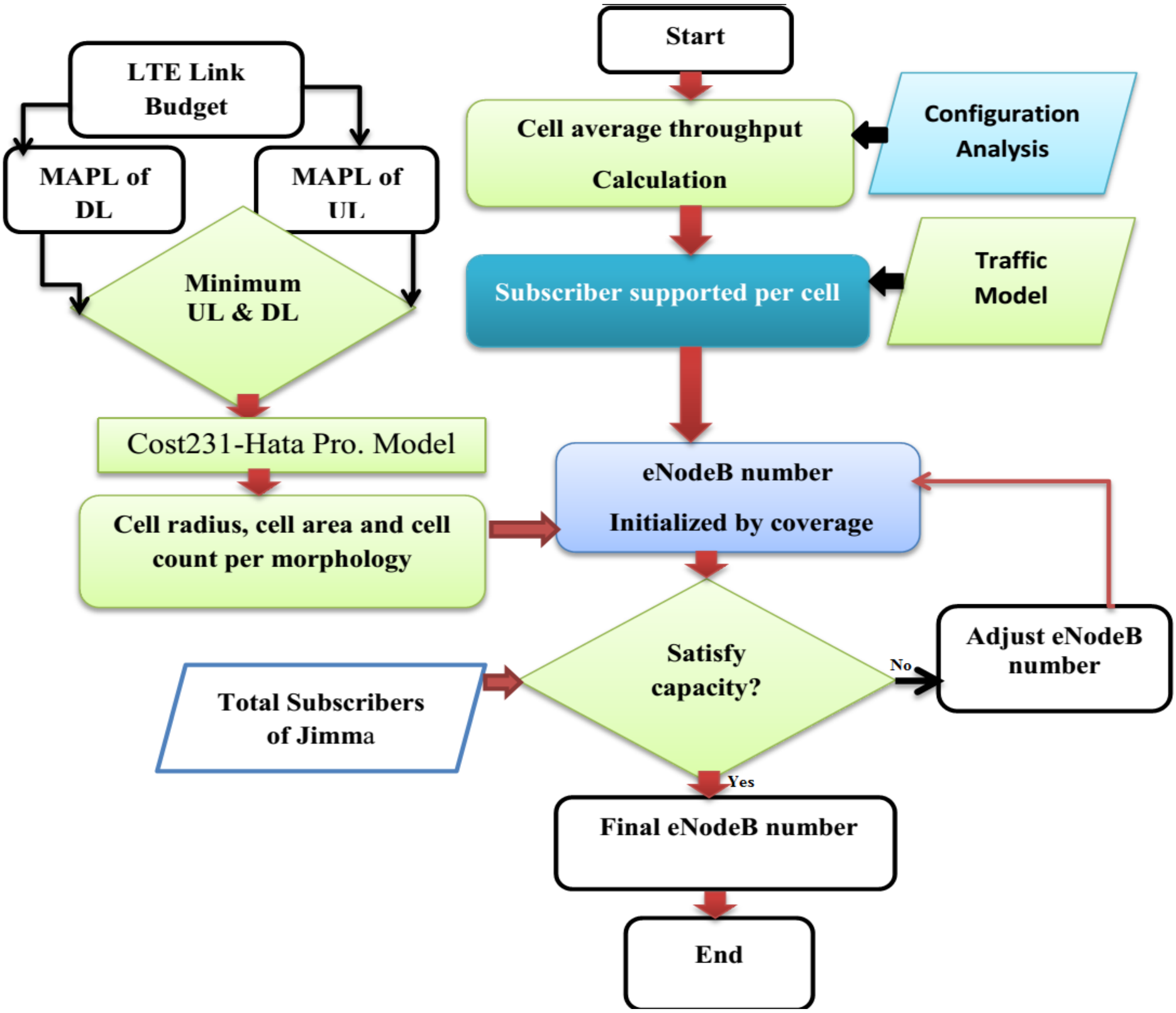


Figure 1.3: LTE Coverage and Capacity Dimensioning Method

For the coverage case,the signal to interference and noise power ratio(SINR) is the basic performance parameter to measure the performance of the link between UE and eNodeB.Therefore,the SINR value corresponding to the target average cell throughput is taken from link level simulation to perform coverage dimensioning exercise.The SINR value was determined via link level simulation by taking in to account all the features of LTE technology on the physical layer such as:synchronization,adaptive modulation and coding schemes(AMCS),channel fading,channel estimation and multi-antenna processing. The link level simulation is performed in a single UE single eNodeB scenario.Finally,Radio link budget(RLB) was performed to know the maximum allowed signal path loss (MAPL).An appropriate propagation model chosen for this study was COST231-Hata model.Tuning it to the frequency of interest 1800MHz leads us to determine the cell range.Considering a tri-sector antenna deployment and hexagonal cell shape,cell area per morphology was determined.Finally,coverage based site count was determined for preliminary geographic coverage.

For the case of capacity target,as LTE release 8 is a data centric technology,cell edge throughput(CET) is considered as a measure of performance and effectiveness than the signal level at the cell edge[14].Therefore,CET and spectral efficiency can be determined by LTE system level simulator.The CET and spectral efficiency are used to determine number of subscribers supported per cell,which finally lead us to know the number of subscribers supported per morphology class and then the number of subscribers supported per geographic area.Finally,the coverage target site count,and capacity target site counts were compared to select the final site.

Dimensioning Tool Description

LTE dimensioning exercise in this thesis is based on MS-Excel spreadsheet,mainly for radio link budget calculation,and data entry.For the graphical display and code generation,Object oriented capabilities of Matlab was used with standard simulation toolboxes specially designed for LTE.The simulators used in this thesis were Link and system level simulators,which were used to evaluate link and system performance parameters.LTE link level simulator was used for SINR to CQI mapping,BLER andcell edge throughput determination,while the system level simulation is performed to evaluate the overall system performance.

1.4 Thesis Layout

This document consists of eight chapters.Chapter 1,introduces problem statement,basic methodology,and objectives for this work.Chapter 2 deals with the necessary background of the study,which includes basics of LTE technology and its features related to network planning.Chapter 3 is literature review,focusing on related works on RNP,interworking and resource sharing scenario.Chapter 4 presents general RLB,like inputs and outputs of dimensioning exercise.Chapter 5 Presents LTE coverage planning and Radio Link Budget(RLB).This chapter illustrates analytical methods of calculating RLB together with the study of factors affecting it to calculate the number of sites for coverage target.Chapter 6 describes the capacity planning,elaborating the methods used and factors impacting the capacity planning process.Cell throughput calculation,traffic demand estimation and capacity based site count estimation are derived in this chapter.Chapter 7 is Implementation and important simulations.In this chapter Jimma city specific coverage based and capacity based sites will be determined through simulation and analytical calculation.Chapter 8 concludes the thesis with summary of the entire study findings by opening possibilities for future research on this subject.

2 LONG TERM EVOLUTION (LTE)

This chapter gives an overview of 3GPP Long Term Evolution as a fourth generation mobile network technology,and explains the key concepts used in LTE.The chapter provides only a brief introduction to LTE systems that form the foundation for the LTE-Radio network planning,such as:LTE physical layer air interface,multiple access scheme(OFDMA& SC-FDMA),MIMO technology,adaptive modulation and coding schemes (AMCS).

2.1 Introduction

From the first experiments with radio communication by Guglielmo Marconi,in the 1890s,which is known as the'First Generation (1G)'systems,the growing path of mobile Radio communication has been quite long [9].Developing mobile technologies has also changed,from being a national or regional concern,to becoming a very complex task undertaken by global specifications developing organizations such as the third generation partnership project (3GPP)[10].3GPP is currently the dominant specification and development group for mobile radio systems in the world.3GPP technologies:GSM/EDGE,WCDMA/HSxPA,and LTE are currently serving nearly 90% of the global mobile subscribers[9].

The work towards LTE standardization was started in Nov 2004 in a 3GPP Radio access network (RAN) evolution workshop in Toronto,Canada.The specification was completed 5-years later in March 2009.It is during this time,the specification for system architecture evolution (SAE) was included in the standard and backward compatibility to existing radio access technology was ensured[11].The 3GPP technical specifications were organized in a series of releases,and the first LTE release,and the one studied in this thesis is Release 8[4].The use of releases allows equipment manufacturers to build devices,and network planning engineers to plan the network using some or all of the features of earlier releases,while 3GPP continues to add new features to the system in a later release.Figure (2.1)shows,Approximate time line of the 3GPP mobile communications standard land scape adopted from[9]

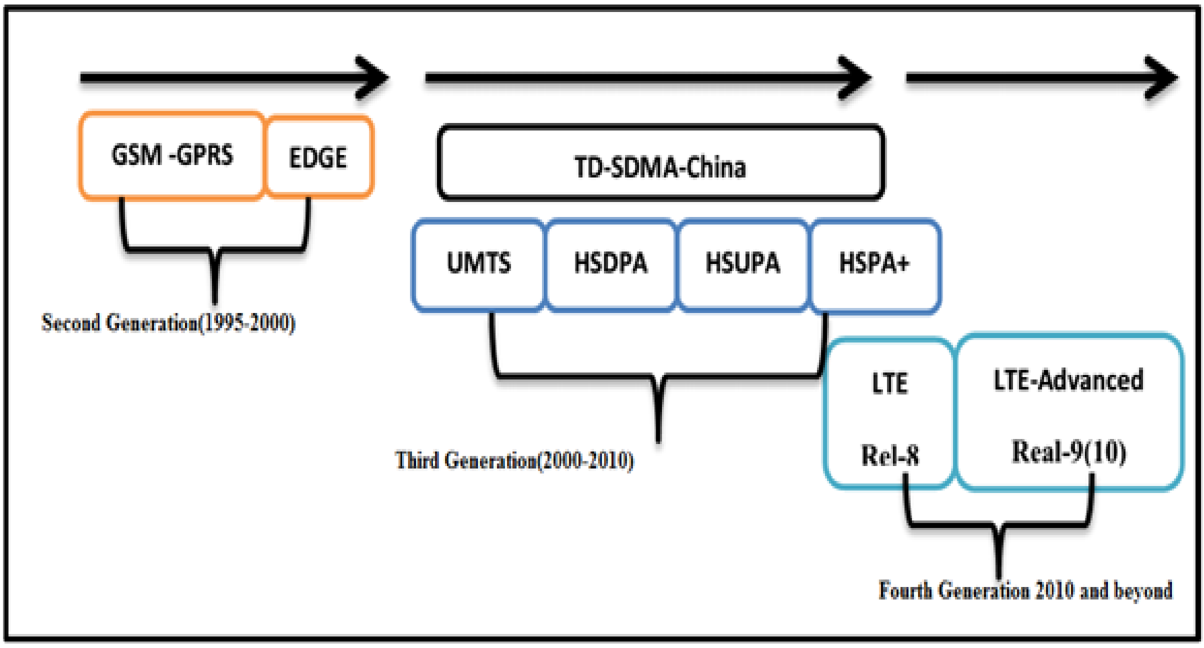


Figure 2.1: Approximate time line of the 3GPP mobile standard landscape

In the entire land scape of Figure(2.1),three multiple access schemes were evident:In 2G (GSM/GPRS/EDGE)TDMA was utilized,in 3G (UMTS/HSPA),the WCDMA system was utilized,while 4G-LTE deviate from 3G,and introduces orthogonal frequency division multiple access (OFDMA).In communication system engineering spectrum is the most scarce resource.Therefore,there should have been an efficient technology to utilize this scarce resource wisely.In this regard,OFDMA is characterized by high spectrum efficiency,and minimum latency as compared to the multiple access scheme utilized in 2G and 3G.This is the motive which drives the evolution of mobile telecommunication foreword.

2.2 Over View of LTE Technical specifications on Release 8

Operators,network planning engineers,and device vendors use 3GPP releases as part of their development roadmap[12].All 3GPP releases are backward compatible[4]. This means that a device supporting one of the earlier releases of 3GPP technologies can still work on a newer release deployed in the network.The 3GPP Rel 8 defines the first standardization of the LTE specifications.The evolved packet system (EPS) is defined, mandating the key features and components of both the radio access network (E-UTRAN) and the evolved packet core (EPC).OFDMA is defined as the air interface with the ability to support multi-layer data streams using MIMO antenna systems to increase spectral efficiency.LTE is defined as an all-IP network topology differentiated over the legacy circuit switched (CS) domain.However, the Release 8 specification makes use of the CS domain to maintain compatibility with the 2G and 3G systems utilizing the voice calls circuit switch Fallback (CSFB) technique for any of those systems [4]

LTE in Release 8 has a theoretical data rate up to 300 Mbps in the DL with 4X4 MIMO.The most common deployment is 100 to 150 Mbps with a full usage of the bandwidth, 20MHz.Several other variants are also deployed in less bandwidth and hence with lower data rates.The bandwidth allocation is tied to the amount of spectrum acquired by the LTE network operators in every country[4].

Requirements for LTE

Requirements for LTE can be summarized as shown in Table (2.1) adopted from [10] and,all of the reference comparison points are in relation to HSPA release 6.The LTE,as one of the latest steps in an advancing series of mobile telecommunications system,can be seen to provide a further evolution of functionality,increased speeds and general improved performance comparing to the third generation systems.Comparison between LTE and UMTS specifications which is adopted from [11] is illustrated in Table 2.2

To fulfill the extensive range of requirements outlined in Table (2.1),many key technologies are applied in LTE.Some of them which are directly related to radio network planning will be outlined in the following sections.These are: OFDM, adaptive modulation and coding (AMC),and MIMO technology.

The requirements discussed in Table(2.1) above were used to determine the choice of air interface technology [13][9].According to the study conducted,keeping in mind all the spectrum requirements,data rates,spectral efficiency,and other performances,it was concluded that the multiple access technology used would be orthogonal frequency division multiple access (OFDMA) in the DL[14].The main reasons LTE selects OFDMA as the basic transmission schemes include the following:robustness

Table 2.1: Requirements of LTE

Description	Comparison with HSPA Real-6
Bandwidth (Mbps)	(scalable bandwidth) (1.4,5,10,15,25)
DL peak data rate(Mbps) UL peak data rate(Mbps)	100 50
DL Spectrum efficiency UL Spectrum efficiency	3-4times 2-3times
DL User Throughput	3-4times(Average) 2-3times(cell edge)
UL User Throughput	2-3times(cell edge) 2-3times(Average)
Transfer Latency delay in RAN Latency for connection setup	5milisecond(one- way) 100milisecond

to the multipath fading channel,high spectral efficiency,low-complexity in implementation,and the ability to provide flexible transmission bandwidths and support advanced features such as frequency-selective scheduling, MIMO transmission,and interference coordination.

Table 2.2: Comparison of LTE with other Radio access technologies

	wcdma	HSPA (HSDPA/HSUPA)	HSPA+ (3.75G)	LTE (4G)
Maximum DL speed(bps)	384K	14M	28M	100M
Maximum UL speed(bps)	128K	5.7M	11M	50M
Latency round Trip	150ms	100ms	50ms (max)	$\leq 10ms$
3GPP Release	Real 99/4	Rel5/6	Real 7	Real 8
Multiple access scheme	CDMA	CDMA	CDMA	OFDMA

Fig (2.2) shows comparison of OFDMA and classical FDMA in terms of spectral efficiency, adopted from[15].For the UL,selection was made in the favor of single-carrier-based frequency division multiple access (SC-FDMA) solution with dynamic bandwidth[9].The basic motivation for this approach is to reduce power consumption of the user terminal or simply due to its low Peak-To-Average Power Ratio (PAPR) properties compared to OFDMA.

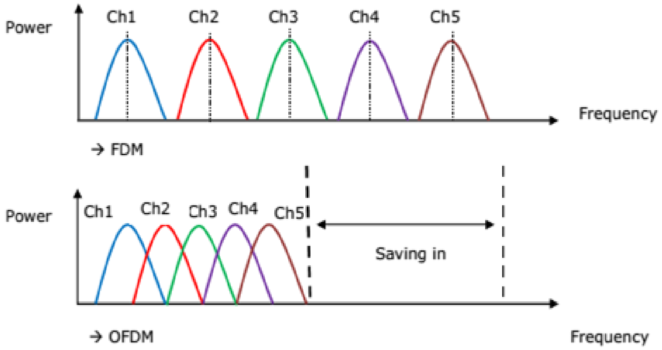


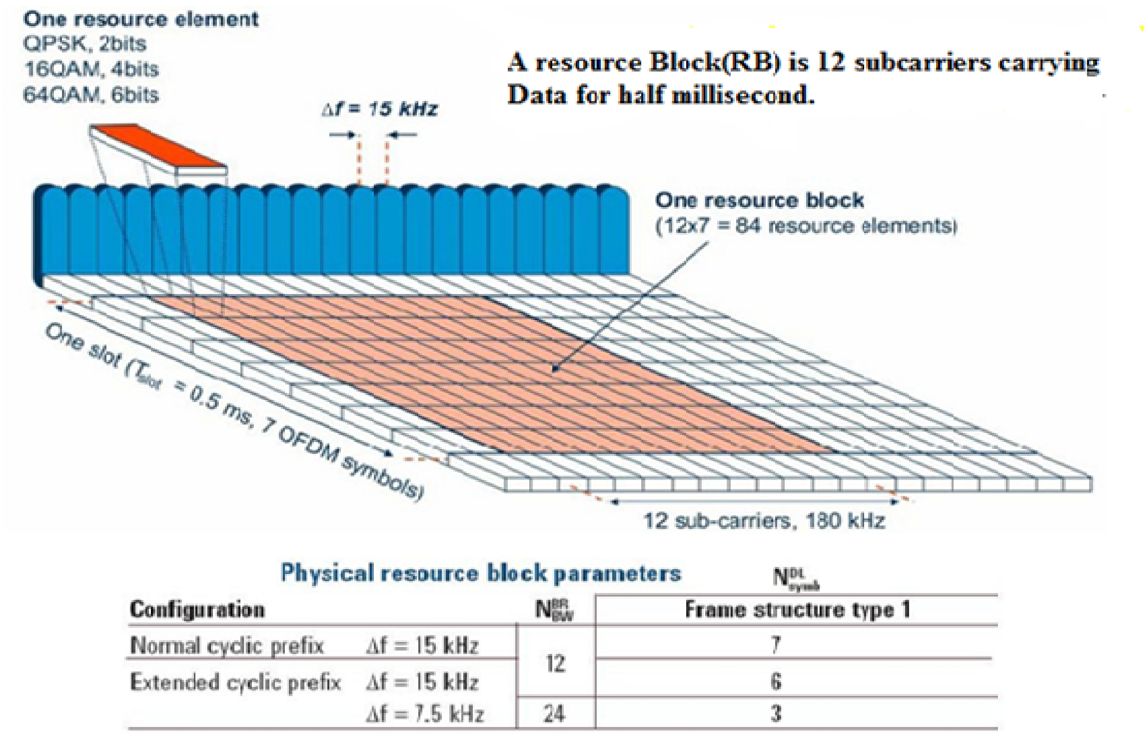
Figure 2.2: Spectral efficiency of OFDM as compared to classical FDMA

2.3 LTE Physical layer

In this section, some more details of OFDMA,SC-FDMA and their frame structures will be described at physical layer level.The concepts and parameters of the physical layer will be used later in LTE Radio network planning.

2.3.1 OFDMA in the DL

In DL,the chosen transmission scheme is OFDM with Cyclic Prefix (CP),mainly due to simplicity of the receiver and good spectral efficiency[9][14].Since the major intension of this thesis is not to discuss details of OFDM and OFDMA techniques for a comprehensive discussion of OFDM and OFDMA,See [16].OFDMA is a multiple access scheme on the base of the Orthogonal Frequency-Division Multiplexing (OFDM) modulation technique [9].In an OFDM system,the available spectrum is divided into multiple,mutually orthogonal subcarriers.Each of these subcarriers is independently modulated by a low rate data stream and can carry independent information streams.The basic LTE downlink physical resource can be seen as a time-frequency grid,as illustrated in Figure (2.3),which is taken from 3GPP physical layer specification [9].Fig (2.3) illustrates the basic physical layer



Physical resource block parameters

Configuration		N^{RB}_{BW}	N^{DL}_{symb} Frame structure type 1
Normal cyclic prefix	Δf = 15 kHz	12	7
Extended cyclic prefix	Δf = 15 kHz		6
	Δf = 7.5 kHz	24	3

Figure 2.3: Frequency and time representation of an OFDM signal

parameters of LTE in both frequency domain and time domain.In frequency domain,LTE have a constant spacing of $\Delta f = 15kHz$.To each OFDM Symbol,a cyclic prefix (CP) is appended as guard time.In addition,the OFDM symbol duration time is $1/\Delta f + cyclicprefix(CP)$.The smallest "atom" of LTE signal is one subscriber during the time when it transmits 1symbol,this is called a resource element (RE) [9].

OFDM symbols are grouped into resource blocks (RB).RB is the smallest unit of bandwidth assigned by the base station scheduler,or it is the smallest assignable traffic carrying part of an LTE signal.As shown in Fig 2.3,RBs have a total size of $180kHz$ with 12 subcarriers in the frequency domain and,$0.5ms$ with 7 OFDM symbols (with the normal CP) in the time domain.Each 1ms Transmission Time Interval (TTI) consists of two slots.Each user is allocated a number of RBs in the time-frequency grid. The more RBs a user gets,and the higher the modulation used in the REs,the higher the bit-rate it becomes.The RB size is the same for all existing LTE bandwidths (i.e.,1.4,3,5,10,15 and 20MHz).Flexibility in channel bandwidth is provided by allowing this six different bandwidth options for operators to choose from One resource element carries QPSK,16QAM or 64QAM with number of different bits and code rates.

