AN ITERATIVE CAPACITY DIMENSIONING SCHEME FOR AN LTE ADVANCED NETWORK UNDER RESOURCE CONSTRAINTS

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Degree of Master of Science

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Thesis submitted in partial fulfillment of the requirements for the degree Master of Science in Telecommunications

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Declaration

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The above candidate has carried out research for the master’s dissertation under my supervision.

Signature of the supervisor: Date:

Name of the supervisor: Dr. Chandika Wavegedara

Signature of the supervisor: Date:

Name of the supervisor: Dr. Tharaka Samarasinghe

Abstract

Since the need for high-speed broadband services is growing exponentially, legacy voice oriented networks are now becoming obsolete. Due to the unceasing demand for data, investors of mobile service providing companies are also keener on investing new technologies other than GSM, which ultimately improves spectrum efficiency and speeds up the access. Long Term Evolution (LTE) is the fastest and latest broadband technology with widespread global development of commercial networks. Until now, scientists are working to improve the communication capabilities while evolving from basic voice services to high definition video streaming and real time video game playing. However, every operator has a limited investment capacity and are highly concerned about the maximum utilization of resources with a higher ROI. As a result, it is imperative to have a properly dimensioned and well-optimized network.

However, LTE network dimensioning is not as easy as legacy pure voice-only networks (circuit switched), which can be easily modeled by Erlang formulae. LTE networks are evolving from circuit switching to packet switching; therefore, both voice and data will be transferred as packets. There can be combinations of different data service requirements such as streaming, browsing, interactive video, gaming etc. with voice. In fact, different types of traffic, which require different QoS are inherent. With the new releases of LTE standards, researchers all over the world are interested in finding most optimum ways of dimensioning LTE networks. Several perspectives have looked at calculating the required number of 4G sites in the initial network-planning phase. Even though there are quality-based models, coverage based models, capacity based models and hybrid models already, due to the complexity of both UL and DL throughput calculations, each model has its own advantages and disadvantages. None of the approaches are discussing about an iterative capacity dimensioning solution to fine tune the required site count. Therefore, in this research thesis author proposes an iterative method under constraints to find the minimum site count while achieving given UL/DL speed requirements for LTE network rollouts. This method will be based on iterations, and varying parameters will be heavily significant in the context of DL and UL throughput.

Acknowledgement

First and foremost my heartiest gratitude goes to my supervisor, Dr.Chandika Wavegedara, for providing me the opportunity to undertake this project and guiding me in many ways to successfully complete the project. I really appreciate his understanding in my hard times and his valuable insights and constructive comments throughout the research.

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Last but not least, I would like to extend my gratitude to my wife and family members for sacrificing the time shared with me and their reinforcement during the study period.

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List of Abbreviations

Abbreviation	Description
2G	2nd Generations
3G	3rd Generations
3GPP	3rd Generation Partnership Project
4G	4th Generations
5G	5th Generations
BCCH	Broadcast Control Channel
BW	Bandwidth
CAPEX	Capital expenses
CCPCH	Common Control Physical Channel
CCSA	China Communications Standards Association
CDF	Cumulative Distribution Function
CDMA	Code Division Multiple Access
CN	Core Network
CP	Cyclic Prefix
CQI	Channel Quality Indicator
DL	Downlink
DSCH	Downlink Shared Channel
eNB	enhanced NodeB
EPC	Evolved Packet Core
E-UTRAN	Enhanced – UMTS Terrestrial Radio Access Network
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
GBR	Guaranteed Bit Rate
GGSN	Gateway GPRS Support Node
GPRS	General Packet Radio System
GSM	Global System for Mobile
HSDPA	High Speed Downlink Packet Access
HS-DSCH	High Speed Downlink Shared Channel
HSPA	High Speed Packet Access
HS-PDSCH	High Speed Physical Downlink Shared Channel
HS-SCCH	High Speed Shared Control Channel

HSUPA	High Speed Uplink Packet Access
IETF	Internet Engineering Task Force
IP	Internet Protocol
L1	Layer 1
L2	Layer 2
LBA	Link Budget Analysis
LTE	Long Term Evolution
MAC	Medium Access Control
MAPL	Maximum Allowed Path Loss
MBMS	Multimedia Broadcast Multicast Service
Mbps	Megabits per second
MBR	Maximum Bit Rate
MCS	Modulation Coding Scheme
MME	Mobility Management Entity
MSC	Mobile Switching Centre
NFFT	Number of Samples of FFT
OBF	Overbooking Factor
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OPEX	Operating Expenses
PBCH	Physical Broadcast Channel
PCRF	Policy and Charging Rules Function
PDCCH	Physical Downlink Control Channel
PDCP	Packet Data Convergence Protocol
PDF	Probability Distribution Function
PDSCCH	Physical Downlink Shared Control Channel
PDSCH	Physical Downlink Shared Channel
PGW	Packet Gateway
PHY	Physical Layer
PS	Packet Switched
PSS	Primary Synchronization Symbol
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel

QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift keying
RAN	Radio Access Network
RB	Resource Block
RLB	Radio Link Budget
RLC	Radio Link Control
RNC	Radio Network Controller
ROI	Retrun of Investment
RRC	Radio Resource Control
SAE	System Architecture Evolution
SAE	System Architecture Evolution
SB	Short Block
SC-FDMA	Single Carrier-Frequency Division Multiple Access
SCTP	Stream Control Transmission Protocol
SFN	System Frame Number
SGSN	Serving GPRS Support Node
SGW	Serving Gateway
SINR	Signal to Interference and Noise Ratio
SISO	Single Input Single Output
SNR	Signal to Noise Ratio
SSS	Secondary Synchronization Symbol
TDD	Time Division Duplex
TTI	Transmission Time Interval
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunication System
UPE	User Plane Entity
U-plane	User Plane
UTRAN	UMTS Terrestrial Radio Access Network
WCDMA	Wideband Code Division Multiple Access

1 INTRODUCTION

1.1 Background

Mobile telecommunication has evolved significantly, and continue to enhance the communication capabilities of people. In the past few decades after the introduction of the first generation mobile network, mobile wireless communication technologies have gone through several evolution stages. Due to huge demand for multiple connections worldwide, mobile communication standards advanced rapidly to support more users. There are major evolution stages of wireless technologies for mobile communication from 1G to 5G. Initially sole requirement was to have voice communication, but gradually basic requirements exceeded resulting people needing to share photos and videos. All over world, mobile communication trend follows the same pattern differentiated only by the time of adaptation. Since 2000, there has been a rapid growth and demand for data communication as well as voice communication. Therefore, after 2G networks, all the developments mainly focused to enhance the data communication capabilities. Traditional GSM voice networks are becoming obsolete, where 3G and 4G networks are emerging to address the unceasing demand for data. Currently 4G networks are preferred over 3G networks for accessing due to following key features.

- Higher data rates (approx. 1Gbps)
- More security and mobility features
- Low latency
- HD video streaming and gaming
- VoLTE (CS network replaced by PS network)

At the same time, transition cost is somewhat higher than the previous occasions. This means transition from 3G to 4G is much expensive than transition from 2G to 3G, where significant core network changes are bound in addition to the radio access equipment changes. GSM only mobile users are declining globally, whereas investors are biased on investing new technologies other than GSM which has lesser data rates compared to 3G and 4G with a large margin. In addition, service providers are interested in introducing new technologies to attract more customers while improving the allocated limited bandwidth (spectrum efficiency). Due to above factors most of the operators are now eying on LTE network rollouts rather than 2G and 3G. This fact is clearly visible in figure 1.1 where Y-axis shows the percentage of connections and X-axis shows the time.

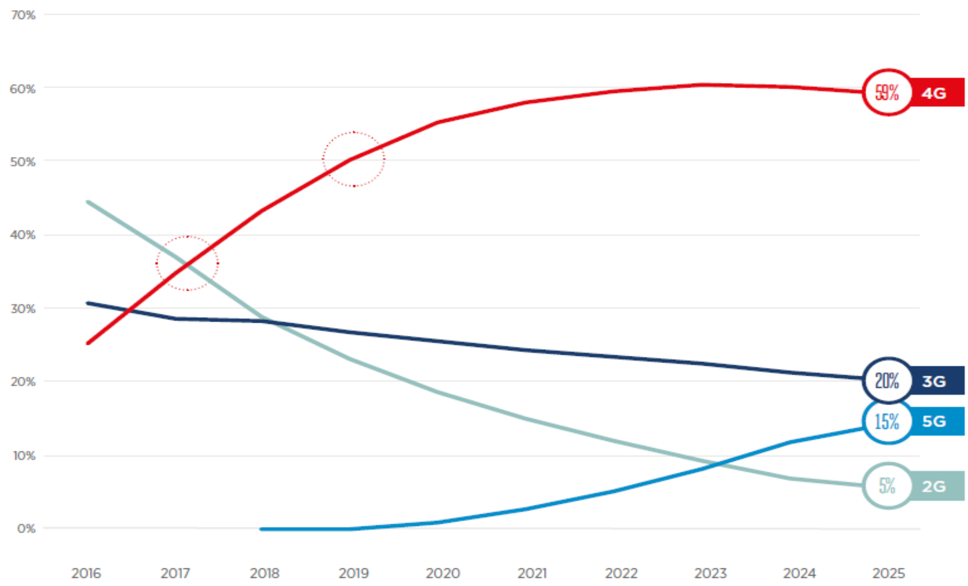


Figure 1.1: Percentage of connections (excluding licensed cellular IoT)

Source: The Mobile Economy 2019, GSMA Intelligence [24]

In brief, all the operators in the world are now working on to deploy 4G networks as both mobile phone manufacturers and network equipment vendors are cashing in.

1.2 Statement of the Problem

1.2.1 What is dimensioning?

Dimensioning refers to the process in which, the size of the network should be designed in a way such that it should meet current and future capacity requirements by considering the traffic growth of the network [25]. In other words, purpose of dimensioning a telecommunications network is to ensure that the expected needs will be met in an economical way for both subscribers and operators.

1.2.2 Why dimensioning is important?

As described in 1.1 most of the people all over the world will be connected via 4G networks. Apart from that, same study [24] reveals that in the next five years' time network data traffic will be incremented by 5 times as at now. Therefore, it is clearly visible that major portion of data will be transferred via 4G networks. Therefore, all the operators are working hard to keep their 4G networks at optimum levels so they can retain the customers. However, there is no significant revenue improvement in both developing and developed countries when it comes to network expansions.

Figure 1.2 shows the expected mobile revenue, which hints the financial pressure for new rollouts. Y axis values shown in dollar billions where X axis shows the year.

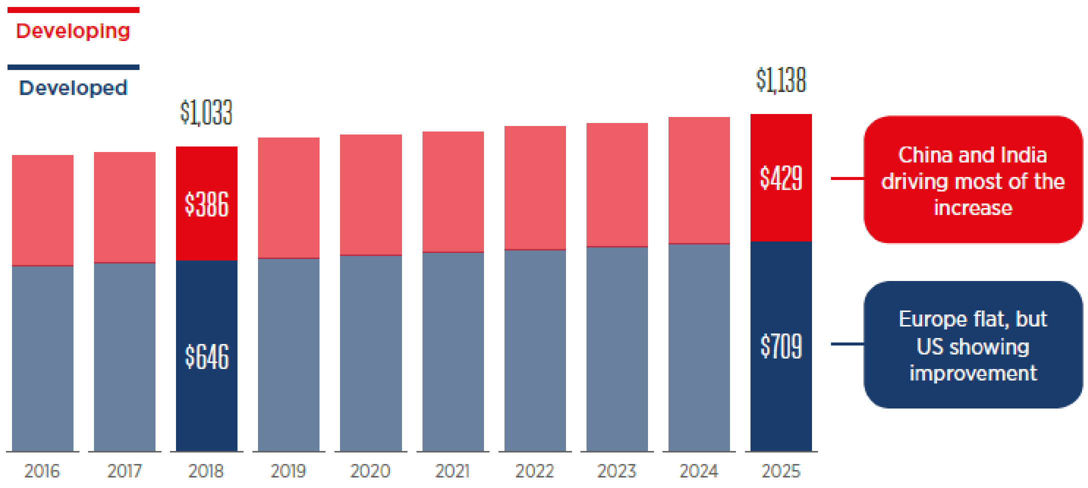


Figure 1.2 : Mobile revenue ($ billion)

Source: The Mobile Economy 2019, GSMA Intelligence [24]

Combining aforementioned two factors it can be clearly said that operators will be looking for options to expand the networks with limited financial resources.

It is vital to obtain the number of 4G sites required to cater the given requirements in a certain expansion project. Since the investment is limited, operators are highly concerned about the maximum utilization of resources to reap maximum ROI. Thus, it is essential to have a well-dimensioned network, which is optimized properly. Therefore, this study was carried out to find out the ways of dimensioning 4G LTE\LTE-A networks and classify them according to their method and solution effectiveness.

In the literature, there are multiple ways to calculate the throughput but none of the theoretical calculations aligns with the real world scenarios. No previous attempts tried to see whether calculated throughput is adequate to cater the actual user requirement. Sometimes it exceeded the actual requirement and sometimes it was below par causing congestion. However, over dimensioning is not a good option for the company since it creates an unnecessary cost for the company. On other hand, under dimensioning would deter the customer experience causing the company to lose its market share. Therefore, a proper method is required to dimension a LTE network, to maximize both customer experience and company revenue. In order to cater both, optimal site count needs to be calculated which gives the best possible user experience.

1.2.3 Existing approaches and their limitations and issues

There are number of methods in the modern day network planning. Some of these are discussed in the literature survey in detail. Table 1.1 shows a summary of those approaches with their limitations and issues.

Table 1.1: Summary of current approaches

Approach	Subject	Pros	Cons
Ap-1[12]	LTE Radio Network Planning by Huawei	Clearly explains the basic capacity dimensioning procedure Introduces traffic models and service models for multi traffic dimensioning	Does not factor all the factors affecting throughput Source of given data is unavailable Accuracy of proposed method is not verified
Ap-2[13]	Design and Simulation of LTE Radio System for Broadband Wireless Access in Central Phnom Penh	Practical approach done for a city with actual data Calculate site quantity in two streams (Coverage and Quality) Result checked by applying in software Factor the future population and market share in the area	In coverage based calculation uniform distribution is assumed In capacity based calculation it follows the method proposed in Ap-1 Inaccurate calculations
Ap-3[14]	Dimensioning of LTE Network - Description of Models and Tool, Coverage and Capacity Estimation of 3GPP Long Term Evolution radio interface	Clear demarcation of input and output parameters Use traffic demand estimation and overbooking factor Practical Outcome: Excel Based Software	No result verification and non-integrity of data used for calculation (not mentioned a proper source) Neglects the effect of QoS Schemes and scheduling
Ap-4[15]	Long Term Evolution Network Planning and Performance Measurement	Practical approach for network dimensioning in Tripoli/Libya Defines a different QoS scheme based on customer usage Result verification through simulations(for both UL/DL)	Neglects few parameters affecting throughput Absence of original data obtained documents Use assumptions for distribution(i.e. MIMO capable device distribution
Ap-5[16]	A Novel Traffic Capacity Planning Methodology For LTE Radio Network Dimensioning	New methodology for dynamic real-time capacity planning Iterated dynamic simulation based optimization process Explains CINR modeling for UL/DL Use of QoS Class Identifiers(QCI)	Absence of calculations and result verifications High level method abstraction (more in to conceptual than a practical approach)
Ap-6[17]	Coverage and Capacity Analysis of LTE Radio Network in Dhaka City	Practical approach for network dimensioning in Dhaka city (Excel Based) Region wise cell throughput analysis (far, intermediate and close) Site quantity calculation for both coverage and capacity basis Use own simulations to obtain data for calculations	Assume uniform morphological distribution all over the city Absence of important throughput affecting parameters (traffic type and its distribution) Lack of information about implementation process of the simulation criteria
Ap-7[18]	Statistical Link Budget Analysis Approach for LTE Cellular Network Dimensioning	Statistical approach to Link Budget Analysis Analyzes the effect of fading, shadowing and loading due to traffic demand in the interference calculation. Result comparison between statistical and simulations	Absence of using traffic profiles and distribution Assumptions for uniform traffic and uniform device distribution Neglects the effect of morphological demarcations
Ap-8[19]	LTE Radio and Network Planning: Basic Coverage and Interference Constraints	Analysis on the use of different frequency bands in the optimization carrier aggregation between two different bands Good analysis on radio propagation Models Proper justification by comparison and calculations	No Analysis on traffic types and patterns Neglects the effect of morphological demarcations Highly conceptual and not practical

Approach	Subject	Pros	Cons
Ap-9[20]	Atoll Software	Mature and commonly used Integrated GIS and clutter data Can be trained with real world data	High cost Need support and maintenance MBR and GBR are same Information absence of internally used algorithms Platform dependent
Ap-10[20]	Asset Software	Mature and commonly used Integrated GIS and clutter data Can be trained with real world data	High cost Need support and maintenance No scheduling gain Information absence of internally used algorithms Platform dependent Very rough approximations
Ap-11	Excel Based Solutions	Fully customizable Convenience (universal compatibility for most of the time/commonly used) Cost effective	Absence of clutter data and GIS
Ap-12[21]	Effect of Quality of Service Schemes on the capacity dimensioning of LTE Networks	Investigates the impact of QoS schemes on the capacity of the network Discusses the capability of the network to deal with the variations in the demography with the proposed QoS schemes including congestion control and admission control	Absence of the data integrity (Application distribution of each user group)

1.3 Objectives and Scope

1.3.1 Objectives

The main objective of this research study is to develop a new methodology to find the minimum number of site count, which satisfies the customer requirement with respect to of uplink (UL) and downlink (DL) speed. The specific objectives of this research can be summarized as follows.

a) To review and analyze in detail about the selected existing approaches of dimensioning.
b) To identify the key system and link parameters which affect the uplink and downlink throughput.
c) To develop a cost function for throughput.
d) To develop a mathematical model to dimension uplink and downlink throughput.
e) To implement the developed method in MATLAB.

1.3.2 Scope

Network dimensioning study will be carried according to the guidelines of 3GPP release 13[7]. The models and values used for traffic distribution (UL/DL service model and traffic model) are hypothetical under this study. These values are inputs for calculations and therefore any user can use their network details to tune these models later in practice.

1.4 Methodology

As the first step, detail analysis will be carried about the selected existing approaches of dimensioning, both in the literature and ones used in the industry.

- Information collecting from the academia and industry.
- Getting feedback from engineers who have considerable experience in network dimensionning about the pros and cons of existing tools and improvements required.

