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Dimensioning of LTE Network

Description of Models and Tool, Coverage and Capacity Estimation of 3GPP Long Term Evolution radio interface

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Masters Thesis submitted in partial fulfillment of the requirements for the Degree of Masters of Science in Technology

Espoo, February, 2009

Supervisor: Professor Riku Jäntti

Instructor: Paolo Zanier

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DEDICATION

To

Prophet of Islam

MUHAMMAD

(Peace and blessings of God be upon him)

HELSINKI UNIVERSITY OF TECHNOLOGY **Abstract of the Master's Thesis**

Author: Abdul Basit, Syed

Name of Thesis: Dimensioning of LTE Network. Description of Models and Tools, Coverage and Capacity Estimation of 3GPP Long Term Evolution

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Long Term Evolution (LTE) is 3GPP enhancement to the current cellular system in use. The purpose of developing this system is to keep 3GPP systems competent enough for decades to come. LTE is designed to have wider channels up to 20MHz, with low latency and packet optimized radio access technology. The peak data rate envisaged for LTE is 100 Mbps in downlink and 50 Mbps in the uplink. With OFDM as the radio access technology, LTE has very promising features, like bandwidth scalability and both FDD and TDD duplexing methods. This thesis is related to the dimensioning of LTE radio access networks and the development of tool for dimensioning purpose.

Different steps of the dimensioning process are listed and explained. Methods and models for coverage and capacity planning are developed for dimensioning of LTE radio access networks. Special emphasis is laid on radio link budget along with detailed coverage and capacity. The results are fabricated in an easy-to-use tool for dimensioning. The tool is made in Excel to serve the ease of working.

Particular importance is given to clarity in the design of dimensioning tool, achieved by dividing the tool into clearly defined sections. Inputs and outputs are placed on separate sheets. The dimensioning tool calculates the number of cells needed to cover a given area with the user-provided parameters. Excel based tool covers all the basic aspects of the dimensioning process for LTE Access Networks.

Keywords: 3GPP, LTE, Dimensioning, Network Planning, Capacity, Traffic Models.

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Syed, Abdul Basit

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List of Abbreviations

2G	2nd Generations
3G	3rd Generations
3GPP	3rd Generation Partnership Project
ACK	Acknowledgment
aGW	Access Gateway
ARIB	Association of Radio Industries and Businesses
ATIS	Alliance for Telecommunications Industry Solutions
ANSI	American National Standards Institute
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
DVB-H	Digital Video Broadcast - Handhelds
E-UTRAN	Enhanced – UMTS Terrestrial Radio Access Network
eNB	Enhanced Node B
EPC	Evolved Packet Core
eSFN	Enhanced System Frame Number
ETSI	European Telecommunications Standard Institute
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
GSM	Global System for Mobile
GPRS	General Packet Radio System

GGSN	Gateway GPRS Support Node
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSUPA	High Speed Uplink Packet Access
HS-DSCH	High Speed Downlink Shared Channel
HS-PDSCH	High Speed Physical Downlink Shared Channel
HS-SCCH	High Speed Shared Control Channel
IP	Internet Protocol
IETF	Internet Engineering Task Force
L1	Layer 1
L2	Layer 2
LB	Long Block
LTE	Long Term Evolution
MAC	Medium Access Control
MBMS	Multimedia Broadcast Multicast Service
Mbps	Megabits per second
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
PDSCH	Physical Downlink Shared Channel
PHY	Physical Layer
PS	Packet Switched
PDSCH	Physical Downlink Shared Channel

PDSCCH	Physical Downlink Shared Control Channel
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
RRC	Radio Resource Control
SAE	System Architecture Evolution
SB	Short Block
SFN	System Frame Number
SGSN	Serving GPRS Support Node
SINR	Signal to Interference and Noise Ratio
SISO	Single Input Single Output
SNR	Signal to Noise Ratio
SC-FDMA	Single Carrier-Frequency Division Multiple Access
SCTP	Stream Control Transmission Protocol
TDD	Time Division Duplex
TE	Terminal Equipment
TTA	Telecommunications Technology Association
TTC	Telecommunication Technology Committee
TTI	Transmission Time Interval
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunication System
UPE	User Plane Entity
UTRAN	UMTS Terrestrial Radio Access Network
U-plane	User Plane
WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access

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1 Introduction

Telecommunication industry is experiencing the emergence of a number of competing and enhancing technologies, including, WiMAX, HSPA, DVB-H. With the user requirements on the ever increasing side cellular networks are facing greater than ever competition from other technologies. HSPA (High speed packet access) and MBMS (multimedia broadcast and multicast service) has enhanced the 3G networks by bringing important capabilities, but these improvements are still not enough to match broadcasting technologies (such as DVB-H) or broadband wireless access (like WiMAX) for delivering modern services, e.g. mobile TV, internet access and other important services[1]. Therefore, 3G networks need a major overhaul to remain competitive in the future.

In order to stay competitive in the long run, 3GPP (Third generation partnership project) has initiated activity on the long term evolution of UTRAN (Universal Terrestrial Radio Access Network), which is eyeing clearly beyond to what the WCDMA can do with HSDPA or High Speed Uplink Packet Access (HSUPA). 3GPP's answer to this demanding situation is 3G LTE (Long term evolution) or Super 3G, which could dramatically boost the capabilities of 3G networks and make it par with the other technologies [2].

LTE is a system with larger bandwidths (up to 20 MHz), low latency and Packet optimized radio access technology having peak data rates of 100 Mbps in downlink and 50 Mbps in the uplink [3,4]. Radio access technology for LTE is OFDM (Orthogonal frequency division multiplexing) which provides higher spectral efficiency and more robustness against mulitpath and fading, as compared to CDMA (Code division multiple access). In order to offer the operators increased flexibility in network deployment, the LTE system supports bandwidth scalability and both FDD and TDD duplexing methods. The system also supports both unicast and multicast traffic – in cell sizes from local area or micro cells (hundreds of meters) up to large macro cells (>10 km in radius) [4,5]. 3GPP is looking for market introduction of LTE around 2012.

1.1 Objectives and Approach

This work describes the dimensioning process of 3GPP LTE access network, its models, methods and the tool developed to dimension the network.
The main objectives are listed below:

- Introduction of LTE features relevant for the dimensioning
- Definition of the basic models for Access Network Dimensioning
- Coverage Estimation
- Network Element Count Estimation
- Capacity Evaluation
- Development and description of dimensioning tool

The paragraphs below clarify the basic approach pursued to achieve the above mentioned objectives, the development of the tool and the factors needed to realize the target.

1.1.1 Methodology

LTE is a new technology, largely in the state of standardization. This means that it is very difficult to find the references and previous works on this subject. Mostly, 3GPP standardization documents and drafts have to be relied up on.

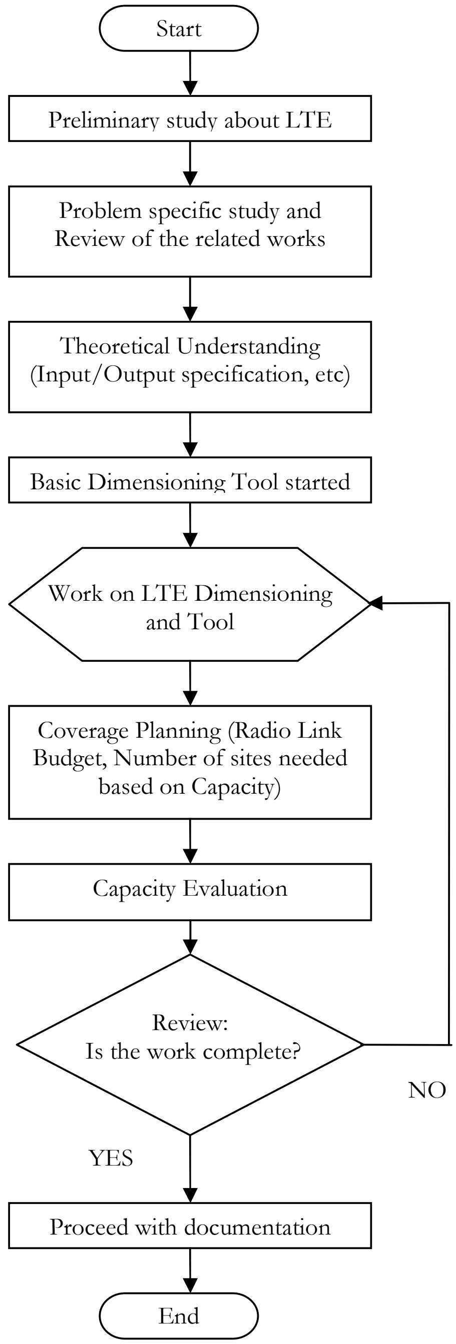


Figure 1-1: Flow chart of Project Work

The above flow chart shows the methodology followed during this project. The work started with the preliminary study of the LTE. This included 3GPP as well as the Nokia documents. This is followed by shifting the focus on the project and study of the material related to the project, especially, dimensioning. Preliminary work on the dimensioning tool is then started, along with the theoretical work on the radio link budget, and capacity planning. After integration of the results in the dimensioning tool, the work is reviewed and iterations are performed till the desired results are reached.

1.1.2 Dimensioning Tool

Excel is chosen for the implementation of the dimensioning tool over the MATLAB. The major reason behind this choice is the simplicity and the universal availability of Excel-based software [6, 7]. The basic ideology behind the tool is to make it as user friendly as possible. This is achieved by clearly separating different functional parts of the tool into separate sheets in the tool. Inputs and outputs are placed on distinct sheets, with all the data on separate sheets. Inspiration for this split is to clearly distinguish the working part and the user part. Users of the dimensioning tool only have to deal with the input sheet. User can enter all the inputs in one place and can then go directly to the output sheet to view the results. This is very different from the previous excel-based dimensioning tools for other technologies. Most of those tools fail to clearly distinguish the inputs and it need a lot of time before the user become acquainted with them. The excel-based dimensioning tool developed during this work caters all these shortcomings.

1.2 Thesis Layout

Thesis report consists of seven chapters. Chapter 1 introduces basic methodology, objectives and approach for this work. Chapter 2 deals with the necessary background. This includes basics of LTE technology and its features related to network dimensioning. Chapter 3 explains the dimensioning fundamentals and features of LTE related to the dimensioning process. Chapter 4 presents LTE coverage Planning. This chapter covers the Radio Link Budget and the related methods and factors with the text explaining the method to calculate the number of sites based on the coverage. Chapter 5 describes the capacity planning for LTE Network elaborating the methods used and factors impacting the capacity planning process. Cell throughput calculation, traffic demand estimation and capacity based site count estimation are derived in this chapter. Chapter 6 relates to the dimensioning tool. It explains the structure and functionalities of the software and discusses a use case. Chapter 7 concludes the thesis with summary of the entire project and possibilities of future research.

2 Long Term Evolution of 3GPP (LTE) and Dimensioning

Although HSDPA and HSUPA have enough capability to remain competitive for many years to come, in order to ensure that the 3GPP communication systems will continue to be competitive, Long Term Evolution of 3GPP access network is undergoing standardization (System Architecture Evolution, SAE, refers to the corresponding core network activity). The basic objectives of LTE framework is to build up a system that meets demands for high data rate, low latency and optimization for packet-domain traffic. LTE system will be designed to have a peak data rate of 100 Mbps in DL and up to 50 Mbps in the UL. The following text describes the basic features of LTE system: the requirements put forth, multiple access techniques to be used, bandwidth scalability, network architecture and channel functions and structure.

This chapter deals with targets set forth for LTE, its features especially those related to the dimensioning of the network. The later part of the chapter discusses the dimensioning exercise, description of the inputs and outputs and different steps carried in order to dimension the network.

2.1 LTE Overview

3GPP started working on evolution of 3G Mobile Systems in November 2004. The occasion was the RAN Evolution Work Shop in Toronto, Canada. This work shop was open for all the interested organizations, members and non members of 3GPP [8]. This led to the participation of more than 40 contributions from all fields of Mobile business. This involved operators, manufacturers and research institutes giving their views on the evolution of Universal Terrestrial Radio Access Network (UTRAN) [9].

A set of high level requirements was identified in the Work Shop to further improve service provisioning and reduce user and operator costs. Talking more explicitly, main objectives and targets of LTE development can be stated as follows:

- Increase in system capacity and reduced cost per bit, as well as utilization of existing 2G and 3G spectrum along with the new spectrum.
- Achieving of notably higher data rates weighed against the existing 3G systems, with goal of 100Mbps in uplink and over 50Mbps in downlink.
- Greater coverage by providing higher data rates over wider areas and flexibility of use of existing and new frequency bands
- Attaining higher system capacity up to three times the capacity of current systems and increased service provisioning – more services at lower cost with better user experience.

2.2 Requirements for LTE

LTE system is expected to be competitive for many years to come, therefore, the requirements and targets set forth for this system are quite stringent. The main objectives of the evolution are to further improve service provisioning and reduce user/operator costs. More specifically, some key requirements and capability targets for the long-term evolution are [10]:

- Low latency : for both user plane and control plane, with a 5MHz spectrum allocation the latency target is below 5 ms
- Bandwidth Scalability : different bandwidths can be used depending upon the requirements (1.25 to 20 MHz)
- Peak Data Rates : 100 Mbps for DL , 50 Mbps for UL
- 2 to 3 times capacity over existing Release 6 scenarios with HSUPA
- 2 to 4 times capacity over existing Release 6 scenarios with HSDPA
- Only Packet Switched Domain support
- Improved Cell edge performance
- Inter-working with the existing 2G and 3G systems and non-3GPP systems
- Optimized for low mobile speed but also support high mobile speeds
- Reduction of complexity in both system and terminals
- Ease of migration from existing networks
- Simplification and minimization of the number of interfaces

A key requirement for LTE is to make possible a seamless transition from current telecommunication systems. This can be made possible by reuse of the current spectrums, interoperability between current and upcoming system, reuse of existing sites and production competitively priced equipment. It gives the operators the ability to migrate to new systems with ease. But this requires adoption of simplified system architecture, stringent limits on spectrum and usage of a new radio-access technology with better characteristics.