As mentioned above sub-carrier spacing is fixed for all the possible bandwidths at $T_b = 15KHz$.Corresponding to the sub-carrier spacing of $15KHz$,symbol time is $1/T_b = 66.68\mu s$. To avoid inter symbol interference (ISI),a Guard Interval is inserted between two consecutive symbols,and the Guard Interval is then filled with the CP.This means that a copy of fixed number of last samples is appended to the start of the symbol.The structure of one full OFDM Symbol is shown in Figure (2.4),adopted from[13]

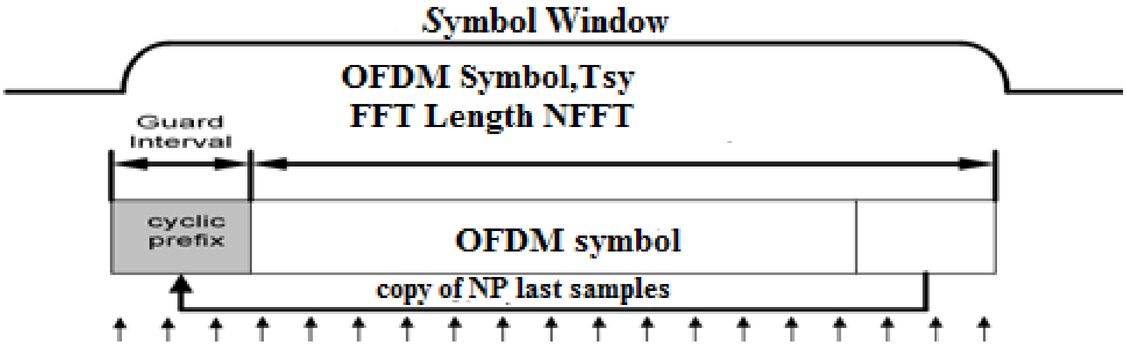


Figure 2.4: OFDM symbol structure

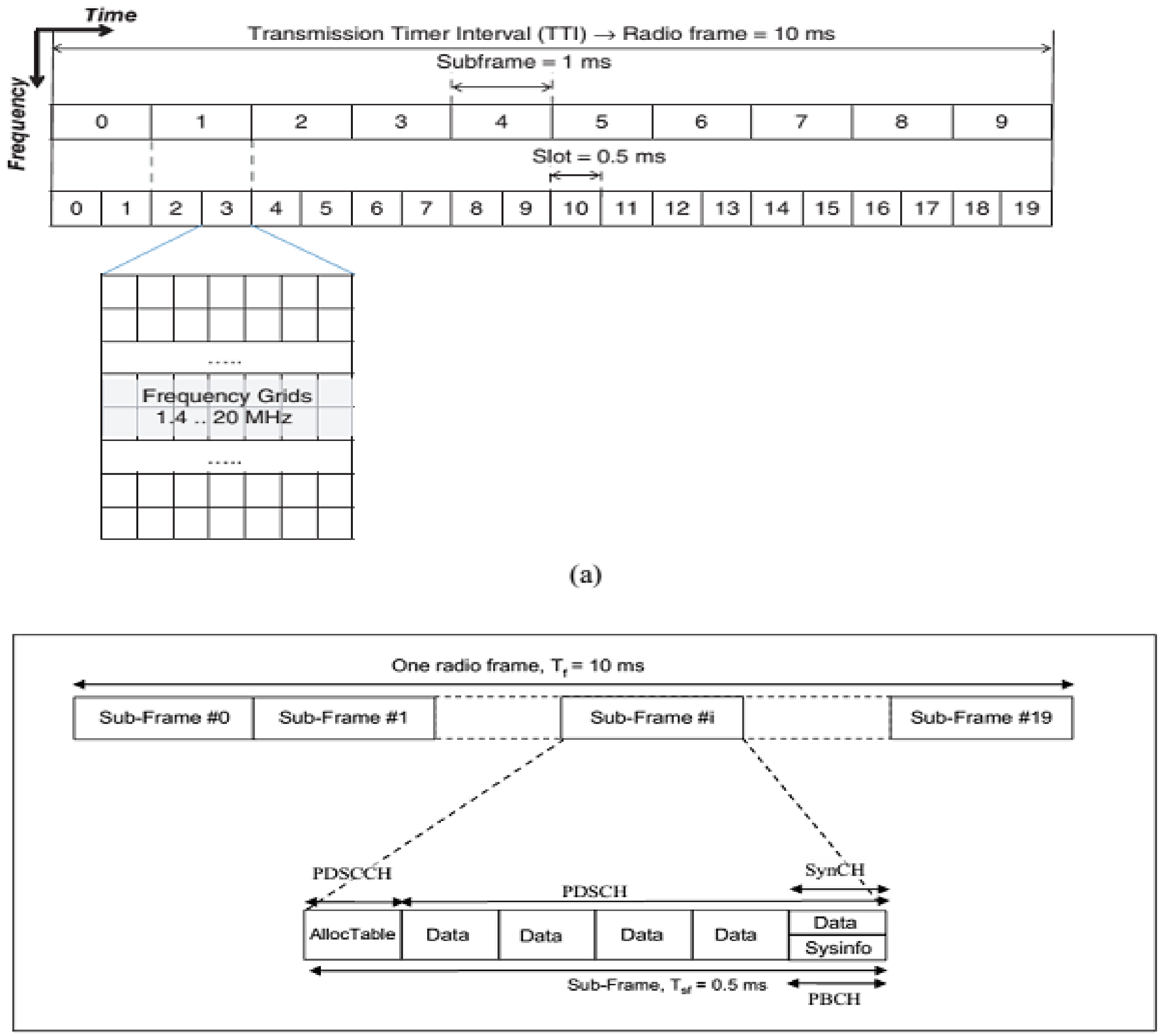
As the spacing of sub-carriers is fixed,the transmission bandwidth is varied by changing the number of sub-carriers.Each sub-frame consists of 6 or 7 OFDM symbols,depending upon the size of CP.For further detail DL Physical layer parameters are summarized in Table (2.3),adopted from 3GPP TS[9].

Table 2.3: LTE Physical layer parameters

Transmission BW(MHz)	1.4	3	5	10	15	20
Sampling frequency (MHz)	1.92	3.84	7.68	1.36	23.04	30.72
FFT size	128	256	512	1024	1536	2048
Copied subcarriers	76	151	301	601	901	1201
Subframe duration(ms)	0.5	0.5	0.5	0.5	0.5	0.5
Subcarrier spacing (KHz)	15	15	15	15	15	15
Long/short(CP)	7/6	7/6	7/6	7/6	7/6	7/6

DL Frame Structure of LTE is depicted in Figures 2-5 (a),and (b) for both short and long CP.One radio frame consists of sub-frames carrying LTE channels:PDSCH, PDSCCH and PBCH.PDSCH and PDSCCH are present in every sub-frame.PBCH is only present in those sub-frames that are scheduled for the system information.System frame number (SFN) is used as the frame time reference and the LTE SFN (eSFN) as the sub frame time reference for all physical channels,for downlink and indirectly for the uplink [5].

The radio frame consists of $T_f = 307200T_s = 10ms$ long and consists of 20 slots of length $T_slot = 15360 * T_s = 0.5ms$, numbered from 0 to 19.A sub-frame is defined as two consecutive slots.Where sub-frame i consists of slots $2i$ and $2i + 1$ [13] [14].For FDD,10 sub frames are available for DL transmission and 10 sub frames are available for UL transmissions in each 10 ms interval.UL and DL transmissions are separated in the frequency domain.DL frame structures for both short and long cyclic prefixes are shown in Figures (2.5 a& b),adopted from [14]



(a)

(b)

Figure 2.5: LTE FDD frame and slot structure for normal CP (a), long CP (b)

2.3.2 SC-FDMA in the UL

The undesirable high PAPR of OFDM led 3GPP to choose a different modulation format for the UL.Obviously,many mobile wireless standards like mobile WiMAX, and other IEEE based wireless standards used OFDM transmission scheme, but LTE is the first standard implementing SC-FDMA transmission scheme.In SC-FDMA,single carrier transmission with CP is used for UL in which the CP is used to achieve UL inter-user orthogonally,and to enable efficient equalization in frequency domain on the receiver side [13].The Modulation can be QPSK, 16QAM or 64QAM whatever is most appropriate for the prevailing radio conditions.SC-FDMA has a low Peak-to-Average Power Ratio (PAPR) which provides more transmit power and longer battery life.The Release 8 3GPP specifications do little to explain the concept of SC-FDMA.For a formal definition of SC-FDMA,a signal processing expert need look no further than the mathematical description of the time-domain representation of an SC-FDMA symbol.But,sometimes we find difficult the formal mathematical approach to follow;Therefore,the graphical comparison between OFDM and SC-FDMA is presented as shown in Fig (2.6),adopted from 3GPP TS[4]. The basic sub-frame structure for the UL is shown in Figure (2.7),and the SC-FDMA resource grid structure,adopted from[13].This structure uses two short blocks (SB) and six long blocks (LB) in each sub-frame.Short block is used for either for coherent demodulation or for control and data transmission,or for both of these purposes.On the other hand,long blocks are used for control and/or data transmission.Both localized and distributed transmission uses the same sub-frame, while data can include either of both of scheduled and contention based data transmission.

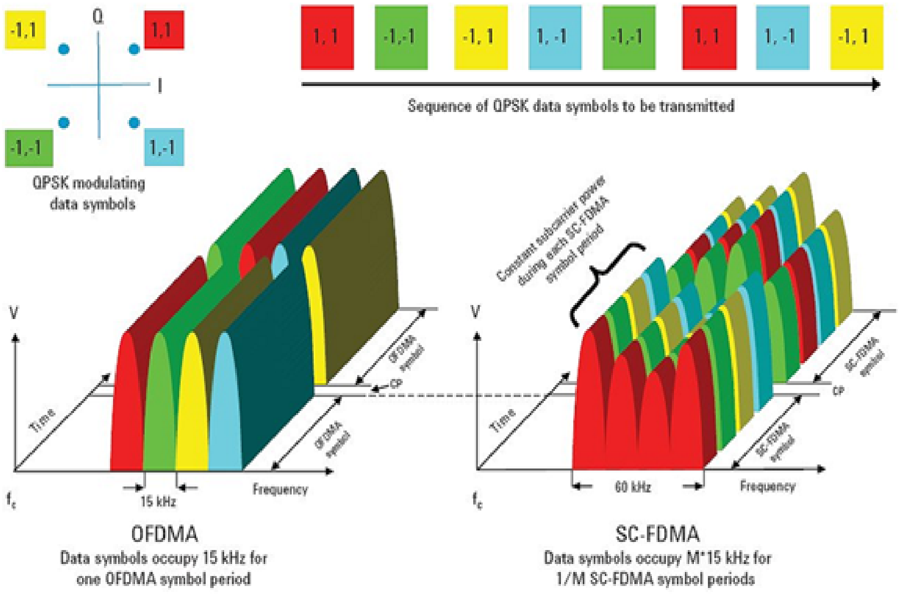


Figure 2.6: Comparison of OFDMA and SC-FDMA on how to transmit QPSK modulated signal

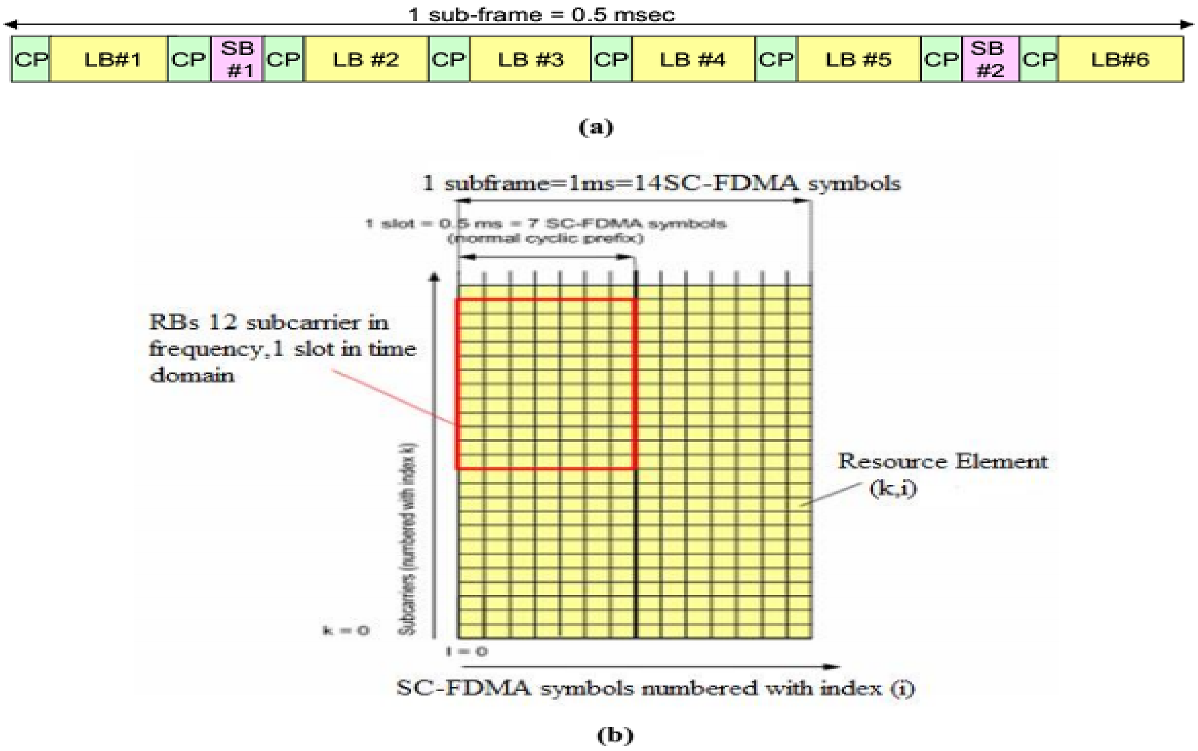


Figure 2.7: UL Frame structure for LTE (a), UL SC-FDMA resource grid(b)

2.4 Adaptive Modulation and Coding Schemes (AMCS) in LTE

In cellular communication systems,the quality of the signal received by a UE depends on the channel quality from the serving cell,the level of interference from other cells,and the noise level.To optimize system capacity and coverage for a given transmission power,the transmitter should try to match the information data rate for each user to the variations in the received signal [9].This is commonly referred to as link adaptation and is typically based on Adaptive Modulation and Coding (AMC).The AMC consists of the modulation Scheme and code rate

- **Modulation Scheme:** Low-order modulation (i.e.few data bits per modulated symbol,e.g. QPSK) is more robust and can tolerate higher levels of interference but provides a lower transmission bit rate. High-order modulation (i.e.more bits per modulated symbol,e.g. 64QAM) offers a higher bit rate but is more prone to errors due to its higher sensitivity to interference, noise and channel estimation errors;it is therefore useful only when the Signal to Interference and Noise Ratio (SINR) is sufficiently high[9]

- **Code rate:** For a given modulation,the code rate can be chosen depending on the radio link conditions:a lower code rate can be used in poor channel conditions and a higher code rate in the case of high SINR[9]

For the downlink data transmissions in LTE,the eNodeB typically selects the Modulation,and Coding Scheme (MCS) depending on the Channel Quality Indicator (CQI) feedback transmitted by the UE in the uplink.CQI feedback is an indication of the data rate which can be supported by the channel,taking into account the SINR and the characteristics of the UE's receiver.In general,in response to the CQI feedback the eNodeB can select between QPSK,16-QAM and 64-QAM schemes with a wide range of code rates.

For the LTE uplink transmissions,UL adaptation process is similar to that for the DL,with the selection of MCS also being under the control of the eNodeB.But the eNodeB can directly make its own estimate of the supportable uplink data rate by channel sounding.An identical channel coding structure is used for the UL, while the modulation scheme may be selected between QPSK and 16QAM, while the 64QAM is optional for the LTE UL.

A simple method by which a UE can choose an appropriate CQI value could be based on a set of Block Error Rate (BLER) thresholds. The UE would report the CQI value corresponding to the MCS that ensures BLER of 10% based on the measured received signal quality.The list of MCS with CQI values supported by 3GPP LTE standards is shown in Table(2.4).

Table 2.4: LTE CQI Table for different MCS

CQI index	Modulation	Code Rate	Code Rate *1024	Efficiency Bit/s/Hz	Minimum C/(I+N)
0	Out of Range				
1	QPSK	0.76	78	0.152	-6
2	QPSK	10.12	120	0.234	-5
3	QPSK	0.19	193	0.377	-3
4	QPSK	10.3	308	0.601	-1
5	QPSK	0.44	449	0.877	+1
6	QPSK	0.59	602	1.176	+3
7	16QAM	0.37	378	1.477	+5
8	16QAM	0.48	490	1.914	+8
9	16QAM	0.6	616	2.406	+9
10	64QAM	0.45	466	2.731	+11
11	64QAM	0.55	567	3.322	+12
12	64QAM	0.65	666	3.902	+14
13	64QAM	0.75	772	4.523	+16
14	64QAM	0.85	873	5.115	+18
15	64QAM	0.93	948	5.555	+20

Generally,Table (2.4)shows the 16-CQI indexes,their MCS details,and the resulting spectral efficiency of the LTE signal in Bits/sec/Hz of Band width, and the approximate Carrier to interference plus noise power ratio required at each CQI index.The modulation is adopted in real time to match the existing RF condition reported by UE,called Channel quality indicator (CQI),and the code rates can also be adjusted through 16-steps.

2.5 MIMO Techniques in LTE

A wireless communication system utilizing multiple transmit antennas (inputs) and multiple receive antennas (outputs) over the wireless channel is often referred to as a Multiple input Multiple output (MIMO) system[14].In a MIMO system,there

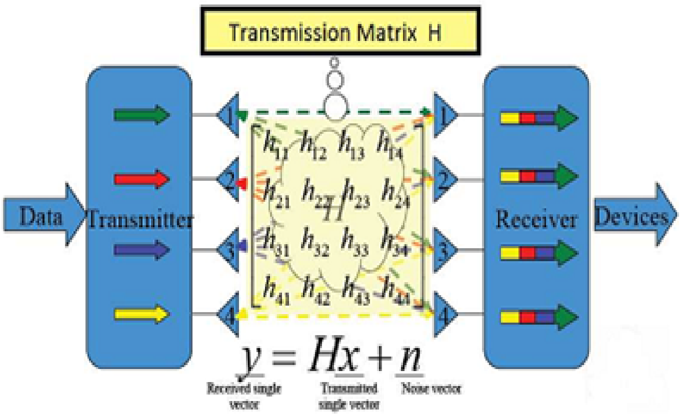


Figure 2.8: MIMO Transmission

are$N * M$signal paths from transmit and receive antennas,and the signals on these paths are not identical.On the transmitter end,the data signal is constructed in such a way that different antennas carry different variations of the signal,such as different phases,amplitudes,or waveforms.At the receiver end,each variation of the data signal is received differently at the antennas due to channel fading.With MIMO, the signals on the transmit (Tx) antennas at one end and the receive (Rx) antennas at the other end are combined so the quality (bit-error rate) or the data rate of the communication for each MIMO user will be better than SISO (single input and single output) or SIMOs (single input and multiple outputs).

The goal of optimizing a MIMO system is to achieve the highest throughput and system capacity in different RF conditions by leveraging the multipath potential of the environment.With the various MIMO options in different transmission modes,operators should optimize the algorithms the eNB uses to select the best MIMO mode given the UE capabilities and multipath conditions.Take a $4x4$ antenna configuration (4 transmit antenna and 4 receiver antenna) as an instance, as Figure (2.8) shows, where each receiver antenna may receive the data streams from all transmit antennas.The transmission relationship can be described with a Transmission Channel Matrix H.The coefficients h_ij stands for transmit antenna j to receive antenna i, thus describing all possible paths between transmitter and receiver sides.Suppose receive vector is y,transmit vector is x,the noise vector is n and H is the transmission channel matrix. Then the MIMO transmission can be described with the formula:

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

In an MxN antenna configuration,the number of data streams which can be transmitted in parallel over the MIMO channel is given by the minimum value of M and N and is limited by the rank of the transmission matrix H [9].For example,a $4x4$ MIMO system could be used to transmit four or fewer data streams.

MIMO methods can improve mobile communication in two different ways:by boosting the overall data rates and by increasing the reliability of the communication link[17].The quality of a wireless link can be described by three basic parameters,namely the transmission rate,the transmission range and the transmission reliability.Conventionally,the transmission rate may be increased by reducing the transmission range and reliability.By contrast,the transmission range may be extended at the cost of a lower transmission rate and reliability,while the transmission reliability may be improved by reducing the transmission rate and range [16].However,with the advent of MIMO assisted OFDM systems,the above-mentioned three parameters may be simultaneously improved.