Secondly, the related parameters (basic and co-related variables) which affect the final results will be studied.

- Need to capture all variables affecting enodeB capacity.
- How those factors are varying upon the service pattern and traffic pattern.
- Drive testing and tracing will be required

Next, it will be required to study about the distribution of each variable and applicability of multi parameter optimization by developing a cost function to find the optimum point, which gives maximum throughput within available resources.

- Matlab simulations will be carried out to find results
- Combine technical and non-technical features to a single equation to minimize the number of sites while achieving throughput targets

Finally, a software program will be developed as the outcome of the study.

1.5 Organization of the Thesis

This thesis consists of five chapters where; first chapter is used to provide an introduction for this study. Further author provides a summary of advantages and disadvantages pertaining to current attempts used for dimensioning. Statement of the problem, objectives and scope is also presented in the same chapter.

In chapter 2, literature review on previous approaches used for LTE capacity network dimensioning is explained. This is elaborated in the table listed in first chapter. In addition, concepts and technical terms are explained to understand the methodology, which will be explained in chapter 3.

Chapter 3 encompasses describing the dimensioning procedure suggested by the author. In the first half of this chapter, mathematical model is presented and the remaining part explains the new procedure, which consists of theoretical calculations followed by optimization techniques.

In chapter 4, author discuss and compare the results of previous attempts with the suggested method. In the final chapter, future studies, which can be extended, is also discussed as the conclusion in fifth chapter.

2 Literature Review

4th Generation or 4G also referred as Long Term evolution (LTE) is the successor of the 3G radio access technology. Unlike the technology advancement from 2G to 3G, there are many changes in both the radio access network and the core network. This chapter explains the radio access network including the nodes and its functionalities with frame structures followed by a brief summary of signaling.

2.1 LTE Radio Access Network (EUTRAN)

According to the advancement, LTE users cannot use the existing core network, which is used for 2G and 3G. Therefore, new access and core network nodes are required. Figure 2.1 shows the radio network architecture with the interfaces and nodes. In addition, same figure shows how LTE network has connected to the existing network nodes.

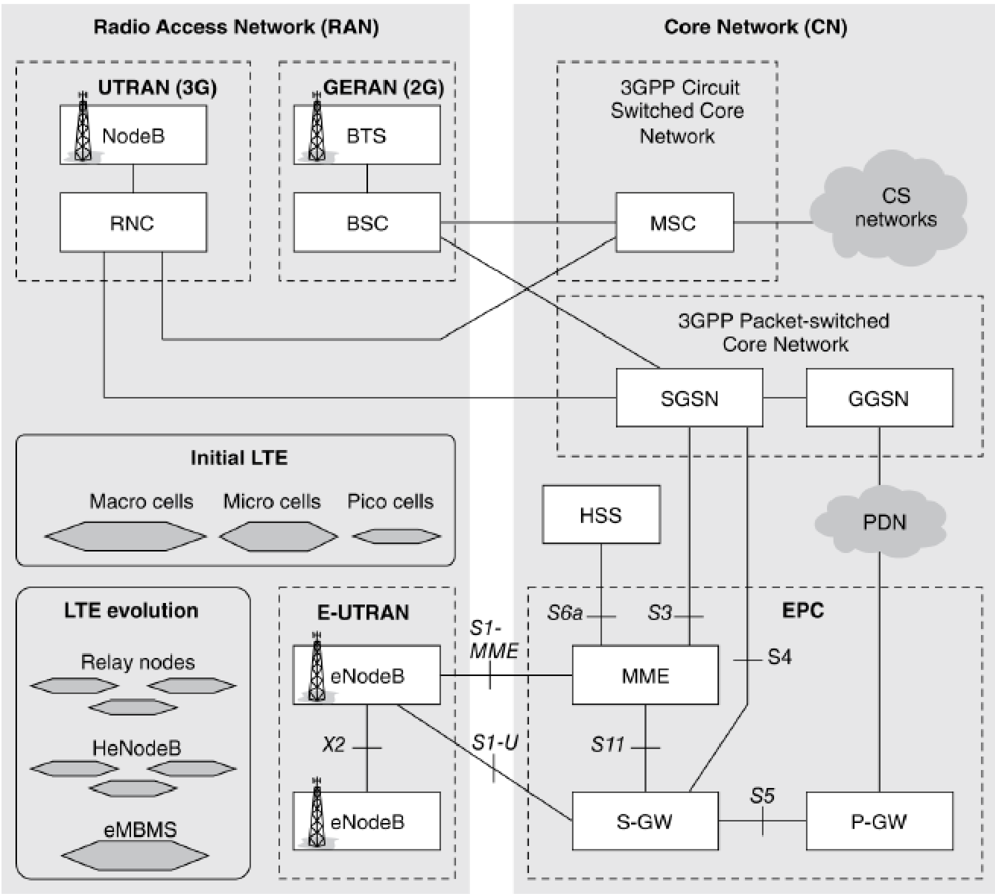


Figure 2.1: Mobile Network Architecture with LTE nodes

Source: LTE Advance development handbook, page 62[3]

Key difference between LTE networks and early networks (2G and 3G) is LTE network does not have CS services. It is purely dedicated for packet switching. Hence, legacy core- network equipment is unable to cope with this radio access technology. With LTE, core network is redefined as EPC (Evolved Packet Core). There is another key change in the access radio network as well. In 2G and 3G networks, all the decisions are taken by the BSC and RNC, but not in the BTS or NodeB. But in LTE there is no such node as BSC, RNC where eNodeB is capable of taking decisions such as handover, reselections and scheduling. These changes are discussed in detail in following paragraphs.

User equipment connect to eNodeB via Uu interface. Frame structure of the radio or the air interface is completely different from the previous technologies and will be discussed later in this chapter. All the neighboring eNodeBs are interconnected via X2 interface. This part is named as Evolved Universal Terrestrial Radio Access Network (EUTRAN). In the core network, there is a new section introduced called as Evolved Packet Core (EPC). Under that there are three new nodes called Serving Gateway (S-GW) and Packet Gateway (P-GW), Mobility Management Entity (MME).

In S1 plane, enodeB is the access point of radio network and EPC is the access point of the core network. Under 3GPP specifications all access nodes either side of the network should complete given specifications of S1 plane. There are many usages of S1 plane such as initial attach management, User context administration, and control mobility procedures. Under initial attachment procedures it covers managing of user equipment context bearers and capability of each user device. In addition, it manages security information and SAE bearer. S1 plane is further use as the interface to control connectivity between EPC and enodeB. As mentioned early, when UE is moving , decisions such as handovers based on the UE reports are also transferred via S1 plane. However, in LTE networks other than legacy networks, each radio access node is connected via another interface called X2. Using this interface, handover decisions within the LTE networks can be taken without the S1 interface. This feature improves the speed and quality of smooth handover. In other X2 interface creates a peer to peer connection between two enodeBs bypassing the S1 interface.

In this manner, it is conceivable to make an X2 interface between two eNBs the latency of communication can be improved [15]. X2 encourages the interconnection between eNBs even though those two enodeBs are belong to two different vendors, because this is a 3GPP standard not a vendor propriety interface or protocol. Therefore, using both S1 and X2 interfaces, LTE network can manage handovers both between legacy networks such as 2G and 3G and within the LTE networks.

Frame Structure of Radio Access Network

In LTE, resource element is introduced as a new concept for both downlink and uplink. Resource element (RE) is the smallest building block of the LTE access network. One RE is capable of carrying one OFDM symbol and its size will be 15 kHz in the frequency domain and 66.7 us (useful symbol length without CP) in the time domain. 84 resource elements will create one resource block (RB). Downlink multiple access technology is OFDMA (Orthogonal Frequency Division Multiple Access). However due to high peak to average power ratio, power consumption is high in this method so not using in the UL. Further more DL, OFDM is using with Cyclic Prefix (CP) sometimes extended CP, depending on the geographical and density of the area. OFDM frame structure has a recurring frame structure that partitions the information over various sub-transporters. The bandwidth of each sub carrier is fixed at 15 kHz. The smallest unit in the perspective of time and spectrum called as the resource unit is characterized to comprise of 12 sub-transporters in recurrence and 14 constant images in time. This makes one resource block with dimensions of 1ms in time domain and 180 kHz in frequency domain. This sub-outline is similar to the base-transmission time interim (TTI). This decision of short TTI accomplishes the necessities of low inertness. Practically, despite the fact that OFDM displays a higher crest to-average-control proportion, this is not viewed as a noteworthy issue on the system side.

Adaptability in channel data transfer capacity is given by permitting six distinctive transmission capacity choices for administrators to browse. Permitted channel data transmissions incorporate 1.25, 2.5, 5, 10, 15 and 20 MHz as noted above, sub-transporter dispersing is fixed for all the potential transmission capacities at 15 kHz. The Guard Interval is then loaded up with the CP. This implies that duplicate of fixed number of last examples is annexed to the beginning of the image. The structure of one full OFDM Symbol is described in Figure 2.2. Relating to the sub-bearer dividing of 15 kHz, image time is 1/Tb = 66.68 us. To avoid Inter Symbol Interference, a Guard Interval is embedded between two successive images.

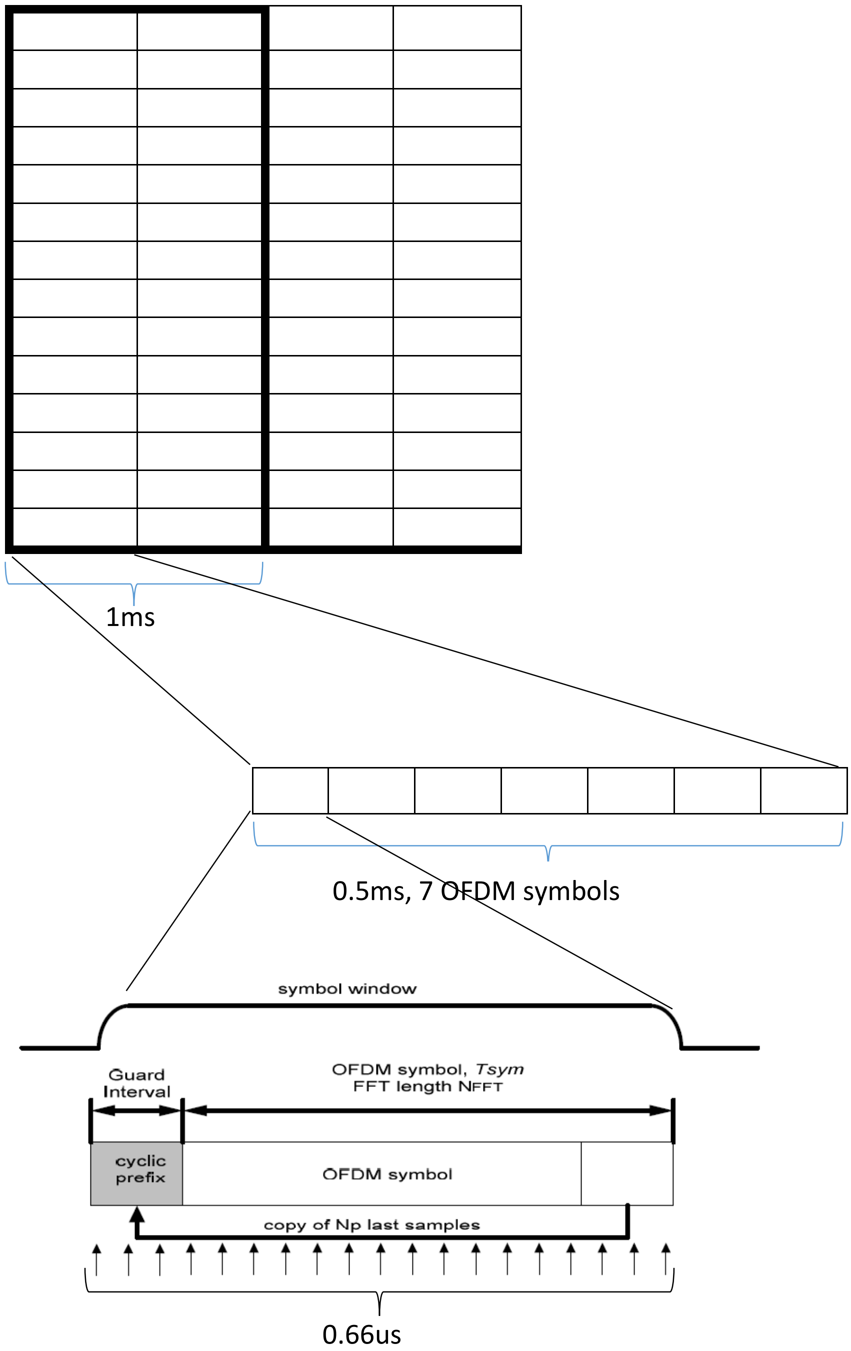


Figure 2.2: LTE Frame Structure

To overcome this, a different technique is used in the uplink. That is SC-FDMA (Single Carrier - Frequency Division Multiple Access).

Channel Quality Indicator (CQI)

The channel Quality Index (CQI) list demonstrates an appropriate downlink-transmission information rate with a reasonable balance and coding plan (MCS) esteem. The CQI is a 4-bit number and depends on the DL SINR at the UE. Before deciding the CQI, UE capability is also considered. After checking all those factors, enodeB will choose an ideal MCS level for the transmission. The revealed CQI records are utilized by the eNodeB for DL booking and connection adjustment. The MCS record is furnished in the vehicle group together with data about the vehicle square size (TBS), asset portion and transmission rank (i.e., a couple of code-words)

Modulation Coding Scheme (MCS)

The throughput over a radio interface is the number of facts bits that can be efficiently transmitted in line with modulation symbol. Coding (greater specifically, ahead blunders correction) provides redundant bits to the information bits, that may correct mistakes in the received bits. The coding is decided by means of its fee, the percentage of statistics bits to coded bits. Coded bits are then transformed into modulation symbols. The order of the modulation determines the range of coded bits that may be transmitted, consistent with modulation symbol. Typical examples are QPSK, 16QAM (quadrature amplitude modulation), and 64QAM which have 2, 4, 8 bits in line with modulation symbol, respectively. The efficiency of a given MCS is the product of the charge and the wide variety of bits in keeping with modulation image. Throughput has gadgets of records bits per modulation image. This is usually normalized to a channel of cohesion bandwidth, which includes one symbol in step with 2d. The gadgets of performance then emerge as bits in keeping with 2d, per hertz. A given MCS calls for a positive SINR (measured on the receiver antenna) to perform with an acceptably low BER (bit errors rate) within the output facts. An MCS with a higher throughput desires a better SINR to perform. AMC (adaptive modulation and coding) works by way of measuring and feeding back the channel SINR to the transmitter, which then chooses an appropriate MCS from a “codeset” to maximize throughput (performance) at that SNIR and to preserve a goal BER. A codeset carries many MCSs and is designed to cover quite a number SNRs (signal to noise ratios).

Signal to Interference Noise Ratio (SINR)

SINR is a measure of quality of the signal. It is not described in the 3GPP specifications though being defined by the UE seller. It is not always mentioned in the network. SINR is used extensively by operators, because it better quantifies the relationship among RF conditions and throughput. LTE UEs typically use SINR to calculate the CQI (Channel Quality Indicator) they record to the network. It is a commonplace practice to apply Signal-to-Interference Ratio (SINR) as a trademark for network excellence. Since SINR is not mentioned in 3GPP specifications, UE does not report SINR to the community. SINR is still internally measured by means of maximum UEs and recorded by drive testing. Unfortunately, UE chipset and RF scanner manufacturers have implemented SINR size in different ways, which are not usually comparable. Before everything it may seem that defining SINR should be unambiguous. In case of LTE downlink this is not the case. This is because, distinct REs within a radio frame carry unique bodily alerts and channels every of which, in flip, see distinct interference strength depending on inter-cell radio frame synchronization. For instance, in a synchronized network, SINR estimation is totally based on synchronization indicators (PSS/SSS) resulting in different values than SINR estimation based on Reference Signals, given that inside the latter case the frequency shift of the RS depends on the PCI plan.

2.2 Current approaches used for dimensioning

Even though there are slight differences in all the approaches for network planning, they follow some basic rules. First, need arises to identify the requirement and then define the appropriate scope of that expansion or investment. As explained in [1], radio network planning mainly consists of three stages. Nominal planning, detailed planning and optimization which can be depicted in Figure 2.3 with their main functionalities in each stage.

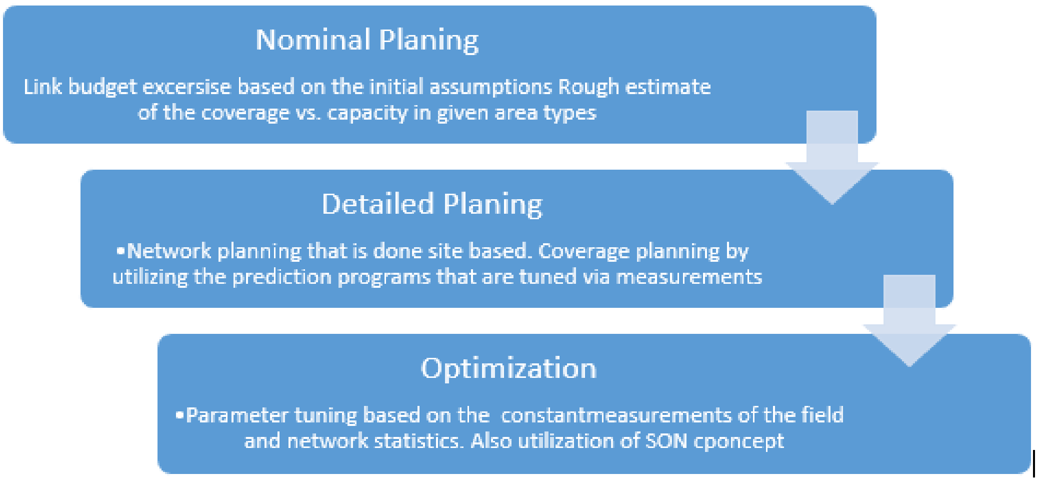


Figure 2.3: General Planning Stages [1]

In the nominal planning stage, required number of sites is roughly assumed based on Radio Link Budget and sufficient QoS. Although the main factors affecting LTE link budget are mostly comparable to GSM and UMTS. The complexity in LTE arises in the computation of the interference degradation margin as a function of cell loading and channel variations. Those can be easily captured through Monte Carlo simulations, but that would compromise the essence of the LBA being purely analytical and fast in generating results. For RLB total subjective are divided in to four major categories as follows and uniform distribution is assumed for each category.