2.3 Multiple Access Techniques

The requirements discussed in section 2.2 above were used to determine the choice of air interface technology [11]. According to the study conducted, keeping in mind all the spectrum requirements, data rates and performance, it was concluded that the multiple access technology used would be orthogonal frequency-division multiplexing (OFDM) in DL.

For the UL, selection was made in the favor of single-carrier-based frequency division multiple access (FDMA) solution with dynamic bandwidth. The basic motivation for this approach was to reduce power consumption of the user terminal. The basic parameters .e.g. sub-frames and TTI were matched with those of the DL.

2.3.1 OFDMA for DL

In DL, the chosen transmission scheme is OFDM with Cyclic Prefix (CP), mainly due to simplicity of the receiver (for a comprehensive discussion of OFDM and OFDMA, See [12] and [13]. OFDM yields a frequency structure that divides the data over a number of sub-carriers. The spacing between two sub-carriers is fixed at 15 kHz. A resource block (smallest unit in time and frequency) is defined to consist of 12 sub-carriers in frequency and 14 continuous symbols in time. The makes one resource block to span 180 kHz and 1ms in frequency and time respectively. This sub-frame is also the minimum transmission time interval (TTI). This choice of short TTI helps to achieve the requirements of low latency. In fact, although OFDM exhibits a higher peak-to-average-power-ratio, this is not considered to be a major problem on the network side.

Flexibility in channel bandwidth is provided by allowing six different bandwidth options for operators to choose from. Allowed channel bandwidths include 1.25, 2.5, 5, 10, 15 and 20 MHz. As mentioned above sub-carrier spacing is fixed for all the possible bandwidths at 15 KHz. Corresponding to the sub-carrier spacing of 15 KHz, symbol time is 1/Tb = 66.68 μs. To avoid ISI, a Guard Interval is inserted between two consecutive symbols. The Guard Interval is then filled with the CP. This means that a copy of fixed number of last samples is appended to the start of the symbol. The structure of one full OFDM Symbol is shown in figure 2-1.

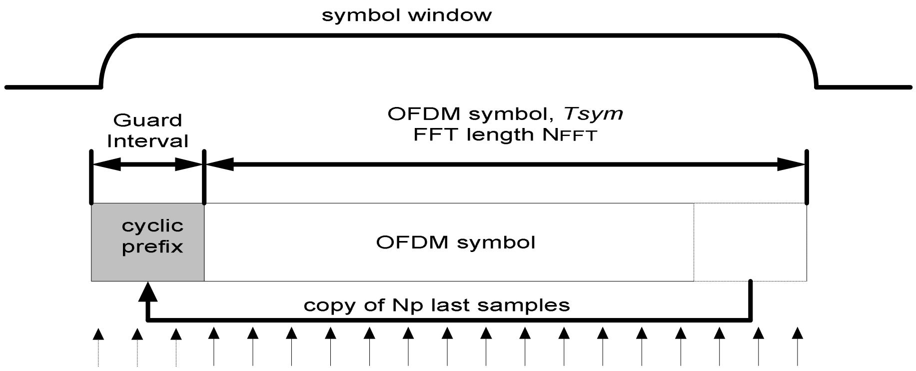


Figure 2-1: OFDM Symbol Time Structure [11]

As the spacing of sub-carriers is fixed, the transmission bandwidth is varied by changing the number of sub-carriers. Each sub-frame consists of 6 or 7 OFDM symbols, depending upon the size of CP. DL Physical layer parameters are summarized in the table below.

Table 2-1: Physical Layer parameters [11]

Transmission BW	1.25 MHz	2.5 MHz	5 MHz	10 MHz	15 MHz	20 MHz
Sub-frame duration	0.5 ms					
Sub-carrier spacing	15 kHz					
Sampling frequency	1.92 MHz (1/2 x 3.84 MHz)	3.84 MHz	7.68 MHz (2 x 3.84 MHz)	15.36 MHz (4x3.84 MHz)	23.04 MHz (6 x 3.84 MHz)	30.72 MHz (8 x 3.84 MHz)
FFT size	128	256	512	1024	1536	2048
Number of occupied sub-carriers	76	151	301	601	901	1201
Number of OFDM symbols per sub-frame (Short/Long CP)	7/6					

DL Frame Structure of LTE is depicted in the figures 2-2 and 2-3 on next page. This frame structure is for DSCH for both short and long CP. One radio frame consists of sub-frames carrying PDSCH, PDSCCH and PBCH. PDSCH and PDSCCH are present in every sub-frame. PBCH is only present in those sub-frames that are scheduled for the System Information. System Frame Number (SFN) is used as the frame time reference and the LTE SFN (eSFN) as the sub-frame time reference for all physical channels, for downlink and indirectly for the uplink. For details of Pilot structure, Modulation Schemes used, multi-antenna techniques, See [4] and [11].

The radio frame consists of T_f = 307200 x T_s =10ms long and consists of 20 slots of length $T_{slot} = 15360 \times T_s = 0.5\,ms$, numbered from 0 to 19. A subframe is defined as two consecutive slots where sub-frame i consists of slots 2i and 2i+1 [29]. For FDD, 10 subframes are available for downlink transmission and 10 subframes are available for uplink transmissions in each 10 ms interval. Uplink and downlink transmissions are separated in the frequency domain. For TDD, a subframe is either allocated to downlink or uplink transmission. Subframe 0 and subframe 5 are always allocated for downlink transmission. In other words, each frame consists of 20 subframes with pilot symbols and synchronization channel multiplexed into each subframe. Synchronization channel is transmitted in the last OFDM symbol of every fourth sub-frame and pilot symbols and training sequences are multiplexed into each sub-frame. To complete the OFDM process, cyclic prefix preceding every OFDM symbol (DL) and SC-FDMA symbol block (UL) [11]. Downlink frame structures for both short and long cyclic prefixes are shown in figures 2-2 and 2-3.

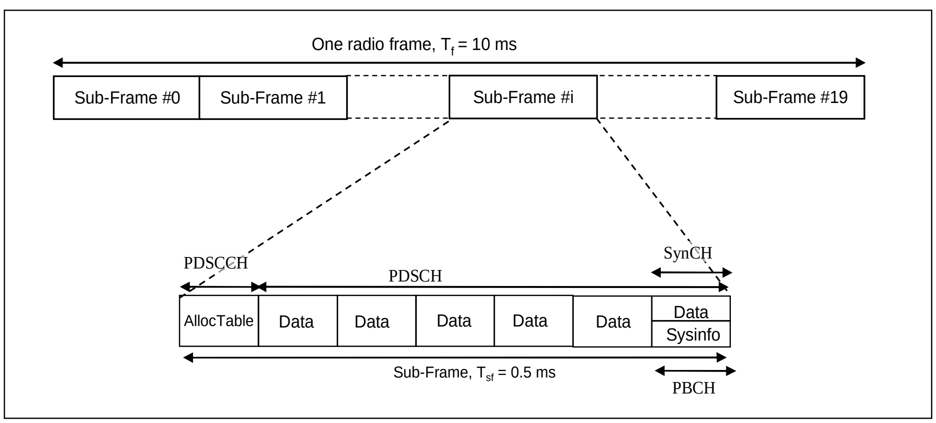


Figure 2-2: Downlink frame structure for frames with short cyclic prefix [11]

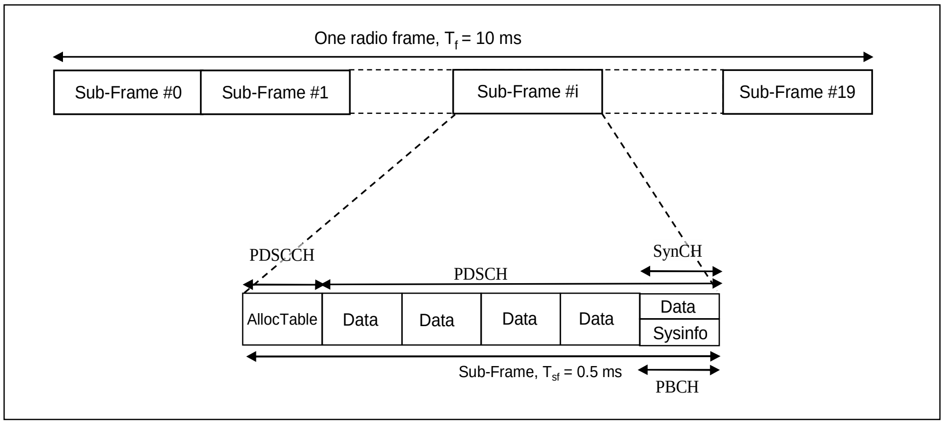


Figure 2-3: Downlink frame structure for frames with long cyclic prefix [11]

2.3.2 SC-FDMA for UL

Single carrier transmission with CP is used for UL. CP is used to achieve UL inter-user orthogonality and to enable efficient equalization in frequency domain on the receiver side [11]. The basic sub-frame structure for the UL is shown in figure 2-4. This structure uses two short blocks (SB) and six long blocks (LB) in each subframe. Short block is used for either for coherent demodulation or for control and data transmission or for both of these purposes. On the other hand, long blocks are used for control and/or data transmission. Both localized and distributed transmission uses the same subframe, while data can include either of both of scheduled and contention based data transmission.

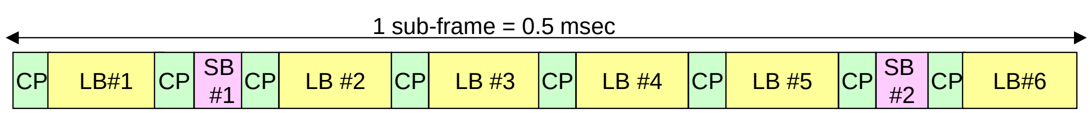


Figure 2-4: UL Frame Structure for LTE [11]

Table 2 shows values for different spectrum allocations for UL physical layer parameters. Minimum TTI for UL is fixed at the duration equivalent to UL subframe duration. TTI can be a semi-static or dynamic transport channel attribute. Semi-static TTI provides with a fixed length TTI with TTI length being adjusted through higher layer signalling. Conversely, as the name suggests, dynamic TTI can be varied. This variation or the number of sub-frames concatenated can be done through initial transmission. Currently, it is assumed that Node-B would control the TTI. This area is still open to further investigation [4, 11].

The same UL subframe format is used for both localised and distributed FDMA cases. In 10-MHz transmission bandwidth, six long blocks comprise of 512/1024 symbols/samples per block, while short blocks (two or three in number) comprise of 256/512 symbols/samples per a block. Short blocks can carry pilot and/or data in 10MHz transmission bandwidth. UL Physical Layer Parameters are summarized in table 2 below.

Table 2-2: UL Physical Layer Parameters [11]

"Transmission bandwidth" (MHz)	Sub-frame duration (ms)	Long block size (μs/samples)	Short block size (μs/samples)
20	0.5	66.67/2048	33.33/1024
15	0.5	66.67/1536	33.33/768
10	0.5	66.67/1024	33.33/512
5	0.5	66.67/512	33.33/256
2.5	0.5	66.67/256	33.33/128
1.25	0.5	66.67/128	33.33/64

2.4 Bandwidth Scalability

LTE system operates on the conventional 2 GHz band, as well as the extended 2.6 GHz and the 900 MHz bands. As discussed above, in order to provide flexible utilisation of the bandwidth, different carrier bandwidths are possible, ranging from 1.25 MHz to 20 MHz (more specifically: 1.25 MHz, 2.5 MHz, 5 MHz, 10 MHz, 15 MHz and 20 MHz). The sub-carrier spacing remains the same for all the above options at 15 KHz, it's the number of sub carriers that changes (see Table 1).

2.5 Network Architecture

LTE architecture is characterised by three special requirements: support for PS domain only, low latency and reduced cost. To achieve the above objectives and to overcome the complexities of the previous network architectures, LTE must be designed to contain fewer network nodes. This is important because smaller number of network nodes reduces overall amount of protocol-related processing, cost of testing and number of interfaces. It also translates into ease of optimizing radio interface protocols. It can be done by merging some control protocols and using shorter signaling sequences resulting into rapid session setups. LTE uses two-node architecture. Figure 2-5 on the next page gives an overview of the E-UTRAN architecture where yellow-shaded boxes depict the logical nodes, white boxes depict the functional entities of the C-plane, and blue boxes depict the functional entities of the U-plane. Detailed discussion of these boxes is out of scope of this document.

