Addis Ababa Institute of Technology

School of Electrical and Computer Engineering

Telecommunication Engineering Graduate Program

Techno-economic Analysis of LTE Deployment Scenarios for Emerging City: A Case of Adama, Ethiopia

By:

Dechasa Negash

Advisor:

Beneyam Berehanu Haile (PhD)

A Thesis Submitted to the School of Electrical and Computer Engineering in Partial Fulfillment of the Requirements for the Degree of Master of Science in Telecommunication Engineering (Network Track)

October, 2018

Addis Ababa, Ethiopia

Addis Ababa Institute of Technology

School of Electrical and Computer Engineering

Telecommunication Engineering Graduate Program

Thesis Title

Techno-economic Analysis of LTE Deployment Scenarios for Emerging City: A Case of Adama, Ethiopia

By: Dechasa Negash

Signed by the Examining Committee:

Dr. Beneyam Berehanu Haile Advisor	_____ Signature	____/____/2018 Date
_____ Internal Examiner	_____ Signature	_____/____/2018 Date
_____ External Examiner	_____ Signature	_____/____/2018 Date
_____ Chair Person	_____ Signature	_____/____/2018 Date

_____

Dean, School of Electrical and Computer Engineering

Declaration

I, the undersigned, declare that this thesis is my original work, has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been fully acknowledged.

Name: -Dechasa Negash

Signature: _____

Place: Addis Ababa

Date of Submission: _____

This thesis has been submitted for examination with my approval as a university advisor.

Advisor's Name: Dr. Beneyam Berehanu Haile

Signature: _____

Abstract

The exponential growth of demand for mobile broadband access in emerging cities has been pushing deployment of long-term evolution (LTE) mobile technology. However, technological advancement towards LTE alone cannot show the performance, acceptance, and economic viability of an investment without detail technical and economic feasibility assessment of possible LTE deployment alternatives. In this thesis, first potential LTE deployment scenarios analyzed and formulated through scenario planning method for emerging city. Then, techno-economic analysis consists of marketing forecast, radio access network dimensioning, cost and revenue modeling, and economic feasibility analysis for seven years study period assuming a monopoly telecom market using modified TERA model performed. For techno-economic evaluation, modified TERA model is implemented in the MATLAB. Results show that market potential and operating frequency have a great impact on network capacity, coverage and number of sites in the area which in turn influences the rate of return on investment. Deployment of LTE in 1800Mhz band under high and low demand capacity, and deployment of LTE in 2100Mhz band under high demand capacity are feasible with the payback period of less than 3.5 years for emerging city. From specially formulated deployments scenarios techno-economic results, coverage favored LTE deployment scenario (in 1800Mhz under low demand capacity) is technically and economically feasible for Adama city of Ethiopia in a monopoly telecom operator market with payback period of 3.25 years.

***Key words**: LTE, RAN, Techno-economic analysis, Deployment scenarios, TERA model*

Acknowledgment

First and foremost, I thank God for giving me all the help and strength to complete my thesis.

Second, I would like to express my deep sense of gratitude to my advisor Dr. Beneyam Berehanu, for his invaluable guidance and encouragement in carrying out my thesis work. His systematic guidance, patience, and enthusiasm helped me in all the time of research and writing of this thesis.

Correspondingly, I would like to offer my sincerest gratitude to Dr. Dereje Hailemariam, Dr. Murad Ridwan, and Dr. Yihnew Wondie for all the constructive comments given to me during the thesis progress report presentation and proposal preparation.

Likewise, let's my deepest thanks go to our friends and colleagues at ethio telecom who helped me in providing the valuable information regarding their respective work areas whenever I needed and during data collection and write-up of this thesis. Although the list is long, it is important to mention few of them: Markos Alemu, Habtamu Abayneh and Miheratu Daka.

In addition, I want to acknowledge my families. Considering the extra effort and time that the thesis requires, I would like to thank them for their support and patience.

Finally, it is essential to thank all the people who have directly or indirectly helped me throughout the course of this thesis work.

Table of Contents

Abstract iii

Acknowledgment iv

List of Figures vii

List of Tables ix

List of Acronyms xi

Chapter 1 : Introduction 1

1.1. Background 1

1.2. Statement of the Problem 3

1.3. Objective 5

1.4. Methodology 6

1.5. Related Works 8

1.6. Scope and Limitations 10

1.7. Contributions 11

1.8. Thesis Layout 12

Chapter 2 : Background on LTE Networks 13

2.1. History of Mobile Communication in Ethiopia 13

2.2. Long Term Evolution (LTE) 15

2.3. LTE Architecture, Frequency Band, Technologies and Advantages 16

Chapter 3 : Methods for Techno-economic Evaluation 22

3.1. Introduction to Techno-economic Analysis (TEA) 22

3.2. Modified TERA Model 23

3.3. Scenario Planning Method 29

3.4. Growth Method for Market Forecast 30

3.5. Network Dimensioning 34

3.6. Mathematical Modeling for Cost and Revenue 46

3.7. Discounted Cash Flow Analysis 50

3.8. Implemented Techno-economic Evaluation Approach 52

Chapter 4 : Deployment Scenarios and Techno-economic Analysis 57

4.1. Deployment Scenarios Analysis 57

4.2. Techno-economic Analysis 66

4.2.1. Marketing Analysis 66

4.2.2. LTE Radio Access Network Dimensioning 72

4.2.3. Cost and Revenue Modeling 82

Chapter 5 : Results and Interpretation 87

5.1. Market Forecast 88

5.2. Technical 90

5.3. Cost and Revenue 95

5.4. Economic 101

5.5. Special Deployment Scenarios 106

Chapter 6 : Conclusion and Future work 108

6.1. Conclusion 108

6.2. Future work 110

References 111

List of Figures

Figure 1.1. Summary of statement of the problem 4
Figure 1.2. General methodology 6
Figure 2.1. Mobile Subscribers in Ethiopia (Ethio telecom). 13
Figure 2.2.Mobile subscribers in mobile generation 14
Figure 2.3.LTE network architecture. 17
Figure 2.4. E-UTRAN architecture 18

Figure 3.1. Techno-economic analysis 22
Figure 3.2.TERA Framework. 23
Figure 3.3. TERA Model 25
Figure 3.4. Modified techno-economic analysis model 27
Figure 3.5.General scenario planning in five phases 29
Figure 3.6.Description of each stage of scenario planning method 30
Figure 3.7.Market forecast model 31
Figure 3.8. RAN dimensioning approach 35
Figure 3.9.Coverage dimensioning flow chart 36

Figure 3.10. Site configuration for cell radius estimation 42
Figure 3.11. Capacity dimensioning procedure 43
Figure 3.12. Bottom up cost modelling approach 46
Figure 3.13.Revenue forecast modeling 49
Figure 3.14. Simulated techno-economic evaluation approach flow chart 53
Figure 3.15. Snap shoot of implemented TE evaluation tool GUI 56
Figure 4.1.Key factors affect LTE deployment via PEST framework. 59
Figure 4.2.Initial LTE deployment scenario theme 64
Figure 4.3. Adama city population forecast. 68
Figure 4.4. Users forecast per defined market potential 69
Figure 4.5. Users forecast in Urban (a) and Suburban (b) areas of the city 69

Figure 4.6.Existing device status and type (Addis Ababa) 70
Figure 4.7.Service users' penetration with respect to population of the city 71
Figure 4.8. Service users' penetration rate with respect to defined market potential... 71
Figure 4.9.Cell radius (DL) 76
Figure 4.10.Number of site (eNodeB's) per total targeted area 76
Figure 4.11. Number of site (eNodeB's) via capacity dimensioning 79
Figure 4.12.Roll out plan 81
Figure 4.13.Initial year investment cost per each parameter. 83

Figure 5.1. Users forecast per each of formulated deployment scenario. 88
Figure 5.2.Service users penetration rate. 89
Figure 5.3.Number of sites per deployment scenarios (Via coverage dimensioning). . 92
Figure 5.4. Number of sites via capacity dimensioning. 94
Figure 5.5.CAPEX cost breakdown. 95
Figure 5.6. CAPEX cost trends. 96
Figure 5.7. OPEX cost breakdown. 97
Figure 5.8. OPEX cost trends. 98

Figure 5.9.Total cost of ownership (TCO) trends. 99
Figure 5.10. TCO and total CAPEX and OPEX cost. 99
Figure 5.11.Projected revenue for each formulated and specially considered DS. 100
Figure 5.12.ARPU. 101
Figure 5.13. Discounted cash flow. 102
Figure 5.14.Net cumulative discounted cash flow. 103
Figure 5.15.Net present Value. 104
Figure 5.16.Internal rate of return (IRR). 104
Figure 5.17.Payback period and discounted payback period 105

List of Tables

Table 1.1. Sample of selected projects status in ethio telecom 3

Table 2.1. History of recent ethio telecom projects 15

Table 2.2. LTE frequency band and band width 19

Table 3.1. TEA models drawn from TERA framework 24

Table 3.2. Application areas of selected TEA models 25

Table 3.3. Penetration loss per clutter type 39

Table 3.4. Downlink and Uplink radio link parameters..... 40

Table 4.1.key factors trends and its descriptions via PEST framework. 60

Table 4.2.Uncertain events. 61

Table 4.3.Ethio telecom 1800 and 2100 Mhz bandwidth status in Adama city 63

Table 4.4.Demography and population density distribution in 2018. 67

Table 4.5. Demo type area size and population distributions. 67

Table 4.6. SINR estimation for cell edge data rate..... 73

Table 4.7. Size and geographical distribution ratio..... 74

Table 4.8.LTE downlink and uplink radio link budget inputs..... 74

Table 4.9. Enviromental characterstics inputs 75

Table 4.10. Maximum allowed propagation los for both UL and DL. 75

Table 4.11. Users forecast per each year 77

Table 4.12. Traffic model. 78

Table 4.13. Average throughput persubscribers. 78

Table 4.14.LTE system peak cell throughput estimation parameters..... 79

Table 4.15.Number of users and throughput estimated per single site 79

Table 4.16. Number of sites..... 80

Table 4.17. Initial year roll out CAPEX cost. 82

Table 4.18. OPEX parameters distribution. 84

Table 4.19.Service usage and connection fee..... 86

Table 5.1.Formulated deployment scenarios. 87

Table 5.2.SINR and MAPL. 90

Table 5.3. Cell radius. 91

Table 5.4.Capacity dimensioning related results. 93

Table 5.5.Maximum number of sites per each deployment scenario. 94

Table 5.6.Techno economic results of special formulated LTE DSs. 107

List of Acronyms

2G	Second Generation
3G	Third Generation
3GPP	Third Generation partnership project
4G	Fourth Generation
ACTS	Advanced Communication Telecom services
ADSL	Asynchronous Digital Subscribers Line
API	Access Point Interface
APN	Access Point Network
ARPU	Average Revenue per User
BB	Broad Band
BSS	Business Support System
BTS	Base Terminal Station
BW	Band width
CAPEX	Capital Expenditure
CC&B	Customer care and Billing
CDMA	Code Division Multiple Access
COST	Cooperative Scientific Research
CP	Control plane
dB	decibel
DL	Down Link
DS	Deployment Scenario
DSs	Deployment Scenarios
DS1	Deployment scenario 1
DS2	Deployment scenario 2
DS3	Deployment scenario 3
DS4	Deployment scenario 4
ECOSYS	Techno-Economics integrated Communication Systems and Services

EDGE	Enhanced Data rates for GSM Evolution
eNodeB	evolved Node B
EPC	Evolved Packet Core
ETB	Ethiopian Birr
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
FDD	Frequency Division Duplex
FDMA	Frequency Division multiple Access
GB	Giga Byte
GPRS	General Packet Radio Service
GSA	Global Mobile Suppliers Association
GSM	Global System for Mobile Communication
GUI	Graphical User Interface
HSDPA	High Speed Downlink Packet Access
HSS	Home Subscriber Server
HSUPA	High Speed Uplink Packet Access
IEEE	Institute of Electrical and Electronics Engineers
IMS	Internet Protocol Multimedia Subsystem
IMT	Institute of Management Technology
IP	Internet Protocol
IRR	Internal Rate of Return
ITU	International Telecom Union
Kbps	Kilo bit per second
Khz	Kilo Hertz
LTE	Long Term Evolution
LTE-A	Long Term Evolution -Advanced
MAPL	Maximum Allowed Propagation Loss
MATLAB	Matrix Laboratory
MB	Mega Byte

Mbps	Mega bit per second
Mhz	Mega hertz
MIMO	Multiple Input Multiple Output
MME	Mobile Management Entity
MVNO	Mobile Virtual Network Operators
NGN	Next Generation Network
NNOC	National Network Operation Center
NPV	Net Present Value
OFDM	Orthogonal Frequency Domain Multiple
OFDMA	Orthogonal Frequency Division Multiple Access
OPEX	Operational Expenditure
OPTIMUM	Optimized Architectures for Multimedia Networks and Services
OSS	Operation Support System
PAPR	Peck to Average Power Ration
PEST	Political Economical Social Technological
PESTE	Political Environmental Social Technological Economical
PESTLE	Political Environment Social Technological Legal and Economical
P-GW	Packet -Gateway
PP	Payback Period
PRB	Physical Resource Block
PRS	Performance Reporting System
QAM	Quadrature Amplitude Modulation
QoE	Quality of Experience
QoS	Quality of Service
QPSK	Quadrature phase Shift Key
RACE	Research in Advanced Communications in Europe
RAN	Radio Access Network
RB	Resource Blocks

RLB	Radio Link Budget
ROI	Return on Investments
SAE	System Architecture Evolution
SC-FDMA	Single Carrier -Frequency Division Multiple Access
SGW	Service Gateway
SINR	Signal interference to Noise Ratio
STEEP	Social Technical Economical Environmental Political
TCO	Total Cost of Ownership
TDD	Time Division Duplex
TE	Techno-economic
TEA	Techno-economic Analysis
TEP	Telecom Expansion Project
TERA	Techno-Economic Results from ACTS
TEXA	Telecom Academy
TITAN	Tool Introduction Scenario and TE Evaluation of Access Network
TONIC	Techno-economics of IP optimized networks and services
UE	User Equipment
UL	Up Link
UMTS	Universal Mobile Telecommunications System
USIM	Universal Subscriber Identity Module
UTRAN	Universal Terrestrial Radio Access Network
VOIP	Voice over Internet Protocol
WiMAX	Worldwide Interoperability for Microwave Access

Chapter 1 : Introduction

1.1. Background

The mobile networks of most operators have been witnessing an unprecedented rise in data traffic [1]. This is happening due to an increase in consumer demand to access bandwidth-intensive content on-the-go and the explosion of many mobile devices such as smartphones and tablets. This trend is exerting extremely high-pressure on network operators. To address this challenge, mobile network providers have been upgrading their network infrastructure to the latest technology such as Long-Term Evolution (LTE) to keep up with data traffic volumes and deliver bits more cost-effectively.

LTE technology represents an important evolutionary step in the development of mobile technology. LTE characterized with improved spectral efficiency, enormous scope for increased speed and the capability to address capacity issues through the dynamic allocation of spectrum bands [2]. In addition, it enables network operators to offer users a wider range of advanced services while achieving greater network capacity through improved spectral efficiency.

Noticing the benefits of LTE, the rising demand for mobile broadband communication system accelerated the deployment of LTE network in different countries [3]. As per Global Mobile Suppliers Association (GSA) report, as of August 2018, globally around 681 LTE networks have been commercially launched [4]. From this, in Africa, greater than 102 LTE networks have been launched, mainly focusing in large cities.

The total number of LTE subscribers in Africa as of April 2017 has reached around 13 million. The current LTE subscriber base is still weak as Africa accounts for less than 1% of the global base. According to the GSA report, approximately 50% of mobile subscriptions in Africa are actively using data [4]. Nevertheless, 4G adoption in Africa will be expected to explode in the years to come due an exponential incremental of

innovative data service demand in developing countries. Hence, the growing number of LTE rollouts in developed markets is driving the rapid migration of mobile broadband in developing countries.

Provisioning of broadband mobile services has higher relevance for developing countries like Ethiopia, given its positive impacts on the economic growth. ethio telecom a sole operator in Ethiopia investing its money in several telecom projects to satisfy customers demand [5] [6]. But, the efficiency (in technical and economic aspects) of telecom projects are in question when related to the operation duration of projects due to low practically of feasibility assessment prior to project deployment.

On other side, the exponential growth of innovative data service demand in emerging cities of Ethiopia has been pushing deployment of LTE technology. However, deployment of mobile technologies is commonly vendor driven in ethio telecom and not supported by localized techno-economic assessments. Thus, to deploy LTE in an emerging city, the feasibility of LTE deployment under different deployment scenarios is crucial for operator due to the high cost of network elements and related deployment costs [7].

Furthermore, the dynamic nature of the existing technical and economical requirements affects the deployments of LTE, which in turn influences the rate for return on investment (ROI) [8]. And, many technological options and migration paths are possible towards LTE. Therefore, it is essential for operators to model the incurred capital expenditure (CAPEX) and operational expenditure (OPEX) and thereby approximate the total cost of ownership (TCO) of deploying LTE for an emerging city under different deployment scenarios.

To be cost-effective from emerging cellular technologies in the telecom sector, techno-economic analysis is essential before deploying the technology [9]. Techno- economic analysis (TEA) is a decision-making tool to evaluate available technology options based on technical, economic, environmental, social and regulatory [10] [11].

LTE is a newly advanced cellular technology and ethio telecom has relatively little experience in deploying LTE. With this status, the operator has a plan to deploy LTE in near future in a selected emerging city. Therefore, it is important to analyze LTE deployment scenarios in an emerging city in techno economic perspective to help the network operator to decide the optimum strategy towards LTE, optimize their network with an evolution of networks and maximize the resource utilization level.

1.2. Statement of the Problem

In telecom sector, each service and technology vary in complexity, network functionality, and overall deployment costs [12]. Particularly, in Ethiopia where resources are scarce, and most deployments are vendors dependent, detail feasibility options assessment is essential in using the resource in glowing and cost-effective manner.

As a basis for this study, sample three ethio telecom projects status have been selected and assessed. As shown in Table 1.1, the target and utilization level of each selected sample project not in step with the operation duration of the projects due to lack of detail localized techno-economic assessments prior to project deployment.

Table 1.1. Sample of selected projects status in ethio telecom ([5]).

Project	**Target**	**Utilization**	**Operation duration**
Fixed line (sample site)	5K subscribers	10%	3 years
CDMA	2.4 Million	21%	10 years
LTE (Addis Ababa)	400K subscribers	6%	3 years

On other side, emerging city in Ethiopia is the city where potential customers revolve, hosts of many governmental and non-governmental conferences and center of trade next to capital city [13]. In these cities; high data rate capable technology is vital for the development of the city and enhancement of quality of life in this era.

In line to developing status of cities, the rising demand for mobile broadband access and the inefficiency of existing 3G/2G technologies to support an exponential growth of data service pursues to find new technology that will be capable of high data rate delivery [5]. However, deployment of LTE technology with low level of feasibility assessment, slight LTE technology deployment experience and inappropriate deployment scenarios in the city come with certain doubts, which results in low performance of networks and quality of service (QoS), unnecessary investments and low level of resource utilization.

Summary of statement of the problem depicted in Figure 1.1.

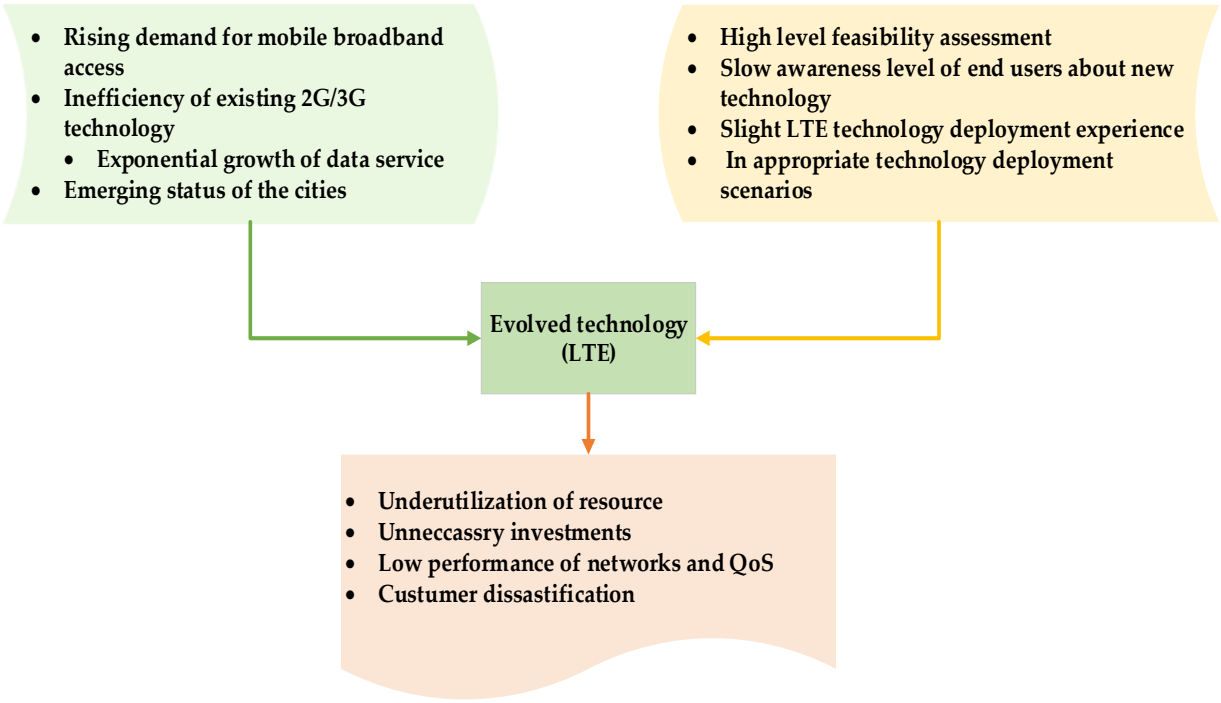


Figure 1.1. Summary of statement of the problem.

In response to these problems, it is important to analyze LTE deployment scenarios for emerging cities of Ethiopia from techno-economic perspective to minimize the underutilization and wastage of resource, low QoS and network performance happen after deployment of LTE.

Considering the stated problems, the study generally answers the following questions;

1. What are the key factors affecting LTE deployment in an emerging city?
2. What are the influencing parameters in marketing forecast and during LTE radio access network dimensioning in each deployment scenario?
3. Which part of the LTE network /parameters takes high share of the network cost in each deployment scenarios?
4. Which deployment scenarios are most likely feasible (in terms of technical and economical) in monopoly telecom operator market to deploy LTE in an emerging city? When return on investment (ROI) achieved?

1.3. Objective

The general objective of this thesis is to undertake techno-economic investigation of LTE technology deployment scenarios for an exemplary emerging city of Ethiopia, Adama.

1.3.1. Specific objectives

The specific aims of this thesis are listed as follows:

- ✓ To analyze and formulate LTE technology deployment scenarios for the exemplary emerging city of Ethiopia, Adama
- ✓ To make marketing analysis and forecast for the city
- ✓ To perform LTE radio access network dimensioning for the deployment scenarios considering the markets of the city
- ✓ To model and estimate capital and operational expenditures cost
- ✓ To analyze the feasibility of each deployment scenarios via economic parameters and indicators
- ✓ To implement the techno economic analysis approach using MATLAB for the techno-economic evaluation

1.4. Methodology

The general methodology used for this study was designed as follows in Figure 1.2. The study entirely basis on primary and secondary source of data. The primary data has been collected with the survey of monopoly telecom operator (ethio telecom), case study city and other relevant organizations. The data has been collected focusing on the three modular such as marketing, technical and economic data.

The secondary data has been collected from different books and literatures related to LTE, techno-economic modelling of wireless network, 3GPP standardization documents, different IEEE articles and journals and previous studies on this subject.

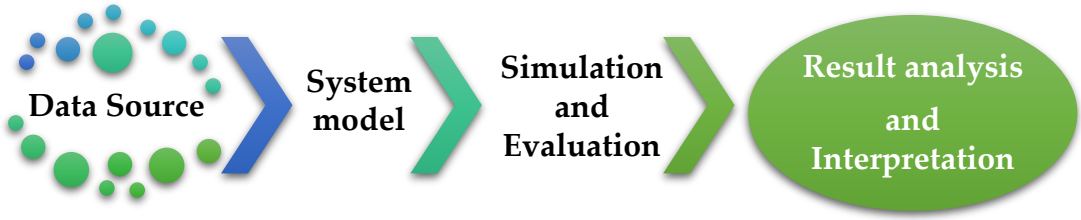


Figure 1.2. General methodology.

Based on the inputs retrieved from data source (primary and secondary) and the statement of the problem in mind; for designed methodology, detail components are described as follows:

System Model

- Formulate the localized LTE deployment scenarios.
- Model each parameter based on the modified TERA model.
- Prepare a mathematical model for marketing, revenue forecasting, radio link budget (RLB), propagation model, cell radius, capacity and network cost (CAPEX and OPEX) and key economic feasibility indicators.
- Setup target network requirement in terms of coverage, capacity and quality.

Simulation and Evaluation

- Outline techno-economic evaluation workflow that can be implemented in MATLAB based on modified TERA Model.
- Simulate the techno-economic evaluation system based on the prepared mathematical model in the MATLAB following the outlined work flow.
- Perform the techno-economic evaluation for each of formulated LTE deployment scenarios.

Results Analysis and Interpretation

- Analyze and describe the formulated LTE deployment scenarios.
- Illustrate and analyze marketing aspects such as user forecast, user's penetration rate and revenue projection for defined city and period.
- Describe the radio link parameters, propagation and environmental model used to estimate cell radius.
- Analyze and illustrate the most influencing parameters in LTE RAN dimensioning.
- Compare number of eNodeB required in both coverage and capacity dimensioning approach based on targeted network requirement.
- Describe the selected LTE deployment strategy for further evaluation of selected LTE deployment scenarios in consideration of existing technology.
- Show and analyze significance of roll out plan in evaluation process.
- Analyze and depict the CAPEX and OPEX cost distribution and its trends
- Compare the total cost of network (TCO) and cash flow for each selected LTE deployment scenario.
- Show the feasibility of each deployment scenarios via economic indicators.
- Compare the feasibility of each formulated and specially considered LTE deployment scenarios with recommended values of economic feasibility indicators.

1.5. Related Works

Several studies are conducted in relation to wireless technology from techno-economic perspectives. The author cited in [8] made an analysis on the deployment of LTE technology in competitive environments for a large city via adapted techno-economic model. The author starts the study with the motivation of high traffic demand and low quality of service observed in urban areas of the capital city of Ethiopia. At the end, the author concludes as the monopoly operators migrate to LTE earlier than competitive operators.

The author cited in [14] analyzed introduction of LTE technology from techno economic perspective to minimize uncertainties observed related to the customer's slow awareness about the benefits of a new technology. The author followed a TERA model for the investigation. Finally, the author concludes as LTE is profitable for the mixed services in the small number of breakeven years compared to Voice over IP (VOIP) service.

Likewise, the author cited in [15] also studied TEA in macro cells with carrier aggregation and small cells with the motivation of increasing indoor mobile broadband demand. The author concluded as all examined technologies can support the mobile broadband demand and recommend as macro cells enhanced with carrier aggregation is the most cost-effective solution.

The author cited in [16] also evaluate the economic gains of a joint deployment of femtocells and macro cells for the provision of LTE mobile broadband services in urban environments of Spain in different frequency bands. A business model approach and LTE system simulator considered in the study. At the last, the important benefits achieved for the case where the service is based on a closed subscriber group access to the femtocells.

The author cited in [17] made an interesting techno-economic assessment in rural India mainly focusing on the 800Mhz frequency band to avoid anxiety observed among cellular operators. The authors customized the techno-economic model to its study context. The author reaches to the conclusion that, in a right mix of data-volume offerings in a product package, the annual average revenue per user (ARPU) affordable to the rural population as well as profitable for the operator.

