**ADDIS ABABA UNIVERSITY**

Addis Ababa institute of Technology

*School of Electrical and Computer Engineering*

# LTE Radio Access Network Dimensioning by Particle Swarm Optimization

*For Partial Fulfilment of MSc in Communication Engineering*

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**Thesis**

**on**

# LTE Radio Access Network Dimensioning by Particle Swarm Optimization

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# Abstract

In this research, Long Term Evolution Radio Access Network Dimensioning by Particle Swarm Optimization (PSO) in the case of Addis Ababa, Ethiopia has been introduced. Currently, mobile network service provision demand is increasing, especially customers' data demand increases time to time. To accommodate this demand, LTE is in hand solution. Preparing nominal plan after dimensioning is tiresome and error prone. The motive of this research is to use PSO for addition of new sites to the existing e-NodeBs in order to simplify LTE planning by considering traffic distribution. Using PSO has good result in order to find optimal position of new site.

There are many researches done on LTE radio network dimensioning. However, they did not consider actual customer distribution or traffic density, which will cause inefficient use of the network resource. With this research, PSO has been checked for LTE dimensioning in the case of Addis Ababa for LTE RAN planning and congestion optimization that it will assist to put new sites on high traffic density area.

LTE coverage dimensioning have been done by two ways: by empirical way using Cost-231 propagation model and by outdoor planning tool, Mentum planet. LTE capacity dimensioning was also done by two scenarios: from traffic history prediction and expectation of the coming big data demand of Internet of Things, Machine to Machine and e-commerce. Live network traffic history and Time Advance measurement of Global Solution for Mobile communication have been taken and average traffic probability distribution function (PDF) and optimal traffic probability density function(pdf) have been developed. From which, inter-site traffic share models have been formulated.

Finally, model for PSO has been developed. For each new site; searching radius, minimum inter-site distance and required point by searching optimal points within searching area as well as total number of sites were determined.

This research shows that number of sites found based on numerical calculation for capacity is not enough to support expected traffic due to uneven traffic distribution. It confirmed that using single type of LTE site is both inefficient and insufficient.

**Key Words:** RAN dimensioning, particle swarm optimization, inter-site traffic share

## Declaration

I declare that this research work is my original work and all sources used for this research have been fully acknowledged.

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# TABLE OF CONTENTS

# LIST OF ABBREVIATIONS

| | |
|---|---|
| 3GPP | Third Generation Partnership Project |
| ABC | Artificial Bees Colony |
| ACS | Ant Colony System |
| BSC | Base Station Controller |
| CAPEX | Capital Expense |
| CP | Cyclic Prefix |
| CSFB | Circuit Switched Fall Back |
| DL-SCH | Downlink Shared Channel |
| E-UTRAN | Evolved Universal Terrain Radio Access Network |
| EIRP | Equivalent Isotropic Radiated Power |
| eMBMS | Evolved Multimedia Broadcast Multicast Services |
| EPC | Evolved Packet Core |
| ETU | Extended Typical Urban model |
| EVA | Extended Vehicular A model |
| FDD | Frequency Division Duplex |
| GMT | Greenwich Mean Time |
| HSDPA | High-Speed Downlink Packet Access |
| HSPA | High-Speed Packet Access |
| HSUPA | High-Speed Uplink Packet Access |
| HS-DSCH | High Speed Downlink Shared Channel |
| HSS | Home Subscriber Server |
| HST | High-Speed Train |
| IMS | IP Multimedia Service |
| IMT | International Mobile Telecommunications |
| IPRB | Index of Physical Resource Block |
| ITM | International Telecommunication |
| ITU-R | International Telecommunication Union Radio |
| MAPL | Maximum Allowable Path Loss |
| MCS | Modulation Coding Scheme |
| MIMO | Multiple input Multiple output |
| MME | Mobility Management Entity |
| NMS | Network Management System |
| OFDMA | Orthogonal Frequency Division Multiplexing |
| P-GW | Packet Gateway |
| PAPR | Peak to Average Power Ratio |

| | |
|---|---|
| PBCH | Physical Broadcast Channel |
| PDF | Probability Distribution Function |
| PCRF | Policy and Charging Rules Function |
| PD | Propagation Delay |
| PDCCH | Physical DL Control Channel |
| PCFICH | Physical Control Format Indicator Channel |
| PCI | Physical Cell ID |
| QoS | Quality of Service |
| RS | Reference Signal |
| RSRP | Reference Signal Received Power |
| RSRP | Reference Signal Received Power |
| RSSI | The Received Signal Strength Indicator |
| RTT | Round Trip Time |
| S-GW | Service Gateway |
| SC-FDMA | Single Carrier Frequency Division Multiplexing |
| SDCCH | Slow Dedicated Control Channel |
| SINR | Signal to Interference and Noise Ratio |
| TB | Transport Block |
| TBS | Transport Block Size |
| TCH | Traffic Channel |
| TDD | Time Division Duplex |
| TEP | Telecom expansion Project |
| TMA | Tower Mounted Amplifier |
| TTI | Transmission Time Interval |
| UMTS | Universal Mobile Telecommunication Systems |
| ViLTE | Video over LTE |
| VoIP | Voice over IP |
| VoLTE | Voice over LTE |
| WiMAX | Worldwide Interoperability for Microwave Access |
| PUCCH | Physical Uplink Control Channel |
| QoS | Quality of Service |
| RS | Reference Signal |
| RSRP | Reference Signal Received Power |
| RSRP | Reference Signal Received Power |
| RSSI | The Received Signal Strength Indicator |
| RTT | Round Trip Time |
| S-GW | Service Gateway |

# LIST OF FIGURES

# LIST OF TABLES

# CHAPTER 1 INTRODUCTION

## 1.1. Introduction to LTE

As demand for wireless voice and data services increases, the capacity of Second Generation(2G) and Third Generation(3G) mobile networks has become insufficient. For better mobile network resources, Third Generation Partnership Project (3GPP) has proposed LTE. Its powerful service bearing capability, efficient resource utilization, low network construction and operation costs, and flexible network deployment, LTE is chosen by leading operators [37].

In telecommunication, LTE is a standard for high-speed wireless communication for mobile devices and data terminals, based on the GSM and Universal Mobile Telecommunication Systems (UMTS) technologies. It increases the capacity and speed using a different radio interface together with core network improvements [37].

LTE does not meet the technical criteria of a Fourth Generation (4G) wireless service, as specified in the 3GPP. However, due to marketing pressures, International Telecommunication Union (ITU) later decided that LTE can be called 4G technology. The LTE Advanced standard formally satisfies the International Telecommunication Union Radio (ITU-R) requirements [36].

LTE was developed from the GSM and UMTS technologies. It increases the capacity and speed using an advanced radio interface together with core network improvements [37].

LTE provides many benefits like high-speed data, bandwidth efficiency, latency, multimedia unicast and multimedia broadcast services to cellular networks and can be summarized as: 4G systems are intended to provide high quality video services providing data transfer speeds up to 100 Mbps [34]. 4G mobile technology offers transmission speeds of more than 20 Mbps and can offer high bandwidth services [30]. 3G due to existence of multiple standards, it is difficult to roam and interoperate with other mobile networks. LTE has a global standard providing global mobility and service portability without binding the customers by vendors' proprietary equipment [34]. And it is not completely new standard, but basically LTE is a collection of previous technologies and is a convergence of more than one technology [34].

LTE Physical layer holds frequency, bandwidth, modulation, cyclic prefix and coding rate, which help in calculation of the throughput. LTE system uses Orthogonal Frequency Division Multiplexing (OFDMA) as access technology in downlink to increase the spectral efficiency and Single Carrier Frequency Division Multiplexing (SC-FDMA) in uplink [30, 32,33].

### 1.1.1. LTE Architecture

In order to provide 1GBps for stationary users and 100 MBps for high-speed mobility, LTE reduced complexity of the network that it removed BSC/RNC. LTE has upgraded UMTS' radio access to Evolved Universal Terrain Radio Access Network (E-UTRAN), while the core part developed to Evolved Packet Core (EPC) [37].

E-UTRAN has evolved user equipment (eUE) and evolved NodeB (eNB); it merged NodeB and RNC and EPC has MME, HSS, PCRF, S-GW and P-GW. It may include IMS if it supports voice over LTE (VoLTE).

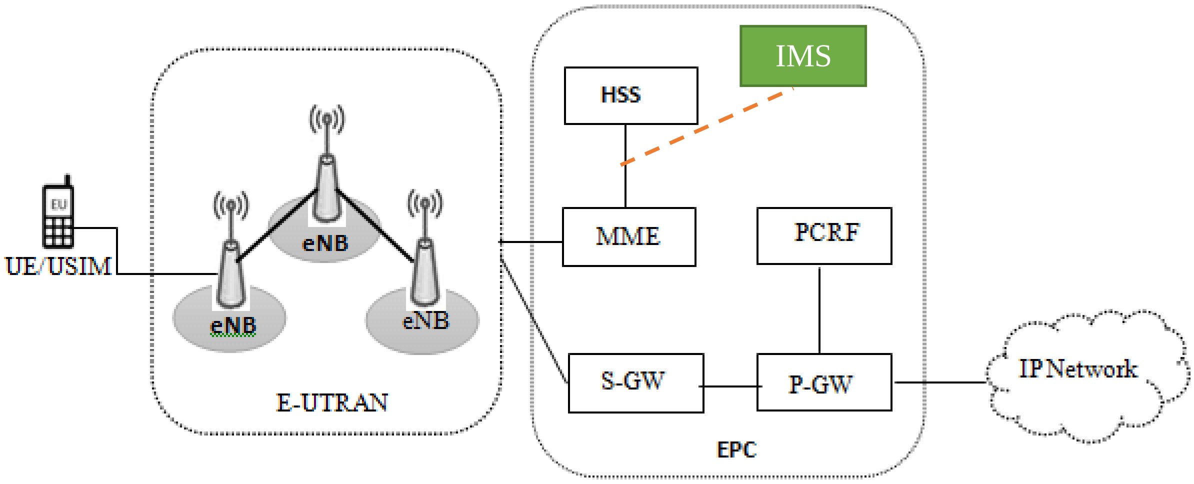


Figure 1.1. Architecture of LTE network [16]

### 1.1.2. LTE Voice Solution

LTE is basically data technology, but it can give voice services by two ways [29, 35].

**CS Fall Back: -** When outgoing call is attempted or terminating call comes, UE releases LTE network and connects to UMTS or GSM circuit switched network components or by double connection system, the UE connected both to LTE and UMTS or GSM at the same time, voice call will be served. The voice call uses GSM or UMTS CS components and the voice codec is the same to GSM or UMTS [29, 35].

**VoLTE (Voice over LTE): -** It needs IMS (IP multimedia system). It is the same to voice over IP [29, 35].

### 1.1.3. LTE Basic Terminologies

LTE has its own features that make it different from GSM/EDGE and UMTS/HSUPA. The following basic terminologies shows LTE's unique nature [34].

**Resource Element (RE): -** RE is the smallest unit of transmission resource in LTE, in both uplink and downlink. It is the smallest element of LTE channel which carries signaling and data. One RE is one OFDMA symbol of one sub carrier (15 kHz) in 0.5 ms [30, 31].

**Subcarrier Spacing: -** It is the time space between the individual subcarriers. In LTE, each subcarrier is 15 kHz without any frequency guard band between subcarriers. However, to prevent Multipath Inter-Symbol Interference between subcarriers a guard period called a Subcarrier Spacing is used [30, 31].

**Cyclic Prefix: -** It is a set of samples, which are duplicated from the end of a transmitted symbol and added cyclically to the beginning of the symbol. This can form a type of guard interval to prevent Inter-Symbol Interference. It preserves orthogonally of the subcarriers in an OFDM transmission [30,31].

**Time slot:** - LTE has 10 time slots with 10-millisecond duration that one-time slot has 1 ms duration and each time slot is divided in to two sub durations of 0.5ms. This 0.5 ms period of LTE frame is corresponding to seven OFDM symbols per subcarrier [30].

**Resource Block (RB): -** RB is a unit of time and frequency. One frame has 10 time slots, each time slot is divided in to two sub durations and each 0.5ms transmits 12 sub carriers. This combination of 12 subcarriers in 0.5ms is called one resource block [30,31].

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

Table 1-1. LTE main time slots of 10ms [30]

One-time slot has two sub-time slots; for instance, the first time slot has the following two sub-time slots.

| | |
|---|---|
| 0.5ms | 0.5ms |

Table 1-2. LTE half time slots [30]

| |
|---|
| 0.5ms and 12 subcarriers |
| 0.5ms and 12 subcarriers |

Figure 1.2. LTE Resource Blocks [30]

One RB is 12 subcarriers each with seven OFDMA symbols within 0.5 ms duration. So, 12 subcarriers with 7 symbols is 84 RE (with Normal CP) makes RB. So, 20MHz LTE channel will have 100 RB [30].

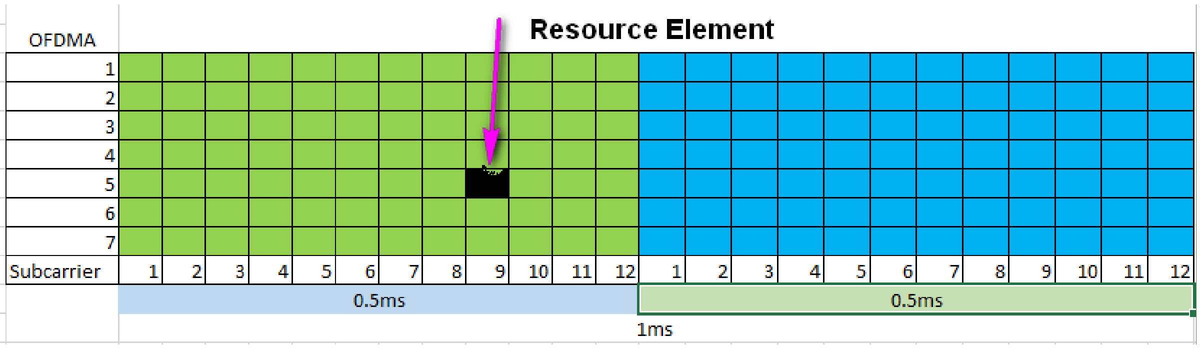


Figure 1.3. Resource Block of Normal CP [30]

In LTE, ten percent of total bandwidth is assumed to be used for guard band, but 10% guard band assumption is not valid for 1.4 MHz bandwidth [30].

Let us take an example of 20MHz, 10% of 20 MHz is 2 MHz, used as guard band, thus effective bandwidth will be 18MHz.Number of subcarriers is the quotient of 18 MHz to 15KHz; 1200. And number of Resource Blocks is the quotient of 18 MHz to 15KHz 180KHz i.e. 100. For other bandwidths, to calculate the number of subcarriers and Resource Blocks is the same; shown below: [30]

| Band Width (MHz) | 1.4 | 3 | 5 | 10 | 15 | 20 |
|---|---|---|---|---|---|---|
| Effective BW (90% of BW) (MHz) | 1.08 | 2.7 | 4.5 | 9 | 13.5 | 18 |
| Number of subcarriers(15KHz) | 72 | 180 | 300 | 600 | 900 | 1200 |
| Resource Blocks (12 subcarriers) | 6 | 15 | 25 | 50 | 75 | 100 |

Table 1-3. Different LTE bandwidths

### 1.1.4. Duplexing and Bandwidth

LTE supports both types of duplexing i.e. Frequency Division Duplex (FDD) and Time Division Duplex (TDD). FDD spectrum has unique bandwidth for Downlink and for Uplink. TDD spectrum has only one BW, which is used for both of Downlink and Uplink [30].

The duplexing technique directly affects throughput; in FDD which has symmetric bandwidth so both Uplink and Downlink can have the same throughput, but in TDD since the same bandwidth is shared by Uplink and Downlink on time sharing basis, the total throughput is also shared [30].

Earliest mobile technologies use single carrier bandwidths i.e. GSM 200 KHz, CDMA 1.25MHz and UMTS 5MHz while LTE has scalable bandwidths (1.4, 3, 5, 10, 15, and 20 MHzs). However, LTE does not use all bandwidth for carrier, that it uses 10% of BW for guard band. For instance, 10MHz carrier has 1MHz guard band and 9MHz usable BW. Each carrier of LTE is divided into 15 KHz subcarrier. Number of subcarriers of 20MHz LTE channel is 1200 subcarriers. Power will be divided into these subcarriers [30, 31, 32 34].

### 1.1.5. Modulation and Coding Rate

As per Release 8 LTE supports modulations like QPSK, 16QAM and 64QAM in Downlink and QPSK and 16QAM in Uplink. Each of Modulations has its bits carrying capacity per symbol. One QPSK symbol can carry 2 bits, one 16QAM symbol can carry 4 bits and 64 QAM symbol can carry 6 bits [30].

Coding rate describes the efficiency of modulation scheme. For example, if we say 64 QAM with coding rate of 0.5, it means this modulation has 50% of efficiency i.e. 64QAM can carry 6 bits but with coding rate of 0.5, it can carry 3 information bits and rest of 3 bits for redundancy of information. LTE uses different coding rate with QPSK, 16 QAM and 64QAM. The combination of Modulation and Coding rate is called Modulation Coding Scheme [30].

Each modulation is used with some MCS. Each MCS have a corresponding TBS (transport block size) index value, which is used for mapping transport block (TB) size with Resource Block numbers to find the throughput [30,34].

TBF index against Physical Resource Block (PRB) index indicates the number of bits that can be transmitted in a sub frame (Transmit Time Interval) used for Modulation with relative to bandwidth. The Transport Block size given in this table is after considering the controlling overhead [30,34].

By using this table, the number of data bits can be calculated, with the combination of MCS Index and Number of Resource Blocks. For example, with 100 RBs and MCS index of 28, the TBS is 75376. Assume 4x4 MIMO, the peak data rate will be 75376 x 4; 301.5 Mbps [30,34].

*Note: MCS table is found in Appendix.*

### 1.1.6. UE Categories in LTE

User Equipment category shows device's DL/UL throughputs, antenna, TBS size and modulation supported. The handset-type groups vary in maximum possible throughput (bits received within a Time Transmission Interval). Let a TTI of 1ms for category 1, the maximum possible throughput is 10296 bits/1ms, which is approximately 10 Mbps of physical layer DL throughput [32].

There are 8 categories of UE; existing UE categories 1 - 5 are for release 8 and 9 and UE categories 6-8 are for release 10, LTE-Advance [32]. Commercial UEs that we have today are mostly Cat 3, which have two receiver chains and one transmitter chain. Cat 3 UE does not support 64 QAM in uplink.  In release 8 and 9, Cat 5 mobiles are the only handsets that can support 64 QAM on the UL [32].

Cat 3, the Max TB size supported in DL is 75376 bits per ms and in Uplink 51024 bits per millisecond. This TB size limits the throughput at UE end while eNodeB do not have such limitation [32].

*Note: Currently UE-5 has maximum data rate [32].*

### 1.1.7. Maximum Throughput with Maximum Bandwidth

For any system throughput is calculated as symbols per second. Further, it is converted into bits per second depending on the number of bits per symbol [34].

In LTE for 20 MHz, there are 100 resource blocks and each RB has $12x7x2 = 168$ symbols per ms in normal CP. Therefore, there are 16800 symbols per 1 ms or 16800000 symbols per second(16.8Msps). If the modulation used is 64 QAM (6 bits per symbol) then throughput will be 16.8x6; 100.8Mbps for a single chain [34].

LTE uses four types of MIMO systems; 2x2,2x4, 4x2 and 4x4 [33, 34]. For 4x4 MIMO the throughput will be four times of single chain throughput. i.e. 403.2 Mbps. If 25% of overhead used for controlling and signaling, the effective throughput will be 300 Mbps. From MCS/TBS table also, with 100 RBs and MCS index of 28, the TBS is 75376. With 4x4 MIMO, the peak data rate will be $75376\ bits/ms\ x\ 4\ =\ 301.5$ Mbps [34].

300 Mbps is for downlink only and is not valid for uplink. In uplink, we have only one transmit chain at UE end. Therefore, with 20 MHz we can get Maximum of 100.8Mbps as the calculation shown above. After considering 25% of overhead, we get 75Mbps in UL [34]. This is the way how we get throughput for Downlink and for Uplink of one LTE cell.

## 1.2. Introduction to LTE RAN Dimensioning

To fulfill the required QoS specifications of various applications, a few important parameters like bit error rate, jitter, latency and minimum throughput must be met [5, 29, 35].

Radio network dimensioning includes coverage dimensioning and capacity dimensioning. It is also obtaining the scale of sites and configuration according to input requirements after the coverage and capacity are balanced [5, 29, 35].

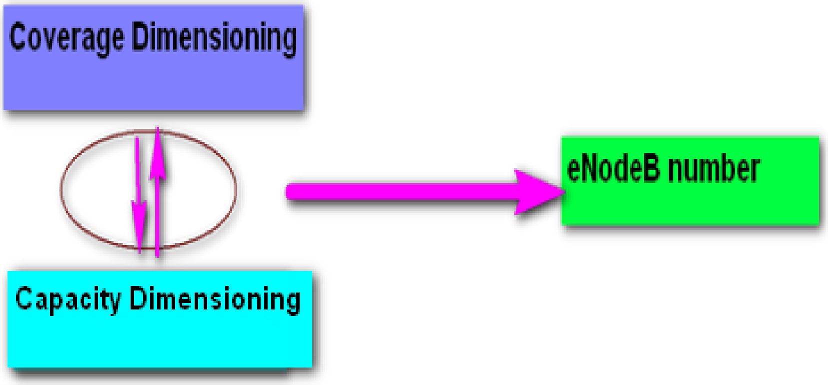


Figure 1.4. Radio Access Network Dimensioning Procedure [35]

Radio network dimensioning is a simplified analysis for radio network; that is, it provides the first evaluation of the network element, number as well as the capacity. The target of the dimensioning phase is to estimate the required site density and site configuration for target area and target number of users. Dimensioning activities include link budget and coverage analysis, capacity evaluation and finally estimation of the amount of eNodeB hardware, cell average throughput and cell edge throughput [5, 29, 35].

Objective of RAN dimensioning is to obtain the network scale (eNodeB number and configuration). RAN dimensioning includes selecting a proper propagation model, traffic model and subscriber distribution, and estimate coverage radius, cell throughput, cell edge throughput and finally number of sites [5, 29, 35].

## 1.3. Radio Network Planning Procedure for LTE

Basically, radio dimensioning has four steps. But this research is limited to high level design and nominal plan only.

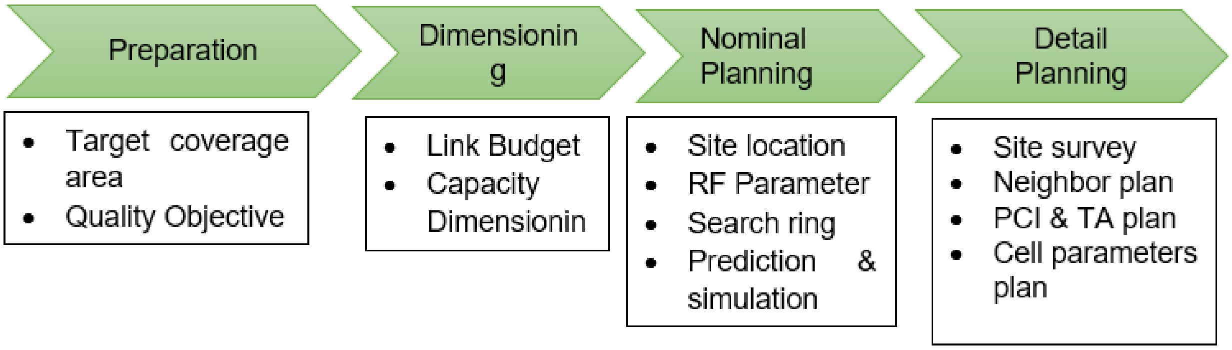


Figure 1.5. Radio access planning procedure for LTE [29]

Before dimensioning, some link budget parameters such as propagation model, penetration loss, fading margin and interference margin should be prepared [5, 29, 35]. Before LTE radio network planning, some targets need to be set, which are target area, target service, target quality, target coverage quality, and target load. The target service may be data only or both data service and voice service. The target quality of the data service is judged by the cell edge throughput. The throughput requirements are different in different target area such as urban and dense urban. The coverage probability is according to the network deployment strategy i.e. for different morphology, we may apply different coverage probability [5, 29, 35].