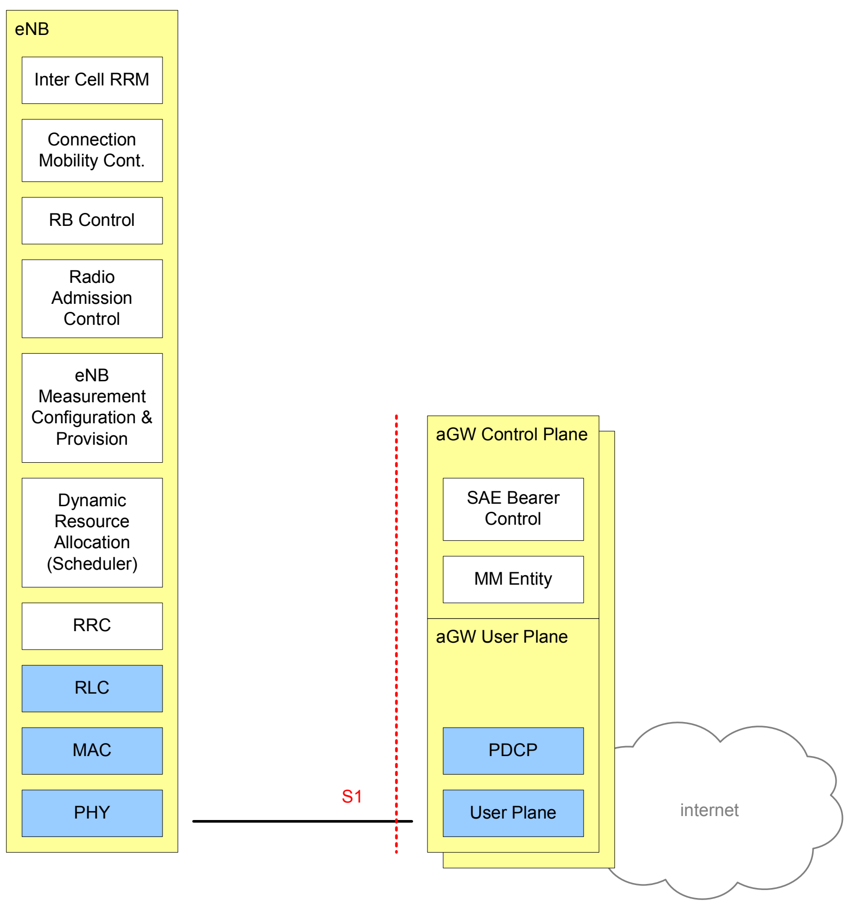


Figure 2-5: E-UTRAN Architecture [4]

The E-UTRAN consists of:

- eNB (Enhanced Node B)
- aGW (access Gateway)

eNB is the basic access network element covering a single cell or installed on one site. It provides the E-UTRA user plane (PDCP/RLC/MAC/PHY) and control plane (RRC) protocol terminations towards the UE [25]. Two eNBs are connected with each other through X2 interface. LTE is designed to give eNBs a greater degree of intelligence to reduce the overhead. As a result, functions for Radio Resource Management are provided by eNB. This includes Radio Bearer Control, Radio Admission Control, Connection Mobility Control, Dynamic allocation of resources to UEs in both uplink and downlink. eNB is involved in security services by encryption of user data stream and routing of user plane data towards serving gateway. Moreover, it also carries out scheduling and transmission of paging messages and BCCH information.

aGW is one level above eNB. A aGW can be connected to one or more eNBs depending upon the network design. aGW performs many different function, together with paging origination, ciphering of user plane data and SAE bearer control. aGW is functionally divided into two parts, MME (Mobility Management Entity) and UPE (User Plane Entity). MME is the control plane part of aGW. Its functionalities include management and storage of temporary user IDs, Termination of U-plane packets for paging reasons and management and NAS security. On the other hand, UPE is responsible for tasks related to user plane. It is accountable for Packet routing and forwarding, allocation of local IP address for mobility, charging for roaming and anchoring for inter eNB mobility, charging of paging messages to eNBs and inter-3GPP access Mobility.

2.6 E-UTRAN Interfaces

One of the objectives of EUTRAN is to simplify and reduce the number of interfaces between different network elements. Interfaces between different network elements are S1 (eNodeB-aGW) and X2 (inter ENodeB) as shown in figure 2-6.

S1 is the interface between eNB and UPE. This interface can be subdivided into two parts [14]:

- C-plane: S1-C is the interface between eNB and MME function in EPC
- U-plane: S1-U is the interface between eNB and UPE function in EPC

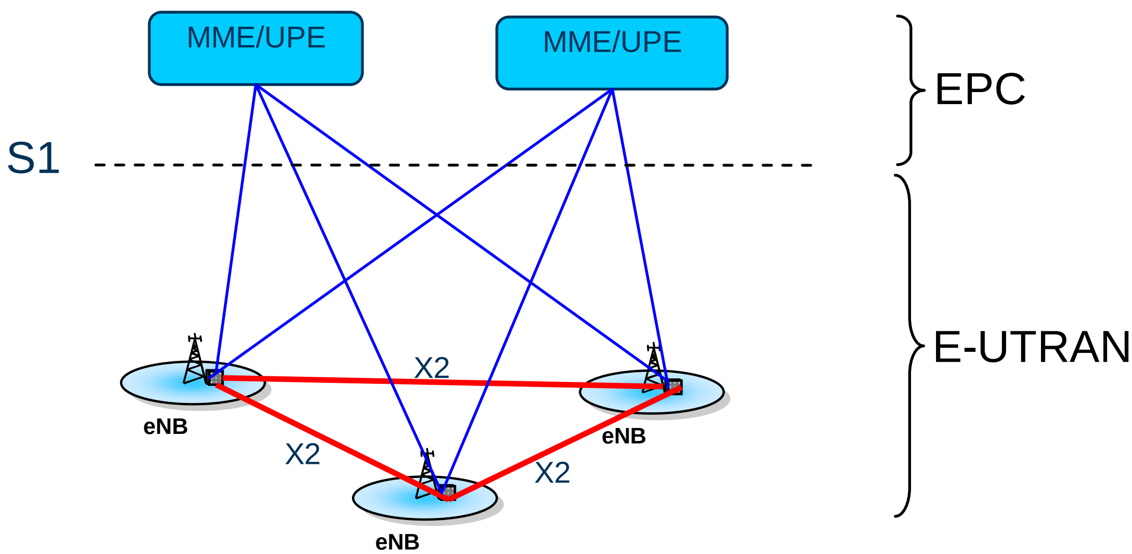


Figure 2-6: E-UTRAN Interfaces [4]

From the S1 perspective, the EUTRAN access point is an eNB and the EPC access point is either the control plane MME node or the user plane SAE gateway logical node. S1 access point shall independently fulfill the requirements of the relevant S1 specifications. S1 interface supports many functions which include initial context setup, UE context management and mobility functions. Initial context setup function supports the establishment of overall initial UE context plus SAE bearer context, security context, roaming restriction, UE capability information, etc. in the eNB to enable idle-to-Active transition. S1 interface also establishes and releases the UE contexts in eNB and in EPC to support user signaling. Moreover, S1 also provide mobility functions for handover. This can be intra-LTE handover or inter-3GPP handover (with a system other than LTE) [14].

X2 interface allows the interconnection between eNBs. X2 has the status of an open interface. It supports the signal information exchange between two eNBs, along with the forwarding of PDUs to their destination. In terms of logical point of view, X2 is a point-to-point interface within E-UTRAN. Therefore, it is possible to create an X2 interface between two eNBs even if there is no physical and direct connection between them [15].

X2 facilitates the interconnection between eNBs of different vendors and offers a continuation of the services offered via S1 interface for a seamless network. In addition, it makes possible the introduction of new future technologies by clearly separating radio network and transport network functionalities.

With significant improvements in the radio interface and other components, enabling a lower data access cost per megabyte, as well as several potentially important new services, 3G Long-Term Evolution (LTE) will bring substantial technological improvements. These efforts are expected to deliver economic benefits to operators, and therefore provide a decisive advantage over alternative wireless technologies, keeping the mobile cellular systems competitive during the next decade.

3 Dimensioning of LTE Network

Dimensioning is the initial phase of network planning. It provides the first estimate of the network element count as well as the capacity of those elements. The purpose of dimensioning is to estimate the required number of radio base stations needed to support a specified traffic load in an area [26].

3.1 Wireless Cellular Network Dimensioning

Dimensioning provides the first, quick assessment of the probable wireless network configuration [17]. Dimensioning is a part of the whole planning process, which also includes, detailed planning and optimization of the wireless cellular network. As a whole, planning is an iterative process covering design, synthesis and realization. The aim of this whole exercise is to provide a method to design the wireless cellular network such that it meets the requirements set forth by the customers. This process can be modified to fit the needs of any wireless cellular network. This is a very important process in network deployment.

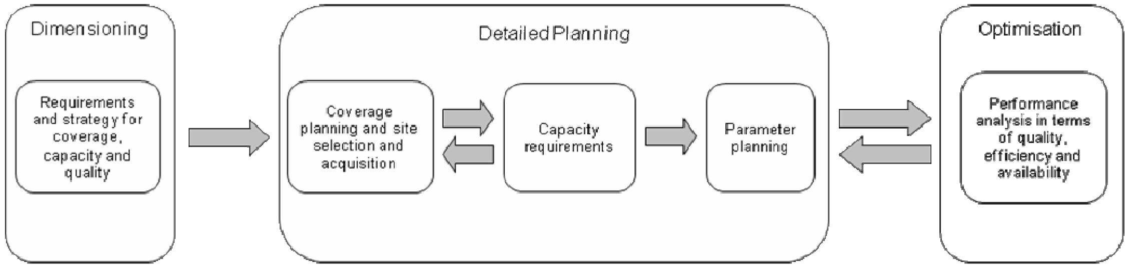


Figure 3-1: General wireless cellular network planning process

Figure 3-1 shows the wireless cellular network planning exercise and the position of dimensioning in the whole process. Dimensioning exercise gives an estimate which is then used for detailed planning of the network. Once the network is completely planned, network parameters are optimized maximising the efficiency of the system.

Dimensioning is based on a set of input parameters and the provided results are relevant for that set of input parameters only. These parameters include area under consideration, expected traffic and required QoS [17]. Dimensioning provides the evaluation of the requirements for network infrastructure. This is done with the help of dimensioning tool for both access and core networks. Dimensioning uses relatively simpler models for modeling of the actual conditions as compared to the detailed planning. Simpler models and methods reduce the time required for dimensioning. On the other hand, dimensioning tool should be accurate enough to provide results with an acceptable level of accuracy, when loaded with expected traffic profile and subscriber base.

Wireless cellular network dimensioning is directly related to the quality and effectiveness of the network, and can deeply affect its development. Wireless cellular network dimensioning follows these basic steps:

- Data/Traffic Analysis
- Coverage estimation
- Capacity evaluation
- Transport dimensioning

A proper set of inputs is vital for dimensioning to yield accurate results. Wireless cellular dimensioning requires some fundamental data elements. These parameters include subscriber population, traffic distribution, geographical area to be covered, frequency band, allocated bandwidth, and coverage and capacity requirements. Propagation models according to the area and frequency band should be selected and modified (if needed). This is necessary for coverage estimation.

System specific parameters like, transmit power of the antennas, their gains, estimate of system losses, type of antenna system used etc, must be known prior to the start of wireless cellular network dimensioning. Each wireless network has its own set of parameters.

Traffic analysis gives an estimate of the traffic to be carried by the system. Different types of traffic that will be carried by the network are modeled. Traffic types may include voice calls, VOIP, PS or CS traffic. Overheads carried by each type of traffic are calculated and included in the model. Time and amount of traffic is also forecasted to evaluate the performance of the network and to determine whether the network can fulfill the requirements set forth.

Coverage estimation is used to determine the coverage area of each base station. Coverage estimation calculates the area where base station can be heard by the users (receivers). It gives the maximum area that can be covered by a base station. But it is not necessary that an acceptable connection (e.g. a voice call) between the base station and receiver can be established in coverage area. However, base station can be detected by the receiver in coverage area.

Coverage planning includes radio link budget and coverage analysis. RLB computes the power received by the user (receiver) given a specific transmitted power (from the transmitter or base station). RLB comprises of all the gains and losses in the path of signal from transmitter to the receiver. This includes transmitter and receiver gains as well as losses and the effect of the wireless medium between them. Free space propagation loss, fast fading and slow fading is taken into account. Additionally, parameters that are particular to some systems are also considered. Frequency hopping and antenna diversity margins are two examples.

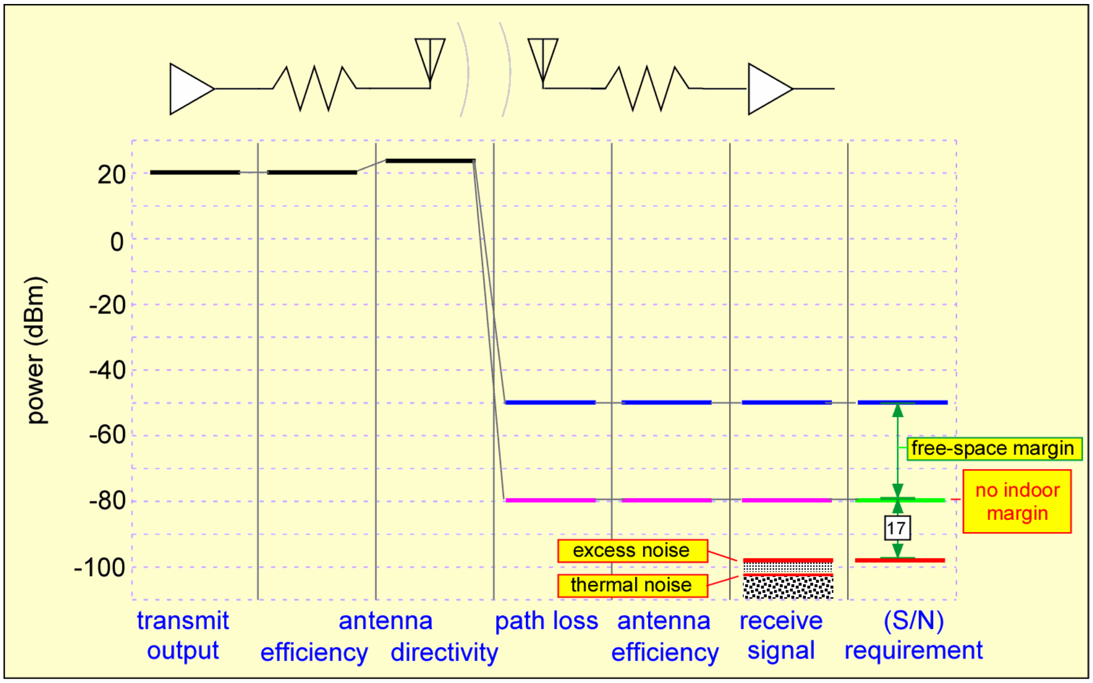


Figure 3-2: General radio link budget of a wireless cellular network [31]

Figure 3-2 shows a typical example of a radio link budget. Transmitting antenna radiates the power in the direction of the receiving antenna. The amount of power aimed at the receiving antenna depends upon the directivity of the transmitting antenna and the path loss encountered due to propagation environment. In figure 3-2, both free space path loss (with blue coloured lines) and indoor path loss (with pink coloured lines) are shown. Noise from different sources also contributes to signal degradation by raising the noise floor, as shown in the figure. After adding and subtracting all the gains and losses, actual power received is calculated. Blue line in the last column of figure 3-2 gives the received power for outdoor free space environment, while green line provides the received power indoors. The value of 17dB is the difference between the received signal and noise in the system for indoor environment. This signal to noise ratio is the performance indicator of the wireless system. Higher the SNR, higher will be the data rate achieved and vice versa.