- Dense Urban - i.e. Colombo City
- Urban – i.e. Cities near Colombo (Malambe, Battaramulla)
- Sub Urban – i.e. Secondary towns in Sri Lanka (Ambalangoda, Matale)
- Rural – Other areas not captured above

In the detailed network planning, it is done on a per site basis, as assumptions regarding geographical location antenna directions, down-tilting, power levels, vary. A tuned radio propagation model using drive testing and planning software is used in this phase. Finally, after commissioning the site, in the optimization phase fine-tuning will be done with drive testing and based on real world user behavior, which will be monitored and changed appropriately. This study will be limited to nominal planning stage where initial dimensioning will be carried out. So in the nominal planning phase it is essential to identify the required site quantity, which can cater expected QoS because over dimensioning can create unwanted cost to company and under dimensioning can lead to poor customer experience. Put in to simpler words, without all these methodologies someone can propose for mega project with thousands of sites where it provide high quality speed access to the user but most of the sites will be underutilized in the non-off peak hours and with low number of sites there will be huge congestion in peak hours. Therefore, it is essential to identify the point where the ARPU (Average Revenue Per User) is maximized. Figure 2.4 shows the importance of finding the optimal point where company should stay on. In conclusion, it is better to implement a mid-quality network, which maximizes the revenue for the company [1].

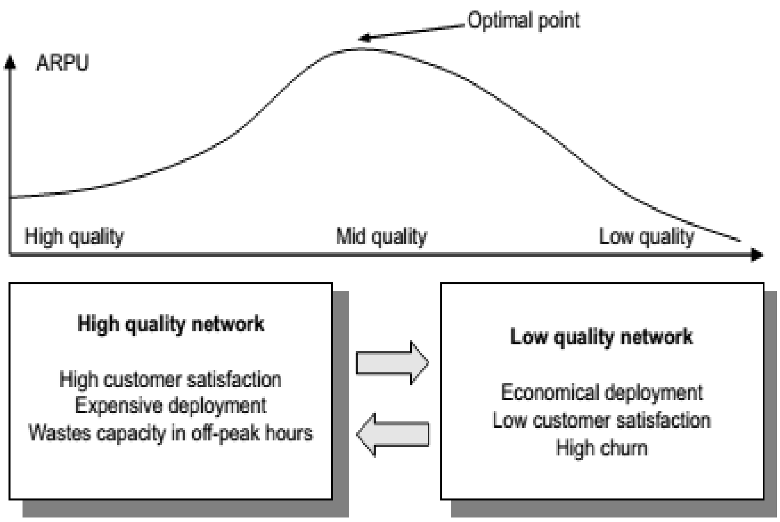


Figure 2.4: ARPU Vs. Network Quality

Since the release of LTE standards, researchers all over the world are highly keen on finding most optimum ways of dimensioning LTE networks. However, it is hard to design sites optimizing for the required capacity and throughput. Resource dimensioning should be based on the coverage footprint of the site, which is unique for a site. In addition to that, market share and population coverage within the coverage footprint should be taken in to consideration. All the design models published are roughly based on the propagation models depending on the clutter type (urban, sub urban and rural).

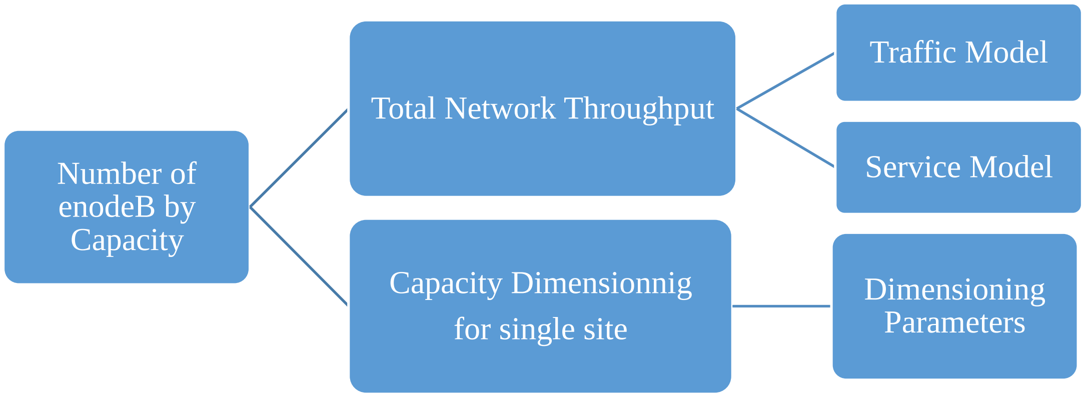


Figure 2.5: Flow of Capacity Dimensioning

Currently capacity dimensioning will be as per the above procedure [3] [4]. Capacity dimensioning will be consisting of two main parts, capacity dimensioning for single site and total network throughput. Total network throughput is calculated based on traffic model and service model. The number of enodeBs will be simply network throughput divided by single site capacity.

<u>Capacity Dimensioning for single site will be a function of</u>

- Cell Radius
- SINR distribution
- Cell average throughput (based on SINR distribution throughput will be calculated)

<u>Total Network Throughput will be function of</u>

- Service Model:
    - service pattern of different service
- Traffic Model:
    - User behavior

In order to identify the number of sites, we have to find the average throughput of total network and average cell throughput. After that, it is simple arithmetic as follows.

Number of sites = Avg. Throughput of Total Network/ (Avg. Cell Throughput*3)

The capacity of a LTE cell depends on the services used (service model) [2], the distribution of services (traffic model) [2], as well as the quality of service level and bandwidth used. Modulation and coding schemes have a direct relationship with capacity where MCS allocated as per the received SINR.

Service Model											
	UL				DL				UL	DL
Traffic Parameters	Bearer Rate	PPP Session Time	PPP Session Duty Ratio	BLER	Bearer Rate	PPP Session Time	PPP Session Duty Ratio	BLER	Throughput per session(kbit)	Throughput per session(kbit)
VoIP	26.9	80	0.4	1%	26.9	80	0.4	1%	869	869
Video Phone	62.53	70	1	1%	62.53	70	1	1%	4421	4421
Video Conference	62.53	1800	1	1%	62.53	1800	1	1%	113687	113687
Real Time Gaming	31.26	1800	0.2	1%	125.06	1800	0.2	1%	11369	90950
Streming Media	31.26	3600	0.05	1%	250.11	3600	0.05	1%	5684	864023
IMS Signalling	15.63	7	0.2	1%	15.63	7	0.2	1%	22	22
Web Browsing	62.53	1800	0.05	1%	250.11	1800	0.05	1%	5684	5684
File Transfer	140.69	600	1	1%	750.34	600	1	1%	85265	85265
Email	140.69	50	1	1%	750.34	50	1	1%	7105	7105
P2P File Sharing	250.11	1200	1	1%	750.34	1200	1	1%	303166	303166

Figure 2.6: Parameters for Service Model

Traffic Parameters	Dense Urban			
	Traffic Penetration Ratio	BHSA	Busy Hour Throughput Per User(bps)	BLER
			UL	DL
VoIP	100	1.4	338	338
Video Phone	20	0.2	246	246
Video Conference	20	0.2	6316	6316
Real Time Gaming	90	0.2	632	632
Streming Media	15	0.2	316	316
IMS Signalling	40	5	31	31
Web Browsing	100	0.6	947	947
File Transfer	20	0.3	7105	7105
Email	10	0.4	789	789
P2P File Sharing	20	0.2	16843	16843
Total			7716	7716

Figure 2.7: Parameters for Traffic Model

<u>From Service Model</u>

$$\text{Throughput per session} = \text{Bearer Rate x PPP Session Time x } \frac{\text{PPP Session Duty Ratio}}{\mathbf{1-}\boldsymbol{BLER}}$$

<u>From Traffic Model</u>

Proportion of service Type and BHSA (Busy Hour Session Attempts)

To get the single user throughput for UL/ DL, have to combine the data from above two models [3]

$$\text{Single User Throughput} = \sum_k^n \text{Throughput per session}_k \ \mathbf{X}\ \boldsymbol{BHSA_k} \text{ X } \boldsymbol{Penetration\ Ratio_k} \text{ X } \left(1+ \frac{\boldsymbol{Peak\ to\ Avg\ Ratio}}{\mathbf{3600}}\right)$$

From the network data predictions number of users is obtained whereas total network throughput is provided vis-à-vis;

Total Network Throughput = Single User Throughput * Total User Number

For single site capacity, cell radius needs to be defined for each morphology [4] first. For that cell area histogram of SINR distribution need to be generated.

$$\text{Cell Average Throughput} = \sum_k^n \text{Throughput}_k \ \mathbf{X}\ \boldsymbol{SINR\ \ Probability}_k$$

Capacity Per Site = $\boldsymbol{3\ X\ Cell\ Average\ Throughput}$ (assumed 3 cells per site)

Throughput per cell can be given as a function of time and SINR. The well-known Monte-Carlo method is practical and relatively straightforward to get that distribution. For each SINR value, MCS is mapped and respective throughput can be expected. [5]

MCS	SINR(min)(dB)	DL Cell Throughput (Mbps)
QPSK 1/3	-0.75	4
QPSK 1/2	1.5	6
QPSK 2/3	3.5	8
16QAM 1/2	7	12
16QAM 2/3	9.5	16.01
16QAM 4/5	11.5	19.2
64QAM 1/2	11.5	21
64QAM 2/3	14.7	24.01

Figure 2.8: DL Cell Throughput Distribution

Cell Throughput will be calculated by varying one parameter while keeping others fixed. If the resulting throughput does not make a significant change, that will remain fixed for an average value in the final formulating cost function. This process will be carried out through simulations and main variable input parameters will be power, bandwidth and antenna scheme. This process can be defined as per the following flow chart.

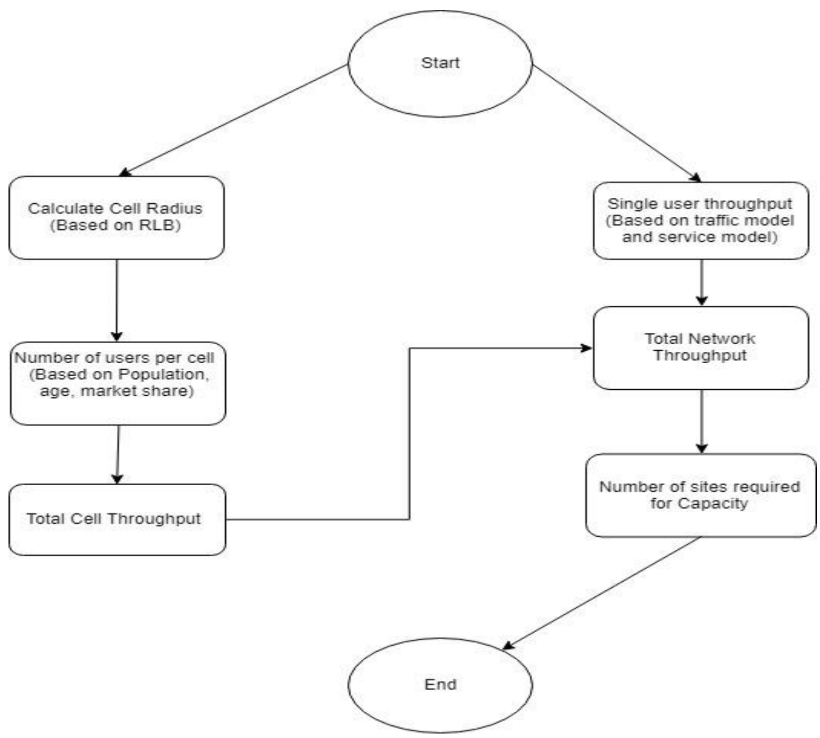


Figure 2.9:Dimensioning procedure

There are several methods proposed for LTE capacity dimensioning. Some suggest calculating number of eNBs based on the coverage and capacity, and get the maximum number. For each category, maximum number of sites required for UL or DL is considered [3]. Another attempt gives out RLB which maximizes either coverage, inter site distance and predefined data rate and find the number of sites to satisfy each criteria. [4] Unlike 2G dimensioning, it is difficult to dimension network when it comes with combined traffic [6]. This makes simulation complexity considerably significant.

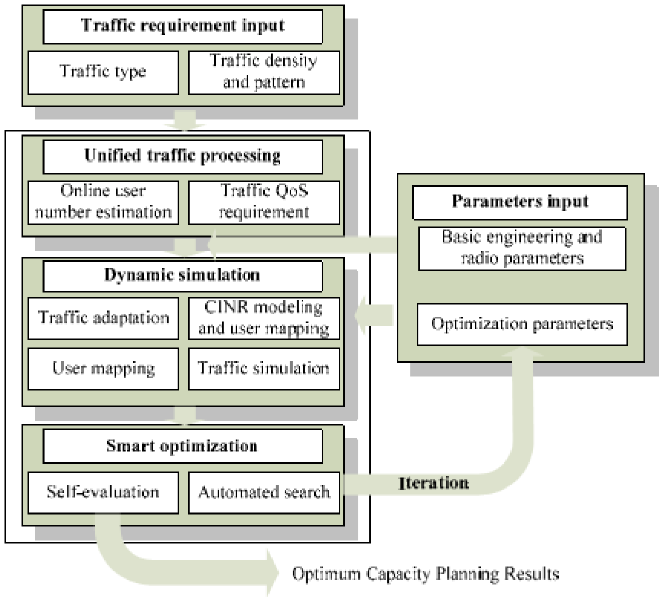


Figure 2.10: Proposed Capacity Planning Model

For GSM dimensioning, simply Erlang formula is evaluated to achieve given blocking probability. However, with the packet level behavior models like “knapsack” become more popular in multi traffic dimensioning. Hence, system level simulation is the key factor for such scenarios. Following model has been proposed by considering key features. Because of using different service QoS profiles are introduced based on the two major categories like GBR and non-GBR. In addition, prior to the simulation, inputs such as (basic parameters) system bandwidth, transmission power, antenna configuration, MIMO mode, ICIC mode, etc. and optimization parameters like inter-site distance (ISD), antenna down tilt, etc. For advanced capacity planning process.

As explained in [7] for link budget calculation COST-Hata model is used, whereas for throughput analysis, system level simulation is used. Throughput variation is considered up to three levels such as close, intermediate and far regions. Also 2x2 mode is used assuming flat fading Rayleigh channel with fast fading 0 to 3 retransmissions. Simulation results indicate the throughput distribution for different re-transmission modes.

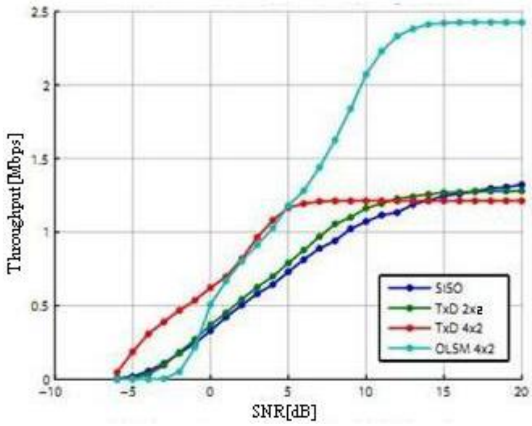
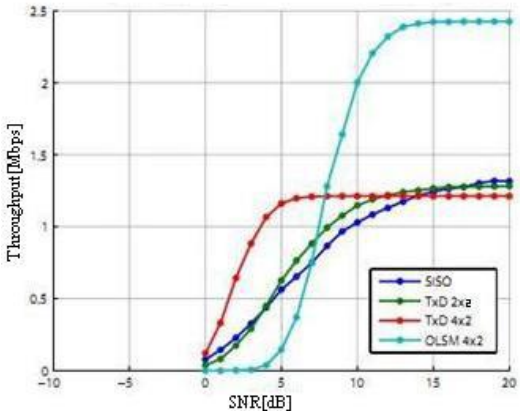
0 re-tx	3 re-tx
	

Figure 2.11:Throughput Vs SNR for 0 & 3 re-tx

This paper shows what is the DL SNR level should be there to achieve expected throughput for different transmission modes. However, small number of users are taken for this analysis while Atoll is used for detailed planning. In this approach eNodeB site quantity is calculated based on both coverage and capacity. At the same time, it follows the basic procedure of three stage planning and continues until second level which is the “Nominal and detailed planning”.

In the site calculation for coverage, it derives the cell radius from propagation model and obtains the number of sites by dividing the total area from single site coverage area (considers the hexagonal cell shape). In throughput-based calculations, number of users per cell with a satisfactory throughput is obtained from the link level simulations. Further, overbooking factor is assumed as 50. Final site count is almost equal, but this approach misses most of the important factors such as traffic types, interference factor from other sites and loading. Nevertheless, authors suggest to use this answers in nominal and detailed radio planning stages. In this stage, software will be used and propagation model tuning, defines thresholds from Link budget.

Another method discussed in [8] about link budget analysis (LBA) is based on statistical approach instead on simulation results; MAPL (Maximum Allowable Path Loss) calculated from LBA and cell radius obtained by applying that in a propagation model. Statistical distributions were calculated for interference margin, MAPL and cell range. Results were analyzed for two fading models (Rayleigh fading and composite fading). The most important thing of this paper is that it reveals the effect of cell loading and inter-site distance to the cell edge user throughput. Under any of the considered fading models there is a drastic impact on the cell edge user performance as in figure 2.12 and 2.13.

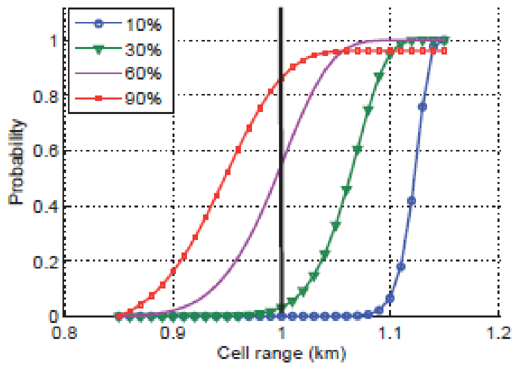


Figure 2.12:Different cell loading and constant inter site distance 1.732km [8]

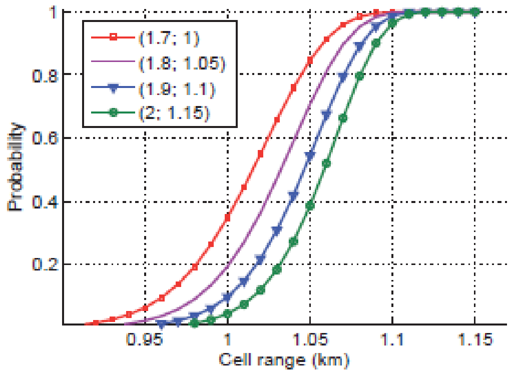


Figure 2.13:Different inter site distances and constant cell loading 50%[8]

At the same time for constant loading, the statistical values are compared with values from simulations to verify the results and they are almost coinciding with each other. Obviously, the interference margin will follow exponential distribution for Rayleigh fading and gamma distribution for Composite fading. Last but not least, this paper highlights the invalidity of only traditional LBA for LTE dimensioning. Also the calculations are presented to over dimensioning (full load) and under dimensioning (less load) scenarios. However, paper does not describe how to decide on loading factor for each morphological area.