The MIMO algorithms used in the LTE standard can be divided into four broad categories:receive diversity,transmit diversity,beam forming,and spatial multiplexing.In transmit diversity and beam forming; we transmit redundant information on different antennas.As such,these methods do not contribute to any boost in the achievable data rates but rather make the communications link more robust[16]. In spatial multiplexing,however,the system transmits independent (non-redundant) information on different antennas.This type of MIMO scheme can substantially boost the data rate of a given link.The extent to which data rates can be improved may be linearly proportional to the number of transmit antennas.In order to accommodate this,the LTE standard provides multiple transmit configurations of up to four transmit antennas in its downlink specification on TS 36.213-820,[18].The LTE-Advanced allows the use of up to eight transmit antennas for downlink transmission.

Conceptually speaking,the MIMO system utilizes the space and time diversity in a multipath rich environment and creates multiple parallel data transmission pipes on which data can be carried[14].MIMO builds on SIMO,also called receive diversity

(RxD), as well as multiple-input single-output (MISO),also called transmit diversity (TxD)[14].Both of these techniques seek to boost the SNR in order to compensate for signal degradation.However,SIMO or MISO systems may not be fully suitable for the high-speed data rates promised in 3GPP next generation cellular systems. Therefore,the full flavor of the MIMO version can achieve benefits for both SNR increase and throughput gains.MIMO in 3GPP exploits several concepts,as highlighted in Table (2.5).All these techniques mentioned in the table fall under two main MIMO categories:open loop or closed loop.

Table 2.5: MIMO Techniques in 3GPP

MIMO Concept	Purpose
Spatial multiplexing	Maximize user throughput in high SNR(for capacity SNR(for capacity improvement planning)
TxD or Beam forming	Improve SNR in cell edge
Multi-User MIMO	Increases the overall cell capacity

2.5.1 Open-Loop and closed loop MIMO

According to [14] both open loop and closed loop MIMO configurations in generally supports transmit diversity(TxD),and spatial multiplexing.The use of either of the two mechanisms depends on the channel condition and rank.In open-loop spatial multiplexing (OLSM) operations,the network receives minimal information from the UE:a rank indicator (RI),and a CQI,while in closed loop spatial multiplexing (CLSM),the UE analyzes the channel conditions of each Tx, including the multipath conditions.The UE provides an RI as well as a pre-coding matrix indicator (PMI),which determines the optimum pre-coding for the current channel conditions.This is unlike open loop spatial multiplexing that uses a fixed set of pre-coding[14].

2.5.2 Multi-User MIMO

Spatial multiplexing allows transmission of different streams of data simultaneously by exploiting the spatial dimension of the radio channel.The different data streams

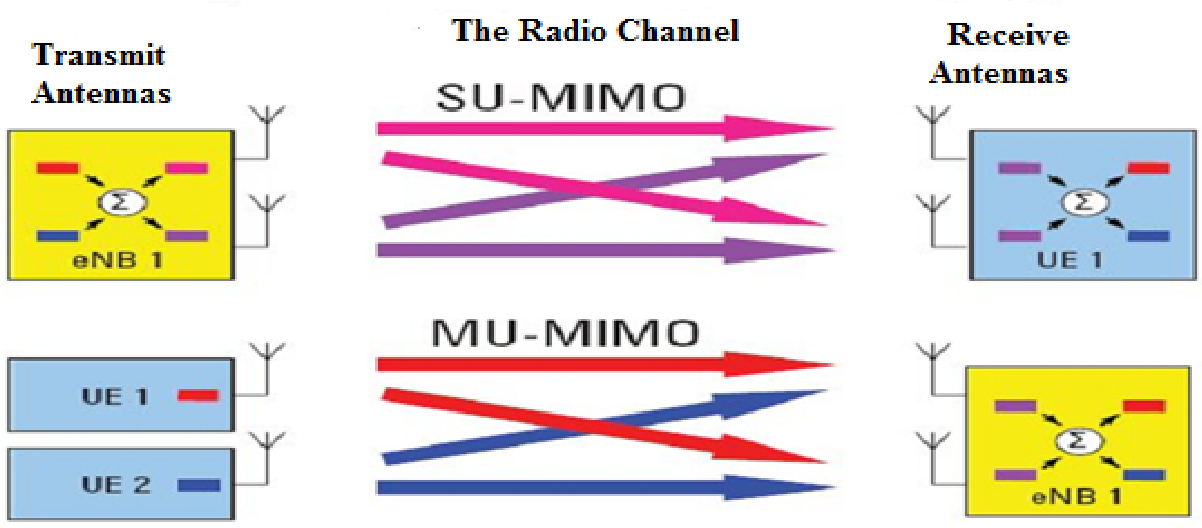


Figure 2.9: SU-MIMO and MU-MIMO configurations

can be arranged by the network scheduler (i.e.,transmitter) to be sent to a single user (known as single user multi-input, multiple-output,SU-MIMO) or to different users (known as multi-user multi-input,multiple-output,MU-MIMO).While SU-MIMO increases the data rate of one user,MU-MIMO allows an increase in the overall system capacity.It is worth mentioning that MU-MIMO is introduced in LTE mainly,but is still rarely deployed due to complexity in design and challenges. Fig (2.9) shows,the configuration of both MIMO types. Single-User MIMO allows the single user to gain throughput by having multiple essentially independent paths for data,while Multi-User MIMO allows multiple users on the reverse link to transmit simultaneously to the eNB,and increasing the overall system capacity

2.6 Scheduling techniques in LTE

In the Medium Access Control (MAC) layer of the eNodeB,the functionality of the scheduler is to distribute the radio resources among UEs served by a given cell.The throughput of each UE and the throughput of the entire cell area are affected by the methodology selected by the scheduling algorithm[39].Thus,there is a need to evaluate the efficiency of different scheduling methods prior to any practical deployment under most circumstances.In 3GPP LTE networks,there are three basic scheduling algorithms.They can be easily compared on the basis of fairness and overall throughput.

1. **Round Robin(RR) scheduling.** RR provides fairness and identical priority among all UEs within a cell.It assigns the radio resources in equal time slots and in an ordered manner.RR schedules resources fairly, without taking into consideration the channel state conditions experienced by different UEs.However,it is less efficient in providing a high data rate to UEs.
2. **Maximum Rate (MR) scheduling:** on the other hand,prioritizes UEs which have favorable channel state condition.In other words,this MR algorithm schedules the UEs that have SINR above the required threshold whereas it does not schedule those UEs which experience severe channel fading.As a result,the MR scheduling algorithm provides higher capacity and throughput than any other kind of scheduling algorithms.However,it completely ignores fairness among UEs within a cell.
3. **Proportional Fair scheduling algorithm (PF):** provides balance between fairness and the overall system throughput[39].

3 REVIEW OF RELATED LITERATURES

In this chapter,efforts have been made to review relevant publications on the extents required to find literature gap, and the review was connected to research problem as well.

3.1 Related works on LTE RNP

Recently,in April,2014 there was an impressive work on" LTE Cellular network planning under demand uncertainty"[19].According to[19] in mobile cellular networks,traffic fluctuates heavily over time which rises uncertainty in the cell load for an eNodeB.Conventional radio network planning (RNP) focuses on a static model for the traffic distribution which is usually taken at hours of peak demand.However,a major disadvantage of such a deterministic model is that the locations of the eNodeBs are not optimized for the various traffic distributions that vary across the day which decreases the average network's throughput or the end user's QoS at off-peak hours.Unlike the conventional RNP which is based on deterministic model,the main contributions of this work were the following.

1. Stochastic approach for LTE RNP which optimizes the eNodeBs locations taking into account various traffic distributions or the uncertainty of the traffic distribution over time
2. Introduce dynamic eNodeB switching on/off strategy to reduce the energy consumption.
3. Finally, as investigated in simulation result of this work, significant increase in the network throughput can be achieved,if RNP is done taking into account the uncertainty of the traffic distribution compared to a deterministic traffic model.
4. Switching off eNodeBs during low traffic states leads to a more energy efficient wireless network operation [19].

Network Capacity,Coverage Estimation and Frequency Planning of 3GPP Long Term Evolution (3GPP-LTE) was discussed on [9].This work,investigated LTE system capacity and coverage based on 3GPP release 8 without an actual deployment area selection.The result covers the interference limited coverage calculation, the traffic capacity calculation and radio frequency assignment.The implementation was achieved on the WRAP Radio network planning tool (software) platform for the LTE Radio network planning and optimization.

Description of models,and tools for coverage and Capacity Estimation of 3GPP Long Term Evolution Radio interface was discussed on [13].This work was related to the dimensioning of LTE Radio access networks and the development of tools for dimensioning purpose. Methods and models for coverage and capacity planning were developed.Special emphasis is laid on radio link budget for coverage planning along with detailed coverage and capacity analysis.Theoretical work was later put into the development of an Excel based dimensioning tool.The final result gives the number of sites (cells) needed in order to support a certain subscriber population with a given capacity.

According to[20] traffic capacity planning is a challenging task in MIMO and OFDM based LTE cellular networks.Due to these challenge the author proposed a novel traffic capacity planning methodology for LTE Radio network dimensioning.In this work,a new methodology for dynamic real-time capacity planning was proposed for LTE radio network dimensioning, based on unified traffic process mechanism,fresh simulation methodology for air interface, and smart self-evaluation and optimization.By corresponding software design and implementation,it provides powerful tool for LTE network planners to get efficient,accurate and professional capacity planning outcome without much manual effort[20].

4 LTE RADIO NETWORK PLANNING (LTE-RNP)

This section includes general LTE-RNP principles,and description of dimensioning inputs and outputs.

4.1 LTE Radio Network Planning Principles

Since 2009,LTE technology has attracted great interests from top operators around the world due to the enhanced technical flexibility and improved network capability[20]. LTE shows to be the great momentum for the convergence of cellular network and internet,which will bring revolutionary transform of traffic pattern in cellular networks[20].According to[14] the target of any RNP should be the compromise between coverage,capacity,quality and cost.Therefore,network designers,and planning engineers should consider these factors during the planning phase of the network.In LTE Radio access network planning,coverage and capacity objectives need to be selected in a smart way to meet the business requirement with minimum expenditure. On the other side,the network should be dimensioned properly to meet the current and future capacity requirement without under estimation and over estimation of the traffic growth [22][24].

In addition according to [19] RNP is an essential task for operators and has a significant impact on the behavior and flexibility of the resulting network. RNP typically takes into account a geographical area,an estimated traffic load,the evolved eNodeB configuration and other network parameters and finds the optimal location for the eNodeBs in order to satisfy coverage and capacity requirements.

The main aim of radio network planning is to provide a cost effective solution for the radio network deployment in terms of coverage,capacity and quality of service.Estimating the optimum number of eNBs together with its location, determining the type of the antenna,the receiver/transmitter power,and the environmental characteristics of the propagation environment are among the main tasks in Radio network planning. Radio network planning is a complex and time consuming task under taken in different phases. According to [14] the planning and rollout of LTE network can be divided into the following phases.

1. **Pre-planning phase:**In this phase,coverage and capacity requirements are identified.This includes traffic profile,cell edge throughput (CET) indoor and outdoor converge probability,Quality of service (QOS) requirement.In addition,the clutter type need to be identified along with relevant indoor penetration loss.The propagation model selection and tuning for link budget calculation is also conducted in this phase.

2. **Nominal planning phase:**This phase is called Radio network dimensioning phase.In this phase,link budget,capacity dimensioning,and RF-prediction are conducted.The outcome of this exercises includes the cell radius for different clutter,supported number of subscribers,number of required sites for each clutter,and coverage maps for target areas.

3. **Detailed planning phase:**In this phase,the nominal planning exercises must be verified by identifying the site coordinates,conducting site surveys,and selecting the proper candidates that meets the coverage targets.
   In addition neighbor list preparation and cell parameters are defined as per vendor recommendation at this stage.Finally,the antenna type selection,antenna height,azimuth,and electrical as well as mechanical down tilt need to be finalized at this stage.

4. **Network Rollout phase:**In this phase the network rallout and site construction is conducted based on the detailed planning phases,and the rollout model.At this stage network acceptance may be conducted in cluster fashion or site by site,or a complete city.

5. **Network pre-optimization:**In this phase the network is pre-optimized by validating the cell parameters,coverage target and throughput.The nominal and detailed planning results are evaluated and compared against the actual network performance and the network parameters can be tuned to meet the agreed KPIs (key performance indicators) before commercial launch.

6. **Soft launch:**This is the final phase when the network has passed all the KPIs and the SLA (service level agreement).As a result it can be launched as a soft

launch mode or as a friendly user trial (FUT).Frist a limited number of customers are allowed to access the network,and the feedback from customers are combined to validate the network KPIs reported by the supplier's network management system(NMS).If the network performance is up to expectation and meets the agreed KPIs, then the operator will offer the network for commercial users.

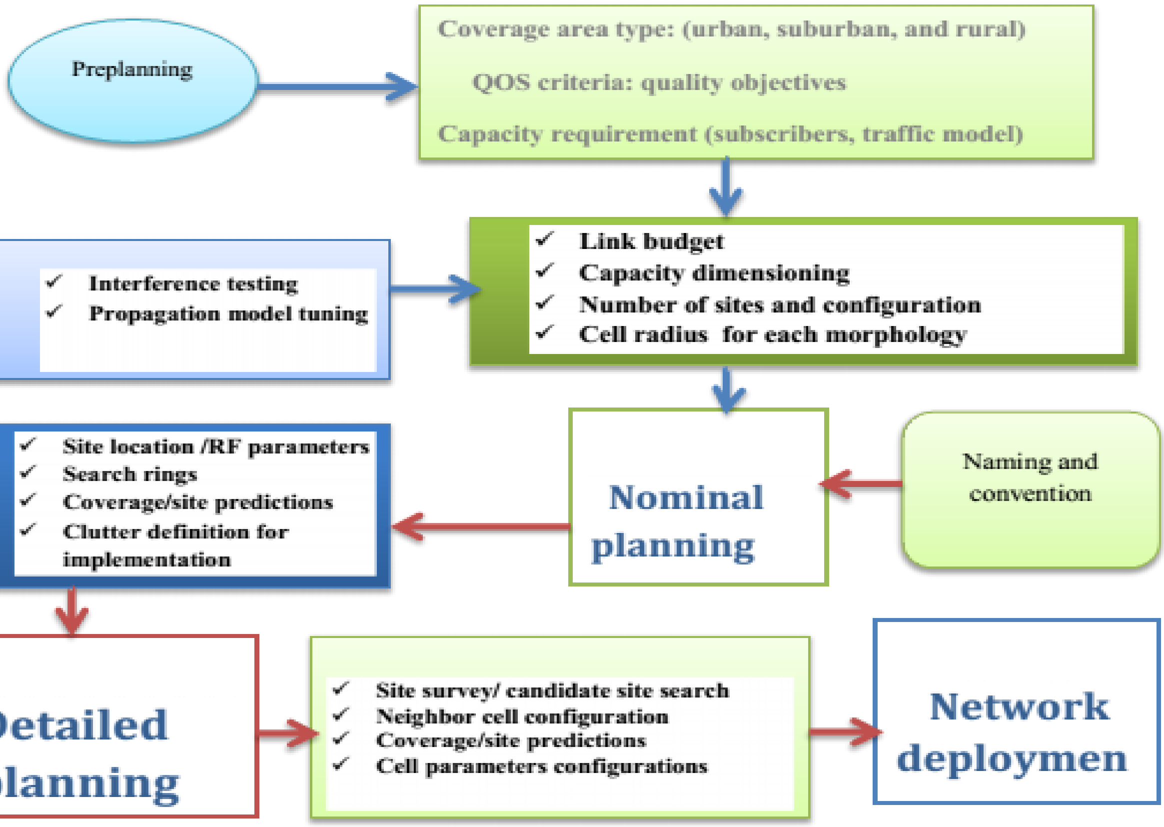


Figure 4.1: End-to-end network planning and deployment phases

Figure4.1 shows the detailed view of the first three network planning phases (i.e.;pre planning,nominal planning,and detailed planning),and the rest three (i.e.;network rollout phase, network pre optimization, and network soft launch) are included in the network deployment block.The scope of this thesis is delimited to the first three phases.

4.2 LTE Network Dimensioning

Dimensioning is the initial phase of network planning, which includes the pre planning and nominal planning phases.It provides the first estimate of the network element count as well as the capacity of those elements.The purpose of dimensioning is to estimate the required number of radio base stations(eNBs) needed to support a specified traffic load in an area[13].Network Dimensioning means determining the areas that need to be covered and computation of number of sites required to serve the target areas while fulfilling the coverage and capacity requirements[17]. Dimensioning is the most critical step in network planning process,which includes coverage planning,radio link budget;capacity estimation,and frequency planning that gives an estimate of the number of sites which is later used for detailed planning of the network [15].Thus,it basically includes the following two analysis.

- **Coverage Analysis:** Coverage or cell range is determined for coverage-limited scenario or for interference-limited scenario.This depends on fading margin,cell edge target throughput,average network load,etc.
- **Capacity Analysis:** The capacity analysis involves assessment of demanded and available traffic considering activity factor,Overbooking Factor (OBF), UL/DL frame ratio,etc.

Since coverage and capacity analysis are an important components of LTE network dimensioning,thus it needs separate chapters for detailed analysis and description of models which will age analysis will be discussed in detail in chapter 5,and 6 respectively.Before the through study of coverage and capacity planning,LTE network dimensioning inputs and outputs will be discussed.

4.2.1 Expected Inputs of LTE network Dimensioning

According to [13] LTE dimensioning inputs can be broadly divided into three categories:quality,coverage and capacity-related inputs.

1.Quality-related inputs:

Include average cell edge throughput and blocking probability [13].These parameters are the customer requirements to provide a certain level of service to its users.These inputs directly translated into QoS parameters.

2.Coverage related inputs:

These mainly include Radio link budget,which have got a central importance to coverage planning.RLB inputs include transmitter power,transmitter and receiver antenna systems,MIMO configuration,conventional system gains,losses,and margins.Additionally:Cell load,propagation models,channel model types and geographical as well as clutter information is needed to start the coverage dimensioning exercise.Geographical inputs consist of area type information,Urban,sub-urban and Rural and size of each area type to be covered. Furthermore,required coverage probability plays a vital role in determination of cell radius.Even a minor change in coverage probability causes a large variation in cell radius [13].

3.Capacity related inputs:

Capacity planning inputs includes the number of subscribers in the system, their demanded services,and subscriber usage level[13].Available spectrum and channel bandwidth by the LTE system are also very important for LTE capacity planning.Traffic analysis and data rate to support available services are used to determine the number of subscribers supported by a single cell and eventually the cell radius based on capacity evaluation.LTE system level simulation results and LTE link level simulation results are used to carry out capacity planning exercise along with other inputs.

4.2.2 Expected Outputs of LTE Network Dimensioning

Cell size is the main output of LTE dimensioning exercise.Two values of cell radii are obtained,one from coverage evaluation and second from capacity evaluation.According to [13] the smaller of the two can be taken as the final output.Cell radius is then used to determine the number of sites. Assuming a hexagonal cell shape,number of sites can be calculated by using simple geometry. In accordance with Outputs of the dimensioning phase are used to estimate the feasibility and cost of the network.These outputs are further used in detailed network planning and can be utilized for future work on LTE core network planning[13].

5 COVERAGE PLANING AND RADIO LINK BUDGET

This chapter covers the theoretical understanding of LTE Coverage Planning exercise.Radio Link Budget calculation followed by the methods used for calculation of required SINR,effect of interference,and finally the calculation of the number of sites based on the coverage target will be presented.