Based on the calculation of RLB, maximum allowed propagation loss is obtained. Maximum allowed propagation loss gives the attenuation of the signal as it travels from transmitted to the receiver. Path loss is converted into distance by using appropriate propagation models. This is the distance from the base station where the transmitter signals can be received by the users (receiver). This distance or the radius of the cell is used to calculate the number of sites required to cover the whole area with respect to coverage estimation.

Capacity planning deals with the ability of the network to provide services to the users with a desired level of quality. After the site coverage area is calculated using coverage estimation, capacity related issues are analysed. This involves selection of site and system configuration, e.g. channels used, channel elements and sectors. These elements are different for each system. Configuration is selected such that it fulfills the traffic requirements. In some wireless cellular systems, coverage and capacity are interrelated, e.g. in WCDMA. In this case, data pertaining to user distribution and forecast of subscriber's growth is of utmost importance. Dimensioning team must consider these values as they have direct impact on coverage and capacity. Capacity evaluation gives an estimate of the number of sites required to carry the anticipated traffic over the coverage area [30].

Once the number of sites according to the traffic forecast is determined, the interfaces of the network are dimensioned. Number of interfaces can vary from a few in some systems to many in others. The objective of this step is to perform the allocation of traffic in such a way that no bottle neck is created in the wireless network. All the quality of service requirements are to be met and cost has to be minimised. Good interface dimensioning is very important for smooth performance of the network.

3.2 LTE Access Network Dimensioning

The target of the LTE access network dimensioning is to estimate the required site density and site configurations for the area of interest. Initial LTE access network planning activities include radio link budget and coverage analysis, cell capacity estimation, estimation of the amount of eNode B and access gateways (MME/UPE) and hardware configuration, and finally, equipment at different interfaces. This section focuses on the issues related to LTE dimensioning.

3.2.1 Inputs of LTE Dimensioning

One of the basic objectives of this work is to clearly differentiate between LTE dimensioning inputs and outputs. This section discusses all the LTE dimensioning inputs used in the development of methods and models for LTE dimensioning. LTE dimension inputs can be broadly divided into three categories; quality, coverage and capacity-related inputs.

Quality-related inputs include average cell throughput and blocking probability. These parameters are the customer requirements to provide a certain level of service to its users. These inputs directly translate into QoS parameters. Besides cell edge performance criterion is used in the dimensioning tool to determine the cell radius and thus the site count. Three methods are employed to determine the cell edge. These include user defined maximum throughput at the cell edge, maximum coverage with respect to lowest MCS (giving the minimum possible site count) and predefined cell radius. With a predefined cell radius, parameters can be varied to check the data rate achieved at this cell size. This option gives the flexibility to optimize transmitted power and determining a suitable data rate corresponding to this power.

LTE dimensioning inputs for coverage planning exercise are similar to the corresponding inputs for 3G UMTS networks. Radio link budget (RLB) is of central importance to coverage planning in LTE. RLB inputs include transmitter power, transmitter and receiver antenna systems, number of antennas used, conventional system gains and losses, Cell loading and propagation models. LTE can operate in both the conventional frequency bands of 900 and 1800 MHz as well as extended band of 2600 MHz. Models for all the three possible frequency bands are incorporated in this work. Additionally, channel types (Pedestrian, Vehicular) and geographical information is needed to start the coverage dimensioning exercise. Geographical input information consists of area type information (Urban, Rural, etc) and size of each area type to be covered. Furthermore, required coverage probability plays a vital role in determination of cell radius. Even a minor change in coverage probability causes a large variation in cell radius.

Capacity planning inputs provides the requirements, to be met by LTE network dimensioning exercise. Capacity planning inputs gives the number of subscribers in the system, their demanded services and subscriber usage level. Available spectrum and channel bandwidth used by the LTE system are also very important for LTE capacity planning. Traffic analysis and data rate to support available services (Speech, Data) are used to determine the number of subscribers supported by a single cell and eventually the cell radius based on capacity evaluation. LTE system level simulation results and LTE link level simulation results are used to carry out capacity planning exercise along with other inputs. These results are obtained from Nokia's internal sources. Subscriber growth forecast is used in this work to predict the growth and cost of the network in years to come. This is a marketing specific input targeting the feasibility of the network over a longer period of time. Forecast data will be provided by the LTE operators.

3.2.2 Outputs of LTE Dimensioning

Outputs or targets of LTE dimensioning process have already been discussed indirectly in the previous section. Outputs of the dimensioning phase are used to estimate the feasibility and cost of the network. These outputs are further used in detailed network planning and can be utilized for future work on LTE core network planning. Dimensioned LTE network can help out LTE core network team to plan a suitable network design and to determine the number of backhaul links required in the starting phase of the network [26].

Cell size is the main output of LTE dimensioning exercise. Two values of cell radii are obtained, one from coverage evaluation and second from capacity evaluation. The smaller of the two numbers is taken as the final output. Cell radius is then used to determine the number of sites. Assuming a hexagonal cell shape, number of sites can be calculated by using simple geometry. This procedure is explained in section 3.4. Capacities of eNBs are obtained from capacity evaluation, along with the number of subscribers supported by each cell. Interface dimensioning is the last step in LTE access network dimensioning, which is out of scope of this thesis work. The reason is that that LTE interfaces (S1 and X2) were still undergoing standardisation at the time of this work.

3.2.3 LTE Dimensioning Process

LTE Dimensioning process starts with the Radio Link Budget Calculations, used to determine the maximum path loss. The result of this step depends upon the propagation models used. The estimated cell size, obtained in this step, leads to the maximum allowed size of the cells. This parameter is used to calculate the number of cells in the area of interest. Thus, a rough estimate of the required number of eNBs is obtained.

Capacity calculations follow the above process for coverage estimation. If the coverage estimates for the given configuration, fulfils the capacity requirements, then there is no addition to the previous plan. On the other hand, suitable number of cell sites is added to achieve the capacity targets. If the highest expected traffic is used, then it can lead to an unnecessarily high number of sites.

Assessment of eNB capacity comes next, which completes the dimensioning process. In this thesis work, focus is on Radio Link Budget, cell capacity estimates and tools and case studies for LTE dimensioning. Figure 3-3 depicts LTE dimensioning exercise in detail.

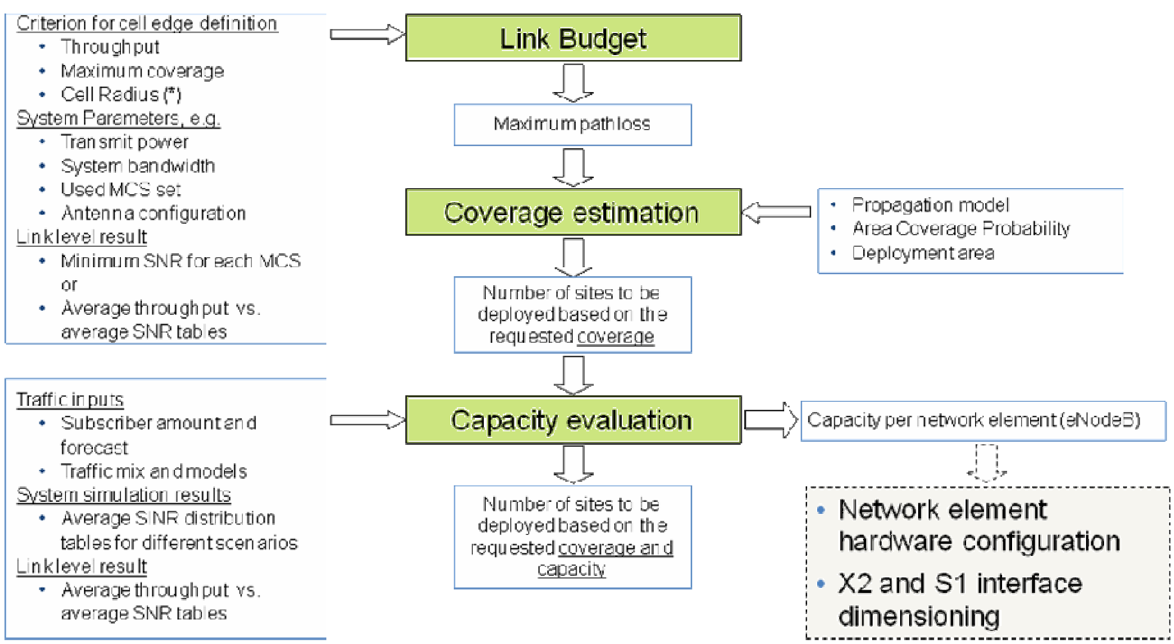


Figure 3-3: LTE network dimensioning

LTE Dimensioning process includes the following steps [18, 19. 20]:

Step 1: Data and Traffic Analysis

This is the first step in LTE dimensioning. It involves gathering of required inputs and their analysis to prepare them for use in LTE dimensioning process. Operator data and requirements are analysed to determine the best system configuration. One other possibility is to stick with a group of configurations and carry out dimensioning for each of them to determine the most suitable choice. For example, this may involve choosing two or three different channel bandwidths for analysis. Essential inputs needed for this step are explained in section 3.2.1.

Step 2: Traffic Analysis

Traffic demand is analyzed to get the best possible network configuration with minimum supplies. In this thesis, three types of traffic are considered for LTE. They are; VoIP, streaming and browsing. Overhead due to higher layers is taken into account while calculating net bit rate for these traffic types. Peak hour traffic is used instead of average values. In the same way, demand for different services should also be considered.

Step 3: Coverage Planning

Coverage analysis fundamentally remains the most critical step in the design of LTE network as with 3G systems. RLB is at the heart of coverage planning, which allows the testing of path loss model and the required peak data rates against the target coverage levels. The result is the effective cell range to work out the coverage-limited site count. This requires the selection of appropriate propagation model to calculate path loss. LTE RLB is explained in chapter 4. With the knowledge of cell size estimates and of the area to be covered, an estimate of the total number of sites is found. This estimate is based on coverage requirements and needs to be verified for the capacity requirements.

Step 4: Capacity Planning

With a rough estimate of the cell size and site count, verification of coverage analysis is carried out for the required capacity. It is verified whether with the given site density, the system can carry the specified load or new sites have to be added. In LTE, the main indicator of capacity is SINR distribution in the cell. This distribution is obtained by carrying out system level simulations. SINR distribution can be directly mapped into system capacity (data rate). LTE cell capacity is impacted by several factors, for example, packet scheduler implementation, supported MCSs, antenna configurations and interference levels. Therefore, many sets of simulation results are required for comprehensive analysis. Capacity based site count is then compared with the coverage result and greater of the two numbers is selected as the final site count, as already mentioned in the previous section.

Step 5: Transport Dimensioning

Transport dimensioning deals with the dimensioning of interfaces between different network elements. In LTE, S1 (between eNB and aGW) and X2 (between two eNBs) are the two interfaces to be dimensioned. These interfaces were still in the process of being standardised at the time of this work. Therefore, transport dimensioning is not included in this thesis work.

An initial sketch of LTE network is obtained by following the above mentioned steps of dimensioning exercise. This initial assessment forms the basis of detailed planning phase. In this thesis, main emphasis is on steps two to four. First step is unnecessary because the data for the test cases is taken from a WiMAX scenario, allowing its bypass. Coverage and Capacity planning is dealt in detail and resulting site count is calculated to give an estimate of the dimensioned LTE network. Dimensioning of LTE will depend on the operator strategy and business case. The physical side of the task means to find the best possible solution of the network which meets operator requirements and expectations.

4 Coverage Planning and Radio Link Budget

Coverage Planning is the first step in the process of dimensioning. It gives an estimatie of the resources needed to provide service in the deployment area with the given system parameters, without any capacity concern. Therefore, it gives an assessment of the resources needed to cover the area under consideration, so that the transmitters and receivers can listen to each other. In other words, there are no QoS concerns involved in this process. Coverage planning consists of evaluation of DL and UL radio link budgets. The maximum path loss is calculated based on the required SINR level at the receiver, taking into account the extent of the interference caused by traffic. The minimum of the maximum path losses in UL and DL directions is converted into cell radius, by using a propagation model appropriate to the deployment area. Radio Link Budget is the most prominent component of coverage planning exercise.

This chapter covers LTE Coverage Planning. Radio Link Budget is explained followed by the methods used for calculation of required SINR, effect of interference and finally the calculation of the number of sites based on the coverage.