Before planning, we should collect as much information as possible, such as if indoor areas' coverage is required or not and if TMA (tower mounted amplifier) is used or not [5, 29, 35].

Generally, five morphologies are considered in network planning with specific channel model.

| **Morphology** | **Channel Mode** | **Velocity** |
|---|---|---|
| Dense Urban | ETU 3 | 3km/h |
| Urban | ETU 30 | 30km/h |
| Sub Urban | ETU 60 | 60km/h |
| Rural | EVA 120 | 120km/h |
| High Speed railway | HST | 350km/h |

Table 1-4. Morphologies for mobile dimensioning [5, 29, 35].

Where, *ETU is extended Typical Urban model, EVA is Extended Vehicular A model and HST stands for High Speed Train.*

The type of area will affect the path loss during the link budget, including; channel model, indoor penetration, standard deviation of shadow fading margin, and path loss. Morphologies determines the propagation model formula using in cell radius calculation, as well as other parameters such as eNodeB antenna height and penetration loss [5, 29, 35]. Channel model has effect on the demodulation threshold and lead to difference in cell radius [30].

Based on network dimensioning results, radio network nominal planning is intended to determine: theoretical location of sites, RF Engineering parameters, system simulation and searching ring [29].

Detail planning includes; site survey, cell parameters (PCI, TA, PRACH, Neighbor) planning and radio algorithm planning [29, 35]. Based on the network dimensioning, geography and traffic distribution, the network is pre-planned in detail by using planning software and digital map. The analysis is made to check whether the coverage of the system meet the requirements. If necessary, the height and tilt of the antenna and the eNodeB quantity are adjusted to optimize the coverage. Then the system capacity is analyzed to check whether it meets the requirements [29, 35].

Finally, implementation parameters such as antenna type/azimuth/tilt/height/ feeder type/length and cell parameters, such as tracking area, PCI, neighbor relation, and PRACH will be planned [29, 35].

LTE dimensioning is different from GSM, UMTS and CDMA planning due to its MIMO, flexible bandwidth, flexible carrier frequency, and MCS [30]. Since LTE carrier configuration is flexible, the coverage is affected by bandwidth. LTE carrier bandwidth could be 6RBs, 12RBs, 25RBs, 50RBs, and 100RBs that the number of RB affects the cell border throughput directly [29]. MIMO application has additional MIMO gain; MIMO is different configuration in LTE, it can improve coverage and capacity. We should consider MIMO gain in planning [5, 29, 35].

Dimensioning is also affected by MCS; which is a radio channel auto adaptive algorithm. With high order MCS, the throughput can be higher, but it is not suitable in poor channel condition. Therefore, we have to select different MCS for different channel quality when calculating the coverage and capacity [29, 35]. Therefore, LTE dimensioning needs variable planning scheme and parameters different from both 2G and 3G.

## 1.4. Introduction to Particle Swarm Optimization

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995, learned from social behavior of bird flocking and fishes [21]. It can be used for radio access network planning and optimization. From the perspective of LTE network dimensioning, area coverage and traffic demand in the required area should be meet before low level design. In order to distribute the required sites on optimal point, Particle Swarm Optimization will have good result [6].

This research will contribute an option for radio frequency (RF) planning that is useful for radio access network dimensioning and network expansion.

## 1.5. Statement of the Problem

Nowadays mobile data traffic demand is increasing globally. Therefore, telecom operators should enhance mobile network capacity in order to accommodate this traffic demand. Due to customer’s experience and global marketing trend, all operators will shift from voice service priority to data service priority. Therefore, in the next, telecom operators will invest on UMTS, 4G and 5G mobiles. To dimension LTE network in Addis Ababa, we must consider area coverage demand, total traffic demand and customer distribution.

After estimating number of sites by considering both coverage and capacity, planting new sites according to customer distribution is difficult. Traditionally, it is installed by guessing customer density. This manual way of planning will cost resource (there will be congestion when there is extra free radio resource), and it is tedious and error prone.

To address this problem, network congestion in specific place whereas total network is under usage, error during planning and tiresome manual work, Particle Swarm Optimization (PSO) is proposed.

## 1.6. Objective

### *General Objective*

The general objective of this research is to improve radio network planning approach by particle swarm algorithm.

### *Specific Objectives*

- To model the coverage estimation in LTE in the case of Addis Ababa
- To model the capacity estimation in LTE system in the case of Addis Ababa
- To design initial RAN planning and expansion phases using PSO

## 1.7. Scope

The scope of this research is only planning high level design for LTE radio access network dimensioning by using Mentum Planet radio frequency planning tool and PSO for the case of Addis Ababa city. For this research, we use Ethio telcom’s network data and Addis Ababa city as target area.

## 1.8. Literature Review

To confirm the feasibility of this research work, several works have been reviewed.

In [5], factors to be considered to design the cellular network and the procedure are discussed and explained in detail for 2G and 3G. For this work, it had constructive guideline, we have used the procedure and considered all factors for LTE dimensioning.

In [15], Dimensioning of LTE network in Addis Ababa, Ethiopia in 2013, different steps of the dimensioning process and methods for dimensioning of LTE radio access networks are listed; models for coverage and capacity planning are developed. Special emphasis is laid on radio link budget along with detailed coverage and capacity dimensioning. The tool used for planning was excel.

Authors in [29], showed traditional dimension objective of LTE to determine the number and location of the radio access sites in order to satisfy certain coverage and capacity requirements with minimum deployment cost and grade of service. It has also detail procedures for LTE RAN dimensioning.

Author in [53], used PSO method combined with a ray propagation method and geometric partitioning in order to optimally locate multiple antennas in an indoor environment.

Authors in [2] used PSO in order to optimize propagation model for LTE radio access network based on drive test measurement result. In addition, they compared the optimized result with famous radio propagation models such as Okumura-Hata, COST 231, Ericsson 999, Egli and ECC-33 models and they evaluated common models for suitability and compared with the modified model for the environments.

For this thesis, factors which should be considered to design cellular networks, methods and models for coverage and capacity planning in [5] have been fully considered. No reviewed work considered geographical landscape and customer distribution; they followed simple mathematical calculations.

This work is different from the reviewed works; it had used currently deployed sites' traffic utilization to estimate traffic distribution and it also used PSO for dimensioning LTE sites with optimal cost and quality of service.

Dimensioning of LTE radio access has been carried out using Mentum Planet radio network planning tool for radio network planning simulation and matlab and excel have been used to simulate particle swarm optimization technique in order to plot sites on the map.

## 1.9. Research Methods, Materials and Procedures

In order to achieve the objective, after studying about mobile communication, general LTE network and LTE radio access network planning, the following three major tasks have been done.

For capacity and coverage dimensioning, we collected data from live network (traffic with geographical coordinates) and geographical data (coverage boundary). After data analysis, we calculated number of eNodeBs in Capacity and Coverage aspects.

To plot sites according to traffic distribution for expansion, we grouped LTE network traffic by site level with geographical coordinates. By considering the larger number of sites (capacity vs coverage), we identified new sites' positions from PSO simulation, and we confirmed total number of sites needed according to traffic distribution. Finally, we simulated the network on Mentum Planet.

**Tools** needed for this thesis were Google earth, Mentum Planet (RF Planning tool) and MapInfo, global mapper, PRS (HUAWEI NMS tool for RAN performance), Matlab and Microsoft office Excel. Structured interview and structured observation were also used.

The following procedure was followed.

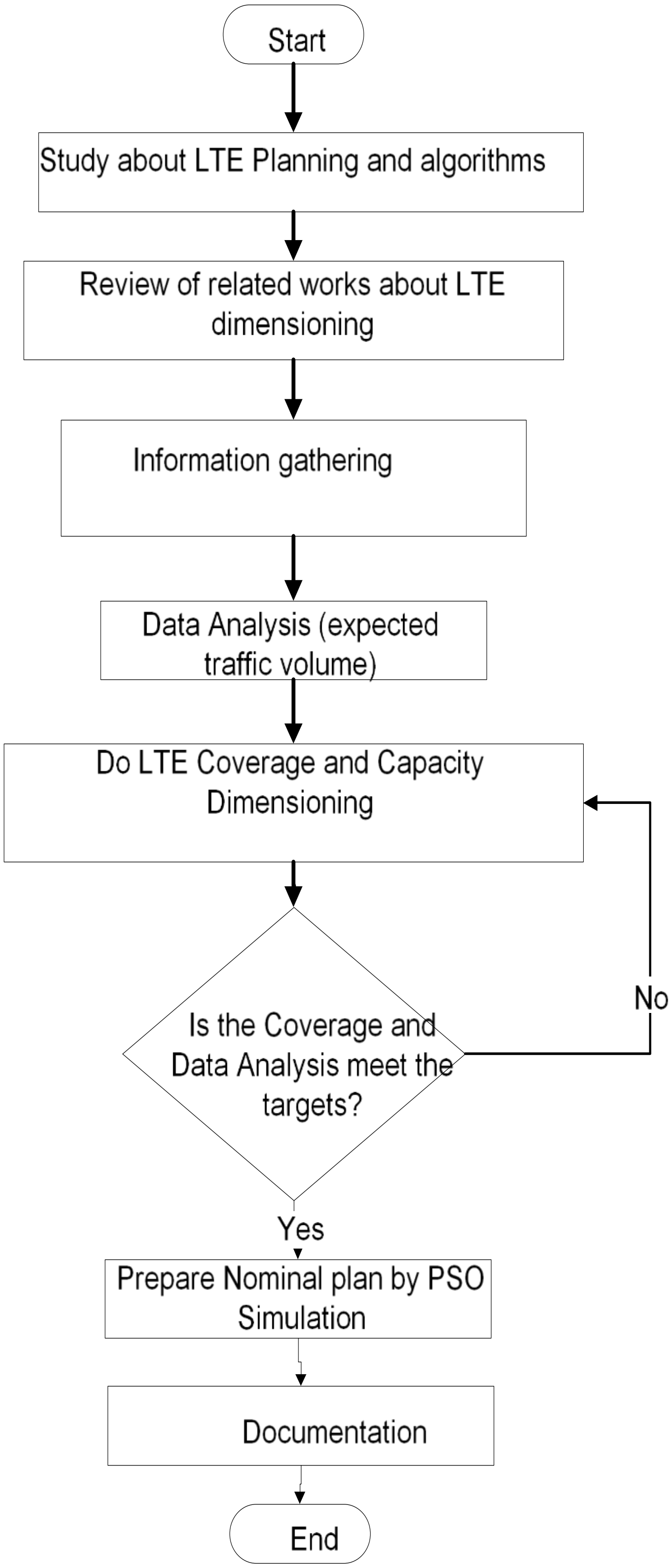


Figure 1.6. Research flow diagram and general procedure

# CHAPTER 2 LTE COVERAGE PLANNING

Generally, LTE has the same dimensioning procedure as other wireless systems. In the coverage dimensioning, the link is estimated according to elements such as planned area, network capacity, and equipment performance in order to obtain the allowed maximum path loss. The maximum cell radius is obtained according to the radio propagation model and allowed maximum path loss. After single site area coverage is calculated, quantity of sites will be estimated. Of course, number of sites is only for ideal cell status, and some additional sites will be needed in actual terrain environment [5,29,35].

For this research, we considered LTE network expansion for Addis Ababa city. Addis Ababa has 129 square kilometer area and most of the place is considered as dense urban even though its borders are sub urban and rural [23].

Since there is random urban expansion in Addis Ababa, it is assumed as dense urban. In addition, we considered Addis Ababa as isolated land; i.e. we will not consider the network availability across the border even though mobile network has no boundary. We use two-way coverage planning schemes, which are resemblance to real environment. The first is by using empirical propagation model, Cost-231 and the second one is by using outdoor RAN Planning simulation tool.

For radio access network planning, the following data based on operator, customer and government demand are needed. Therefore, radio access network planning engineer should collect these data from the owner of the network. We have taken the following data.

**Population size and population growth rate:** In 1999 EC/ 2007 GC, Addis Ababa's population was 2917295 with 2.1% growth rate [9]. Since there is no latest census result, Addis Ababa's population is not only resident and some of the traffic generated from visitor customer, we have not used the population size for this dimensioning purpose.

**Economic Growth rate:** Ethiopia's economy is growing fast in two digits [17]. Let in the coming six years, the economic growth rate continues with this rate, Addis Ababa's over all traffic demand will increase; especially data traffic will increase rapidly.

**Penetration ratio:** Based on Ethio telecom's planning trend, Addis Ababa's penetration is two hundred percent [23].

**Life span of the network:** It is based on operator's demand, but for this research purpose, the network is assumed to be used for six years without expansion. Because mobile projects from Next Generation Network (NGN) to Telecom Expansion Project (TEP-1) and from TEP-1 to TEP-2 were as long as six years [23].

**Project accomplishing time:** It is assumed that the project will be accomplished within one year [23].

**Futurity of coverage area (if there is area expansion):** Since Addis Ababa's population distribution is dynamic and random, we considered all Addis Ababa's area (dense urban, urban and suburban) as dense urban [23, 48].

**Traffic model:** Since there is no good statistical data of population and customer interest, traffic estimation will be based on network history of deployed mobile networks.

**Technology upgrade and customer interest shift:** Based on global telecom trend i.e. based on customers', telecom operators' and mobile network vendors' experience, national customer interest will shift to the latest technology. 2G traffic demand is assumed to be transferred to 3G and 4G networks [23]. In the coming few years there will be internet of things and machine to machine communication in Addis Ababa and LTE and 3G must support this traffic demand [23, 48, 51].

We have found some requirements from network history, and we decided other requirements based on global telecom trend.

## 2.1. Coverage Planning by LTE Radio Link Budget

The initial planning of any RAN begins with a Radio Link Budget calculation. In a telecommunication system, link budget is the sum of all the gains and losses from the transmitter, through the medium (free space, cable, waveguide, fiber, etc.) to the receiver. Link Budget is an important step to get the maximum cell radius, which meets coverage and quality requirements, it includes frequency information, cable loss, hard handover gain, pilot power and so on. It is used for defining the cell radius [5,29,35].

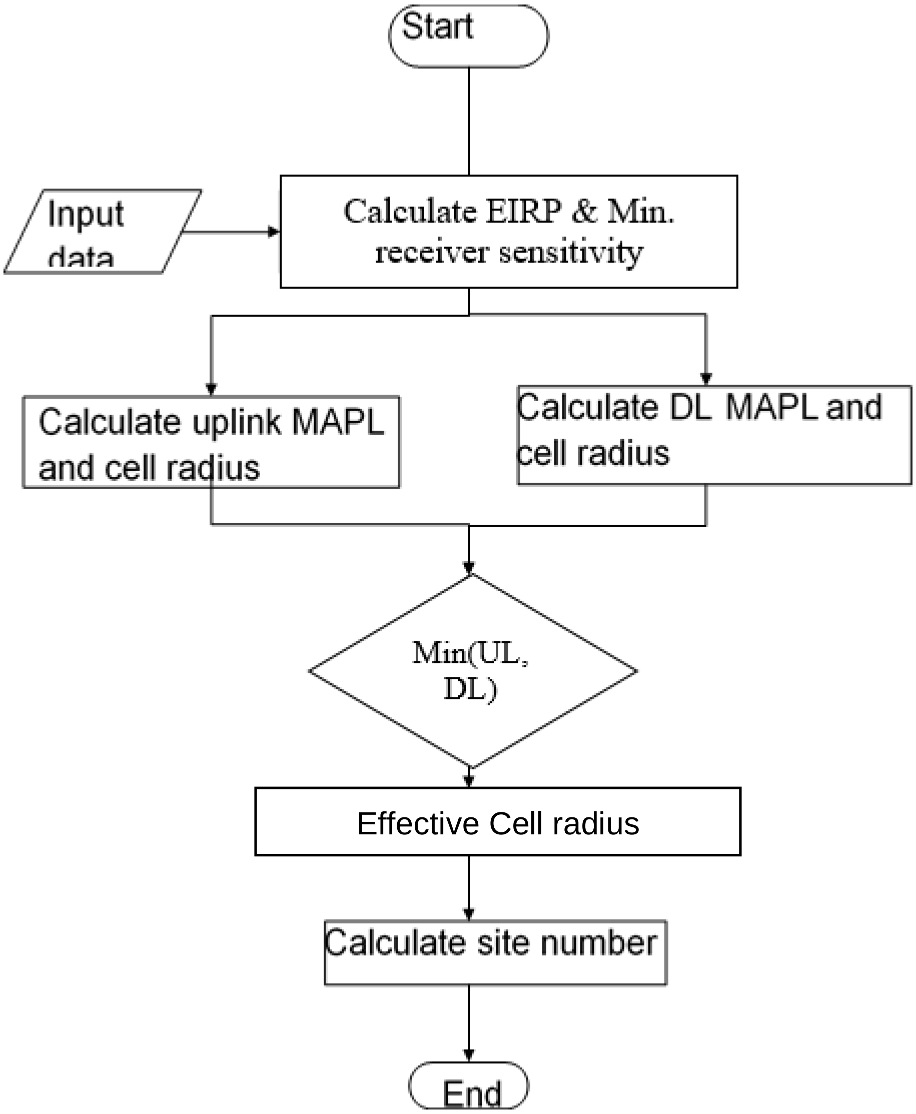


Figure 2.1. LTE coverage dimensioning Procedure [35]

| **Morphology** | **Dense Urban** | |
|---|---|---|
| Data Channel Type | PUSCH | PDSCH |
| Duplex Mode | FDD | |
| User Environment | Indoor | |

Table 2-1. LTE Link Budget [15]

Link budget is performed to calculate the Maximum Allowed Path Loss (MAPL), and then MAPL is used to calculate the cell radius by propagation model [29].

The link budget calculations estimate the maximum allowed signal attenuation between the mobile and the base station antenna. The maximum path loss allows the maximum cell range to be estimated with a suitable propagation model. The cell range gives the number of base station sites required to cover the target geographical area [35].

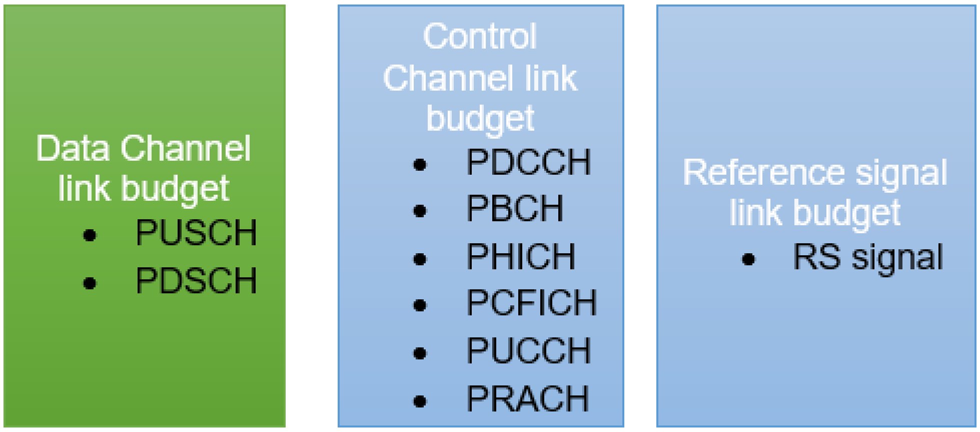


Figure 2.2. Channels of LTE [35]

Normally the link budget is limited by data channel [35].

### 2.1.1. DL Maximum Allowed Path Loss

The figure below shows LTE link budget for the downlink, assuming a one Mbps data rate (assuming antenna diversity and 20 MHz bandwidth).

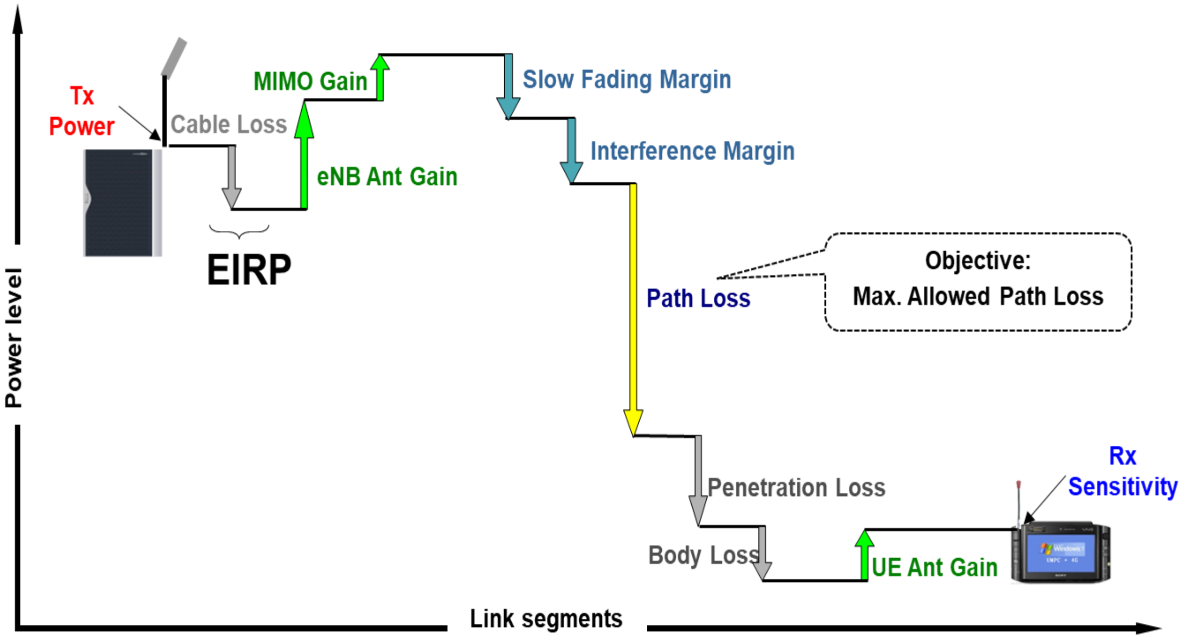


Figure 2.3. Path loss calculation [8,29,49]

MAPL in dB is found by deducting Min Signal Reception Strength (dBm), Penetration loss (dB) and shadow fading margin (dB) on Equivalent Isotropic Radiated Power (EIRP) per Subcarrier (dBm) [26,41].

EIRP per subcarrier (dBm) is found by deducting transmitter cable loss(dB) and transmitter body loss(dB) on the sum of subcarrier power (dBm) and transmitter antenna gain (dBi). Subcarrier power is distributed power of maximum total transmission power to number of subcarriers to distribute power [26].

Parameters to calculate path loss are listed and estimated as follows.

**Max Total Tx Power (dBm):** The eNodeB power is assumed to be 46 dBm, a value is common for most manufacturers; 40w or **46dBm** [35].

**Subcarrier Power** (dBm) for 20MHz bandwidth i.e. $46 - 10 * log\ (1200)$ is 6.19 watt or **15.2082dBm.** Where, number of subcarriers of 20 MHz is 1200. In downlink, the total power is distributed evenly over all subcarriers at the whole [15,30].

**Tx Antenna gain** of 1800MHz in dense urban is **18dB**. It is manufacturer dependent, the value taken from currently deployed HUAWEI antenna [35].