5.1 Introduction

Coverage Planning is the first step,prior to capacity dimensioning in the process of dimensioning [13].It gives an estimate of the resources needed to provide service in the deployment area with the given system parameters,without any capacity concern,or without quality of service concern.Therefore,it gives an assessment of the resources needed to cover the area under consideration,so that the transmitters and receivers can listen to each other.Coverage planning mainly consists of evaluation of DL and UL radio link budgets.The MAPL is calculated based on the required SINR level at the receiver,taking into account the extent of the interference caused by traffi.The minimum of the maximum path losses in UL and DL directions is converted into cell radius,by using a propagation model appropriate to the deployment areas as shown in Fig 1.3,under the methodology part of this thesis.Radio Link Budget is the most prominent component of coverage planning exercise.The work flow is as indicated in Fig (5.1)

5.2 LTE Radio Link Budget

The aim of link budget calculation is to identify the maximum allowable path loss (MAPL) between transmitter and receiver for both UL and DL.Therefore,cell radius can be calculated for different terrain morphologies.The minimum SINR requirements for both UL and DL are achieved with the MAPL and maximum transmit power[14].The link budget considers many factors,such as transmit power,building penetration loss,feeder loss,antenna gains,diversity gain,interference and fading margins of the radio links to calculate all losses and gains that affect the final cell coverage[14].The

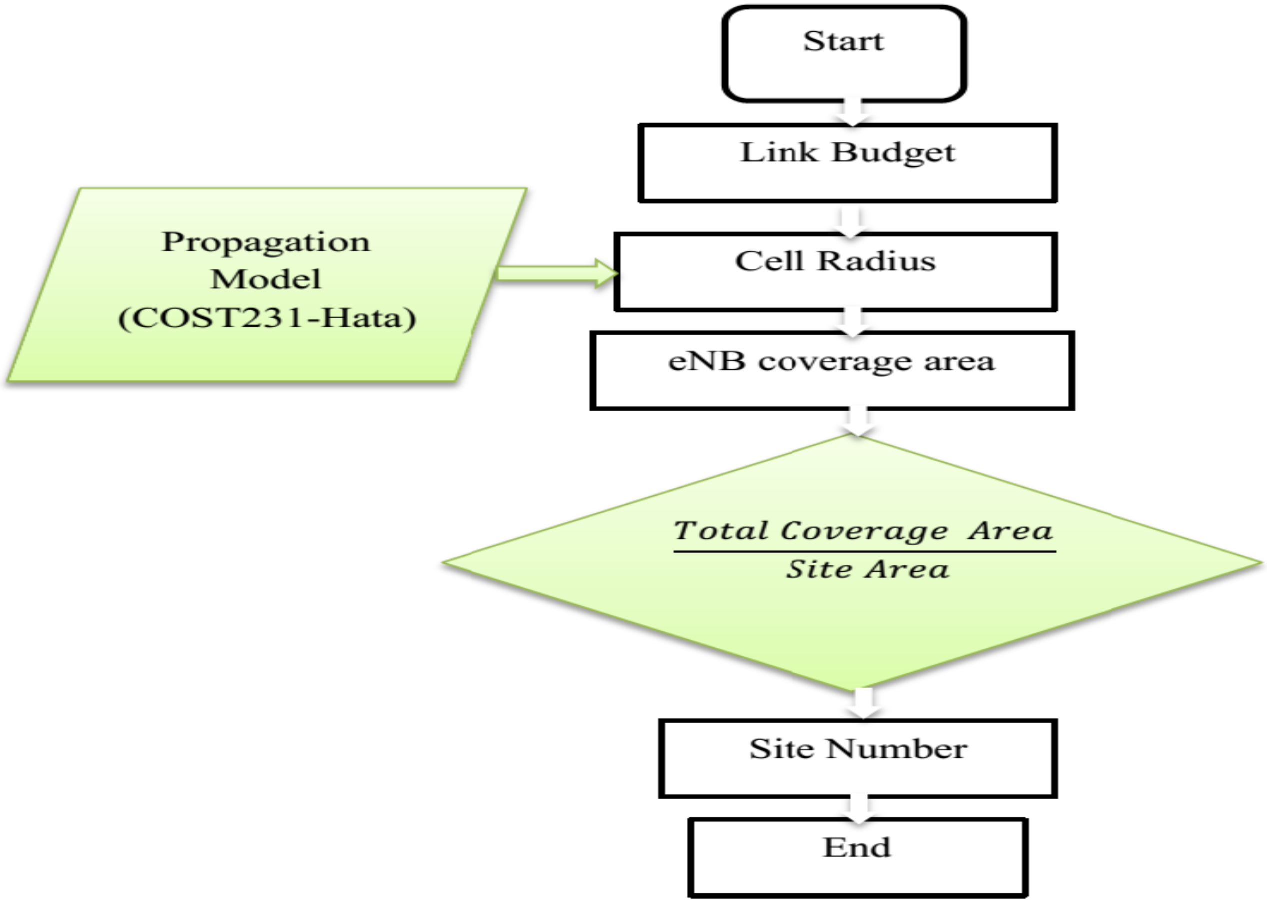


Figure 5.1: Work flow of Coverage Dimensioning

cell radius of an eNodeB can be obtained according to the MAPL under the tuned propagation modeling.The cell radius can be used to estimate the total number of sites that needed to provide the RF coverage that meets the predefined coverage objectives.Figure (5.2) shows the inputs and outputs of RLB.According to [14],LTE release 8 is a data centric technology,then the critical coverage constraint for the link budget is the data rate at the cell edge rather than the received signal level.SINR is popular with operators since it better quantifies the relationship between RF conditions and throughput than RSRP or RSRQ thus why most UEs use SINR to calculate the CQI (Channel Quality Indicator) they report to the network.The components of the SINR calculation are:

- **S:** The power of measured usable signals,such as Reference signals (RS) and physical downlink shared channels (PDSCHs).
- **I:**The power of measured interference from other cells in the current system.

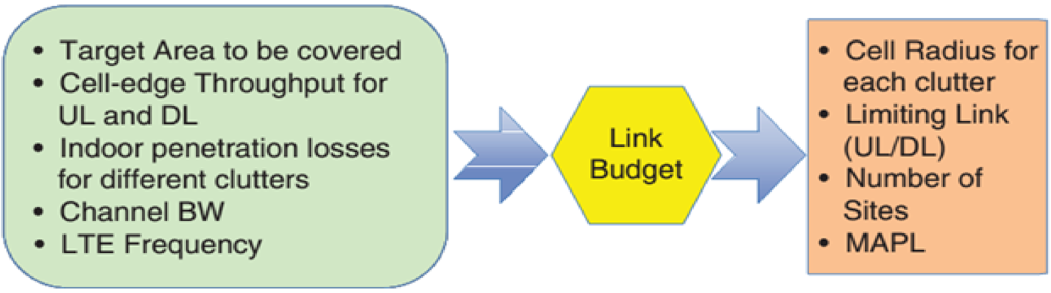


Figure 5.2: RLB inputs and outputs

- **N:** Background noise power.

Therefore,SINR can be defined as Wideband or Narrowband (for specific sub-carriers or a specific resource element).Maximum allowed path loss can be modeled as equation: (5.1).

$$P_l = P_{Tx} + G_{Tx} - L_{Tx} - S_{Rx} + G_{Rx} - P_{Rx} - L_{Rx} - SM \tag{5.1}$$

The signal to interference noise ratio (SINR) as shown below.

$$SINR = \frac{RecevedPower}{noise + I_{(othercell)}} = \frac{RecevedPower}{noice(1 + interferencemargin)} \tag{5.2}$$

Receiver sensitivity is given by:

$$S_{Rx} = -174\frac{dB}{Hz} + 10\log(15 * 12 * \#RB) + NF + SINR_{Req} \tag{5.3}$$

Where:

- P_l is the total path loss encountered by the signal from eNodeB to UE in (dB)
- P_{Tx} and P_{Rx} are the transmitter and receiver power in (dBm) respectively
- G_{Rx} and G_{Rx} are the transmitter and receiver antenna gain in(dBi) respectively
- L_{Tx} and L_{Rx} are body loss and other losses in transmitter and receiver side respectively
- S_{Rx} is receiver sensitivity in (dBm)
- SM is system margin

- $\#RB$ is the number of resource blocks in DL or UL
- $SINR_{Req}$ is the required signal to interference power ratio.
- NF noise figure.

In doing link budget calculation,it is important to note that the calculation is for a single mobile (user) located at cell edge;for a single service and transmitting at maximum power[15].i.e.,in order to calculate the maximum coverage,the minimum received signal strength that can be detected by the receiver has to be considered.

Link Budget parameter Description

The link budget parameters are LTE Coverage dimensioning exercise inputs,which was already discussed in section 3.1.1.The LTE physical layer parameters which might be used for link budget calculation were adopted from 3GPP-LTE technical specifications[4].The eNB and UE power is found from typical device manufacturer specifications.Typical LTE coverage design targets at 1.8GHz is as shown in Table(5.1),adapted from [14].Figure (5.3) shows the link budget parameter estimation points for down link.The same sketch can be drown for the reverse link (UL),but different path loss can be obtained from both links.

Table 5.1: Typical coverage design targets of LTE at 1800MHZ

Criteria	Target
RSRP	≥ -116
Average coverage probability	95%
Cell-edge coverage probability	90%
SINR	$\geq -3dB$
Cell edge throughput DL/UL(Mbps)	512/128

- LTE link budget parameters are discussed as follows:

1. **eNodeB Output Power:**This is one of the main factors that impact the link budget.In the link budget.According to [14],46dBm output power per each branch

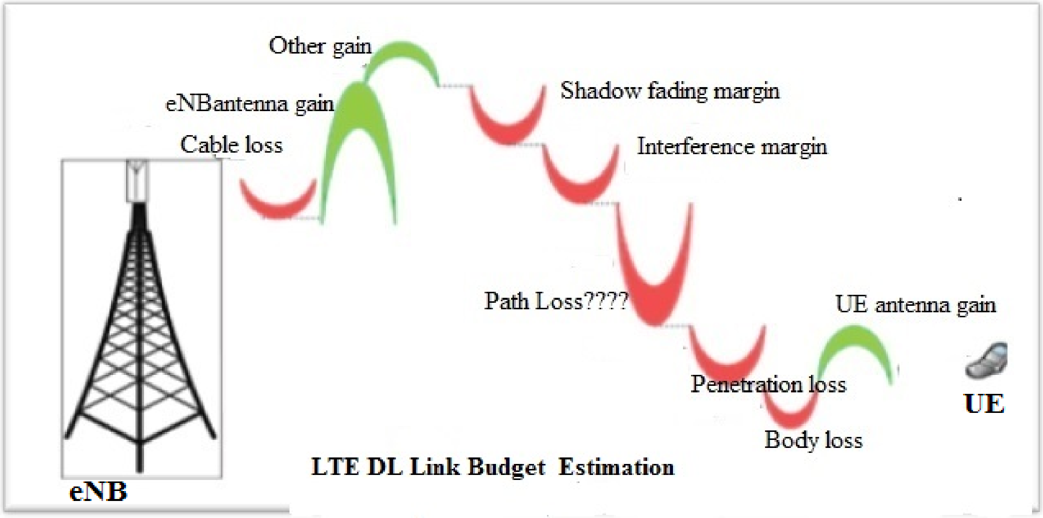


Figure 5.3: LTE DL link budget estimation

of the MIMO 2×2 which means 2×40 watts can be considered in LTE link budget.Therefore,if we have the RRU scenario,three RRUs with 2×40 watt each are deployed to provide three sectors with MIMO 2×2 operation.Most of the suppliers currently support 2×60 watt for MIMO 2×2 operation and even 2×80 watt. The higher power RRU can be used for either MIMO 4×4 evolution if the eNB support this evolution in same Hardware.

2. **Cell Edge User Throughput(CET:)** The CET is the target throughput requirement to be achieved at the cell edge;minimum net single UE throughput requirement in DL and UL[14].The CET determines the service that can be provided at the cell edge.Accordingly it can limit the minimum MCS to be used.The CET is usually provided by the network operator according to the required services at cell edge.It depends on the operator strategy and the business requirement.The CET is a key input to the link budget and it directly impacts the cell radius and accordingly the number of required sites to cover a certain area.According to [14] the CET used in the link budgets is 512kbps in the DL and 128kbps in the UL for the sake of maximum cell radius estimation.But,in a practical exercise, a typical CET would be 512kbps for the UL and 1Mbps for the DL. Alternatively,an aggressive requirement may consider 1Mbps for the UL and 2Mbps for the DL.

3. **Channel Model:**The channel model is characterized by delay profiles that are selected to be representative of low, medium, and high delay spread environments [25].The delay profiles of the Channel models are defined in Table (5.2).The most typical UE speed and multipath.

Table 5.2: Antenna heights,coverage probability,and channel model for different morphology

Morphology	Denseurban	Suburban	Rural
Antenna height(m)	25	40	50
Coverage probability(%)	95	95	95
Shadowing std.deviation(dB)	11.7	7.2	6.2
Channel model	ETU (3Km/hr)	ETU (120Km/hr)	EVA120Km/hr (120Km/hr)

profiles are considered according to the type of environment (e.g.,dense urban,urban,rural, etc.).In the link budget,the ETU (extended typical urban) at 3 km/h is used for dense urban and urban morphologies.The channel model ETU at 120 km/h and EVA (extended vehicular A) at 120 km/h are used for suburban and rural,respectively.

4. **eNodeB Antenna gain:**The antenna gain is proportional to the antenna size,LTE band,and beam-width of the antenna patterns (horizontal and vertical) [14].A large antenna with narrow beam-width provides a high gain while a short antenna with wider beam-width provides less gain.The selection of antenna gain and beam-width depends on the clutter type and coverage requirement.The low gain antenna (15-17 dBi) can be used in urban and suburban clutters.A typical LTE 1800MHz antenna with two dual polarized antennas (four antenna ports) that can accommodate LTE 1800MHz and GSM 1800 or LTE 1800MHz with 4RX diversity or MIMO4×4 is used for interworking with the existing GSM-UMTS network.

5. **MCS Selection:**The selection of minimum MCS for the link budget depends on the required CET that is usually provided by the operator. A robust MCS should be selected to guarantee the required CET under the worst RF channel condi-

tion. With the LTE-FDD system and due to change in the UL and DL channels and change in power allocation,the selection of the MCS for UL and DL is different at the cell edge in the link budget and also in the practical scenario.Each MCS is mapped to a certain modulation group (QPSK, 16QAM,64QAM),and each MCS index is assigned a TBS index.The TBS reflects the amount of user data bits sent during one TTI (1ms) and the TBS depends on the number of scheduled RBs.

6. **Equivalent Isotropic Radiated Power (EIRP):**EIRP indicates the power that would be radiated by the theoretical isotropic antenna to achieve the peak power density observed in the direction of maximum antenna gain [15].The power radiated by a directional antenna is transposed into the radiated power of an isotropic antenna by consideration of antenna gain and power at the antenna input.For the LTE system,the EIRP per subcarrier in the DL and UL are calculated,respectively,as follows:

$$EIRP_{DL} = P_{(eNB(sc))} + AG_{eNB} - FL + MG \tag{5.4}$$

Where $EIRP_{DL}$ is the EIRP per subscriber in the downlink,$P_{(eNB(sc))}$ is the power per subscriber in the DL,AG_{eNB} is the antenna gain of the eNB, FL is the feeder loss,and MG is the MIMO gain.

$$EIRP_{UL} = P_{(UE(sc))} + AG_{UE} - BL \tag{5.5}$$

Where $EIRP_{UL}$ is the EIRP per subscriber in the uplink,$P_{(U(sc))}$ is the power per subscriber in the UL,AG_{UL} is the antenna gain of the UE,BL is the body loss. The EIRP in the DL is calculated based on the total number of RB due to the OFDMA (orthogonal frequency division multiple access) while in the UL,the allocated RBs(i.e.,three RBs) are only used due to the SC-FDMA

7. **Receiver Sensitivity:**The eNB receiver sensitivity is the signal level/threshold at which the RF signal can be detected with a certain quality.This threshold refers to the antenna connector and should take into account the further demodulation and the required output signal quality. The receiver sensitivity

depends on the following factors:Data rate targeted at cell edge,Target quality/HARQ (hybrid automatic repeat request) (i.e.,block error rate (BLER), maximum number of retransmissions),Radio environment conditions (multipath channel,mobile speed),and Noise figure (NF) of the eNodeB receiver.The receiver sensitivity per subcarrier is calculated as follows:

$$RXSen_{subscribr} = SINR + NF + NP + 10\log_{10}(\Delta f) \tag{5.6}$$

Where SINR is the threshold of the receiver that can demodulate the signal and it is related to the MCS for the UL and DL,respectively,the BLER target, MIMO gain,and HARQ setting.The SINR is obtained from the system simulation results.The SINR value is vendor specific and depends on the receiver design. The NP is the density of the thermal white noise power,which is $-174dBm/Hz$ and estimated as follows:

$$NP_{subscriber} = 10log_{10}(290 * 1.38 * 10^{(-23)} * 203) \tag{5.7}$$

In the LTE system,a single subcarrier is 15 kHz.Therefore,the thermal noise power per subcarrier for the DL and UL are calculated as below:

$$NP_{subscriber} = NP + 10log_{10}(15 * 1000) = -132.24dBm \tag{5.8}$$

As a result,the DL and UL receiver sensitivity are estimated based on the number of sub- carriers allocated in the DL and UL as follows[14]:

$$RxSen = SINR + NF + NP_{subcarrier} + N_{subcarrier} \tag{5.9}$$

where $N_{subscrber}$ is $10 * \log_{10}$ $(the\ number\ of\ allocated\ subcarriers)$.The number of allocated subcarriers equals the total number of received subcarriers in the available system bandwidth of 20MHz in the case of the DL OFDMA transmission.In the UL with SC-FDMA transmission,the total number of allocated subcarriers equals the number of subcarriers allocated to the user to achieve the target CET of 128 kbps or more at the cell edge which is 36 subcarriers (3 RB×12 subcarriers per RB).

The adopted link budget in this thesis is based on subcarrier receiver sensitivity and accordingly the EIRP used is based on the output power per subcarrier.In other approaches,the receiver sensitivity on the DL and UL is used and in this case total power for all allocated subcarriers should be used in the EIRP.

8. **Noise Figure:**The NF in dB is the ratio of the input SINR at the input end to the output SINR at the output end of the receiver.It is a key factor to measure the receiver performance.Therefore,the receiver sensitivity together with the NF should be considered to benchmark the eNB receiver performance. The NF depends on the bandwidth and the eNB capability. For LTE terminals,the NF is between 6 and 8 dB [26]

9. **UE Characteristics:**The transmitter characteristics are specified at the antenna connector of the UE with a single or multiple transmit antenna(s). For the UE with an integral antenna only,a reference antenna with a gain of 0 dBi is assumed [6].The maximum transmit power of an LTE UE depends on the power class of the UE.Currently,only one power class is defined in 3GPP TS 36.101 [6],which is 23 dBm output power with 0 dBi antenna gain. In the link budget exercise,a USB dongle with 1.5m height and 23dBm output power can be considered.It is recommended to consider a safety factor for UE output power in the link budget,which depends on the frequency band as per Table (5.3)

Table 5.3: UE antenna gain for different LTE bands

LTE frequency band(MHz)	UE Antenna gain(dBi)
The short band(LTE700/800)	-5
LTE Band 3(LTE1800)	-3
The extended band(LTE1600)	0

10. **SINR Performances:**The SINR performance figures are derived from link level simulations[27] or,better,from equipment measurements (lab or field measurements).The SINR depends on the eNodeB performance, radio conditions (multi path fading profile,mobile speed), receive diversity configuration (two branch by default and optionally four branch with MIMO 4×4 or MIMO4×2),targeted data rate,and the required QOS[17].

11. **Penetration Loss:**-The penetration loss indicates the fading of radio signals from an indoor terminal to a base station due to obstruction by a building and vice versa.The penetration loss depends on the type of the clutter and the nature of the buildings in the target coverage area. Table(5.4) summarizes typical penetration losses for different clutters,and adopted from[14].

Table 5.4: UE antenna gain for different LTE bands

Clutter type	Penetration loss range(dB)	Typical value in RLB
Dense urban	19-25	19
Urban	15-18	15
Suburban	10-14	11
Rural	5-8	8

12. **Body Loss:**Body loss is the loss generated due to signal blocking and absorption when a terminal antenna is close to the body of the user. This affects handsets in particular.The body loss depends on the position of the terminal and the user.For terminals such as a USB dongle,a mobile WiFi device,and an LTE fixed router the position of such terminals is far from the user's body and,therefore,the body loss can be ignored.Therefore,it is normal to consider dB in the link budget for data dongle in this data only scenario[14].Therefore,the body loss will be considered only in the case of a smart phones or voice handset and will not be considered with other devices as well as the eNodeB,since the antennas of the eNodeB are installed away from the user's body.

13. **Feeder Loss:**Feeder loss is the losses due to RF feeders,RF jumpers,and connecters in the path between the antenna and the eNB. The feeder loss is calculated according to the feeder type,feeder material,length,and diameter.If the eNodeB is installed inside the shelter and a feeder system is used between the antenna and the eNodeB, then all losses from the feeders,jumpers,combiners (if any),splitters (if any),and so on,are considered in the link budget.On the other hand,if the distributed eNodeB with baseband unit and remote radio units (RRUs) is considered,then only the loss of the jumper between the RRU and

antenna is considered and it is about 0.5 dB loss with a full feeder system the losses may be 3dB or more according to the aforementioned characteristics.