As a summary of the above-stated studies, all the studies quantified that as TEA is an essential tool for operators specially to evaluate a new and evolved emerging technology in a different network environment. Each author follows a different approach in a different perspective to evaluate techno-economic in each of their studies. In addition, most of the studies only considered the geographical scenarios and technology comparison mainly focused on input data assumption.

But this study examined the possible LTE technology deployment alternatives in emerging city by considering the future possible geographical type, technical features and future market conditions. Further, in this thesis work TERA model is modified for investigation of LTE deployment scenarios. The study starts in analyzed the factors affecting LTE deployment in an emerging city to formulate LTE deployment scenarios which later evaluated in techno-economic perspective based on techno-economic analysis modeling approach.

Moreover, the cited studies used different analysis tool such as an excel spreadsheet, funded project tool (only allowed for project members) etc. But in this thesis work technology-oriented (LTE) techno-economic evaluation approach implemented in MATLAB based on modified TERA model. The implemented techno-economic evaluation approach evaluates the formulated LTE deployment scenarios in techno-economic perspective in different future possible network environments.

1.6. Scope and Limitations

1.6.1. Scope

This thesis mainly focuses on techno-economic investigation of LTE technology before deploying in an emerging city under different possible deployment alternatives. The investigation performed for a defined period and it was limited to seven years. The study explicitly carried out for Adama city which was found in Ethiopia. Detail techno-economic evaluation was limited to data service, monopoly telecom operator market and radio access network part of LTE technology.

1.6.2. Limitations

Although we have tried to collect as much as data for the analysis, but there are some limitations of our study. To highlight some of them;

- Earlier in-service ethio telecom pricing policy was considered to project the revenue with in study period. Pricing trends and variable pricing schema were not considered in the study.
- User forecast progress within a year was taken as uniform distribution in the study within an interval of 3 months when forecasting the revenue.
- Data used to model and estimate the business-driven costs of OPEX mainly dependent on the literature reviews and in-service LTE in Addis Ababa.
- User equipment subsidy was not accounted in the study due to the complexity to find the relation between user equipment subsidy and number of users.
- Currently existing LTE device status and its type ratio in Addis Ababa was considered in the study to model the revenue parameter.
- The total cost of LTE deployment scenarios was estimated based on previous experience and vendor-oriented data due to confidentiality reasons.

1.7. Contributions

This thesis work is mainly important for network operators to prepare the strategy towards LTE to optimize their network and improve the resource utilization level. Specifically, the detail techno-economic analysis for all formulated deployment scenarios can be used as an input for network operators of emerging markets to plan evolution of their networks in an emerging city with possible LTE deployment alternatives.

As the demand for service users and usage level of services are the basis for both revenue and cost modelling and calculations. In this thesis, TERA model is modified to improve the quality of inputs to techno-economic analysis modeling for meaningful analysis and reasonable forecasts for future users and services. Likewise, CAPEX and OPEX costs also modeled for each formulated LTE deployment scenarios in this study which are used as input for further researches and investment decision.

Currently, techno-economic evaluation tool was limited to project sponsors and commercially not freely available. But, in this study LTE technology-oriented techno economic evaluation approach is implemented in MATLAB. The implemented tool can help the network operators to evaluate techno-economic aspects of LTE technology deployment under different deployment scenarios and network environments. Further, it can be uses as a starting point to develop the portable and easily accessible analysis tool.

This thesis work entirely uses as input for ethio telecom to choose cost-effective possible LTE deployment alternative to extend coverage of LTE to main emerging regional cities of Ethiopia. Moreover, all marketing analysis, network dimensioning parameters and simulation results are used as input for detail LTE RAN planning and market strategy preparation for the specified city and other cities that have the same environmental characteristics.

1.8. Thesis Layout

This thesis work is organized in to six chapters. The first Chapter deals with an introduction of this thesis. It introduces problem statement, thesis objectives, methodologies used, scope and limitations of study. Following is Chapter two, which discusses the background of country mobile communication and LTE technology. Further, overview of LTE architecture, operating frequency band, technologies and advantages also included in the Chapter 2.

Chapters three explains the background of techno-economic analysis, detail modified techno-economic model considered in the thesis work, methods applied for techno-economic evaluation and implemented techno-economic approach flow chart. The Chapter also explains scenario planning method, growth method, network dimensioning approach, mathematical modeling for cost and revenue and discount cash flow analysis.

Chapter four illustrates the case study analysis mainly focuses on LTE deployment scenario analysis and techno-economic parameters modeling. It consists localized LTE deployment scenario formulation, marketing forecast, LTE RAN dimensioning and, cost and revenue modeling. Chapter five presents detail results obtained from techno-economic analysis modelling approach in to five categories. And the last one is Chapter six, which summarize this thesis work with future research area direction.

Chapter 2 : Background on LTE Networks

2.1. History of Mobile Communication in Ethiopia

The development of telecommunication industry is one of the important indicators of social and economic development of a given country [18]. From the early analog mobile generation (1G) to the last implemented fourth generation (4G) the paradigm has changed. The aim is to reach communication ubiquity (every time, everywhere) and to provide users with a new set of services [19] [18].

In Ethiopia, ethio telecom is a monopoly operator on all telecom services including fixed, mobile, internet and data communications [20] [21]. As shown Figure 2.1, the status of mobile subscription in Ethiopia growing from year to year rapidly. The first digital mobile network Global mobile system (GSM) deployed in Ethiopia as late of released time.

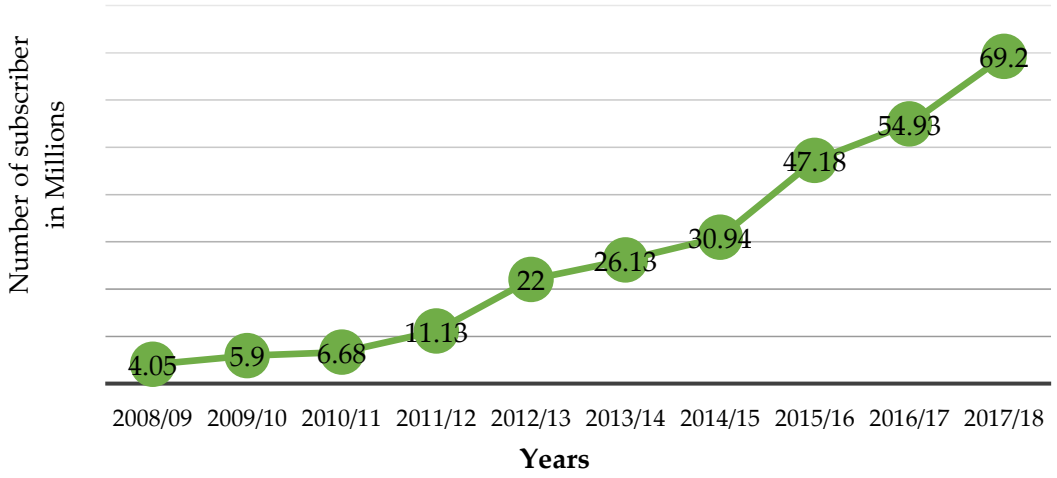


Figure 2.1. Mobile Subscribers in Ethiopia (ethio telecom) [5].

The GSM network was the first to offer voice service followed by short message service (SMS) text messaging and evolved to handle internet service to 2.5G and 2.75G such as General Packet Radio Service (GPRS) and Enhanced Data rates for GSM Evolution (EDGE) for improved data transfer rates.

3G networks deployed and succeed 2G after several years of release time to improve data rate and multiservice requests of the nations, offering faster data transfer rates and are the first to enable video calls and known as Multimedia mobile. 4G is a successor of 3G technology and provides ultra-broadband internet access. The high data transfer rates make 4G networks suitable for use anywhere and anytime [19].

Currently, most of the area in Ethiopia was covered by GSM network that means mobile network everywhere. 3G network takes high share of GSM network in Addis Ababa and main regional city where as GSM network is dominant across region cities and rural areas. The mobile subscriptions status in Ethiopia (ethio telecom) with respect to mobile generation are illustrated in Figure 2.2.

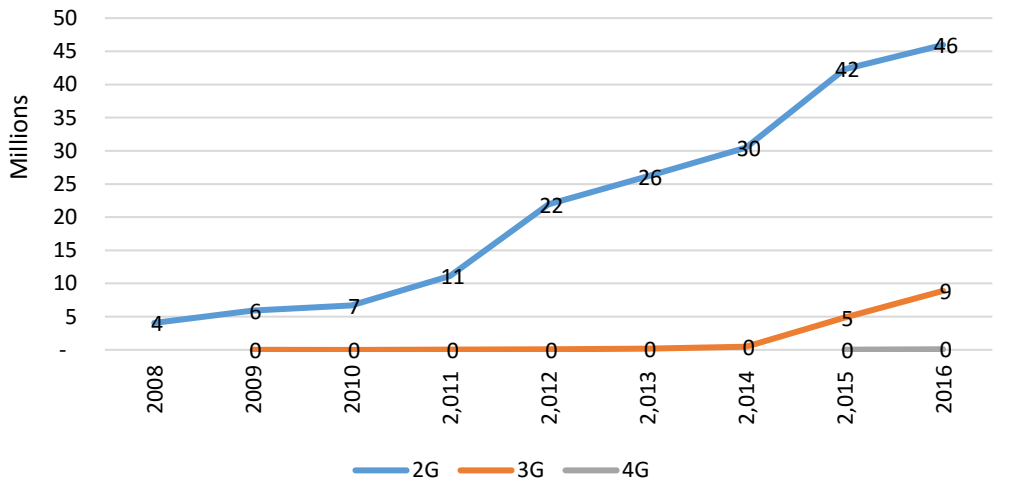


Figure 2.2.Mobile subscribers in mobile generation [5] [6].

Mostly in Addis Ababa city, to address the business activities enormously expanding throughout the city, ethio telecom launched LTE technology in 2015 [6]. Yet, limited number of users actively participated in LTE network as contrast to planned target.

To improve network coverage and capacity and service quality ethio telecom has made significant investments in various technologies during the past decade. Table 2.1 shows some of the recent projects deployed in ethio telecom. In each projects the cost and type of technologies deployed described with relation to initial year of deployment.

Table 2.1. History of recent ethio telecom projects [6].

Year	Project Name	Investment	Technologies
2007	Next Generation Network (NGN)	1.5B $	Mobile technology: 2G, 3G, CDMA
			Optical fiber, Fixed line Voice and BB
			CC&B, NGN Call Center and NNOC
2012	Telecom Expansion Program (TEP)	1.6B $	4G,3G and 2G
			BSS/OSS

To get the best out of the costly investments in telecom sector, its necessary to assess and evaluate all new and evolved technology in technical and economic aspects. The assessment and evaluation of new and evolved technology helps to avoid unnecessary investments, wastage and underutilization of resources and customer dissatisfaction happens after the projects enters the service.

2.2. Long Term Evolution (LTE)

LTE, commonly known as 4G LTE, is a standard given for wireless communication of high-speed data for mobile phones and data terminals. LTE mobile broadband technologies will allow wireless carriers to take advantage of greater download and upload speeds to increase the amount and types of content made available through mobile devices [2].

4G technology offer greatly improved data rates over previous generations of wireless technologies. Faster wireless broadband connections enable wireless carriers to support higher-level data services, including business applications, streamed audio and video, video messaging, video telephony, mobile TV, and gaming [22].

To insure high speed demand, 3GPP introduces its new radio access technology (LTE) to support extensively high throughput and low latency system with improved coverage and capacity performance [23].

The 3GPP body began its initial investigation of the LTE standard as a viable technology in 2004. In March 2005, 3GPP began a feasibility study whose key goals of developing a framework for the evolution of the 3GPP Radio Access Network (RAN) with the intention of reducing cost per bit, increased service provisioning, flexible use of new and existing frequency bands, reasonable terminal power consumption, and simplified architecture with open interfaces.

The 3GPP has been progressing to setup the standardization and evolution of the LTE after the first standard frozen in 2008 for the Release 8. Even though this study focuses on Release 8 the standardization and evolution has continued with the releases of LTE-Advanced and beyond.

2.3. LTE Architecture, Frequency Band, Technologies and Advantages

2.3.1. LTE Architecture

One of the main driving forces for a 4G system is the evolution of the network architecture. As being part of the 4G system, LTE's network architecture is introduced to be all - internet Protocol based simplified network architecture with open interfaces. The architecture is designed to be more simplified and compact when it is compared to the previous 3GPP releases [24].

As shown in Figure 2.3, the LTE architecture consists of the evolved NodeB (eNodeB), evolved packet core (EPC) and user equipment (UE). The eNodeB provides the E-UTRA user plane (UP) and control plane (CP) protocol terminations towards the UE. The eNodeB's are interconnected with each other by means of the X2- interface [25].

The eNodeB's are connected by means of the S1-interface to the EPC. The S1- interface supports a many-to-many relation between eNodeB's and mobility management entity/serving-gateway (MME/SGWs).

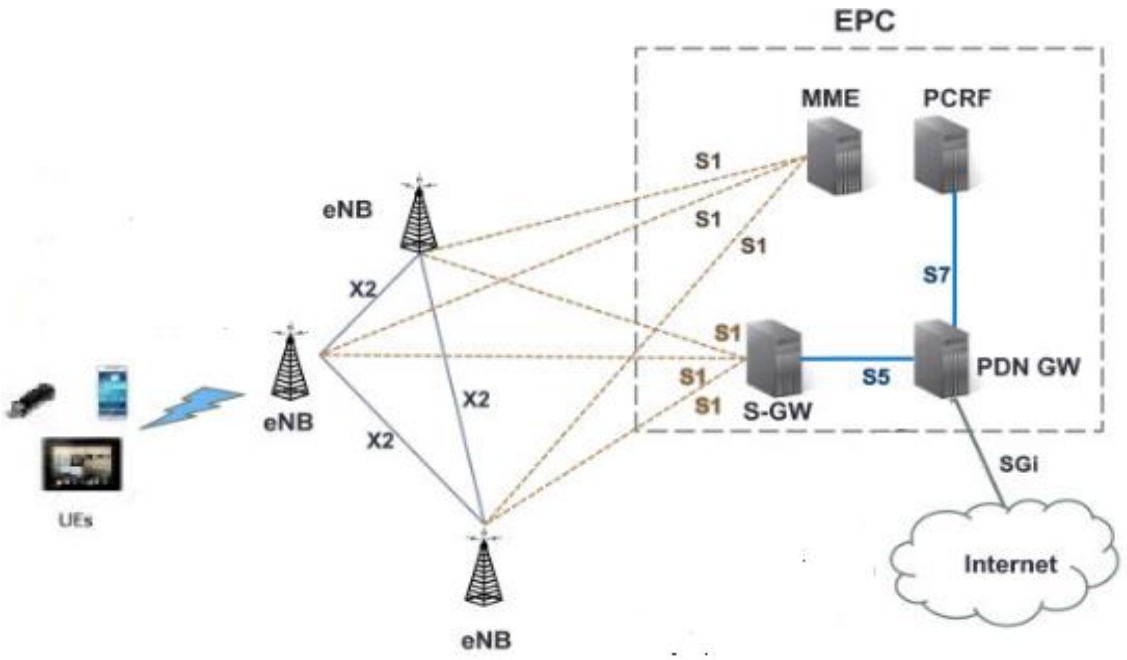


Figure 2.3.LTE network architecture [24].

***i) User equipment*: -** In 3GPP, user equipment's are defined as any devices which are used directly by the end users for communications. They can be hand held device like smart phones or a data cards or they could be embedded into a laptop or tablets.

A UE contains the Universal Subscriber Identity Module (USIM), which is an application placed into a removable smart card called the Universal Integrated Circuit Card (UICC). The USIM derive a security keys for protecting, identifying, and authenticating the users in the radio interface transmission.

3GPP has defined about five UE categories for LTE user equipment's in Release 8. the specification considers features such as downlink (DL) and uplink (UL) physical layer parameters, supported modulation types, type of MIMO used, and so on.

ii) The Evolved UMTS Terrestrial Radio Access Network (E-UTRAN): - **E**-UTRAN is the network architecture defined for the E-UTRA radio interface as a part of 3GPP LTE physical layer specification [23]. The E-UTRAN consists of BTS (node-B's), providing the E-UTRA user plane and control plane protocol terminations towards the UE.

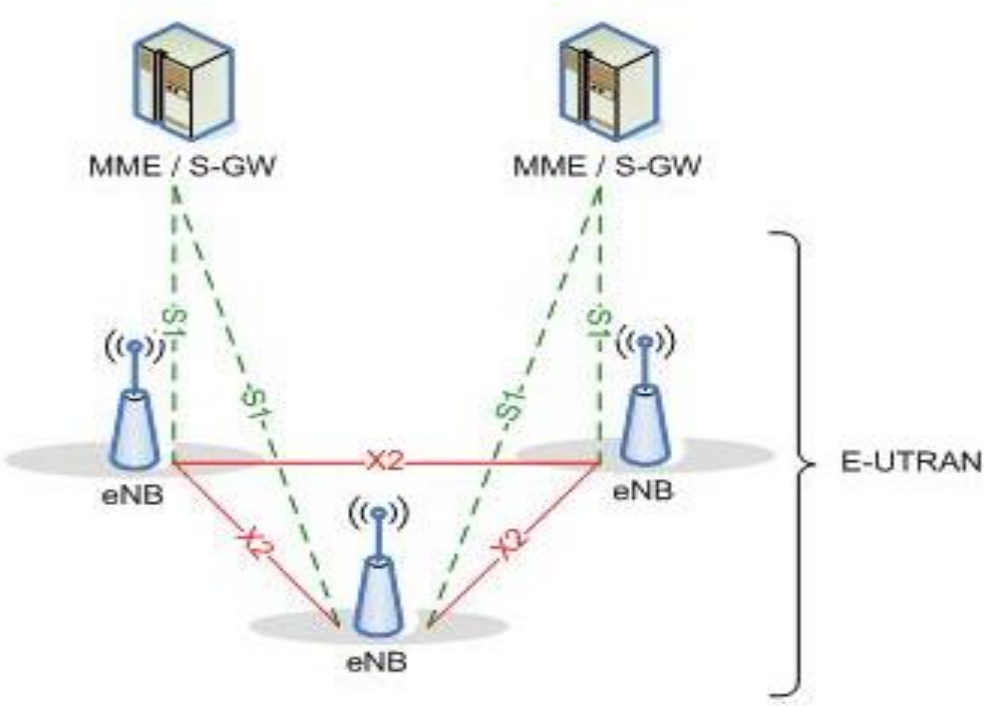


Figure 2.4. E-UTRAN architecture [23].

The BTS are interconnected with each other by means of the X2 interface as shown in Figure 2.4. They are also connected by means of the S1 interface to the EPC (Evolved Packet Core), more specifically to the MME (Mobility Management Entity) by means of the S1-MME and to the Serving Gateway (S-GW) by means of the S1-U.

iii) The Evolved packet core (EPC): - The network architecture of the EPC consists of three main nodes. MME, S-GW, and packet data network-gate way (PGW). The MME connects to the E-UTRAN via the S1-MME interface. It is responsible for handling mobility and security procedures, such as network attach, tracking area updates (like location/routing area updates) and authentication.

The MME also connects to the serving general packet radio service support node (SGSN) via the S3-interface. The SGW connects to the E-UTRAN via the S1-U interface. Its prime responsibility is routing and forwarding of user IP-packets. P–GW communicates with the outside world i.e. PDN, using S-Gi interface. Each packet data network is identified by an access point name (APN).

2.3.2. LTE Frequency Band

There are many frequency bands potentially available for the deployment of LTE; the bands listed in Table 2.2 have been identified through work done by the ITU and the 3GPP [26]. The bands are part of the IMT spectrum and many are in use already with cellular technologies like GSM, UMTS, LTE and WiMAX.

The chosen spectrum will have a very large impact on dimensioning process since the nominal radius of the LTE radio cell is dependent on the frequency of operation. That is why operating frequency taken in the scenario formation as key factor.

Table 2.2. LTE frequency band and band width [24].

LTE Band Number	Uplink (MHz)	Downlink (MHz)	Width of Band (MHz)	Duplex Spacing (MHz)	Band Gap (MHz)
1	1920 - 1980	2110 - 2170	60	190	130
2	1850 - 1910	1930 - 1990	60	80	20
3	1710 - 1785	1805 -1880	75	95	20
4	1710 - 1755	2110 - 2155	45	400	355
5	824 - 849	869 - 894	25	45	20
6	830 - 840	875 - 885	10	35	25
7	2500 - 2570	2620 - 2690	70	120	50
8	880 - 915	925 - 960	35	45	10
9	1749.9 - 1784.9	1844.9 - 1879.9	35	95	60
10	1710 - 1770	2110 - 2170	60	400	340
11	1427.9 - 1452.9	1475.9 - 1500.9	20	48	28
12	698 - 716	728 - 746	18	30	12
13	777 - 787	746 - 756	10	-31	41
14	788 - 798	758 - 768	10	-30	40
15	1900 - 1920	2600 - 2620	20	700	680
16	2010 - 2025	2585 - 2600	15	575	560
17	704 - 716	734 - 746	12	30	18
18	815 - 830	860 - 875	15	45	30
19	830 - 845	875 - 890	15	45	30
20	832 - 862	791 - 821	30	-41	71
21	1447.9 - 1462.9	1495.5 - 1510.9	15	48	33
22	3410 - 3500	3510 - 3600	90	100	10
23	2000 - 2020	2180 - 2200	20	180	160
24	1625.5 - 1660.5	1525 - 1559	34	-101.5	135.5
25	1850 - 1915	1930 - 1995	65	80	15

Lower the frequency the larger the radio cell, the better building penetration. This is of great interest to operators since the cost of deploying LTE networks is likely to be very high, lower frequency allocations can save many millions of dollars in CAPEX, i.e. there will be less eNodeB's to buy.

The band was regulated in terms of the allowed operating bandwidth. This is driven largely by the amount of available spectrum in each of the bands. The amount of allocated spectrum will impact the overall network capacity and the individual sector capacity [27]. As with many aspects of system planning more is better.

In some cases, the operator may have the flexibility to choose the channel bandwidth depending on the total amount of spectrum they have. Common bandwidth available in most of the defined spectrum were in 3,5,10 and 20 Mhz.

2.3.3. LTE Technologies

LTE introduced with several new technologies when compared to the previous cellular systems. They enable LTE to be able to operate more efficiently with respect to the use of spectrum, and to provide the much higher data rates.

i) Multiple-input and multiple-output (MIMO): - MIMO is one of the LTE major technology innovations used to improve the performance of the system. It employs multiple transmit and receive antennas to substantially enhance the air interface.

One of the main problems that previous telecommunications systems had encountered is that of multiple signals arising from the many reflections that are encountered [28]. By using MIMO, multipath signals paths can be used to increase the throughput. Multiple antennas are also used to transmit the same data stream, thus providing redundancy and improved coverage, especially close to cell edge.

ii) Orthogonal frequency-division multiplexing (OFDM): - One of the key elements of LTE is the use of OFDM, as the signal bearer and the associated access schemes. OFDM selected in downlink as the air interface for LTE.

OFDM is well suited for high data rate systems that operate in multipath environments because of its robustness to delay spread [2]. Due to its frequency domain nature, OFDM enables flexible bandwidth operation with low complexity [25]. Smart antenna technologies are also easier to support with OFDM, because each subcarrier becomes flat faded and the antenna weights can be optimized on a per-subcarrier or block of subcarriers basis.

iii) Single Carrier - Frequency Division Multiple Access (SC-FDMA): - For the LTE uplink, a different concept is used for the access technique. Although still using a form of OFDMA technology, the implementation is called SC-FDMA [26]. It was chosen to reduce Peak to Average Ratio (PAR), which has been identified as a critical issue for use of OFDMA in the uplink- where power-efficient amplifiers are required in mobile devices beside to maximize the coverage [2].

2.3.4. Advantages of LTE

LTE technology offers several distinct advantages over other wireless technologies. These advantages include increased performance attributes, such as high peak data rates and low latency, and greater efficiencies in using the wireless spectrum [2]. Improved performance and increased spectral efficiency will allow wireless carriers using LTE as their 4G technology to offer higher quality services and products for their customers.

LTE technology can offer the following benefits,

- ✓ High peak speeds
- ✓ Low latency: less than 5 milliseconds user plane latency for small IP packets
- ✓ Scalable bandwidth
- ✓ Improved spectrum efficiency
- ✓ Improved cell edge data rates
- ✓ Enhanced support for end-to-end quality of service

Chapter 3 : Methods for Techno-economic Evaluation

3.1. Introduction to Techno-economic Analysis (TEA)

When various competing wireless technologies are made available for customers, a new technology that is about to be introduced to a market needs to have a significant advantage both in technological and economic terms [14]. To justify the investment feasibility, technical and economic assessment is an essential step.

TEA is one of the major stages that gives direction in the investment and optimal service or technology selection. It is a decision-making tool used to evaluate available technology options based on technical, economic, environmental, social and regulatory criteria [11].

To provide results that are meaningful and actionable, a TEA needs to utilize high-quality datasets that are comprehensive and up-to-date. Accordingly, meaningful, acceptable and actionable TEA results obtained in considering the technical, economic, environmental, regulation and market criteria or factors for defined technology as shown in Figure 3.1. Once the criteria identified, then the technology analyzed based on the selected TEA model which is suitable for the technology.

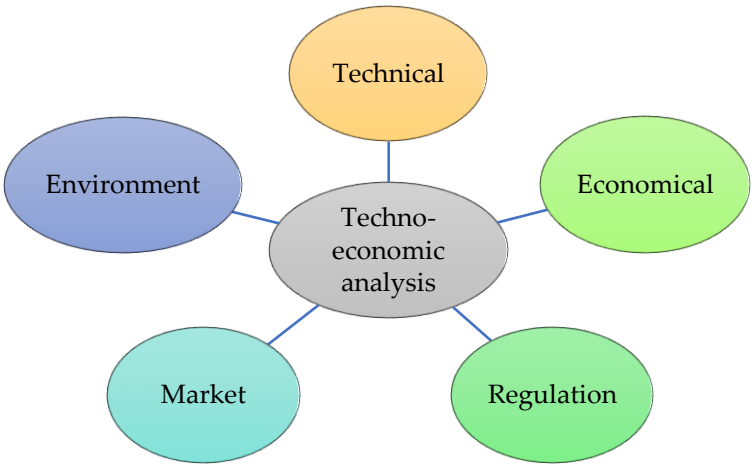


Figure 3.1. Techno-economic analysis.

Specifically, TEA is used to [10]: -

- Compare different technical options to find the optimum.
- Look at the feasibility of different evolution scenarios.
- Identify parts of the network that contribute major investment cost.
- Find efficient technology, service in terms of social, environmental, regular.
- Identify strategies which are robust to different patterns of demand.
- Check cost effectiveness of investments before entering new/ existing market.
- Check scenarios in deploying new technology or utilizing available resources
- Study feasibility of emerging mobile technologies in access and core networks.

3.2. Modified TERA Model

Many researches were done to develop techno-economic analysis models since 1980s'. In the context of telecommunications, the term techno-economics was introduced during the European research program called RACE in 1985-1995 [10]. These research project resulted in providing framework, model, methods and tools used for evaluating the techno-economics. The development process is still not matured, and extension and improvement of earlier model is continuous.