***Note:*** *1727.5 up to 1747.5MHz will be used to the UL of LTE and the 1822.5 up to 1842.5MHz will be used to the DL of LTE in Addis Ababa [15].*

**Tx body loss** in DL is **0** [26].

**Tx Cable Loss (dB):** In DL, it is eNB cable loss. It includes all the loss between the antenna and RRU such as feeder loss, connector loss and jumper loss. If RRU is installed on tower, TX cable loss can be set as 0.5dB, else 3dB. In Ethio telecom case, RRU is tower mounted, optical fiber connects RRU to BBU [35], so cable loss is 0.5dB.

Therefore, EIRP is 15.21+18-0.5; **32.71dBm**.

The received signal will also be affected by receiver antenna property i.e. receiver sensitivity. Receiver sensitivity (dBm) in DL is the sum of thermal noise per subcarrier (dBm), noise figure of UE (dB) and required SINR (dB); -128.62dBm [26]

a) **Thermal Noise per subcarrier**= $10 * log(K * T * W) = \mathbf{-132.2dBm}$

Where, K *is Boltzmann constant, 1.38*10$^{-23}$, T is temperature in Kelvin, normally 290K and W stands for one subcarrier bandwidth, 15000Hz [26].*

b) **Noise Figure** of UE is normally set as **7dB** [35].

c) **Required SINR (dB):** It is the main performance indicator for LTE. Cell edge is defined according to the required signal to interference noise ratio (SINR) for a given cell throughput [35].

Required SINR depends up on the following factors: MCS and Propagation Channel Model [35]. Higher the MCS used, higher the required SINR and vice versa. This means that using QPSK will have a lower required SINR than 16-QAM [29].

HUAWEI simulation result for the case of Addis Ababa with QPSK, FDD, 20 MHz and similar edge throughput of 1Mbps, DL SINR **is -3.42dB** [15]. We used this value for this research.

**Rx Antenna Gain (dBi)** of UE in down link is [26].

**Rx cable loss (dB)** of UE in DL is [26].

**Rx body loss (dB)** in DL is 0 for PS and **3dB** for CS. Since the network will have VoLTE, we used 3dB for Rx body loss [29].

**Interference Margin (dB):** To consider the interference from neighboring cells, interference margin should be added in link budget calculation. It depends on the target load. It is a result of simulation [26].

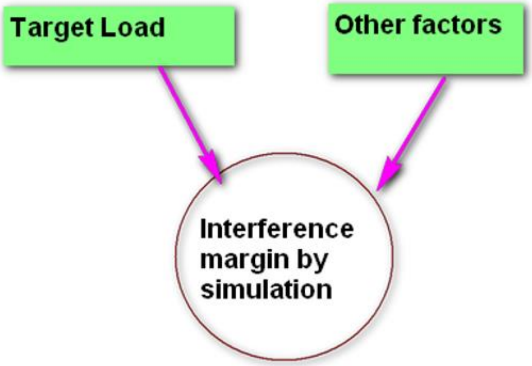


Figure 2.4. Interference margin limiting factors [35]

The interference margin in practice depends heavily on the planned capacity; it is a tradeoff between capacity and coverage. It is taken **5.41 dB,** which is found from Ethio telecom [29].

**Penetration loss:** It indicates the fading of radio signals from an indoor UE to eNodeB due to building obstruction. It is dependent to the incident angle, building materials, terrain and carrier frequency. It is **19 dB** in dense urban at 1800MHz [26].

**Shadow Fading Margin (dB):** It depends on the area coverage probability requirement and the standard deviation of fading. To minimize the effect of shadow fading and ensure a certain edge coverage probability, certain value must be added. Standard deviation requirement in dense urban area with highly integrated building layout and deeper indoor coverage requirement is higher than typical urban environment [35].

The following are typical values.

| | Dense urban | Urban | Suburban | Rural |
|---|---|---|---|---|
| Standard deviation of shadow fading(indoor) | 11.7dB | 9.4dB | 7.2dB | 6.2dB |
| Aea coverage probality | 95% | 95% | 90% | 90% |
| Shadow Fading Margin | **9.4dB** | 8dB | 2.8dB | 1.8dB |

Table 2-2. Shadow fading margin [35]

For higher the area coverage probability requirement, more shadow fading margin is required and also for higher the standard deviation, more shadow fading margin is required [35].

**Hard Handover Gain:** Due to orthogonal subcarriers in OFDM system, only hard handover is supported in LTE. Hard handover can decrease the Rx signal strength requirement, which can bring a gain of 2 to 5dB for coverage. This value will affect the shadow-fading margin. Higher the hard handover gain is lower the shadow-fading margin is. Therefore, shadow-fading margin in LTE should consider hard handover gain [35].

For dense urban with 95% area coverage probability, shadow fading margin is 9.4dB [29].

**Control channel overhead (dB):** One dB is considered for control channel [35].

Summary of Downlink Link Budget for 2 Mbps with dual-antenna receiver terminal

| **Data rate (Mbps)** | | **1** |
|---|---|---|
| ***Transmitter – eNode B*** | | |
| **a** | HS-DSCH Power (dBm) | 46.0 |
| **b** | Subcarrier Power (dBm) | 15.21 |
| **c** | Tx Antenna gain (dBi) | 18.0 |
| **d** | Tx Body Loss | 0 |
| **e** | Cable Loss (dB) | 0.5 |
| **f** | EIRP (dBm) | $EIRP = b + c - d - e = 32.71$ |
| ***Receiver – UE*** | | |
| **g** | Thermal Noise (dBm) | -132.2dBm |
| **h** | UE Noise Figure (dB) | 7.0 |
| **i** | Required SINR (dB) | -3.42 |
| Receiver Sensitivity(dBm) | | $\mathrm{RS} = \mathrm{g} + \mathrm{h} + \mathrm{i} = -128.62$ |
| **j** | Rx Antenna Gain(dBi) | 0 |
| **k** | Rx Cable Loss(dB) | 0 |
| **l** | Rx Body Loss (dB) | 3 |
| **m** | Interference Margin(dB) | 5.41 |
| Min Signal Reception Strength(dBm) | | $\mathrm{Rxmin} = \mathrm{RS} + \mathrm{j} + \mathrm{k} + \mathrm{l} + \mathrm{m} = -120.21$ |
| **Path Loss and Shadow Margin** | | |
| **n** | Penetration Loss(dB) | 19 |
| **o** | Shadow Fading Margin (dB) | 9.4 |
| ***p*** | Control Channel Overhead(dB) | 1 |
| ***Maximum path loss*** | | $\boldsymbol{MAPL = EIRP - Rxmin - h - i = 123.52}$ |

Table 2-3. Downlink Link Budget

### 2.1.2. UL Maximum Allowed Path Loss

The table below shows LTE link budget for the uplink of Addis Ababa of 256 kbps UL edge data rate and 4 resource block allocation (giving a $720\ KHz = 4 * 12 * 15KHz$ transmission bandwidth) [35]. The UE terminal power is assumed 23 dBm. eNodeB receiver has a noise figure of **2.3 dB** *(taken from HUAWEI eNodeB, which is currently deployed in Addis Ababa)*, and the required Signal to Noise and Interference Ratio (SINR) has been taken from link level simulations i.e. **2.21dB** [15]. An interference margin of **0.94 dB** [29]. A cable loss of **0.5 dB** is considered for tower mounted RRU i.e. only for jumper cable and connectors. An Rx antenna gain of **18 dB** is assumed by considering a 3-sector macro-cell [35].

The table below shows an UL LTE link budget

| **Data rate (kbps)** | | **64** |
|---|---|---|
| ***Transmitter – UE*** | | |
| **a** | Max. TX Power (dBm) | 23.0 |
| **b** | Subcarrier Power (dBm) of 48 subcarriers | $b = a - 10 * \log 48 = 6.1876$ |
| **c** | TX Antenna Gain (dBi) | 0.0 |
| **d** | Body Loss (dB) | 0 |
| **e** | EIRP (dBm) | $b + c - d = 6.1876$ |
| ***Receiver – eNodeB*** | | |
| **f** | eNodeB Noise Figure (dB) | 2.3 |
| **g** | Thermal Noise (dBm) | $-132.2\text{dBm} = 10 * \log(k * T(290K) * W)$ |
| **h** | Receiver Noise Floor (dBm) | $f + g = -129.9$ |
| **i** | SINR (dB) | -2.21 |
| **j** | Receiver sensitivity (dBm) | $h + i = -132.11$ |
| **k** | Penetration Loss (dB) | -19 |
| **l** | Interference Margin (dB) | 0.94 |
| **m** | Shadow Fading Margin (dB) | 9.48 |
| **n** | Cable Loss (dB) | -0.5 |
| **o** | Rx Antenna Gain (dBi) | 18.0 |
| **p** | Rx Body Loss | 0 |
| **q** | Control Channel Overhead(dB) | 1 |
| ***Maximum path loss*** | | $\mathbf{e - j - k - l - m - o - n - q = 125.3776}$ |

Table 2-4. Uplink Link Budget for 64 kbps with dual-antenna receiver base station

### 2.1.3. Single Site Coverage and Total Sites Required

Single site coverage radius will be found from Propagation (Path Loss) Model. A propagation model converts the maximum allowed propagation loss to the maximum cell range. It depends on environment: urban, rural, dense urban, suburban, open, forest, sea and others. We must consider; distance, frequency, atmospheric conditions, and indoor/outdoor coverage [26, 29, 35].

Common examples of propagation model include Free space, Walfish–Ikegami, Okumura–Hata, and Longley–Rice models. The most used model in urban environments is the Okumura-Hata model [52].

**COST-231 Model:** Most future PCS systems are expected to operate in the 1800-2000 MHz frequency band. It has been shown that path loss can be more dramatic at these frequencies than those in the 900 MHz range. COST231-Hata model extends Hata's model to use in the 1500-2000 MHz frequency range. The model is expressed in terms of the following parameters [52].

- Carrier Frequency ($f_c$) 1500-2000 MHz
- BS Antenna Height ($h_b$) 30-200 m
- MS or UE Antenna Height ($h_{U)}$ 1-10 m
- Transmission Distance (d) 1-20 km

The path loss according to the COST-231-Hata model is expressed as:

$Lp\ (dB) = A + B * log10\ (d) + C$ ………..……………………………………………… 2-1 [35]

Where;

$A = 46.3 + 33.9 * \log_{10}(f_c) - 13.28 * \log_{10}(h_b) - a\ (h_U)$

$B = 44.9 - 6.55 * \log_{10}(h_b)$

$f_c$ *is given in MHz and d in km.*

The function a(hu) and the factor C depend on the environment. The function a(hU) in suburban and rural areas is the same as urban (small and medium-sized cities) areas.

$a(h_U) = (1.1*\log(f_c) - 0.7) * h_U - (1.56*\log(f_c) - 0.8)$

$C = \begin{cases} 0, \text{for medium city and suburban areas} \\ \mathbf{3}, \text{for metropolitan areas} \end{cases}$ [35].

From link budget calculation maximum allowed path loss for downlink is lower than uplink i.e. PL is 123.52 dB. DL MAPL determines the radius of the site. Maximum radius will be found from downlink frequency range: FDL: 1822.5 to 1842.5, $fc = (1842.5 + 1822.5)/2 = 1832.5$ MHz and DL MAPL; 123.52 dB.

Base station antenna height is usually from 20m to 35 meters, we considered eNodeB antenna height as 30 meter, hB=30 m and height of subscriber as 1.5-meter, hU= 1.5m.

$(h_U) = (1.1\log(f_c)-0.7) * h_U - (1.56\log(f_c)-0.8)$

$= (1.1*\log1737.5-0.7) *1.5-(1.56*\log1737.5-0.8) =\mathbf{0.0437}$

$A= 46.3+ 33.9 \log_{10}(f_c) - 13.28 \log_{10}(h_b) - a (h_U) =\mathbf{137.301}$

$B= 44.9 - 6.55 \log_{10}(h_b)= \mathbf{35.225}$

$C=\mathbf{3}$

$d= \text{antilog} [(L_p -A -C)/B] = \text{antilog} [(123.52-137.301-3)/ 35.225]$

$R=d= \text{antilog} [-0.476] = \mathbf{0.334\ Km}$

Therefore, radius of single site will be **0.334 kilometer.**

Single site coverage for sectorial site is:

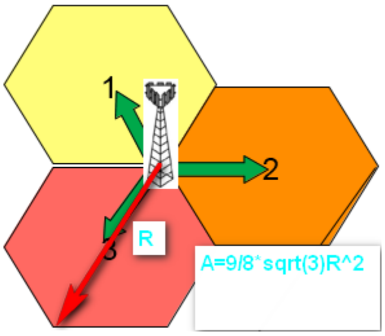


Figure 2.5. Three sector eNodeB [5,7, 26,29,35]

$As = \frac{9}{8}\sqrt{3}R^2 = 0.217$ square kilo meters

Total sites to cover Addis Ababa, N is

$N = A/As = 129/0.217 = 593.842 = \mathbf{594}$ **sites**

Where, *A is total area of Addis Ababa and $A_s$ is single site coverage.*

**Additional scenario (25-meter Base Station height):** For antenna height of $h_B$=25 m, radius will be 0.317 Km and single site area will be 0.196 square Kilo meter and total number of sites will be 659 sites.

## 2.2. DL Coverage Planning by Real Environment

Since there is deployed LTE network in Addis Ababa, estimating single site coverage with actual network simulation can be good indicator for coverage dimensioning. Thus, three areas in Addis Ababa which are inside LTE network serving area were checked. The prediction was done with -95 dBm, which is the margin of medium signal strength with consideration of 3 dB for body loss of VoLTE [35].

| Scope of RSRP | Signal Strength |
|---|---|
| DL RSRP (dBm)>-88 | Good Signal |
| -88>DL RSRP (dBm)>-98 | Middle Signal |
| DL RSRP (dBm)<-98 | Bad Signal |

Table 2-5. The Remark of Coverage of signal quality by RSRP [35]

In order to sustain indoor coverage with medium RSRP (-98 dBm), signal should reach with -75 dBm to compensate 19 dB penetration loss, 1dB control channel overhead and 3dB body loss. However, the outdoor prediction result considers building penetration loss since the tool has building map. By considering only 3dB body loss for VoLTE service, we simulated with -95dBm RSRP and try to compensate coverage hole and inefficiency of the tool by 200% area coverage (penetration ratio) [24].

Mentum planet has digital terrain map, clutter and building maps, therefore it is almost like real environment. Antenna parameters (BW, power), azimuths (0°, 120°, and 240°), mechanical tilts (MT) and electrical tilts (ET) were taken as of configured on sites [14].

### Procedure

We created polygon on google earth for Addis Ababa's map from Map agency and after changing the polygon to .tab file format, we inserted required polygon to Mentum Planet and created area. We selected specific site and created group with required radio frequency and antenna parameters of three eUcells and predicted site's (three sectors) with minimum required signal strength and quality. We saw statistics of the predicted result on required area and have seen how wide one site will cover.

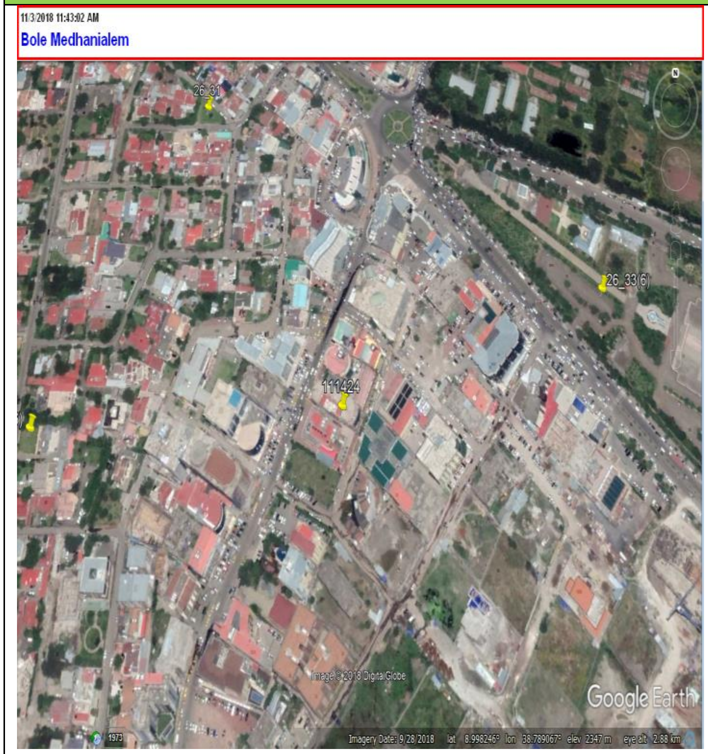
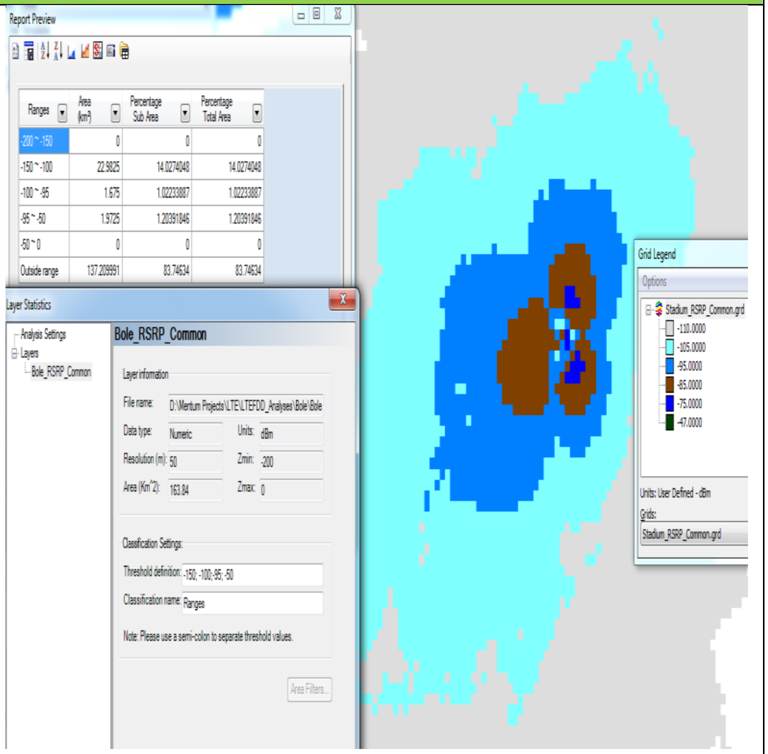
**Note:** Outdoor UL MAPL is 144.3776 dBm and maximum coverage radius is 1.374 kilo meter.

We have taken the following three existing sites which can represent the most obstructive and reflective areas of Addis Ababa.

| Area | Latitude | Longitude | Antenna Height(m) | MT(°) | ET(°) |
|---|---|---|---|---|---|
| Bole Medhanialem | 8.9957 | 38.78612 | 37 | 3/4/2 | 2/3/3 |
| Kazanchis | 9.01651 | 38.766019 | 36.5 | 3/0/2 | 2/0/2 |
| Stadium | 9.013664 | 38.753561 | 21 | 5/2/2 | 6/1/3 |

Table 2-6. Sample Sites in Addis Ababa [14]

**Sample I (Bole Medhanialem):** It is roof top site near Edna mall. It is dense building area therefore; there are many electromagnetic threats; fading and blockings.

| Area | Coverage |
|---|---|
|  |  |

| Ranges | Area (km²) | Percentage Sub Area | Percentage Total Area |
|---|---|---|---|
| -200 ~ -150 | 0 | 0 | 0 |
| -150 ~ -100 | 22.9825 | 14.0274048 | 14.0274048 |
| -100 ~ -95 | 1.675 | 1.02233887 | 1.02233887 |
| -95 ~ -50 | 1.9725 | 1.20391846 | 1.20391846 |
| -50 ~ 0 | 0 | 0 | 0 |
| Outside range | 137.209991 | 83.74634 | 83.74634 |

Bole_RSRP_Common

Layer infomation
File name: D:\Mentum Projects\LTE\LTEFDD_Analyses\Bole\Bole
Data type: Numeric
Units: dBm
Resolution (m): 50
Zmin: -200
Area (Km^2): 163.84
Zmax: 0

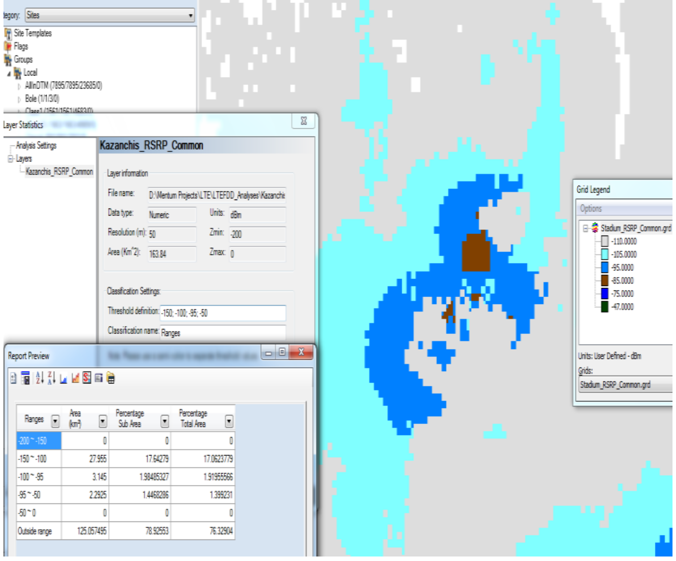
Classification Settings:
Threshold definition: -150; -100;-95; -50
Classification name: Ranges
Note: Please use a semi-colon to separate threshold values.