Paper [9] discussed about LTE radio network planning related constraints such as interference and coverage. Under system parameters, selection of correct propagation model and frequency band is considered and further analyzed by performance simulations. As per the 3GPP recommendations for DL CINR and spectral efficiency will be as in Table 2.1.

Table 2.1: Minimum CNIR, modulation and spectral efficiency versus CQI

CQI	CNIR	Modulation	f=800MHz	f=26GHz
0		Out of Range		
1	-4.63	QPSK	9359	4432
2	-2.6	QPSK	8009	3793
3	-0.12	QPSK	6621	3135
4	2.26	QPSK	5515	2612
5	4.73	QPSK	4563	2161
6	7.54	QPSK	368	1743
7	8.67	16-QAM	3372	1597
8	11.43	16-QAM	2751	1303
9	14.23	16-QAM	219	1041
10	15.21	64-QAM	2042	967
11	18.63	64-QAM	157	744
12	21.32	64-QAM	1277	605
13	23.47	64-QAM	1083	512
14	28.49	64-QAM	737	349
15	34.6	64-QAM	461	218

Considering the values in above table and propagation models, modified Friis and Hata models, paper depicts the values of interference to noise ratio M, in the DL for f=800 MHz which depends on the CQI values and the MCS associated to it.

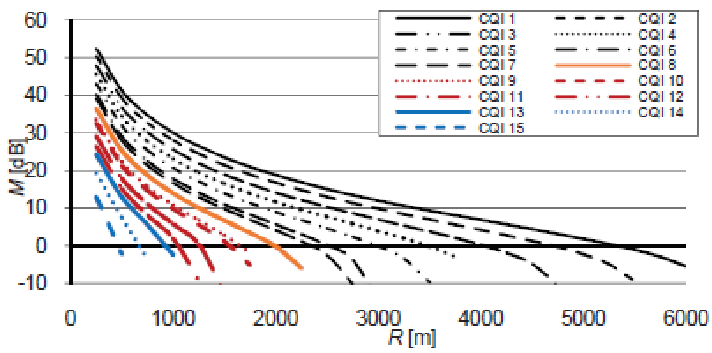


Figure 2.14: Interference to noise ratio as a function of the coverage distance with CQI as a parameter for DL in the 800 MHz band and Hata model

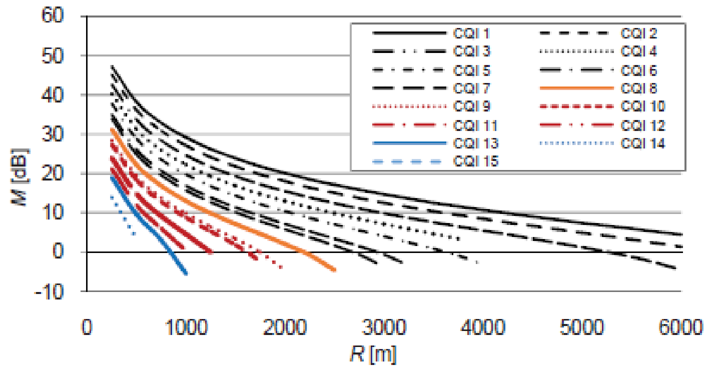


Figure 2.15: Interference to noise ratio as a function of the coverage distance with CQI as a parameter for DL in the 800 MHz band and FRIIS model

In conclusion, higher CNIR will get higher CQI and ultimately higher throughputs. In other words, when cell radius is above 4000m user will not get any QAM which gives the user a low throughput. As a consequence, for both modified Friis and Hata models, with CQI up to 7, low reuse patterns are achievable while with CQI 8, K lower than 7 is obtained for 1500 and 1400m. However, another analysis reveals the CINR behave with the frequency band (between 800 MHz and 2.6GHz) and physical throughput with the co-channel reuse factor.

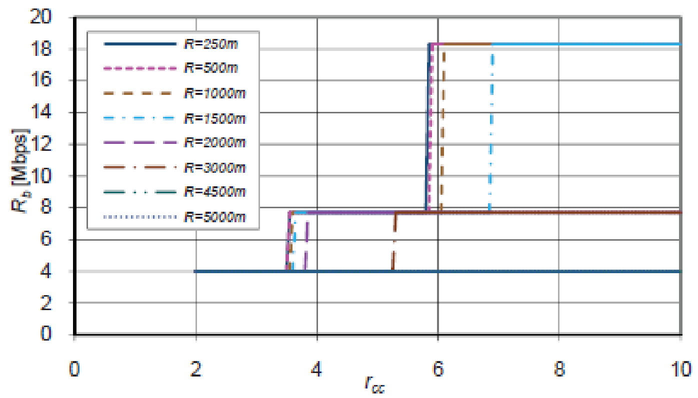


Figure 2.16: DL Throughput in 800MHz Vs. Co-Channel Reuse Factor

There are lots of LTE network dimensioning tools, both vendor specific (Huawei RND and UNET) and vendor independent (Atoll and Asset). Those Capacity analyses require Monte Carlo simulation, which requires traffic layer as its input. The capacity comparison was based on number of served terminals and total peak RLC throughput. All the above tools are based on the universal propagation model developed in orange labs thus giving similar results. With product cost itself being 8000 USD, this would cost a fortune with installation, fine-tuning and maintenance charges.

Therefore, operators used to have excel based planning tools. Built in formula functions in excel will be used with manual data feed for link budget calculations and other data for morphological demarcations. However, this method is very rough and basic due to ignorance of cell interference for throughput calculations. Most of the time calculations are limited to constant throughput for all the users in a cell and both the DL/UL throughput and user number is given.

Apart from the all the approaches, paper [11] makes notes on the effects of QoS schemes for LTE capacity dimensioning. The objective of this study is to determine the capability of the network to deal with the variations in the demography of the covered area and the user's traffic profile with the proposed QoS schemes including congestion control (CC) and Radio Admission Control (RAC). Since this paper discusses about QoS of LTE, LTE uses a concept of bearer to provide QoS. The QoS profile of each bearer includes QoS Class Identifier(QCI) and Allocation and Retention priority (ARP) where QCI defines the forwarding treatment of IP packets received on a bearer. In addition to that, Fair Intelligent Congestion Control (LTE-FICC) and Fair Intelligent Admission Control (LTE-FIAC) has proposed to utilize the elastic feature of the TCP traffic and the flexibility in bandwidth allocation between Maximum Bit Rate (MBR) and Guaranteed Bit Rate (GBR) of a bearer in the latest releases of 3GPP. As mentioned earlier in the paragraph, all the methods described above confine their discussions on pre-network deployment dimensioning. None of the papers discusses how to deal with the changes in the network characteristics once the network has dimensioned.

This paper has highlighted several points though much attention is not given in LTE capacity estimation, which are as follows.

1. Effect of capacity occupied control channels
2. Effect of scheduling
3. Effect of usage of bandwidths and applications

For this analysis, traffic types and user groups are classified as follows.

Table 2.2: User Groups and Application Distribution

User groups based on application demand distribution	Applications
Households	Streaming
Public and Health Services	VoIP
	Online Gaming
Business	Web
	FTP

Further, application distribution is considered under two major categories as AD-1 and AD-2 where AD-1 covers the areas which have relatively more businesses, health and public service offices. Whereas AD-2 covers the areas that have more households, which relatively utilizes more streaming services to upload/download videos.

Table 2.3: Application Distribution with QCI

Application	QCI	MBR(Kbps)	GBR(Kbps)	A1(%)	A2(%)
Streaming	2	850	850	20	40
VoIP	1	64	64	30	10
Online Gaming	3	50	50	20	20
Web	4	32	15	20	20
FTP	4	256	50	10	10

In the coverage analysis with the use of COST-231 Hata model it shows how the cell radius varies with the Channel Quality Indicator (CQI) and for different bandwidths.

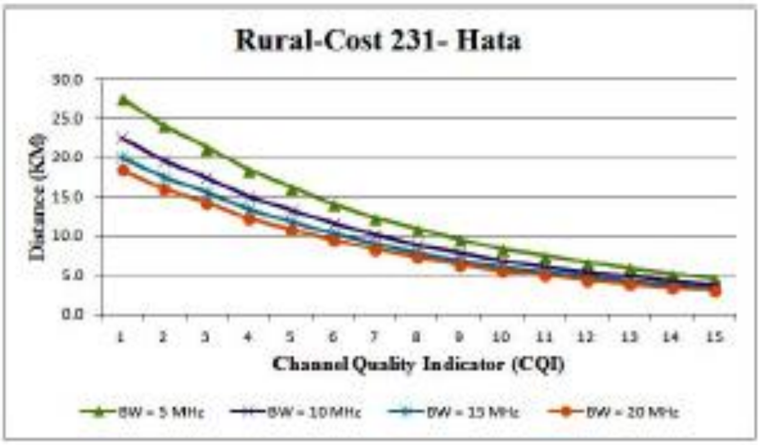


Figure 2.17: Cell Radius for various CQI

This graph reveals following two facts.

1. Lower the frequency throughput will be higher
2. Lower the bandwidth cell radius will be higher

In capacity planning, capacity (CPC) is modeled as a function of parameters such as frequency (f), bandwidth, frame duration (T_f), SNR, modulation (E), code rate (CR), cyclic prefix (CP), and overhead (OH).

$$CPC = f\,(f, BW, T_{f,}\ SNR, E, CR, CP, OH)$$

With above mentioned factors, calculations have been presented for different use cases to verify how the RAC will behave in different traffic demands. The results show that in instances of sources shortage, the RAC does no longer provide low priority FTP and web connections by degrading the connections at identical precedence, in order to maintain resources for incoming excessive priority connections. So, the blockading possibility (BP) of low precedence services could be high compared to excessive priority services. Hence, via using these QoS schemes at an eNodeB, the community, to a positive extent, is capable of controlling the adjustments inside the call for and loading within the middle network without the need to re-dimension. Once the RAC admits the high priority connections with the aid of degrading all low precedence connections to their respective minimal charge (GBR), the BP of high priority offerings also begin to increase. The network operator can outline a number proper BPs for distinct offerings. Once the BP of a provider inclusive of voice or blend of service consisting of voice and video is going past the range, it can mark it as a demonstration to re-dimension the network excessive compared to excessive priority offerings.

3 CAPACITY DIMENSIONING

3.1 Introduction

As per the methodology, initial task was to study in detail the selected existing approaches of dimensioning, which was discussed in chapter 2. The approaches describe the parameters affecting LTE throughput, and it can be seen that there are a number of inter related parameters. None of the approaches has provided an optimum solution to the minimum site count while achieving the cell throughput (UL/DL) thresholds defined initially. It should be noted that it will be difficult to formulate and optimize a cost function for throughput due to having a lot of varying parameters. In this chapter, the author discusses about a solution which is capable of providing such an optimum solution.

3.2 Mathematical Model for Problem formulation

First and foremost, it is essential to define the system model. All dimensioning procedures proposed by the author are based on this model.

This process will be done for all LTE standard bandwidths, and the number of sites required per each bandwidth will be recorded. Then, the revenue per 1Mbps will be calculated and the highest revenue generating option will be selected. In order to calculate the radio link budget (RLB), the affecting parameters will be studied [1]. Since release 13 is the most recent frozen release, this work will be based on R13[7]. Under the guidelines of 3GPP release 13, a new strategy is proposed for Capacity Dimensioning. Before discussing the process, author will define few parameters, which will be used later.

Required Cell Throughput (RCT) = Sum of individual user throughputs distributed over the cell

Theoretical Cell Throughput (TCT) = Cell throughput as per the theoretical calculations. For a given bandwidth and antenna scheme (transmit x receive), the theoretical maximum cell throughput is a constant.

These terms are valid for both uplink and downlink.

Following are the input and output variables of the model, which are depicted in figure 20.

A= Area (km^2)

N = Population

$\boldsymbol{P}_{\mathbf{max}}$= Maximum cell power (W)

$\boldsymbol{B}_{\mathbf{max}}$ = Maximum allowable bandwidth (MHz)

$\boldsymbol{M}_{\mathbf{max}}$ = Maximum number of transmit antennas

$\boldsymbol{T}_{\mathbf{minsu}}$ = Minimum single user throughput (kbps)

$\boldsymbol{T}_{\boldsymbol{su}}$ = Final single user throughput (kbps)

S = Number of Sites

R = Cell radius (km)

U = Number of users per cell

$\boldsymbol{P}_{\mathbf{req}}$= Required cell power (W)

$\boldsymbol{B}_{\mathbf{req}}$= Required bandwidth (MHz)

$\boldsymbol{M}_{\mathbf{req}}$= Required number of transmit antennas

$\boldsymbol{UTh}_{\mathbf{k}}$= Throughput of kth single user within the cell (kbps)

$\boldsymbol{TCT}_{\boldsymbol{max}}$= Theoretical maximum cell throughput (Mbps)

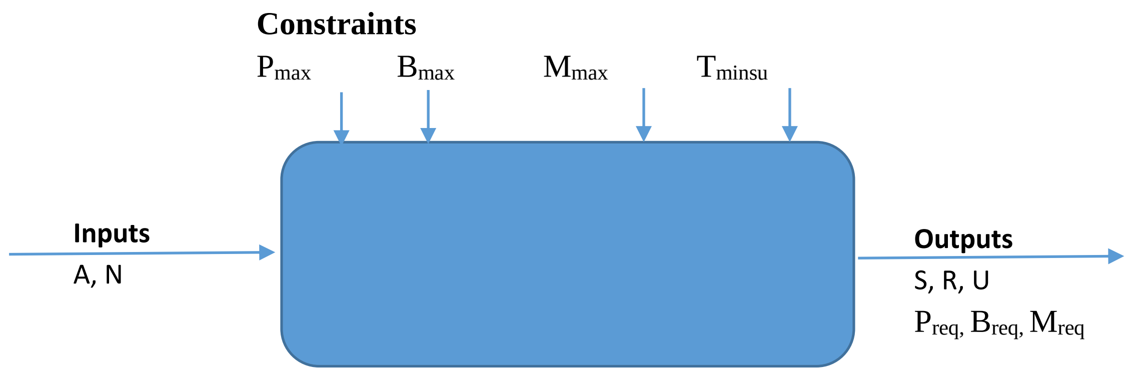


Figure 3.1: Mathematical Model

In a practical scenario, Required Cell Throughput (RCT) should be less than the Theoretical Cell Throughput (TCT). Otherwise, there will be congested situation due to under dimensioning. That is,

$$\text{RCT} \leq \text{TCT}.$$

Hence, at the optimum point, RCT should be equal to TCT. Therefore, in this problem, using this system model, the difference (absolute value) between RCT and TCT will be minimized. Even for a fixed bandwidth, when cell radius changes due to power and transmitting antenna scheme, TCT varies. Therefore, TCT cannot be fixed. This cost function will be subjected to following constraints. However, TCT can be modified to get a more practical perspective since it is quite impractical to provide the same throughput as the theory suggests. This is mainly due to numerous uncertainties in the real world. Therefore, TCT is modified, introducing a factor as below.

TCT’ = k.TCT; where $0<k<1$

Therefore, final cost function will be minimizing |TCT’-RCT|, which can be written as

F=maximize (RCT)

Design engineer can decide on the k factor according to the dimensioning requirement of the operator.

a) $UTh_k > T_{minsu}$

Minimum cell throughput per user (for both UL and DL) is defined (can be set by regulatory body) initially and this will be guaranteed in the result.

b) $\sum_{k=0}^{U} UTh_k < TCT_{max}$

The algebraic summation of throughput of all the users in the cell should be less than the theoretical maximum cell throughput for a given spectrum bandwidth and antenna scheme. Otherwise, this cannot be implemented.

c) $P_{req} \leq P_{max}$

Transmit power from the network should be less than or equal to the maximum power that can be configured. This limitation comes from the hardware (power amplifier limitation)

d) $B_{req} \leq Bmax$

Bandwidth which will be using for calculations should be less than or equal to the maximum bandwidth allocated for LTE services. (There spectrum allocation limitation from the regulator or each operator share the allocated spectrum to other radio access technologies 2G, 3G)

e) $M_{req} \leq Mmax$

Transmit and receiving antenna combination should be less than or equal to the maximum supported number of antenna by both network antenna and user device antenna.

Apart from the above constraints, the model is under below mentioned assumptions.

a) Cell radius of all the sites will be equal and all the cells will have an equal coverage area.
b) Users are uniformly distributed throughout the considered area and user behavior will be based on a random function.
c) All cells are geometrically hexagonal.

Under the above-mentioned constraints and assumptions, by minimizing the gap between RCT and TCT, maximum practical throughput can be obtained. Cell edge throughput is also calculated using the same input parameters where gap between RCT and TCT is minimized.

Using this method, number of sites to cater UL and DL speed requirements can be calculated. That means, the minimum site count required to provide UL speed requirements and the minimum site count to provide DL speed expectations.

Sites $_{N,\ UL}$ = UL site count

Sites $_{N,\ DL}$ = DL site count

Out of these numbers, the higher number will be selected because if the lower number of sites is selected, the speed constraints will be violated. Therefore, final site count which is required to be implemented can be presented as below.

Final site count = max ($\boldsymbol{Sites_{N,DL}}, \boldsymbol{Sites_{N,UL}}$)

3.3 Dimensioning Procedures

In section 3.2, the mathematical model was introduced. In that model, there are very few input parameters mentioned for calculations, but in reality, there are more than that. Below mentioned are the most significant parameters among them because some of them do not significantly affect the final result, irrespective of being fixed or variable.

a) CINR distribution

b) Traffic types and Application distribution
c) Device Capability distribution
d) QoS Schemes
e) Network hardware Parameters
f) Technology gains
g) Frequency band and available bandwidths
h) Demography and Morphological demarcations
i) Market Share

Parameters from a to d, are user dependent whereas parameters from e to f are network dependent. Last two parameters are not technically defined, but very vital to calculate the number of users and user applications.