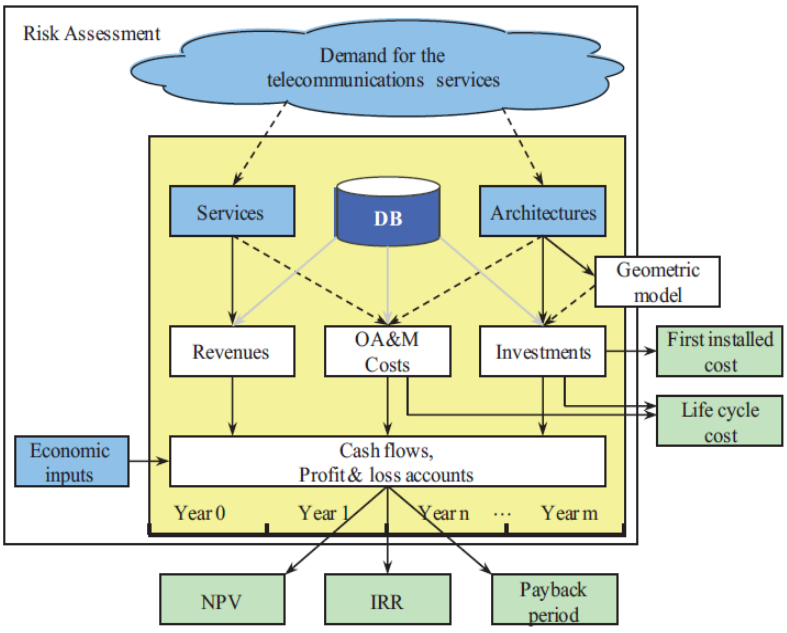


Figure 3.2.TERA Framework ([29]).

The popular techno economic analysis framework in telecom industry is Techno-Economic Results from ACTS (TERA) framework. As shown in Figure 3.2 , the TERA framework shows clearly the two main starting points of techno-economic modelling: services and (technical) architectures.

Based on demand forecasts and inputs assumptions as well as few generic economic inputs such as the discount factor and study period, the value of investments at the end of the period calculated. The internal models calculate revenues, operational costs, and investments. As well cumulative cash flows and decision-making indicators such as net present value (NPV), internal rate of return (IRR), and payback period included.

A techno-economic model is used to determine the feasibility of the system considering all the system parameters based on the framework the model derived. Sample of widely used TEA models drawn from TERA framework are ECOSYS, TERA, TITAN and TONIC models [30]. Table 3.1 shows TEA models drawn from the TERA framework and the project year.

Table 3.1. TEA models drawn from TERA framework[10] [30].

Model		Project year
TITAN	Tool for Introduction Scenario and Techno-economic Evaluation of Access Network	1990 – 1994
OPTIMUM	Optimized Architectures for Multimedia Networks and Services	1994 – 1998
TERA	Techno-Economic Results from ACTS	1994 – 1998
TONIC	Techno-economics of IP optimized networks and services	1998 – 2002
ECOSYS	Techno-economics of integrated communication systems and services	2004 – 2007

Compared to TEA framework, the difference of each TEA model basically lays in input scenario the models considered and area of the models applied. Application areas of widely used TEA models are summarized in Table 3.2.

Table 3.2. Application areas of selected TEA models [30] [31] [12].

Model	Area	Example
TERA	Fixed and wireless technology (2G, 3G, LTE), Multimedia BB services on the system	Fixed WiMAX vs. ADSL, LTE
TONIC	Mobile IP service provisioning, 3G mobile in MVNO's, IP service over fixed networks	Feasibility study of MVNO, BB over cable TV network
ECOSYS	General telecommunication projects Emerging mobile	Virtual service operator, TV on mobile, BB service on fixed WiMAX

Techno-economic Results from ACTS (TERA) model was selected as base for this study. It was widely used techno-economic model in wireless technology and industry. TERA model enables techno-economic evaluations and strategic analyses that combine high level parameters, such as density of subscribers and service penetration, with relevant low-level parameters, such as costs of key network components [14].

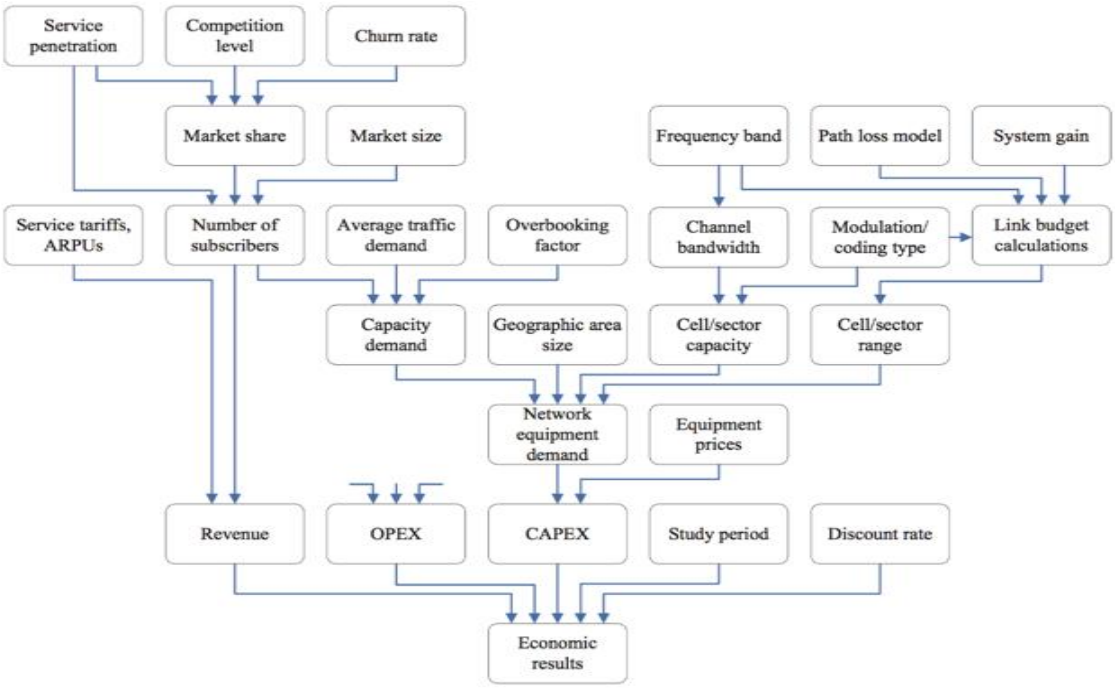


Figure 3.3. TERA Model [11].

As shown in Figure 3.3, the inputs of this model designed to take the network dimensioning of the technology. TERA model requires certain market and technology related inputs, as well as general economic inputs to carry out the techno-economic analysis. Outputs from the analysis include revenues, costs, and investments, as well as profits and cash flows.

Techno-economic analysis modeling methods are suitable for analyzing alternative technology architectures [10]. However, if the objects of analysis are further in the future and uncertainty regarding technologies conditions increases the modelling task becomes more challenging. To handle these conditions, scenario planning method provide a way to bound this uncertainty and thereby create detailed descriptions of alternative futures that form a basis also for quantitative techno-economic modelling [11]. For this reason, the TERA model is modified in this study to handle the LTE deployment scenarios formulation as input.

The demand for and usage of services are the basis for both revenue and cost modelling and calculations. For meaningful analysis, reasonable forecasts for future service users and usage are essential. To make good forecasts for the future, the present situation must first be understood as reliably and in as much detail as possible. Hence, to improve the quality of inputs to techno-economic analysis modeling, TERA model is further modified in the marketing part to account market forecast.

Similarly, the technology dimensioning approach is different in different service requirements and technologies. Hence, it is essential to customize techno-economic analysis model mainly TERA model for all formulated LTE deployment scenarios. In addition, there are also some common parameters like economics aspects adapted from TERA model. These parameters are mostly common standard for all technology and modified for this specific case study also (i.e. consideration of rollout plan and energy consumption in OPEX model).

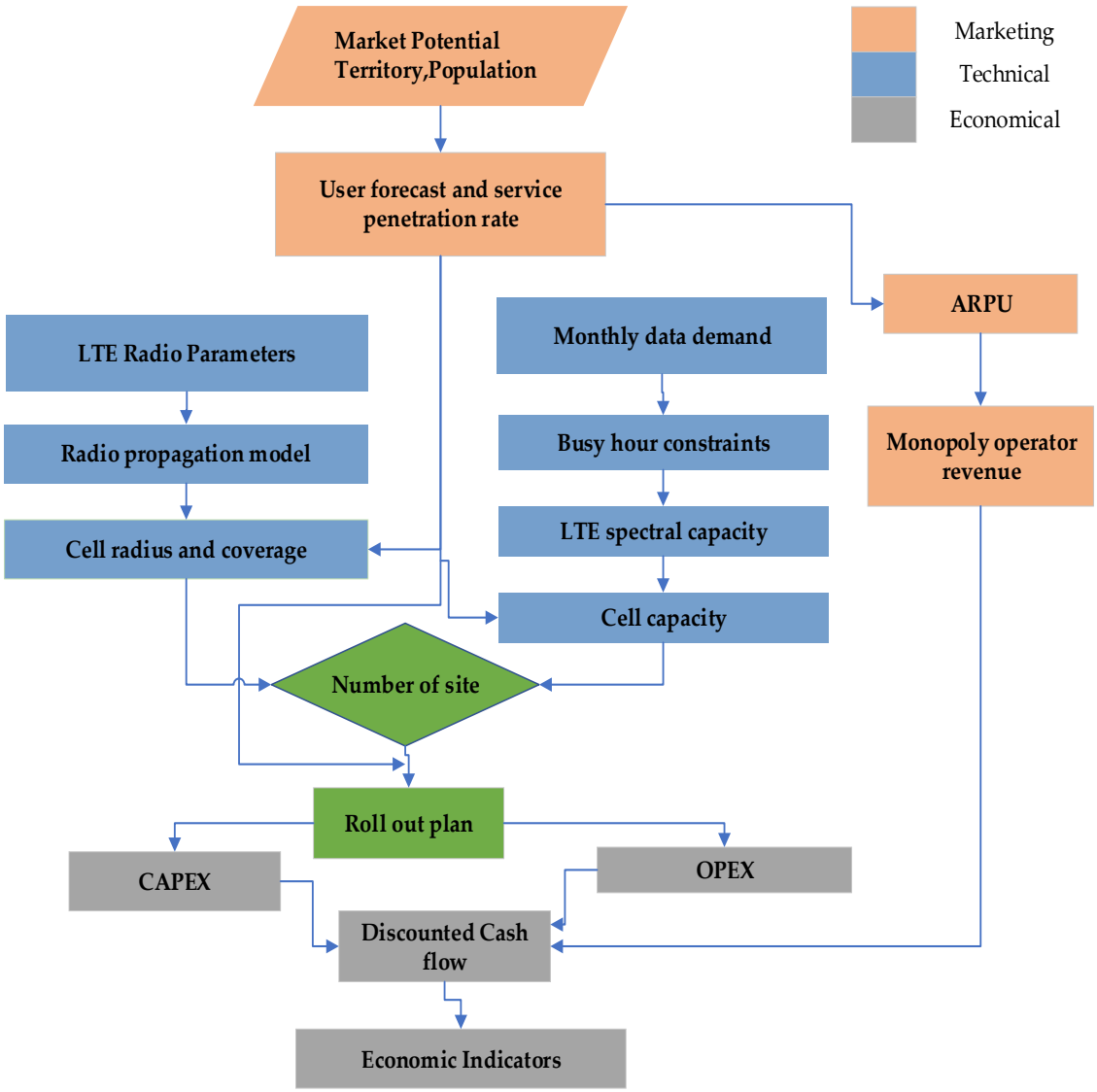


Figure 3.4. Modified techno-economic analysis model.

Figure 3.4 shows various components of the modified techno-economic model for this study. The modified techno-economic model is composed of marketing, technical and economic components. In general, each of formulated LTE deployment scenarios were operated on modified model.

Once, the formulation of LTE deployment scenario formed via scenario planning method, the first part of the model is the marketing data where the output of this components is provided directly to technical and economical blocks. The essential parameters of marketing components are the number of users; the service user's penetration rate and the revenue estimated based on the populations and service

pricing policy. The number of service users is determined from the existing market conditions via a growth method

The second component is the technology dimensioning part. In this part, there are two parameters to be considered in this part. There are capacity and coverage estimation. Capacity requires input from two sides; from the estimated users in the marketing section and the technology characteristics as per formulated deployment scenarios.

Coverage analysis, on the other side, takes inputs of the environmental condition to determine the path loss model and technology parameters, which in turn measures the system gain and loss. With system gain and loss, radio link budget estimated, which has a direct contribution in determining the coverage area of the cell.

In modified techno-economic model, a comparison of both site number results compared from both approaches. Roll out plan prepared to compare the number of network elements with forecasted service users to determine the optimum number of network elements deployed per each year in the study period.

The third component is the economic part, this block modeled into two CAPEX and OPEX cost structures. The network dimensioning output, rollout plan results and the associated price of the network elements is determined and defined, which directly fed to the CAPEX cost. In the same way, OPEX cost also determined and defined.

The discounted cash flow analysis was performed in considering the CAPEX and OPEX cost with estimated revenue. Lastly, economic indicators like NPV, payback period and internal rate of return are measured for each formulated deployment scenarios.

3.3. Scenario Planning Method

Scenario is defined as a description of possible actions or events in the future [10]. The scenario planning method is a strategic planning method to devise flexible long-term plans such as to explore possible future. And, it sees the future broadly in terms trends and uncertainties.

Scenario planning also used to build shared framework for strategic thinking [32, 33]. It works effectively in the telecommunication industry. For instance, the scenarios were utilized in the wireless industry evolution, fixed line and wireless local area access market.

Scenario planning method was well defined by author cited in [34] who divides the method process into 10 steps. A rough picture for analysis is defined and identified by the first five steps as shown in Figure 3.5. As described in the Figure, the key uncertainties and trends are the main input for further analysis such as thesis.

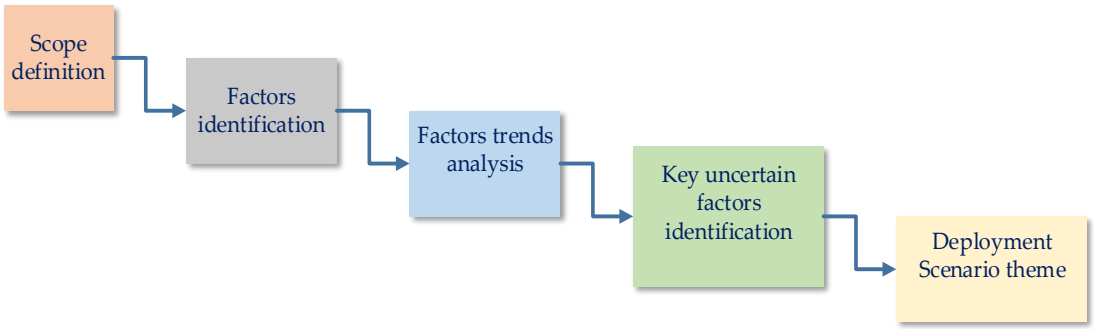


Figure 3.5.General scenario planning in five phases [35].

The scenarios are further developed and analyzed by rest of the steps: such as 6) consistency and plausibility check 7) development of learning scenarios 8) identification of research needs 9) development of quantitative models and 10) evolve towards decision scenarios.

As summarized by author cited [36, 37] the scope of the scenario planning should be set in the very beginning. Description of each steps in the scenario planning was summarized in Figure 3.6.

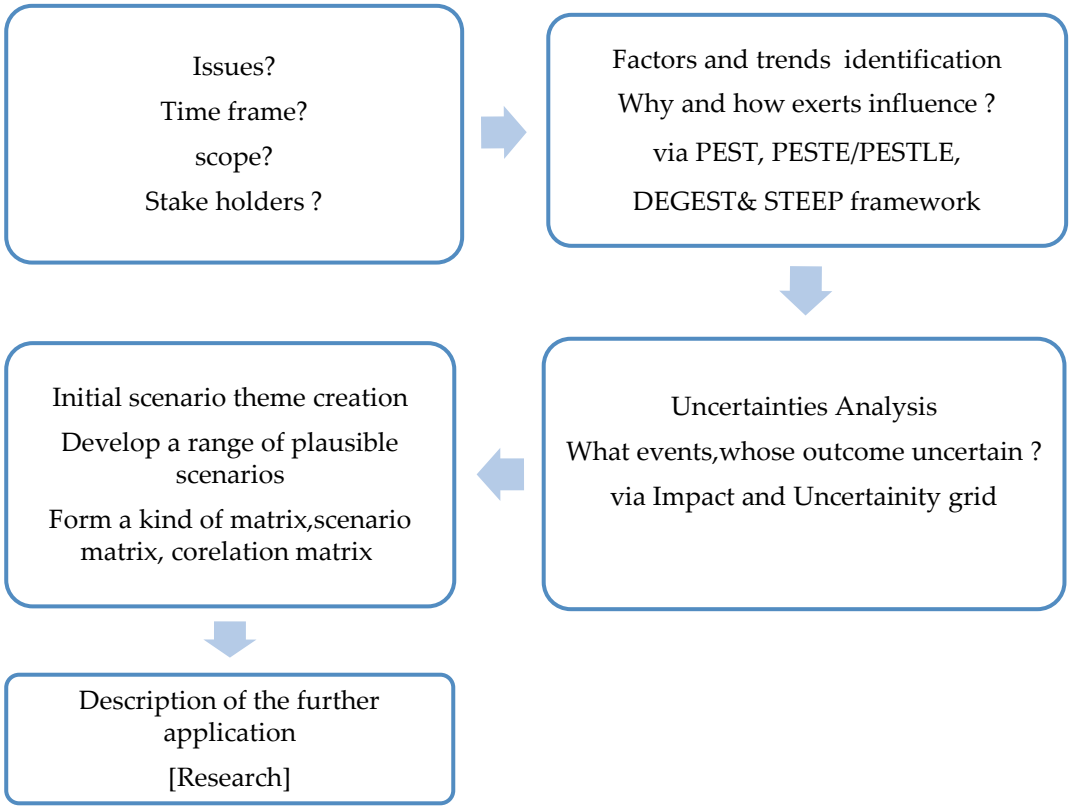


Figure 3.6.Description of each stage of scenario planning method [36, 37].

3.4. Growth Method for Market Forecast

Before deploying a new technology in telecom industry, market evaluation is the crucial element to minimize the uncertainty of return on investment (ROI) [36]. As studied by different operators, the future market condition is usually determined by the existing market situation.

Understanding market segmentation, service profile and existing revenue collection is always the starting point for forecasting as noted from different operators experience and literatures [8]. Market segmentation, geographic and demographic size, service profiles, market share of operators, penetration rate of the service and existing total population are the key marketing parameters considered in most of studies [17, 8, 11].

In this thesis, first an emerging city geographical area considered to analyze the required marketing parameters in a way to see their effect on techno economic modelling system of the LTE deployment within a specified period of the time.

As shown in Figure 3.7 , TEA process starts by analyzing the territory size and target coverage. In territory analysis, several geographical areas can be analyzed at the same time or independently. Each geographic area is characterized by considering key territorial and social-demographic parameters such as area in square kilometers and distribution of demographic type such as urban and suburban scenarios [10].

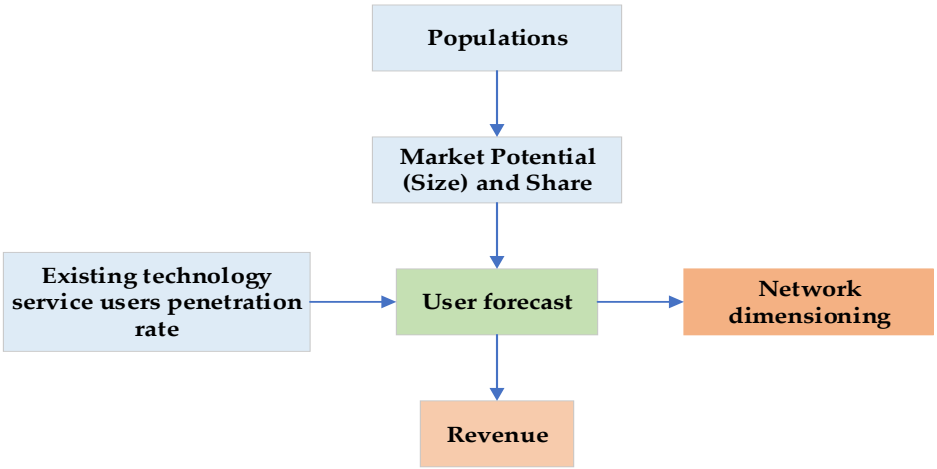


Figure 3.7.Market forecast model [10].

Main data in territory analysis are total area, distribution percentage of area within defined geographical scenarios. Main demographic data that are considered are the number of inhabitants, households, customers segmentation. All this data obtained from primary source data such as operator, municipality, central statistics agency.

Once a population number of the city obtained from the census, number of populations with study period is forecasting using different population forecasting methods. From different population forecasting methods geometric progression method is selected for this study. This type of forecasting method is applicable for short term (i.e. 1-10 years) period and best for an emerging city with rapid growth status [38].

Geometric progression method basically depends on mean growth rate which was obtained by considering previous year census data of the city. Geometric mean is used to find out the future increment in the population. And defined as follows [38].

$$P(t) = Pr(1 + Gm/100)^t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, Pr is current population, Gm is a geometric mean which is obtained from earlier years growth rate, t is time in year and P(t) is population forecast at time t.

In the service profile analysis, the type of services required in the defined areas need to be identified. The capacity/traffic intensity in the service type are essential factors to be considered in offering the services. The portfolio of service profiles to be offered is defined considering both technical features and pricing policies [8].

It also important to define the user's equipment where the identified services are to be accessed. User equipment considerations is the basic part in service characterization to define the service and connection fee as factors. In addition to user equipment definition, it is also important to define the user equipment distribution according to market/customers segmentation.

The next most important for analyzing the market situation is service users forecast within the study period and defined market potential [39]. Proper forecast of service market diffusion enables optimal planning of resources, investments, revenue, marketing and sales. Based on literatures, software tools and the general experience in telecommunications, forecasting a new telecom service penetration done via growth models mostly, the logistic and the Bass growth model. Growth models represent similarities between growth in nature and growth in economy.

To forecast the service users for a new technology, researchers frequently use the Bass-model. Particularly, in diffusion of innovation and new technology and subscription services [39, 40]. The model predicts the first time use of a product or an innovation in a given potential market.

The Bass model equation used in this study is stated below [39, 40].

$$Y(t) = M\left[1 - e^{-t(P+Q)}\right] / \left[1 + \frac{Q}{P}\right] e^{-t(P+Q)}] \text{ .... } (2)$$

Where, M is the market potential, P is innovation coefficient, Q is the imitation coefficient and Y(t) is the number of subscribers at a time t.

The market potential is the population, which is yet to adopt the product, and the past adopters drive the members of this population towards adoption. It is the entire size of the market for a service at a specific time. The model assumes this population as a constant value.

The coefficient of innovation's contribution to the new adoptions does not depend on prior adoptions, while the coefficient of imitation's effect is proportional to the cumulative adoptions. The two parameters account for the external and internal influences on the new adoption, respectively [17]. Both innovations and imitation coefficients obtained in considering in-service technology service users' trends.

Service penetration rate and revenues are forecasted considering the users forecasted based on available market potential. Penetration rate is the percentage of the relevant population that has purchased a given service at least once in the study period. The penetration of the service users in this study considered in two ways. The first one is the service penetration rate with respect to each year population city [39].

$$SPc(t) = {}^{y(t)}\!/_{P(t)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . (3)$$

Where SPc(t) is service penetration with respect population of the city at time t, y(t) is forecasted users at year t and P(t) forecasted population in the city

Whereas the second one was the service user's penetration rate with respect to defined market potential. And its defined as follows [17].

$$SPm(t) = {}^{y(t)}/_{M} = [1 - e^{-t(P+Q)}]/[1 + \frac{Q}{P}] e^{-t(P+Q)}] \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where, SPm(t) is the service penetration with respect to assumed market potential at time t, y(t) is users forecast at year t, M is market potential of each LTE deployment scenarios, P is innovation coefficient and Q is the imitation coefficient.

Acquired users obtained by multiply forecasting users per year with churn rate. Churn rate is the percentage of subscribers to a service who discontinue their subscriptions to the service within a given period. Since, this study limited to a monopoly telecom operator simply zero percent churn rate (0%) is considered [17].

$$\text{Acquired Users} = \text{forecasted service users} * (1 - \text{churn rate}) \quad \ldots\ldots\ldots (5)$$

3.5. Network Dimensioning

Network planning is a significant step in establishment of wireless communication system. The main aim of radio network planning is to provide a cost-effective solution for the radio network deployment in terms of coverage, capacity and quality of service by estimating the optimum number of base stations and its locations, determining the type of the antenna, receiver /transmitter power and environment characteristics [28].

Network dimensioning is the initial phase of network planning. The target of the radio access network dimensioning (RAN) is to estimate the required site density and site configurations information. RAN dimensioning activities include radio link budget and coverage analysis, cell capacity estimation, estimation of the amount of eNodeB. Figure 3.8 shows RAN dimensioning approach applied for LTE.

Dimension inputs can be broadly divided into three categories; quality, coverage and capacity-related inputs. Quality-related inputs include average cell throughput and blocking probability. RLB is central importance to coverage planning in LTE [28, 26]. Coverage related inputs are RLB inputs, propagation model, geographical information and required coverage probability.

Whereas, capacity decisioning inputs gives the number of subscribers in the system, their demanded services and subscriber usage level. Available spectrum and channel bandwidth used by the LTE system are also very important parameters in capacity dimensioning [13].

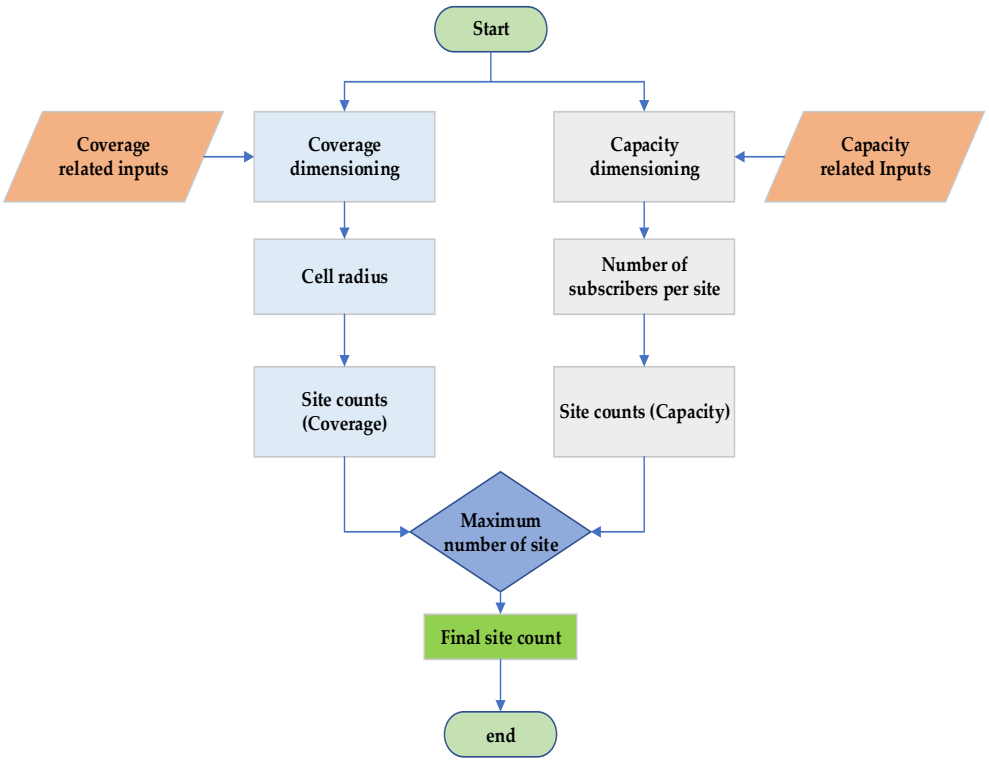


Figure 3.8. RAN dimensioning approach [13].

Outputs of the dimensioning phase are used to estimate the feasibility and cost of the network. Cell size is the main output of LTE dimensioning exercise. Two values of site numbers are obtained, one from coverage evaluation and second from capacity evaluation. The larger of the two numbers is taken as the final output.

3.5.1. Coverage Dimensioning Approach

Coverage analysis gives an estimation of the resources needed to provide service in the deployment area with the given system parameters [14]. That means it estimates the number of eNodeB required to cover the specified area with good signal strength.