4.1 Radio Link Budget

Radio Link Budget (RLB) is calculated in order to estimate the allowed path loss. Transmission powers, antenna gains, system losses, diversity gains, fading margins, etc. are taken into account in a RLB. RLB gives the maximum allowed path loss, from which cell size is calculated using a suitable propagation model.

For LTE, the basic RLB equation can be written as follows (in units of dB):

$$PathLos_{dB} = TxPower_{dB} + TxGains_{dB} - TxLosses_{dB} - \mathrm{Re}\,quiredSINR_{dB} + RxGains_{dB} - RxLosses_{dB} - RxNoise_{dB} \quad \textbf{(1)}$$

Where,

Path Loss	= Total path loss encountered by the signal from transmitter to receiver (W)
$TxPower_{dB}$	= Power transmitted by the transmitter antenna (dBm)
$TxGains_{dB}$	= Gain of transmitter antenna (dB)
$TxLosses_{dB}$	= Transmitter losses (dB)
$RequiredSINR_{dB}$	= Minimum required SINR for the signal to be received at the receiver with the required quality or strength (dB)
$RxGains_{dB}$	= Gain of receiver antenna (dB)
$RxLosses_{dB}$	= Receiver losses (dB)
$RxNoise_{dB}$	= Receiver Noise (dBm)

Equation 1 is shown in units of decibel for the sake of clarity. However, all the derivation will be done with terms in absolute units. Equation 1 can be written in absolute terms as follows:

$$PathLoss = \frac{TxPower \bullet TxGains \bullet RxGains}{TxLosses \bullet \mathrm{Re}\,quiredSINR \bullet RxLosses \bullet RxNoise} \quad \textbf{(2)}$$

Where,

Path Loss = Total path loss encountered by the signal from transmitter to receiver (W)

TxPower = Power transmitted by the transmitter antenna (W)

TxGains = Gain of transmitter antenna

TxLosses = Transmitter losses (W)

RequiredSINR = Minimum required SINR for the signal to be received at the receiver with the required quality or strength

RxGains = Gain of receiver antenna

RxLosses = Receiver losses (W)

RxNoise = Receiver Noise (W)

In LTE, the basic performance indicator is 'Required SINR'. Maximum allowed path loss is calculated according to the condition:

$$\begin{cases} SINR \geq RequiredSINR \\ SINR = \dfrac{AveRxPower}{Interference + RxNoise} = \dfrac{AveRxPower}{OwnCellInterference + OtherCellInterference + RxNoise} \end{cases} \quad \textbf{(3)}$$

Where,

SINR = Signal to interference and noise ratio

AveRxPower = Average received power (W)

Interference = Interference power (W)

OwnCellInterference = Power due to own cell interference (W)

OtherCellInterference = Power received for neighboring cells (W)

In downlink, assuming the maximum available transmission power is equally divided over the cell bandwidth, the average received power (AveRxPowerDL) in the bandwidth allocated to the user is derived as follows:

$$AveRxPowerDL = \frac{AveTxPower}{LinkLossDL} = \frac{MaxNodeBTxPower}{CellBandwidth} \cdot \frac{AllocatedBandwidth}{LinkLossDL} \quad \textbf{(4)}$$

Where,

SINR = Signal to interference and noise ratio

AveTxPower = Average transmitted power (W)

LinkLossDL = Total link loss in downlink (W)

MaxNodeBTxPower = Maximum Power transmitted from NodeB (W)

CellBandwidth = Allocated bandwidth of LTE network cell (MHz)

AllocatedBandwidth = Bandwidth of channel over which the signal is transmitted (MHz)

The *MaxNodeBTxPower* in LTE depends on the cell bandwidth, which can range from 1.25 to 20 MHz [1]. Specifically, *MaxNodeTxPower* is 20 Watt (43 dBm) up to 5 MHz and 40 Watt (46 dBm) above this limit [22].

In uplink, assuming no power control, the average received power (AveRxPowerUL) is:

$$AveRxPowerUL = \frac{MaxUETxPower}{LinkLossUL} \quad \textbf{(5)}$$

Where,

MaxUETxPower= Max transmission power of user equipment (W)

LinkLossUL = Total link loss in uplink (W)

The *MaxUETxPower* can be either 0.125 W or 0.25 W (21 or 24 dBm) [22]. The *LinklossUL* includes the distance-dependent *Pathloss* and all other gains and losses at the transmitter and the receiver. The gains include antenna gains and amplification gains (e.g. Mast Head Amplifier (MHA) in the UL direction). The above gain does not need to be considered explicitly, in case antenna configuration is taken into account in link level simulations (i.e., the effect is included in the *RequiredSINR* value). The losses include body loss at the terminal side, cable losses and Mast Head Amplifier noise figure at the eNodeB and finally some margins (*OtherLosses*) needed to take into account shadow fading and indoor penetration loss. Therefore, link loss (LinkLoss) can be written as:

$$Linkloss = \frac{RxGains \cdot TxGains}{Pathloss \cdot RxLosses \cdot TxLosses \cdot OtherLosses} \quad \textbf{(6)}$$

Where,

OtherLosses= Includes all losses not covered by the mentioned RLB terms (W)

The received noise power (RxNoise) in Watts:

$$
\begin{aligned}
RxNoise &= ThermalNoise \cdot ReceiverNoiseFigure \\
&= (ThermalNoiseDensity \cdot AllocatedBandwidth) \cdot ReceiverNoiseFigure
\end{aligned} \tag{7}
$$

Where,

ThermalNoise = Thermal Noise (W)

ReceiverNoiseFigure = Receiver Noise Figure

Thermal Noise Density = -174 dBm

In the DL direction, due to the OFDM access technology and assuming the appropriate length of cyclic prefix, we can assume there's no own cell interference (*OwnCellInterference* is zero). *OtherCellInterference* is the total average power received from other cells in the allocated bandwidth. Similarly, in the UL direction the *Interference* (also called Noise Rise) is the power received from terminals transmitting on the same frequency in the neighbouring cells (*OtherCellInterference*).

Above set of equations lay the basis for calculation of RLB equation for maximum allowed path loss. Here, we give the results.

$$
SINR = \frac{AveRxPwr(own)}{I + N} = \frac{AveRxPwr(own)}{I_{other} + N} = \frac{\dfrac{AveTxPwr(own)}{LinkLoss(own)}}{\sum_{k \neq own} \dfrac{AveTxPwr(k)}{LinkLoss(k)} + N} \tag{8}
$$

Putting the values of the parameters in the equation and manipulating, we get the following form for SINR.

$$
SINR = \frac{\dfrac{1}{LinkLoss(own)}}{\sum_{k \neq own} \dfrac{1}{LinkLoss(k)} + \dfrac{CellBW}{MaxTxPwr} \cdot ThermalNoiseDensity \cdot RxNoiseFigure} \tag{9}
$$

Now, the requirement is:

$$SINR \geq \text{Re}\,quiredSINR \quad \textbf{(10)}$$

Putting the values from the previous equation, we get the following form for the Path Loss:

$$PathLoss(own) \leq \frac{1}{\left(\sum_{k \neq own} \frac{1}{PathLoss(k)} + NoiseComponent\right) \cdot \text{RequiredSINR}} \quad \textbf{(11)}$$

4.1.1 Other-to-own cell interference (i)

To include the effect of interference, we will introduce Other-to-own cell interference for DL (i).

$$i = \sum_{k \neq own} \frac{PathLoss(own)}{PathLoss(k)} \quad \textbf{(12)}$$

Introducing this other-to-own cell interference in the equation above, we get:

$$\frac{1}{i + NoiseComponent \cdot PathLoss(own)} \leq \text{Re}\,quiredSINR \quad \textbf{(13)}$$

Thus, we get:

$$MaxPathLoss = \frac{1 - i_{MaxPathLoss} \cdot \text{Re}\,quiredSINR}{NoiseComponent \cdot \text{Re}\,quiredSINR} \quad \textbf{(14)}$$

The above equation gives the maximum path loss for LTE. It is important to note that all the conventional RLB components are in the Noise Component. Noise component is in fact the inverse of the conventional path loss.

4.2 Required SINR

Required SINR is the main performance indicator for LTE. Cell edge is defined according to the Required SINR for a given cell throughput. Therefore, the accurate knowledge of Required SINR is central to the authenticity of the RLB and thus the process of dimensioning. Required SINR depends up on the following factors:

- Modulation and Coding Schemes (MCS)
- Propagation Channel Model

Higher the MCS used, higher the required SINR and vice versa. This means that using QPSK ½ will have a lower required SINR than 16-QAM ½.

Required SINR can be estimated by two different methods.

- By using the 'Throughput vs. average SNR' tables. These tables are obtained as an output of link level simulations. For each type of propagation channel models and different antenna configurations, different tables are needed. One important thing to note here is that noise is modelled as AWGN noise; therefore, SNR is used instead of SINR.
- By using the Alpha-Shannon formula [22]. Alpha-Shannon formula provides an approximation of the link level results. Thus, in this case, no actual simulations are needed, but factors used in Alpha-Shannon formula are needed for different scenarios.

4.2.1 Spectral Efficiency

In case the cell edge is defined by the input required throughput, the corresponding spectral efficiency has to be derived. The spectral efficiency is derived under the following assumptions:

- The layer 2 protocol overhead (MAC and RLC) is negligible [23]
- Link level simulation do not take into account the L1 overhead due to control channels (pilot and allocation table)

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

$$Layer1Throughput = \frac{CellEdgeThroughput}{OverheadFactor} \quad \textbf{(15)}$$

Where

$$OverheadFactor = \frac{DataSymbolperSubFrame}{TotalSymbilperSubFrame} \quad \textbf{(16)}$$

The OverheadFactor values for DL and UL are respectively 5/7 and 4/7 [11], assuming short cyclic prefix.

Thus, the spectral efficiency is:

$$SpectralEfficiency = \frac{Layer1Throughput}{CellBandwidth} \quad \textbf{(17)}$$

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

$$SpectralEfficiency = \alpha \bullet \log_2\left(1 + 10^{\frac{SNR}{10}}\right) \quad \textbf{(18)}$$

This maximum capacity cannot be obtained in LTE due to the following factors [3]

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

Thus, in order to fit the Shannon formula to LTE link performance two elements are introduced

- "bandwidth efficiency factor" α
- "SNR efficiency factor", denominated *ImpFactor*

The modified Alpha-Shannon Formula can be written as:

$$SpectralEfficiency = \alpha \bullet \log_2\left(1+10^{\frac{SNR}{10\bullet \mathrm{ImpFactor}}}\right) \qquad \textbf{(19)}$$

Note that 'α' also depends on the antenna configuration. The formula is valid between the limits specified by a minimum and a maximum value of spectral efficiency. The figure below shows how the Shannon-Alpha formula is used to approximate the envelope of the spectral efficiency vs. SNR curve in case of SISO (1 transmission and 1 reception antenna) and AWGN. Two values of α and *ImpFactor* are considered.

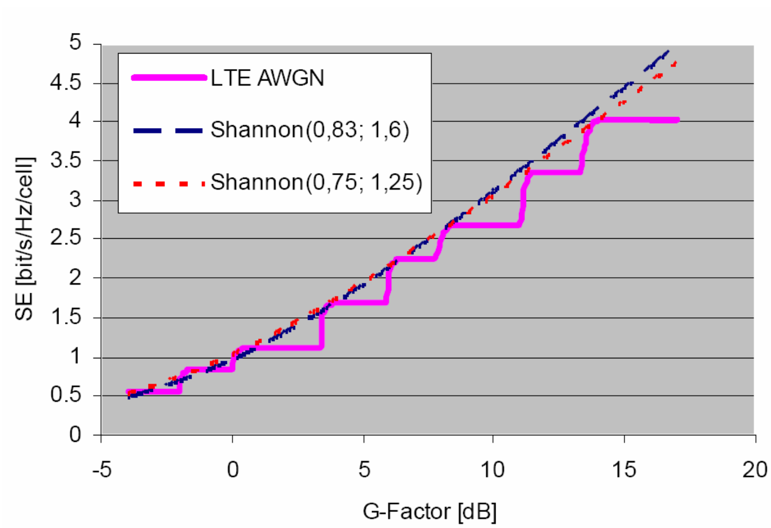


Figure 4-1: LTE spectral efficiency as function of G-factor (in dB) including curves for best Shannon fit [21]

To map these results to system level performance, we need to consider the G-factor distribution, PDF(G), over the cell area. Assuming uniform user distribution, the obtained G-factors for the LTE capacity evaluation are plotted in Figure 4-1. The distributions are obtained by deploying Macro Cell and Micro Cell hexagonal cellular layouts according to [11]. The probability density function of G is obtained from Figure 4-2. It is assumed that all users have equal session times (e.g. infinite buffer assumption) [21].