Approximate cell radius can be calculated after RLB calculation. With tri-sector configuration of 65^0 beam width, the cell area can be calculated. Uniform population is assumed, and number of users per cell can be obtained. Then the traffic model and service model are applied to obtain the cell throughput. If the user required cell throughput is provided by the existing cell radius, cell radius will be reduced and the coverage area will be shrunk until the required cell edge throughput per user is observed. This is the most favored or the commonly followed method in the literature. According to the following flow chart, it is clearly visible that in this approach, no iterations are carried out and the output is generated by one single calculation.

Therefore, the mathematical model proposed in 3.1 will be iterated until it reaches an optimum solution according to the flow chart shown in figure 3.1.

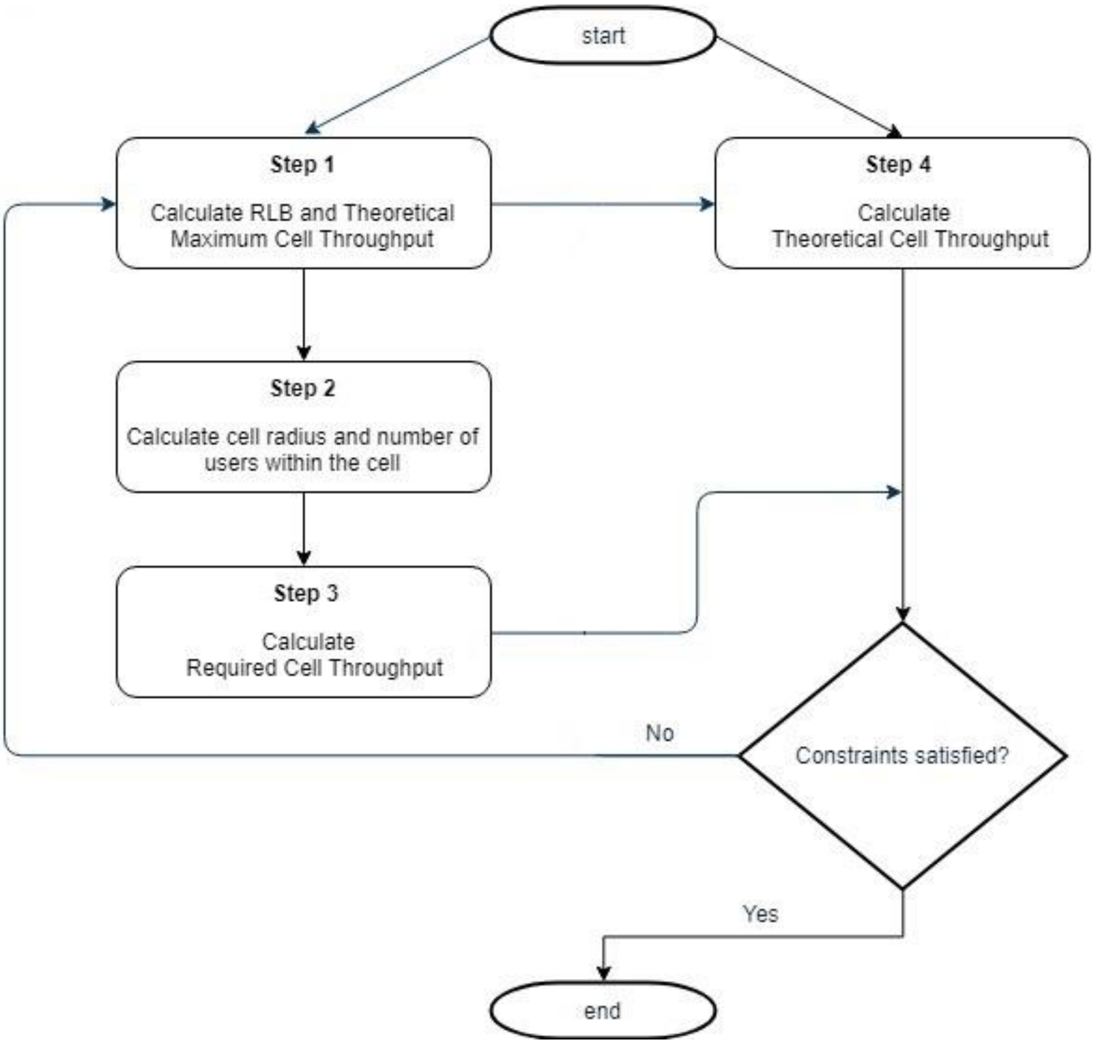


Figure 3.2: Dimensioning procedure with iterations

Above depicted process is common for DL and UL capacity dimensioning. Independent variables for channels are quite different and therefore UL capacity dimensioning process and DL capacity dimensioning process are discussed separately.

As mentioned in the process, both UL and DL dimensioning has two sections. One is calculating the theoretical maximum with the available resources. Other one is to calculate the required throughput in the real world. If the required throughput is higher than the theoretical maximum, there will be congestion perceived by the customer. For example, if the cell capacity is 100 Mbps and there are 60 users which require 2 Mbps on average, eNodeB cannot give the requested services and the customer will experience low speed.

Uplink Capacity Dimensioning

There are three independent variables for UL dimensioning apart from the bandwidth and frequency range. They are as follows.

1. Site-to-Site Distance Expressed as Signal Attenuation

To make the formulae invariant of the wave propagation characteristics, it is convenient to represent the site-to-site distance in terms of a signal attenuation value rather than a distance value. The most convenient value is the median signal attenuation experienced at the cell border, signal attenuation at cell range. Starting from an initial value, it is increased until the quality requirements are exactly fulfilled. As an initial assumption, a (low) value is selected that fulfills the quality requirements. A good starting point is a value in the range of 110 to 120 dB.

2. Power Control Target

The power control algorithm allows the operator to adjust the power control target. The default value can be used as a starting value in the uplink dimensioning process. The setting can be optimized at a later stage to meet the specific quality requirements and to maximize the required site-to-site distance.

3. PUSCH Load

The PUSCH load, is defined as the fraction of the PUSCH resource blocks carrying user data. Often the load level for which dimensioning should be done is specified as a prerequisite. If not, different load levels can be tested for maximizing the site-to-site distance. If no load level is specified, a suitable starting point for the iteration is in the range of 80% to 100%.

After understanding the behavior of all the underlying parameters, each step mentioned in Figure 21 will be explained as below.

Step 1

Based on the variations of the above parameters, the following values are calculated.

i. Thermal noise
ii. Noise rise

iii. Resource block allocation
iv. Power level
v. Bit rate
vi. Cell edge bit rate
vii. High bit rate
viii. Uplink link budget

Table 3.1: Uplink link budget Related Parameters [3]

Field	Description	Comments
a. Max tx power (dBm)	UE maximum transmission power for power class 3. Different power classes would have different power levels. The power can be reduced depending on the modulation.	Transmitter related parameters
b. Tx antenna gain (dBi)	UE antenna gain depends on the type of device and on the frequency band. Small handheld terminal at a low frequency band (like Band VIII) can have an antenna gain of −5 dBi while a fixed wireless terminal with directive antenna can have a gain of up to 10 dBi.	
c. Body loss (dB)	Body loss is typically included for voice link budget where the terminal is held close to the user's head.	
d. EIRP (dBm)	Calculated as a + b − c	
e. NodeB noise figure (dB)	Base station RF noise figure. Depends on the implementation design. The minimum performance requirement is approximately 5 dB but the practical performance can be better.	Receiver related parameters
f. Thermal noise (dB)	Terminal noise can be calculated as k (Boltzmann constant) × T (290K) ×bandwidth. The bandwidth depends on bit rate, which defines the number of resource blocks. We assume two resource blocks for 64 kbps uplink.	
g. Receiver noise (dBm)	Calculated as e + f	
h. SINR (dB)	Signal-to-noise ratio from link simulations or measurements. The value depends on the modulation and coding schemes, which again depends on the data rate and on the number of resource blocks allocated.	
i. Receiver sensitivity	Calculated as g + h	
j. Interference margin (dB)	Interference margin accounts for the increase in the terminal noise level caused by the interference from other users. Since LTE uplink is orthogonal, there is no intra-cell interference but we still need a margin for the other cell interference.The interference margin in practice depends heavily on the planned capacity – there is a tradeoff between capacity and coverage. The LTE interference margin can be smaller than in WCDMA/HSUPA where the intra-cell users are not orthogonal. In other words, the cell breathing will be smaller in LTE than in CDMA based systems.	
k. Cable loss (dB)	Cable loss between the base station antenna and the low noise amplifier. The cable loss value depends on the cable length, cable type and frequency band. Many installations today use RF heads where the RF parts are close to the antenna making the cable loss very small. The cable loss can also be compensated by using masthead amplifiers.	
l. Rx antenna gain (dBi)	Base station antenna gain depends on the antenna size and the number of sectors. Typical 3-sector antenna 1.3 m high at 2 GHz band gives 18 dBi gain. The same size antenna at 900 MHz gives smaller gain	

Following equations are used to calculate the cell radius (coverage planning).

Power Control Target

P_0 = *pZeroNominalPusch* ----> *(1)*

This is used to control the cell power. If this value is set high, the cell throughput will be high, at the same time noise rise will be high.

Thermal Noise

$$\mathbf{N_{RB,UL}} = \mathbf{N_t} + 10 \log (\mathbf{W_{RB}}) + \mathbf{N_{f,RBS}} \text{ ----> } (2)$$

In equation 2, thermal noise will be written as a function of thermal noise power density (N_t -174 dBm/Hz), W_{RB} which is the bandwidth per resource block (180 kHz) and $N_{f,RBS}$ which is the RBS noise figure at the RX reference point [dB]. The RBS noise figure at the RX reference point will be calculated as

RBS Noise Figure

$$\mathbf{N_{f,RBS}} = 10 \log \left(\mathbf{N_{f,TMA}} + \frac{\mathbf{N_{f,RU}} \ \mathbf{x}\ \mathbf{L_f} - \mathbf{1}}{\mathbf{GTMA}}\right) \text{ ----> } (3)$$

$N_{f,TMA}$ is the noise figure of the TMA in linear units. A typical value is 1.4 dB (1.4 linear)

$N_{f,,RU}$ is the noise figure of the RU in linear units. A typical value is 2 dB (1.6 linear)

L_f is the feeder loss between the TMA and the RU in linear units

G_{TMA} is the gain of the TMA in linear units.

Noise Rise

$$\mathbf{B_{IU\,L}} = 10 \log \left(1 + \frac{\mathbf{Q_{PUSCH}} \ \mathbf{x}\ \mathbf{I_{RB,UL}}}{\mathbf{N_{RB,UL}}}\right) \text{ ----> } (4)$$

$\mathbf{I_{RB,UL}}$ is the average inter-cell interference per resource block expressed in a linear scale. This is modified for interference rejection combining as in equation 5 so the operator can decide the value of $\boldsymbol{\beta}$ for given amount of rejection of noise in the network.

Noise Rise with IRC

$$\mathbf{B_{IU\,L,IRC}} = 10 \log \left(1 + \frac{\mathbf{Q_{PUSCH}} \ \mathbf{x}\ (\mathbf{1} - \boldsymbol{\beta})\mathbf{I_{RB,UL}}}{\mathbf{N_{RB,UL}}}\right) \text{----> } (5)$$

Resource Block Allocation

$\mathbf{n_{RB}}$ = *max* {$\mathbf{n_{RB,min}}$; *min* $\mathbf{n_{RB,max}}$;*10*($\mathbf{P_{UE}} - \mathbf{L_{sa}} - \mathbf{N_{RB,UL}} - \mathbf{B_{IU\,L}} - \gamma_0)/\mathbf{10}$]} ----> *(6)*

Equation 6 is used to know how many resource blocks n'_{RB} that a UE is allocated as a function of the signal attenuation.

TX Power per resource block

$$\mathbf{P_{UE,RB}} = \min [\mathbf{P_{UE}} - 10 \log (\mathbf{n_{RB}}) ; \mathbf{P_0} + \alpha \, \mathbf{L_{sa}}] \text{ ----> } (7)$$

This is used to calculate the transmit power of the resource block. P_0 is the power control target defined in equation 1 and α is the path-loss compensation factor. In equation 8, the receive power for a resource block is calculated.

Knowing the TX power, the RX power level per resource block is simply given

RX Power Per RB

$$\mathbf{P_{rx,RB}} = \mathbf{P_{UE,RB}} - \mathbf{L_{sa}} \text{ ----> } (8)$$

Equation 9 is used to calculate the SINR based on the receive power per RB, thermal noise and noise rise.

SINR

$$\gamma = \mathbf{P_{rx,RB}} - \mathbf{N_{RB,UL}} - \mathbf{B_{IU\,L}} \text{ ----> } (9)$$

Bit Rate

When SINR and allocated number of RBs are known, UL bit rate can be calculated using equation 10.

$$\mathbf{R_{UL}} = (\mathbf{n_{RB}}) \times (\mathbf{R_{RB(\gamma)}}) \times (\mathbf{k_{s\,ubf,UL}}) \text{ ----> } (10)$$

Bit Rate per Resource Block

$$\left.\begin{array}{ll} \mathbf{R_{RB\,(\gamma)}} = \max [0, \mathbf{a_3} + (\mathbf{a_0} - \mathbf{a_3})\, \mathbf{e}^{-\ln(2)\,[(\gamma - \mathbf{a_1})/\mathbf{a_2}]^{\mathbf{a_4}}} ; & \gamma < \mathbf{a_1} \\ \mathbf{R_{RB\,(\gamma)}} = \mathbf{a_0} ; & \gamma \geq \mathbf{a_1} \end{array}\right\} \text{ ----> } (11)$$

This equation is used to calculate the bit rate per resource block. Therefore, the achieved bit rate can be calculated for an arbitrary signal attenuation. Coefficient details can be found in [4].

Next requirement is to find the cell edge throughput, and for that throughput, the cell edge coverage need to be estimated. Equation 12 is used for that.

Signal Attenuation at Cell Edge

$\mathbf{L_{sa,cell\ edge}} = \mathbf{L_{sa,cell\ range}} + \mathbf{B_{LNF}}$ ----> *(12)*

In this equation, $B_{LN\,F}$ is the log normal fade margin, where $\mathbf{L_{sa}}$, cell range is used to denote the median signal attenuation at the cell border.

Resource Block Allocation at Cell Edge

$\mathbf{n_{RB,cell\ edge}} = max\{\mathbf{n_{RB,min}}\ ;min[\ \mathbf{n_{RB,max}}\ ;$
$\mathbf{10}^{(\mathbf{P_{UE}} - \mathbf{Lsa,cell\ edge} - \mathbf{N_{RB,UL}} - \mathbf{B_{IU\,L}} - \gamma_0\ )/10}\ ]\}$ -> *(13)*

Using equation 12 and 13, SINR of the cell edge can be found, which can then be used to find the bit rate per resource block using equation 11.

SINR at Cell Edge

$\gamma_{\mathbf{cell\ edge}} = min\ [\mathbf{P_{UE}} - 10\log(\mathbf{n_{RB,cell\ edge}});\mathbf{P_0} + \alpha\ \mathbf{L_{sa,cell\ edge}}] - \mathbf{L_{sa,cell\ range}} - \mathbf{N_{RB,UL}} - \mathbf{B_{IU\,L}}$ -> *(14)*

Cell Edge Bit Rate

$\mathbf{R_{cell\ edge,UL}} = (\mathbf{n_{RB,cell\ edge}})\ x\ (\mathbf{R_{RB,cell\ edge}})\ x\ (\mathbf{k_{s\ ubf,UL}})$ -----> *(15)*

Author will compare the bit rate calculated in equation 15 with the defined cell edge throughput, which is given as a design constraint.

SINR for UE close to Site

$\gamma_{\mathbf{h}} = \mathbf{P_0} - \mathbf{N_{RB,UL}} - \mathbf{B_{IU\,L}}$ -----> *(16)*

High Bit Rate

$\mathbf{R_{h,UL}} = (\mathbf{n_{RB,max}})\ x\ (\mathbf{R_{RB,h}})\ x\ (\mathbf{k_{s\ ubf,UL}})$ -----> *(17)*

When users are near the site, they can meet the power control requirements easily which means those users can have higher speeds. Therefore, speed is calculated as per equation 17. Equation 18 shows the power control requirement.

Signal Attenuation where Power Control Target is met.

$\mathbf{L_{sa}} \leq \mathbf{P_{UE}} - 10\log(\mathbf{n_{RB,max}}) - \mathbf{P_0}$ -----> *(18)*

<u>Step 2</u>

Calculated uplink link budget is used to calculate the cell radius. Based on that cell radius, cell area is calculated.

Uplink Link Budget

$\mathbf{L_{pmax}} = \mathbf{L_{sa,cell\ range}} - \mathbf{L_{BL}} - \mathbf{L_{CPL}} - \mathbf{L_{BPL}} + \mathbf{G_a} - \mathbf{L_j}$-----> *(19)*

Uplink link budget is calculated using equation 19. Maximum path loss due to loss in the propagation will be given as a function of following factors.

L_{BL} is the body loss [dB]

L_{CPL} is the car penetration loss [dB]

L_{BPL} is the building penetration loss [dB]

G_a is the sum of the maximum gain in the forward direction network antenna, and UE antenna gain [dBi]

L j is any losses due to jumpers installed between the antenna and the RX reference point [dB]

Uplink Link Budget Based on Receiver Sensitivity

$\mathbf{L_{pmax}} = \mathbf{P_{UE,RB}} - \mathbf{S_{RBS}} - \mathbf{B_{IUL}} - \mathbf{B_{LNF}} - \mathbf{L_{BL}} - \mathbf{L_{CPL}} - \mathbf{L_{BPL}} + \mathbf{G_a} - \mathbf{L_j}$-----> *(20)*

Substituting $L_{sa,\ cell\ range}$ in equation 19 for L_{sa}, cell range equation 20 observed and equation 21 used to show the connection for receiver sensitivity.

Receiver Sensitivity

$\mathbf{S_{RBS}} = \mathbf{P_{UE}} - \mathbf{L_{sa,cell\ range}} - \mathbf{B_{LNF}} - 10 \log (\mathbf{n_{RB}}) - \mathbf{B_{IUL}} -$ -----> *(21)*

<u>Step 3</u>

Within the cell area calculated in step 2 and assuming the population has a uniform distribution, number of users per cell is calculated. Figure 22 shows the user distribution. Based on the user profiles, required mean cell throughput is calculated by summing up all individual throughputs [6]. User profiles are defined as below tables.