Coverage dimensioning process starts with RLB calculations, used to determine the maximum path loss. The link budget calculations estimate the maximum allowed

signal attenuation, called path loss, between the mobile and the base station antenna based on the required Signal-to-Interference-Noise Ratio (SINR) level at the receiver and by putting interference ad shadow into consideration [25].

The maximum path loss allows the maximum cell range to be estimated with a suitable propagation model. The cell range gives the number of base station sites required to cover the target geographical area. The link budget calculation can also be used to compare the relative coverage of the different scenarios or systems.

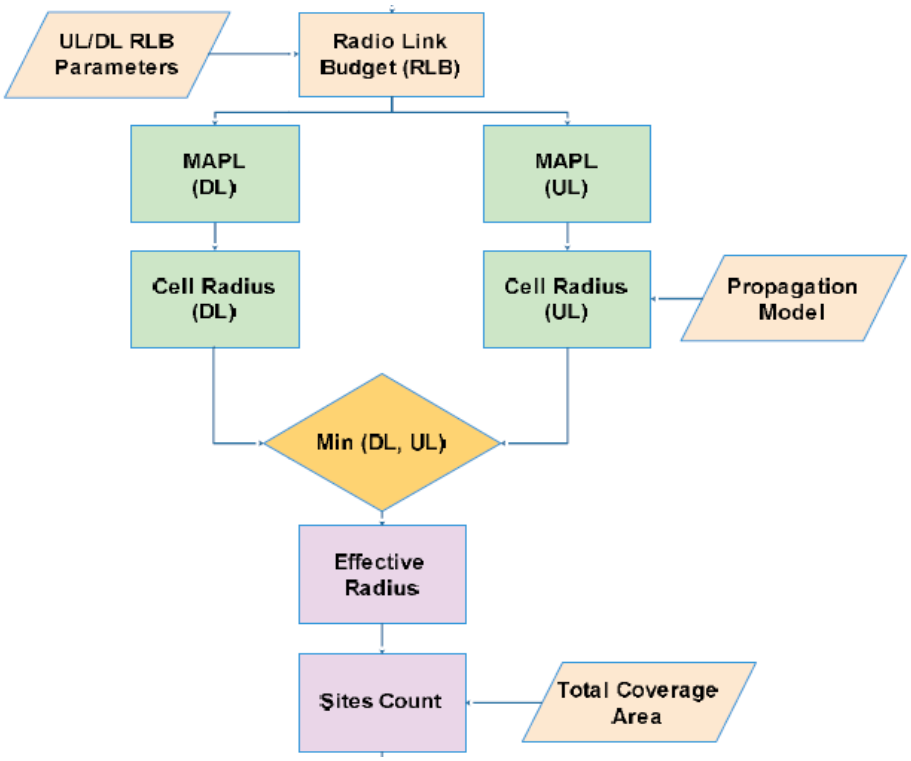


Figure 3.9.Coverage dimensioning flow chart [25].

Network coverage depends mainly on natural factors such as geographical aspect, propagation conditions, and on human factors such as the landscape (urban, suburban, rural), subscriber behavior etc. Both downlink and uplink maximum allowed propagation loss (MAPL) used to calculate the cell radius for different terrain morphologies based on the appropriate propagation model for the deployment area.

Cell radius depends upon the propagation models used. The estimated cell size, obtained in this step, leads to the maximum allowed size of the cells. This parameter

is used to calculate the number of cells required in the area. Thus, a rough estimate of the required number of eNodeB is obtained.

i) Radio link budget parameters modelling

Radio Link Budget (RLB) is used to determine the maximum path loss based on the required Signal-to-Interference-Noise Ratio (SINR) level at the receiver by putting interference ad shadow into consideration. Several parameters considered to estimate the radio link budget.

Transmitter Power: Is base station (eNodeB) maximum transmission power having a typical value for macro cell from 43-46 dBm at the antenna connector and UE maximum transmission power of 23 dBm.

Antenna Gain: Is mainly dependent on the carrier frequency, on the size of the antenna and device type. Diversity antenna gain can as well be included. Typical base station antenna gain is 15 -18 dBi. Similarly, depending upon the type of the device, UE antenna gain varies from –5 dBi to 10 dBi.

Losses: Includes cable and body loss both at the eNodeB and UE. Cable loss is loss between the equipment antenna and the low noise amplifier which depends on the cable length, cable type and frequency band. The cable loss value depends on the cable length, cable type and frequency band. It varies from 1-6 dB for eNodeB and also 0 dB for UE. Body loss occurs when UE is held close to the user's head and in practical planning it is 0 dB.

EIRP: Stands for effective isotropic radiated power; the term is used to express how much transmitted power is radiated in the desired direction.

$$\mathrm{EIRP} = \mathrm{PTx} + \mathrm{GTx} - \sum \mathrm{Total\ Tx\ losses} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where, PTx is the Transmitter power (dBm), GTx is the transmitter antenna gain (dBi) and $Total\ Tx\ losses$ is cable and other losses on the transmitter side (dB).

Operation frequency and Bandwidth: LTE operates in different carrier bandwidths including 1.25 MHz, 2.5 MHz, 5 MHz, 10 MHz, 15 MHz and 20 MHz in both the uplink and downlink. Depending on whether FDD-LTE or TDD-LTE is used, there are different numbers of frequency bands available. In most cases, the higher frequency is used for coverage improvements whereas the lower frequencies are preferred for wider coverage area. For this study, this parameter was directly related to scenario formulation process.

Cell Edge User Throughput: - It is the minimum net single UE target throughput requirement to be achieved at the cell edge. It determines the service that can be provided at the cell edge. This parameter usually sated based on the required services at cell edge for a given operator.

Thermal Noise: The thermal noise is a loss due to heat and can be formulated as [26]

$$N = KBT \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (7)$$

Where, K is Boltzmann constant (1.38 x 10 (- 23) J/K), T is absolute temperature at a value of 290K and B is channel bandwidth which is 20MHz for this study

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

$$\text{Receiver Sensitivity} = \text{Noise figure} + \text{SINR} + \text{Thermal Noise} \ldots\ldots (8)$$

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

Penetration Loss: The penetration loss indicates the fading of radio signals due to building obstruction from an indoor terminal to the eNodeB and vice versa. It depends on the nature of the buildings and the clutter type of the targeted coverage area

Table 3.3. Penetration loss per clutter type [25].

Clutter type	Penetration loss range (dB)	Typical values (dB)
Dense urban	19 – 25	19
Urban	15 – 18	15
Suburban	10 – 14	11
Rural	5 – 8	8

Shadow Fading Margin: Indicates the fading due to obstruction like building. To minimize the effect of shadow fading and ensure a certain edge coverage probability, certain allowance is required.

This allowance is called the shadow fading margin. The slow fading margin can be obtained by using a Q function from cell edge coverage probability and standard deviation of slow fading [27].

$$\mathrm{CPe} = 1 - \mathrm{Q}\left(\frac{\mathrm{Fm}}{\mathrm{Std\ SF}}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

$$\mathrm{Fm} = [\mathrm{Q}^{-1}(1 - \mathrm{CPe})] * \mathrm{std\ SF} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Where, CPe is Cell edge coverage probability, Fm is fading margin and Std SF is standard deviation of slow fading.

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

The maximum allowable path loss expressed as [41]:

$$\begin{aligned}\mathrm{MAPL} = \mathrm{EIRP} - \ & \mathrm{Reciever\ sensativity} - \mathrm{Penetration\ loss} - \mathrm{shadow\ fading\ margin} \\ & - \ \mathrm{interferenace\ margin} - \mathrm{reciever\ body\ loss} \\ & + \mathrm{Reciever\ antenna\ \ gain} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)\end{aligned}$$

Table 3.4. Downlink and Uplink radio link parameters.

Parameters	Variable for both UL and DL
Duplex Mode	FDD
Operating frequency	1800/2100
System Bandwidth (MHz)	5,10,20
Number of PRB per assigned BW	100 for 20
MIMO Scheme (MS)	1x2 UL, 2X2 DL
Cell Edge Rate (Mbps)	1 for UL, 2 for DL
Allocated RB at cell edge (10%)	10 for 20BW
Factor A	0.42 X2 for 2x2 MIMO, 0.42 for 1x2 MIMO
Factor B	0.85 for 2x2MIMO
PRB bandwidth (Mbps)	180Khz
Rate per PRB(Mbit/s)	Cell edge/Allocated PRB
Required Spectral efficiency (bits/s/hz)	Rate per PRB/PRB
SINR(LINEAR)	Factor B*(2^ (SE/Factor A)-1)
SINR (dB)	10*log SINR(Linear)
eNodeB - UE	
Number of PRBs (10%)	10
Downlink data rate (Mbps)	1 for UL, 2 for DL
eNodeB TX power (dBm)	43/46
eNodeB antenna gain (dBi)	~18
eNodeB antenna cable loss (dB)	1~2
EIRP (dB)	= gains-losses
UE receiver characteristics	
UE noise figure (dB)	~7 dB
Thermal noise	B*T*PRB*BW
Receiver noise floor(dBm)	NF+B*T*PRB*BW
Required SINR (dB)	10*log SINR (Factor B*(2^ (SE/Factor A)-1))
Receiver sensitivity	Required SINR+ Receiver Noise
Control channel overhead(dB)	5%-25% (1dB-4dB overhead)
Rx antenna gain	0 for handset
Body loss	3-5dB
Environmental characteristics	
Indoor Penetration Loss (dB)	12-16 dB
Cell Edge Coverage Probability (%)	90-95%
Shadowing Margin	S
Interference margin	5-8
Maximum Allowed propagation loss (MAPL)(dB)	= gains-losses

ii) Propagation model

The signal strengths difference from the transmitter antenna to the receiver antenna is called Path Loss (PL). There are two categories of propagation model namely empirical and deterministic models. Empirical models are based on practically measured data and consider all environment factors, whereas the deterministic model basis on theoretical analysis and they can be applied in different scenarios without affecting accuracy [25].

This thesis is mainly basis on the empirical propagation model. There are various propagation models available to predict the path loss encountered. According to 3GPP specification, path loss models such as Okumura Model, Hata Model, COST 231 Hata model, and COST 231 Walfish-Ikegami (W-I) model are those which are acceptable for LTE planning and path loss calculation [41].

Each model has its own limitation, input requirements and operation environment. For instance, COST 231 Hata model is suitable for dense urban, urban and sub-urban areas and require only central frequency and distance between the transmitter and the receiver as its input variable for computation; whereas COST 231 Walfish-Ikegami (W-I) is suitable for urban, sub-urban and rural areas requiring several input parameters such as building height, transmitter and receiver height, building distance .. etc. [42]. COST-231 Hata model is expressed as follow and developed to extend the frequency range of Okumura Hata model.

$$\mathrm{PL(dB)} = 46.3 + 33.9(\mathrm{f}) - 13.82\log(\mathrm{h_{BS}}) + [44.9 - 6.55\log(\mathrm{h_{BS}})]\log(\mathrm{d}) - \mathrm{a}(\mathrm{h_{UE}}) - \mathrm{c_m} \quad \ldots\ldots\ldots (12)$$

Where d is the distance (Km) between the transmitter and receiver antenna, f is the frequency used in MHz, h_{UE} is UE antenna height(m), h_{BS} is BTS antenna height(m), c_m is 0 dB for suburban and 3dB for urban areas.

The parameter $a(h_{UE})$ is mobile station antenna height correction factors and it is defined for different areas as follows.

Urban areas: $a(h_{UE}) = 3.2[\log(11.75 * h_{UE})]^2 - 4.79$ ……. (13)

Suburban/Rural areas: $a(h_{UE}) = [1.11\ \log(f) - 0.7]h_{UE} - [1.5\ \log(f) - 0.8]$ …. (14)

iii) Cell radius and Site count

Once the MAPL calculated in both UL and DL, the next step is to determine the cell radius by using appropriate propagation model. In most of network planning documents the site coverage area modelled as hexagonal in shape.

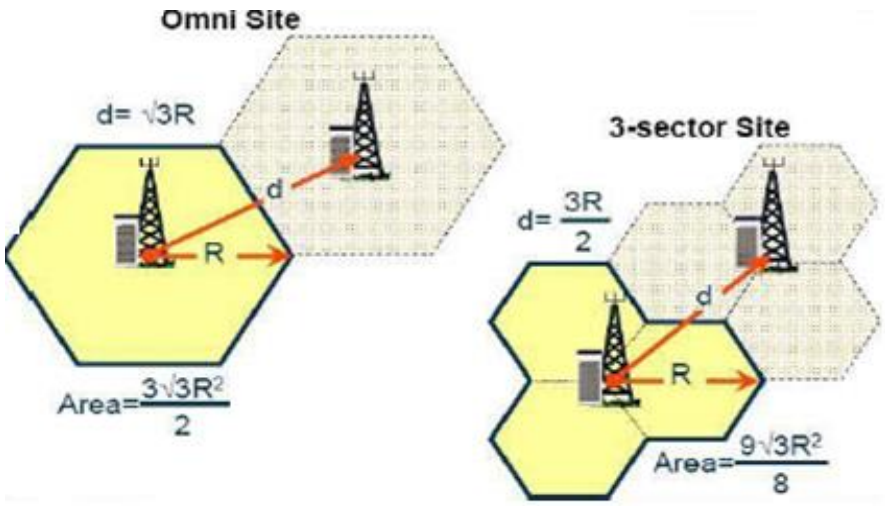


Figure 3.10. Site configuration for cell radius estimation [42].

As shown Figure 3.10, the cell area depends on sites configuration. It can be omni directional, 2 sectors or 3 sector sites. Thus, the cell radius is calculated for each configuration. Finally, the total site count is calculated by dividing the targeted area by singe site area as shown in the formula.

$$\text{Site Area} = 9/8 * \sqrt{3} * R^2 \quad \text{for 3 sector site} \ldots\ldots (15)$$

$$\text{Site Area} = 3/2 * \sqrt{3} * R^2 \quad \text{for omnidirection} \ldots\ldots (16)$$

$$\text{Required site number} = \text{Area to be covered} / \text{Site area} \ldots\ldots (17)$$

3.5.2. Capacity Dimensioning Approach

In LTE radio network dimensioning, aside from the coverage planning, factors of capacity are also considered. That means, the radio resources needed to maximally support users with a certain level of QoS (e.g. throughput or blocking probability, transfer delay).

It is known that for sustainable end-to-end communication among UEs the planning of air interface must be well thought-out. The air interface determines the radio resource each UE can get. The higher the air interface utilization, the lower will be the average UE throughput because of the congestion over the air interface. Thus, to estimate the cell performance, it is important to model properly capacity factors [28].

For the sake of simplicity, the process of LTE capacity dimensioning is sub-divided in to two as shown in Figure 3.11. The first part is estimating a single eNodeB capacity via spectral efficiency. And the second part is, estimating the average number of mobile users/ subscribers that can be served in a cell using traffic model.

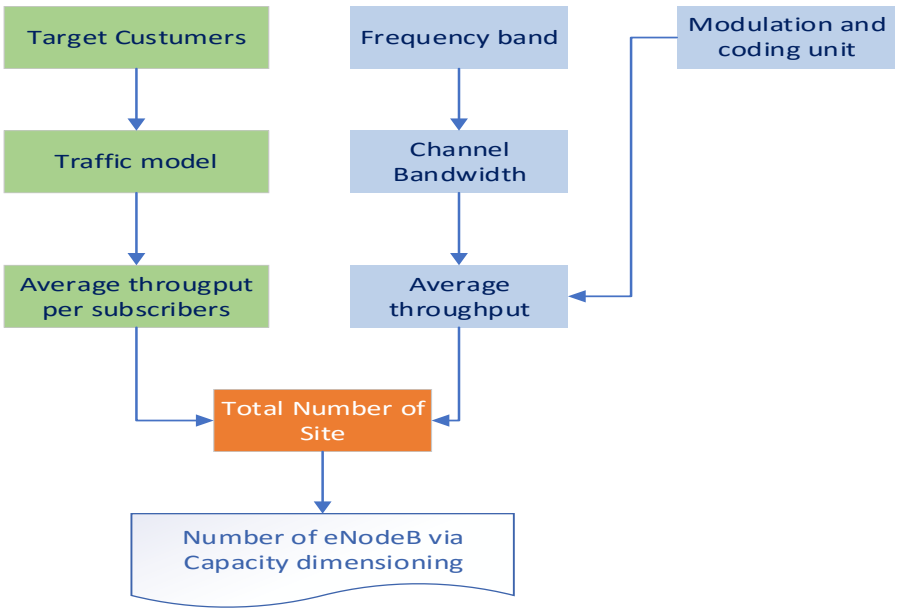


Figure 3.11. Capacity dimensioning procedure [28].

To dimension the capacity, first it needs to model the traffic. The main purpose of traffic model is to describe the average subscriber behavior during the most loaded day period (the Busy Hour) and the capacity of site should be based on busy hour as the traffic is not equality distributed for 24 hours [26].

The average throughput per subscriber based on traffic usage within a month in Gigabytes is calculated using [26]:

$$\Omega(\text{Kbps}) = \rho * \alpha * \left({}^{8\text{bit} * 10^6}/_{30\text{ day} * 24 * 60 * 60} \right) * \text{k} \ldots\ldots\ldots\ldots\ldots (18)$$

Where, Ω(Kbps) is average throughput per subscriber in busy hour (UL and DL), α is traffic ratio of busy hour to the traffic of the whole day, K is Busy hour convergence ratio=1 Traffic ratio of busy hour to whole day and ρ is the Traffic Usage in Month/User.

The total average throughput per subscriber in busy hour is given by [27]:

$$\Phi\ (\text{Kbps}) = \sum (\Omega(\text{Kbps}) * \text{Usage ratio of the services}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (19)$$

Where, $\Phi\ Kbps$ is the total throughput per subscriber in busy hour (UL + DL), Usage ratio of each service/package to the total services/package.

Based on the traffic of services, the average throughput per subscriber for uplink and downlink written as:

$$\Gamma\ (\text{Kbps}) = \Phi\ (\text{Kbps}) * \text{UL traffic ratio} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (20)$$

$$\eta\ \text{Kbps} = \ \Phi\ (\text{Kbps}) * \text{DL traffic ratio} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (21)$$

Where $\Gamma\ (Kbps)$ is the average throughput for uplink and $\eta\ (Kbps)$ average throughput for downlink

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

Based on the frame structure and coding rate the peak throughput per site is given by [26]:

$$\delta(\text{Mbps}) = {}^{\text{data RE}}/_{\text{sec}} * \text{ bits per RE} * \text{MIMO effect} * \text{ coding rate} \ldots\ldots\ldots (22)$$

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

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

$$\lambda \text{ Mbps} = \delta(\text{Mbps}) * \text{Traffic ratio of UL} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (23)$$

$$\mu \text{ Mbps} = \delta \text{ Mbps} * \text{Traffic ratio of D} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (24)$$

Where, λ $Mbps$ is the average throughput per site for uplink and μ $Mbps$ is the average throughput per site for downlink.

The number maximum subscriber number per site is calculated for both uplink and downlink from Equations (21) and (22) as follow:

$$\text{Max Subscriber number per site (UL)} = {}^{\lambda \text{ Mbps}}/_{\Gamma \text{ (Kbps)}} \ldots\ldots\ldots\ldots\ldots\ldots (25)$$

$$\text{Max Subscriber number per site (DL)} = {}^{\mu \text{ Mbps}}/_{\eta \text{ (Kbps)}} \ldots\ldots\ldots\ldots\ldots\ldots (26)$$

At the last, the total site based on the capacity estimated, in taking the minimum number of subscribers from uplink and downlink or from equation (23) and (24) is calculated as:

$$\text{Total site number} = \frac{\text{forecasted users per each deploymnet scenarios}}{\text{Maximum subscriber number per site}} \ldots (27)$$

3.6. Mathematical Modeling for Cost and Revenue

The cost of the network is one of the core elements for measuring the feasibility of LTE deployment scenarios [43]. The cost of network directly depends on coverage, capacity and traffic demand requirements. Consequently, network cost depends on network dimensioning results. In this thesis, the cost analysis is designed to be starting at the output side of network dimensioning. The network cost generally splits into investments and operational costs, or CAPEX and OPEX.

Two approaches exist for cost modelling [11], differing in their starting point for the modelling process. In a top-down approach, the modelling starts from an existing business and network infrastructure, using the observed CAPEX, OPEX, and service usage levels as inputs to calculate costs per e.g. service or scenarios [44].

In a bottom-up approach, the forecast demand for services is used as a starting point and the required costs are modelled so that all customers can be served with sufficient quality. In techno-economic modelling, the bottom-up approach is preferable and typically used when calculating investments. Operational costs are often modelled using a combination of the two approaches [45].

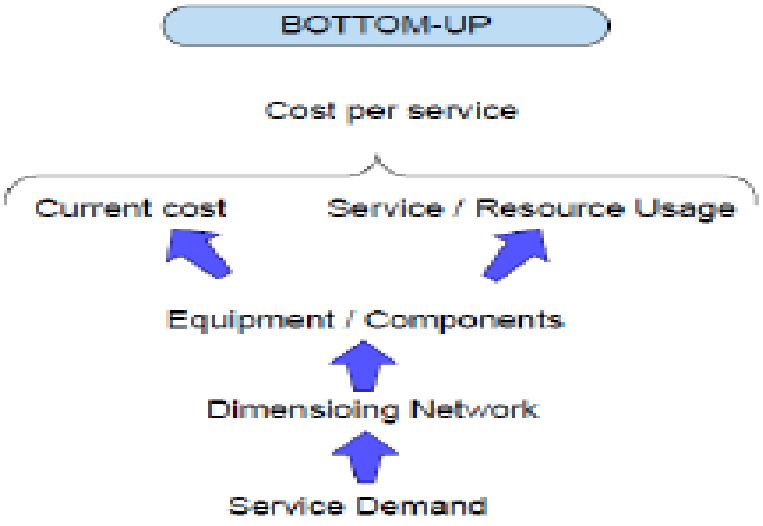


Figure 3.12. Bottom up cost modelling approach [45].

i) Capital Expenditure (CAPEX)

CAPEX is simply a cost comes from result of network dimensioning in this study. Network dimensioning is carried out to calculate the investments in network equipment required to offer the planned services to the end customers. Based on the technical architecture of the modelled system, the characteristics and performance of the nodes and links within, as well as the service usage forecasts, the numbers of network elements and related investments are calculated [43].

CAPEX modelled mathematically [37]

$$CAPEX^{(i)} = \sum M_j^{(i)} C_j^{capex} \left(1 + P_j^{capex}\right)^{i-1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (28)$$

Where, j ∈ (key components of CAPEX listed above), $M_j^{(i)}$ is the number of items of type j purchased in year i, c_j^{capex} are the per-unit investment for each asset j in the 1st year, P_j^{capex} its yearly price trends, is $CAPEX^{(i)}$ the investment in year i.

key components of CAPEX model in this study was categorized in to five main parameters. Such as cost related to spectrum licensee (one time), site survey and network planning, eNodeB related cost (New eNodeB cost (including network elements), MIMO enabled eNodeB cost, co site installation cost, site acquisition cost (for new site) and service cost related to eNodeB implementation), UE related cost (subsidy, startup), core element and backhaul link costs.

Since network elements are vendor dependent and comes with different costs, for this analysis we consider data from some of selected vendors cost database, well know industry standard price catalog, documentation from previously deployed LTE project in Addis Ababa and from several literatures studied related to cost model of wireless network.

ii) Operational Expenditure (OPEX)

OPEX is defined as cost comes after deployment of dimensioned networks. It generally modelled as network driven and business driven costs. It includes operational costs such as network-related OPEX (i.e. operations and maintenance), sales and marketing costs, billing and customer care costs, and general and administration costs [46].

Network-related costs are typically modelled using the calculated numbers of network elements as inputs. Sales and marketing costs depend heavily on strategy and market conditions, and are affected by handset subsidies, and advertising campaigns. Cost of billing and customer care depends on number of subscribers, whereas, general & administration costs are often modelled simply as e.g. some percentage of revenues.

$$OPEX^{(i)} = \sum N_j^{(i)} C_j^{opex} \left(1 + P_j^{opex}\right)^{i-1} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (29)$$

Where j ∈ (network driven and customer driven costs category parameters), $N_j^{(i)}$ is the number of items of type j operated during year i, $C_j^{opex)}$ is Per unit operating cost for each asset j in the 1st year, P_j^{opex} j its yearly price trends.

Unlike to CAPEX, the operational expenditures related to a certain project are often more difficult to predict than the capital expenditures. Since LTE technology not yet deployed in the study area OPEX estimated by taking the sample LTE site currently service. Accordingly, for this study, annual OPEX considered from monthly report generated from the operators and targeted literature reviews.

Total cost commonly called in telecom industry as Total cost of ownership (TCO) and simply it is network deployment cost. TCO is the sum of CAPEX and OPEX cost. It was obtained using the following general formula

$$TCO = CAPEX + OPEX \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (30)$$

Where, CAPEX is capital expenditures cost resulted from dimensioned network, OPEX is operation cost assumed for the system and TCO is total cost of the network.

iii) Revenue

The most important key parameter in marketing analysis is revenue forecast. Revenue is forecasted in consideration of data consumption level (monthly basis) of service users, pricing policy stated (service charging and connection fee) and number of forecasted data service users. Accordingly, the adapted revenue model for this study shown in Figure 3.13.

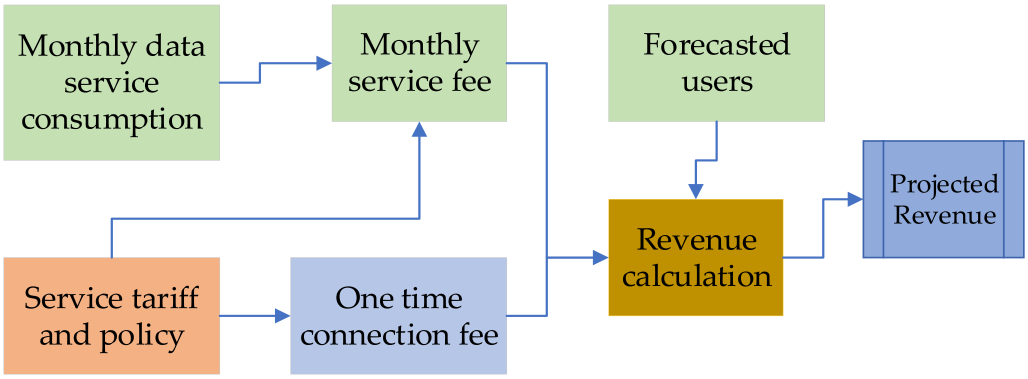


Figure 3.13.Revenue forecast model [39,40].

Based on above stated revenue forecast process, revenue was projected for each deployment scenarios using the following formulated revenue projection formula.

$$R(t) = \sum_{k=1}^{t}(((y(k) - y(k-1)) * (\mathrm{Monthly}_{\mathrm{service}_{\mathrm{fee}}} * 12 * \sum_{i=0}^{n}\left(\left(\frac{n-i}{n}\right) * \frac{1}{n}\right) + \mathrm{One\ time}_{\mathrm{connectionfee}}) + y(k-1) * 12 * \mathrm{Monthly}_{\mathrm{service\ fee}}) * mt^{(k-1)}), \quad y(0) = 0, \ \dots \dots \dots (31)$$

Where, R(t) is revenue at year t, y(k) is forecasted users at year k and $\mathrm{Monthly}_{\mathrm{service\ fee}}$ and $\mathrm{One\ time}_{\mathrm{connectionfee}}$ are monthly service fee and one-time SIM activation fee respectively, n is number of months considered for forecasted users' trends within each year and mt is the percentage of monthly data consumption level trends in the study period.

Once revenue is projected, average revenue per users (ARPU) in yearly or monthly basis obtained through the following equation. ARPU is a measure used primary by operator for this study and defined as

$$\text{ARPU} = {}^{\text{projected Revenue per year}}/_{\text{Number of users}} \quad \ldots\ldots\ldots\ldots\ldots (32)$$

3.7. Discounted Cash Flow Analysis

A prime answer from a techno-economic analysis is whether the investment project in question is economically feasible or not. The economic justification carried out via discounted cashflow analysis [10]. The two major cost elements (CPEX and OPEX) needs to be compared with the revenue expected to be collected within the deployment period. This is the decision point where the operators can measure their total cost of ownership (TCO).