14. **Interference Margin (IM):**The interference margin is encountered in the link budget due to the possibility of noise rise according to the load level. Unlike the UMTS system,LTE has no intra-cell interference thanks to the OFDM subcarriers'orthogonally. Therefore,the UL RB load can reach 100%, depending on the UL eNodeB scheduler mechanism and subscribers distribution.However,inter-cell interference should be considered in the UL and DL.IM is calculated considering other-cell loading,target SINR, and minimum achievable SINR.It is affected by many factors,such as frequency reuse scheme, inter-site distance,cell load,system bandwidth,and the ICIC algorithm,which is vendor specific.IM accounts for the increase in the terminal noise level caused by the interference from other users.For the UL and due to the change in scenario on a per TTI basis and non-deterministic distribution of users,it is recommended to estimate the interference margin using an actual dynamic simulation.While for the DL, the interference margin can be computed analytically as the relation between signals received with and without interference and can be estimated as follows:

    $$IM_{DL} = -10log[_{10}(1 - Load_{DL}I_N * 10^{(0.1*SINR_{PDSCH})}] \qquad (5.10)$$

    Where,$Load_{DL}$ is the DL load, I_N is the adjacent cells interference factor,and $SINR_{PDSCH}$ is the required SINR for PDSCH detection.In practice, the interference margin depends on the planned capacity and coverage,so there is a trade-off between capacity and coverage similar to other cellular technologies.Interference margin Vs.load is shown in Table (5.5) and the corresponding plot is shown in Fig (5.4) taken from [13]

Table 5.5: Load vs.Interference margin

Load(%)	35	40	50	60	70	80	90	100
Interference margin(db)	1	1.3	1.8	2.4	2.9	3.3	3.7	4.2

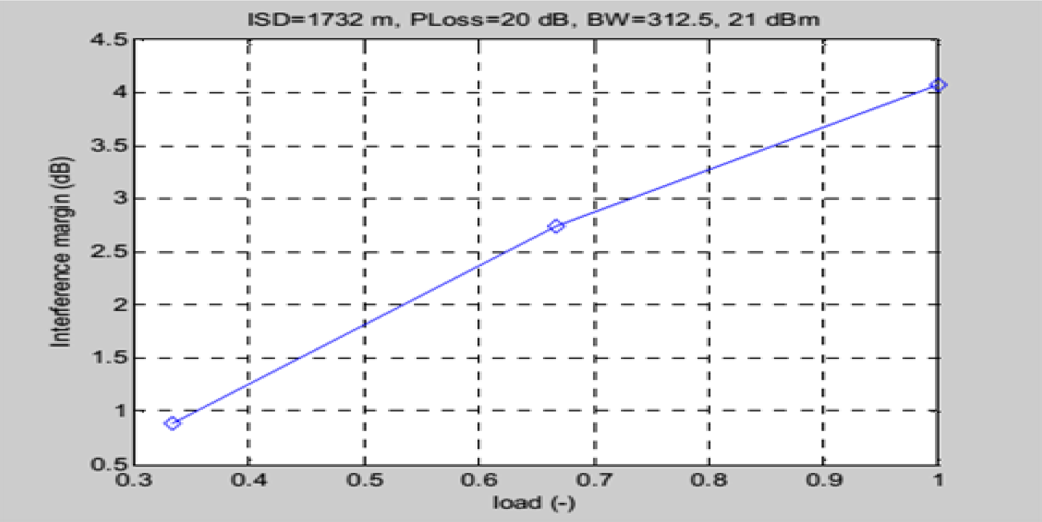


Figure 5.4: Load to interference Relation ship

5.3 RF Propagation Model and Path Loss

In LTE RF coverage prediction using a planning tool is important to select the appropriate propagation model[14].The basic aim behind using RF propagation model in link budgeting is to determine the path loss.There are many propagation models and different models have been developed to meet the needs of realizing the propagation behavior in different conditions.Each propagation model is valid in a specific scenario and specific frequency[28][29].If the model is not chosen correctly,the model will either overestimate or underestimate the path loss,and then the predicted coverage[14]. So, path loss prediction should be as accurate as possible.Radio propagation models are classified as empirical models and deterministic models[14].Since empirical models are more applicable than deterministic models,the proceeding discussion is on empirical models only.Even,It is not the aim of this thesis to discuss detail of empirical RF propagation models. For detail discussion of RF propagation models see [29][30] .

5.3.1 Empirical and semi-empirical RF -propagation models

Empirical or semi-empirical models are based on extensive measurements,and the model coefficients should be calibrated for different clutters based on field measurement. Okumara model, Okumara-Hata model,and COT231-Hata model are families of empirical model[29]. Okumara model is purely experiment based statistical model,so its statistics are presented by curves without an actual formula [31]. Okumara -Hata model is intended for manual use,and finding the formula for Okumara's curve for computational use.Okumara-Hata model can handle a frequency range between(400-1500MHZ),which is obviously cannot support LTE1800MHZ and LTE 2.6GHZ [31].Therefore,another appropriate propagation model should be selected in such a way that it includes the LTE bands.

5.3.2 The COST231-Hata Model

Due to its suitability for LTE1800MHz band, and its applicability for different clutters and terrain morphologies,the chosen RF-propagation model for this study is COST231-Hata model.COST is a European union forum for cooperative scientific research [29][32].COST231 group extends the studies of Okumara-Hata, which only works for frequencies below 1500MHz,and thus does not work for UMTS2.1GHZ and LTE bands.Therefore,the COST231-Hata model extends the frequency range of OKumara-Hata from 1500 to 2000MHZ.The path loss equation of COST231-Hata model is given by:

$$PL_{COST231} = A + Blog(R) + C_o - a(h_R) \tag{5.11}$$

$$A = 46.3 + 33.9log(f) - 13.82log(h_{(eNB)} \tag{5.12}$$

$$B = [44.9 - 6.55log(h_{(eNB)}] \tag{5.13}$$

The terms $a(h_R)$ and C_o are constants to be accounted for different terrain environments. $a(h_R)$ is UE Antenna height correction factor as described in the COST231-Hata Model for medium cities and suburban areas.

$$a(h_R) = [1.1log(f) - 0.7] * h_U E - 1.56[log(f) - 0.8] \tag{5.14}$$

$C_o = 0dB$,for medium cities and suburban area ,and 3dB for Urban and Dense urban areas[32] Where f is the carrier frequency in MHz. h_{eNB} and h_R are effective heights of antenna for eNB and UE in meter.R is the cell radius in $Km.$

5.4 LTE Site Count for Coverage Target

The maximum allowable path loss (MAPL) between the eNB and UE is obtained from the RLB . By equating the MAPL obtained from the link budget, and the COST231-Hata path loss model,it is possible to determine the distance between UE and eNB as shown in Equation (5.15) .

$$CellRange = Log^{-1}\{\frac{MAPL - A - C_o + a(h_R)}{B}\} \tag{5.15}$$

Given the cell radius, the cell coverage area is calculated for an assumed cell structure and type.The cell structure can be circular or hexagonal.Both are ideal representations where circular cell gives simpler analysis and hexagonal gives best fit coverage site without middle gaps[15].The assumption here in this thesis is tri-sector hexagonal cell structure where the cell area depends on the site/antenna configuration(see Fig.5.5)[15].The corresponding cell area is given by Equation(5.17)

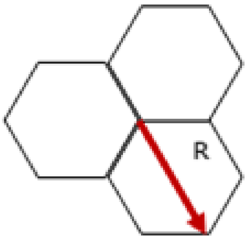


Figure 5.5: Hexagonal shape tri-sector antenna

$$CellArea = 3 * \frac{9}{8}\sqrt{3} * R^2 \tag{5.16}$$

$$IntersiteDistance = \frac{3}{2} * R \tag{5.17}$$

6 LTE CAPACITY PLANNING

The purpose of this chapter is to describe capacity planning for LTE network,and to explain methods used to calculate number of subscribers supported per cell based on average cell edge throughput.In addition, factors enhancing,and impacting capacity planning is illustrated.For clarity,the chapter is divided into three sections.The first section describes the serving physical layer throughput calculation and sector throughput calculation while the second part is about traffic demand estimation.Finally,capacity target site count evaluation techniques was illustrated.

6.1 Introduction

Capacity planning gives an estimate of the resources needed for supporting a specified offered traffic with a certain level of QoS(e.g.throughput or blocking probability).Theoretical capacity of the network is limited by the number of eNodeB's installed in the network[13].Cell capacity in LTE is impacted by several factors,which includes interference level,packet scheduler implementation and supported AMCS, and MIMO configuration.The capacity of an eNodeB indicates the maximum number of users that can be served by the eNodeB with a desired quality of service or the maximum cell throughput that can be achieved for a particular site at a given time.Increasing the capacity would mean increasing the number of users that can be accommodated by a cell or eNodeB,which in turn means that the number of eNodeBs or cells.

Capacity planning,like coverage planning,also aims at providing an estimate on the number of resources or eNodeBs required for a given service area.However,in capacity planning,the quality of service that is provided to the users within the service area is the key factor.

Typically,the resource calculation from capacity planning for a given service area is higher in comparison with the resource calculations made by coverage planning[33]. Capacity planning is initially done by using a system level simulation tool.In this thesis Vienna institute of telecommunications system and link level simulators will be used for capacity evaluation.The simulation will performed to at least derive these results[34]:

- Average throughput for a close-range user
- Average throughput for a mid-range user
- Average throughput for a far-range user
- Number of UEs that can be placed inside the cell with a throughput for each UE above the acceptable levels.

LTE exhibits soft capacity like its predecessor 3G systems[13].Therefore,the increase in interference and noise by increasing the number of users will decrease the cell coverage forcing the cell radius to become smaller.In LTE,the main indicator of capacity is SINR distribution in the cell.In this study,for the sake of simplicity,LTE access network is assumed to be limited in coverage by UL direction and capacity by DL[13].

The evaluation of capacity needs the following two tasks to be completed:

- Estimate the cell throughput corresponding to the settings used to derive the cell radius
- Analyzing the traffic inputs provided by the operator to derive the traffic demand, which include the amount of subscribers, the traffic mix and data about the geographical spread of subscribers in the deployment area.

6.2 Served Physical Layer Throughput Calculation

The DL and UL capacities (achievable throughput) are impacted by the total BW (1.4,3,5,10,15,and 20 MHz),the total overheads,and the spectral efficiency,which is determined by the DL SINR[14].In the LTE system,the UL capacity is divided between control channels and signals (SRS,DM-RS,PRACH),and the traffic channel, that is,PUSCH.Based on the RE/RB definition in the previous chapter 2,we can define again the following points for the sake of LTE achievable physical layer throughput:

$1RB$ =84 RE, $1subframe$ $contains$ $168RE$, and one $subframe$ $contains$ $2RB$.

$1subframe = 12(subcarriers) \times 7symbols \times 2(Slots) = 168RE(normalCP)$

$MCS = CodeRate \times CodeBits$ Then, the served physical layer UL throughput can be estimated based on Equations (6.1)& (6.2):

$$TP_{UL(kbps)} = (1 - BLER) * (168 - 24) * MCS * N_{UL}^{RB} \tag{6.1}$$

Assuming the control channels/signals in the UL consumes 24 RE and N_{UL}^{RB} is the number of RB in the UL.Similarly,the served physical layer DL throughput can be calculated according to the following formulas:

$$TP_{DL(kbps)} = (1 - BLER) * (168 - 36 - 12) * MCS * N_{DL}^{RB} * MG \tag{6.2}$$

Assuming the control channels in DL consume 36 RE and the RSs in DL occupy 12 RE. The MG is the MIMO gain and it equals =2,if 2T2R with dual stream transition on TX antennas and equals 4 with 4T4R with MIMO 4*4 based on MIMO mode and equals =1 with TX diversity modes where only one stream is transmitted on different antennas for diversity.$N_{DL}^{RB}$is the number of RB in the DL.

6.2.1 Average spectral efficiency estimation

We can calculate the average spectrum efficiency using SINR method,and the spectral efficiency is derived under the following assumptions:

- The layer 2 protocol overhead (MAC and RLC) is negligible.
- Link level simulation do not take into account the L1 overhead due to control channels (pilot and allocation table).

Given the required cell throughput at cell border or Cell Edge Throughput,the L1 throughput is calculated follows:

$$Layer1Throughput = \frac{CelledgeThroughput}{Overheadfactor} \tag{6.3}$$

$$Overheadfactor = \frac{Datasymbolpersubframe}{totalsymbolpersubframe} \tag{6.4}$$

The Overhead factor values for DL and UL are respectively$\frac{5}{7}$ and $\frac{4}{7}$,assuming normal cyclic prefix.[14].Thus,the spectral efficiency (SE) is:

$$SE = \frac{Layer1Throughput}{Cellbandwidth} \tag{6.5}$$

Spectral efficiency is then used to find out the Required SINR using Alpha-Shannon formula.Shannon capacity formula for maximum channel efficiency as a function of SNR can be written as Equation (6.6):

$$SE = \alpha * \log_2[1 + 10^{\frac{SINR}{10}}] \tag{6.6}$$

This maximum capacity cannot be obtained in LTE due to the following factors[13]

- Limited coding block length
- Frequency selective fading across the transmission bandwidth
- Non-avoidable system overhead
- Implementation margins (channel estimation,CQI)

Thus,in order to fit the Shannon formula to LTE link performance two elements are introduced bandwidth efficiency factor SNR efficiency factor,denominated asβ,and the modified Alpha-Shannon Formula for LTE can be written as:

$$SE = \alpha * \log_2[1 + 10^{\frac{SINR}{10*\beta}}] \tag{6.7}$$

Note that $'\alpha'$ also depends on the antenna configuration.The formula is valid between the limits specified by a minimum and a maximum value of spectral efficiency.The spectral efficiency can be approximated with an attenuated and truncated form of the Shannon bound as shown in Figure (6.1) this figure shows how the Shannon-Alpha formula is used to approximate the envelope of the spectral efficiency vs.SNR curve in case of SISO and AWGN channel model.Two values of $'\alpha'$ and $'\beta'$ are considered[13].In these results for system level performance,G-factor distribution was considered,PDF(G),over the cell area.Assuming uniform user distribution,the obtained G-factors for the LTE capacity evaluation are plotted in the right hand side of Figure (6.1), adopted from[11].

6.3 Average Sector Capacity

The average sector throughput is an important factor in the LTE capacity dimensioning.The available channel bandwidth for PDSCH is calculated as follows:

$$RB_{PDSCH} = RB - Overhead_{fixed} - Overhead_{channel} - Overhead_{Paging} \tag{6.8}$$

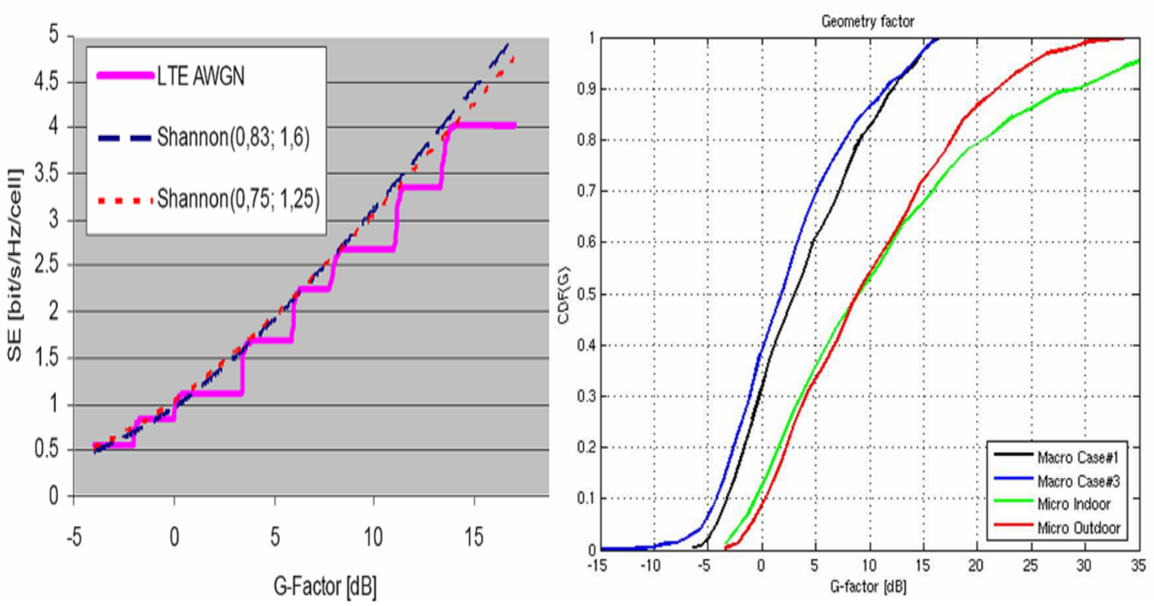


Figure 6.1: LTE spectral efficiency as function of G-factor (in dB) including curves for best Shannon fit (left). CDF for G-factors of an LTE system (with different scenarios (Right)

$$PDSCH_{Symbol} = RB_{PDSCH} * 12 * \#of symbols/subcarrier \tag{6.9}$$

Total PDSCH throughput capacity per sector-carrier is calculated as:the available symbols for the $PDSCH * SE$.The number of sub-carriers depends on the system bandwidth.The number of DL symbols is 7 or 6 according to the normal or extended CP,respectively.The total number of RE is the number of sub-carriers according to the BW multiplied by twice the number of symbols (7or6).Therefore,the theoretical average sector throughput at a certain DL loading can be calculated as follows:

$$AST = [\frac{RB_{PDSCH}(\%) * DLloading(\%) * SE * N * S * RB_{DL}}{1000}]Mbps \tag{6.10}$$

Where AST is Average sector throughput,$RB_{PDSCH}(\%)$ is the available PDSCH resource block percentage,$load(\%)$ is DL loading,SE is average spectral efficiency,S is total number of symbols,and N is number of subcarriers/symbol,RB_{DL} is total resource block in the DL.

6.4 Capacity Dimensioning Process

According to [14] the LTE capacity dimensioning process consists of the following steps:

1. Traffic profile to determine the target capacity
2. Estimate the average sector throughput.This can be obtained via system level simulation or based on field measurement.
3. Calculate the number of eNB/sectors needed for the total traffic demand.The work flow of capacity dimensioning is as shown in Fig(6.4)

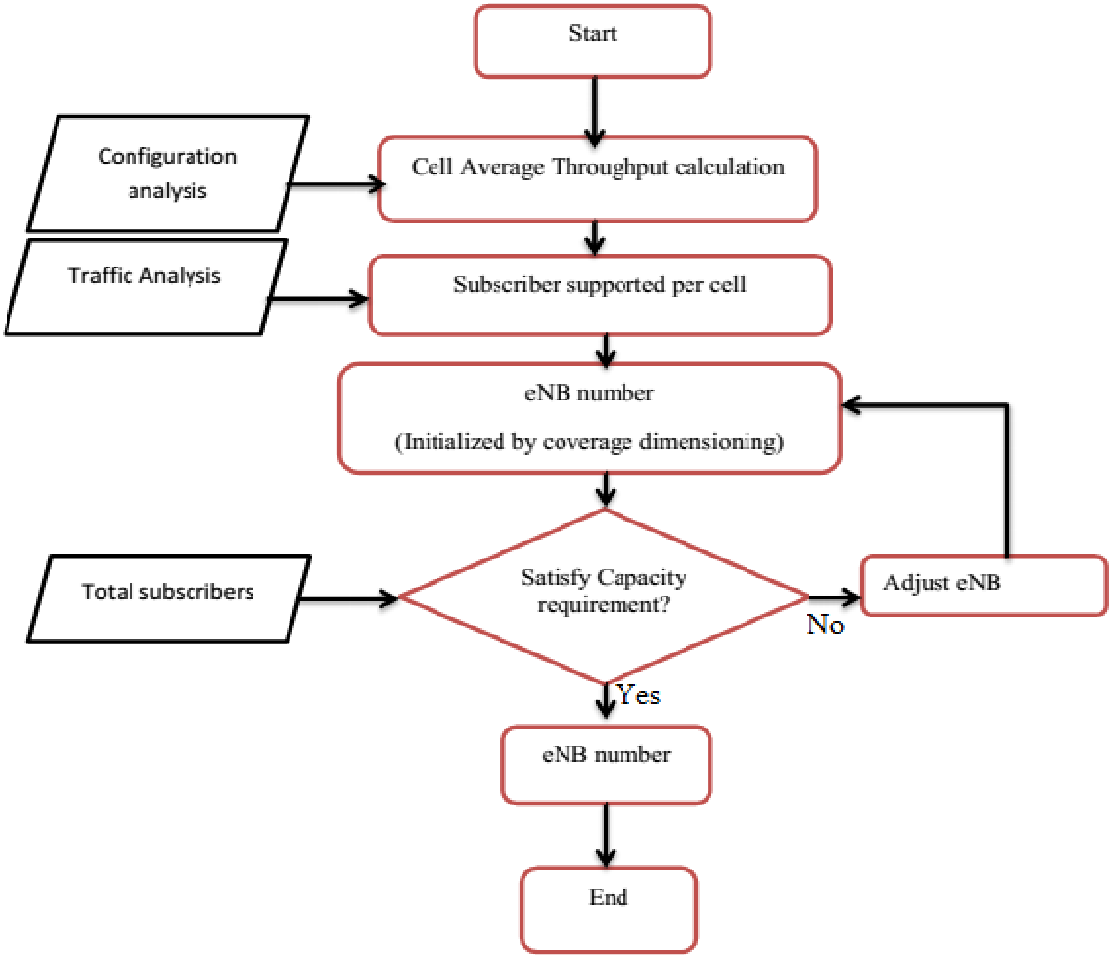


Figure 6.2: Capacity Dimensioning Flow

6.5 Traffic Demand Estimation and Overbooking Factor

Since the given bandwidth can only deliver a certain amount of capacity,then the traffic demand needs to be understood.The complex part is the analysis of the peak hours of different subscriber types and traffic profiles.The required result is the overbooking factor that describes the level of multiplexing or number of users sharing a given channel or capacity.The main inputs are listed below:

- Traffic mix and busy hour analysis
- Subscriber density
- Data volume/ User
- Peak and Average Data Rate
- Daily Traffic Profiles

If we use requirements corresponding to the peak hour traffic in capacity dimensioning,it would lead to over-dimensioning.Precious resources will be wasted in other hours of the day and network cost will go significantly higher.For this reason it is important to define the overbooking factor (OBF), OBF is the average number of users that can share a given unit of channel.The channel unit used in dimensioning is the peak data rate.If we assume a 100 percent channel loading, then the OBF is simply equal to the ratio between the peak and the average rates (PAR).
However,it is not safe to dimension the network with 100 percent loading[13].Hence, the parameter utilization factor is introduced.In most of data networks,the utilization factor is less than 85 percent in order to guarantee Quality of Service (QoS).So the higher this parameter,the longer will be the average waiting time for users accessing the channel.Thus,the overbooking factor is derived as follows:

$$OBF = PAR * \gamma \tag{6.11}$$

Where OBF is overbooking factor,PAR is peak to average ratio,and γ is the utilization factor

6.6 Capacity based site count

With the knowledge of traffic demand estimation and the factors involved in it,Overall data rate required can be calculated.Based on the overbooking factor described above,the total data rate for the capacity calculation is:

$$OverallDataRate = NumberOfUsers * PeakDataRate * OBF \tag{6.12}$$

The number of sites necessary to support the above calculated total traffic is simply

$$Numberofsitecapacity = \frac{(overalldatarate)}{(sitecapacity)} \tag{6.13}$$

7 IMPLEMENTATION,SIMULATIONS,RESULT AND DISCUSSION

In this section,the theoretical studies done so far will be implemented via simulation and analytical calculation.There are three main parts under this section:the first part is coverage analysis,link level simulation along with link budget preparation,while the second part is about capacity analysis,system level simulations,and cell throughput determination.Finally,summary of the obtained result will be presented,through comparison of coverage target site count with capacity target site count.