Table 3.2: UL user profiles

Profile Index	Service	Bearer Rate	PPP Session Time	PPP Session Duty Ratio	BLER	Resource Type	Priority	QCI
1	IMS Signaling	15.63	7	0.2	0.01	Non-GBR	1	5
2	Conversational Voice(VoIP)	26.9	80	0.4	0.01	GBR	2	1
3	Real Time Gaming	31.26	1800	0.2	0.01	GBR	3	3

4	Conversational Video(Live Streaming)	62.53	1800	1	0.01	GBR	4	2
5	Non-Conversational Video (Buffered Streaming)	31.26	3600	0.05	0.01	GBR	5	4
6	Web Browsing	62.53	1800	0.05	0.01	Non-GBR	6	6
7	File Transfer	140.69	600	1	0.01	Non-GBR	7	7
8	Email	140.69	50	1	0.01	Non-GBR	8	8
9	P2P File Sharing	250.11	1200	1	0.01	Non-GBR	9	9
10	Combination of 2+6	89.43	1800	0.05	0.01		2	1
11	Combination of 2+7	167.59	600	1	0.01		2	1
12	Combination of 2+8	167.59	50	1	0.01		2	1
13	Combination of 2+9	277.01	1200	1	0.01		2	1

From the initial link budget calculation, the cell radius will be calculated. From that, cell area will be calculated. Then the number of cells required to cover the whole area can be found. At the same time, number of users per cell can be calculated.

Here, the population is assumed to be uniformly distributed as shown in Figure 20, and for each iteration, the number of users within the cell is known. Users will be randomly placed within the cell area and total cell throughput will be calculated by monte carlo simulations. Users will be having user profiles as per the device category and requirements as per the table 3.3.

Table 3.3: User profiles

User Profile	Device Category	Requirement	QoS	Required Throughput
1	Category 1	Browsing	high	xxxx
2	Category 1	Browsing, Streaming	high	xxxx
3	..	…	..	…

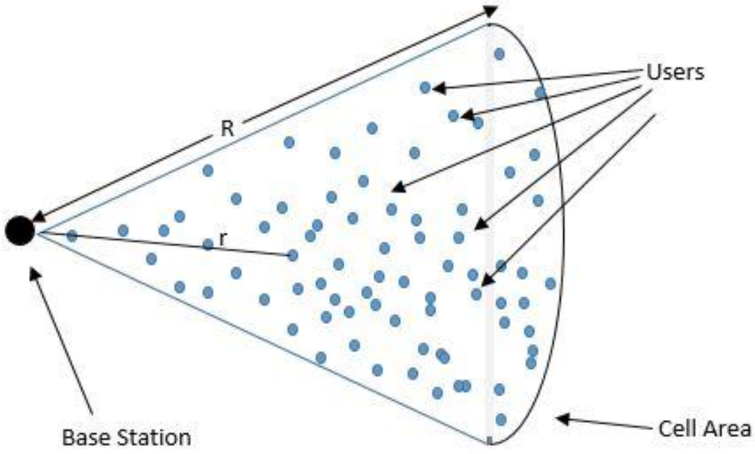


Figure 3.3: User Distribution in a cell area

As mentioned before, PDSCH is used to transfer application data. Number of PDSCHs for that purpose will depend on the following factors.

1. Number of REs allocated for PDSCH. (depends between the choice of bandwidth, normal cp and extended cp)
2. RE allocation for PDCCH (Control signaling) and other signaling.
3. Use of MIMO
4. UE Category

As a result, the cell area around the eNodeB is divided into number of zones with different SINR inside. The next step is to match a certain SINR with a corresponding CQI (Channel Quality Indicator). CQI is a specified parameter, but the relation between CQI and SINR is not straightforward. Using computer simulations, the approximation curve of CQI as a function of SINR at a user receiver input is shown in Figure 3.4.

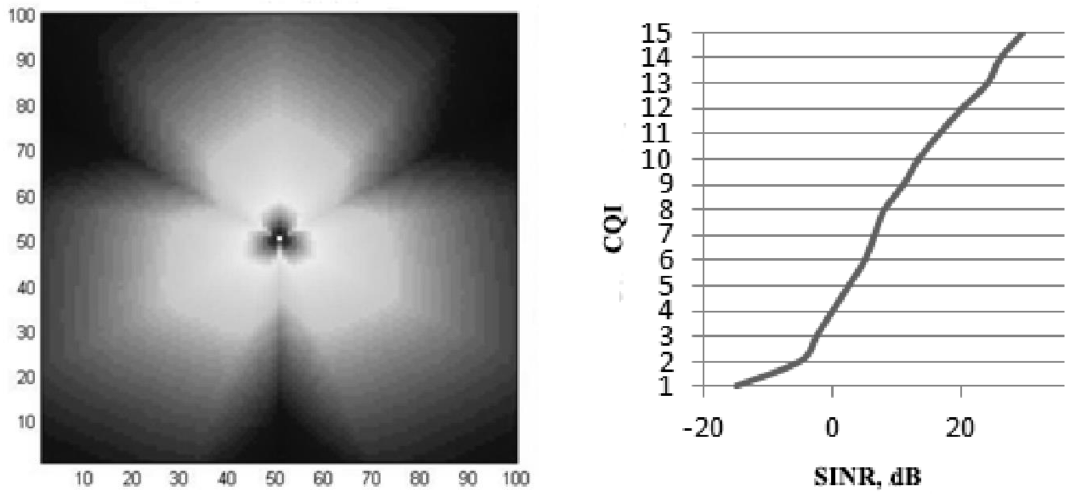


Figure 3.4: CQI distribution of a cell

. SINR distribution is assumed to be inversely proportionate to distance from the site. Please refer the following table for further details. Table 3.4 is for 2x2, 10MHz system.

Table 3.4: CQI distribution for equal sections

CQI	Modulation Code Rate	Bit Rate	Mbit/s	Distance
1	QPSK	0.08	0.95	(R/15)*14 < r < (R/15)*15
2	QPSK	0.12	1.46	(R/15)*13 < r < (R/15)*14
3	QPSK	0.19	2.35	(R/15)*12 < r < (R/15)*13
4	QPSK	0.3	3.75	(R/15)*11 < r < (R/15)*12
5	QPSK	0.44	5.47	(R/15)*10 < r < (R/15)*11
6	QPSK	0.59	7.34	(R/15)*9 < r < (R/15)*10
7	16-QAM	0.37	9.21	(R/15)*8 < r < (R/15)*9
8	16-QAM	0.48	11.94	(R/15)*7 < r < (R/15)*8
9	16-QAM	0.6	15.02	(R/15)*6 < r < (R/15)*7
10	64-QAM	0.46	17.04	(R/15)*5 < r < (R/15)*6
11	64-QAM	0.55	20.73	(R/15)*4 < r < (R/15)*5
12	64-QAM	0.65	24.35	(R/15)*3 < r < (R/15)*4
13	64-QAM	0.75	28.23	(R/15)*2 < r < (R/15)*3
14	64-QAM	0.85	31.92	(R/15) < r < (R/15)*2
15	64-QAM	0.93	34.66	0 < r < (R/15)

For deeper and complex calculations, relation between TBS and MCS is defined in 3GPP [7]. For DL calculations, the Transport Block Size (TBS) is determined by the number of RB and MCS according to TS36.213 Table 7.1.7.1-1 and Table 7.1.7.1-2. For the UL Transport Block Size (TBS) is defined in TS36.213 Table 8.6.1-1. Relation between CQI and MCS can be given as per Table 3.5,3.6 and 3.7 [8].

Table 3.5: Relation between CQI and MCS

CQI	Modulation	Bits/Symbol	MCS
1	QPSK	2	0
2	QPSK	2	0
3	QPSK	2	2
4	QPSK	2	5
5	QPSK	2	7
6	QPSK	2	9
7	16QAM	4	12
8	16QAM	4	14
9	16QAM	4	16
10	64QAM	6	20
11	64QAM	6	23
12	64QAM	6	25
13	64QAM	6	27
14	64QAM	6	28
15	64QAM	6	28

Table 3.6: Modulation and TBS index table for PDSCH

MCS Index	Modulation Order	Modulation Order	TBS Index
0	2	2	0
1	2	2	1
2	2	2	2
3	2	2	3
4	2	2	4
5	2	4	5
6	2	4	6
7	2	4	7
8	2	4	8
9	2	4	9
10	4	6	9
11	4	6	10
12	4	6	11
13	4	6	12
14	4	6	13
15	4	6	14
16	4	6	15
17	6	6	15
18	6	6	16
19	6	6	17
20	6	6	18
21	6	6	19
22	6	6	20
23	6	6	21
24	6	6	22
25	6	6	23
26	6	6	24
27	6	6	25
28	6	6	26/26A
29	2	2	reserved
30	4	4	
31	6	6	

Table 3.7 : Modulation, TBS index and redundancy version table for PUSCH

MCS Index	Modulation Order	TBS Index	Redundancy Version
0	2	0	0
1	2	1	0
2	2	2	0
3	2	3	0
4	2	4	0
5	2	5	0
6	2	6	0
7	2	7	0
8	2	8	0
9	2	9	0
10	2	10	0
11	4	10	0
12	4	11	0
13	4	12	0
14	4	13	0
15	4	14	0
16	4	15	0
17	4	16	0
18	4	17	0
19	4	18	0
20	4	19	0
21	6	19	0
22	6	20	0
23	6	21	0
24	6	22	0
25	6	23	0
26	6	24	0
27	6	25	0
28	6	26	0
29	Reserved		1
30			2
31			3

PHY layer throughput in bits per second =Transport Block Size (bits) per sub frame x Number of the scheduled sub frames per second

Cell edge throughput will have a minimum requirement. Even though there are number of throughput affecting factors, only power, bandwidth and antenna configurations are considered to be the most significant. Therefore, in this research, the best combination of the above three parameters will be found such that the cell edge throughput is maximized. Therefore, the solution will be optimized as per the constraints mentioned in 3.2. If sum of single user throughput is larger than theoretical throughput, power, bandwidth and antenna configurations will be optimized to achieve the constraint.

Following figure shows the behavior of iteration steps. Orange color hexagons are for the first iteration and blue color hexagons are for the second iteration. From this we can clearly see that coverage area of one hexagon has increased from first iteration (orange) to second iteration (blue) and number of hexagons has reduced from first to second as in figure 3.5.

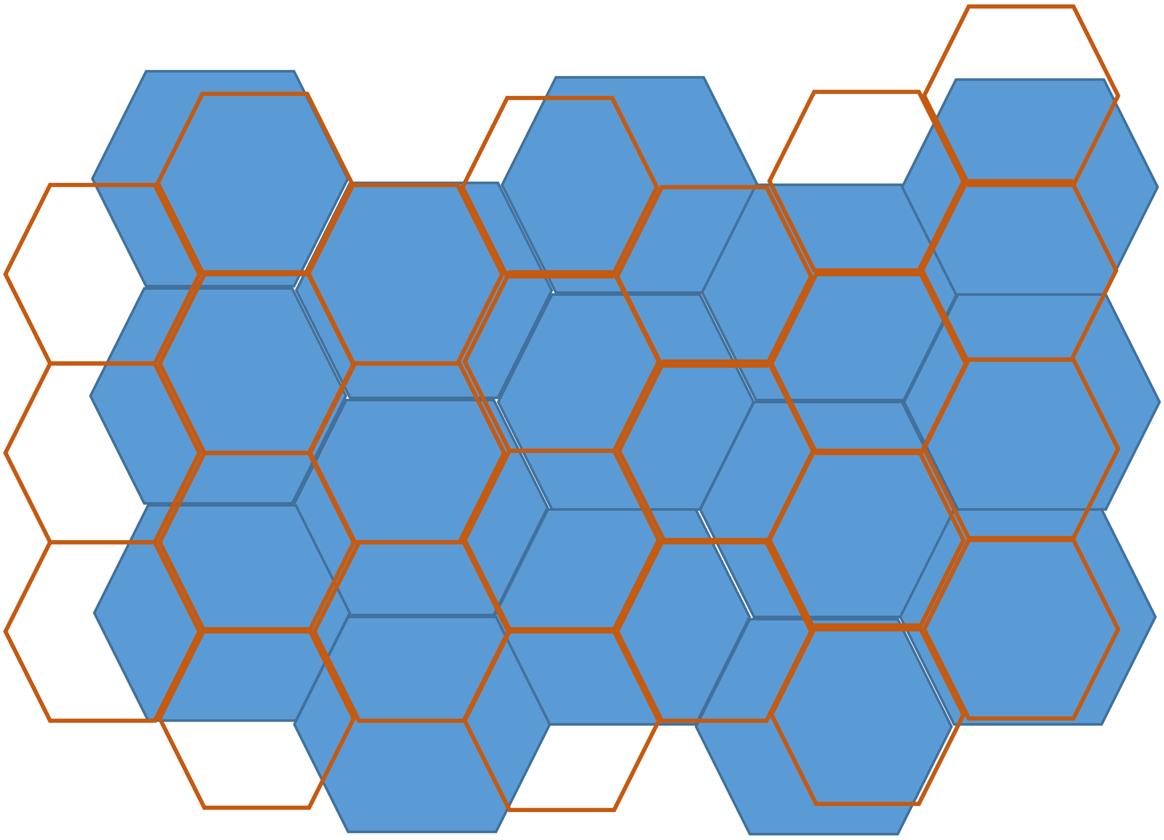


Figure 3.5: Cell density change with Cell radius

Step 4

In step 4, the theoretical maximum cell throughput is calculated as below.

Average SINR

$\boldsymbol{\gamma}_{\mathbf{ave}} = \mathbf{P}_{\mathbf{avrx,RB}} - \boldsymbol{N}_{\mathbf{RB,UL}} - \mathbf{B}_{\mathbf{IUL}}$ -----> *(22)*

Uplink Cell Throughput

$\mathbf{T}_{\mathbf{cell,UL}} = \mathbf{Q}_{\mathbf{PUSCH}} \; x \; \mathbf{n}_{\mathbf{RB,PUSCH}} \; x \; \mathbf{R}_{\mathbf{RB,UL,ave}}$ -----> *(23)*

Average Number of Resource Blocks Available for PUSCH

$\mathbf{n_{RB,PUSCH}} = \mathbf{n_{RB}} - \mathbf{n_{RB,PUCCH}} - \mathbf{n_{RB,PRACH}}$ -----> *(24)*

UE TX Power Per Resource Block when at Maximum Power

$\mathbf{P_{UE\,RB}} = \mathbf{P_{UE}} - 10\log(\mathbf{n_{RB}})$ -----> *(25)*

Signal Attenuation for Certain Rate

$$\mathbf{L_{sa}} = \mathbf{P_{UE}} - 10\log(\mathbf{n_{RB}}) - \boldsymbol{N}_{\mathbf{RB,UL}} - \mathbf{B_{IUL}} - \mathbf{a_1} + \mathbf{a_2}\left[\frac{\ln\left(\frac{a_0 - a_3}{\frac{R_{v1}}{n_{RB} \times k_{subf,UL}} - a_3}\right)}{\ln 2}\right]^{1/a_3} \quad \text{---->}(26)$$

$0 \le \boldsymbol{R}_{\mathbf{UL}} / (\mathbf{n_{RB,min}} \times \mathbf{k_{subf,UL}}) \le \mathbf{a_0}$

Signal Attenuation at Cell Border for Quality Requirement

$\mathbf{L_{sa,cell\,edge}} = \mathbf{L_{sa,cell\,range}} + \mathbf{B_{LNF}}$

$$\mathbf{L_{sa,cell\,edge}} = \mathbf{P_{UE}} - 10\log(\mathbf{n_{RB}}) - \boldsymbol{N}_{\mathbf{RB,UL}} - \mathbf{B_{IUL}} - \mathbf{a_1} + \mathbf{a_2}\left[\frac{\ln\left(\frac{a_0 - a_3}{\frac{R_{v1}}{n_{RB} \times k_{subf,UL}} - a_3}\right)}{\ln 2}\right]^{1/a_4}$$

$0 \le \boldsymbol{R}_{\mathbf{req,UL}} / (\mathbf{n_{RB,min}} \times \mathbf{k_{subf,UL}}) \le \mathbf{a_0}$

Later in this step, constraints will be checked, and most importantly it is required that the cell throughput is less than theoretical maximum. Otherwise, the iteration cycle continues by changing initially mentioned three parameters.

There is a point where the required cell throughput becomes less than the theoretical maximum. This cell radius is the optimum cell radius which determines the number of sites and the number of users.

Following figure will show the simulation results. Here, sites are optimized for one parameter and that is for UL signal attenuation. Bandwidth is fixed (10 MHz). Since the input values used for iterations are limited to fewer values, brute force method is used for optimization.

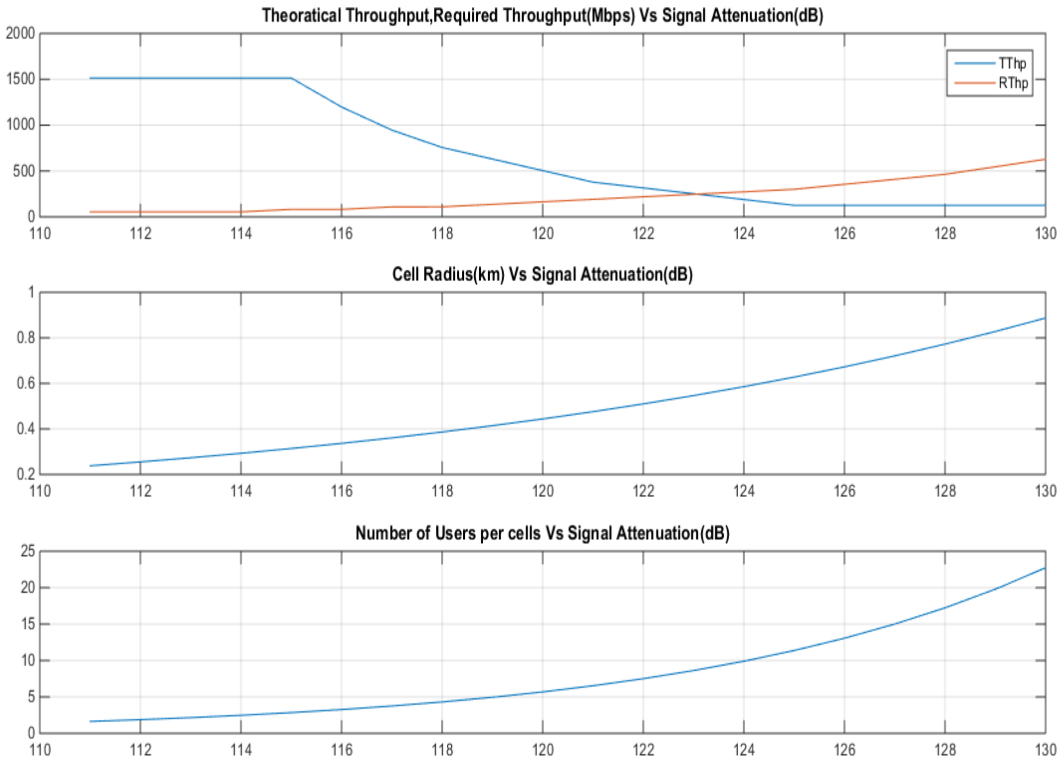


Figure 3.6: UL simulations result

Here the optimum point occurs when cell edge signal attenuation is 123 dB. At that time, the cell radius is 0.5465km and number of users per cell is 9.