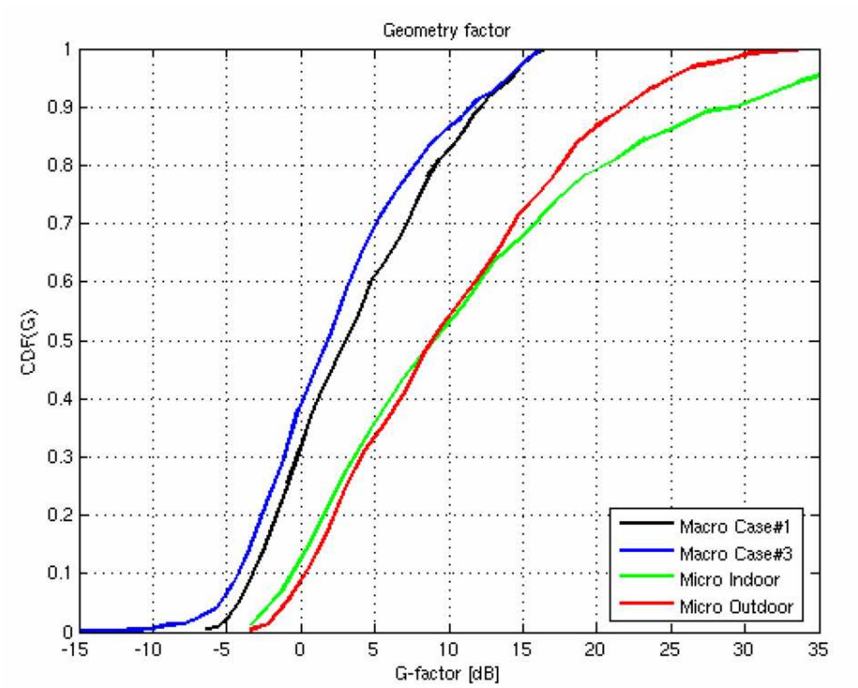


Figure 4-2: CDF for G-factors of an LTE system (with different scenarios)[21]

4.3 Interference

In order to evaluate the other-cell interference, a simple network model in which the load is equally distributed among cells is assumed. The overall effect of interference can be estimated the following factors

- A term that takes into account the loss in G due to the handover margin (CellOverlapMargin). The G-factor distribution is defined as the average own cell power to the other-cell power plus noise ratio. In fact, a handover margin is needed for avoiding ping-pong effect. As a consequence, the serving cell is not necessary the one that is received with the strongest signal.
- A gain due to interference control mechanisms (e.g. Soft Frequency Reuse or Smart Frequency Domain Packet Scheduler), denominated IntControlGain.

For the uplink, the issue of interference is dealt as follows. The uplink other cell interference margin (*OtherCellInterferenceUL* in the maximum uplink pathloss equation) was studied by means of system level simulations, using a network scenario with 19 three-sector sites, i.e., in total 57 cells. The sites were positioned on a regular hexagonal grid. Inter-site distanced of 1732 m with penetration loss of 20 dB and UE power class of 21 dBm was used. Interference coordination was not used in this simulation. Simulations were carried out with three different values of system load. Allocated bandwidth per user equals to 312.5 kHz.

- Slow power control was used in this simulation.
- Target for power control was set in such a way that it provides a good trade-off between the cell edge throughput and average cell throughput

The interference margin was calculated using the following expression

$$\text{InterferenceMargin} = SNR\,/\,SINR \qquad \textbf{(20)}$$

Figure 4-3 shows the obtained interference margin as a function of load. The interference margin is observed from 5% point of CDF. The table instead, shows the list of Interference Margin Values obtained using linear interpolation.

Table 4-1: load versus Interference margin

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

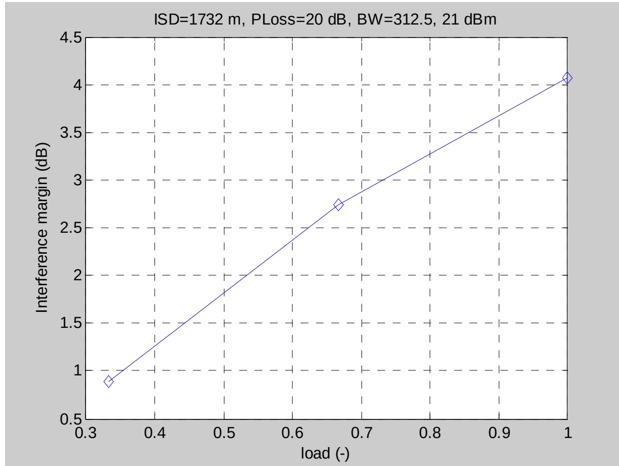


Figure 4-3: load versus Interference margin

4.4 Coverage-based Site Count

The maximum allowed path loss can be used to calculate the cell radius (*CellRadius*) by using a propagation model. COST231 model is use to compute the path loss for cell radius. This model is normally used for carrier frequencies between 1500 and 2000 MHz. The same COST231 model can be used for carrier frequency of 2600 MHz, since we assume that the loss due to the higher frequency is compensated by the increase in the antenna gain. For the 900 MHz deployment option, the Hata model can be used instead. Other propagation models can be included as well, for instance, UMTS models [18]. Given the cell radius, the cell coverage area (that we assume to be hexagonal) depends on the site configuration.

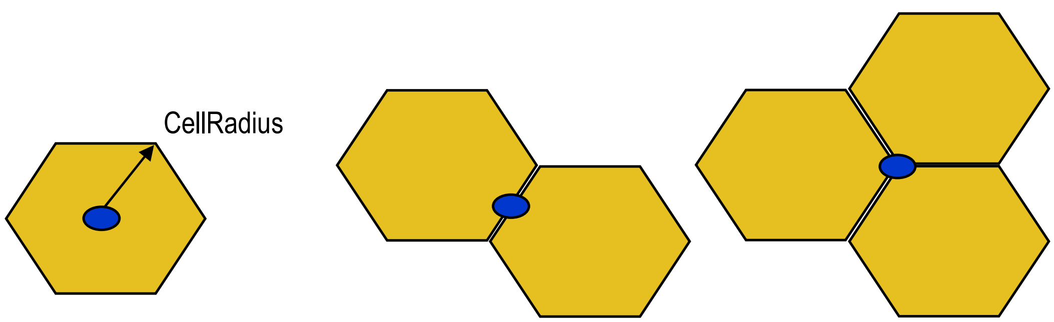


Figure 4-4: Three different types of sites (Omni-directional, bi-sector, tri-sector)

For three hexagonal cell models, site areas can be calculated as follows.

Omni-directional site $\quad SiteArea = 2.6 * CellRadius^2$ **(22)**

Bi-sector site $\quad SiteArea = 1.3*2.6 * CellRadius^2$ **(23)**

Tri-sector site $\quad SiteArea = 1.95 * 2.6 * CellRadius^2$ **(24)**

The number of sites to be deployed can be easily calculated from the *CellArea* and the input value of the deployment area (*DeploymentArea*).

$$NumSitesCoverage = \frac{DeploymentArea}{SiteArea} \tag{25}$$

5 Capacity Planning

The purpose of this chapter is to describe the capacity planning for the LTE network and to explain the methods used and factors impacting the capacity planning process. The chapter is divided into several sections. The first section describes the cell throughput calculations, while the second part is about traffic demand estimation. Later sections shed light on capacity based site count evaluation.

5.1 LTE Capacity Planning

Capacity planning gives an estimate of the resources needed for supporting a specified offered traffic with a certain level of QoS (e.g. throughput or blocking probability). Theoretical capacity of the network is limited by the number of eNodeB's installed in the network. Cell capacity in LTE is impacted by several factors, which includes interference level, packet scheduler implementation and supported modulation and coding schemes. Link Budget (Coverage Planning) gives the maximum allowed path loss and the maximum range of the cell, whereas coverage Planning takes into account the interference by providing a suitable model. LTE also exhibits soft capacity like its predecessor 3G systems. Therefore, the increase in interference and noise by increasing the number of users will decrease the cell coverage forcing the cell radius to become smaller.

In LTE, the main indicator of capacity is SINR distribution in the cell. In this study, for the sake of simplicity, LTE access network is assumed to be limited in coverage by UL direction and capacity by DL.

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

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

5.2 Average Cell Throughput Calculations

The target of capacity planning exercise is to get an estimate of the site count based on the capacity requirements. Capacity requirements are set forth by the network operators based on their predicted traffic. Average cell throughput is needed to calculate the capacity-based site count.

The most accurate evaluation of cell capacity (throughput under certain constraints) is given by running simulations. Since, the dimensioning is usually done using an excel workbook, the best solution to derive cell throughput is direct mapping of SINR distribution obtained from a simulator into MCS (thus, bit rate) or directly into throughput using appropriate link level results.

Thus, capacity estimation requires the following simulation results

- Average SINR distribution table (system level result), which provides the SINRprobability
- Average throughput or spectral efficiency versus average SINR table (link level result)

Among other factors, different propagation environments (propagation models, inter-site distance) and antenna configurations have an impact on the above results. Thus, multiple tables should be available for example for urban, suburban and rural areas. SINR probability is obtained by calculating the probability of occurrence of a given SINR value at cell edge. All these system level simulations are run with a predefined inter-site distance. In this method, the bit rates for each MCS are derived from the OFDM parameters for LTE. Then the SINR values to support each MCS are derived from look-up tables that are generated from link level simulations.

Subsequently, MCS supported by each value of SINR is selected by using the minimum allowed SINR from the link level results. This gives the corresponding data rate that is supported by that MCS. In this way, data rate corresponding to each SINR value is obtained for a specific scenario. For urban channel model and a fixed inter-site distance of 1732m, downlink throughput for LTE is shown in table 5-1.

Table 5-1: DL average cell throughput for LTE

MCS	SINR(min) (dB)	DL cell throughput (Mbps)
QPSK 1/3	-0.75	4.00
QPSK 1/2	1.50	6.00
QPSK 2/3	3.50	8.00
16QAM 1/2	7.00	12.00
16QAM 2/3	9.50	16.01
16QAM 4/5	11.50	19.20
64QAM 1/2	11.50	21.0
64QAM 2/3	14.7	24.01

Let us consider an example regarding table 5-1 (Urban/1732m inter-site distance). For an SINR value of 2dB, QPSK ½ is selected from the above table, and it gives a throughput of 6Mbps at 2dB. In the same way, an SINR value of 3dB corresponds to 6Mbps, 4dB to 8Mbps and 7dB to 12Mbps in DL. Once all the values are calculated by using the lookup table, cell throughput is derived as follows:

$$CellThroughput = \sum_{allSINRvalues} \left(SINR\_Occurrence\_Probability \cdot AverageThroughputSINR \right) \quad (26)$$

Where,

SINR_Occurrence_probabaility = Probability of occurrence of a specific SINR value at cell edge obtained using simulations

AveThroughputSINR = Average throughput corresponding to SINR value

5.3 Traffic demand estimation and Overbooking factor

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

The main inputs are listed below:

- Traffic mix and busy hour analysis
- Subscriber Density
- Data Volume per User
- Peak and Average Data Rate
- Daily Traffic Profiles

As coverage planning, also capacity planning is done separately for different service areas (urban, suburban and rural).

If we use requirements corresponding to the peak hour traffic, then it would lead to over-dimensioning. Precious resources will be wasted in other hours of the day and network cost will go significantly higher. For this reason it is important to define the overbooking factor (OBF), OBF is the average number of users that can share a given unit of channel. The channel unit used in dimensioning is the peak data rate. If we assume a 100 percent channel loading, then the OBF is simply equal to the ratio between the peak and the average rates (PAR).

However, it is not safe to dimension the network with 100 percent loading. Hence, the parameter utilisation factor is introduced. In most of data networks, the utilisation factor is less than 85 percent in order to guarantee Quality of Service (QoS). So the higher this parameter, the longer will be the average waiting time for users accessing the channel. Thus, the overbooking factor is derived as follows:

$$\text{OverbookingFactor} = \text{PeakToAverageRatio.UtilisationFactor} \quad \textbf{(27)}$$

5.4 Capacity based site count

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

$$\text{OverallDataRate} = \text{NumberOfUsers.PeakDataRate.OverbookingFactor} \quad \textbf{(28)}$$

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

$$NumSitesCapacity = \frac{OverallDataRate}{SiteCapacity} \quad \textbf{(29)}$$

Where the SiteCapacity is a multiple of the Cell Throughput, which depends on the number of cells per site (Not considering any hardware limitation)

As already done for the coverage evaluation, the site count is performed for each type of service area. Capacity based site count is usually higher than the coverage based counterpart in a fully functional network. In real networks, this number is smaller in the earlier years of network operation, when the number of users is quite less. But as the demand increases and more users are added to the service, the capacity based site count takes the lead and smaller cells are required. The larger of the two counts is used as a final number as a dimensioning output.

6 Tool for LTE Dimensioning

LTE dimensioning tool is excel-based software developed to carry out dimensioning of LTE networks. This chapter explains different parts of this tool including its structure and contents. This chapter also discusses how does this excel-based tool works, its advantages and limitations.

6.1 Methodology and Structure

The dimensioning tool is designed to carry out both coverage and capacity calculations for the dimensioning of the Long Term Evolution (LTE) Network. It performs the required calculations, providing the site count on the basis of traffic forecast as the final result.

Excel is chosen over MATLAB as the implementation software for the dimensioning tool. Excel is a spreadsheet application with special features for performing calculations and providing a wide variety of graphics, making it one of the most popular and widely used PC applications [24]. The basic motive for preferring Excel is its ease of use and unproblematic accessibility. The critical idea during the design and development of this software is to make it as simple and intelligible as possible. This goal is primarily achieved by having an unambiguous distinction between different functional parts. Inputs and outputs are clearly notable. All the inputs are available on a single sheet of excel tool with main outputs placed on the last sheet.

The intermediate calculations and detailed formulas are placed on separate sheets. As a result, a user can use the tool without going into details of implementation. Ideally, user is required to look only at the input and output sheets. User can enter all the inputs on one sheet and can then directly go to the output sheet to view the detailed results.

The workbook (Excel-based dimensioning tool) is structured so that there is a clear separation between planning inputs, system inputs (e.g. link and system level results), working section and results. It consists of eight sheets.

- Inputs
- Tables
- Radio Link Budget (RLB)
- Capacity Evaluator
- Traffic Forecast
- Dimensioning Output
- Version and history of change

6.2 Dimensioning inputs

'Input sheet' lists all the required inputs for dimensioning process of LTE networks. Inputs are grouped into three clusters.