7.1 Background of the Study Area

Jimma city administration is found in south-western part of Ethiopia.Jimma is among the largest cities in the country,and the densely populated city in south-western part of Ethiopia.The telecom service provider is $ethiotelecom^{TM}$,the only operator in the country.

Pre-Planning Information

The pre-planning information is summarized in Table(7.1).Regarding the morphology type,this study categorizes Jimma city in to two morphology classes.The first one is Jimma merkato area,which is categorized as urban clutter morphology.The rest part of jimma is considered as suburban.In this study,the indoor macro-cellular network planning scenario is considered.Indoor planning scenario is considered to give high priority for indoor users by considering building penetration losses and other losses associated to indoor users in the link budget. System band width is scalable in LTE technology (i.e.:1.4,3,5,10,15,20MHz).The selection of bandwidth is truly depends on the operator strategy for capacity and target throughput.In this study,20MHz system bandwidth is considered for the major intension to show the maximum data rate LTE can have.Internationally,there are three spectrum options for LTE deployment:the short band (700/800MHz),the 1800MHz (GSM refarming),and the extended 2.6GHz band [35].The selection of appropriate spectrum depends on many factors,such as the regulatory policy,spectrum fees,existing technologies.

According to GSMA report [1] on Sub-Saharan Africa,LTE1800MHz is by far better to hold capacity traffic,and almost the same in coverage with GSM1800MHz counterpart.Therefore,there should be a strategy to re-farm GSM1800MHz spectrum for LTE1800MHZ spectrum.

Table 7.1: Preplanning information

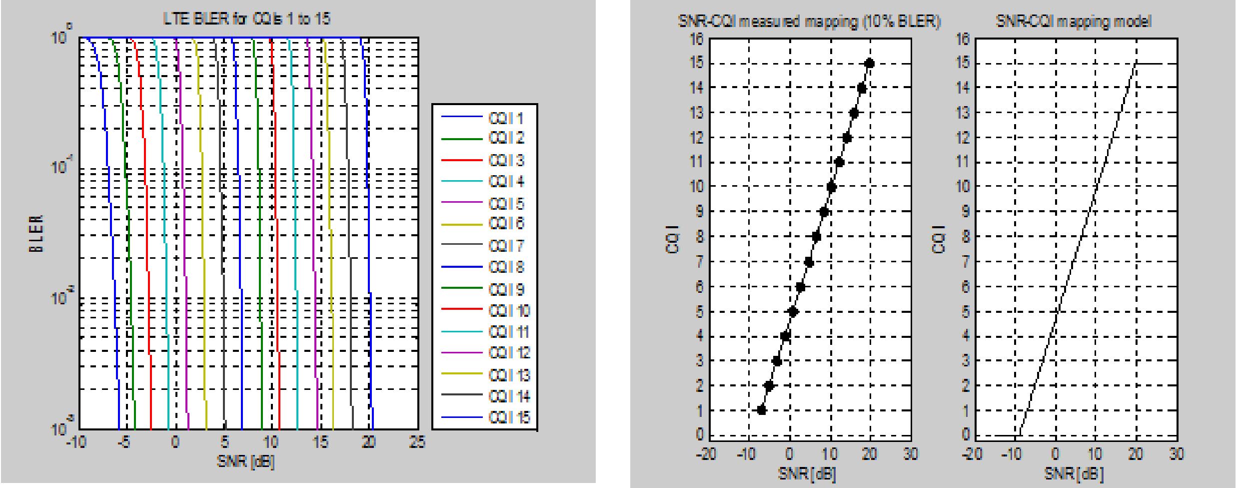
S.no	Description	Preplanning information
1	Population	400,000
2	Coverage Area(Sq.Km)	225
3	User environment	Indoor
4	System frequency(MHz)	1800
5	System Bandwidth(MHz)	20
6	Duplexing mode	FDD

7.2 Coverage Planning and Important Simulations

To carry out coverage planning exercise,LTE Radio performance metrics and link performance indicators (like SINR-to-BLER mapping,cell edge throughput-to-SNR mapping,and the 15CQI-to-SNR mapping) were needed to be determined by taking in to account study area morphological and radio characteristics.These link performance parameters were determined via LTE link level simulation performed by [36].

7.2.1 LTE Link Level Simulation Result

For efficient deployment of LTE Radio network planning,performance analysis of different radio parameters are worth important.Simulations are necessary to test and optimize algorithms and procedures.These have to be carried out on both the physical layer and network context.Link level simulations were used for simulating the link between UE nd eNodeB,while the system level simulators were used for simulating the overall network performance.The target of link level simulation is mainly to determine SINR at the target cell edge throughput,at which the link budget need



(a)

(b)

Figure 7.1: (a) 15 CQI-BLER vs SINR plot.(b) CQI-to-SINR mapping obtained at 10%BLER

to be calculated.The simulation environment is single UE single eNodeB scenario.All the parameters used in the link budget to determine the cell range were configured in the simulator.The analysis with link level simulations was carried out using parameters stated in Table(7.2).The focus was to analyze throughput and BLER values with the change of SNR. Figure (7.1) shows,the Block error ratio (BLER)curves,and CQI-SINR mapping plot.Fig 7.1(a) is the 15 CQI-BLER curves versus SINR plot while Figure 7.1(b) is the CQI-SINR mapping plot.The CQI-SINR mapping is done at the (10%) BLER points,basically linear mapping.

Table 7.2: Basic Setting Used in LTE Link Level simulator

S.no	Parameter setting	Parameter setting
1	Band width	20Mhz
2	Re-transmission	0&3
3	Channel type	Pedestrian-B(PedB)
4	System frequency	1800Mhz
5	Filtering	Block fading
6	Receiver	Soft Sphere decoder
7	simulation length	1000subframes
8	Transmission mode	SISO,TxD (2x1 and 4x2) and CLSM (4x2)

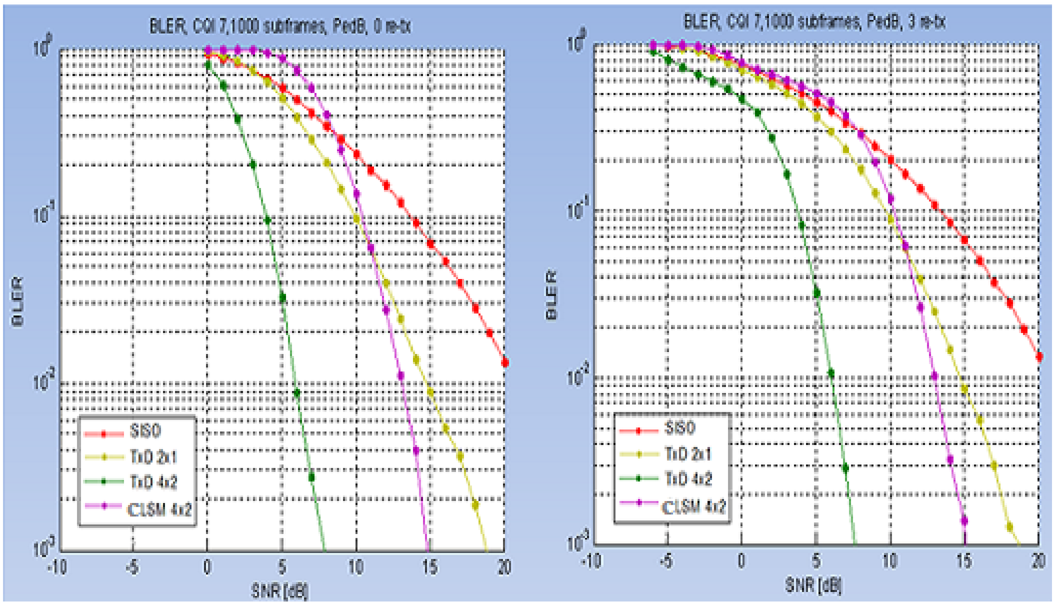


Figure 7.2: BLER vs SNR for 1500 Subframes with 0 and 3 re-tx: PedB channel

Table 7.3: SNR Requirement for different Transmission mode

S.no	Transmission mode	SNR
1	TxD4x2	4dB
2	TxD2x1	10dB
3	CLSM4x2	12dB
4	SISO	14dB

The results of BLER vs SNR are presented in Fig(7.2).With different transmission modes: SISO,TxD2×1,TxD4×2 and CLSM4x2.The simulation was performed taking Pedestrian B(PedB) channel model,considering CQI-7.The required SNR obtained from simulation result of Fig(7.2) is summarized in Table (7.3). In LTE,adaptive modulation and coding has to ensure a BLER value smaller than 10% [14].As per Fig(7.2),if BLER value is limited at 10^{-1} (10% of the max.);this means that,for TxD4x2 transmission mode,low signal power is needed for minimum possible BLER.The same BLER can also be achieved with a maximum SNR of 14dB given by SISO and this implies that more signal power has to be given using that scheme.So,SISO is supposedly not a good choice for BLER sensitive environment because of its higher power requirement.Again for the same transmission modes,channel model and CQI values,results of throughput vs SNR were obtained as shown in Fig(7.3).

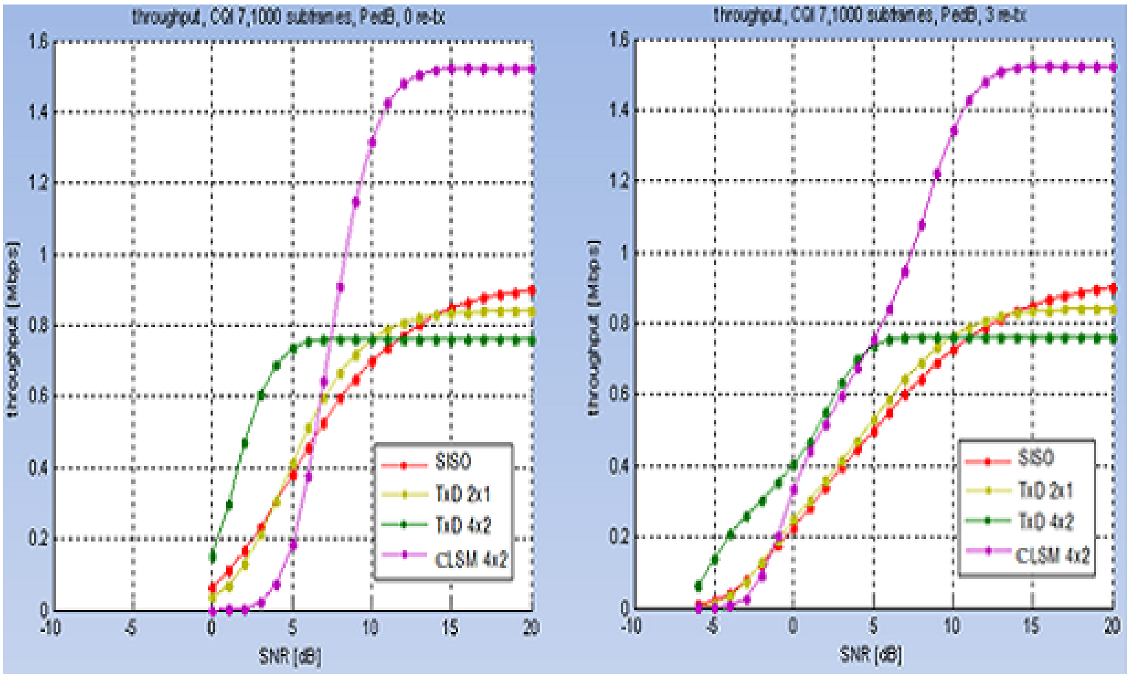


Figure 7.3: Throughput vs SNR with 0 and 3 re-tx: PedB channel model

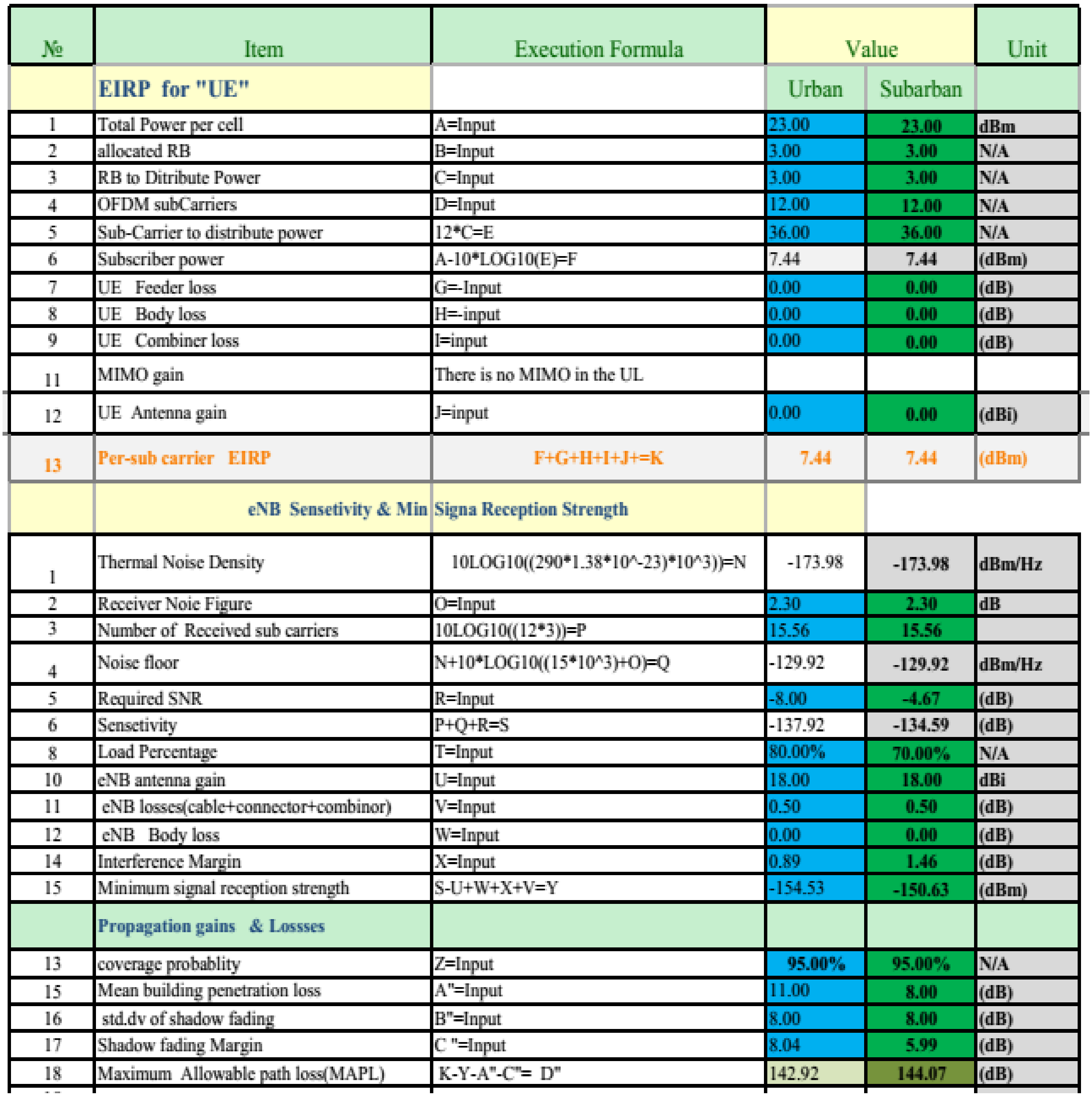
Cell edge throughput (CET) is usually provided by the network operator according to the required services at cell edge.It depends on the operator strategy and the business requirement.The CET is a key input to the link budget and it directly impacts the cell radius and accordingly the number of required sites to cover a certain area.According to [14] an aggressive requirement for cell edge throughput may consider 1Mbps for the UL and 2Mbps for the DL.In the simulation result of Fig (7.3),the cell throughput for different transmission modes was determined.For a high SNR requirement,CLSM4x2 yields the maximum throughput,while for the minimum SNR requirement the TxD4x2 yields the maximum throughput.From Fig(7.3) the cell throughput of 1Mbps for UL and 1.2Mbps for DL was chosen for link budget calculation.The corresponding SNR requirement at the chosen value of cell throughput is $8dB$ and $9.6dB$ respectively.This value can only be achieved through transmission mode-4(CLSM4x2).Therefore,the SNR value of $8dB$ and $9.6dB$ can be used for UL and DL link budget calculation.

7.2.2 LTE Radio Link budget calculation

The theoretical explanation of LTE specific radio link budget analysis was already explained in section (5.2) of this thesis.At this stage,the actual implementation of RLB was illustrated to know the signal coverage in the study area.
The key objectives at this stage are:

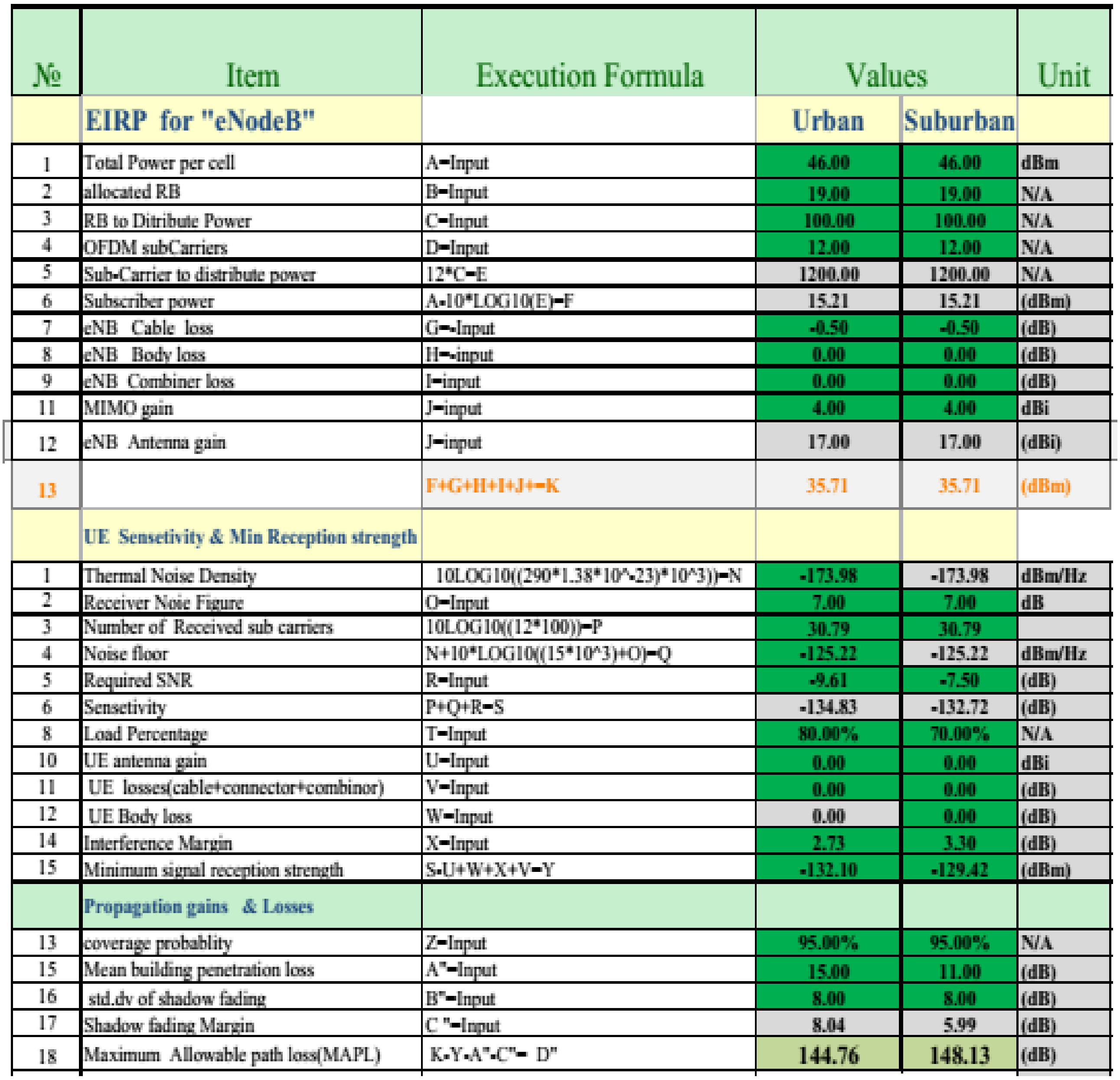
- To know the limiting link, (UL or DL?)
- To know the limiting channel, (PUSCH or PDSCH?)
- To determine Maximum allowed path loss (MAPL) per morphology
- To determine cell radius and service area per morphology

The link budget calculation was done separately for UL and DL on the bases of MS-excel spreadsheet at a cell edge throughput of 1Mbps and 1.2Mbps for UL and DL respectively.The screen shoot of the link budget calculation result is shown in Fig (7.4) & (7.5) for both UL and DL respectively.