Downlink Capacity Dimensioning

This method generates an optimization problem and cases are as follows.

1. When the number of users is increasing, the signaling load and time duration between successive scheduling will increase where RBs allocated for PDSCH will decrease causing lesser throughput
2. Therefore, number of cells has to be increased to reduce the number of users and throughput will be improved but that will create more interference and affects the throughput
3. When number of antennas is increasing, RBs allocated for reference signal will increase and RBs allocated for PDSCH will go down

Step1:

The first step will be the calculating the RLB. For that, we have to consider the parameters related to UL and DL which can be listed as follows [3].

Table 3.8: Downlink related parameters

Field	Description	Comments
a. Max tx power (dBm)	Base station maximum transmission power. A typical value for macro cell base station is 20–60 W at the antenna connector.	Transmitter related parameters
b. Tx antenna gain (dBi)	Base station antenna gain depends on the type of device and on the frequency band.	
	Small handheld terminal at a low frequency band (like Band VIII) can have an antenna gain of −5 dBi while a fixed wireless terminal with directive antenna can have a gain of up to 10 dBi.	
c. Cable loss (dB)	Cable loss between the base station antenna connector and the antenna. The cable loss value depends on the cable length, cable thickness and frequency band. Many installations today use RF heads where the power amplifiers are close to the antenna making the cable loss very small	
d. EIRP (dBm)	Calculated as a + b − c	
e. UE noise figure (dB)	Depends on the frequency band, Duplex separation and on the allocated bandwidth. For details.	Receiver related parameters
f. Thermal noise (dB)	Terminal noise can be calculated as k (Boltzmann constant) × T (290K) ×bandwidth. The bandwidth depends on bit rate, which defines the number of resource blocks. We assume two resource blocks for 64 kbps uplink.	
g. Receiver noise (dBm)	Calculated as e + f	
h. SINR (dB)	Signal-to-noise ratio from link simulations or measurements. The value depends on the modulation and coding schemes, which again depend on the data rate and on the number of resource blocks allocated.	
i. Receiver sensitivity	Calculated as g + h	
j. Interference margin (dB)	Interference margin accounts for the increase in the terminal noise level caused by the other cell. If we assume a minimum G-factor of −4 dB, that corresponds to 10*log10(1+10^(4/10)) = 5.5 dB interference margin	
k. Control channel overhead	Control channel overhead includes the overhead from reference signals,PBCH, PDCCH and PHICH	
l. Rx antenna gain (dBi)	UE antenna gain depends on the antenna size and the number of sectors. Typical 3-sector antenna 1.3 m high at 2 GHz band gives 18 dBi gain. The same size antenna at 900 MHz gives smaller gain	
m. Body loss (dB)	Body loss is typically included for voice link budget where the terminal is held close to the user's head	

Thus, the MAPL (Maximum Allowed Path Loss) will be simply as follows.

MAPL(DL) = Radiating Power – (Minimum Received Power + Indoor loss)

Radiating Power (a+b-c) = Max Tx Power(dBm) + TX antenna gain(dBi) – cable loss(dB)

Minimum Received Power (i+j+k-l+m) = Receiver sensitivity + Interference margin+ Control channel overhead- Rx antenna gain + Body loss

Indoor loss = value between 0-15db will be reduced randomly. Same will be carried out for UL path loss calculations.

Required Power Control Target

$$\boldsymbol{P}_{\mathbf{0,hreq}} = \boldsymbol{N}_{\mathbf{RB,UL}} - \mathbf{B}_{\mathbf{IUL}} - \mathbf{a_1} + \mathbf{a_2}\left[\frac{\ln\left(\frac{a_0 - a_3}{\frac{R_{v1}}{n_{RB} \times k_{subf,UL}} - a_3}\right)}{\ln 2}\right]^{1/a_4} \text{-----> } (28)$$

$0 \leq \boldsymbol{R}_{\mathbf{req,UL}}$ / $(\mathbf{n}_{\mathbf{RB,min}}\ \mathbf{x}\ \mathbf{k}_{\mathbf{subf,UL}}) \leq \mathbf{a_0}$

Bit Rate Requirement per Downlink Resource Block

$$\boldsymbol{R}_{\mathbf{req,RBDL}} = \frac{\boldsymbol{R}_{\mathbf{req,DL}}}{\mathbf{n}_{\mathbf{RB}}\ [\mathbf{k}_{\mathbf{subf,DL}} - \mathbf{k}_{\mathbf{subf,PRS}} + \left(\frac{\mathbf{k}_{\mathbf{subf,ss\ n\ symb,DL}}}{\mathbf{14}}\right)]} \text{-----> } (29)$$

Power per Resource Block at the TX Reference Point

$\boldsymbol{P}_{\mathbf{tr,RB}}$ = 10 log ($\boldsymbol{P}_{\mathbf{nom,ref}}$)- $\boldsymbol{L}_{\boldsymbol{f}}$ - 10 log ($\mathbf{n}_{\mathbf{RB}}$) [dB] -----> *(30)*

Calculation of Downlink Noise Rise

$$\mathbf{B}_{\mathbf{IDL,cell\ edge}} = 1 + \frac{\boldsymbol{P}_{\mathbf{tr,RB}}\ \boldsymbol{xF_c}\ [\boldsymbol{\rho_{CCH}} + (\mathbf{1} - \boldsymbol{\rho_{CCH}})\boldsymbol{Q_{PDSCH}}]}{\boldsymbol{N}_{\mathbf{RB,DL}}\ \mathbf{Lsa,cell\ edge}} \text{-----> } (31)$$

Calculation of Downlink Signal Attenuation at the Cell Range

$\mathbf{L}_{\mathbf{sa,cell\ range}} = \mathbf{L}_{\mathbf{pmax}} + \mathbf{L}_{\mathbf{BL}} + \mathbf{L}_{\mathbf{CPL}} + \mathbf{L}_{\mathbf{BPL}} - \mathbf{G}_{\mathbf{a}} + \mathbf{L}_{\mathbf{j}}$ [dB] -----> *(32)*

Equation 33 Downlink Budget Calculation

$\mathbf{L}_{\mathbf{pmax}} = \boldsymbol{P}_{\mathbf{tr,RB}} - \boldsymbol{P}_{\mathbf{UE}} - \mathbf{B}_{\mathbf{IDL,cell\ edge}} - \mathbf{B}_{\mathbf{LNF}} - \mathbf{L}_{\mathbf{BL}} - \mathbf{L}_{\mathbf{CPL}} - \mathbf{L}_{\mathbf{BPL}} + \mathbf{G}_{\mathbf{a}} - \mathbf{L}_{\mathbf{j}}$[dB]-->*(33)*

Step 2

After calculating the MAPL, cell radius has to be calculated. For that Cost231 – Hata model is selected [11] because application conditions are mostly aligned with that one.

Therefore, the equation would be,

MAPL = 46.3 + 33.9 log f – 13.82 log $\boldsymbol{h_B}$– a($\boldsymbol{h_R}$)+ [44.9 -6.55 log $\boldsymbol{h_B}$]log d+C

For sub urban and rural environments:

a($\boldsymbol{h_R}$) = (1.1 log f – 0.7) $\boldsymbol{h_R}$ - (1.56 log f – 0.8)

$$\text{where } C = \begin{cases} 3\text{ dB for metropolitan areas} \\ 0\text{ dB for medium cities and suburban areas} \end{cases}$$

f = Transmitting frequency (MHz)

$\boldsymbol{h_B}$ = Effective height of base station antenna (m)

d = Link distance or cell radius

$\boldsymbol{h_R}$ = Effective height of mobile station antenna (m)

a($\boldsymbol{h_R}$) = Mobile station antenna height correction factor

<u>Step 3</u>

After calculating the cell radius, cell area can be calculated as per cell geometrical shape. Normally a network has hexagonal three sector structure. Therefore, the formula for cell area will be as follows.

Coverage area of the site = $\frac{3\sqrt{3}}{2}\,\boldsymbol{d^2}$

Coverage area of the cell = $\frac{\sqrt{3}}{2}\,\boldsymbol{d^2}$

It is assumed that the population is uniformly distributed, therefore the number of users in a single cell can be calculated. (Given the figures of total population, market share and area of the interested area). User profiles used for calculations are given below in table 3.9.

Table 3.9: DL user profiles

		DL						
Profile Index	Service	Bearer Rate	PPP Session Time	PPP Session Duty Ratio	BLER	Resource Type	Priority	QCI
1	IMS Signaling	15.63	7	0.2	1%	Non-GBR	1	5
2	Conversational Voice(VoIP)	26.9	80	0.4	1%	GBR	2	1
3	Real Time Gaming	125.6	1800	0.4	1%	GBR	3	3
4	Conversational Video(Live Streaming)	62.53	1800	1	1%	GBR	4	2
5	Non-Conversational Video (Buffered Streaming)	250.11	3600	0.95	1%	GBR	5	4
6	Web Browsing	250.11	1800	0.05	1%	Non-GBR	6	6
7	File Transfer	750.34	600	1	1%	Non-GBR	7	7
8	Email	750.34	15	1	1%	Non-GBR	8	8
9	P2P File Sharing	750.34	1200	1	1%	Non-GBR	9	9
10	Combination of 2+6	277.01	1800	0.05	0.01		2	1
11	Combination of 2+7	777.24	600	1	0.01		2	1
12	Combination of 2+8	777.24	15	1	0.01		2	1
13	Combination of 2+9	777.24	1200	1	0.01		2	1

Step 4

In this step, the actual throughput of users will be calculated. The value that can be anticipated in the field users will be placed randomly and individual throughout will sum up. This operation will be carried out around 10,000-20,000 iterations until the mean value converges.

UE Receiver Sensitivity

$\boldsymbol{S}_{\mathbf{UE}} = \boldsymbol{N}_{\mathbf{t}} + \boldsymbol{N}_{\mathbf{f,UE}} + 10\log(\boldsymbol{W}_{\mathbf{RB}}) + \Upsilon = \boldsymbol{N}_{\mathbf{RB,DL}} + \Upsilon$ [dB] -----> *(34)*

Calculation of SINR at Cell Edge

$\Upsilon_{\mathbf{Cell\ edge}} = \boldsymbol{P}_{\mathbf{tr,RB}} - \mathbf{L_{pmax}} - \boldsymbol{N}_{\mathbf{RB,DL}} - \mathbf{B_{IDL,cell\ edge}} - \mathbf{B_{LNF}} - \mathbf{L_{BL}} - \mathbf{L_{CPL}} - \mathbf{L_{BPL}} + \mathbf{G_a} - \mathbf{L_j}$ --> *(35)*

Bit Rate at Cell Edge

$\mathbf{R}_{\mathbf{Cell\ edge,DL}} = \mathbf{R_{RB,Cell\ edge,}}\ \mathbf{x}\ \boldsymbol{n}_{\mathbf{RB}}\ [\mathbf{k_{subf,DL}} - \mathbf{k_{subf,PRS}} + \left(\frac{\mathbf{k_{subf,ss\ n\ symb,DL}}}{\mathbf{14}}\right)]$ -----> *(36)*

Average Downlink Noise Rise

$\mathrm{B}_{\mathrm{IDL,\ ave}} = 1 + \frac{\boldsymbol{Ptr,RB\ F[\rho CCH+(1-\rho CCH)Q\ PDSCH]}}{\boldsymbol{NRB,DL\ x\ L}_{\mathbf{sa,cell\ range}}}$ -----> *(37)*

$\mathbf{B_{IDL,ave}} = 1 + \frac{\boldsymbol{P}_{\mathbf{tr,RB}}\ \boldsymbol{xF}\ [\boldsymbol{\rho_{CCH}}+(\mathbf{1}-\boldsymbol{\rho_{CCH}})\boldsymbol{Q_{PDSCH}}]}{\boldsymbol{N}_{\mathbf{RB,DL}}\ \mathbf{x}\ \boldsymbol{L}_{\mathbf{sa,cell\ edge}}}$

Average Downlink SINR

$$\gamma_{ave} = \frac{P_{tr,RB}}{B_{IDL,ave} \times N_{RB,DL} \times L_{sa,cell\ range}} \text{ -----> } (38)$$

Average Downlink User Bit Rate per Subframe

$$R_{ave,sub\ f,DL} = n_{RB} \times R_{RB} \text{ -----> } (39)$$

Average Downlink User Bit Rate per Cell

$$R_{ave,DL} = R_{ave,sub\ f,DL}\ [\ k_{subf,DL} - k_{subf,PRS} + \left(\frac{k_{subf,ss\ n\ symb,DL}}{14}\right)] \text{ -----> } (40)$$

Downlink Cell Throughput

$$T_{cell,UL} = Q_{PDSCH}\ x\ R_{ve,DL} \text{-----> } (41)$$

Step 5

Finally, the practical value will be compared with the theoretical value [4][5]. If the practical value is less than the theoretical value, process continues from Step 1 with different input values.

Iteration will compute the number of sites required, based on the uplink requirement (UL_Site_Count). Same procedure will be continued to find the number of sites required such that it suits the downlink requirements (DL_Site_Count).

After that, maximum out of both the counts will be considered as the final site count.

Final site count = max(UL_Site_Count, DL_Site_Count)

4 Results and Discussion

This chapter is used to discuss the practical implementations of the method proposed in Chapter 3 to optimize the final site count, which gives the highest practical cell throughput while satisfying operator requirements. As mentioned earlier, there will be a constraint on the minimum cell throughput. Although there are number of factors that affect throughput, only few of them can be considered significant. They are transmitting power, bandwidth, and antenna configuration. Therefore, in this research, the best combination of the above three variables will be found, such that the cell DL and UL throughputs are maximized. Calculations are based on parameter values as defined in Table 4.1 and results are shown in Table 4.2.

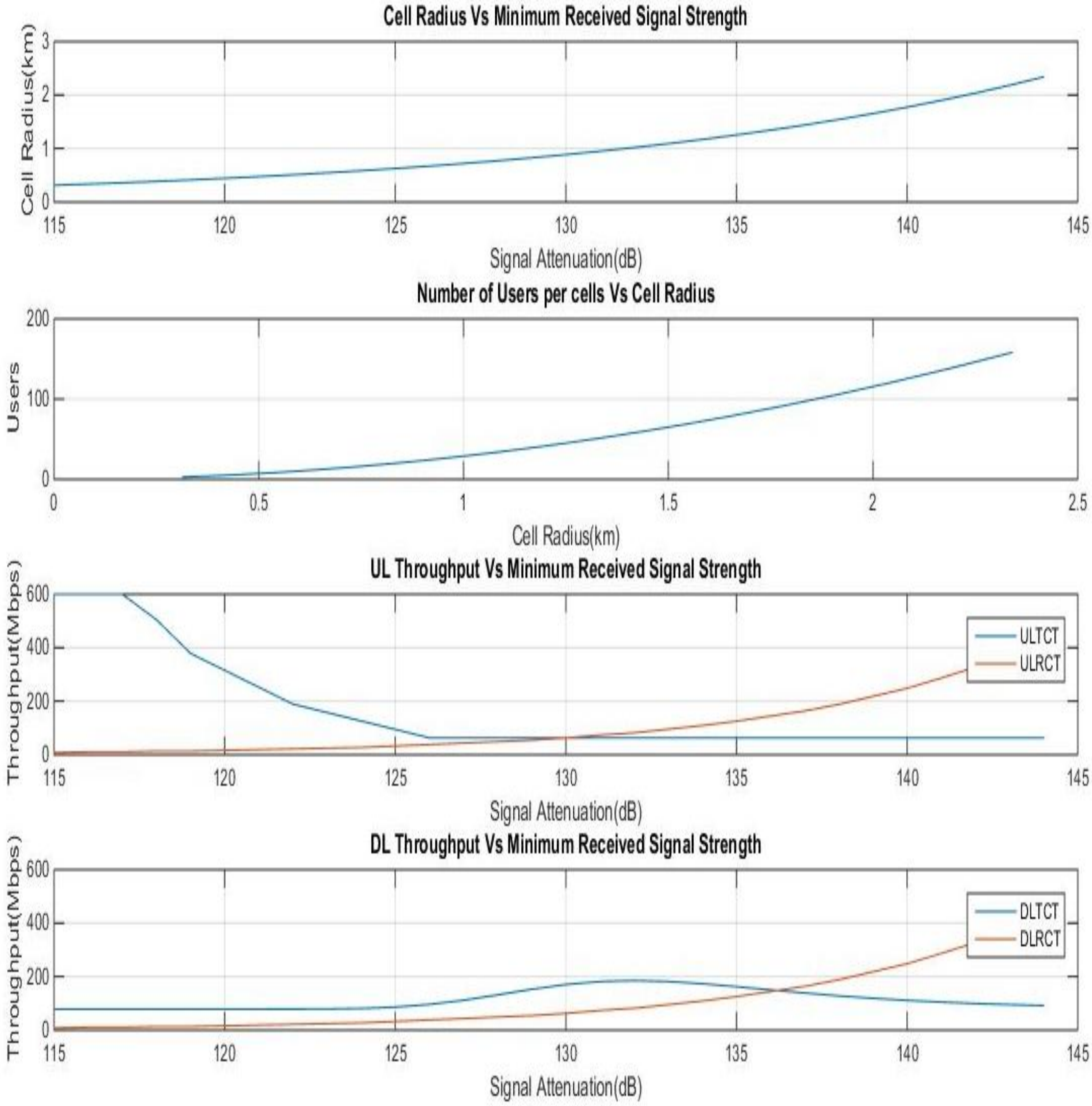
Table 4.1: Input parameters for sample calculation

Parameter	Value
Bandwidth (Bmax)	10MHz
Antenna scheme (Mmax)	2x2
Power (Pmax)	10W
Frequency Band	1800 Band (Band 3)
Total Geographic area	10,000 km2
Total Subscriber Base	1,000,000
PUSCH Load	75%
PDSCH Load	90%

Table 4.2: Results

Parameters	Uplink	Downlink
Cell access threshold	-131 dBm	-135 dBm
Required Cell Throughput	65.64 Mbps	125.6 Mbps
Cell Radius	0.951 km	1.254 km
Site Count	4255	2448
Number of Users per cell	78	136

Figure 4.1: Simulation output of capacity dimensioning for dense area



As shown in Figure 4.1, cell radius can be found for each minimum signal strength, and TCT and RCT are calculated for each scenario. In order to satisfy the UL user requirement, it is required to deploy 4255 sites. Since this is a highly dense area needing a lot of sites, the DL site count is less than the UL requirement. Therefore, as suggested in the procedure, by choosing the UL site requirement, both UL and DL user requirements can be catered. That means by deploying 2448 sites, DL cell speed will be 125.6 Mbps. Since in this approach the minimum site count will be given at the point where the least gap between required cell throughput and theoretical cell throughput. Figure 4.2 and figure 4.3 confirms that the optimum solution has been obtained for the requirement, respectively, for uplink dimensioning and downlink dimensioning.