- System inputs
- Coverage planning inputs
- Capacity planning inputs

Input sheet is an important part of the structure of the dimensioning tool. It collects all the possible inputs in one place. This is quite a different approach when compared to other available dimensioning tools for other systems. In other dimensioning software, it is always a difficult process to collect all the inputs in one place. User has to switch from one part to another to change the input parameters. This is time consuming as well as difficult to use. The purpose of having clearly separated inputs is to allow users to change dimensioning inputs from one place.

To make a clear distinction between inputs, coverage and capacity related inputs are arranged into two columns. System inputs are placed on the top of the coverage inputs as they are directly used by the coverage evaluator. This allows the user to control the output of coverage and capacity evaluators independent of each other.

System inputs include carrier frequency, channel bandwidth and area of deployment. Coverage related inputs available in the dimensioning tool are RLB inputs and propagation model. Along with these inputs general RLB parameters, like antenna transmitter powers, system gains and losses, etc are also present. Capacity related inputs are traffic forecast for each type of traffic, utilization factor and subscriber geographical spread. Subscriber geographical spread gives the percentage of population to be covered by the network in each type of deployment area. There are three types of deployment areas considered; city/urban, suburban and rural. These inputs are vendor-specific. screen shots of 'input sheet' are shown in figures 6-1 and 6.2.

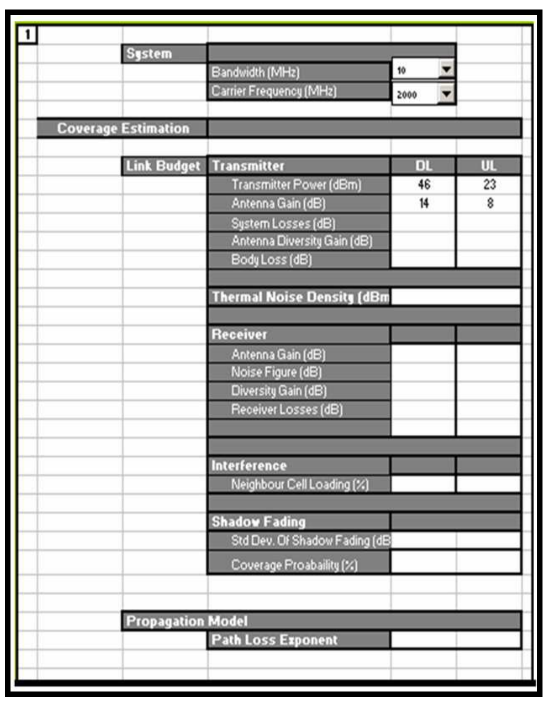


Figure 6-1: Dimensioning tool: Capacity Inputs

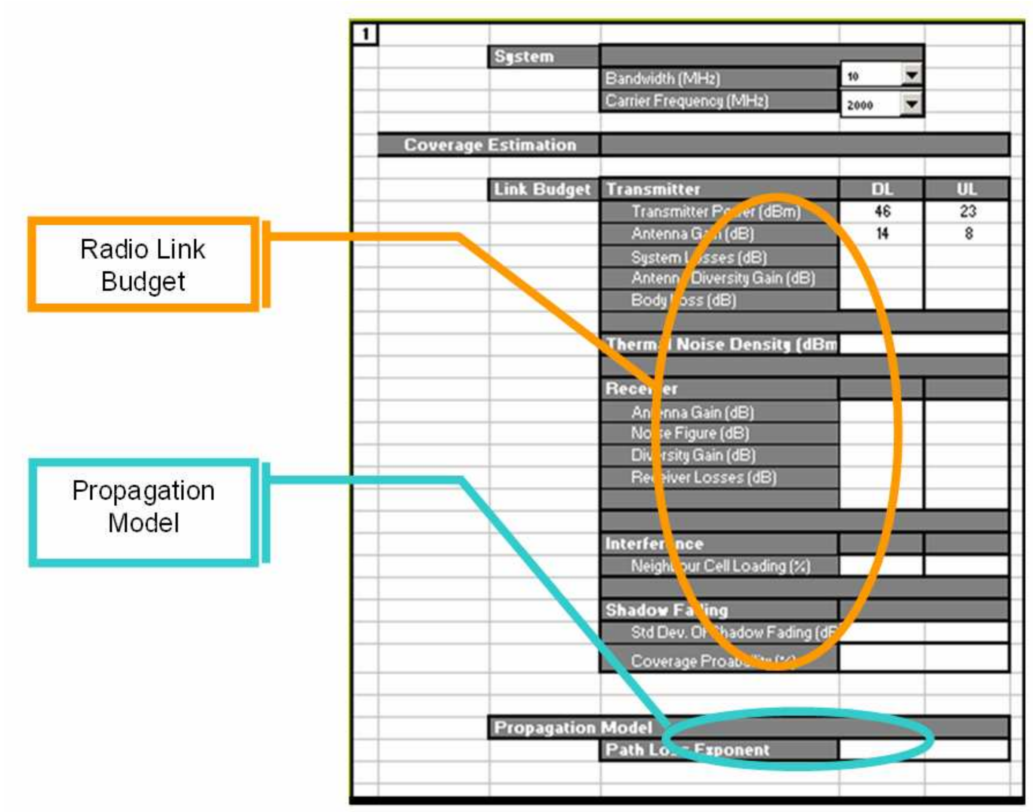


Figure 6- 2: Dimensioning tool: Coverage Inputs

6.3 Tables and background data

All the required information to carry out the coverage and capacity calculations is positioned on 'Tables' sheet. This sheet contains all the data needed for number crunching. Sheet is partitioned into different parts.

First part contains the tables for adaptive modulation coding schemes. It lists all the allowed modulation schemes like, QPSK, 16QAM and allowed coding rates for these schemes in LTE networks. The most important section of this part is Shannon-Alpha tables. Shannon-Alpha formula is used for coverage estimation. Tables for four different antenna configurations are available (See section 4.2.1).

Second part carries details of different antenna configuration, channel models used and system parameters. System parameters are operating frequency and channel bandwidth. Third section details the maximum available data rates for different modulation and coding schemes. These tables are used to calculate the data rate supported by one eNB in capacity planning. This procedure is explained in chapter 5.

Fourth section holds the link level simulation results. This table gives the minimum required SINR for each modulation and coding scheme e.g. for QPSK ½. Currently, dimensioning tool has the data for two combinations of channel model and antenna configuration. Fifth section features system level results from simulator. These are SINR distribution tables for different environments. These tables are presented in the form of the graph in figure 4-2.

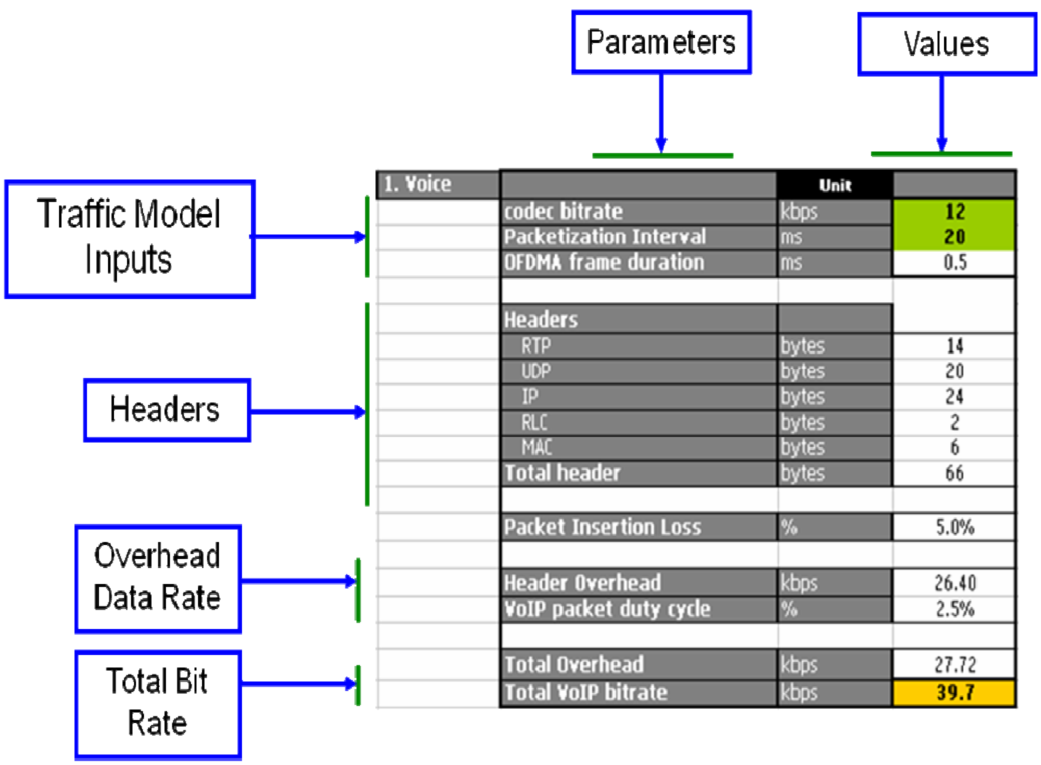


Figure 6- 3: Dimensioning tool: Traffic models

6.4 Radio link budget

Radio link budget calculations deal with the coverage estimation of LTE network. RLB is evaluated with respect to different criteria. All the factors effecting RLB are listed in the sheet with DL and UL budgets calculated side by side. Figure 6-4 is the snapshot of radio link budget sheet.

One of the main features of this dimensioning tool is the facility to calculate RLB using three different methods. The detailed theory behind radio link budget is already elucidated in chapter 4. User of the software can adopt anyone of these methods, depending upon the analysis strategy.

Maximum coverage is the primary criteria, which is usually used for RLB. LTE is a packet optimized network. All the traffic is carried in form of data packets. Therefore, using a modulation scheme will affect the amount of data carried by the network. For example, using a MCS of 16QAM 4/5 instead of QPSK ½ will allow a better utilisation of the network and higher data rate. But 16QAM 4/5 can only be used in favourable channel condition. Otherwise error rate will be high enough to cancel the advantage of using a better MCS. In maximum coverage criteria, it is assumed that lowest MCS is used. Lowest MCS corresponds to the lowest data rate. Use of lowest MCS allows the estimation of farthest reach of eNB. In this way, an estimate of maximum possible cell radius is obtained.

A second criterion available for RLB is 'fixed inter-site distance'. For this criterion, user is allowed to fix the inter-site distance. With a fixed inter-site distance, RLB is calculated in reverse to find out the allowed MCS for a given channel model and thus the maximum available data rate of the cell. The data rate obtained in this process is the theoretical maximum and it will be higher than the achievable data rate.

To provide the user with full freedom, a third criterion of 'User defined target data rate' is also available. In this RLB criterion, user can set the desired or target data rate that should be provided by a cell. RLB calculations are then carried out to find out the MCS needed to support this data rate. This MCS is then used to compute the allowed cell radius. Therefore, this criterion is the converse of 'fixed inter-site distance' criterion. These three criteria make this software a very versatile and powerful LTE dimensioning tool.

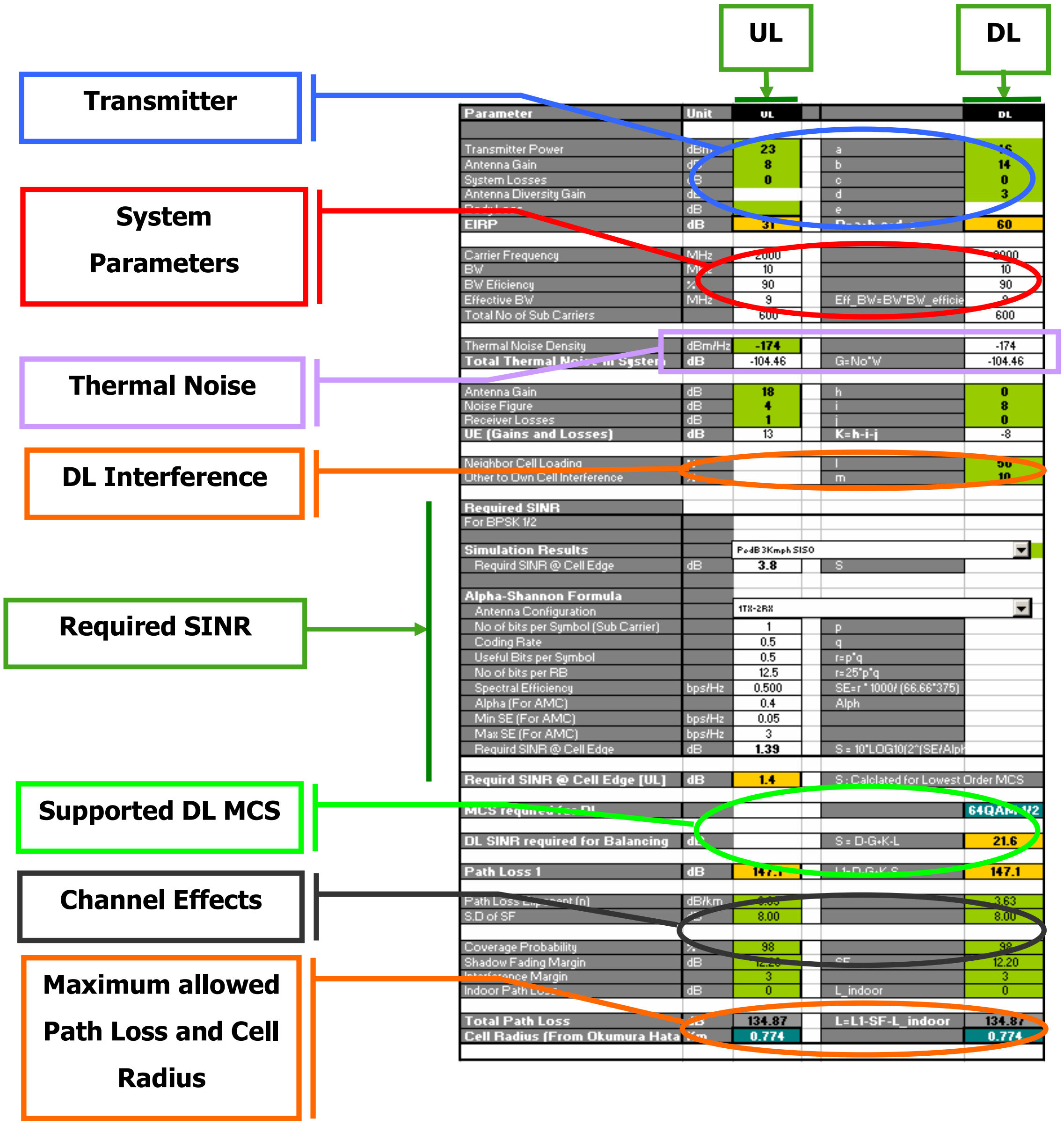


Figure 6-4: Dimensioning tool: Capacity evaluator

6.5 Capacity Evaluator

Capacity evaluator sheet calculates maximum cell throughput for a specific Cell Range. Thus, it provides the capacity of a single eNB in LTE access network. Calculation of maximum cell throughput is based on SINR distribution tables which are obtained from system level simulations of LTE network. A simple approach of direct SINR-MCS mapping is used to calculate the cell throughput. SINR distribution tables from system level simulations are placed in 'tables' sheet. Minimum required SINR for each MCS is calculated. Data rate that can be achieved, using a specific MCS is known by using system parameters. Detailed capacity evaluation method is explained in section 5.2.