№	Item	Execution Formula	Value		Unit
	EIRP for "UE"		Urban	Subarban	
1	Total Power per cell	A=Input	23.00	23.00	dBm
2	allocated RB	B=Input	3.00	3.00	N/A
3	RB to Ditribute Power	C=Input	3.00	3.00	N/A
4	OFDM subCarriers	D=Input	12.00	12.00	N/A
5	Sub-Carrier to distribute power	12*C=E	36.00	36.00	N/A
6	Subscriber power	A-10*LOG10(E)=F	7.44	7.44	(dBm)
7	UE Feeder loss	G=-Input	0.00	0.00	(dB)
8	UE Body loss	H=-input	0.00	0.00	(dB)
9	UE Combiner loss	I=input	0.00	0.00	(dB)
11	MIMO gain	There is no MIMO in the UL			
12	UE Antenna gain	J=input	0.00	0.00	(dBi)
13	Per-sub carrier EIRP	F+G+H+I+J+=K	7.44	7.44	(dBm)
	eNB Sensetivity & Min	**Signa Reception Strength**			
1	Thermal Noise Density	10LOG10((290*1.38*10^-23)*10^3))=N	-173.98	-173.98	dBm/Hz
2	Receiver Noie Figure	O=Input	2.30	2.30	dB
3	Number of Received sub carriers	10LOG10((12*3))=P	15.56	15.56	
4	Noise floor	N+10*LOG10((15*10^3)+O)=Q	-129.92	-129.92	dBm/Hz
5	Required SNR	R=Input	-8.00	-4.67	(dB)
6	Sensetivity	P+Q+R=S	-137.92	-134.59	(dB)
8	Load Percentage	T=Input	80.00%	70.00%	N/A
10	eNB antenna gain	U=Input	18.00	18.00	dBi
11	eNB losses(cable+connector+combinor)	V=Input	0.50	0.50	(dB)
12	eNB Body loss	W=Input	0.00	0.00	(dB)
14	Interference Margin	X=Input	0.89	1.46	(dB)
15	Minimum signal reception strength	S-U+W+X+V=Y	-154.53	-150.63	(dBm)
	Propagation gains & Lossses				
13	coverage probablity	Z=Input	95.00%	95.00%	N/A
15	Mean building penetration loss	A"=Input	11.00	8.00	(dB)
16	std.dv of shadow fading	B"=Input	8.00	8.00	(dB)
17	Shadow fading Margin	C "=Input	8.04	5.99	(dB)
18	Maximum Allowable path loss(MAPL)	K-Y-A"-C"= D"	142.92	144.07	(dB)

Figure 7.4: The screen shoot of UL Radio link budget calculation at 1Mbps



№	Item	Execution Formula	Values		Unit
	EIRP for "eNodeB"		**Urban**	**Suburban**	
1	Total Power per cell	A=Input	46.00	46.00	dBm
2	allocated RB	B=Input	19.00	19.00	N/A
3	RB to Ditribute Power	C=Input	100.00	100.00	N/A
4	OFDM subCarriers	D=Input	12.00	12.00	N/A
5	Sub-Carrier to distribute power	12*C=E	1200.00	1200.00	N/A
6	Subscriber power	A-10*LOG10(E)=F	15.21	15.21	(dBm)
7	eNB Cable loss	G=-Input	-0.50	-0.50	(dB)
8	eNB Body loss	H=-input	0.00	0.00	(dB)
9	eNB Combiner loss	I=input	0.00	0.00	(dB)
11	MIMO gain	J=input	4.00	4.00	dBi
12	eNB Antenna gain	J=input	17.00	17.00	(dBi)
13		F+G+H+I+J+=K	35.71	35.71	(dBm)
	UE Sensetivity & Min Reception strength				
1	Thermal Noise Density	10LOG10((290*1.38*10^-23)*10^3))=N	-173.98	-173.98	dBm/Hz
2	Receiver Noie Figure	O=Input	7.00	7.00	dB
3	Number of Received sub carriers	10LOG10((12*100))=P	30.79	30.79	
4	Noise floor	N+10*LOG10((15*10^3)+O)=Q	-125.22	-125.22	dBm/Hz
5	Required SNR	R=Input	-9.61	-7.50	(dB)
6	Sensetivity	P+Q+R=S	-134.83	-132.72	(dB)
8	Load Percentage	T=Input	80.00%	70.00%	N/A
10	UE antenna gain	U=Input	0.00	0.00	dBi
11	UE losses(cable+connector+combinor)	V=Input	0.00	0.00	(dB)
12	UE Body loss	W=Input	0.00	0.00	(dB)
14	Interference Margin	X=Input	2.73	3.30	(dB)
15	Minimum signal reception strength	S-U+W+X+V=Y	-132.10	-129.42	(dBm)
	Propagation gains & Losses				
13	coverage probablity	Z=Input	95.00%	95.00%	N/A
15	Mean building penetration loss	A"=Input	15.00	11.00	(dB)
16	std.dv of shadow fading	B"=Input	8.00	8.00	(dB)
17	Shadow fading Margin	C "=Input	8.04	5.99	(dB)
18	Maximum Allowable path loss(MAPL)	K-Y-A"-C"= D"	144.76	148.13	(dB)

Figure 7.5: The screen shoot of DL Radio link budget calculation at 1.2Mbps

Limiting Link and Limiting channel

As it was already evaluated in link budget(Fig 7.4),$MAPL_{UL}$ is 142.92dB,and 144.07dB for urban and suburban clutter class respectively.In the same way, see Fig (7.5) for $MAPL_{DL}$,which is 144.76dB,and 148.13dB for urban and suburban clutter classes respectively.As a result,the $MAPL_{UL}$ is less than $MAPL_{DL}$ for both clutter classes.This implies that UL is the limiting link and the corresponding channel, Physical Uplink shared channel (PUSCH) is the limiting channel.This result agrees with literatures,as LTE technology is Uplink limited in coverage and DL limited in capacity[13].

7.2.3 Coverage Target Site Count and Cell Range Determination

Since UL is identified as the limiting link for coverage analysis,the MAPL corresponding to UL will be used for Cell range calculations.The MAPL from link budget together with the standard propagation model is used for cell range estimation.In this thesis,COT231-Hata model was chosen for propagation model prediction.The COST231-Hata path loss Equation (7.1-7.4) was used.

Table 7.4: COST231-Hata model parameters for Urban and Suburban morphology

S.no	Description	Morphology	
		Urban	Suburban
1	MAPL from RLB (dB)	142.92	144.07
2	Co(dB)	0	3
3	Coverage area (sq.km)	100	125
4	Antenna type	tri-sector 65^o tilt	tri-sector 65^o tilt
5	UE Antenna height(m)	1.5	1.5
6	eNodeB Antenna height(m)	20	30

$$PL_{COST231} = A + Blog(R) + C_o - a(h_R) \tag{7.1}$$

$$A = 46.3 + 33.9log(f) - 13.82log(h_{(eNB)}) \tag{7.2}$$

$$B = [44.9 - 6.55log(h_{(eNB)}] \tag{7.3}$$

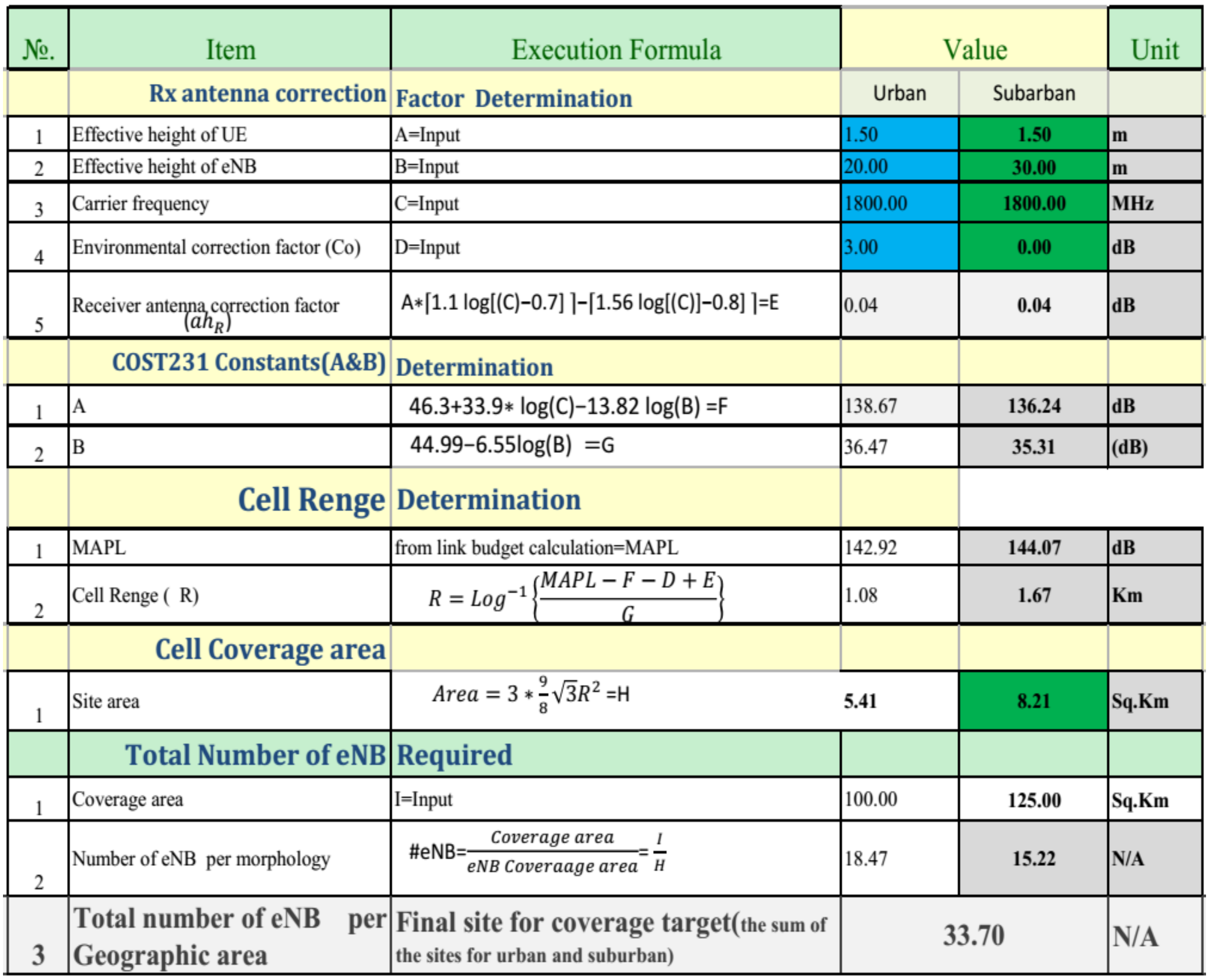
The terms $a(h_R)$ and C_o are constants to be accounted for different terrain environments. $a(h_R)$ is UE Antenna height correction factor as described in the COST231-Hata Model for medium cities and suburban areas.

$$a(h_R) = [1.1log(f) - 0.7] * h_{UE} - 1.56[log(f) - 0.8] \tag{7.4}$$

$C_o = 0dB$,for medium cities and suburban area , and 3dB for Urban and Dense urban areas[32]. Where f is the carrier frequency in MHz.h_{eNB} and h_{UE} are effective heights of antenna for eNodeB and UE in meter.R is the cell radius in Km.

$$a(h_R)_{1800Mhz} = 1.5 * [1.1log(1800) - 0.7] - 1.56[log(1800) - 0.8] = 0.04dB$$

The corresponding cell range for both morphology classes was evaluated by using Equation (5.15).The cell area per morphology was determined by equation (5.17), considering a tri-sector antenna configuration and hexagonal shape. Finally,considering all the parameters in Table 7.4 as input to COST-Hata propagation model,cell range per morphology,cell area per morphology, and number of sites per geographic area was determined.For simplicity of calculation,MS-Excel was used,and the screenshoot of the result is shown in Fig 7.6, which shows the output of coverage di-



№.	Item	Execution Formula	Value		Unit
	Rx antenna correction	**Factor Determination**	Urban	Subarban	
1	Effective height of UE	A=Input	1.50	**1.50**	**m**
2	Effective height of eNB	B=Input	20.00	**30.00**	**m**
3	Carrier frequency	C=Input	1800.00	**1800.00**	**MHz**
4	Environmental correction factor (Co)	D=Input	3.00	**0.00**	**dB**
5	Receiver antenna correction factor (ah_R)	A∗[1.1 log[(C)−0.7]]−[1.56 log[(C)]−0.8]]=E	0.04	**0.04**	**dB**
	COST231 Constants(A&B)	**Determination**			
1	A	46.3+33.9∗ log(C)−13.82 log(B) =F	138.67	**136.24**	**dB**
2	B	44.99−6.55log(B) =G	36.47	**35.31**	**(dB)**
	Cell Renge	**Determination**			
1	MAPL	from link budget calculation=MAPL	142.92	**144.07**	**dB**
2	Cell Renge (R)	$R = Log^{-1}\left\{\frac{MAPL - F - D + E}{G}\right\}$	1.08	**1.67**	**Km**
	Cell Coverage area				
1	Site area	$Area = 3 * \frac{9}{8}\sqrt{3}R^2$ =H	**5.41**	**8.21**	**Sq.Km**
	Total Number of eNB	**Required**			
1	Coverage area	I=Input	100.00	**125.00**	**Sq.Km**
2	Number of eNB per morphology	#eNB=$\frac{Coverage\ area}{eNB\ Coveraage\ area}=\frac{I}{H}$	18.47	**15.22**	**N/A**
3	**Total number of eNB per Geographic area**	**Final site for coverage target(the sum of the sites for urban and suburban)**	33.70		N/A

Figure 7.6: Cell range, Cell area,and Number of site determination

mensioning exercise.As the result,the cell range was determined to be $1.08km$ and $1.68km$ for Urban and suburban classes of the city respectively.The coverage target number of sites was 18.47,and 15.22 for urban and suburban morphology classes respectively.It can be normalized to 19 and 15 for convenience of number of sites.As a result,the total number of sites determined for coverage target was34.

Figure (7.7 & 7.8) is the simulation result, which shows the macroscopic path loss for COST231-Hata model at the carrier frequency of LTE1800MHz,for suburban and urban scenario respectively.This simulation was performed considering transmission mode 4 (CLSM4x2).The path loss determined for both urban and suburban morphology class agrees with the path loss determined through the link budget calculation

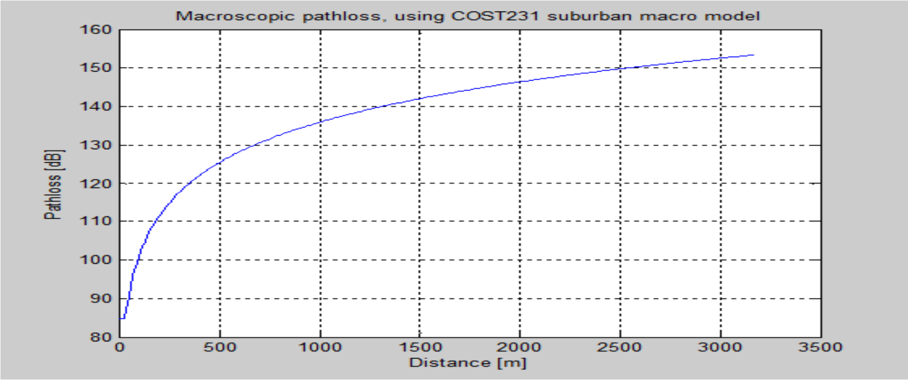


Figure 7.7: Macroscopic Path loss prediction using COST231 at 1800MHz for SU

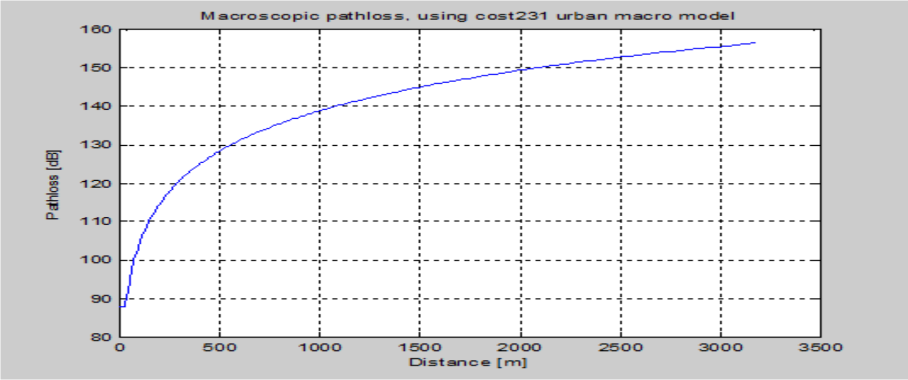


Figure 7.8: Macroscopic Path loss prediction using COST231 at 1800MHz for urban

7.3 LTE Capacity Estimation

To know the level at which the predicted link level gains impact network performance,system level simulations were quite essential[34].The capacity and throughput analysis for this study was done with the help of LTE system level simulator,and performed by[34].

7.3.1 LTE System Level simulator Implementation issues

System level simulations(SLS) focus more on network-related issues such as scheduling,mobility handling or interference management.For implementation,extensive use of the Object-oriented programming (OOP) capabilities of MATLAB was used.System level simulators are better than link level simulators in network related issues. Table(7.5)shows some of the LTE system level simulator config parameters.The system simulation is performed by defining a Region of Interest (ROI) in which the eNodeBs and UEs are positioned and a simulation length in Transmission Time Intervals (TTIs).It is only in this area where UE movement and transmission of the Downlink Shared Channel (DLSCH) are simulated,and the simulator flow follows the pseudo-code below:

```
for each simulated TTI do
    move UEs
    if UE outisde ROI then
        reallocate UE randomly in ROI
    for each eNodeB do
        receive UE feedback after a given feedback delay schedule users
        for each UE do
            1.Channel state → link quality model → SINR
            2.SINR,MCS → link perf.model → BLER
            3.Send UE feedback
```

Where,"→" represents the data flow in and out of the simulator's link abstraction model.In the MATLAB implementation,the separated structure in the pseudo-code is maintained, allowing for easy adding of new functionalities and algorithms[34].

Table 7.5: System level simulation LTE config Parameters

Parameter	Value
Frequency	1.8GHz
LTE Band width	20MHz
eNB TX Power	40watt/46dBm
eNB antenna gain	17dBi
RHH antenna gain	Omni-directional
Path loss model	COST231-Hata
Minimum Coupling loss	70dB
Channel model	ITU-R pedestrian-B
Receiver Type	Zero forcing
Noise power spectral density	-174dBm/Hz
Receiver Noise figure	9dB
Active UEs	30
UE speed	5Km/hr
UE distribution	Uniform
MIMO mode	CLSM
Feedback delay	3TTI
Channel knowledge	perfect
Simulation length	1500TTI
Inter eNodeB distance	500m
Scheduler type	best CQI,proportional fair
Feedback type	AMC,CQI,MIMO,PMI ,and RI
Shadow fading model	Correlated log normal,8dB std.deviation

Considering the LTE config parameters in Table(7.5),the simulation result on Fig(7.9) was obtained.This simulation result shows the ROI for eNodeB -UE distribution for 30UEs/cell.