Stadium_RSRP_Common.grd
- ⬜ -110.0000
- 🟦 -105.0000
- 🟦 -95.0000
- 🟫 -85.0000
- 🟦 -75.0000
- 🟩 -47.0000

Units: User Defined - dBm
Grids: Stadium_RSRP_Common.grd

Figure 2.6. LTE outdoor coverage around Bole Medhanielem, Addis Ababa [14]

**Sample II (Kazanchis, near to Economic Commission for Africa):** It has building and vegetation. Therefore, there is reflection and refraction.

| **Area** | **Coverage** |
|---|---|
|  |  |

Layer Statistics

Kazanchis_RSRP_Common

Layer information

File name: D:\Mentum Projects\LTE\LTEFDD_Analyses\Kazanchi
Data type: Numeric
Units: dBm
Resolution (m): 50
Zmin: -200
Area (Km^2): 163.84
Zmax: 0

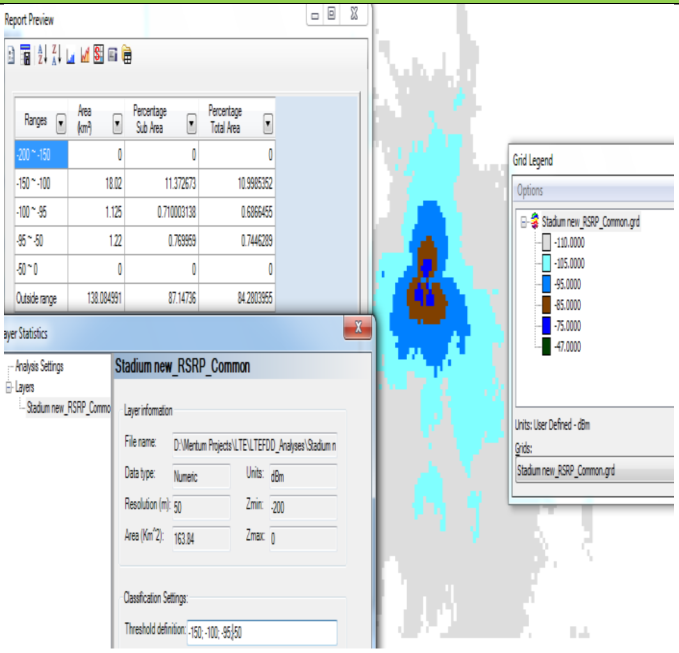
Classification Settings:
Threshold definition: -150; -100; -95; -50
Classification name: Ranges

Report Preview

| Ranges | Area (km²) | Percentage Sub Area | Percentage Total Area |
|---|---|---|---|
| -200 ~ -150 | 0 | 0 | 0 |
| -150 ~ -100 | 27.955 | 17.64279 | 17.0623779 |
| -100 ~ -95 | 3.145 | 1.98485327 | 1.91955566 |
| -95 ~ -50 | 2.2925 | 1.4468286 | 1.399231 |
| -50 ~ 0 | 0 | 0 | 0 |
| Outside range | 125.057495 | 78.92553 | 76.32904 |

Figure 2.7. LTE outdoor coverage around Kazanchis, Addis Ababa [14]

**Sample III (Addis Ababa National Stadium):** It is dense urban area. It has full of reflection, refraction and obstruction.

| **Area** | **Coverage** |
|---|---|
|  |  |

Report Preview

| Ranges | Area (km²) | Percentage Sub Area | Percentage Total Area |
|---|---|---|---|
| -200 ~ -150 | 0 | 0 | 0 |
| -150 ~ -100 | 18.02 | 11.372673 | 10.9985352 |
| -100 ~ -95 | 1.125 | 0.710003138 | 0.6866455 |
| -95 ~ -50 | 1.22 | 0.769959 | 0.7446289 |
| -50 ~ 0 | 0 | 0 | 0 |
| Outside range | 138.084991 | 87.14736 | 84.2803955 |

Layer Statistics

Stadium new_RSRP_Common

Layer information

File name: D:\Mentum Projects\LTE\LTEFDD_Analyses\Stadium n
Data type: Numeric
Units: dBm
Resolution (m): 50
Zmin: -200
Area (Km^2): 163.84
Zmax: 0

Classification Settings:
Threshold definition: -150; -100; -95;-50

Figure 2.8. Addis Ababa Stadium area one & LTE site outdoor coverage simulation [14]

## Summary of Sample Single Site Coverages

| **Area** | **Outdoor Coverage(>-95dBm)in km$^2$** |
|---|---|
| Stadium | 1.22 |
| Kazanchis | 2.2925 |
| Bole | 1.9725 |
| Average | 1.828 |
| Total sites to cover 129 km$^2$ | 70.556 |
| Number of sites to have 200% outdoor coverage | 142 |

Table 2-7. Summary of Simulation result for LTE outdoor coverage

In worst case, average coverage of one site is 1.828 square kilometer. Therefore, to cover 129 square kilometer area, it needs 71 sites. Since there will be obstruction and penetration loss, to cover perfectly most of the indoor environment and the outdoor environment without black hole, two-fold overlapping or 200% area coverage is proposed, and it needs maximum of 142 sites according to Mentum Planet simulation result.

By comparing number of total sites calculated by empirical coverage planning model (594 sites) with total number of sites found from RF planning tool simulation (200% coverage, 142 sites) is **594** sites are required to cover the required area.

## Conclusion

In order to cover 129 square kilo meter of dense urban area of Addis Ababa by delivering 1 Mbps DL edge throughput and 256 Kbps UL edge throughput with good indoor coverage, by using 20MHz bandwidth, FDD, QPSK, 2x2 MIMO and sectorial site, as well as supporting VoLTE, **594** sites are required (before simulation).

There is huge difference between real planning tool, which Ethio telecom is using, and empirical propagation model. It is open for further investigation.

# CHAPTER 3 LTE RAN CAPACITY PLANNING

The purpose of capacity dimensioning is to get the number of sites that satisfies the capacity requirement. The following is the basic capacity dimensioning procedure.

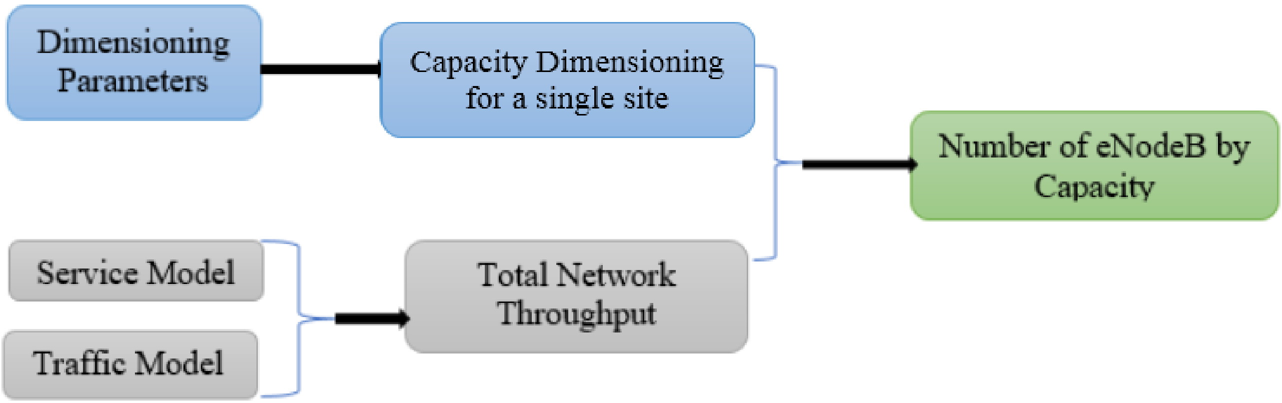


Figure 0.1. Procedure of capacity dimensioning [26, 29,35]

Basically, LTE capacity planning includes two parts which are capacity dimensioning for a single site and total network throughput calculation. Capacity dimensioning for a single site is performed based on some dimensioning parameters such as duplex mode, system bandwidth, etc. Total traffic volume calculation is performed based on service model and traffic model. First single user throughput is calculated from service and traffic models, and then total network throughput is the output based on total potential customer number [35].

The number of eNodeB by capacity is found by dividing total traffic volume with single site capacity. Total traffic will be developed from service model and traffic model [35]. Both service model and traffic model need small data, but due to scarcity of reliable data, we used deployed network traffic history in order to develop both of service model and traffic model.

## 3.1. Model Future Traffic from Mobile Traffic History

Future traffic will depend on population growth, economic growth, technology advancement and customer interest shift. For capacity planning, we should know expected number of subscribers from current population and population growth rate, expected data rate per customer from statistics and expected customer interest shift. Since there is no latest accurate census result and customer interest survey result, and traffic in the target area, Addis Ababa, is not only resident traffic but also there is huge guest traffic due to being both political and economic center, we tried to model future traffic from deployed mobile network service's traffic usage history.

So, total mobile network deployed in Addis Ababa i.e. GSM, DCS, UMTS and LTE traffic history for three years have been taken to project future traffic demand [12,13.16].

The following four assumptions were considered.

I. This planning has been done from the reference of January 2019 in order to give LTE service for the next six years with acceptable grade of service without any expansion [23].
II. From interview, Ethio telecom will not deploy additional 2G sites i.e. future mobile network will be 3G and 4G [23, 39].
III. Based on global telecom experience, customer interest will shift to the latest technology and subscriber data rate will increase time-to-time [39].
IV. Globally, many telecom operators are planning way-out strategy not only from 2G but also from 3G [39].

Hence, based on these data, we assumed that let LTE will support more than fifty percent of future traffic demand in Addis Ababa. In order to estimate future traffic from deployed mobile networks, we should find out average total busy hour traffic and manipulate monthly traffic to busy hour traffic.

### 3.1.1. Average Busy Hour Traffic Ratio

Traffic history found in Network Monitoring System (NMS) is based on monthly summation for UMTS and LTE and for GSM hourly average of monthly traffic. It must be changed to hourly-based busy hour equivalent traffic. In order to estimate proper traffic demand in Addis Ababa from monthly level traffic history found in NMS (monthly average traffic per hour for 2G and monthly sum of 3G and 4G traffics per month), we have identified traffic busy hour and busy hour traffic ratios of Addis Ababa from hourly-based two weeks' traffic history [12,13.16].

Both GSM and UMTS have both CS and PS services, therefore we should map CS service to equivalent LTE services. Since LTE has no normal CS service instead it has VoLTE, one

Erlang voice traffic will be changed to equivalent of one VoIP bearer rate i.e. 26.9 Kbps for an hour for both of UL and DL [1]. The available bit rates for mobile are: 6.60, 8.85, 12.65, 14.25, 15.85, 18.25, 19.85, 23.05 and 23.85 kbps. But in order to give flexibility of the capacity, we preferred VoIP bitrate [1].

$$1Erl = 26.9kps * 3600/1024 = 94.5703\ Kbit\ per\ hour \ldots\ldots\ldots\ldots\ldots\ldots \quad 3\text{-}1$$

For two weeks, in the end of February 2019, hourly sum of all fourteen days' traffic for five BSCs in Addis Ababa was analyzed hourly based. Busy hour traffic ratio to all daily traffic in UL and DL also estimated i.e. GSM network busy hour traffic is eight percent of daily traffic for both of UL and DL [12]. Traffic data has been extracted in the end of February 2019 for five RNCs, for 120 hours. UL and DL busy hour traffic ratio is identified i.e. DL is six percent and UL is seven percent of daily traffic [16]. Traffic data for all LTE sites working in Addis Ababa was taken in the end of February 2019 for five days. Busy hour traffic ratio of LTE in Addis Ababa has six percent for UL and seven percent for DL of daily traffic [13].

The summary is the following table.

| Time | 2G CS % | 2G PS% | 2G UL% | 2G DL% | 3G CS% | 3G PS% | 3G UL% | 3G DL% | 4G DL% | 4G UL% |
|---|---|---|---|---|---|---|---|---|---|---|
| 00:00 | 0.59% | 3.81% | 0.73% | 1.16% | 0.76% | 5.06% | 1.67% | 3.53% | 3.61% | 3.01% |
| 01:00 | 0.24% | 2.12% | 0.32% | 0.58% | 0.26% | 2.75% | 0.74% | 1.88% | 2.39% | 2.29% |
| ……... | | | | | | | | | | |
| 19:00 | 7.20% | 5.35% | 7.12% | 6.88% | 6.66% | 5.37% | 6.41% | 5.82% | 5.77% | 5.80% |
| 20:00 | 7.27% | 6.52% | 7.25% | 7.13% | 6.42% | 5.82% | 6.39% | 5.99% | 6.00% | 5.57% |
| **21:00** | **7.84%** | **8.18%** | **7.90%** | **7.87%** | **7.09%** | **6.27%** | **7.12%** | **6.45%** | **6.65%** | **6.34%** |
| 22:00 | 4.43% | 9.20% | 4.70% | 5.22% | 3.96% | 6.69% | 4.81% | 5.57% | 7.01% | 5.97% |
| 23:00 | 1.69% | 6.91% | 1.94% | 2.59% | 1.64% | 5.96% | 2.70% | 4.34% | 5.56% | 3.90% |

Table 3-1. Addis Ababa's Traffic busy hour identification [12,13,16]

| Technology | UL Busy Hour Traffic (%) | DL Busy Hour Traffic (%) | Busy Hour CS Traffic (%) | Busy Hour PS Traffic (%) |
|---|---|---|---|---|
| GSM | 8 | 8 | 8 | 8 |
| UMTS | 7 | 6 | 7 | 6 |
| LTE | 6 | 7 | 0 | 7 |

Table 3-2. Busy hour traffic proportion of Addis Ababa's mobile traffic usage

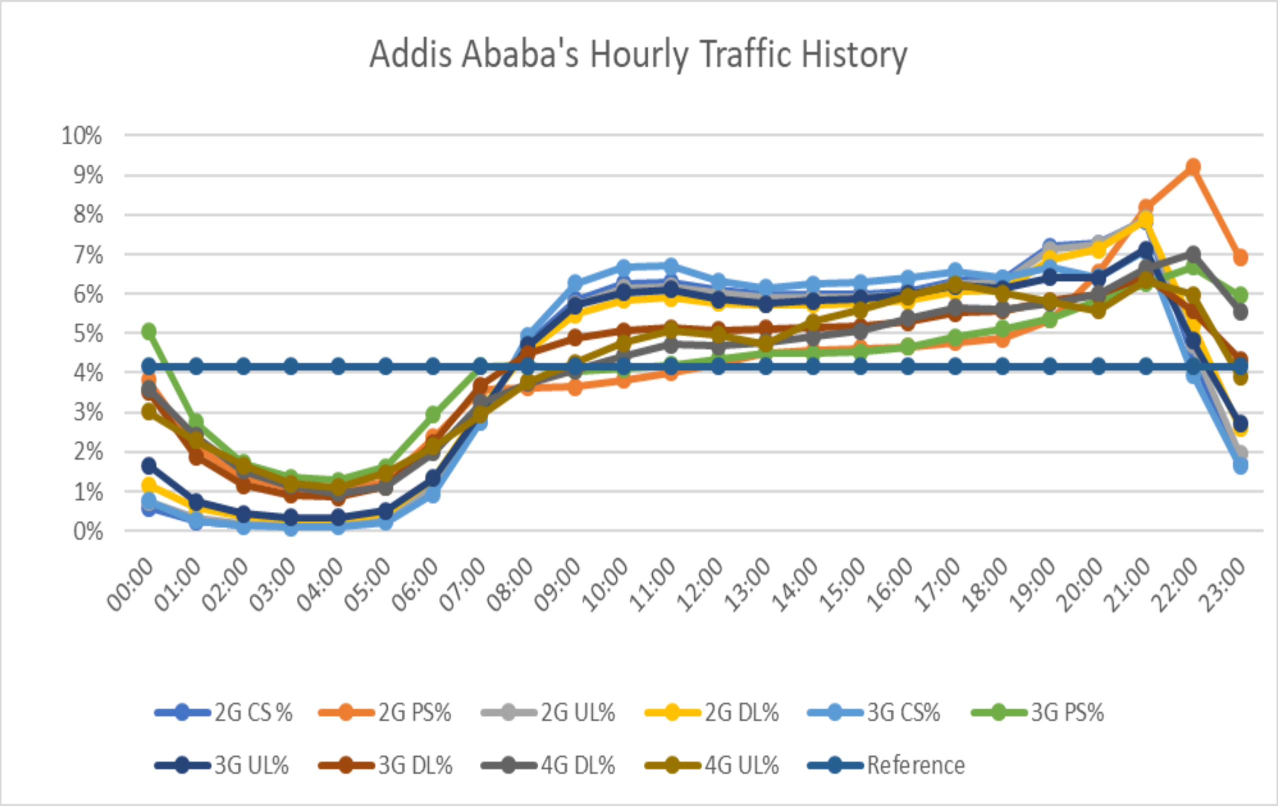


Figure 3.2. Addis Ababa's Traffic busy hour identification [12,13,16]

According to traffic usage history in Addis Ababa, traffic peak hour is identified i.e. from 9:00 pm to 10:00 pm (GMT+3) both for CS and PS traffics.

Based on busy hour traffic ratio and according to number of days in the month, total Monthly traffic will be changed to daily busy hour traffic.

### 3.1.2. Traffic Usage History

In Addis Ababa, GSM has both EDGE packet data and voice traffic for both UL and DL. In addition, UMTS has also both packet data and voice traffic for both UL and DL but LTE has only data traffic [12, 13,16].

In order to know busy hour traffic history, by using busy hour traffic ratio we tried to manipulate raw traffic data found from NMS based on the following procedures.

1. For LTE, uplink and downlink traffic measurements will be correspondent to integrity.

$$LU = \frac{CU}{I} \tag{3-2}$$

$$LD = \frac{CD}{I} \tag{3-3}$$

*Where; LU is LTE UL traffic, LD is LTE DL traffic, CU is UL LTE exported traffic, CD is DL LTE exported traffic, I is integrity that is data export quality, unit Gb*

2. For UMTS, uplink and downlink traffic measurements will be correspondent to integrity. Voice traffic of 3G and 2G will be changed to LTE VoIP equivalent i.e. 1Erl= 26.9 kbps.

$$WU = 8 * \frac{HU+UR}{I} \tag{3-4}$$

$$WD = 8 * \frac{HD+DR}{I} \tag{3-5}$$

$$WC = \frac{WCErl*3600*26.9}{I*1024*1024} \tag{3-6}$$

*Where; WU is 3G UL traffic, WD is 3G DL traffic, HU is HSUPA exported traffic, UR is UL R99 exported traffic, HD is HSDPA exported traffic, DR is UL R99 exported traffic, WCEr is exported 3G voice traffic in Erlang, and WC 3G voice converted to VoLTE equivalent.*

*Unit for HU, HD, RU and RD is GB but for WU, WD and WC is Gb.*

1 GB = 8 * 1024 * 1024 Kb and

1 Erlang is a circuit being used for a duration of one hour. Therefore, 1 Erl is equivalent to 26.9Kbps for an hour of VoLTE [1].

3. For GSM uplink and downlink traffic measurements will be equivalent to integrity. GSM CS traffic is the sum of TCH traffic and SDCCH traffic. Where SDCCH is equivalent to one eighth of TCH and it is used for signaling and SMS traffic. 1 Time slot has eight SDCCH [7].

$$GU = \frac{8*GUL}{I*1024} \tag{3-7}$$

$$GD = \frac{8*GDL}{I*1024} \tag{3-8}$$

$$GCErl = \frac{TCH}{I} + \frac{SDCCH}{I*8} \tag{3-9}$$

$$GC = \frac{GCErl*26.9*3600}{1048576} \tag{3-10}$$

*Where, GU is GSM UL PS traffic in Gb, GD is GSM DL PS traffic in Gb, GUL is exported 2G UL PS traffic in MB and GDL is exported 2G DL PS traffic in MB, TCH is TCH traffic in Erl,* *SDCCH is SDCCH traffic in Erl and GCErl is exported TCH and SDCCH CS traffic sum and GC is GSM CS traffic equivalent to VoLTE in Gb.*

$1Gb\ = 1024Mb,\ 1Gb = 8 * 1GB$; *lower case b stands for bits and B for bytes [24].*

### 3.1.3. Summary of Traffic History

It is the sum of both CS and PS busy hour traffic for the three technologies.

$UL\ = LU + WU + GU + WC + GC$…………………………………………………..…. 3-11

$DL\ =\ LD + WD + GD + WC + GC$………………………………………………….... 3-12

*Where, UL is total UL traffic and DL total DL traffic.*

Average busy hour traffic is calculated by dividing total monthly traffic to number of days in the month and then multiply the daily traffic by average busy hour traffic percentage. By constant coefficient proportionally changed, Addis Ababa’s busy hour traffic is as shown below.

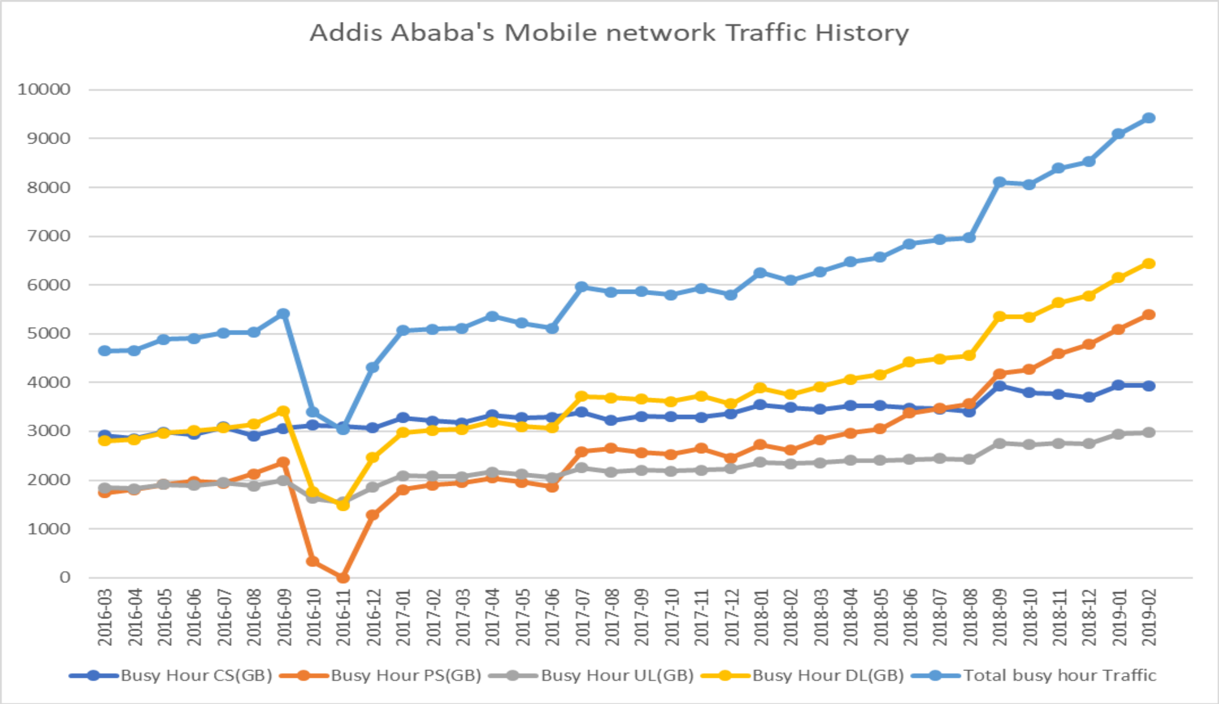


Figure 3.3. Total busy hour throughput monthly history [12,13, 16]

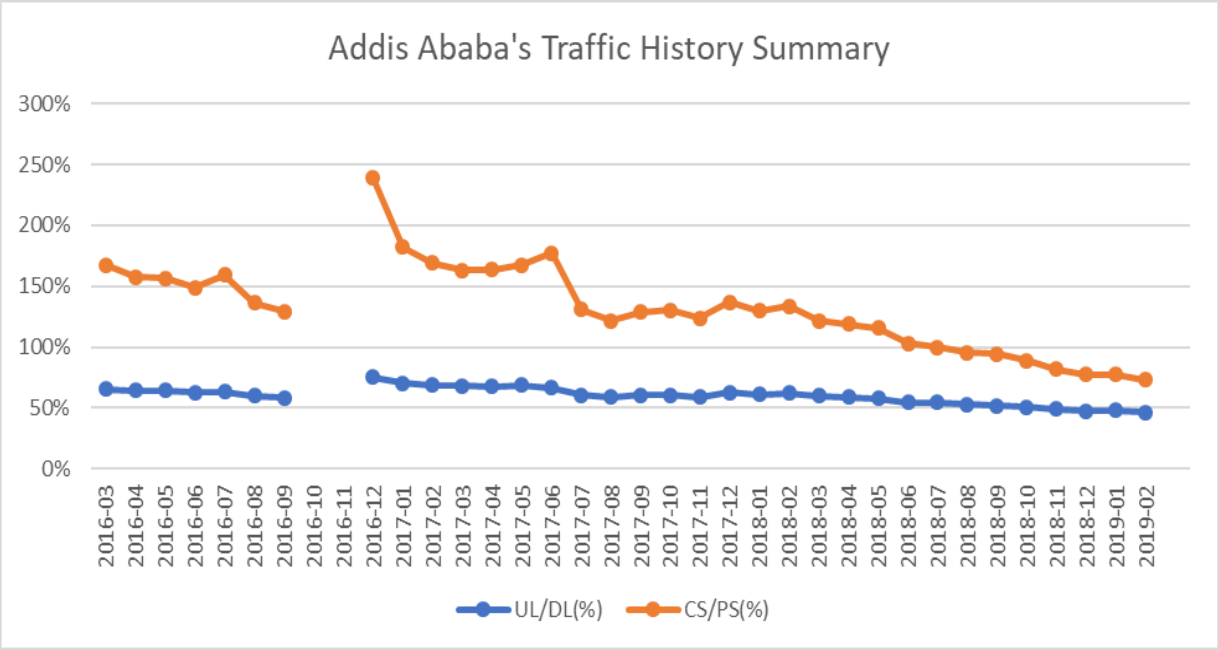


Figure 3.4. Addis Ababa's Three Years Mobile Traffic History (CS/PS and UL/DL) [12,13, 16]

From traffic history, we saw both of CS and PS traffic increase. But, in normal condition CS to PS ratio is decreasing i.e. monthly PS traffic growth rate is much greater than monthly CS traffic growth rate; which shows future traffic will be more data than voice. Now average UL to DL ratio is 43%. Next traffic will be more DL PS traffic than CS and UL PS traffic. Therefore, our concern of planning will be DL traffic [12,13, 16].