Usually, if the return on investment (ROI) is greater that total cost of ownership it is believed that the investment can make money and can be forecasted that the deployment scenarios are feasible [8]. However, this is not enough to decision as this the only shows gross profit or cash flow. For this reason, we have considered the indicators like net present value (NPV), internal rate of return (IRR), and payback period (PP) to maximize the decision indicators [2, 11].All these economic indicators calculated based on obtained cash flow or discounted cash flow.

Net present value (NPV) is the most favorable measure of profitability and leads to better investment decisions than the other criteria. The NPV of a project is calculated as the difference between the discounted value of the future incomes and the amount of the initial investment. In short it is defined as expected future cash flow discounted to present value [2,10].

$$\text{NPV} = \sum_{t=0}^{T} \frac{\text{CF}_t}{(1+\text{r})^t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (33)$$

Where, t – the length of the study period, CFt – cash flow occurring in time period t and r – discount rate (industry average). As NPV rule: If NPV is **positive**, the deployment is feasible economically. The discount rate described here known as the opportunity cost of capital, represents the expected return that is forgone by investing in the project.

The internal rate of return (IRR) is closely related to the NPV. It is the discount rate at which the present value of all future cash flow is equal to the initial investment. It is the rate at which an investment break even [10]. It is discount rate that makes NPV=0.

$$\mathrm{NPV} = \sum_{t=0}^{T} \frac{\mathrm{CF}_t}{(1+\mathrm{IRR})^t} = 0 \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (34\ )$$

Where, t= Period, t is a positive Integer, T is total no of period, NPV is Net Present Value, IRR is Internal Rate of Return and Ct is cash flow. From IRR principle, the higher IRR, the more desirable it is to undertake the deployment and deployment with the highest IRR would be considered the best and undertaken first.

Payback period is the number of years it takes before the cumulative incomes equal the initial investments. When using the payback rule in investment decisions, all projects that pay themselves back before a defined cutoff date are considered profitable. In this thesis, it is the number of years the chosen LTE deployment scenarios takes before the cumulative incomes equal to the initial investments[2].

$$\text{Payback period , time(T) at which } \sum_{t=1}^{T} \frac{\mathrm{CCF}_t}{(1+r)^t} = 0 \ldots \ldots \ldots \ldots . . (33)$$

Where, CCFt cumulative cash flow at year t, T is time, r is discount rate and for Payback period estimation r was zero.

$$\text{Discounted payback period , time(T) at which } \sum_{t=1}^{T} \frac{\mathrm{DCCF}_t}{(1+r)^t} = 0 \ldots \ldots . (34)$$

Where, DCCFt is discounted cumulative cash flow at year t, T is time, r is discount rate and for discounted payback period estimation r was needs to be defined.

If length of recovery time in the study period shorter the system can be considered as profitable. In most of the studies and operators experience if payback period is less than 3.3 years in span of 8 years deployment period the investment considered as feasible economically. On other side, less attractive if length of time relatively long.

3.8. Implemented Techno-economic Evaluation Approach

Most of the techno economic evaluation tools developed were limited to project sponsors so that their commercial availability is rare, and it were expensive to buy. Considering these problems, in this thesis the evaluation tool was implemented in MATLAB based on the modified TERA model to evaluate LTE deployment scenarios in an emerging city. As shown in Figure 3.14, to implement the techno-economic evaluation approach, first three modular components such as marketing, technical and economical part based on selected TEA model designed. In this study, the evaluation tool was simulated to operate on formulated LTE deployment scenarios.

i) Marketing part

Marketing forecast starts with territory and demography analysis. In this part, population forecast performed using geometric progression method with defined geometric mean. The geometric mean was obtained in taking sample of earlier years with their population growth rates. The demographic and population distribution in the targeted area calculated considering of existing(inputted) population density and demography type ratio.

In implemented evaluation approach, only data service considered. Distribution of data service users calculated based on customers segmentation stated in the input part. As per defined market potential range, number of LTE data service users were forecasted for each deployment scenario using a bass model of growth method.

In the analysis tool, the innovation and imitation coefficient related to bass model were defined based on existing technology users' trends. After data service users forecasted, service penetration was calculated in consideration of the market potential initially stated and population of the city with in defined study period. Acquired users also considered and calculated in checking the defined churn rate.

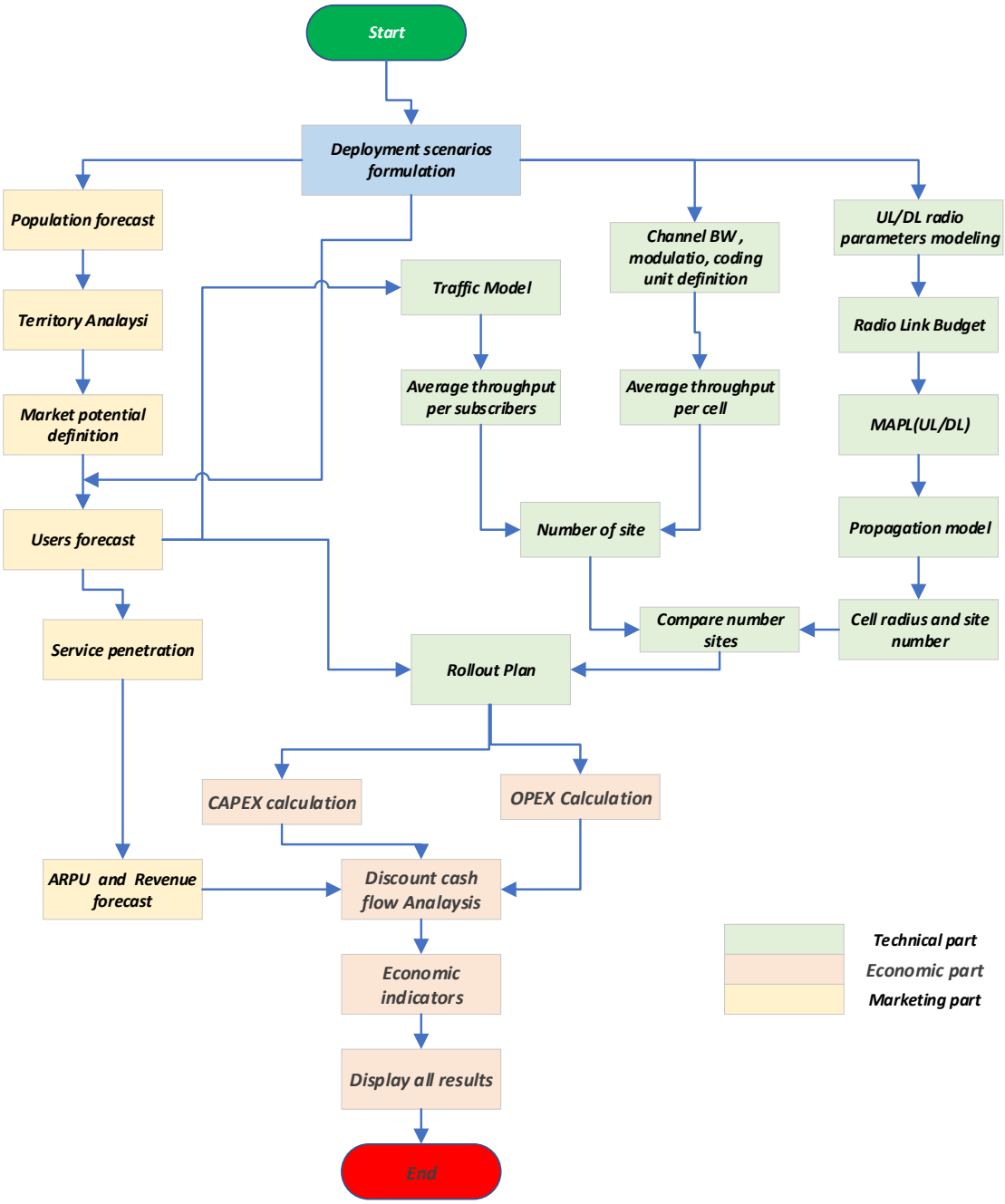


Figure 3.14. Simulated techno-economic evaluation approach flow chart.

Consistent with monthly data consumption level of users, charging and pricing policy stated, and number of forecasted data users of each LTE deployment scenarios ARPU and revenue were projected. Lastly, projected revenue was taken as an input to economic components for further economic evaluation.

ii) Technical part

The technical part mainly performs the radio access network dimensioning of LTE technology. The technical part has radio coverage and capacity demand estimation sub parts. The main aim of technical part is to dimension the number of eNodeB, other backhaul and core network elements required for the area of interest. The coverage sub part considered parameters such as channel model that incorporates path loss, shadowing, coverage probability… etc., network model parameters related to the technology specifications (transmit power, antenna gain, available radio resource per frame, etc.), scenario factor mainly operating frequency.

The evaluation tool calculates the maximum pathloss, the coverage radius in both uplink and downlink and per demo type considered. During estimation of cell radius, COST-231 propagation model and popular used base station and UE height were considered. Average cell radius was taken for each LTE deployment scenario based on stated environmental model. Further, the required site counts are estimated in consideration of hexagonal eNodeB site configuration setup and obtained cell radius.

Capacity demand sub considered parameters such as traffic model, total traffic intensity, the modulation and coding schema requirements, operating bandwidth and network configuration elements. The simulated evaluation tool calculates average throughput per user, busy hour average user and peak cell throughput parameters. Finally, the maximum number of users served per each cell calculated to obtain the total capacity required per each deployment scenarios considering three sectored site configurations. Once the number of sites obtained from both approaches, the tool

compares the capacity and coverage results. Using the maximum argument, the optimum number of eNodeB counts are selected.

Once the network is dimensioned, the required network elements in year with relation to forecasted users correlated using the roll-out plan to avoid underutilization of resource. In the tool popular used rollout plan strategy (70/30) considered for each deployment scenarios. Finally, the dimensioned network elements transferred to economic parts for further cost evaluation and feasibility investigation.

iii) Economic part

This component in the tool designed to treat the economic feasibility of the network element estimated via network dimensioning part. The economic evaluation started from cost estimation. The first one is CAPEX cost, which was used for estimating the capital investment cost. The main cost element for CAPEX cost are the network elements dimensioned from the technical part. The tool configured with the cost and quantity of the eNodeB, user equipment's, the core network and other related elements. Then tool calculates total CAPEX cost and its trends in yearly basis based on formulated CAPEX model.

In this study and tool, the formulated CAPEX model mainly uses for evaluating the LTE deployment scenarios for an emerging city (It can be modified further). The second cost type was operational cost. The operational costs assumed to be an input parameter for determining the operation cost of the system. The main OPEX costs considered in the tool categorized as network driven and business driven costs.

Accordingly, the OPEX costs considered in the analysis are maintenance and spare cost, energy consumption, marketing, customer care, sales and administrative costs, site lease and utilities and technical support costs based on formulated OPEX model. Like CAPEX estimation, the tool also configured to calculate the OPEX and its trends in year basis as per modelled OPEX cost. The combined result of CAPEX and OPEX is called total cost of ownership (TCO), commonly known as total network cost.

The last part in the economic component is economic statement to analyze profit, cash flow, discounted cash flow etc. The stage is connected to the revenue estimation (which was obtained from marketing analysis part), network dimensioning and roll out plan of the technical component. The economic statement calculation starts in calculation of net cash flow and net discounted cumulative cash flow. Once cumulative and discounted cash flow estimated the next is to execute economic indicators such as net present value and payback period to estimate return on investment (ROI) years and rate. This step is the final output of analysis tool where the feasibility of the investment compared and decided.

For further techno economic evaluation, the simulated analysis tool was supported with graphical user interface (GUI) which was developed in MATLAB. The GUI designed in such way that to take marketing, technical and economic key input parameters. Once the input parameters taken, the key parameters in each module (marketing, technical and economic) also calculated based on methods, models and approach described in earlier sub Sections. The result of important parameters per each module displayed in one window to easily analyze the results. Snap shot of graphical user interface developed for the simulated evaluation tool in the MATLAB is shown in Figure 3.15.

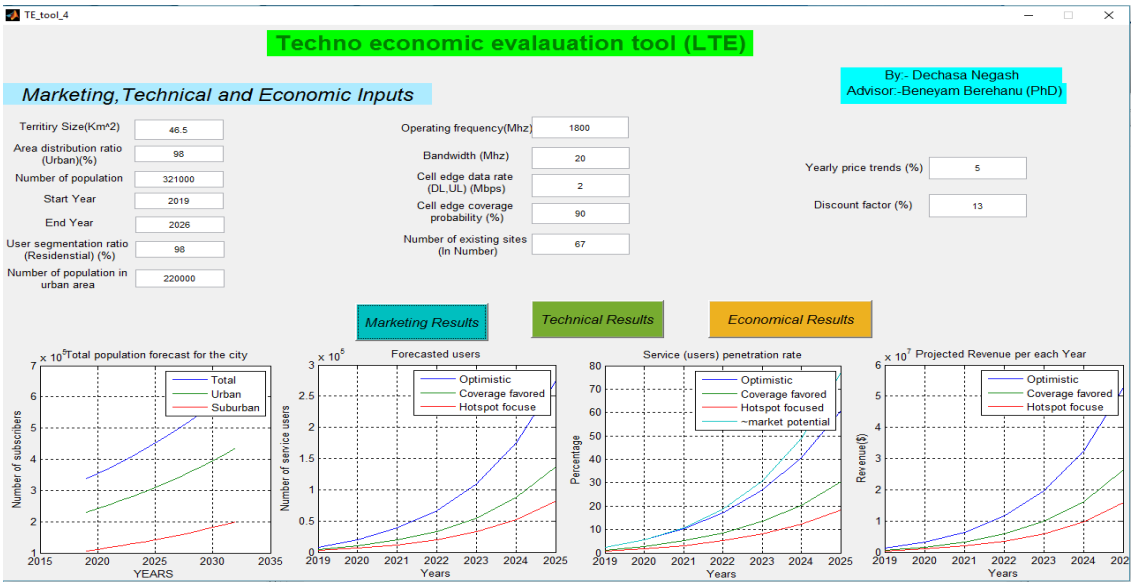


Figure 3.15. Snap shoot of implemented TE evaluation tool GUI.

Chapter 4 : Deployment Scenarios and Techno-economic Analysis

4.1. Deployment Scenarios Analysis

To clarify the big picture and the possible evolution towards LTE technology, possible LTE deployment alternative construction will be an essential step as the technology is new for an emerging city. Possible LTE deployment alternatives were created via scenario planning method to address the question "What are the future possible LTE deployment alternatives in an emerging city? ".

Emerging city in this study defined as the developing city which have a population of greater than 300,000 [53]. It is the city where potential customers revolve, hosts of many governmental and non-governmental conferences and center of trade next to capital city in Ethiopia and Africa context.

Currently, the LTE technology is not deployed in an emerging city mainly in Ethiopia context. Hence, scenario planning method was the appropriate tool to build possible LTE deployment alternatives in Adama city of Ethiopia. Scenario planning method proposed by authored cited in [34, 36] has recently gained popularity as a tool for managing the uncertainty, complexity, and disruptiveness of new technologies in telecom industry mainly in an emerging cellular technology.

To formulate the LTE deployment scenarios (DSs) in an emerging city several data sources were considered. Survey of the operator (ethio telecom), documentation and reports, literature reviews and experts' interview are some of the mostly considered data sources. For each parameter in the scenario planning method, the specific data model used described in detail in the steps as follows. To analyze and formulate the LTE deployment scenarios (DSs), scenario planning method proposed by authored cited in [34, 36] is applied. The steps for DSs formulation described as follows.

i) Defining the time frame, scope and actors

Time frame: As noted from several studies related to scenario formulation, the time frame is in an interval of five to ten years. Considering this time interval as input, the status of the city and technology lifetime trends (rate) the selected time frame for this study was defined to seven years.

***Scope*:** During LTE deployment scenario formulation, the scope is limited to radio access part of LTE technology, emerging city demography mainly in African /Ethiopia context and monopoly network (service) operators.

***Actors*:** The key actors involved in the LTE deployment are end users, mobile network (service) operators and vendors or suppliers.

ii) Key factors affect LTE deployment

Key factors which were potentially affected the LTE deployment in an emerging city were analyzed based on the available macro-environmental framework. For this study, PEST (Political, Economic, Social and Technological) framework was selected as it was widely used in the telecom sector especially in an emerging cellular technology.

To collect and group the factors via PEST framework, several literatures considered, a survey of existing technology users' trends and marketing strategy and plan in ethio telecom made. Project documents and yearly based reports also reviewed to analyze the status of existing network performance, set up and network plan [5] [6] [47].

In addition, interviews and discussion with ethio telecom experts and stakeholders also performed to identify the factors which are greatly affects the LTE deployment contextually. The identified factors were affecting the LTE deployment process either in a positive or negative manner in an emerging city.

The compiled form of the factors affecting the LTE deployment in an emerging city via PEST framework summarized as shown in Figure 4.1.

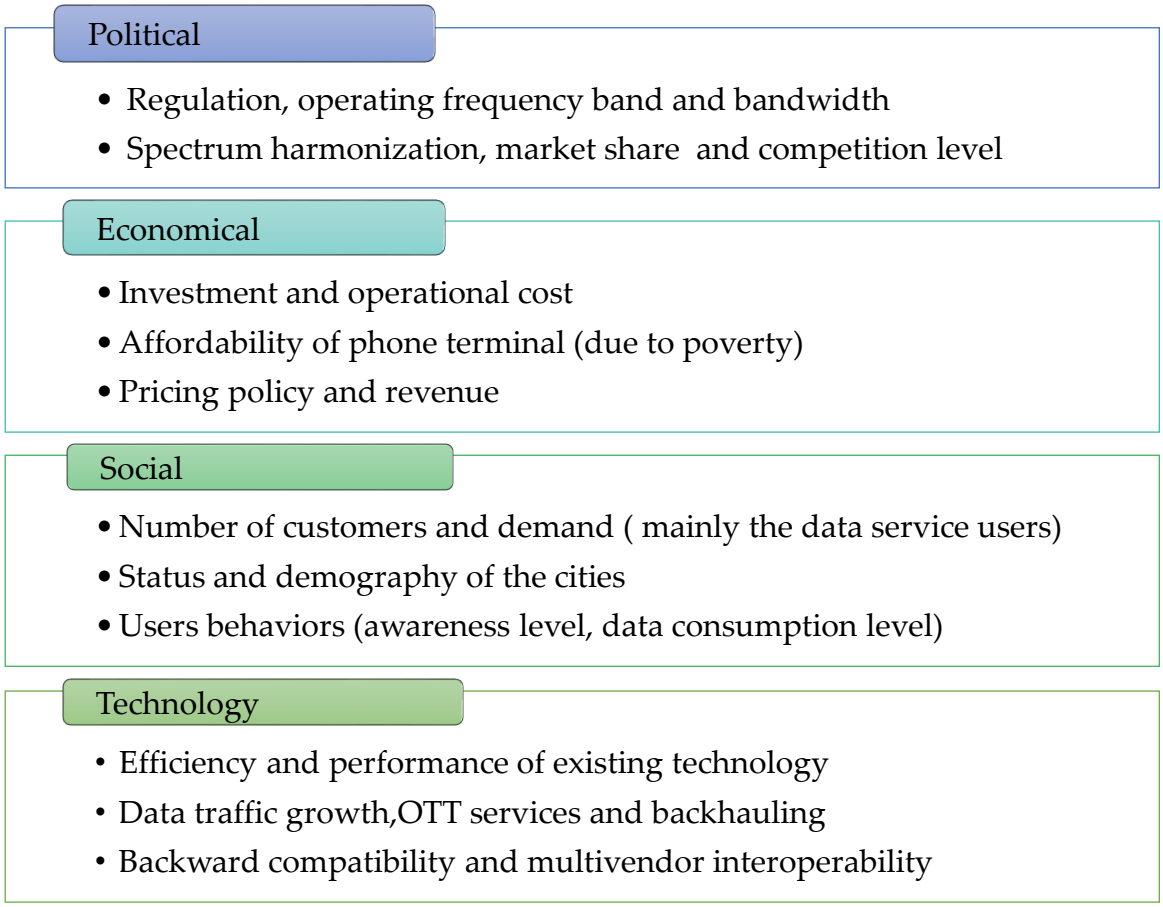


Figure 4.1.Key factors affect LTE deployment via PEST framework [5] [6] [47].

iii) Trends

Based on identified factors in the Figure 4.1, once more intensive literature reviews and discussion with Ethio telecom experts were performed to analyze trends of each factors. Likewise, the operator (ethio telecom) survey mainly focusing on the status of existing technology and marketing strategy was done to analyze trends of the factors.

Moreover, survey of leading operators in market and network deployment strategy aspects were done to analyze further the trends of identified factors. Accordingly, trends of each factor were summarized as shown in Table 4.1.

Table 4.1.key factors trends and its descriptions via PEST framework [5] [6] [47].

PEST	Factors trends	Description /Examples
Political	Presence of several LTE operating frequency band and bandwidth (BW)	• LTE popular operating band [GSA, 2017] 1800 (47 %), 2600/2100 and 700/800 Mhz [in 5,10,20 BW] • Availability of unused bandwidth in existing frequency band (1800/2600) greater than 20Mhz.
Economical	Increased operational and investment costs related to cellular network	• High cost of network elements, network maintenance and running cost
	Low affordability level of mobile phone terminals mainly in Africa/Ethiopia [Poverty]	• Ability to buy mobile phones terminal which support LTE • High cost of handset which support varies frequency band
Social	Growing of high-bandwidth demand, Increasing of number of data service users	• Increasing of monthly data consumption • Growth of data services such as online Streaming video, social networks
	Increasing of role of developing cities	• Growing of several activities in the cities (in almost all sectors), Ex: -Trade, Hotels, industry …
	Slow end users' awareness level about new technology benefit mainly in Africa/Ethiopia setting	• Especially related to emerging technologies such LTE, LTE-A
Technology	Evolution of cellular technology with enhanced features	• Improvement in data rate, resource utilization, QoS (LTE, LTE-A), to handle growth of data traffic
	Incompetence of existing technologies(2G,3G) with exponential growing demand of data service	• Low efficiency and performance [in terms of technological features, interference, handover, Integration, backward compatibility]

iv) Uncertain Events

To select key uncertain factors based on the obtained factors trends, the impact and uncertain grid method applied to identify the impact and importance of each factor during LTE deployment process. Concentrated interview and discussion with ethio telecom experts performed to identify and categorize contextually uncertain factors.

Accordingly, the factors are categorized as low-performance impact, comparatively high-performance impact and relatively predictable and critical uncertainties. Based on the results of impact and uncertain grid method, the uncertain events identified and described in Table 4.2.

Table 4.2.Uncertain events.

	Uncertain events
1	Which network deployment options will handle the growing demand for data service in the future?
2	Which frequency band will be optimal with bandwidth and coverage considerations in place?
3	What will be LTE data service demand capacity in the future?
4	What will be end user's LTE phone affordability level in the future?
5	Will LTE significantly improve the demand of data service?
6	Which cell type will be the best to handle capacity and coverage in the future?
7	Will data traffic growth increase significantly in the future?
8	How will deal/deploy LTE network with the existing network?
9	Which environmental model will represent the future growing status of city?
10	Will LTE deployment significantly improve current power utilization level?
11	Will LTE technology deployment opens new growing business opportunity in the area?

Following the impact and uncertainty grid method, the two most uncertain factors were identified from the critical uncertain category. Hence, the identified uncertain factors for this study were operating frequency band and demand capacity. Then the uncertain events related to each factor was defined as shown below.

Key selected uncertain events
1. Which frequency band will be optimal with bandwidth and coverage considerations in place?
2. Will the demand of data service capacity increase significantly in the future?

In the selection of these two key uncertain events; each uncertain event described in Table 4.2 relation was considered in detail. To that end, most of the previously listed uncertain events are almost all are interrelated and one for others acts as function and variable.

The selected uncertain events are highly correlated to each other's to create the problem stated in the statement of the problem. And, have a high impact on the techno-economic evaluation of the LTE deployment scenarios especially in the growing city. To justify the selected uncertain events furthermore; in addition to the global status of the LTE operating frequency band, it is essential to see the existing spectrum allocation plan contextually.

Accordingly, the existing technology (GSM and UMTS) operated with frequency band described in **Error! Reference source not found.** in the case study city. As noted from t he spectrum plan, more than 20Mhz bandwidth was unused at operating frequency band of both 2G and 3G technologies. Unused bandwidth for each of in-service frequency band was marked in "X" in Table 4.3 in both operating frequency bands.

Table 4.3.Ethio telecom 1800 and 2100 Mhz bandwidth status in Adama city [48].

Operator	Bandwidth /Technology	1800Mhz			
		Uplink		Downlink	
Ethio Telecom	1800	1710~1747.5		1805~1842.5	
	GSM	1710-1727.5	**X**	1805-1822.5	**X**
	2100	1920-1980		2110-2170	
	UMTS	1925-1935	**X**	2115-2125	**X**

v) Initial scenario theme creation

This step deals with the initial development and description of specific scenarios for the case study. The major tool that used in this step is 'Scenario Matrix'. The Scenario matrix is a visual framework for deriving scenarios. The two key uncertain events which have been identified in the previous step serve as the dimensions that span the matrix. For each scenario dimension, two extreme values were defined.

Consequently, for the frequency band, extreme values are defined as 1800 and 2100Mhz. whereas for the demand capacity, extreme values are defined as high and medium (low) customers base.

Explicitly, the selection of extrema value for both frequency band (1800 and 2100Mhz) and demand capacity (high and Low) uncertain factors was done based on

- Global popular bands status ([4])
- LTE handset operating frequency status([49] [27])
- Status of currently existing devices operating frequency band and the number of devices supporting LTE. More than 33.7% of the device supports LTE in all defined popular bands)
- Extra bandwidth size of existing technology operating band (Table 4.3)

- Spectrum and its associated cost, especially to reduce cost related to spectrum in using existing frequency band
- Trends of existing technology users (i.e. goes in slow exponential increment trends) and performance. That means underutilization of the capacity at the start of deployment and after some years slowly goes to saturation level (nature of telecom service).
- Marketing plan and strategy (contextually and experience of leading operators)

Once extreme value defined, the next step is formulating the deployment scenarios. The formulated deployment scenarios are a function of operating frequency and demand capacity. Indirectly it was a function of coverage and capacity. The formulated deployment scenarios were illustrated in Figure 4.2. DS represent Deployment scenario.

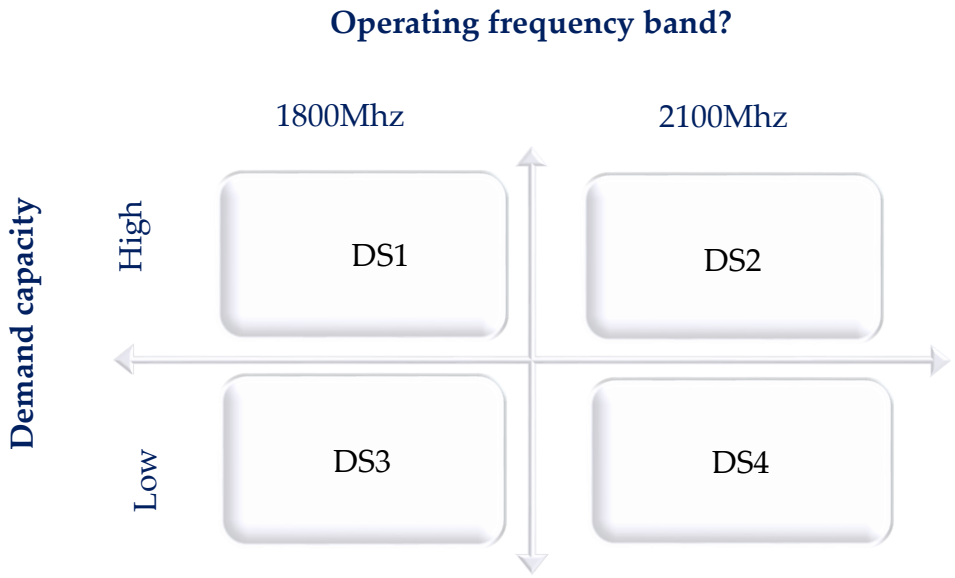


Figure 4.2.Initial LTE deployment scenario theme.