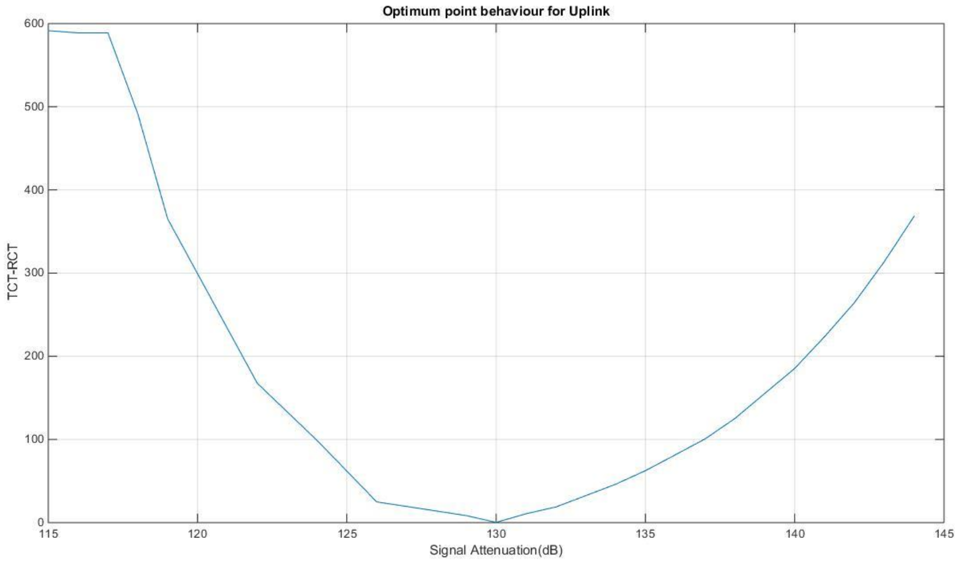


Figure 4.2: Minimum point calculation for uplink

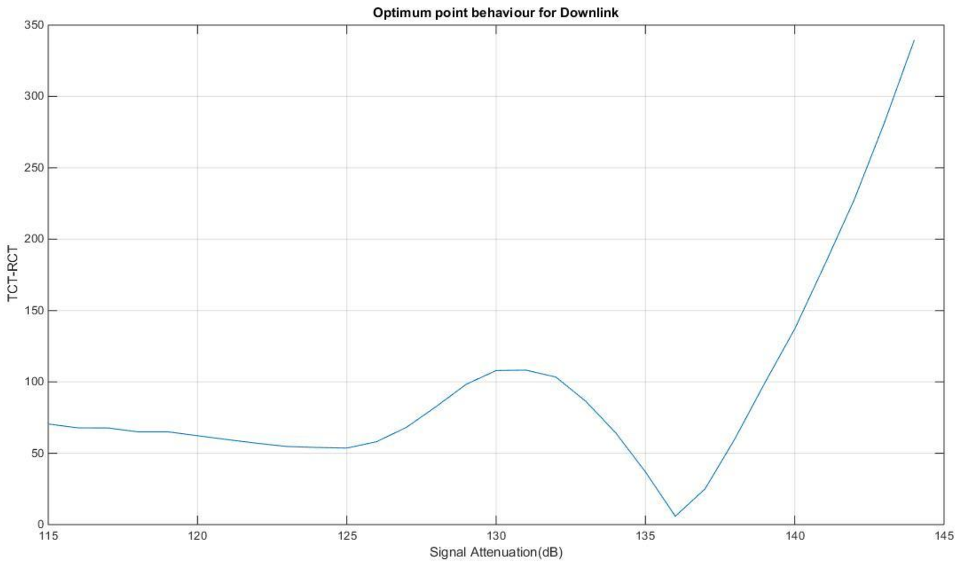


Figure 4.3: Minimum point calculation for downlink dimensioning

According to the above graphs, it is clearly visible that the optimum site count is achieved with the highest possible throughput and the cell edge coverage would be 131dBm for the UL, and 133dBm for the DL, respectively. DL speed requirement is simultaneously satisfied when the UL requirement is satisfied, but not vice versa. Therefore, site count required to cater UL requirement is considered as the final site count to be implemented.

The second set of calculations is done for a rural area. Same parameters will be considered as above, excluding the population within the area, which is now 10,000. Results are shown in figure 4.4 and figure 4.5 .

Figure 4.4: Simulation output of capacity dimensioning for rural area

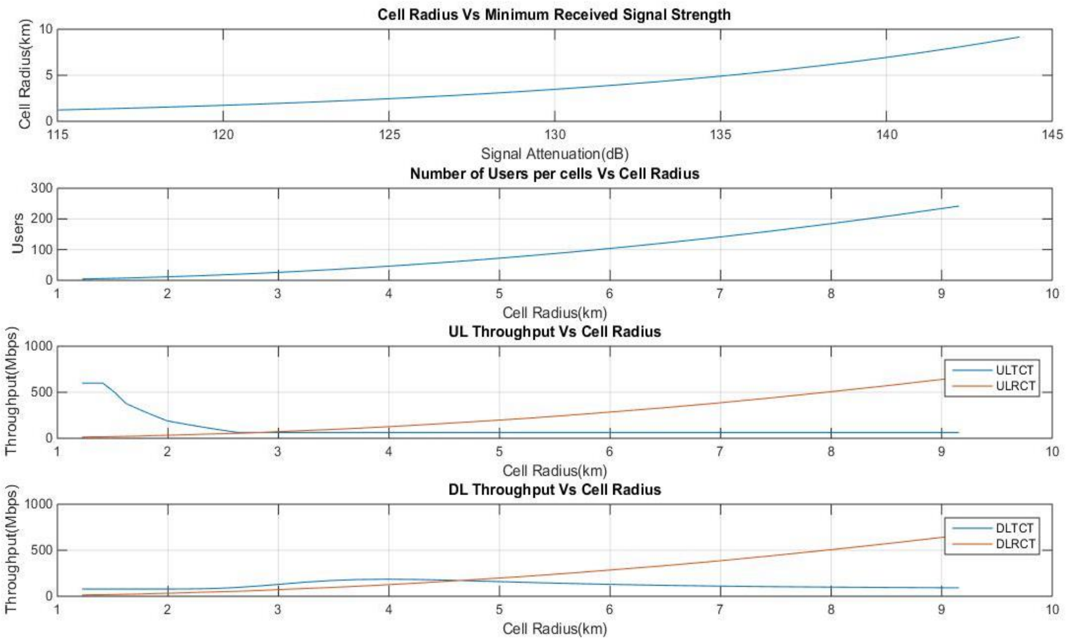
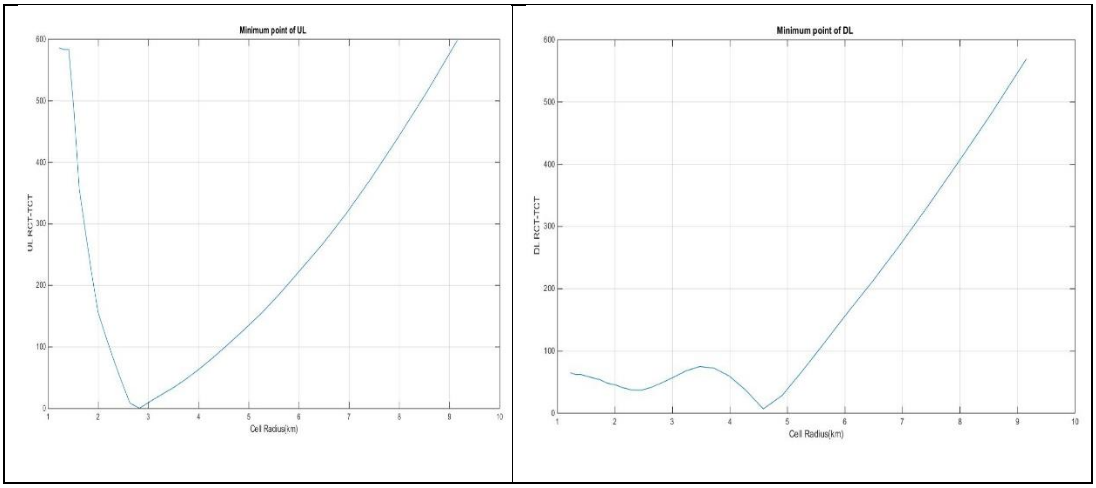


Figure 4.5: Optimum point calculation for rural area



The results for rural area are tabulated in Table 4.3.

Table 4.3: Calculation results for rural area

Parameters	Uplink	Downlink
Cell access threshold	-133 dBm	-135 dBm
RCT	71.33 Mbps	138.2 Mbps

Cell Radius	2.89 km	4.76 km
Site Count	460	169
Number of Users per cell	8	20

A similar methodology is adhered in [25], and their results are shown in Table 4.4.

Table 4.4:LTE link budget for best effort services

Morphology	Dense urban		urban		Suburban		Rural	
Data channel type	PUSCH	PDSCH	PUSCH	PDSCH	PUSCH	PDSCH	PUSCH	PDSCH
Duplex mode	FDD		FDD		FDD		FDD	
User environment	Indoor		Indoor		Indoor		Indoor	
System bandwidth(MHz)	20		20		20		20	
Cell edge rate (kbps)	128	512	128	512	128	512	128	512
Transmitter								
Maximum total Tx power (dBm)	23	46	23	46	23	46	23	46
Allocated RB	3	19	3	19	3	19	3	19
RB to distribute power	3	100	3	100	3	100	3	100
Subcarriers to distribute power	36	1200	36	1200	36	1200	36	1200
Subcarrier power (dBm)a	7.44	15.21	7.44	15.21	7.44	15.21	7.44	15.21
Tx antenna gain (dBi)	0	17	0	17	0	17	0	17
Tx cable loss (dB)	0	0.5	0	0.5	0	0.5	0	0.5
Tx body loss (dB)	0	0	0	0	0	0	0	0
EIRP per subcarrier(dBm)	7.44	31.71	7.44	31.71	7.44	31.71	7.44	31.71
Receiver								
SINR (dB)	−4.19	−5.37	−4.19	−5.37	−2.33	−4.94	−2.20	−4.43
Rx noise figure (dB)	2.3	7	2.3	7	2.3	7	2.3	7
Receiver sensitivity (dBm)	−134.13	−130.61	−134.13	−130.61	−132.26	−130.18	−132.14	−129.67
Rx antenna gain (dBi)	17	0	17	0	17	0	17	0
Rx cable loss (dB)	0.5	0	0.5	0	0.5	0	0.5	0
Rx body loss (dB)	0	0	0	0	0	0	0	0
Target load (%)	75	90	75	90	75	90	75	90
Interference margin(dB)	0.89	2.72	0.89	2.72	1.46	3.13	2.71	3.74
Minimum signal reception strength(dBm)	−149.74	−127.89	−149.74	−127.89	−147.31	−127.05	−145.93	−125.93
Path loss and cell radius								
Indoor penetration loss(dB)	19	19	15	15	11	11	8	8
Standard deviation of shadow fading (dB)	11.7	11.7	9.4	9.4	7.2	7.2	6.2	6.2
Area coverage probability (%)	95	95	95	95	95	95	90	90
Shadow fading margin (dB)	9.43	9.43	8.04	8.04	5.99	5.99	1.87	1.87
Maximum allowable path loss (dB)	128.74	131.16	134.13	136.56	137.76	141.77	143.5	147.77
eNodeB/UE antenna height (m)	25	1.5	30	1.5	40	1.5	50	1.5
Cell radius (km)	0.47	0.55	0.87	1.02	2.13	2.78	5.64	7.54

According to this result, for an urban area, cell radius is 1.02km, where UL/DL throughputs are less. Also, bandwidth usage is less, where the UL and DL minimum signal reception strengths are more likely to be the same. Below table 4.5 shows the comparison of both attempts.

Table 4.5: Comparison between the user method and similar method

Indicators	Proposed Method	Alternate Method [25]
Morphology	Urban	Urban
TX Power(UL/DL)- dBm	23/46	23/46
Bandwidth – MHz	10	10
Target Load(PUSCH/PDSCH)	75/90	75/90
Minimum Signal Reception Strength(UL/DL) – dBm	-131.23/-134.85	-149.74/-127.89
Cell Edge Throughput(UL/DL) - kbps	233/708	128/512
Cell Radius (UL/DL) - km	0.95/1.254	0.87/1.02

Moreover, there are similar attempts discussed in the literature review showing similar values. According to the results of Abdul Basit,2009[16] similar cell radius can be observed, but with different throughput due to using early stage of LTE releases. [Figure from Abdul is referred will further reveal the similarity of results.]

Figure 4.6: Sample calculations from the Literature

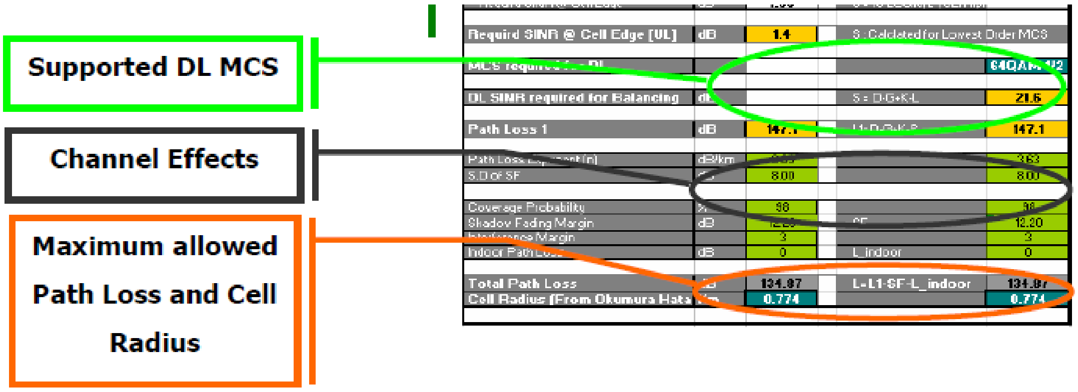


Figure 6-4: Dimensioning tool: Capacity evaluator

Source: Abdul Basit, Syed,2009 [16]

From the comparison of the results given in Table 17, it is clear that the minimum signal reception strength and the cell radius are quite similar. However, it is difficult to compare all the input and output parameters since there are no attempts performed on similar data. In this approach, the optimum site count is dimensioned by fixing the bandwidth and the antenna scheme.

5 CONCLUSION AND FURTHER RESEARCH WORK

In this chapter, author intends to summarize the proposed network dimensioning scheme. Further, author explains on the results obtained and key observations made and comparison with the existing schemes. Finally, it discusses how this research can be extended for further research and other related work which can evolve with this.

LTE networks are the fastest broadband service providing method all over the world as at now. Most of the operators utilizing their spectrum in this technology refarming 2G and 3G by understanding the importance of this technology. Even though LTE is completely packet switching technology it has been able to satisfy real time services such as voice communication through packet forwarding. However, transition from 3G to 4G is not simple as changing from 2G to 3G. Existing core network cannot be used to connect LTE access network equipment, therefore both access and core equipment need to be replaced. Therefore, these projects require lot of funding and correct dimensioning is essential to avoid unnecessary expenditures.

Knowing the importance of LTE network dimensioning, all over the world engineers are using different techniques for both initial and detailed planning. These methods inherit advantages and disadvantages in its own way and in this study a new method has proposed to find the minimum site count while satisfying the operator defined throughput. This is an iterative method under resource constraints such as power, bandwidth and number of antennas used to transmit and receive. In this report all the steps were exhibited using flow charts and tables to convey the concept. Constraint optimization is the main concept used by the author, which uses multiple iterations to figure out the optimum point that satisfies initially defined conditions.

The proposed method in this research is can't be compared with the sophisticated software tools which are already in the market, due to complexity handled with more detailed parameters (detailed planning with ground clutter). But this method can be integrated to that software to enhance the final outcome. Hence for operators, using this method basic idea can be taken to start an expansion project without incurring lot of cost for a high end planning tool. In the thesis, results have been compared with existing nominal planning approaches. In chapter 4, sample calculations have been shown for two scenarios (Urban and rural scenarios) and compared the result with a similar approach [25].

All the input parameters are equal and therefore output can be compared without less difficulties. In conclusion, since this method is built around quality perspective and is more concerned about guaranteeing minimum throughput, number of site count is slightly higher than the traditional output. However, it is operator's choice to decide on the adjusting factor so the site count can be adjusted as per the allocated budget.

As stated before, the dimensioning scheme has been implemented in MATLAB. It has been observed that it took considerable amount of time to provide the expected result. Hence it is required to improve the efficiency of coding in a way that can provide faster results.

Also thesis work can be easily extended along the bandwidth and antenna scheme axis, since in this particular attempt both are fixed for simplicity of iterations. Eventually optimum power to transmit, optimum antenna combination and bandwidth can be obtained while satisfying given conditions. For a more advance extension this can be implemented with machine learning.

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