From the traffic progress (from 1st month to 36th month), we can formulate traffic-time relation in the future months.

Traffic Equation starting from December 2016 is nearly linear i.e. monthly busy hour traffic is

$T = m * t + c$ ……………………………………………………………………..…..... 3-13

*Where; T is monthly busy hour traffic, t is number of months, from March 1st 2016 (1st month) to 108th month (March 2025).* Traffic progress is as follows:

$T = 196.2775 * t + 1509.612$ ………………………………………………………..…3.14

$DL = 183.8616 * t - 80.9783$ ……………………………………………………..……3.15

$UL = 43.0759 * t + 1311.1753$ ……………………………………………………………3.16

$CS = 33.5393 * t + 593717.2522$ ……………………………….………...………………3.17

$PS = 157.9812 * t - 984.3076$ …………………………..…………..……………………3.18

Summary of Traffic Projection, initial busy hour traffic, traffic after six years (6*12+36; 108th) month is formulated as the table below.

| Traffic Type | February 2019 Traffic (GB), t=36 | Traffic after 6 years (GB), t=108 |
|---|---|---|
| T | 9422.7257 | 22707.5804 |
| DL | 6447.6907 | 19776.0697 |
| UL | 2975.035 | 5963.3762 |
| CS | 3938.4602 | 597339.4963 |
| PS | 5389.6496 | 16077.6665 |

Table 3-3. Traffic prediction

*Where, T is total traffic, CS is total CS traffic and PS is total PS traffic.*

Therefore, daily busy hour traffic in Addis Ababa after six years will be **UL 5963.3762 GB** and **DL 19776.06996 GB.** After we know single site capacity, we can estimate total number of sites.

## 3.2. Single Site Capacity (DL and UL) and Total Sites

In LTE, site capacity is measured by resource block, modulation, and duplexing scheme. One frame has 10 time slots within 10 ms duration. In one sub frame (0.5ms), there are 12 subcarriers that is 180 KHz and each subcarrier is divided into 7 OFDMA symbols. Or one resource block is 12 subcarriers each with seven OFDMA symbols within 0.5 ms duration. Therefore, 20MHz LTE channel will have 100 resource blocks [30].

The smallest element of LTE channel is resource element, which carries signaling, and data. It is one OFDMA symbol within 0.5 ms duration carried by one subcarrier. Its capacity depends according to modulation type and antenna system used [30].

Table 3.4 shows data rate of each bandwidth before considering MIMO scheme.

| Band Width (MHz) | 1.4 | 3 | 5 | 10 | 15 | 20 |
|---|---|---|---|---|---|---|
| Effect BW (90% of BW) | 1.08 | 2.7 | 4.5 | 9 | 13.5 | 18 |
| Number of subcarriers(15KHz) | 72 | 180 | 300 | 600 | 900 | 1200 |
| RB (12 subcarriers) | 6 | 15 | 25 | 50 | 75 | 100 |
| Total Symbols per second (7 symbols per subcarrier per 0.5ms) | 1008000 | 2520000 | 4200000 | 8400000 | 12600000 | 16800000 |
| DL Kilo bit rate per second QPSK (2 bits per symbol) | 2016 | 5040 | 8400 | 16800 | 25200 | 33600 |
| DL Kilo bit rate per second QAM16(4 bits per symbol), | 4032 | 10080 | 16800 | 33600 | 50400 | 67200 |
| DL Kilo bit rate per second QAM 64(6 bits per symbol) | 6048 | 15120 | 25200 | 50400 | 75600 | 100800 |

Table 3-4. DL bit rates according to modulation and bandwidth before MIMO [30]

There are different types of transmission and receiving antenna structures; 2x2, 2x4, 4x2 and 4x4 (max for LTE) MIMOs [30].

By taking 20 MHz bandwidth, the data rate(kbps) with different modulations and MIMOs is:

| Modulation | QPSK | QAM16 | QAM64 |
|---|---|---|---|
| Single Chain | 33600 | 67200 | 100800 |
| 2x2 | 67200 | 134400 | 201600 |
| 2x4 | 67200 | 134400 | 201600 |
| 4x2 | 134400 | 268800 | 403200 |
| 4x4 | 134400 | 268800 | 403200 |

Table 3-5. Data rate with different modulations and MIMO [30]

From MCS Index table; for three sector, 20 MHz FDD or 100 RB, maximum DL throughputs in GB per hour of LTE with different modulations and MIMOs is given as:

| Modulation | TBS(bits/ms) | 2x2 | 2x4 | 4x2 | 4x4 |
|---|---|---|---|---|---|
| QPSK | 15840 | 42.768 | 42.768 | 85.536 | 85.536 |
| QAM16 | 30576 | 82.5552 | 82.5552 | 165.1104 | 165.1104 |
| QAM64 | 75376 | 203.5152 | 203.5152 | 407.0304 | 407.0304 |

Table 3-6. Effective eNodeB data rate (3 eUcells) in GB per hour

In Ethio telecom TEP document, “Based on Huawei experience, average eNodeB can bear 162Mbps” [9]. When we deduct single chain UL throughput, DL throughput is 108Mbps or 48.6GB per hour, this is greater than the value found from MCS table **(42.768 GB per hour)** and less than single site throughput found by average carrier efficiency of seventy-five percent (63.367GB per hour). For this research purpose, for QPSK 2x2 MIMO, 20 MHz, FDD, 3-sector eNodeB, we took 42.768 GB/hr DL speed based on MCS table; which is the smallest possible value.

Currently, February 2019, the sum of peak hour down link traffic in the month is 6447.6907 Giga byte per hour. After six years, projected peak hour DL traffic from monthly average peak hour traffic history will be 19776.06996 GB. Number of sites with different modulations will be:

| Total eNodeB for Total DL busy hour data is of 19776.06996 GB | Data rate (GB per hour) | | | Number of eNodeB for all data | | |
|---|---|---|---|---|---|---|
| Modulation | QPSK | QAM16 | QAM64 | QPSK | QAM16 | QAM64 |
| Single Chain | 21.384 | 41.2776 | 101.7576 | | | |
| eNodeB 2x2 MIMO | 42.768 | 82.5552 | 203.5152 | 463 | 240 | 98 |
| eNodeB 2x4 MIMO | 42.768 | 82.5552 | 203.5152 | 463 | 240 | 98 |
| eNodeB 4x2 MIMO | 85.536 | 165.1104 | 407.0304 | 232 | 120 | 49 |
| eNodeB 4x4 MIMO | 85.536 | 165.1104 | 407.0304 | 232 | 120 | 49 |

Table 3-7. Total number of sites according to MCS table (100% LTE)

Therefore, in order to support half of expected traffic; (19776.06996/2)/42.768, two hundred thirty-two (232) sites are needed, which are much less than to existing 329 LTE sites and 743 multi-rat sites.

## 3.3. Capacity Estimation by Considering 5G Network Impact

Dimensioning RAN networks look very different today than they were in the past; now complexity, the amount of traffic, and the number of network elements are all increasing i.e. all being aggravated by HetNets and small cells [22].

With today’s LTE networks, which can carry VoLTE, ViLTE, OTT, IoT, and eventually eMBMS i.e. service and product complexity are increasing as well. Today’s advanced mobile operators are thinking about customers’ real experiences, instead of taking more technical view of cell coverage and capacity. Network planners must consider the user experience.

Social media creates a lot of cell traffic, and there may be congestion even though the network is well planned. Capacity is not an end [20,21,23].

In Addis Ababa traffic history, PS traffic is growing faster than CS, and CS-PS ratio is decreasing fast. This shows Addis Ababa's traffic is shifting from CS to PS and in the global trend; data volume and required data rate are growing faster. Starting from now in the next few years, 5G will be commercialized that it will drastically affect data volume of all countries [8]. GSMA Intelligence forecasts the first commercial 5G services to be launched in the sub Saharan region by 2021, with 5G connections accounting for 2.6% of the total connections base by 2025 [20, 21].

The introduction of fifth generation wireless technology in 2019 and 2020 will provide a big speed boost to mobile networks, approximately one hundred times or more. All that extra bandwidth will be a boon for consumers, who will be presented with all manner of new entertainment options. But 5G will also bring new opportunities and challenges for enterprises. Companies that start preparing now will hold the advantage [21].

Therefore, we are enforced to consider global telecom experience that is whether Addis Ababa will use 5G or not, it must support global telecom services. There will be incoming traffic from international 5G services.

Most of Ethiopian data traffic has offshore server [23] that Addis Ababa's traffic is vulnerable to both of local traffic demand and global telecom services generated due to international 5G network. Indirectly, external 5G network will affect local traffic demand of Addis Ababa.

Since Addis Ababa is center of international diplomacy, tourism and trade and also from Ethio telecom's mobile service usage trend, high data users are foreigners and diaspora who seat around big hotels [23] that affirms global 5G traffic avalanche influence will come to Addis Ababa's even on non-5G network. Therefore, LTE should support this indirect 5G traffic demand. So, Addis Ababa's traffic demand is influenced by immigrant traffic demand from diplomats, tourists, investors, diasporas, and travelers.

In addition to external 5G data avalanche influence, there will be local high data demand that e-Commerce will start within three years and IoT and Machine-to-Machine communication will be expanded. For example, now fleet management, POS machines and VAT machines use Ethio telecom's wireless network and Alibaba is working to open e-commerce center in Addis Ababa [23, 48].

From the previous listed reasons, we seat the following assumptions.

In worst scenario, there will no 5G service in Addis Ababa in the life span of this project that is within the coming six years. One hundred-fold 5G network influence on global data rate will have at least two times effect on Addis Ababa's DL traffic usage; since it is center of diplomacy, tourist and economy and there is no network boundary. Let LTE will support 82% of mobile traffic in Addis Ababa due to 5G influence. Because LTE has better capacity than UMTS and GSM [23].

- Ethio telecom will deploy QPSK 2x2 MIMO [15].
- Traffic busy hour will not be shifted.
- Traffic distribution property will be the same as current traffic distribution.

Based on the above assumptions, Addis Ababa's DL traffic will be $2 * 19776.06966$; 39552.13932 GB at busy hour. Then, 82% of total traffic will be 32432.75424GB [12,13,16]. Based on DL traffic requirement, total number of sites will be as the follows.

| Total eNodeB for 82 % of DL busy hour data is of 32432.75424 GB | Data rate (GBpH) | | | Number of eNodeB for all data | | |
|---|---|---|---|---|---|---|
| Modulation | QPSK | QAM16 | QAM64 | QPSK | QAM16 | QAM64 |
| Single Chain | 21.384 | 41.2776 | 101.7576 | | | |
| eNodeB 2x2 MIMO | 42.768 | 82.5552 | 203.5152 | 759 | 393 | 160 |
| eNodeB 2x4 MIMO | 42.768 | 82.5552 | 203.5152 | 759 | 393 | 160 |
| eNodeB 4x2 MIMO | 85.536 | 165.1104 | 407.0304 | 380 | 197 | 80 |
| eNodeB 4x4 MIMO | 85.536 | 165.1104 | 407.0304 | 380 | 197 | 80 |

Table 3-8. Total eNodeBs based on global traffic influence expectation [12,13,16,30]

Based on MCS table, three sector eNodeB with QPSK 2x2 MIMO and 20 MHz FDD will have 42.768 GB per hour DL throughput. Therefore, in order to support eighty-two percent of expected traffic, by considering external traffic influence because global 5G traffic and local e-commerce, $(19776.06996 * 2 * 0.82)/42.768$, seven hundred fifty-nine (759) sites are needed.

# Conclusion

Addis Ababa’s mobile traffic in the next six years and its coverage are estimated and dimensioned by four different perspectives. Since it is based on currently deployed network, it is similar to real scenario. The result is summarized as follows.

| Planning Scenario | Number of eNodeBs |
|---|---|
| Coverage planning by Propagation Model | 594 |
| Coverage planning by RF Planning Tool | 142 |
| Capacity Planning by DL Traffic History (for 50% of all traffic) | 232 |
| Capacity Planning by Empirical Formula (82% of future traffic) | **759** |
| Currently deployed mobile Sites | 743 |
| Currently deployed LTE Sites | 329 |
| Additional Sites | **16** |

Table 3-9. Summary of total number of LTE sites

The results of both capacity planning based on network usage history and coverage planning are under the number of currently serving sites. However, in this research, total number of eNodeBs is estimated by the global trend of mobile traffic and future global traffic impact of 5G network. In order to serve Addis Ababa without expansion for next six years, 759 outdoor LTE sites are required. We plotted additional 16 LTE sites on existing 743 sites by using particle swarm algorithm. Next Chapter shows nominal plotting of additional sixteen sites on the existing mobile sites.

**Note:** All existing 743 mobile sites were assumed to be upgraded to LTE.

# CHAPTER 4 NOMINAL SITE PLOTTING BY PARTICLE SWARM OPTIMIZATION

## 4.1. Overview of Algorithms from Swarm Intelligence

People learn a lot from nature. Applying the analogy to biological systems with lots of individuals, or swarms, we can solve the challenges in the algorithm and apply for optimization techniques. Swarm intelligence is the evolving collective intelligence of groups of simple agents. With swarm intelligence, the developed algorithms need to be flexible to internal and external changes, dynamic when some individuals fail, decentralized and self-organized. There are many popular algorithms for swarm intelligence optimization, including particle swarm optimization (PSO), ant colony system (ACS), and Artificial Bees Colony (ABC) algorithms [2, 53].

PSO was first introduced by Kennedy and Eberhart. In PSO, an individual in the swarm, called a particle, represents a potential solution. Each particle has a fitness value and a velocity, and it learns the experiences of the swarm to search for the global optima [2, 53].

Steps of PSO are described as follows.

**Initialization:** We first decide how many particles used to solve the problem. Every particle has its own position, velocity and best solution. If we use M particles, their best solutions, and their velocities can be represented [2, 53].

**Velocity Updating:** This step is update velocity randomly up to maximum value of velocity [2]

**Memory Updating:** If we find a better solution than previous iteration, the previous value will be replaced by new value. Otherwise, there will be no change. These recursive steps continue unless we reach the termination condition. With the descriptions above, we can observe that the solution in PSO can be influenced by both the global and the local characteristics in the training procedure [2].

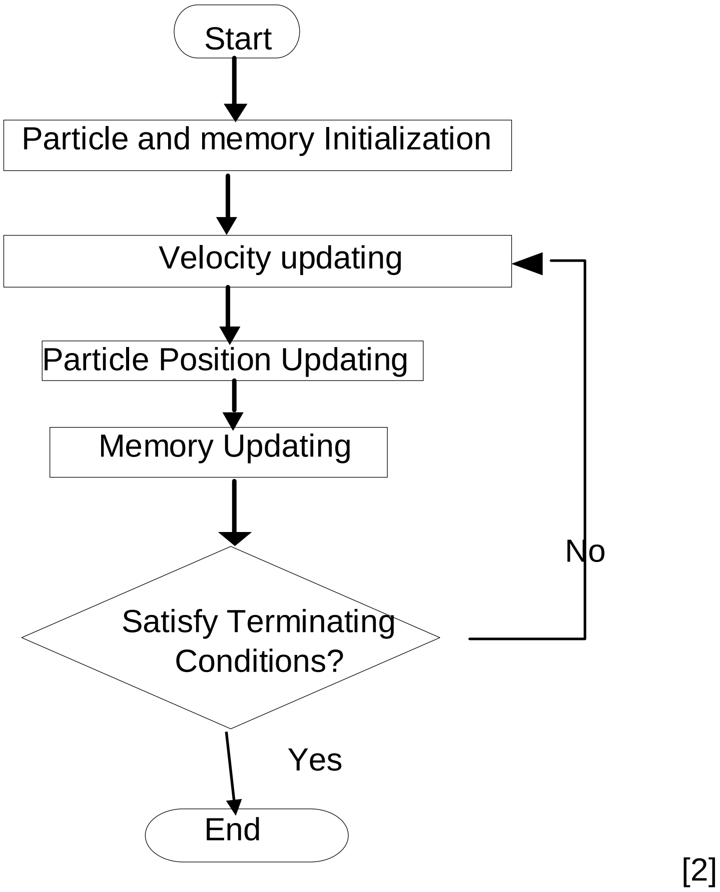


Figure 4.1. Procedures for particle swarm optimization

In order to do simulation with PSO and to plot nominal plan, we need existing sites with assigned traffic and geographical positions. Therefore, projected future traffic will be distributed to existing sites proportionally to current traffic.

## 4.2. Inter-Site Traffic Share

As confirmed by drive test, RF planning tool and user experience, wherever there is common area, common service and common users, there is traffic share among LTE sites. Traffic share between two sites depends on number of customers in overlapping coverage area. This traffic distribution was estimated based on GSM UL/DL measurement with Time Advance [7,12].

### 4.2.1. Time Advance Measurement of GSM

To predict inter-site traffic share, we developed traffic distribution property from TA measurement of GSM network, by considering average TA measurement of all cells (5 BSCs) in Addis Ababa for a month. Since LTE does not cover overall the area and GSM can show average traffic distribution relative to existing mobile sites, GSM TA is selected. Wherever GSM traffic exists, LTE traffic will exist in the near future and also GSM TA shows better traffic distribution nature than both UMTS' propagation time and LTE's propagation delay [7,12,23].

**Note:** One TA represents a distance of 554 meters [7]. We used 550 meters.

The following table shows the sum of all measurements in TA for a month.

| **TA** | **0** | **1** | **2** | **3** | **…** | **55-63** | **>63** |
|---|---|---|---|---|---|---|---|
| Busy hour TA measurement | 2618377416 | 5786641748 | 1.06E+9 | 2.83E+8 | | 16822 | 1 |
| Total MR/TA/Site at busy hr | 4065803.44 | 8985468.55 | 1642897 | 439150.4 | | 26.1211 | 0.00155 |
| Distance of TA(x) | 550 | 550 | 550 | 550 | | 4950 | 4950 |
| Radius of TA[R] | 550 | 1100 | 1650 | 2200 | | 35200 | 40150 |
| Initial point of TA[r] | 0 | 550 | 1100 | 1650 | | 30250 | 35200 |
| Area=1.9485*($R^2$-$r^2$) of TA | 589421.25 | 1768263.75 | 2947106 | 4125949 | | 6.31E+8 | 7.27E+8 |
| Center pt of TA | 275 | 825 | 1375 | 1925 | | 32725 | 37675 |
| PDF | 0.26085 | 0.57649 | 0.10540 | 0.02818 | | 1.68E-6 | 9.96E-11 |
| Average PDF per $m^2$ | 4.4256E-7 | 3.2602E-7 | 3.58E-8 | 6.83E-9 | | 2.65E-15 | 1.37E-19 |

Table 4-1. Average GSM TA measurement [12]

### 4.2.2. Traffic Probability Distribution Function (PDF)

GSM traffic is proportional to TA measurement [7, 23]. Traffic PDF depends on the position and size of the required place. The position determines traffic probability density function.

Traffic proportional to total traffic and radial distance will depend on area coverage of three sector-GSM site. Around eighty-four percent of the traffic found within TA 1 radius i.e. traffic PDF is denser in lower TA than higher TA value [3,4].

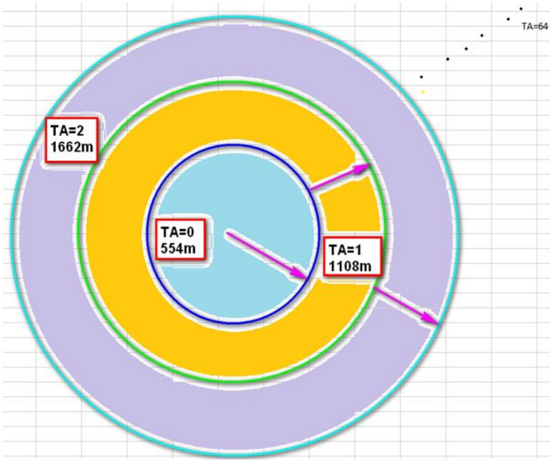


Figure 4.2. GSM UL/DL Time advance to estimate traffic distribution [12]

Let us generate traffic model proportional to distance or TA measurement.

$PDF_{TA=i} = MR_{TA=i}/total\ MR$ ………………………………………………………………….. 4-1

*It is unit less.*

$Total\ MR = \sum_{i=0}^{64} MR_i$ ……………………………………………………….................................4-2 *i= [0,63]*

*Where,* $MR_i$ is total UL/DL measurement of a site in the TA=i

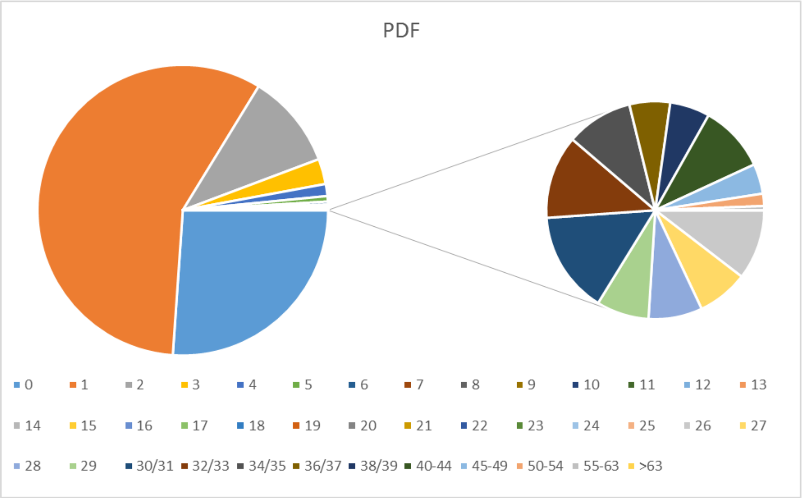


Figure 4.3. Traffic probability distribution proportional to TA

### 4.2.3. Traffic probability density function (pdf)

It is calculated from PDF per area against radial distance. It is decreasing exponential function.

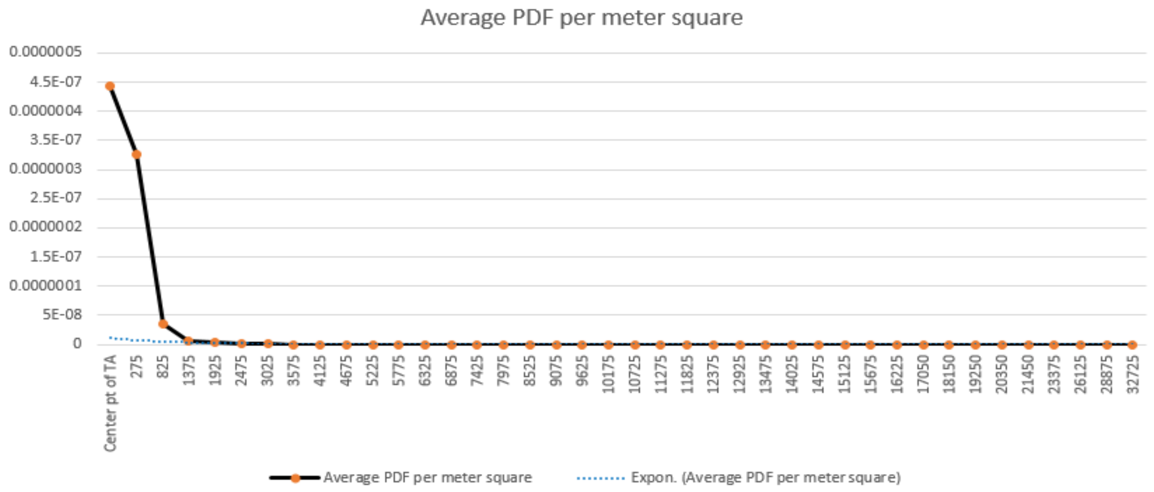


Figure 4.4. Graph of mean PDF vs distance and approximate exponential graph

$pdf = PDF/A$ ………………………………………………………………………… 4-3

$PDF = pdf * A$ ………………………………………………………………………… 4-4

*Where, pdf unit is per $m^2$ and A is area.*

From the trend of PDF to distance graph, we can select the probable equation for pdf; that is decreasing exponential function. Let pdf is $e^{\frac{k}{r}}$ and find the value of k from total PDF and individual PDFs counted in each time advance or specific area within specific radius range [3, 4].