Each formulated deployment scenario named based on their joint characteristics of uncertain factors in the LTE deployment process and their influence on actors.

Below is the description of each formulated deployment scenarios. Furthermore, while naming the formulated deployment scenarios, the uncertain factors impact (either in a positive or negative manner) related to each actor was considered.

As shown in Figure 4.2, the correlation of LTE deployment in 1800Mhz with a high demand capacity creates Deployment Scenario1(DS1). In the same manner, DS2, DS3 and DS4 were created based on the two extrema value of uncertain factors considered.

The characteristics of each LTE deployment scenarios (DS) are listed below

- Deployment Scenario 1 (1800Mhz-High demand capacity)
  - Provide attractive combination of capacity and coverage
  - Operator can use existing assets of GSM 1800 such as Antenna, feeder cable...etc.
  - High revenue generation rate resulted from high demand of data service
  - Reduced uncertainty related to ROI rate in contrast to others DS2
- Deployment Scenario 2 (2100Mhz-Low demand capacity)
  - Highly capacity favored and leads to high site density
  - High investment cost for operators
  - Operator can /can't use existing assets of UMTS 2100
  - High customer base leads to high revenue generation
- Deployment Scenario 3 (1800Mhz-Low demand capacity)
  - Low demand base (concentrated or sparsely distributed users)
  - Relatively reduced site number compared to DS4 i.e. highly coverage favored in proper environment model consideration
  - Operator can use existing assets of GSM 1800 such as Antenna, feeder cable...etc.
- Deployment Scenario 4 (2100Mhz-Low demand capacity)
  - Low customers base (concentrated or sparsely distributed users)
  - Relatively high coverage compared to DS2 in proper environment model
  - Operator can/can't use existing assets of UMTS2100

4.2. Techno-economic Analysis

4.2.1. Marketing Analysis

The future market condition is usually determined by the existing market situation. Hence, understanding the market segmentation, service profile and existing revenue collection is always the starting point for forecasting the future market conditions.

The market analysis allows for evaluating the potential market of LTE data services by characterizing target markets, defining service profiles, and forecasting market penetration and revenues. The data source considered for marketing analysis are census data, municipality data and survey of ethio telecom (operator) on user's trends, users data consumption level and pricing policy.

The targeted city in this study was Adama city which is found around 90 Km from the capital city of Addis Ababa via Addis -Adama expressway. It is one of the emerging cities in Ethiopia in which the potential customers revolve, hosts of many governmental and non-governmental conferences held and center of trade next to capital city [13].

Territory size of the city is around 133.6 Km^2 according to recent new master plan [50]. But in this study, the targeted area defined to 65.2 Km^2 [48] based on current 3G technology network coverage area. As per the census of 2015 the demography of the city divided into urban and others (suburban) by considering the population density within the city. According to projected census in 2015, the population density in 30 km^2 estimated to 7333 persons per square kilometer [51] [52] [53]. Via this data, current demography distribution and population density projected.

The number of populations in the city for the year of 1994, 2007, 2016 and 2017 recorded as 127842, 220212, 338940 and 356344 respectively with a yearly growth rate of 5.1,5.3,5 and 5 respectively [53]. The demography type and demography distribution analyzed and illustrated in the Table 4.4.

Table 4.4.Demography and population density distribution in 2018 [53].

Demography type	Demography distribution (%)	Population distribution (%)	Population density per Km^2
Urban	46%	69	7927
Others (Suburban)	54%	31	4353

After targeted area and territory size defined, the next step was forecasting the population in the city within the defined study period. As per data obtained from the municipality, the population of Adama city was estimated to be 375, 871 with a growth rate of 4.5% in 2018. The city also contains 90365 housed holds. Detail area size and population per demography area were illustrated as shown in Table 4.4.

Table 4.5. Demo type area size and population distributions.

Demo type	Area size in KM^2	Population in number
Urban	29.992	259351
Others (Suburban)	35.208	116520

The total population of the city within 14 years is forecasted via a geometric progression method in view of the previous five years population data. The geometric progression method for forecasting the population of the city is that based on earlier year population growth trends and its one of the widely used progression method in rapid growing city.

The estimated geometric mean used in the forecasting process was 5.1%. The geometric mean was obtained in taking a geometric mean of five-year based on their yearly growth rates. Hence, the forecasted population of the city in 14 years span with respect to the demography type illustrated in Figure 4.3.

To find the number of LTE data service users within the defined study period, it is essential to define the market potential first.

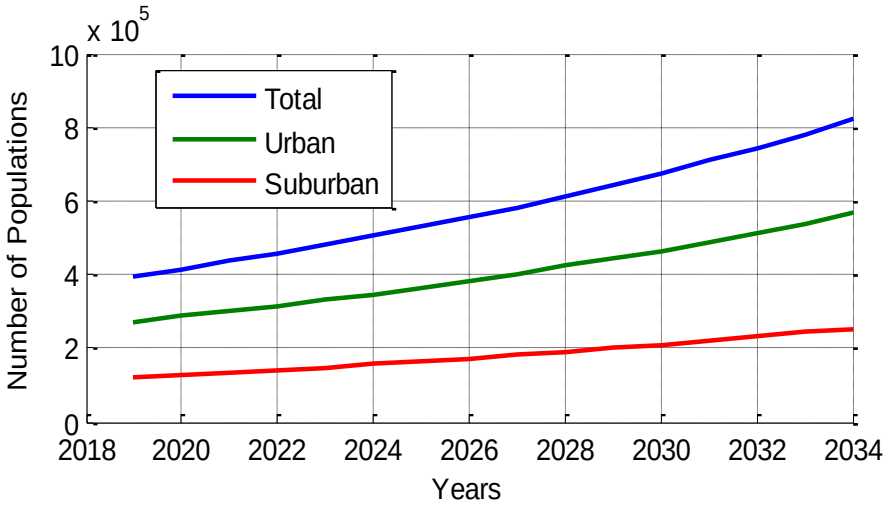


Figure 4.3. Adama city population forecast.

To define the market potential, it is necessary to consider the population of the city and deployment scenario formulated.

As noted from several literatures, the market potential defined with respect to population number of the city. Accordingly, to relate the number of service users with deployment scenarios formulated, the market potential defined as 100%,80%,50% and 30% of current population city.

Before forecasting the service users, it is essential to identify the service type considered in the system. Since existing LTE technology that was deployed in the capital city of Addis Ababa not supporting voice service (VoIP service not implemented). Based on this, the scope of the study is also limited to LTE data service. Hence, the service type considered in the service profile category of marketing part was data service only.

Numbers of LTE data users in defined market potential obtained using bass model. As described in section 3, bass model has a characteristic of S-shape form within some interval of years. In bass model, internal and external adoption parameters (innovation (P) and imitation coefficient (Q)) value are estimated in considering existing 3G and 4G technology users subscription trends in both Adama and Addis Ababa city through curve fitting approach [48] [47].

Likewise, considering the previous five years ethio telecom 3G and 4G users' trends in both Addis Ababa and Adama (described in section 2.1), the value of P and Q approximated to 0.02 and 0.4 via curve fitting approach. Then the LTE data service users forecasted with respect to each defined market potential as shown in Figure 4.4. In Figure 4.4, MP represent the market potential defined with respect to current population number of the city.

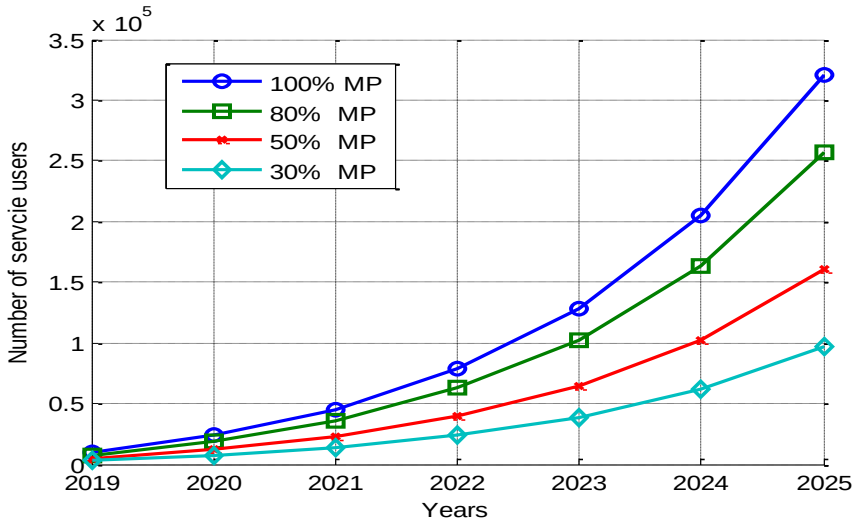
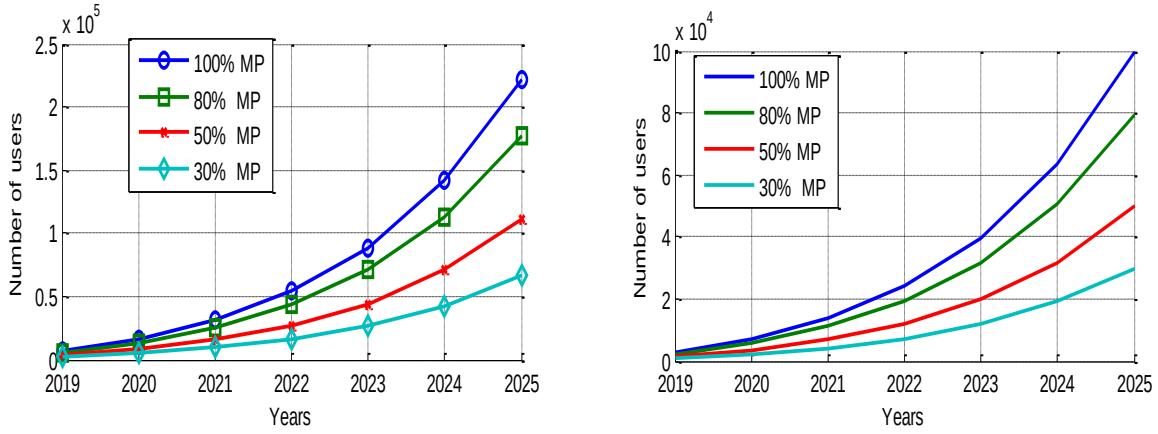


Figure 4.4. Users forecast per defined market potential.

Number of forecasted service users with respect to demography type (urban and suburban areas) also obtained and depicted in Figure 4.5 .



(a) (b)

Figure 4.5. Users forecast in Urban (a) and Suburban (b) areas of the city.

One of the factors which greatly affecting the LTE deployment in emerging city was LTE handset availability and affordability. Unfortunately, as observed from manufacturer data and report from GSA, the number of LTE handset goes in an increasing rate from year to year and expected to explode quickly in near future.

Likewise, as per sample survey of active device status in the Addis Ababa (7 days sample data), from the total number of active devices around 33.7% can support LTE technology in all its operating popular bands. Hence, it is logical to use this status and ratio in an emerging city also. The device and type status illustrated in Figure 4.6.

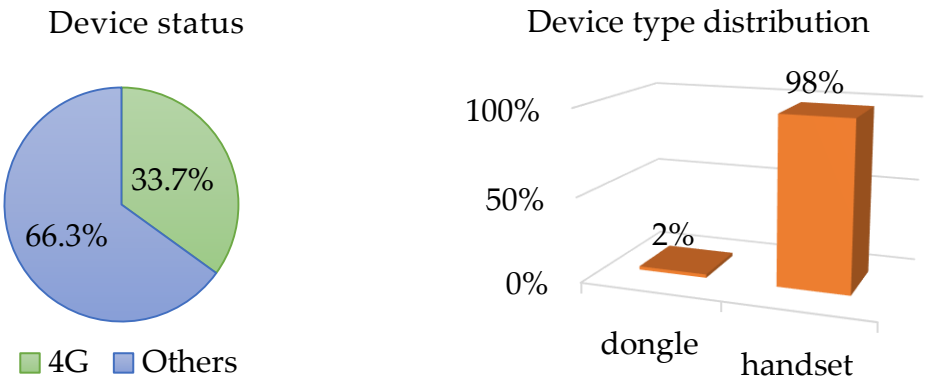


Figure 4.6.Existing device status and type (Addis Ababa).

Thus, the status of the LTE device at the start of the deployment was enough for the case study when compared to forecasted data service users.

For further accuracy, customer segmentation was an essential parameter in marketing analysis part. Currently, in ethio telecom customers are segment into an enterprise and residential customers based on data usage level.

As per data obtained from ethio telecom yearly report, the number of enterprise users in 3G technology was approximated to 2% [54]. For this study, the same ratio of user's segmentation level applied. That means 2% for enterprise and 98% for residential users.

The other parameter used in the market analysis is the service user's penetration rate. It was obtained based on the forecasted users and market potential previously define for each deployment scenarios. The user's penetration rate also compared with yearly growing market size.

Accordingly, the service penetration rate for each defined market potential with respect to the population city is generated and depicted in Figure 4.7. In the figure, SPR represent the service penetration rate whereas MP represent the market potential.

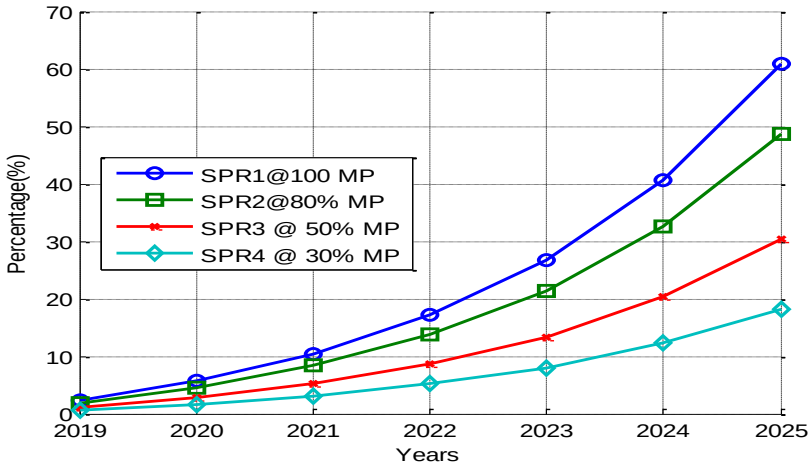


Figure 4.7.Service users' penetration with respect to population of the city.

The service user penetration rate based on the initial defined market potential is illustrated as shown in Figure 4.8.

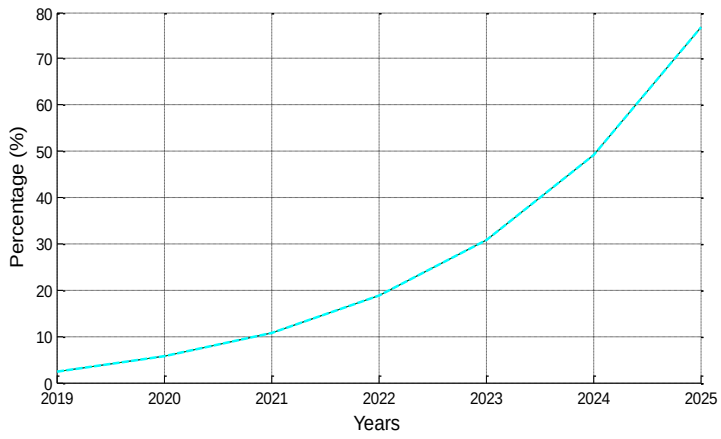


Figure 4.8. Service users' penetration rate with respect to defined market potential.

4.2.2. LTE Radio Access Network Dimensioning

The main aim of LTE radio access network (RAN) dimensioning as described in section 3.4 was to estimate the required site density and to model the site configurations parameters for the area of interest [55].RAN dimensioning activities includes estimation of radio link budget parameters, cell radius, cell capacity and the optimum amount of eNodeB required in each LTE deployment scenario for the targeted area.

Outputs of the dimensioning phase were directly used to estimate the cost of the network and economic feasibility of formulated deployment scenarios. It is the main input for cost and economic component. LTE RAN was performed in coverage and capacity dimensioning approaches.

i) Coverage Dimensioning

The first one is coverage dimensioning. To dimension the coverage, main input considered were operating frequency band and bandwidth, cell edge target and requirements, RLB inputs (transmitter and UE characteristics), size and geographical information, coverage probability, enviromental charcterstics and propagation model.

The operating frequency band was selected based on the deployment scenario formulated and selected. That means, two center operating frequency band (1800Mhz and 2100Mhz) were considered. The reason why the two-center frequency selected in this study was described in detail in chapter 4.1.

The uplink and downlink operating frequency for 1800Mhz band defined as 1727.5-1747.5Mhz (UL) and 1822.5-1842.5 Mhz (DL). In the same way, the uplink and downlink operating frequency for 2100Mhz band defined as 1940-1960Mhz in UL and 2130-2150Mhz in DL.

The UL and DL operating frequency assignment were done based on existing technology operating frequency band status. For more, Table 4.3 shows current ethio telecom frequency band plan/allocation status in Adama city.

As stated in LTE deployment scenario formulation process, for each center frequency 20 Mhz bandwidth considered. This bandwidth selected to handle the future growing capacity of data service demand in the future. And, to use wisely the planned spectrum bandwidth of existing technology operating frequency band.

The cell edge data rate tareget was defined for the system as 2Mbps for DL and 1Mbps for UL based on network planning experience noticed from the studies and project documents. The cell edge data rate also translated to SINR as shown in the Table 4.6.

Table 4.6. SINR estimation for cell edge data rate.

Parameters	Downlink	Uplink
Defined cell edge rate (Mbps)	2	1
Allocated RB at cell edge (10%)	10	10
MIMO Scheme (MS)	2X2	1x2
Factor A	0.84	10
Factor B	0.85	1.24
PRB bandwidth (Mbps)	0.18	1.8
Rate per PRB(Mbit/s)	0.2	0.18
Required Spectral efficiency (bits/s/hz)	1.11	0.2
SINR(LINEAR)	1.28	1.11
SINR (dB)	1.06	1.55

Size and geographical informations were taken as input in to radio access network dimensioning based on the formulated deployment scenarios and defined market potential. The geographical and size of the targeted area distribution was illustrated as shown in Table 4.7.

Table 4.7. Size and geographical distribution ratio.

Deployment Scenarios	Size (65.2Km^2)	Geographical area distribution (%)	
		Urban	Suburban
DS1 and DS2	100%	46	54
DS3 and DS4	46%	46	0

To estimate the MAPL, the coverage related parameters requires are radio link budget (RLB) inputs (such as transmitter and reciever characterstics for both UL and DL), propagation model, geographical information and required coverage probability. For RLB estimation, all parameters are modelled (defined) and summarized in Table 4.8.

Table 4.8.LTE downlink and uplink radio link budget inputs.

Parameters	**DL**		**UL**	
	1800 Mhz	2100 Mhz	1800 Mhz	2100 Mhz
eNodeB – UE				
Number of PRBs (10%)	10	10	10	10
eNodeB TX power (dBm)	46	46	46	46
eNodeB antenna gain (dBi)	18	18	18	18
eNodeB antenna cable loss (dB)	2	2	2	2
EIRP	62	62	62	62
UE receiver characteristics				
UE noise figure (dB)	7	7	7	7
Thermal noise(dBm)	-101.42	-101.42	-104.43	-104.43
Receiver noise floor(dBm)	-94.42	-94.42	-97.43	-97.432
Required SINR (dB)	1.06	1.06	1.90	1.90
Receiver sensitivity	-93.36	-93.36	-95.53	-95.53
Control channel overhead(dB)	1	1	1	1
Rx antenna gain	0	0	0	0
Body loss	2	2	2	2

The enviromental characterstics also defined as shown in Table 4.9. Cell edge coverage probabaility was defined to 90 % for all deployment's scenarios. Indoor penetration value was considered based on geographical area type and its distribution ratio within the targeted area. Shadow margin also calculated based on coverage probability and Q-function as described in Section 3.5.

Table 4.9. Enviromental characterstics inputs.

Environmental characteristics				
Parameters	DL		UL	
	1800 (Urban)	1800/2100 (suburban)	1800 (Urban)	1800/2100 (Suburban)
Indoor Penetration Loss (dB)	13	11	13	11
Coverage Probability (%)	90	90	90	90
Shadowing loss	9.25	9.25	9.25	9.25
Interference margin	5	4	5	4

As per defined coverage related inputs , the maximum allowed propagtion loss (MAPL) calculated for both uplink and downlink and depicted in Table 4.10.

Table 4.10. Maximum allowed propagation los for both UL and DL.

		1800/2100 Mhz (Urban)	1800/2100Mhz (suburban)
Maximum Allowed Propagation loss (MAPL) (dB)	UL	130.21	130.28
	DL	126.11	128.27

Based on obtained MAPL from both up and down link, the smaller value of MAPL taken to estimate the cell radius. As shown in table, a smaller value of MAPL recorded in the downlink for both considered operating frequency and environmental models. That means the system is downlink limited for all formulated deployment scenarios.

Once the maximum allowable downlink propagation loss calculated and the cell radius estimated in consideration of proper propagation model. In this study, COST - 231 propagation model selected as it was suitable for urban and suburban areas. In addition, it only requires the central frequency and distance between the transmitter and the receiver as its input variable for computation.

To estimate the cell radius, two environment models and geographical size assumption considered for all formulated deployment scenarios. That means, 46% urban and 54% suburban environment models considered based on targeted area. Keeping this in mind, cell radius for both center frequency estimated and depicted in Figure 4.9.

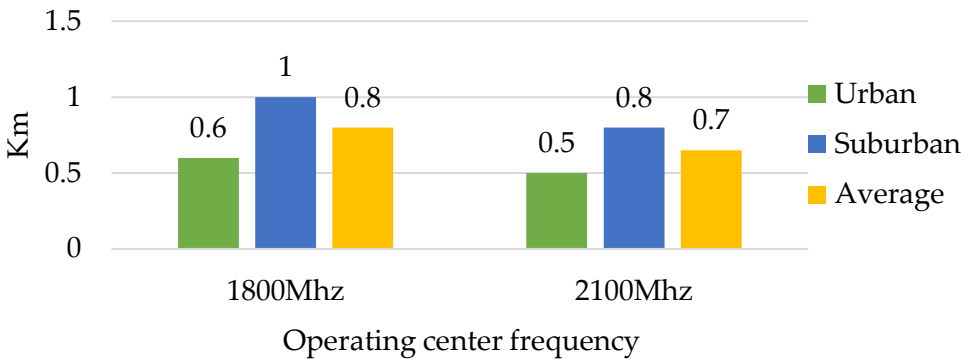


Figure 4.9.Cell radius (DL).

The number of sites was calculated considering total size of the targeted area. To estimate the number of sites per each center frequency , the eNodeB coverage area was assumed as hexagonal in shape and the site configured with 3- sector cell . The number of sites requires via each center frequency are illustrated in Figure 4.10.

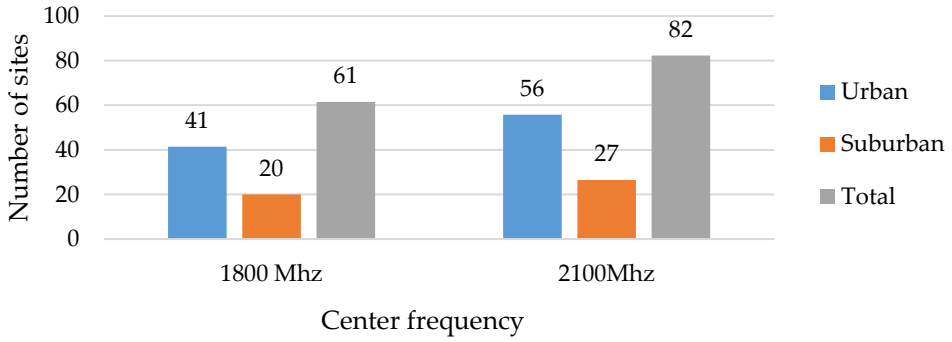


Figure 4.10.Number of site (eNodeB's) per total targeted area.

ii) Capacity Dimensioning

In LTE radio network dimensioning, aside from the coverage dimensioning, capacity dimensioning was also an essential factor. The inputs for capacity dimensioning are the number of forecasted users, their demanded service type, subscriber monthly data usage level, traffic model, channel bandwidth and modulation coding rate.

It is recalled that, deployment scenarios were formulated based on operating frequency and demand capacity uncertain factors. Demand capacity uncertain factor extrema value defined as high and low demand capacity. The high and low value defined based on current existing 3G capacity (168,000) [48].

This demand capacity is directly related with the forecasted users as described in marketing analysis section That means, if service user forecasted at end of the study year greater that 168,000 it is considered in high capacity demand deployment scenarios (DS1 and DS2). Whereas, if the service user less than 168,000 it is considered in low capacity demand deployment scenarios (DS3 and DS4).

In order to handle all forecasted users, the system needs to be dimensioned with the maximum number of forecasted users in capacity aspects (i.e value obtained at the end of the study year) . Table 4.11 shows the number of users forecasted in each year within the defined study period.

Table 4.11. Forecasted users per each year.

	Y1	Y2	Y3	Y4	Y5	Y6	Y7
DS1 and DS2	9350	23580	45250	78240	128460	204910	321300
DS3 and DS4	4670	11790	22630	39120	64230	102460	160650

The capacity dimensioning was done only for data service considering the predefined monthly users usage level. Monthly data service consumption per subscribers defined mainly based on the existing 3G network plan in Adama city and 4G network plan in Addis Ababa.

Users segmentation with three categories was considered in the study in order to correlate the future growth of data demand service with a capacity of the network as shown in Table 4.12.

Table 4.12. Traffic model.

Customers category	Traffic usage/ Month/user (GB)	Service usage ratio (%)	Traffic ratio (%)	
			DL	UL
Category 1	15	10	70	30
Category 2	10	30	70	30
category 3	5	60	70	30

The Traffic model starts with monthly user data service consumption, then tuned with service usage ratio followed by traffic model (UL and DL traffic) ratio. During traffic model, two busy hours within a day was taken. Thus, average throughput per users estimated and summarized as shown in Table 4.13.

Table 4.13. Average throughput persubscribers.

Average throughput per subscriber (Kbps)		Average throughput per subscriber in busy hours (Kbps)	
Category 1	44.44	Dl and UL	32.70
Category 2	29.63	DL	22.89
Category 3	14.81	UL	9.81

To estimate the peak cell throughput, the channel bandwidth and modulation coding rate were essential parameters. For the LTE system, all parameters used to estimate the cell throughput was defined as shown in the Table 4.14. The modulation coding rate, for all QPSK,16QAM, and 64QAM was taken as to 0.3,0.38 and 0.45 respectively based on earlier technology network plan and experience, and literature reviews.

Table 4.14.LTE system peak cell throughput estimation parameters.

Channel bandwidth	20Mhz
Used BW (Mhz)	20
Effective BW(Mhz)	19
BW of one carrier (Khz)	15
Total subcarrier	1200
Symbol per 1ms for RB	15360
Symbols per 1ms (Mbps)	15.36

The average number of users that can be served in a cell was obtained by considering a single eNodeB peak throughput capacity with traffic model obtained from a defined monthly data consumption plan. Accordinlgy, peak cell (site) throughput and the number of users served by single enode B estimated and shown Table 4.15.

Table 4.15.Number of users and throughput estimated per single site.

	Site (3-Cell) througput (Mbps)	Average throughput per subscribers (kbps)	Max number of users / Site
DL	117.99	241.46	4442
UL	58.99	103.48	5182

The number of sites estimated via capacity dimensioning for each deployment scenarios were illustrated as follows in Figure 4.11.