- If (SNR<Lowest_SNR_for_MCS)
- Then: Data Rate = 0;
- else

  Data Rate = Table (SNR, DL Rate corresponding to MCS)

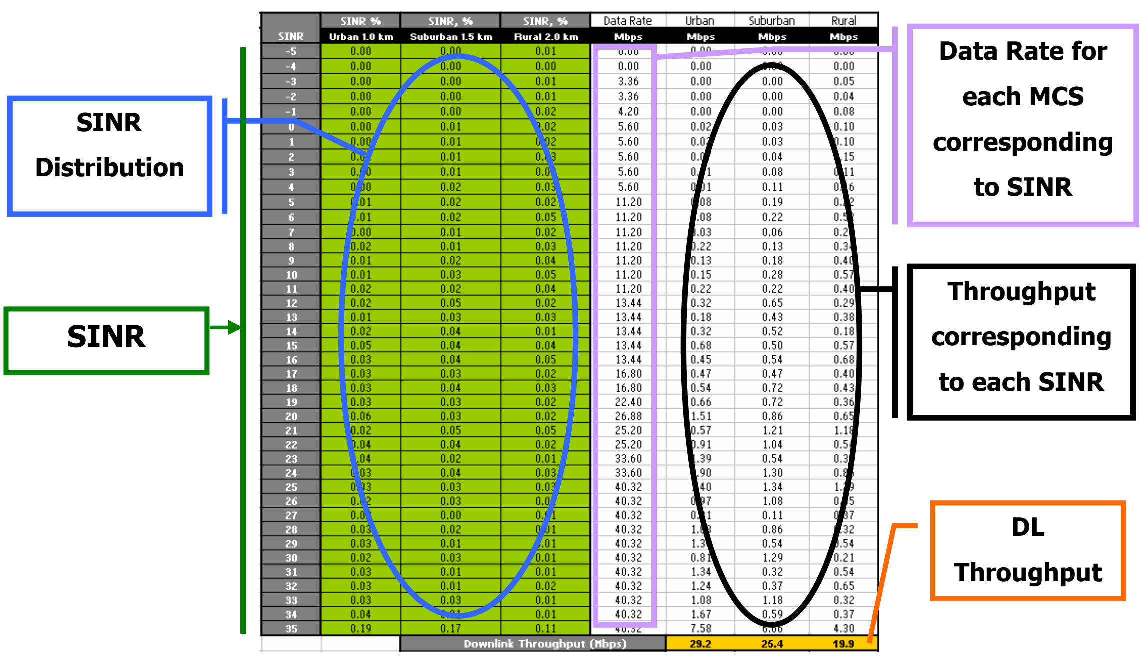
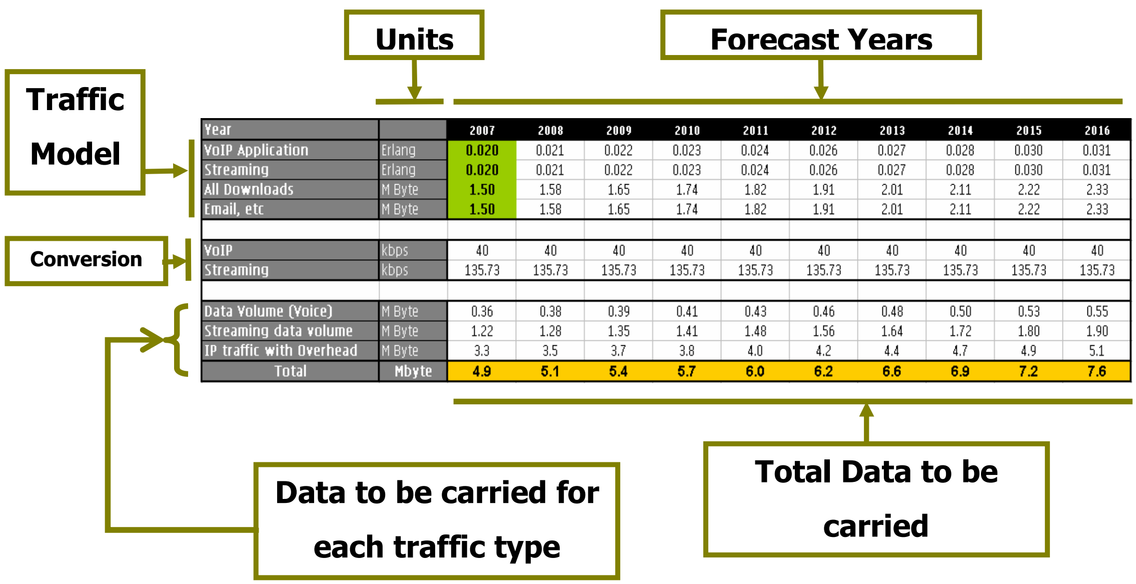


Figure 6-5: Dimensioning tool: Capacity evaluator

6.6 Dimensioning Output

This sheet contains the detailed outputs, which are calculated by using the data from previous sheets. This sheet displays the final dimensioning results. A screen shot of 'output' sheet is given below. As shown in the figure 6-6, each column corresponds to one year, mentioning the results calculated on the basis of current year data and forecast provided by the customer. Rows are bunched together in different groups.

- Population statistics
- Number of subscribers
- Area to be covered by the network
- Subscriber geographical spread
- Cell Throughput
- Capacity-based site count
- Final site-count



Year		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
VoIP Application	Erlang	0.020	0.021	0.022	0.023	0.024	0.026	0.027	0.028	0.030	0.031
Streaming	Erlang	0.020	0.021	0.022	0.023	0.024	0.026	0.027	0.028	0.030	0.031
All Downloads	M Byte	1.50	1.58	1.65	1.74	1.82	1.91	2.01	2.11	2.22	2.33
Email, etc	M Byte	1.50	1.58	1.65	1.74	1.82	1.91	2.01	2.11	2.22	2.33
VoIP	kbps	40	40	40	40	40	40	40	40	40	40
Streaming	kbps	135.73	135.73	135.73	135.73	135.73	135.73	135.73	135.73	135.73	135.73
Data Volume (Voice)	M Byte	0.36	0.38	0.39	0.41	0.43	0.46	0.48	0.50	0.53	0.55
Streaming data volume	M Byte	1.22	1.28	1.35	1.41	1.48	1.56	1.64	1.72	1.80	1.90
IP traffic with Overhead	M Byte	3.3	3.5	3.7	3.8	4.0	4.2	4.4	4.7	4.9	5.1
Total	Mbyte	4.9	5.1	5.4	5.7	6.0	6.2	6.6	6.9	7.2	7.6

Figure 6-6: Dimensioning tool: Forecast

Population statistics enlists the total population and number of persons in a households expected to use the service. Number of subscribers is calculated according to the criteria that there is one customer per household. This number is simply obtained by dividing the total population by number of persons in a household.

$$NumberOfHouseholds = \frac{TotalPopulation}{NumberOfPersonsInHousehold} \quad \textbf{(30)}$$

Actual number of subscribers using the service is always lower than the total number of households. Therefore, actual subscriber count is estimated next. Penetration for different mobile services is used to evaluate the real number of subscribers. This figure is provided by the operator itself. Geographical area to be covered and area types are provided next, followed by the subscriber spread in each of different area types. For the delivered version of dimensioning tool, values of 20%, 30% and 50% are assumed for urban, suburban and rural areas respectively.

Traffic models and traffic forecast is used to compute the total traffic that has to be carried by the whole network for each area type. This computation takes into account utilisation factor, overbooking factor and traffic demand. Capacity of a single eNB is calculated by capacity evaluation exercise from 'capacity evaluator sheet'. Equation 29 is used to evaluate the number of eNB to cover each area. It is important to note that these calculations are made for each area type separately.

Dimensioning exercise gives the number of sites needed from both coverage and capacity dimensioning. Maximum of the two values is taken as the final site count. Site count for different area types is then added to get the final figure for the whole area. Final output is depicted in figure 6-7 on next page.

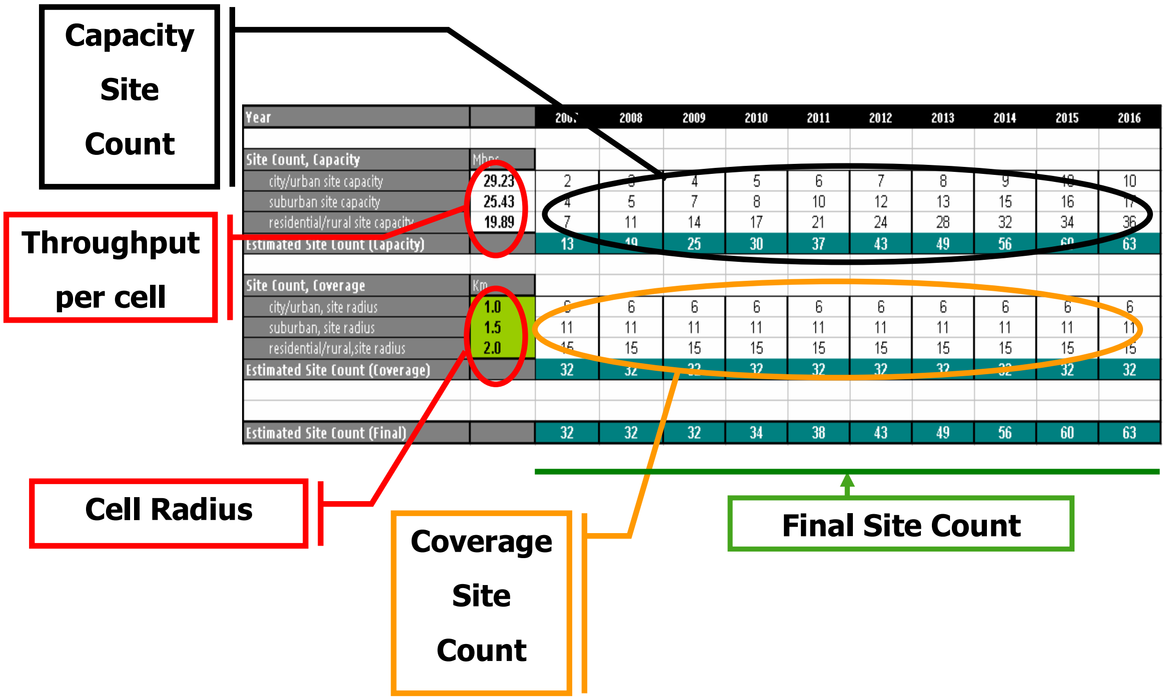


Figure 6-7: Dimensioning tool: Outputs

7 Conclusion and Future Work

This chapter presents a summary of the thesis work. It gives a synopsis of work performed and the final results. Possible future word and improvements are also discussed in this chapter.

7.1 Conclusion

To maintain its competitive edge in the world of mobile networks in the future, 3GPP has initiated work on LTE. LTE is a packet optimized radio access technology with low latency and large bandwidths. This thesis work is based on the dimensioning of LTE Networks. During the course of this research work models and tools for LTE dimensioning have been developed. Both coverage and capacity estimation is carried out. Radio link budget is investigated for coverage planning and different factors affecting the RLB are looked into. Theoretical work is later put into the development of an Excel-based dimensioning tool. Dimensioning tool is designed to keep the interface simple and to set the functional parts clearly distinguishable. The final product gives the number of sites (cells) needed in order to support a certain subscriber population with a given capacity.

7.2 Future Work

Great effort has been made in order to make this work complete in all aspects. But as with all the projects, there is always room for improvements and further enchantments. Same is the case with this thesis work. There are number of ways in which this work can be carried forward. The work done in this thesis covers the access network dimensioning of LTE network. This can be extended to include interface dimensioning. Moreover, the unavailability of reliable LTE network simulators is a big hurdle in full calibration of this tool. Using a more accurate simulator will yield better results for capacity planning exercise. Currently, the simulation results for only a limited antenna configurations and scenarios are available. These available scenarios are used in the dimensioning tool (developed for this thesis work). If the results for other antenna configurations and scenarios are obtained, this tool will become more comprehensive. Dimensioning tool has been designed to accommodate these extensions.

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