$pdf_i = e^{\frac{k}{r}}$ ………………………………………………………………………… 4-5

$PDF = \int_0^{2\pi}\int_{r_i}^{r_{i+1}} e^{k/r} r\,dr\,d\theta + C = e^k \int_0^{2\pi}\int_{r_i}^{r_{i+1}} e^{k/r} r\,dr\,d\theta + C$ ……………………………… 4-6

Integrate the above equation

$\int_0^{2\pi} d\theta = 2\pi$ but for tri-sector mobile site area is 1.9485*R$^2$, therefore $\int_0^{2\pi} d\theta = 1.9485$

Integrate $\int e^{1/r} r\,dr = UV - \int V dU$

Let $U = r, dU = dr$

$dV \ = e^{1/r}$

$V = \int e^{1/r}$dr

Let $m = {}^{1}/_{r}$, $dr = \frac{-dm}{m^2}$

$V = -\int e^{m} \frac{dm}{m^2} = MN - \int NdM$

Let $M = e^{m}$, $dM = e^{m}$ and $dN = \frac{-1}{m^2} dm$, $N = \frac{1}{2m}$

So,

$V = \ e^{m} \frac{1}{2m} - \int e^{m} \frac{1}{2m} dm \ldots\ldots.\ m = {}^{1}/_{r}$ and $-m^2, dr = \ dm$

$V = e^{1/r} * \frac{r}{2} - V$

$V = e^{1/r} * \frac{r}{4}$

$\int e^{1/r} * r\, dr = UV - \int VdU =$r*$e^{1/r} * \frac{r}{4} - \int e^{1/r} * \frac{r}{4} dr$

$\int e^{1/r} * r\, dr = \frac{1}{4}(r^2 * e^{1/r} - \int e^{1/r} * r\, dr)$

$\int e^{1/r} * r\, dr = \frac{1}{5} r^2 * e^{1/r}$

$$PDF_i = 1.9485 e^{k} * \frac{1}{5}({r_{i+1}}^2 * e^{1/r_{i+1}} - {r_i}^2 * e^{1/r_i}) + C \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 4\text{-}7$$

$$PDF_{total} = 1 = e^{k} * \sum_{TA=0}^{TA=63} \left(\int_0^{2\pi} \int_{r_i}^{r_{i+1}} e^{1/r} * r\,dr\,d\theta\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 4\text{-}8$$

$$1 = 1.9485 e^{k} * \frac{1}{5} * \sum_{TA=0}^{TA=63} ({r_{i+1}}^2 * e^{1/r_{i+1}} - {r_i}^2 * e^{1/r_i}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 4\text{-}9$$

$$e^{k} = \frac{5 * PDF_i}{1.9485 * ({r_{i+1}}^2 * e^{1/r_{i+1}} - {r_i}^2 * e^{1/r_i})} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 4\text{-}10$$

$$k_i = ln\left(\frac{\mathbf{2.5661 * PDF_i}}{({r_{i+1}}^2 * e^{1/r_{i+1}} - {r_i}^2 * e^{1/r_i})}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 4\text{-}11$$

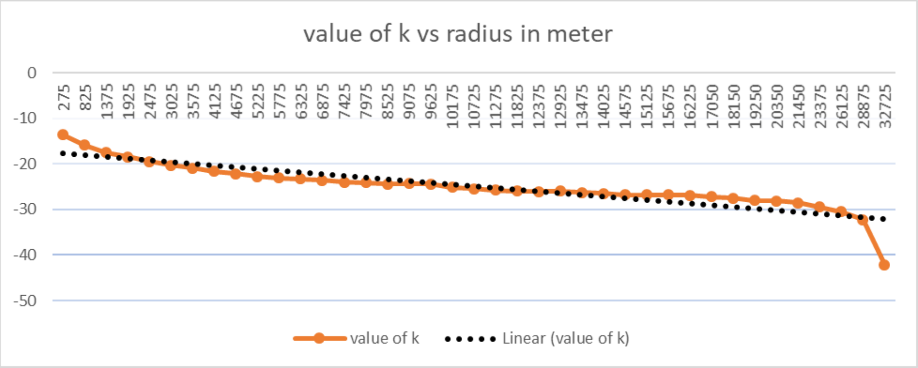


Figure 4.5. Value of k at different TA values

Value of k is decreasing linear function.

$k = -13.30657 + m * r$ ……………………………………………………………………... 4-12

$m = 0.00052$

$k = -13.30657 - 0.00052 * r$

Finally

$pdf = e^{\frac{k}{r}} = e^{\frac{-13.30657 - 0.00052 * r}{r}}$ ……………………………………………... 4-13

$C = PDFi = 1.9485 * e^{k * \frac{1}{5}} (r_{i+1}^{2} * e^{1/r_{i+1}} - r_i^{2} * e^{1/r_i})$

$C = -3.78278e^{-06}$

$PDF_i = 1.9485e^{k} * \frac{1}{5}(r_{i+1}^{2} * e^{1/r_{i+1}} - r_i^{2} * e^{1/r_i}) - 3.78278e^{-06}$ ……………………………... 4-14

| TA | Whole Network (MR) | Distance of TA(x) | Radius of TA[R] | Initial point of TA[r] | Area= 1.9485(R*R-r*r) of TA | Center pt of TA | PDF | Average PDF per meter square | k | c | PDF out of R |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **0** | 2.62E+9 | 550 | 550 | 0.1 | 6E+5 | 275 | 0.2609 | 4.43E-7 | -13.0223 | -2.39E-6 | 7.39E-1 |
| **1** | 5.79E+9 | 550 | 1100 | 550 | 2E+6 | 825 | 0.5765 | 3.26E-7 | -13.3275 | -5.29E-6 | 1.63E-1 |
| **2** | 1.06E+9 | 550 | 1650 | 1100 | 3E+6 | 1375 | 0.1054 | 3.58E-8 | -15.5372 | -9.67E-7 | 5.73E-2 |
| **…** | … | | | | | | | | | | |
| **13** | 2358070 | 550 | 7700 | 7150 | 2E+7 | 7425 | 0.0002 | 1.48E-11 | -23.3296 | -2.15E-9 | 1.37E-3 |
| **14** | 1719436 | 550 | 8250 | 7700 | 2E+7 | 7975 | 0.0002 | 1.00E-11 | -23.7169 | -1.57E-9 | 1.20E-3 |
| **15** | 1695635 | 550 | 8800 | 8250 | 2E+7 | 8525 | 0.0002 | 9.25E-12 | -23.7975 | -1.55E-9 | 1.03E-3 |
| **…** | ….. | | | | | | | | | | |
| **50-54** | 49085 | 2750 | 30250 | 27500 | 3E+8 | 28875 | 4.89E-6 | 1.58E-14 | -30.1692 | -4.48E-11 | 1.68E-6 |
| **55-63** | 16822 | 4950 | 35200 | 30250 | 6E+8 | 32725 | 1.68E-6 | 2.65E-15 | -31.9530 | -1.54E-11 | 9.96E-11 |
| **>63** | 1 | 4950 | 40150 | 35200 | 7E+8 | 37675 | 9.96E-11 | 1.37E-19 | -41.8243 | -9.14E-16 | -4.28E-17 |

Table 4-2. Value of exponent, k, in each TA [3,4,12]

### 4.2.4. Inter-Site Traffic Share

Any two sites will have inter-site traffic sharing. Consider two sites; site 1(target site) and site 2(remote site) for sample calculation. For iteration purpose i will be used for the target site for which traffic influences will be calculated and j is used for remote sites. Both i and j extend to total number of required sites [12, 13, 16, 23].

There will be three types of traffic influence of one site on another site.

**By generating incoming traffic to the target site:** All global network, the nearby sites and even the site itself can generate incoming traffic to the target site.

**By supporting both incoming and outgoing traffic directly:** Sites which have common service area with target site will share the same traffic. This is our concern.

**By supporting both incoming and outgoing traffic indirectly:** Sites which have no common service area may share traffic due to mutual neighbor cells with target site.

To calculate traffic share of new sites on existing sites, first we should calculate:

- Traffic distribution of existing site (site 1)
- Traffic distribution of new site (site 2)
- Overlapping traffic distribution of site 1 and site 2

This overlapping traffic distribution is direct traffic share and other non-overlapping sites will have indirect traffic influence.

**Direct Traffic Share: -** It is overlapping traffic of two sites or more.

**Indirect Traffic Share: -** Traffic will be pushed to another nearby site if one site is not working or overloaded. And by turn the nearby site will have traffic influence on its other neighbor sites even if they have no common coverage area to the first site. This is indirect traffic share.

For this research purpose, we considered only direct traffic influence.

Traffic share cannot be bounded to the specific boundary (Addis Ababa’s boundary); that any two sites may have common traffic area out of Addis Ababa’s boundary. In order to include indirect traffic influence of remote site’s traffic on target cell, we extended maximum coverage radius to LTE maximum outdoor UL coverage radius.

**Note:** Outdoor UL MAPL is 144.3776 dBm (maximum MAPL) and maximum coverage radius is 1.373978 kilo meter.

For any two sites, there are three possible conditions of traffic sharing.

**Case 1:** No direct traffic share that inter site distance is greater than two times of maximum coverage radius of single site ($S > 2R$).

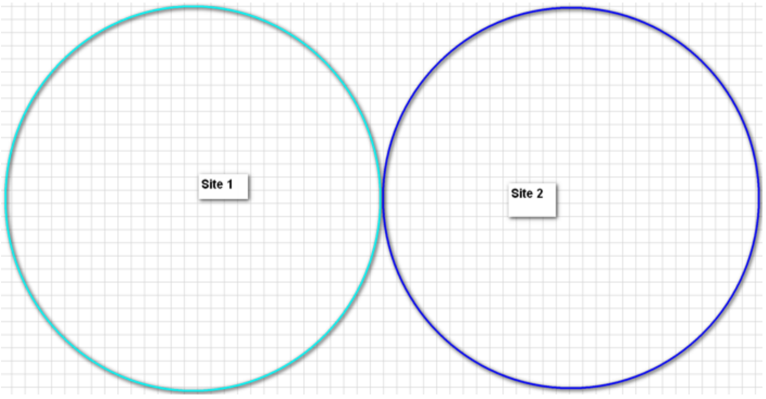


Figure 4.6. No overlapping traffic share

*Where, S is inter-site distance and R is maximum possible outdoor coverage radius of a single site; 1.373978km. Geographical coordinates; Site 1's center is (*$x_1$, $y_1$*),and Site 2's center is (*$x_2$, $y_2$*) [40].*

There is no direct traffic share between these two sites.

**Case 2:** Inter-Site distance is greater than maximum coverage radius of single site and less than two times of the radius i.e. $R < S < 2R$ [40]:

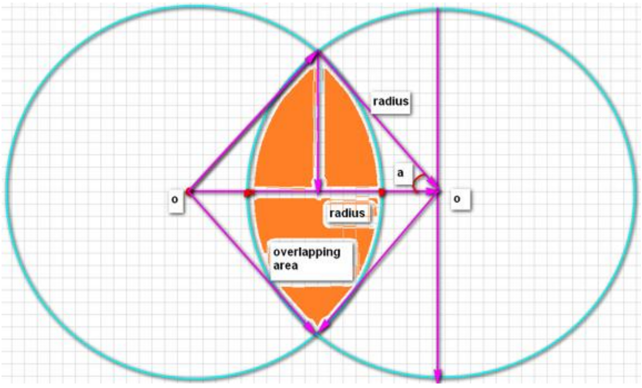


Figure 4.7. Overlapping distance is less than maximum coverage radius

**Case 3:** Inter-Site distance is equal to or greater than maximum coverage radius of single site i.e. $S >= R$:

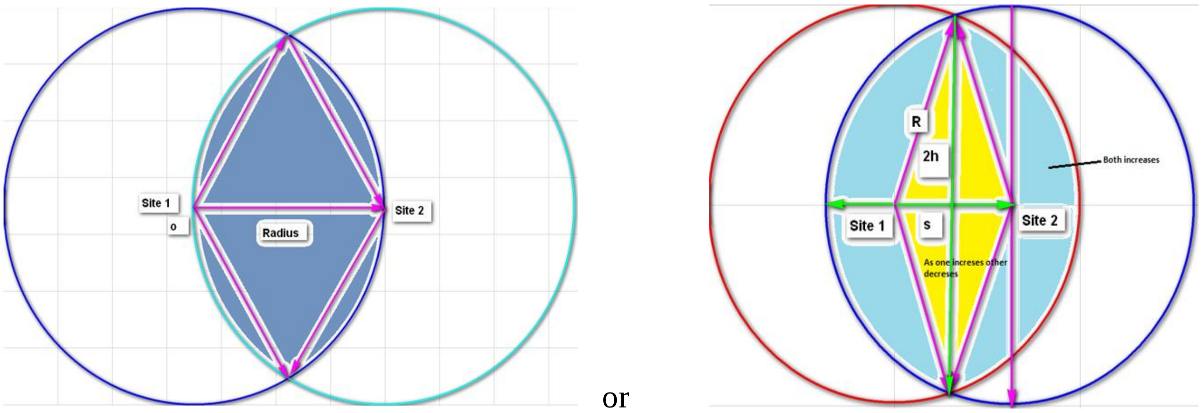


Figure 4.8. Overlapping distance is not less than maximum coverage radius

In order to simplify, we changed geographical coordinates' degree to distance equivalent (x, y coordinate) and to minimize number size, we subtracted the smallest x value to "x" s and the smallest y value to "y" s [40].

Distance between site 1 and site 2, $S_{12}$ is

$$S = S_{12} = \sqrt[2]{(x_1 - x_2)^2 + (y_1 - y_2)^2} \ldots\ldots\ldots\ldots\ldots\ldots \quad \textit{4-15}$$

Angle α between S and R which inscribe the overlapping area

$$\cos\alpha = \frac{S_{12}}{2R} \ldots\ldots\ldots\ldots\ldots\ldots \quad \textit{4-16}$$

*α in degree*

$$\alpha = \cos^{-1}\left(\frac{S}{2R}\right) \ldots\ldots\ldots\ldots\ldots\ldots \quad \textit{4-17}$$

Where, h is the perpendicular distance from crossing points of two sites' radius to line connecting two sites' locations.

$$h = R * \sin\alpha = R * \sin\left(\cos^{-1}\left(\frac{S}{2R}\right)\right) = \sqrt{R^2 + \left(\frac{S}{2}\right)^2} \ldots\ldots\ldots\ldots\ldots\ldots \quad \textit{4-18}$$

## Overlapping Area, A

**Note: -** Single site coverage area for hexagonal three sectored site is 1.9486$\boldsymbol{R^2}$ [16].

Overlapping area is the difference of two inscribed sectors' areas and the area of rhombus. The overlapping area is bounded by the required network area.

$A = 2 * 2\,\alpha/360^0 * 1.9486R^2 - h * S$ ………………………..…………………………... 4-19

replace α and h

*Where,* $1.9486R2$ *is the area of three-sectored mobile site,* $2h * S$ *is area of the rhombus, A is overlapping area of two coverage areas.*

$A = 4 * (cos^{-1}(\frac{S}{2R})/360^0) * 1.9486R^2 - S\sqrt{R^2 + (\frac{S}{2})^2}$

For LTE network, there will be traffic share on both of indoor and outdoor traffics, for indoor coverage, radius is 0.3968 Km and for outdoor traffic, the radius will be 1.374 Km (by ignoring indoor penetration loss of 19 dB, and with 144.377dB path loss).

$A = 0.04096 * cos^{-1}(\frac{S}{2.748}) - S\sqrt{1.888 + (\frac{S}{2})^2}$ ……………………................................. *4-20*

## Overlapping Traffic

On overlapping coverage, there will be traffic share; in order to find this traffic share, we will find average overlapping traffic density of two sites. The probability of getting resource for a load of remote site from target site depends on the distance from target site. Therefore, traffic share of remote site will be $\mathrm{PDF}_1 * \mathrm{PDF}_2 * T_2$ [12, 40].

Overlapping PDF is

$PDF_{12} = PDF_1 * PDF_2$ ………………………………………..………………...…………... *4-21*

According to the overlapping area, overlapping PDF manipulation may vary as the following cases.

**Case 1:** as PDF of site one increases PDF of site 2 decreases, combined PDF will be

$PDF_{12} = \int_{-\alpha}^{\alpha}\int_{x}^{R} pdf_1 rdrd\theta * \int_{-\alpha}^{\alpha}\int_{-R}^{x} pdf_2 rdrd\theta$ ……………………..……..………………. .. *4-22*

**Case 2:** as PDF of site one increases PDF of site 2 increases, combined PDF will be

$PDF_{12} = (\int_{-\alpha}^{\alpha}\int_{x}^{R} pdf_1 rdrd\theta)^2$ ………………………………..……..……...……...……… .. *4-23*

Traffic influence of site 2 on site 1, $T_{12}$

$T_{12}= PDF_{12}{*}T_2$ ……………………………………………..……………….…..…. .. *4-24*

*Where, $T_2$ is total estimated traffic of site 2.*

Total traffic share of all N sites on specific site, i will be

$T_i= \sum_{j=1}^{N} PDF_{ij} * T_j$ ……………………………….……………..….......................... *4-25*

*Where, i is target site, j is remote site, N is number of sites in the specific simulation.*

Total traffic of a single site after traffic share, $tT_i$ is

$tT_i = t_i + T_i$……………………………………………………………………….…... *4-26*

*Where, $t_i$ is initial traffic and $\mathrm{T_i}$ is traffic influence from other sites.*

GSM TA measurement in Addis Ababa shows around 84% of traffic found within two TAs; $TA = 0$ and $TA = 1$ distance (less than 1.1 Km) and good outdoor LTE UL coverage radius is 1.374Km. Therefore, we can take total direct traffic share within $2 * 1.374 = 2.748\ Km$ of maximum distance.

Overlapping traffic share is proportional to site's traffic and size of overlapping area. For simple manipulation purpose only, we assumed that PDF is equivalent to ratio of overlapping area to single site coverage area.

Overlapping area is $0.04096 * cos^{-1}\left(\frac{S}{2.748}\right) - S\sqrt{1.888 + \left(\frac{S}{2}\right)^2}$

*Where, S is in kilometer and* $R = 1.374\ Km,\ area = 3.6786Km2$

$PDF_1 = A/Atotal = 0.0111 * cos^{-1}\left(\frac{S}{2.748}\right) - \frac{S}{3.6786}\sqrt{1.888 + \left(\frac{S}{2}\right)^2}$ ….……………….…....*4-27*

$PDF_{12} = \left[0.0111 * cos^{-1}\left(\frac{S}{2.748}\right) - \frac{S}{3.6786}\sqrt{1.888 + \left(\frac{S}{2}\right)^2}\right]2$…………………….………… ... *4-28*

Traffic from overlapping site to target site is

$T_{12} = T_1 * PDF_{12}$…………………………………………….………..……..…........... *4-29*

## 4.3. Project Estimated Future Traffic to Existing Sites

### 4.3.1. Site Naming

In order to differentiate research sites with real sites, existing sites have been named as ETH001, ETH002……and ETH743 and new sites have been named WR001, WR002…...and WR016.

### 4.3.2. Traffic Mapping

In real scenario, Addis Ababa's population distribution and traffic demand are random that the existing populated areas may be vacant as well as current rural areas and farmlands may be densely populated residential areas [15, 23]. However, for this research purpose, we assumed that the population and wireless traffic demand would increase proportional to current traffic distribution i.e. even though there will be both population and traffic increase in number and size, relative distribution will stay constant.

Therefore, in order to locate additional sites within the existing sites, we projected existing $(2G + 3G + 4G)$ traffic to LTE equivalent and mapped expected future traffic to the existing sites proportional to current traffic distribution.

To plot additional sites according to current traffic distribution, we assumed the following points.

I. Today, there is no unserved traffic demand, that existing sites are serving full traffic demand, though practically there is coverage vacuum and congestion.

II. In the future, traffic increases proportional to current traffic distribution, even though Addis Ababa's population density and city expansion is very random.

III. Expected future traffic will be distributed to existing sites; proportional to existing traffic of sites.

New Traffic, $T_N$ is

$$T_N = \frac{T*32432.754242}{6447.6907} \quad \text{………….…..……………………………………….…...………. .. 4-30}$$

*Where, 6447.6907GB is total busy hour DL traffic on Mar 2019, and 32432.7542424 GB is total expected DL traffic after six years [12,13,16,40].*

## 4.4. Prepare PSO for Projected Existing Sites

We assigned longitude value as x, and latitude value as y. According to distance from google map, we set minimum x and y values on Addis Ababa map as zero. Finally, geographical coordinates were changed to equivalent Cartesian coordinates.

From the google earth, we got the following values.

- Minimum latitude is 8.84005°, which is used as reference y point.
- Minimum longitude is 38.65270°, which is used as reference x point.

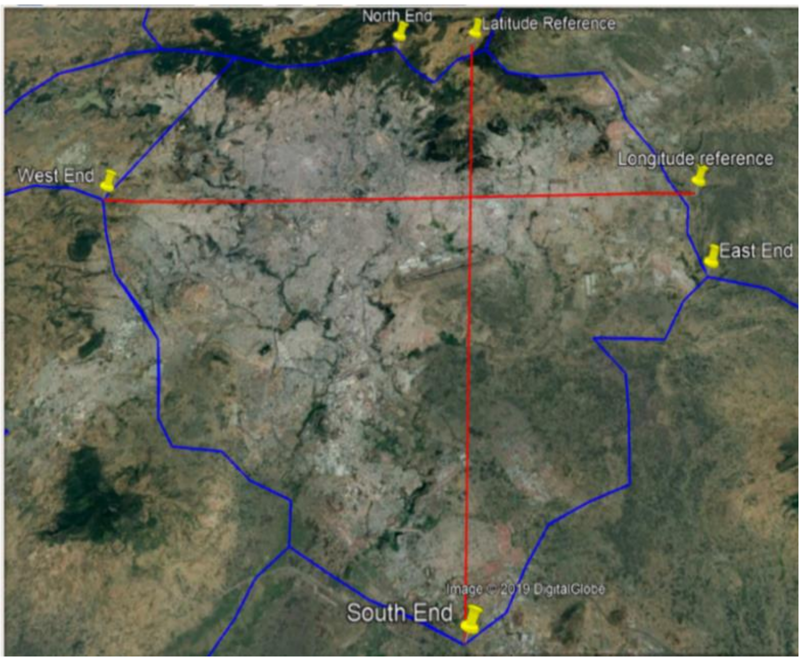


Figure 4.9. Addis Ababa's Map [14]

| Points | Lat (°) | Long (°) | Lat D/c(°) | Long D/c(°) | Northing(m) | Eastern(m) | 1 Lat(m) | 1 Long(m) |
|---|---|---|---|---|---|---|---|---|
| North End | 9.09430 | 38.7734 | 0.25425 | 0.2542 | 28133 | 27955 | 110649.629 | 109963.811 |
| South End | 8.84005 | | | | | | | |
| East End | 8.97230 | | | | | | | |
| West End | 9.01242 | 38.80956 | | | | | | |
| Latitude Reference | 9.09430 | 38.90692 | | | | | | |
| Longitude Reference | 9.01242 | 38.90692 | | | | | | |

Table 4-3. Addis Ababa boundary [14]

From google earth we get the following results.