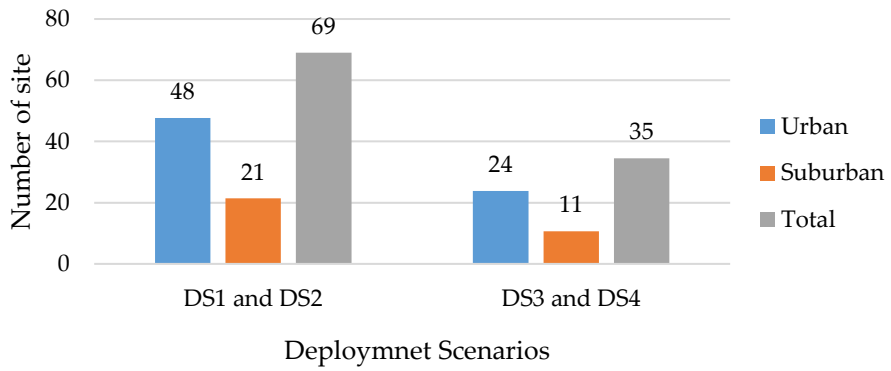


Figure 4.11. Number of site (eNodeB's) via capacity dimensioning.

As described as the start of this chapter, the output of radio access dimensioning was used to estimate the feasibility of the formulated deployment scenarios. Hence, the obtained number of eNodeB is the main output of LTE dimensioning exercise.

Two values of site numbers are expected, one from coverage and second from capacity evaluation. As described in Figure 2, the number of sites with respect center frequency calculated. To estimate the number of sites for all formulated deployment scenario it is essential to re define the target area to relate with demand capacity.

Accordingly, total targeted area of the city considered for DS1 and DS2. In the same manner, urban area of the city considered for DS3 and DS4. Hence, the obtained number of sites via capacity and coverage dimensioning for all deployment scenarios summarized in Table 4.16.

Table 4.16. Number of sites.

Deployment Scenario	Coverage	Capacity
DS1 (1800Mhz-High demand capacity)	61	69
DS2 (2100Mhz-High demand capacity)	82	69
DS3(1800Mhz-Low demand capacity)	41	24
DS4 (2100Mhz-Low demand capacity)	46	24

As per network dimensioning rule, the maximum number of sites taken and considered further in the cost estimation.

In accordance with existing 2G/3G technology deployment setup in the Adama city, there are around 68 sites in both single RAN (3G) and co-site setup [48]. Based on this, the overlay network strategy was chosen in this study to avoid uncertainty and risks related to cost.

As noted from several studies, overlay network strategy was a common strategy for operators already deployed 3G and 2G technology to migrate in to LTE [49] [55]

[56]. Accordingly, for the emerging city, co-site location of LTE network with existing 2G/3G technology defined to avoid cost relate to BTS tower implementation. For this specific case existing 68 sites taken into cost evaluation based on each deployment scenario characteristics.

iii) Rollout Plan

Roll out plan used in this study was to determine the number of network elements to be deployed in each year of the study period. It is essential parameters to avoid underutilization of resource (related to capacity) and uncertainty related to cost due to financial factors, technology lifetime and risks happens due to estimation errors.

Most of studies usually used 70/30 approach as strategic planning for roll out plan. And, in this study the same approach considered as strategic plan. Number of eNodeB distribution in each year via 70/30 approach was depicted in Figure 4.12.

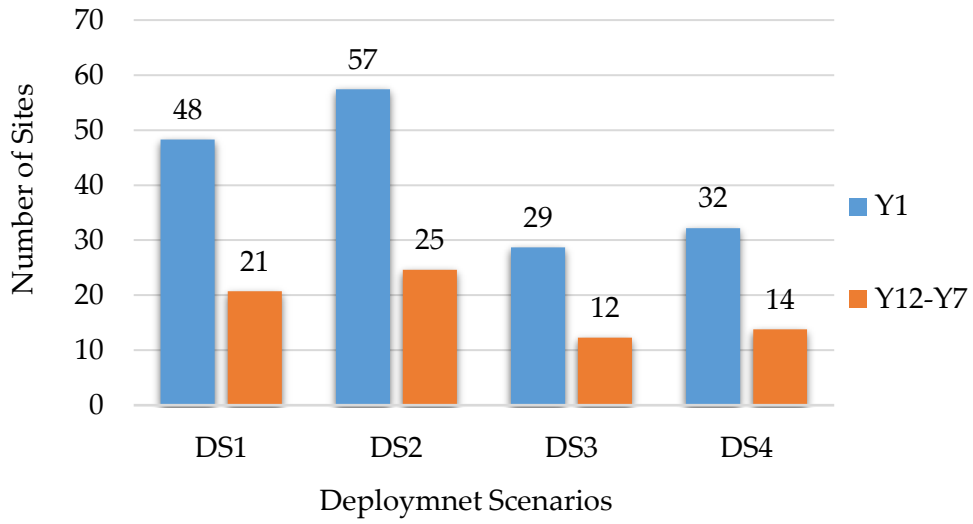


Figure 4.12.Roll out plan.

4.2.3. Cost and Revenue Modeling

The cost of the network is one of the core elements for measuring the feasibility of LTE deployment scenarios. The cost of network directly depends on coverage, capacity and traffic demand requirements.

The cost of the network generally splits into investments and operational costs. After the network elements estimated from the RAN dimensioning, the next step is to estimate the capital investment required to deploy the system in consideration of roll out plan. As per CAPEX mathematical modeling defined in section 3.5 the per unit value of each parameters in CAPEX cost defined as follows in Table 4.17.

Table 4.17. Initial year roll out CAPEX cost.

		DS1	DS2	DS3	DS4
1	Spectrum	200000	200000	200000	200000
2	Site Survey and Network design	172500	205000	102500	115000
3	New eNodeB (including network elements, installation)	94500	1323000	0	0
	Cost related to eNodeB on existing site	2856000	2856000	1722000	1932000
	Co site installation	71400	86100	43050	48300
	Service related to eNodeB implementation	2450	34300	0	0
4	UE related costs	0	0	0	0
5	Backhaul link cost	120750	143500	71750	80500
6	Coe network costs	800000	800000	800000	800000
Total ($)		4317600	5647900	2939300	3175800

The cost of each parameter in CAPEX estimation was vendor specific. In this study, the CAPEX cost was modeled and estimated based on already deployed LTE technology CAPEX cost in Addis Ababa (Huawei) and per unit cost database of industry standard.

To model and estimate the CAPEX Cost for each deployment scenario first network overlay strategy was chosen to deploy the LTE network on already existing sites(technology) to avoid the cost for installation and acquisition of a new site, BTS installation and site rental/lease charges.

Accordingly, considering the data from vendor equipment lists cost, industry standard per unit cost data base and other operators experience the initial year investment cost per each CAPEX parameters for each deployment scenarios are depicted in Figure 4.13. In this study, most of data considered in the investment cost estimation mainly from vendor specification equipment cost (Huawei) of deployed LTE in Addis Ababa.

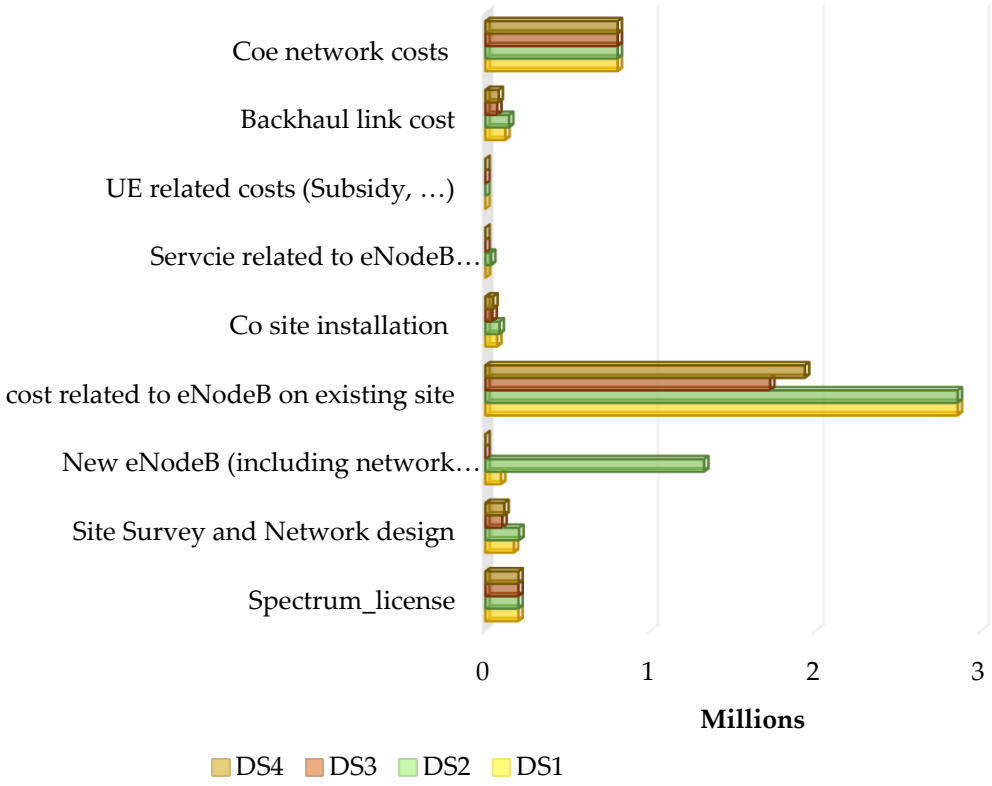


Figure 4.13.Initial year investment cost per each parameter.

Considering the above stated initial CAPEX cost as an input and equation (30), the CAPEX cost breakdown with respect to its component parameters and the CAPEX cost trends within the study year has been estimated via simulated evaluation tool in the MATLAB and the results depicted in the results and interpretation Chapter.

To model and estimate the operational expenditures, all OPEX estimation parameters required must to be defined first as per the stated OPEX cos mathematical modeling in section 3.5 and calculated based on Equation (31). In the calculation, all network and business - driven parameters were considered.

As described in the Section 3.4, the operational expenditures related to a certain project are often more difficult to predict than the capital expenditures. In this study, the data for OPEX cost estimation mainly taken from annual OPEX data received from currently in-service Addis Ababa LTE network yearly report

Table 4.18. OPEX parameters distribution.

OPEX parameters		Distribution (%)	Cost per unit ($)
Network driven per site /year		60	32500
i	Network maintenance and operation	36	19250
	Site rental		250
	License renewal		0
	Energy consumption	15	8125
	Backhaul costs per site/year	9	4875
Business driven		40	21667
ii	Marketing and sales (advertising)	20	10833
	Billing and customer care	8	4333
	Customer service related costs	6	3250
	General Administration	6	3250
Total ($)			54167

And, targeted literatures (other operators experience) considered for business-driven OPEX cost parameters model. Estimated OPEX costs trends and its distribution with respect to the parameters illustrated in results and interpretation section.

Total network cost is commonly known as total cost of ownership (TCO) and its obtained by the sum of total investment and operational expenditure cost. All total cost of CAPEX, OPEX and TCO and its the trends within the study period for all LTE deployment scenarios presented in the result section.

One of the most important key parameters in marketing analysis is revenue forecast. Revenue projection per year is obtained based on monthly or yearly basis data consumption level of service users, charging and pricing policy sated and number of forecasted data service users. For this, study the revenue modelling approach modeled in Section 3.4 used for revenue analysis.

As noted from several studies [8] [9] [40], each LTE service user's monthly data consumption forecasted in multiplying existing 3G technology data consumption level with 110% so as to account new technology benefits (10% monthly data consumption additional due to new technology deployment).

Monthly data usage level (data traffic) per user for this study obtained in considering the existing 3G technology user's monthly data consumption level. During the definition of monthly data usage of users, sample bill data and survey of selected sample user's monthly data usage level (31 users) considered mainly targeted on high data service consumers users.

Monthly data traffic usage level with respect to each user, user's segmentation and device type distribution ratio defined in Table 4.19. Service charging and activation fee also considered in this study based on current ethio telecom pricing policy [57].

As defined in Table 4.19, 1GB traffic was stated by users who have handset device whereas 10GB traffic for users using the service through dongle device type [48]. In addition, in each year 5% additional data consumption rate also considered to consider the future increasing data service demand capacity.

Table 4.19.Service usage and connection fee.

Service usage and Connection fee			
Service type: - Data Service		Service tariff 0.30MB= 0.3ETB [57]	
Monthly service fee	Handset (98%)	1 GB	0.30/MB*1000MB= 300ETB
	Dongle (2%)	10 GB	0.30/MB*10000MB= 3000ETB
One-time activation fee	Handset	60 ETB	Monthly service charge = 300*0.98+3000*0.02 =354 ETB
	Dongle	60ETB	

During revenue modelling and estimation, monthly data consumption level of 3G users, forecasted users per year, and ethio telecom service charging policy and one-time activation price mentioned in Table 4.19 and Equation (31) were considered.

Revenue forecasting approach described in section 3.4 was considered based on bass model (user forecast model) to estimate the users in the given study period. The projected revenue results presented in result section.

Chapter 5 : Results and Interpretation

As per LTE deployment scenarios analysis described in Section 4.1, the formulated deployment scenarios for emerging city are summarized as shown in Table 5.1. Accordingly, four deployment scenarios are formulated based on selected uncertain events extrema values. The formulated deployment scenarios also named as Deployment Scenario 1,2,3 and 4 as shown in Table 5.1.

Table 5.1.Formulated deployment scenarios.

LTE deployment scenario Name	Abbreviation	Description
Deployment scenario 1	DS1	1800Mhz under high demand capacity
Deployment scenario 2	DS2	2100Mhz under high demand capacity
Deployment scenario 3	DS3	1800Mhz under low demand capacity
Deployment scenario 4	DS4	2100Mhz under low demand capacity

As noted from the deployment scenarios matrix in Section 4.1, all formulated LTE deployment scenarios are a function of coverage and capacity. That means it is indirectly a function of frequency and number of users.

The formulated deployment scenarios (DSs) can represent the future possible LTE deployment alternatives in an emerging city of Ethiopia. Further, it is essential to perform a feasibility assessment for each formulated deployment scenario to justify it is viability in terms of technical and economic aspects.

Based on the formulated deployment scenarios, the techno economic results and its interpretation are illustrated in the following subsections.

5.1. Market Forecast

Understanding the existing population is essential as the future market condition is usually determined by the existing market situation. The service users forecast results for each formulated deployment scenarios via growth model (specifically Bass model) are illustrated in Figure 5.1.

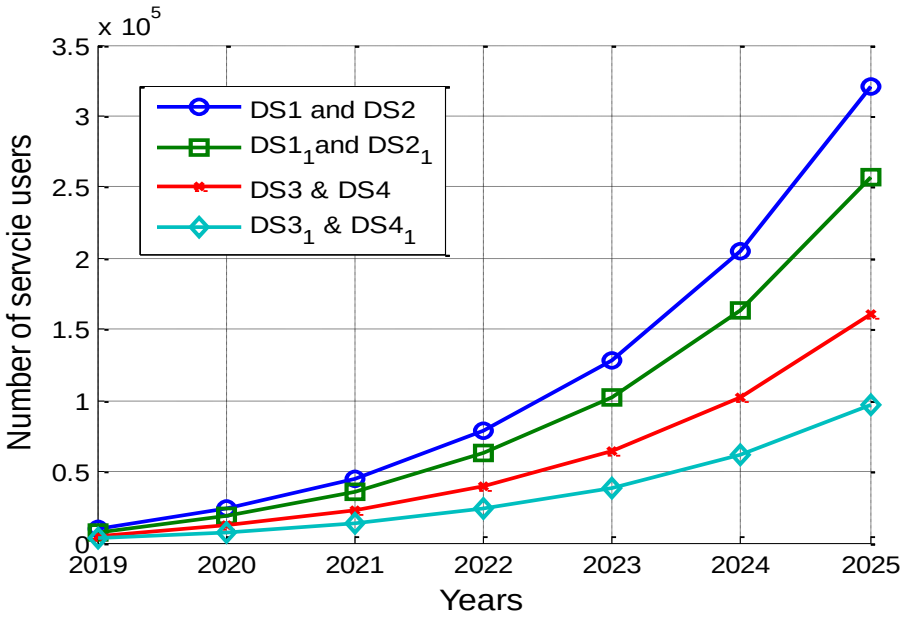


Figure 5.1.Users forecast for each of formulated deployment scenario.

As shown in Figure 5.1, the total LTE data service users in the next 7 years will increases for all formulated deployment scenarios. Users forecast in DS1 and DS2, and DS3 and DS4 are basis on the market potential of 100% and 50% respectively.

As described in Section 4.2.1, the market potential defined in percentage with respect to the population of the city. In the same way, $DS1_1$&$DS2_2$and $DS3_1$&$DS4_1$ are specially considered deployment scenarios which are formulated based on 80% and 30% market potential.

At the end of seven years, expected LTE data service users are 321, 300 and 160,650 for DS1 and DS2, and DS3and DS4 respectively. Similarly, expected LTE data service users for $DS1_1$&$DS2_2$&and $DS3_1$&$DS4_1$(for special considered deployment scenarios) are 257,047 and 96,390 respectively.

The second most important parameter in the marketing analysis is the service user's penetration rate. The service user's penetration rate results with respect to defined market potential and the population of the city depicted in Figure 5.2.

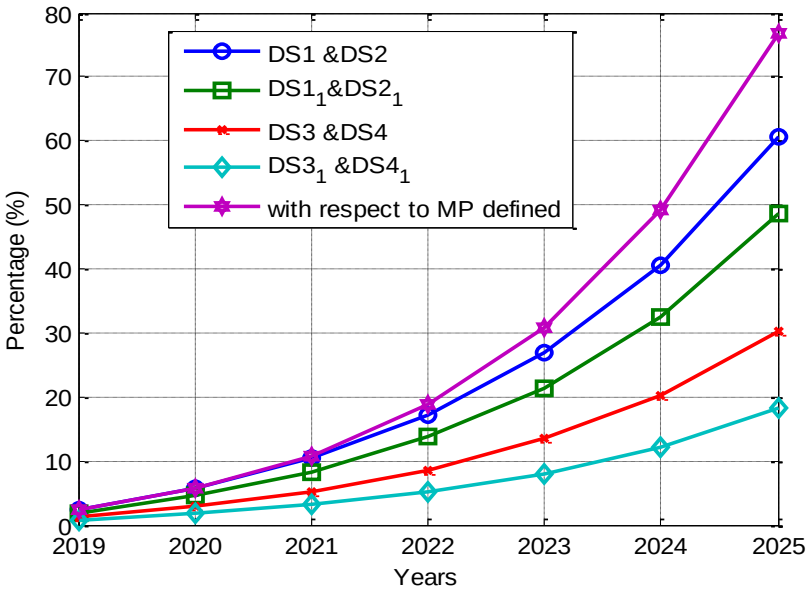


Figure 5.2.Service users penetration rate.

As shown in Figure 5.2 (violet color), at the starting time of the deployment period, the service users' penetration rate is less than 10%. However, the penetration after 7 years is estimated to 75% with respect to the initially defined market potential for all deployment scenarios. The data service penetration rate value obtained for all deployment scenarios are the excepted quantity as the new telecom technology once the deployment is started the penetration usually faster due to the network externality effect.

Similarly, the data service user's penetration rate with respect to population forecast is that at the starting of the deployment period the user penetration rate almost less than 5% for all formulated deployment scenarios. Whereas, at the end of years it is estimated to be 60.75%,48.6%, 30.37% and 18.22% for all DS1 and DS2, $DS1_1\&DS2_2$, DS3 and DS4, and $DS3_1\&S4_1$respectively. The volatile nature of mobile service and the user's behavior in accessing information and service on mobility will contribute to the rise of the penetration rate for mobile network subscriptions in the next 7 years.

When compare the penetration rate of the users in the user segmentation level, the residential user segmentation category takes the lion share of the market when compared to the enterprise user's category. This also the nature of the service type as mobile telecom service is most volatile, and users usually tend to use this service when they are out of office and out of their house unlike that of enterprise user category which is limited to the office.

5.2. Technical

Once marketing requirements defined, the next part in TE modelling approach is dimensioning the LTE RAN based on network requirement stated and users forecast. As noticed from the cell edge data rate target definition result in Table 5.2, the estimated signal interference to noise ratio (SINR) in downlink is less than uplink. This is an expected result, as SINR depends on multiple input multiple output (MIMO) antenna type, spectral efficiency and assigned physical resource block (PRB) to the cell edge users by the serving cell.

Table 5.2.SINR and MAPL.

	Cell edge data rate	**SINR (dB)**	**MAPL (dB)**	
			1800/2100Mhz	
			Urban	Suburban
UL	2Mbps	1.06	128.28	132.11
DL	1Mbps	1.55	126.11	128.27

Hence, it is confirmed that SINR is directly proportional to spectral efficiency and defined cell edge data rate. Whereas, it is inversely related to the multiple input multiple output antenna types and allocated physical resource block (PRB) to the cell edge users by the serving cell.

Correspondingly, the MAPL greater in uplink in both defined frequency band. This difference resulted from the environmental characteristics of the targeted area, required SINR at the cell edge, indoor propagation loss, coverage probability,

interference and shadow margin considered. Similarly, the indoor propagation loss was higher in an urban environment due to the presence of several building compared to suburban.

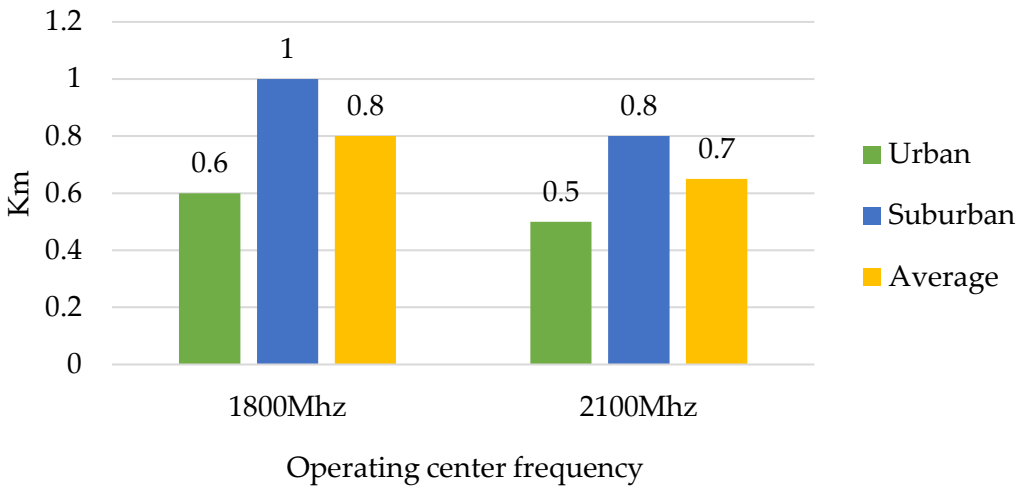


Table 5.3. Cell radius.

As observed from the coverage dimensioning results, the obtained cell radius in an urban area is smaller compared to suburban for both defined center frequency band. This result also the likely one as the multipath effect (from reflection, diffraction and scattering of environment surrounding) in an urban environment is highly significant for the decreasing the coverage due to the high floor buildings and other loss components which contribute for the increase of multipath.

It is quite general that, cell radius depends on environmental and propagation model considered. To comprise the effect of multipath average cell radius was taken based on geographical information and environmental model considered in each LTE deployment scenario. Accordingly, in downlink 0.6Km for urban, 1Km for suburban and 0.8Km average cell radius attained for 1800Mhz based on stated network requirements, selected propagation and environmental model. In the same manner, 0.7Km cell radius attained for 2100Mhz operating frequency.

Correspondingly, small cell radius recorded in the higher frequency band and comparatively large cell radius recorded in the small frequency band within the same

environmental characteristics. In another way, small cell edge data rate requirement leads to higher cell radius and vice versa.

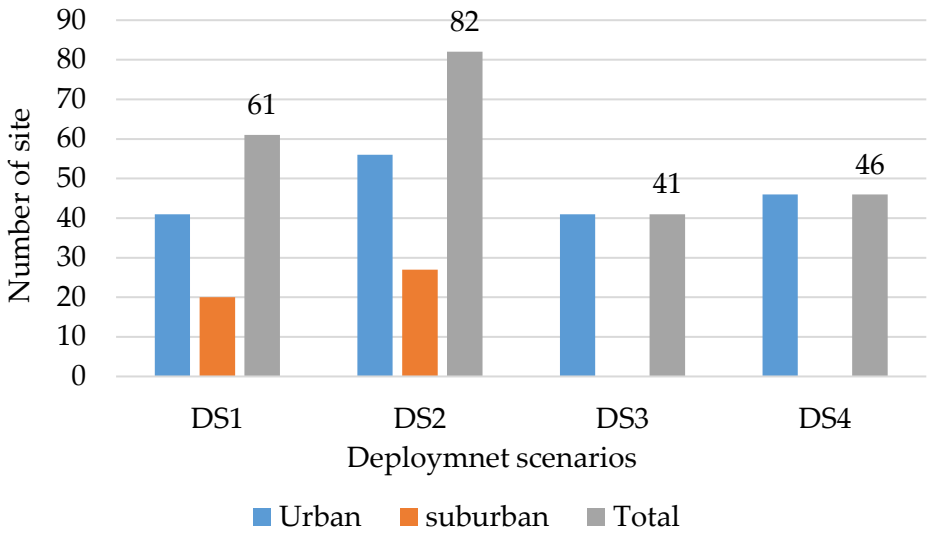


Figure 5.3.Number of sites per deployment scenarios (Via coverage dimensioning).

The number of sites (eNodeB's) obtained via coverage dimensioning illustrated in Figure 5.3. Based on the stated size and geographical information of each deployment scenarios numbers of eNodeB's estimated via coverage dimensioning approach are 61,82,41 and 46. In estimating the number of sites, the geo type distribution also considered to find the optimum number of eNodeB's for each deployment scenarios. As shown in Figure 5.3, there are more numbers of eNodeB's in the urban areas and comparatively less number in the suburban areas for both DS1 and DS2.

The size of the urban area is only 46%, but the urban area needs a greater number of eNodeB's to cover the targeted area. This is because, the cell radius coverage in urban is smaller compared to suburban because of environmental effects. Urban environmental conditions require a high number of eNodeB's to mitigate the loss due to a multipath effect of transmission system compared to suburban areas.

Like coverage dimension, capacity dimensioning also essential in the radio access network dimensioning and techno economic analysis. Capacity related results are depicted as follows in Table 5.4.

Table 5.4.Capacity dimensioning related results.

	Site (3-Cell) througput	Average throughput per subscribers	Average throughput per subscriber's (busy hour)	Maximum number of users / Site
DL	117.99Mbps	241.46 kbps	22.89kbps	4442
UL	58.99Mbps	103.48	9.85kbps	5182

The maximum number of users forecast within the study period was taken as input to dimension the system capacity. Based on stated inputs, dimensioned average throughput per subscriber in the busy hour are 22.89 and 9.85 Kbps for DL and UL respectively. As noticed from the table, the average DL throughput per subscriber was almost twice that of the UL average throughput in the busy hour. This result also the predictable value due to the natures of the service users (most of the time the users download the files, show live streaming).

The peak eNodeB throughput obtained are 104.34Mbps for downlink and 44.24Mbps for uplink. Again, these figures are the expected one like that of average throughput per subscribers even though it is slightly far from the LTE system theoretical capacity. The downlink throughput was greater than uplink. This always true due to the uplink transmission is slower than downlink. That means it uses less rate modulation (16QAM compared to 64QAM) and a single antenna.

The higher user throughput in the cell means there will be always high average cell throughput and vice versa. But there is also a possibility that a cell can have high average cell throughput and very low average user throughput. Because a cell can have some users which are in excellent radio frequency conditions while others are in poor radius frequency conditions.