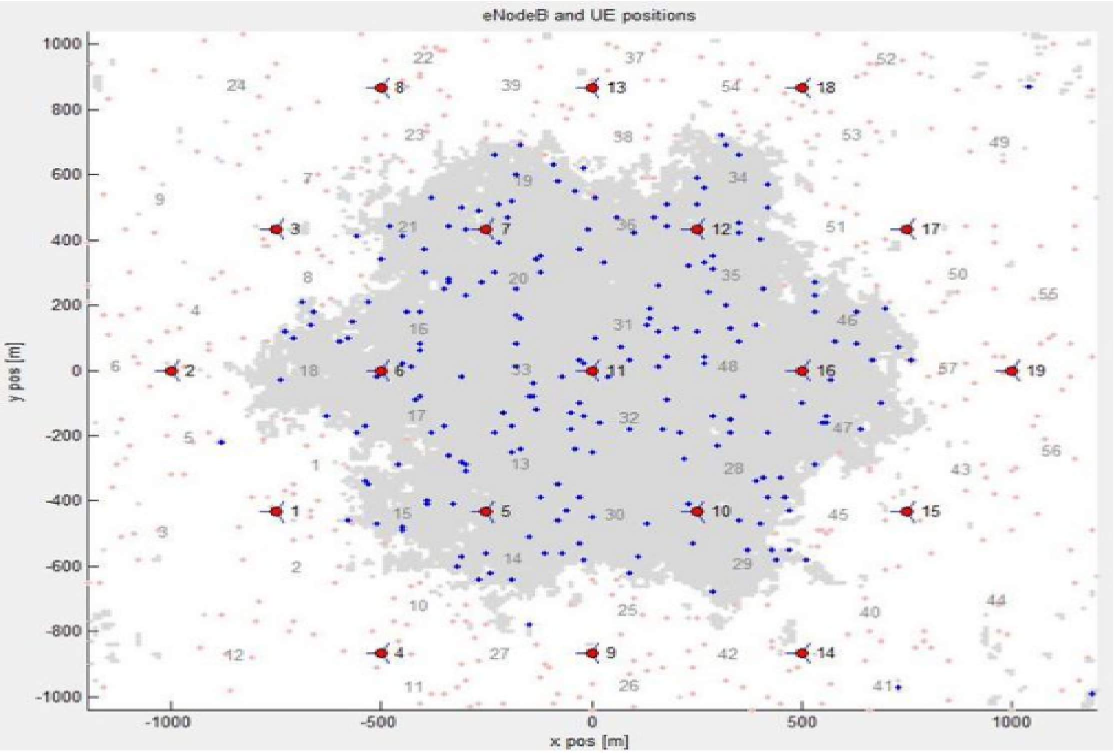
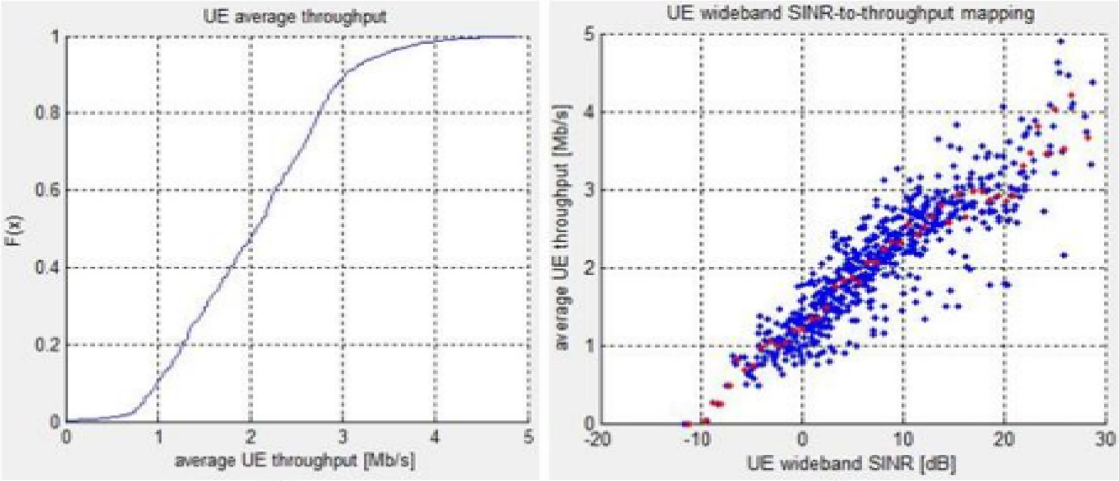


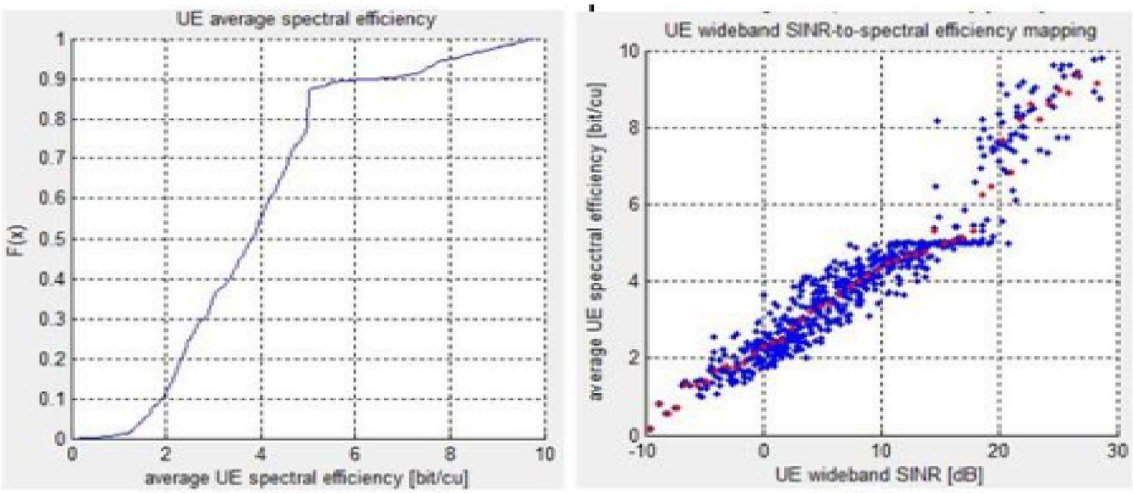
Figure 7.9: Region of Interest,eNodeB-UE Distribution for 30 UEs/cell

From Fig.7.10(a),in order to ensure 50% cumulative probability required,UE average throughput is around 2.2 Mbps.Fig.7.10(b) shows the UE wideband SINR to throughput mapping.From this plot required SINR value is around 5dB to maintain throughput level of 2.2 Mbps.In the same way,from Fig.7.11(a),in order to keep 50% cumulative probability required, UE average spectral efficiency is around 3.8bits/s/Hz.Fig.7.11(b) shows the UE wideband SINR to spectral efficiency mapping.From this plot required SINR value is around 7dB to maintain the spectral efficiency of 3.8bits/s/Hz.In this case,SINR level for required spectral efficiency exceeds that of average throughput.To sum it up,an aggregate SINR level of 7dB is required for 50% cumulative probability considering both UE average throughput and spectral efficiency.But if SINR is increased to 7dB this will resulted into slightly higher UE average throughput of 2.4 Mbps.The aggregate SINR level can be verified from the Empirical Cumulative Distribution Function (ECDF) vs SINR plot of Figure7.12.Average throughput and spectral efficiency results varying consecutively with number of UEs/cell.From here a spectral efficiency of 3.79bit/s/Hz and 3.94bits/s/Hz was obtained for 20UEs and 30 UEs/cell respectively.The corresponding Average throughput for 20UEs and 30 UEs/cell was determined to be 3.1Mbps and 2.4Mbps respectively.



(a) (b)

Figure 7.10: UE Wideband SINR to Throughput Mapping



(a) (b)

Figure 7.11: UE Wideband SINR to Spectral Efficiency Mapping

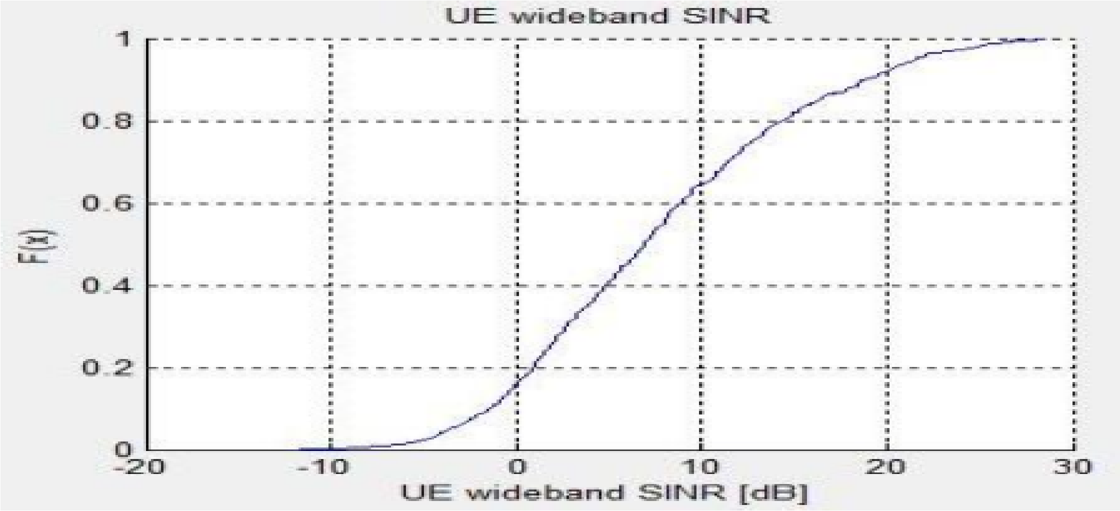


Figure 7.12: Aggregate SINR Level: ECDF vs SINR

7.4 DL Average Sector Throughput Determination

The DL average sector throughput (AST) can be calculated by Equation (6.10).Considering 20MHz bandwidth, 80% available RB in the DL 80% DL loading factor.In addition,from the simulation result in Fig:7.11 considering 30UEs/cell the spectral efficiency of 3.94 bits/s/Hz.

$$DesignedDLAveragesectorthroughput = 0.8 * 0.8 * 3.94 * 12 * 14 * \frac{100}{1000} = 42.36Mbps/sector$$

7.4.1 Number of Subscribers Supported Per Site Based on Data Service Only

Since LTE release 8 is a data centric technology,the dimensioning exercise and the type of traffic considered is data service only.The average UE throughput and spectral efficiency,obtained from SL simulation are the key input for capacity dimensioning exercise.In addition,the over booking factor (OBF),and DL loading factors are also considered.The outcome of capacity dimensioning is the number of subscribers based on the provided traffic profile.Since LTE is downlink limited in capacity planning,our focus is only the downlink for capacity dimensioning exercise.This section presents how to convert the cell throughput values to the maximum number of broadband subscribers.Two methods are used:a traffic volume based approach and a data rate based approach[13],while this study is based on the data rate based approach.

$$SubscribersSupported/site = \frac{3sector * DesignedDLCellThroughput/sector}{(1+PAR) * averageDLBHthroughput/subscriber} \tag{7.5}$$

Traffic is not equally shared within the hours of the day,studies show that the busy hour for data network carries 7% of the networks daily traffic[15].Demand traffic vary from geographical area (urban,suburban) to other depend on the subscriber density in each area,and the services usage level at the busy hours,for that we will provide the subscribers density in each area and percentage of services usage in each area.If we assume a 1Mbps minimum data rate at the cell edge, and the 7% busy hour share corresponds to 20kbps average data rate per subscriber during the busy hour,then this results an overbooking factor of $1Mbps/20kbps = 50$.Cell capacity provided from the system level simulation(ie:UE average throughput of 2.4Mbps)as input to these approach.Since only some of the subscribers are downloading data simultaneously,we can apply an overbooking factor.This essentially means that the average busy hour data rate is:

$$AverageBusyHourDataRate/sub = \frac{targetdatarate/sub}{OBF} = \frac{2.4Mbps}{50} = 48kbps$$

By assuming 20% peak to average ratio(PAR) and $48Kbps$ BH throughput per subscriber,and the calculated DL Average sector throughput.

$$SubscribersSupported/site = 2206subscribers$$

7.4.2 Capacity Based Site Count

$$CapacityTargetNumberofSite = \frac{(ApproxmatedTotalSubscribers)}{(SubscribersSupported/site)} \tag{7.6}$$

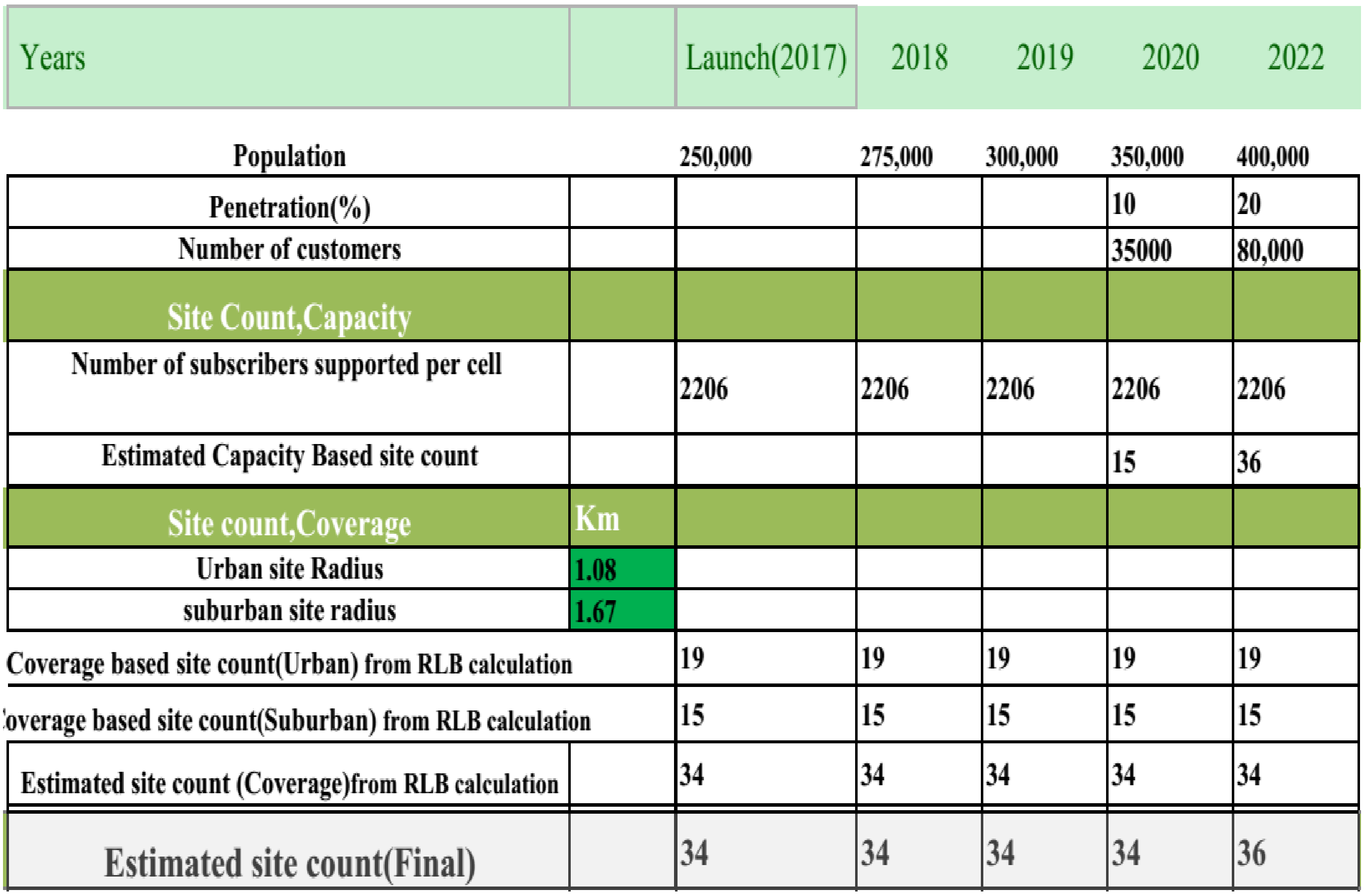
If the penetration of LTE network reaches 20% by the year 2022,the approximated number of LTE customers will be approximated to 80,000.Therefore capacity target number of sites reaches$\frac{80000}{2206} = 36$ by using Equation(7.6)

7.5 Summary of the Obtained Result

In this work coverage analysis i.e.link level simulation result along with Radio link budget preparation,and capacity planning analysis together with important system level simulation has been performed.Finally,the coverage based site count and capacity based site count was determined.Table (7.6) shows the details of LTE dimensioning outputs.

As already determined in the prior sections of RLB calculation,the total number of sites for coverage target was obtained to be 34.As LTE is a new technology,and 3G network is currently launched in jimma,to not overestimate the LTE customers in the initial years,minimum number of customers were considered for capacity calculation.The maximum penetration of 20% was assumed by the year 2022.Average throughput per cell was used as a measure of performance and effectiveness for capacity estimation.From system level simulation result,a spectral efficiency of 3.79bit/s/Hz and 3.94bits/s/Hz was obtained for 20UEs and 30 UEs/cell respectively.The corresponding Average throughput for 20UEs and 30 UEs/cell was determined to be 3.1Mbps and 2.4Mbps respectively.The average cell throughput was determined to be 42.36Mbps/setor.As a result,the total number of subscribers supported per cell was determined to be 2,206.As a result the number of sites for capacity target was determined to be 36.As we compare the capacity target site count with that of coverage target site count,the number of sites for capacity target exceeds that of coverage.Therefore capacity is target number of sites (ie:,36 sites) is the limiting site count and can be taken as the final site count.

Table 7.6:Determination of final site count



Years		Launch(2017)	2018	2019	2020	2022
Population		250,000	275,000	300,000	350,000	400,000
Penetration(%)					10	20
Number of customers					35000	80,000
Site Count,Capacity						
Number of subscribers supported per cell		2206	2206	2206	2206	2206
Estimated Capacity Based site count					15	36
Site count,Coverage	Km					
Urban site Radius	1.08					
suburban site radius	1.67					
Coverage based site count(Urban) from RLB calculation		19	19	19	19	19
overage based site count(Suburban) from RLB calculation		15	15	15	15	15
Estimated site count (Coverage)from RLB calculation		34	34	34	34	34
Estimated site count(Final)		34	34	34	34	36

As shown in a Table (7.6),coverage is given priority at the initial launching year,while the number of sites for capacity target increases substantially as more customers added to the network.In this case,capacity target number of sites exceeds that of coverage target.This result shows that,coverage should be given priority for immature LTE operators,like ethiotelecom at the initial launching year.As more customers are added to the network,capacity should be given much attention,and capacity enhancement is the major challenge in the future.

8 CONCLUSION AND FUTURE WORK

The ultimate objective of this study was coverage and capacity estimation of LTE radio network,for future deployment in Jimma,Ethiopia.In the process of planning,the study introduces the relevant LTE features,to define the basic models for radio propagation,traffic estimation to predict coverage and capacity element counts.The prepared guideline for RNP at this stage may assist the radio network planners in the detailed planning phase of the future network in this city.The methodology introduced and the result obtained in this study can be used as a quick reference material while planning LTE network for other main cities in Ethiopia

8.1 Future Work

As a continuation of this work,one can extend the concepts and results obtained at nominal planning stage of this work to detailed planning phase,considering digital map of the city.The obtained result up to this point are expected to be used in nominal and detailed planning stage where Atoll or any planning tool might be used for the radio planning purpose involving digital map of the study area.In this way, using the obtained coverage and capacity analysis from this study,Atoll simulation can provide a detailed traffic map with coverage and capacity.

In another regard,one can extend the concept of LTE Radio network planning on release 8 to LTE-Advanced on release 9 and 10,where the truly 4G mobile broadband is fully defined by 3GPP,and the advantage of several MIMO configurations can be utilized for capacity enhancement.

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Appendix-A

LTE Release 8 DL Transmission modes

Because network conditions and UE capabilities can vary greatly, MIMO systems must be highly flexible in order to maximize gains in throughput.Since each eNodeB can be configured differently in terms of how it adapts transmissions in real time,it is important to understand the key transmission modes available in LTE,as well as the conditions under which they are most useful.Network operators can then compare scanning receiver measurements to UE-reported data logged by the network to determine if the eNodeB is effectively adapting transmissions to the RF environment.

Table 8.1: Downlink Transmission Modes for LTE Release8[5]

Transmission mode	DL transmission Scheme
Mode 1	Single Antenna Port (SISO or SIMO)
Mode 2	Tranmit diversity(TxD)
Mode 3	Open-Loop Spatial Multiplexing(OLSM)
Mode 4	Closed loop spatial multiplexing(CLSM)
Mode 5	Multi user MIMO(MU-MIMO)
Mode 6	Closed-Loop Rank-1 Spatial Multiplexing
Mode 7	Single Antenna Port Beamforming
Mode 8	Dual-Layer $Beamforming^4$

Appendix-B

The Possible LTE Frequency Bands

Table 8.2: LTE Frequency Band

LTE Band	Uplink	Down link	Duplexing Mode
1	1920-1980Mhz	2110-2170Mhz	FDD
2	1850-1910Mhz	1930-1990Mhz	FDD
3	1710-1785Mhz	1805-1888Mhz	FDD
4	1710-1755Mhz	2110-2155Mhz	FDD
5	824-849Mhz	869-894Mhz	FDD
4	2500-2570	2620-2690Mhz	FDD
5	880-915Mhz	925-960Mhz	FDD
6	830-840Mhz	835-875Mhz	FDD
7	2500-2700Mhz	2620-2690Mhz	FDD
8	880-915Mhz	925-960Mhz	FDD
9	1749.9-1452.9Mhz	1844.9-1879.9Mhz	FDD
10	1710-1770Mhz	2110-2110Mhz	FDD
11	1427.9-1452.9	1775.9-1500.9	FDD
12	698-716Mhz	728-746Mhz	FDD
13	777-787Mhz	746-756Mhz	FDD
14	788-798Mhz	758-768Mhz	FDD
17	704-716Mhz	734-746MHz	FDD
18	815-830Mhz	860-875Mhz	FDD
19	830-845Mhz	875-890MHz	FDD