- One latitude distance around Addis Ababa is 110649.63 meter.
- One longitude distance around Addis Ababa is 109963.81 meter.

Therefore, we changed geographical locations, from degree format, to local Cartesian form.

$X = (long - 38.65270°) * 109963.8109$………………………………………….…….. *4-31*

$Y = (lat - 8.84005°) * 110649.6285$……………………………………..……….….*4-32*

*Where, X is longitude and Y is latitude [14,40].*

## 4.5. PSO for New Site Plotting

In order to plot new site, we assumed that each site has uniformly planar traffic distribution in all direction that we used each site as Omni-directional. Because we used traffic at site level (intentionally, we did not use sectorial traffic distribution).

To add K new sites on N existing sites that among N sites, $N_0$ are initially congested sites, we need minimum number of congested sites after each iteration. For each iteration, there will be location update, velocity, and test point. After iteration fitted, one site will be added.

There are two options of iterations.

I. **Isolated mode of iteration:** This is done by creating a group of sites around global best, do iteration and add one additional site per iteration, and update number of particles for the next iteration. PSO will be done within the group i.e. particle are sites within the group.

II. **Fully connected topology:** Where every site is active participant of the iteration and communicate each other, by selecting global best, iterate all sites in the area to choose all additional sites by one iteration.

Due to its simplicity, we selected the first case and the step was developed as:

**For the first site plot:** The target, after inserting the new site, its traffic will be average traffic of proximate sites. In each iteration the following conditions will meet.

- We used the most overloaded site's location as global best.

- New site’s load should be the average of the nearest 10 sites’ traffic or average traffic of sites within overlapping area.
- New site’s load should take one third of overflow traffic of the most overloaded site and take the rest load by distance proportion from all overloaded sites within maximum possible overlapping distance.
- We used each of N sites’ location as local position.
  - ✓ Particles will be some of the nearest sites to the most congested site.
  - ✓ We will identify possible searching area as shown in the figure.
- Traffic of each of existing sites will have its own new traffic value proportional to expected total traffic and current traffic distribution.

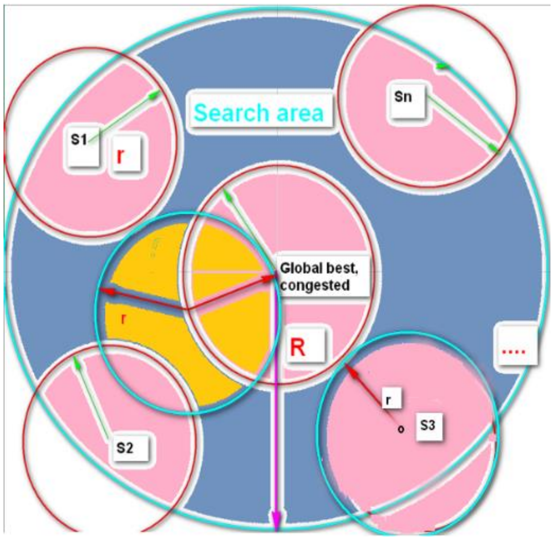


Figure 4.10. Searching area of new site is blue shaded space

*Where, R is searching radius and r is expected minimum inter-site distance taken from existing sites’ locations.*

Searching radius(R) will be the distance on which the new site will share at least one third of the overflow traffic of the most congested site in that iteration. Minimum inter-site distance(r) will be decided by the nature of the place (for denser area smaller r and for scattered area larger r). It is traffic density dependent value.

Iteration will be done within searching radius R and if possible, out of minimum inter-site distance, r. Identifying the most congested sector is better than searching all around.

Choosing the new site’s location should fulfil the following expectations.

a) It should share at least one third of the most congested site’s overflow traffic.
b) In minimum, it should support average traffic of ten nearby sites’ traffic.
c) Possible minimum number of congested sites is the best option.

**Test point:** The best solution is, the maximum of the sum of one third proportion of expected results. Each expected result will have equal weight.

**Manipulation:**

$G = Max\{[1/3 * OO/O + 1/3 * TT/T + 1/3 * [LL/ (1/3 * (L - C)]]\}$……….………….. *4-33*

Where, G is global best, *i is iteration, N is total number of sites, K is additional sites, C is single site capacity,* $T_i$ *is traffic of new site, O is number of overloaded sites before iteration,* $O_i$ *is number of overloaded sites after iteration, i, T is total overflow traffic before iteration,* $T_i$ *is total overflow traffic after iteration, L is traffic of the most overloaded site before iteration,* $L_i$ *is traffic of the most overloaded site after iteration, LL is* $L - Li,$ *traffic share for the most overloaded site. OO is O-*$O_{i,}$ *minimizing overloaded sites, and TT is* $T - Ti,$ *maximizing traffic share for overloaded sites.*

Traffic for the additional site will be average traffic of nearby ten sites. Then this traffic will be distributed to distance proportion of all sites’ traffic.

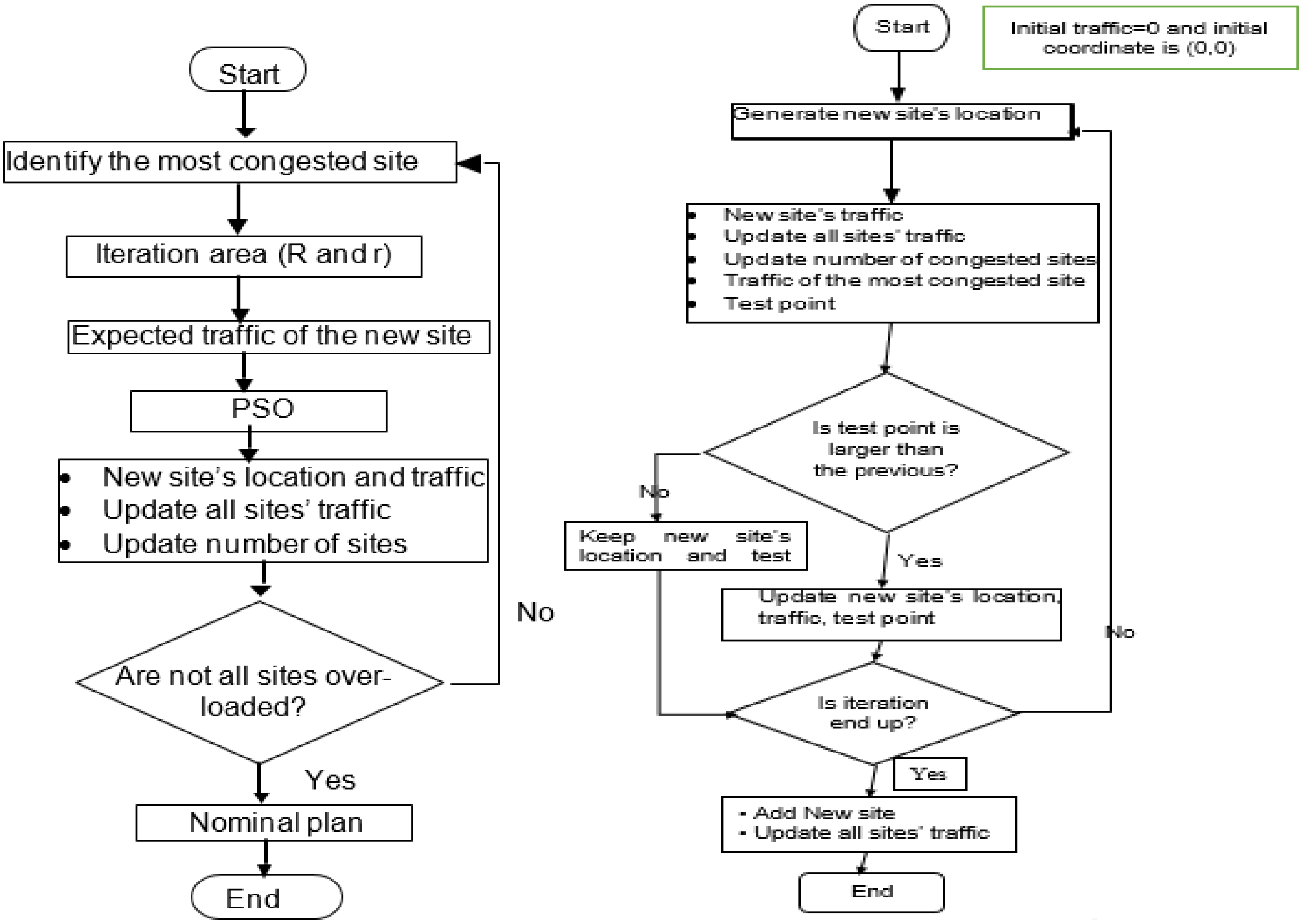


Figure 4.11. Placement procedure of new site

## 4.6. Result of PSO

Initially, total number of sites are 743 (*including 74 sites out of geographical boundary of Addis Ababa city which use the same BSC and RNC, therefore their traffic contribution for traffic analysis was included)*, total projected traffic is 32432.75424 GB at network busy hour. Total overloaded sites are 391 and overflow traffic is 7991.573GB per hour. Figure 4.12 shows total existing sites.

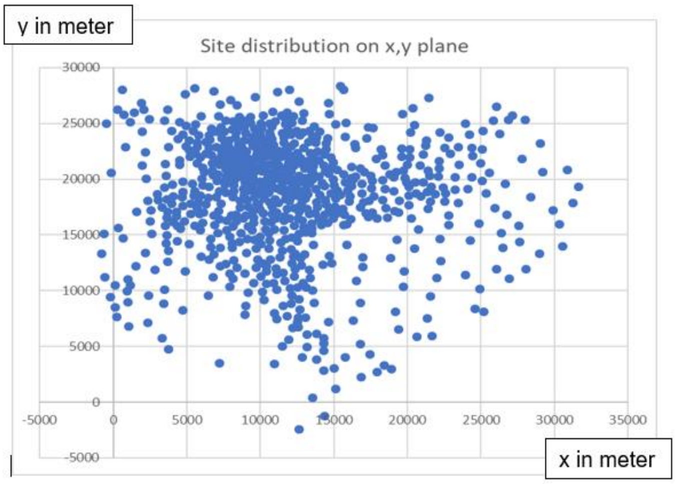


Figure 4.12. Distribution of existing sites in (x, y) plane

**Plotting the First New Site (WR001):** We identified the most overloaded site; ETH064 on (14024.784m, 18586.925m) has 133.4295 GB per hour is the most overloaded site. Overflowed traffic of the most overloaded site is the difference of 133.4295 and 42.768; 90.6615GB per hour. The new site should support one third of overflow traffic of ETH064, i.e. 30.221 GB. Traffic of WR001 will be the average of the nearest ten sites including the most overloaded site; 133.429, 70.788, 112.610, 40.366, 50.407, 108.199, 54.164, 55.240,72.288 and 23.948; it will be 72.144 GB.

The new site shares outdoor traffic in the radius of 1.374Km or in the area of 3.6786Km2. Inter-site distance, r is the minimum inter-site distance that is 209.39 meter, the distance between ETH540 (38.77992, 8.98827) and ETH273 (38.78153, 8.98726) which is minimum inter-site distance in existing network.

S is maximum distance of new site from the most overloaded site. From the above equations, overlapping traffic of ETH064 on WR001 will be the product of 72.144 and $PDF_{12}$ i.e. $1/3 * 90.6615$.

*Where 72.144 is traffic load of the new site and 90.6615 is overflow traffic of ETH064.*

$$72.144 * \left[0.0111 * cos^{-1}\left(\frac{S}{2.748}\right) - \frac{S}{3.6786}\sqrt{1.888 + \left(\frac{S}{2}\right)^2}\right] 2 = 1/3 * 90.6615$$

$$0.0111 * cos^{-1}\left(\frac{S}{2.748}\right) - \frac{S}{3.6786}\sqrt{1.888 + \left(\frac{S}{2}\right)^2} = 90.6615/(3 * 72.144),$$ S in kilo meter

$$0.0111*cos^{-1}\left(\frac{s}{2.748}\right) = \frac{s}{3.6786}\sqrt{1.888 + \left(\frac{S}{2}\right)^2 + 90.6615/(3*72.144)}$$

$$cos\left[\left\{\frac{S}{3.6786}\sqrt{1.888 + \left(\frac{S}{2}\right)^2 + 90.6615/(3*72.144)}\right\}/0.0111\right] - \frac{S}{2.748} = 0$$

By iteration, s was found 0.1402 kilo meter, which is less than existing sites' minimum inter-site distance. New site, WR001, support one third of the most overloaded site, maximum inter- site distance between WR001 and ETH064 should be 0.1402 Km. Therefore, searching area is within 140.2-meter radius from center of ETH064.

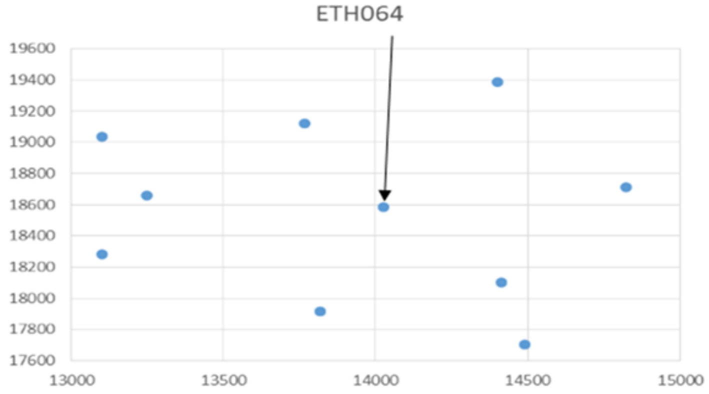


Figure 4.13. Searching area for the first site

The position of the first new site, WR001, is (14150, 18524.1) i.e. 140.1 meter far from the most overloaded site, ETH064.

$$Test\ Point = Max\left\{1/3*[(391-392)/391 + (7998.3888-7953.832356)/7998.3888 + (133.4295 - 103.209)/\left(1/3*(133.4295-42.768)\right)]\right\} = 0.33434$$

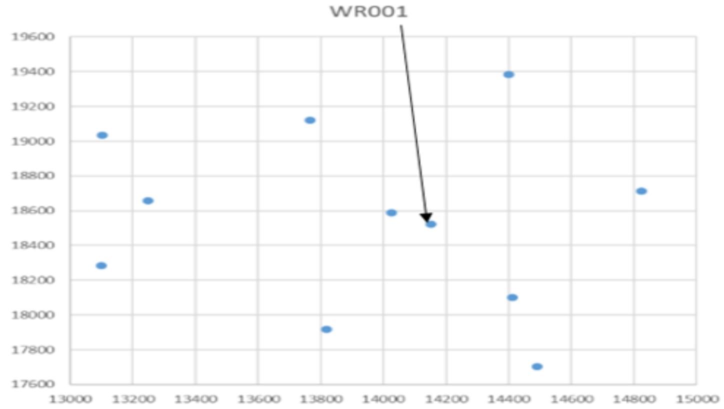


Figure 4.14. Position of the first new site

It updated traffic of existing sites after shared by new site. Total sites became 744 and sites which have overflow traffic are 392 and overflow traffic minimized from 7998.3888 GB to 7953.8324 GB.

**For the 2nd Site:** The most over-loaded site is ETH095 (16796.9721,17449.4464) with 128.6066GB. New site WR002 was plotted according to the first site and other fourteen sites used the same procedures.

After plotting sixteen sites which are found by capacity (16th iteration), coverage meets completely. However, we found 759 sites in which 393 sites are overloaded and 7340.1006 GB traffic is over-flow and 365 sites are underload. These 393 overloaded sites include 16 new sites and 377 existing sites. From 391 previously overloaded sites, only fourteen sites become optimal by addition of 16 new sites. Therefore, it needs additional sites beyond total traffic demand in order to cover this unevenly distributed traffic.

Then, we did traffic share among 759 sites within 1.374 Km radius of outdoor coverage and 2.748 Km inter-site distance up to new site's load reaches its maximum physical capacity of 42.768 GB per hour. Some sites cannot share their load to nearby sites due to the nearby sites being full loaded and other sites cannot share load from other overloaded sites because overloaded sites are far from maximum possible outdoor coverage of a site. After doing inter-site traffic share, the result showed 64 sites were underutilized with 1763.9427 GB un-utilized resource, and 141 sites were overloaded and 1735.7849 GB overflow traffic. Therefore, we should proceed the iteration until overflow traffic and over-utilized sites becomes zero.

The iteration continued by giving new traffic of 42.768 GB per hour and share it to nearby overloaded sites based on traffic PDF. The new site should support at least one third of the most congested site's overflow traffic and the remaining traffic should support other sites' overflow traffic.

Fifty sites were added extra to capacity requirement of the specified area due to traffic distribution randomness. Total number of new sites reached sixty-six and there was no over loaded site but the number of underload sites increased from sixty-four to eighty-five and traffic wastage became 2138.40 GB per busy hour.

Therefore, in order to serve Addis Ababa with $2 x 2$ MIMO antenna system, 20 MHz FDD, QPSK modulation three-sectored LTE site, we need eight hundred nine (809) sites.

**Note: -** This PSO simulation considers only direct traffic share but in actual case, there might be in-direct traffic share. If we consider indirect traffic share for plotting new sites, it will decrease number of overloaded sites using a few additional new sites. Indoor sites and pico-cell sites were not considered in this research. However, in actual scenarios, there will be indoor sites to afford traffic demand of potential users. Therefore, capacity gap between traffic demand and planning result i.e. unutilized radio resource was left to see other options.

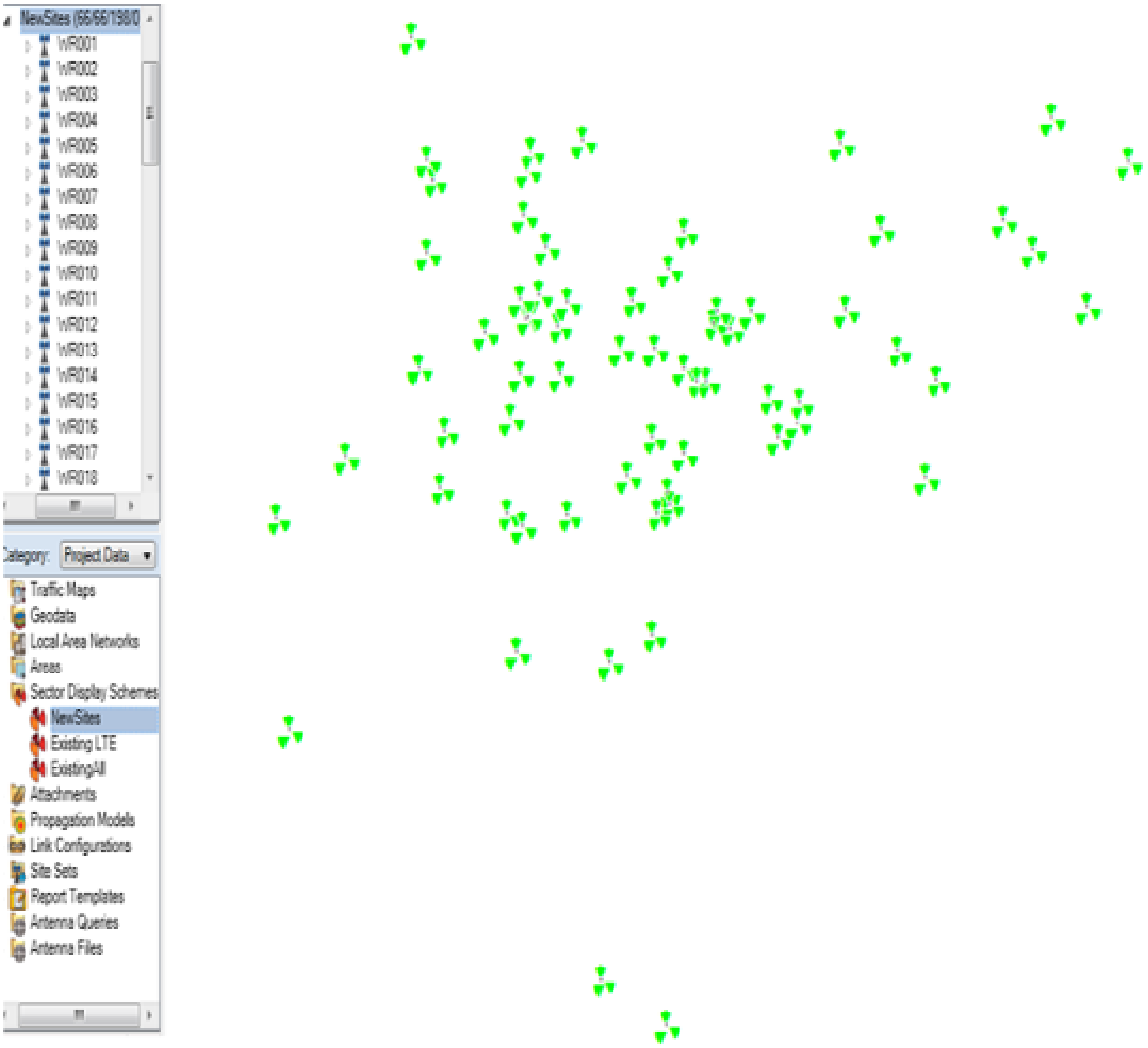


Figure 4.15. Total new sites

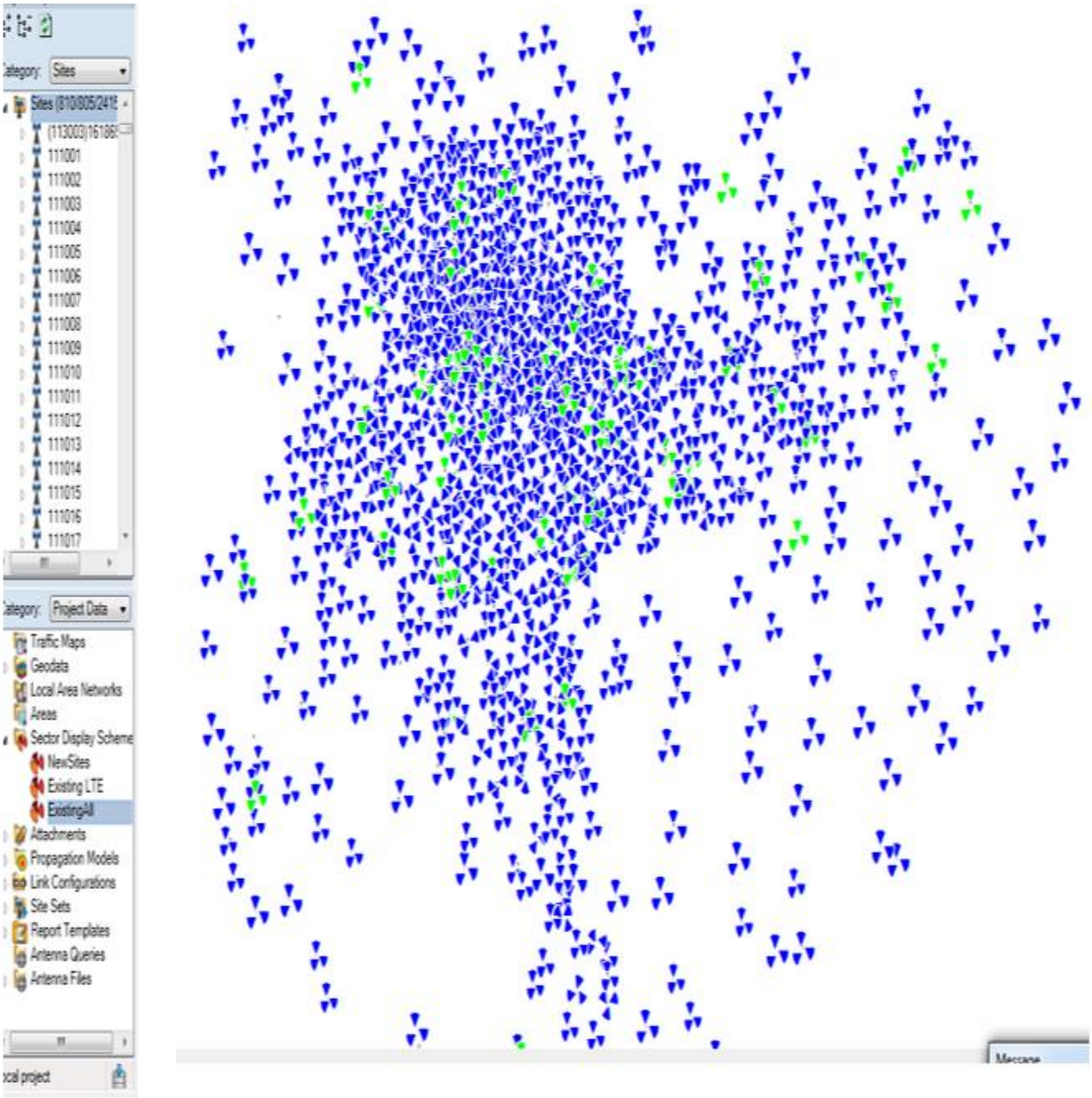


Figure 4.16. Total sites after dimensioning

# SUMMARY AND FUTURE WORK

LTE is state of the art mobile technology to support mobile broad band. Addis Ababa's traffic is increasing very fast. In order to accommodate this increasing data intensive traffic and in order to accommodate the coming international 5G traffic, deploying 4G is mandatory.

After finding number of sites based on coverage and capacity demand, preparing nominal plan according to traffic distribution is difficult, but Particle Swarm Optimization makes it simple and shows the gap of theoretical dimensioning and actual demand distribution. Preparing nominal plan using PSO helps to simplify the task of RAN dimensioning and in order to use radio resource efficiently.

Many researches done on LTE radio network dimensioning did not consider actual customer distribution or traffic density which will cause inefficient use of the network resource. With this research, PSO assisted to put new sites on unevenly distributed traffic area. LTE Radio Access Network Dimensioning by PSO, in the case of Addis Ababa, has been done for addition of new LTE sites on the existing LTE e-NodeBs by considering traffic distribution.

LTE coverage dimensioning have been done by two ways: by empirical way using Cost-231 propagation model and by planning software, Mentum Planet. There is huge gap between the two results. Ethiotelecom's outdoor planning tool has digital terrain map, building map and clutter map, its simulation result of three sites in Addis Ababa have a great difference of coverage to empirical coverage result. It needs further investigation.

LTE capacity dimensioning have been also done by two techniques: from traffic history prediction and expectation of the coming big data demand of IoT, M2M and e-commerce based on global telecom trend. Traffic estimation based on traffic progress is more real than using theoretical service and traffic models. Since total customer number and customer interest are not easy to grasp, predict from service history has convincing result. Theoretically, total number of LTE sites to accommodate both capacity and coverage are 759.

In this research, live network traffic history of three technologies and TA measurement of GSM have been taken. Time advance measurement is proportional to customer distribution at a time relative to GSM cell and traffic distribution is directly proportional to customer distribution. GSM customer distribution shows both of LTE and UMTS customers. From TA distribution, average traffic probability distribution function (PDF) and optimal traffic probability density function(pdf) have been developed. From PDF and pdf, inter-site traffic share models have been formulated.

Model for PSO has been developed i.e. for each new site; searching radius, minimum inter-site distance and required nominal points (by searching optimal points within searching area) were determined. After plotting new sites in the existing site distribution, number of overloaded sites increases even though the new sites shared much traffic. Therefore, the number of sites should increase extra to the planned number since there are overloaded sites. Numerical calculation is not enough to deliver adequate traffic. Because numerical capacity dimensioning never considers traffic distribution per specific area.

Therefore, by using PSO simulation still total unserved traffic and overloaded sites became zero, total number of sites increased to eight hundred nine and total underutilized sites became eighty-five and traffic wastage is 2138.40 GB per busy hour.

## Findings

The summary of findings is as follows;

| N/o | Scenario | Area (Km2) | Estimated Total Traffic (GBpH) | Number of Sites | Number of congested sites | Overflow Traffic(GBpH) | Number of under-loaded sites | Unutilized Traffic(GBpH) |
|---|---|---|---|---|---|---|---|---|
| 1 | Coverage by Cost-231 | 129 | 19776.06996 | 594 | | | | |
| 2 | Coverage by Mentum planet | 129 | 19776.06996 | 142 | | | | |
| 3 | Capacity from traffic history Estimation (50%) | 129 | 19776.06996 | 232 | 391 | 7998.38883 | 352 | 7375.4777 |
| 4 | Capacity from future Technology Influence | 129 | 39552.13932 | 759 | 393 | 7340.1006 | 364 | 7438.1484 |
| 5 | Capacity after Traffic share (82%) | 129 | 39552.13932 | 759 | 141 | 1735.7849 | 64 | 1763.942 |
| 6 | Capacity based on Traffic distribution | 129 | 39552.13932 | 809 | 0 | 0 | 85 | 2138.40 |

Table 5-1. Summary of results

Total number of sites required based on coverage and capacity dimensioning are not enough number of sites to accommodate the required traffic demand. Estimating number of sites based on traffic distribution and inter-site traffic share is a good approach which can accommodate all traffic demand. But estimating number of sites by PSO also has unutilized traffic resource that shows using single eNodeB type is not economical.

## Advantages

This research considers real traffic distribution from real traffic measurement of network elements. There are plenty of RAN planning tools both for capacity and coverage planning. This research has the following main findings which the existing tools can support.

1. Traffic estimation based on traffic volume history and current traffic distribution: which can tell us more reliable customer distribution and customer movement on busy hours rather than residential population density data.
2. Since it is not totally random simulator, new site placement based on traffic distribution and inter-site traffic share is near to real environment.
3. Population density can be prepared from census, but to estimate population flow and time-based population density is not easy task. This research shows that estimating population distribution based on traffic measurement is good solution in hand.
4. Based on current traffic density distribution, estimating future traffic distribution is near to real traffic.
5. The research is flexibly useful for all mobile technologies' RAN planning including LTE-Advanced.

## Draw backs of this PSO Planning

Since it does not consider elevation of the topography, obstruction, real geography and directional traffic density, there will be inefficiency of the planning. The first three parameters directly affect coverage of a site that coverage also affects overlapping area among sites and as well as traffic share proportion.

In reality, three sectors of a base station will not have the same traffic. But this research considers uniform traffic distribution of a site to minimize complexity that is different from actual traffic distribution.

Though the research stands on actual traffic distribution, it considers that all customer traffic demand is served, and all area is covered. But there may be unserved traffic in some areas of Addis Ababa. And it does not consider congestion and call setup success rate.

The research analyzed thirty-six months' traffic per BSC level for GSM and per RNC level for UMTS and for all eNodeBs for LTE that it does not consider individual site/cell busy hour that may make capacity vacuum. Because each area has unique peak traffic hour according to public movement. For example, residence areas and market areas have opposite busy hours.

This research is limited on single bandwidth (20 MHz FDD), single Modulation and single MIMO (QPSK 2x2 MIMO) and only three sector macro cells. Therefore, there is wastage of resource since there is no uniform traffic distribution.

## Future Work

The future work will be developing an application which can incorporate or adapt directional traffic distribution and real geographical (clutter, building, and elevation) maps with PSO. Traffic analysis per cell level in hourly base by considering congestion and unserved traffic gives more reliable result than this research. Future work will consider unserved traffic demand and traffic congestion in addition to served traffic.

## Recommendation

If RF planning tool vendors incorporate this PSO technique with digital map, building file, clutter map and population density map, it will give more accurate outdoor planning tool than Today's.

For the case of Addis Ababa and Ethiopia; since the traffic is unevenly distributed, we recommend that using multi band, multi modulation, multi-MIMO, multi carrier, multi-sector, and multi- cell type i.e. micro cell, pico cell and femto-cell and indoor LTE sites is effective.

# APPENDICES

## Digital Data Traffic Units

| Unit | Name | Bits | Byte | Bits |
|---|---|---|---|---|
| Kbit | Kilo bit | 1,024 | 128 | $2^{10}$ |
| KB | Kilo Byte | 8,192 | 1024 | $2^{13}$ |
| Mbit | Mega bit | 1,048,576 | 131075 | $2^{20}$ |
| MB | Mega Byte | 8,388,608 | 1048576 | $2^{23}$ |
| Gbit | Giga bit | 1,073,741,824 | 134217726 | $2^{30}$ |
| GB | Giga Byte | 8,589,934,592 | 1,073,741,824 | $2^{33}$ |

Table 0-1. Data rate units

## UE Categories

| UE category | Max data rate (DL/UL) (Mbps) | DL | | Supports 64QAM |
|---|---|---|---|---|
| | | Max # DL SCH TB bits/TTI | Max # DL SCH bits/TB/TTI | |
| Cat 1 | 10/5 | 10296 | 10296 | No |
| Cat 2 | 50/25 | 51024 | 51024 | No |
| Cat 3 | 100/50 | 102048 | 75376 | No |
| Cat 4 | 150/50 | 150752 | 75376 | No |
| Cat 5 | 300/75 | 299552 | 149776 | Yes |
| Cat 6 | 300/50 | [299552] | | No |
| Cat 7 | 300/150 | [299552] | | Yes/No |
| Cat 8 | 1200/600 | [1200000] | | Yes |

Table 0-2. UE categories and DL capabilities [30]

## Addis Ababa’s population

| Year in EC | Year in GC | Population | Growth Rate |
|---|---|---|---|
| 1999 | 2007 | 2917295 | 2.1 |
| 2000 | 2008 | 2978559 | 2.1 |
| ….. | | | |
| 2010 | 2018 | 3666605 | 2.1 |
| 2011 | 2019 | 3743604 | 2.1 |
| …… | | | |
| 2016 | 2024 | 4153545 | 2.1 |
| 2017 | 2025 | 4240770 | 2.1 |

Table 0-3. Addis Ababa’s population projection

# LTE MCS Table

IPRB= Index of Physical Resource Block

| MCS Index | Modulation Index | TBF index | IPRB | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 94 | 95 | 96 | 97 | 98 | 99 | 100 |
| 0 | 2 | 0 | 2600 | 2664 | 2664 | 2728 | 2728 | 2728 | 2792 |
| 1 | 2 | 1 | 3496 | 3496 | 3496 | 3496 | 3624 | 3624 | 3624 |
| 2 | 2 | 2 | 4264 | 4264 | 4264 | 4392 | 4392 | 4392 | 4584 |
| 3 | 2 | 3 | 5544 | 5544 | 5544 | 5736 | 5736 | 5736 | 5736 |
| 4 | 2 | 4 | 6712 | 6712 | 6968 | 6968 | 6968 | 6968 | 7224 |
| 5 | 2 | 5 | 8248 | 8248 | 8504 | 8504 | 8760 | 8760 | 8760 |
| 6 | 2 | 6 | 9912 | 9912 | 9912 | 10296 | 10296 | 10296 | 10296 |
| 7 | 2 | 7 | 11448 | 11448 | 11832 | 11832 | 11832 | 12216 | 12216 |
| 8 | 2 | 8 | 12960 | 13536 | 13536 | 13536 | 13536 | 14112 | 14112 |
| 9 | 2 | 9 | 14688 | 15264 | 15264 | 15264 | 15264 | 15840 | 15840 |
| 10 | 4 | 9 | 14688 | 15264 | 15264 | 15264 | 15264 | 15840 | 15840 |
| 11 | 4 | 10 | 16416 | 16992 | 16992 | 16992 | 16992 | 17568 | 17568 |
| 12 | 4 | 11 | 19080 | 19080 | 19080 | 19848 | 19848 | 19848 | 19848 |
| 13 | 4 | 12 | 21384 | 21384 | 22152 | 22152 | 22152 | 22920 | 22920 |
| 14 | 4 | 13 | 24496 | 24496 | 24496 | 25456 | 25456 | 25456 | 25456 |
| 15 | 4 | 14 | 27376 | 27376 | 27376 | 28336 | 28336 | 28336 | 28336 |
| 16 | 4 | 15 | 29296 | 29296 | 29296 | 29296 | 30576 | 30576 | 30576 |
| 17 | 6 | 15 | 29296 | 29296 | 29296 | 29296 | 30576 | 30576 | 30576 |
| 18 | 6 | 16 | 30576 | 30576 | 31704 | 31704 | 31704 | 31704 | 32856 |
| 19 | 6 | 17 | 34008 | 34008 | 35160 | 35160 | 35160 | 35160 | 36696 |
| 20 | 6 | 18 | 37888 | 37888 | 37888 | 37888 | 39232 | 39232 | 39232 |
| 21 | 6 | 19 | 40576 | 40576 | 40576 | 42368 | 42368 | 42368 | 43816 |
| 22 | 6 | 20 | 43816 | 43816 | 45352 | 45352 | 45352 | 46888 | 46888 |
| 23 | 6 | 21 | 46888 | 46888 | 48936 | 48936 | 48936 | 48936 | 51024 |
| 24 | 6 | 22 | 51024 | 51024 | 51024 | 52752 | 52752 | 52752 | 55056 |
| 25 | 6 | 23 | 55056 | 55056 | 55056 | 55056 | 57336 | 57336 | 57336 |
| 26 | 6 | 24 | 57336 | 57336 | 59256 | 59256 | 59256 | 61664 | 61664 |
| 27 | 6 | 25 | 59256 | 61664 | 61664 | 61664 | 61664 | 63776 | 63776 |
| 28 | 6 | 26 | 68808 | 71112 | 71112 | 71112 | 73712 | 73712 | 75376 |
| 28 | 6 | 26 | 68808 | 71112 | 71112 | 71112 | 73712 | 73712 | 75376 |
| 29 | 2 | | Reserved | | | | | | |
| 30 | 4 | | | | | | | | |
| 31 | 6 | | | | | | | | |

*Table 0-4. LTE MCS table [13]*

## New Sites

| Site ID | x(in meter) | y (in meter) | Traffic in GB |
|---|---|---|---|
| WR001 | 14150 | 18524.1 | 42.7680 |
| WR002 | 16944 | 17400 | 42.7680 |
| WR003 | 14915 | 19850 | 42.7680 |
| WR004 | 13415 | 15900 | 42.7680 |
| WR005 | 5313 | 23350 | 42.7680 |
| WR006 | 11386 | 17800 | 42.7680 |
| WR007 | 8406 | 20000 | 42.7680 |
| WR008 | 13400 | 15450 | 42.7680 |
| WR009 | 12707 | 18000 | 42.7680 |
| WR010 | 20200 | 19146.5 | 42.7680 |
| WR011 | 14400 | 18284 | 42.7680 |
| WR012 | 8131 | 14800 | 42.7680 |
| WR013 | 13,768 | 22400 | 42.7680 |
| WR014 | 12,670 | 13085 | 42.7680 |
| WR015 | 16,655 | 17509 | 42.7680 |
| WR016 | 15,090 | 20085 | 42.7680 |
| WR017 | 11118 | 3300 | 42.7680 |
| WR018 | 8850 | 24225 | 42.7680 |
| WR019 | 21870 | 18441 | 42.7680 |
| WR020 | 12750 | 12013 | 42.7680 |
| WR021 | 6070 | 17162 | 42.7680 |
| WR022 | 12110 | 20470 | 42.7680 |
| WR023 | 10007.6965 | 15055.1084 | 42.7680 |
| WR024 | 670.3394 | 14946.4021 | 42.7680 |
| WR025 | 5936.9462 | 15716.6466 | 42.7680 |
| WR026 | 14821 | 20200 | 42.7680 |
| WR027 | 9125 | 20600 | 42.7680 |
| WR028 | 9800 | 18614 | 42.7680 |
| WR029 | 25561 | 25070 | 42.7680 |
| WR030 | 20063 | 22275 | 42.7680 |
| WR031 | 1100 | 9644 | 22.0288 |
| WR032 | 11376 | 11344 | 39.9147 |
| WR033 | 24959.5858 | 21761.06414 | 42.7680 |
| WR034 | 12800 | 19243 | 42.7680 |
| WR035 | 7350 | 19650 | 42.7680 |
| WR036 | 5500 | 21650 | 42.7680 |
| WR037 | 9350 | 21800 | 42.7680 |
| WR038 | 10500 | 24500 | 42.7680 |
| WR039 | 13205.059 | 2195.62058 | 31.5950 |
| WR040 | 8750 | 20050 | 42.7680 |
| WR041 | 8598.0704 | 14796.1322 | 42.7680 |
| WR042 | 8600 | 22600 | 42.7680 |
| WR043 | 18794.465 | 24428.6717 | 21.4574 |
| WR044 | 17400 | 17400 | 42.7680 |
| WR045 | 8500 | 18600 | 42.7680 |
| WR046 | 11955.815 | 16036.4507 | 42.7680 |
| WR047 | 13250 | 21250 | 42.7680 |
| WR048 | 26700 | 20300 | 27.9526 |
| WR049 | 10000 | 20400 | 42.7680 |
| WR050 | 13750 | 18750 | 42.7680 |
| WR051 | 8200 | 17500 | 42.5656 |
| WR052 | 5000 | 27100 | 33.8910 |
| WR053 | 5500 | 24000 | 28.7040 |
| WR054 | 2900 | 16500 | 36.8646 |
| WR055 | 21500 | 16000 | 35.5442 |
| WR056 | 28000 | 24000 | 10.6661 |
| WR057 | 15900 | 20200 | 23.3320 |
| WR058 | 8500 | 20500 | 42.7680 |
| WR059 | 11733.068 | 19238.3636 | 26.8891 |
| WR060 | 13750 | 16600 | 8.7622 |
| WR061 | 24000 | 22500 | 22.4758 |
| WR062 | 8400 | 11600 | 17.6922 |
| WR063 | 18954.352 | 20217.4022 | 10.1624 |
| WR064 | 16800 | 17000 | 4.5400 |
| WR065 | 8725 | 23750 | 6.0153 |
| WR066 | 5250 | 18750 | 1.9605 |

Table 0-5. New sites

## Under Load Sites

| N/o | Site ID | Traffic |
|---|---|---|
| 1 | ETH522 | 0.0179 |
| 2 | ETH691 | 0.0530 |
| 3 | ETH516 | 0.3355 |
| 4 | ETH449 | 0.6184 |
| 5 | ETH500 | 0.6362 |
| 6 | ETH693 | 0.7522 |
| 7 | ETH702 | 1.1937 |
| 8 | ETH340 | 1.3639 |
| 9 | ETH489 | 1.6114 |
| 10 | ETH508 | 1.6662 |
| 11 | ETH520 | 1.8186 |
| 12 | ETH507 | 1.8545 |
| 13 | WR066 | 1.9605 |
| 14 | ETH502 | 2.1098 |
| 15 | ETH686 | 2.2003 |
| 16 | ETH517 | 2.3206 |
| 17 | ETH707 | 2.5256 |
| 18 | ETH448 | 2.5560 |
| 19 | ETH503 | 2.7653 |
| 20 | ETH704 | 2.9127 |
| 21 | ETH714 | 2.9442 |
| 22 | ETH305 | 3.1054 |
| 23 | ETH680 | 3.2550 |
| 24 | ETH649 | 3.4202 |
| 25 | ETH254 | 4.0186 |
| 26 | ETH650 | 4.1104 |
| 27 | ETH695 | 4.1980 |
| 28 | ETH512 | 4.2163 |
| 29 | ETH523 | 4.4259 |
| 30 | ETH643 | 4.4291 |
| 31 | WR064 | 4.5400 |
| 32 | ETH676 | 4.8342 |
| 33 | ETH709 | 5.6967 |
| 34 | ETH696 | 5.7379 |
| 35 | WR065 | 6.0153 |
| 36 | ETH629 | 6.4038 |
| 37 | ETH627 | 6.6419 |
| 38 | ETH501 | 6.9938 |
| 39 | ETH616 | 7.0034 |
| 40 | ETH667 | 7.4459 |
| 41 | WR060 | 8.7622 |
| 42 | WR063 | 10.1624 |
| 43 | WR056 | 10.6661 |
| 44 | ETH740 | 12.1929 |
| 45 | WR062 | 17.6922 |
| 46 | ETH394 | 18.6071 |
| 47 | WR043 | 21.4574 |
| 48 | WR031 | 22.0288 |
| 49 | ETH605 | 22.1006 |
| 50 | ETH712 | 22.2441 |
| 51 | WR061 | 22.4758 |
| 52 | WR057 | 23.3320 |
| 53 | ETH669 | 24.8112 |
| 54 | ETH450 | 24.8112 |
| 55 | ETH521 | 24.8112 |
| 56 | ETH638 | 25.3116 |
| 57 | ETH729 | 25.4141 |
| 58 | ETH679 | 26.8686 |
| 59 | ETH509 | 26.8686 |
| 60 | WR059 | 26.8891 |
| 61 | ETH306 | 27.5000 |
| 62 | WR048 | 27.9526 |
| 63 | WR053 | 28.7040 |
| 64 | ETH642 | 29.9566 |
| 65 | WR039 | 31.5950 |
| 66 | ETH628 | 32.6129 |
| 67 | WR052 | 33.8910 |
| 68 | ETH606 | 34.0775 |
| 69 | ETH252 | 34.8104 |
| 70 | WR055 | 35.5442 |
| 71 | ETH630 | 36.1396 |
| 72 | WR054 | 36.8646 |
| 73 | ETH675 | 37.2981 |
| 74 | WR032 | 39.9147 |
| 75 | ETH658 | 39.9213 |
| 76 | ETH681 | 39.9925 |
| 77 | ETH506 | 40.4068 |
| 78 | ETH657 | 40.4068 |
| 79 | ETH668 | 40.5437 |
| 80 | ETH633 | 40.5812 |
| 81 | ETH324 | 41.7551 |
| 82 | ETH619 | 42.4135 |
| 83 | ETH022 | 42.4997 |
| 84 | ETH733 | 42.5601 |
| 85 | WR051 | 42.5656 |

Table 0-6. Under-load sites

## Interview Questions

## Interview Protocol – for Ethio telecom Engineering department

Date: January 8 2019

Department: **Engineering**

Current Position: RAN Planning and Design Specialist

Address: Dereje.fekadu@ethiotelecom.et

**Part I. About Current Mobile Network Capacity and Coverage status and Future Plan**

1) Which Mobile Technologies are serving in Addis Ababa Today? Is there any unserved service demand?

2) What is future Ethio telecom's mobile technology strategy?

3) What is your penetration ratio for mobile service both in coverage and capacity in Addis Ababa?

4) How much Addis Ababa's mobile customers are served?

5) What is Ethio telecom's readiness to support the coming external 5G traffic?

**Concluding Questions and Statements**

a) Is there anything else you would like to share or add about this topic that you feel it is important for me to know?

**Concluding Statement**

Thank him for his kindness.

## Glossary

- dBi, dB(isotropic). It is the forward gain of a certain antenna compared to the ideal isotropic antenna which uniformly distributes energy to all directions.
- dBm, dB (1 mW) is a measured power relative to 1 mW (e.g. 20W is $10 * log\ (1000 * 20)$; 43 dBm.

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