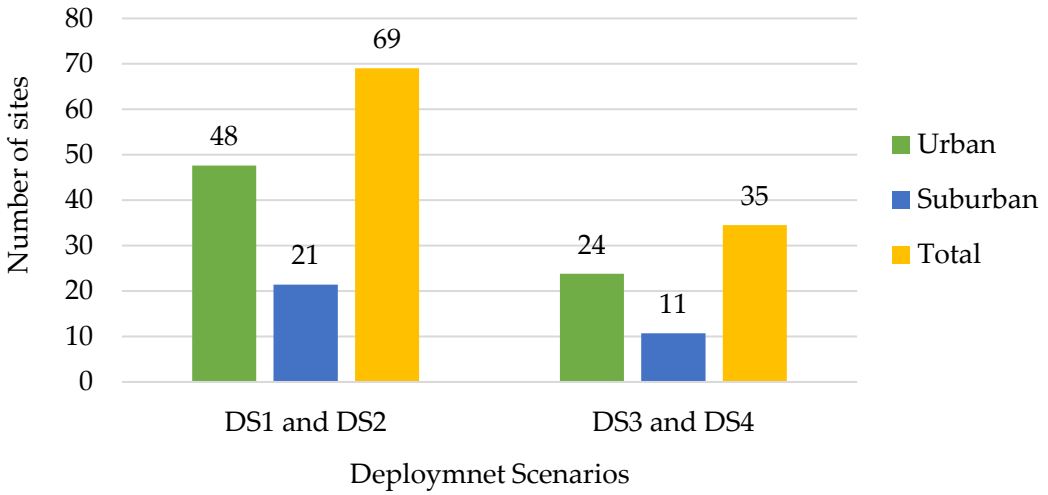


Figure 5.4. Number of sites via capacity dimensioning.

The number of eNodeB's also projected via traffic model and peak cell throughput of the system as shown in Figure 5.4. Accordingly, the numbers of eNodeB obtained via capacity dimensioning are 69 and 35 for DS1and DS2, and DS3 and DS4.

As described in the deployment scenario formulation section, in DS1 and DS2 high matured users will be defined and expected. In these deployment scenarios, to meet the demand of the users within defined cell edge data rate it is essential to have a number of eNodeB's to serve the users within the eNodeB's range.

Table 5.5.Maximum number of sites per each deployment scenario.

Deployment scenarios	Coverage	Capacity	Maximum value taken	System description
DS1	61	69	69	Capacity limited
DS2	82	69	82	Coverage limited
DS3	41	24	41	Coverage limited
DS4	46	24	46	Coverage limited

To decide the number of eNodeB's required for the system, it is necessary to compare the results obtained from both coverage and capacity dimensioning approach per each deployment scenarios. The maximum number of sites documented for all deployment

scenarios depicted and summarized in Table 5.5. Hence, the number of eNodeB's taken for cost and feasibility evaluation were 69,82,41 and 46 for all DS1, DS2, DS3 and DS4 respectively.

To minimize the cost of the network elements and use existing resource wisely, the existing technology site number and setup considered with overlay network deployment strategy. Furthermore, to avoid underutilization of resource and financial risks, 70/30 rollout approach applied for cost evaluation.

5.3. Cost and Revenue

The network dimensioning results are the starting point to calculate the cost of the network. The cost of the network generally categorized into capital expenditures and operational expenditures cost.

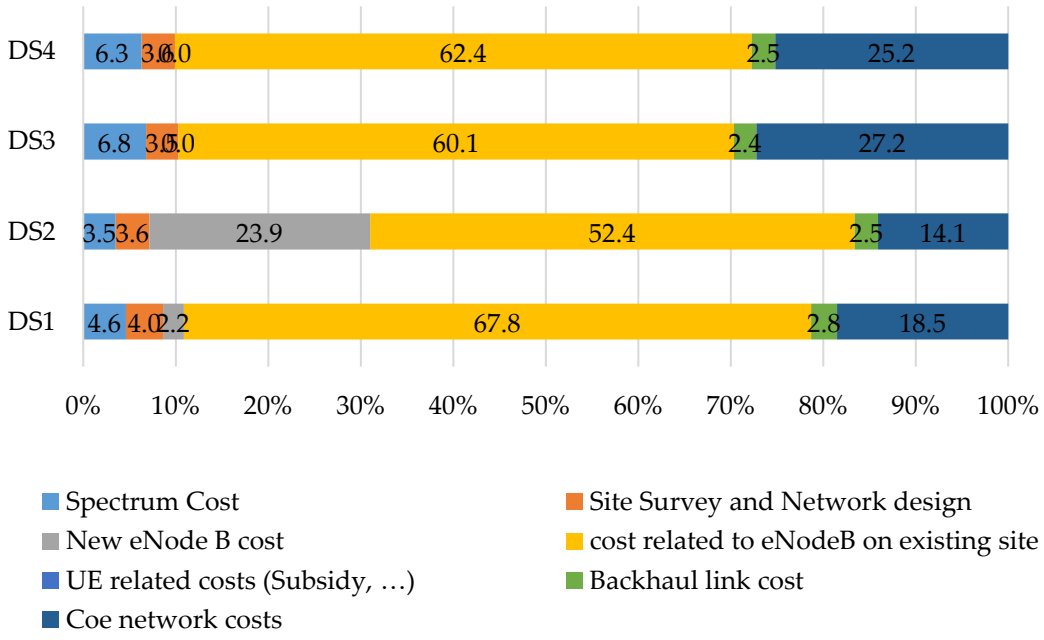


Figure 5.5.CAPEX cost breakdown.

Based on chosen network deployment strategy (overlay network), defined rollout plan (70/30 approach) and CAPEX cost parameters model, the initial year investments cost percentage with respect to its modeled parameters for each deployment scenarios are shown in Figure 5.5.

The yearly CAPEX cost within the study period calculated via CAPEX model described in Section 3.6 and in consideration of 5% yearly price trends. The CAPEX cost trend within study period for all deployment scenarios are depicted in Figure 5.6.

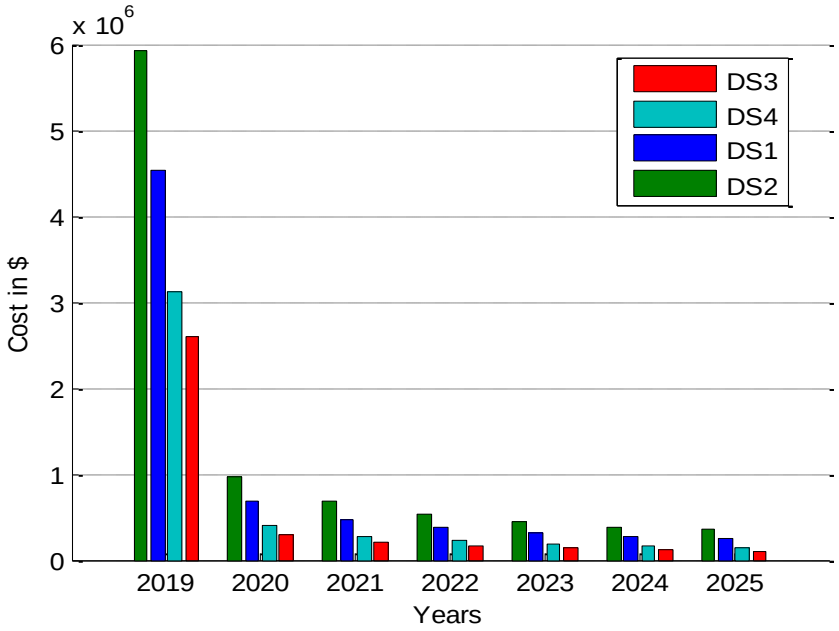


Figure 5.6. CAPEX cost trends.

As shown in Figure 5.6, the investment (CAPEX) cost significantly decreases with the study periods. This trend was also the expected one as the deployment cost of new technology during the beginning of the deployment was high and as time goes, it gets decreased.

As noticed from Figure 5.5, the lion share of the investment costs is taken by eNodeB related costs such as the implementation of LTE radio access network and enabling of multiple input multiple output antenna and transmitter on the existing sites. The second and third CAPEX cost share taken by core networks and spectrum costs for all selected LTE deployment scenarios. And, it also noticed that all these costs lessen as the time goes within the study period.

The reason why the high share of CAPEX cost taken with eNodeB implementation on existing sites is that due to the chosen network deployment strategy (i.e. overlay network). Further, LTE is the successor of 3G technology. Hence, overlay network

deployment strategy is a recommended migration path towards LTE as noticed from several studies and also for an emerging city [22] [49] [58].

The obtained value also logical, because the city is in an emerging status and it is a good reason to handle the growing demand and use the existing resource. Likewise, based considered input data source and OPEX cost model, the operation cost estimation parameters percentage share for each deployment scenarios per annual is depicted in Figure 5.7.

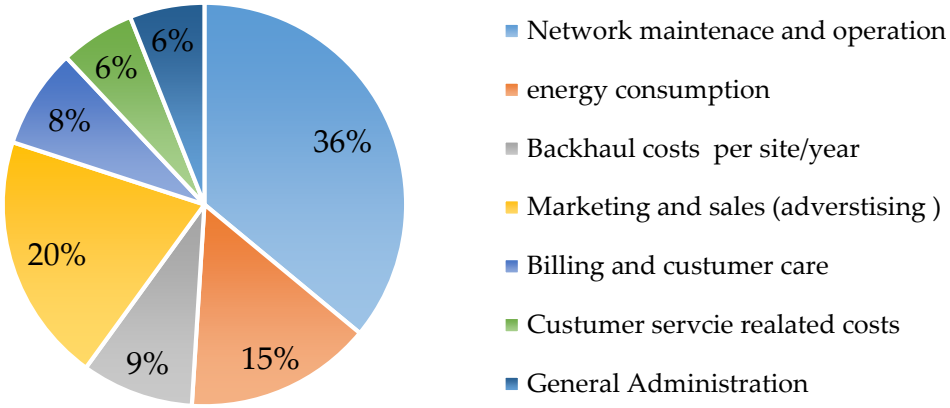


Figure 5.7. OPEX cost breakdown.

Using Equation (31), the estimated OPEX trends within the study period via simulated tool was depicted in Figure 5.8. During OPEX calculation, the rollout plan and 5% yearly price trends are considered.

The next and most important category of cost of the network was OPEX cost. As shown in Figure 5.8, the operational cost increases as the time goes. This trend also reliable due to the high dependence of operational cost on numbers of users and deployed network elements. Mostly, a great value of operational cost recorded after the third year of the deployment period.

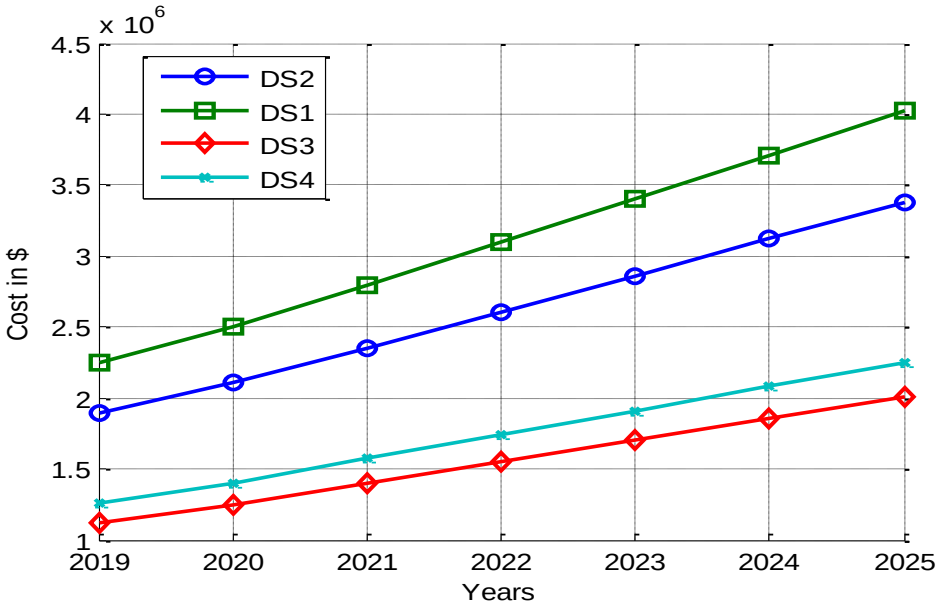


Figure 5.8. OPEX cost trends.

As observed in Figure 5.7, the high share of operational cost taken by network driven costs such as operational and maintenance, site rental and energy consumption costs. This due to the network driven costs direct relation to the numbers of users served and sites required to serve the users.

Business-driven costs such as marketing and sales cost, billing and customer service costs and general administration costs also generally depend on the numbers of users and market potential assumed. Marketing and sales costs are gradual decreases as the time goes due to increment of user's awareness level for the service and technology. Whereas the billing and customers related, and administration costs rise with the number of users.

The next high share of OPEX cost are taken by backhaul and core network operational costs. The backhaul cost almost related to the number of eNodeB or sites. It is contribution to the OPEX cost is gradual increment.

The network cost or commonly called total cost of ownership (TCO) projected and estimated as shown in Figure 5.9. At the start of the deployment year, the total cost of the network is at high level, in the second and three years its reduced almost to half.

For the rest of the year, it is increasing linearly with the equation of 0.16$M/year) (∗ y) + 3M$ where, y is the number of years.

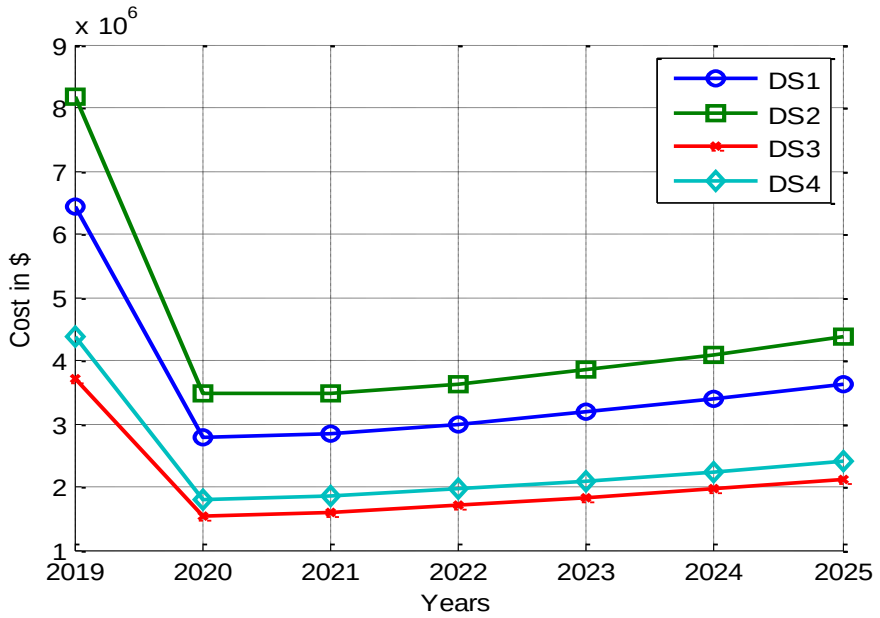


Figure 5.9.Total cost of ownership (TCO) trends.

This result obtained also quite logical. That means for the first one and two years the CAPEX cost takes the high share whereas in the rest of the year OPEX cost takes the high share. This also happens due to the OPEX cost dependencies on the number of users and network elements.

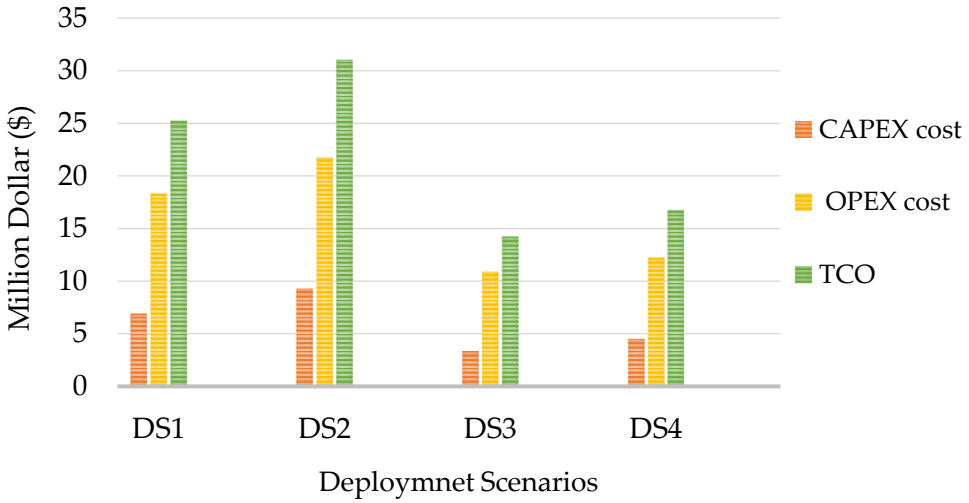


Figure 5.10. TCO and total CAPEX and OPEX cost.

The total CAPEX cost, OPEX cost and TCO per each deployment scenarios estimated and illustrated in Figure 5.10. As shown in Figure 5.10, the total estimated CAPEX costs

for all DS1, DS2, DS3 and DS4 are 6.90M$, 9.27M$,3.6M$and 4.5M$ respectively. Likewise, the total estimated OPEX cost within the study period are 18.32M$, 21.72M$, 10.88M$ and 12.21M$ for all DS1, DS2, DS3 and DS4 respectively.

In addition, the TCO estimated for all DS1, DS2, DS3 and DS4 are 25.22M$,30.99$, 14.22M$ and 16.72M$ respectively. As noticed in the figure, the total OPEX cost for all deployment scenarios is almost twice that of the total CAPEX cost. The result was the expected one as OPEX cost is directly proportional to users and sites. And, once the investment deployed the cost present was the operational cost.

Similarly, as shown in Figure 5.10, the TCO, CAPEX and OPEX cost related to DS1 and DS2 are high unlike to DS3 and DS4. This is due to the high percentage of market potential and large area coverage consideration during the deployment scenario formulation in DS1 and DS2.

Revenue projection is one of the key marketing and economic analysis parameters.

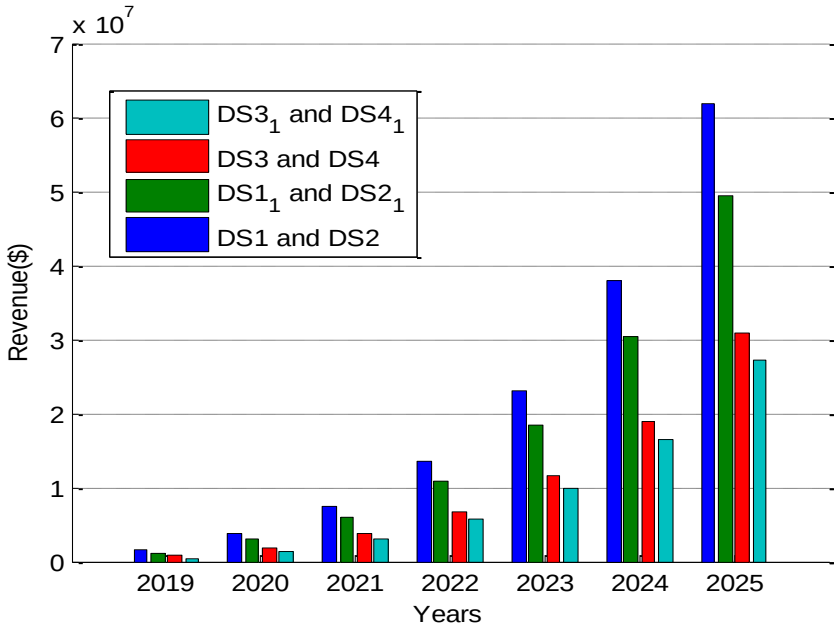


Figure 5.11.Projected revenue for each formulated and specially considered DS.

As shown in Figure 5.11, the projected revenue is directly proportional to the number of users and increasing in an exponential form for all deployment scenarios within the

deployment period. At the end of the study period, the projected revenue was 61.77M$ and 30.88M% for DS1 and DS2, and DS3 and DS4.

Likewise, the projected revenue at the end of the seventh year for specially considered deployment scenario such as &and $DS1_1$&$DS2_1$, and &and $DS3_1$&$DS4_1$are 49.4 M$ and 27.173 M$. This projected revenue may allow the operators to expand the network elements for high coverage and more network capacity.

Likewise, based on the projected revenue the average revenue per users' results depicted in Figure 5.12. The average revenue per user in monthly basis also in an increasing rate with a flat slope of 0.35$/Year after the second year.

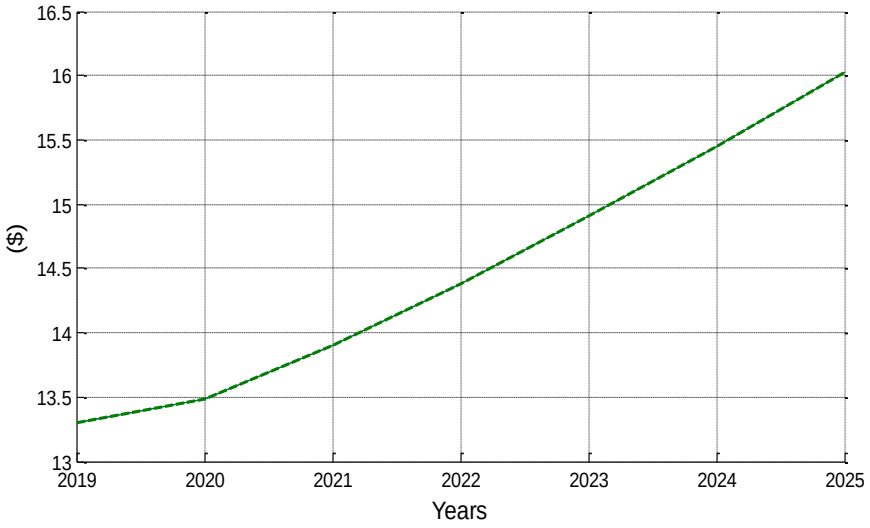


Figure 5.12.ARPU.

The ARPU incremental mainly results from an increasing rate of a number of data service users and user's data service consumption level as the time goes.

5.4. Economic

The last part of the techno economic analysis is to evaluate the economic feasibility of formulated deployment scenario. Accordingly, the economic feasibility of each deployment scenario evaluated via discounted cash flow analysis method and the results of each economic parameters and indicators illustrate in this subsection.

Based on obtained total network cost, projected revenue (from marketing analysis part) and defined discount factor (13%) the results of the net discounted cash flow per each year and deployment scenarios are illustrated as shown Figure 5.13.

In most of the studies, the discount factor value is taken in the range of 10-15% for new investments/technology deployment. Accordingly, in this study, 13% discount factor considered for discounted cash flow analysis.

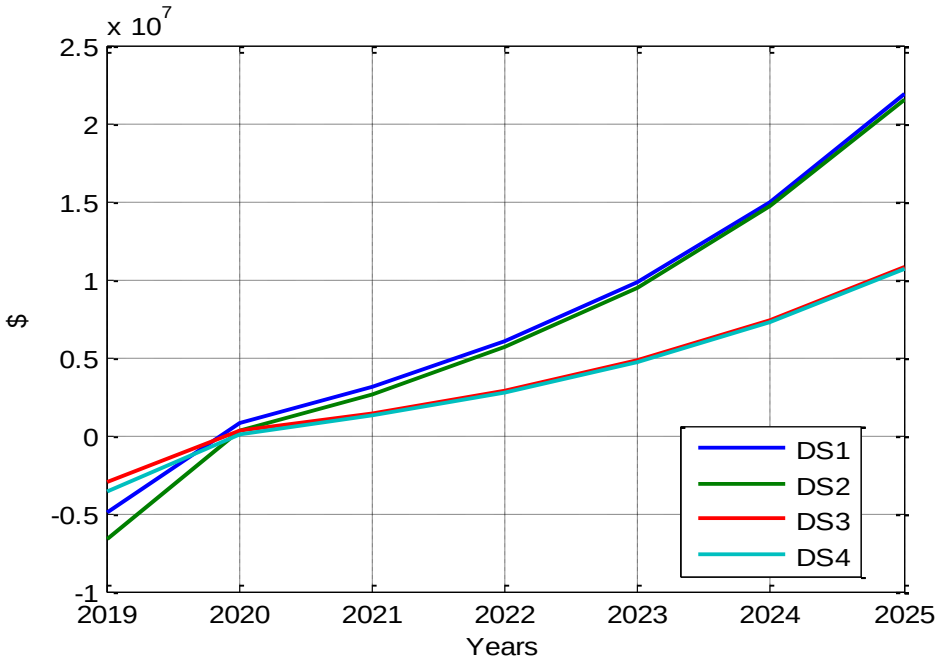


Figure 5.13. Discounted cash flow.

As shown in Figure 5.13, after the second year of the deployment period, the discounted cash flow increasing in linearly fashion for all deployment scenarios. For both DS1 and DS2, and DS3 and DS4 the discounted cash flow approaching to the same value as the time goes especially after the second year.

The net discount cash flow is linearly starting at the high slope and gradually linearly increasing from a negative to high positive value after the second year. This trend arises, due to the number of data users forecasted and its dynamic data usage behaviors which in turn related to the revenue projected.

The result of cumulative cash flow trends within the study period for each deployment scenarios shown in Figure 5.14. After the 3rd year of the deployment net discounted cumulative cash flow reaches zero and increases exponentially for the rest of the years.

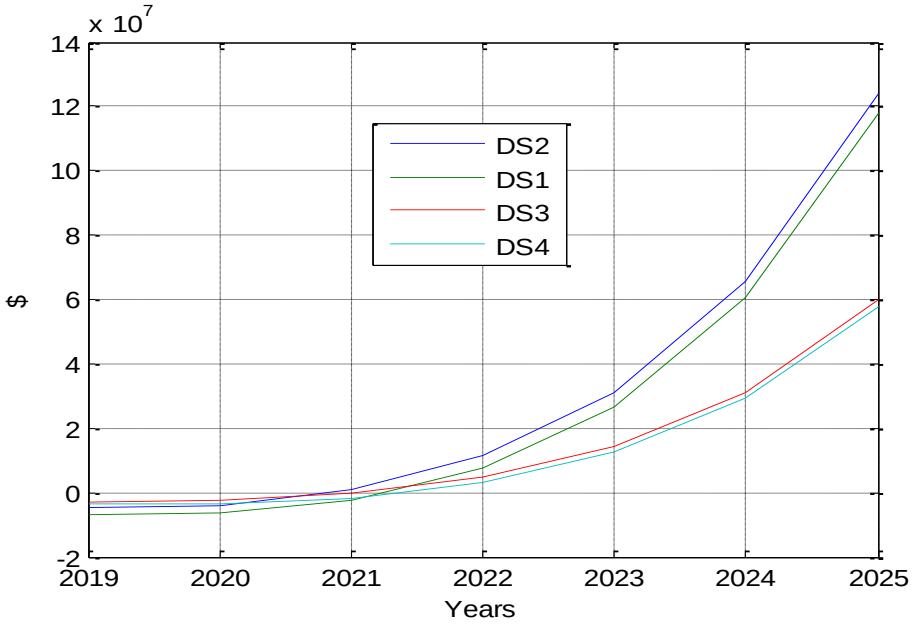


Figure 5.14.Net cumulative discounted cash flow.

From an earlier section, it is recalled that the total cost of ownership and discounted cash flow were not enough to decide the feasibility of each deployment scenarios. Therefore, it is essential to check the economic feasibility using an economic indicator.

The most popular used economic feasibility indicators are the net present value (NPV), internal rate of return (IRR), and payback period (PP) which are used to maximize the decision indicators. Accordingly, the net present value trends in each year and its value per each deployment scenario were estimated and depicted in Figure 5.15.

The net present value was negative in the first three years and after the third year of the deployment, it is exponentially increasing to high positive value. This exponential increment results from the service user's behavior. That means after third year of deployment, the number of forecasted users exponentially increases compared to the earlier three years which in turn increases the data service consumption level and revenue. Moreover, each formulated deployment scenario economically feasible if greater than zero net present value recorded.

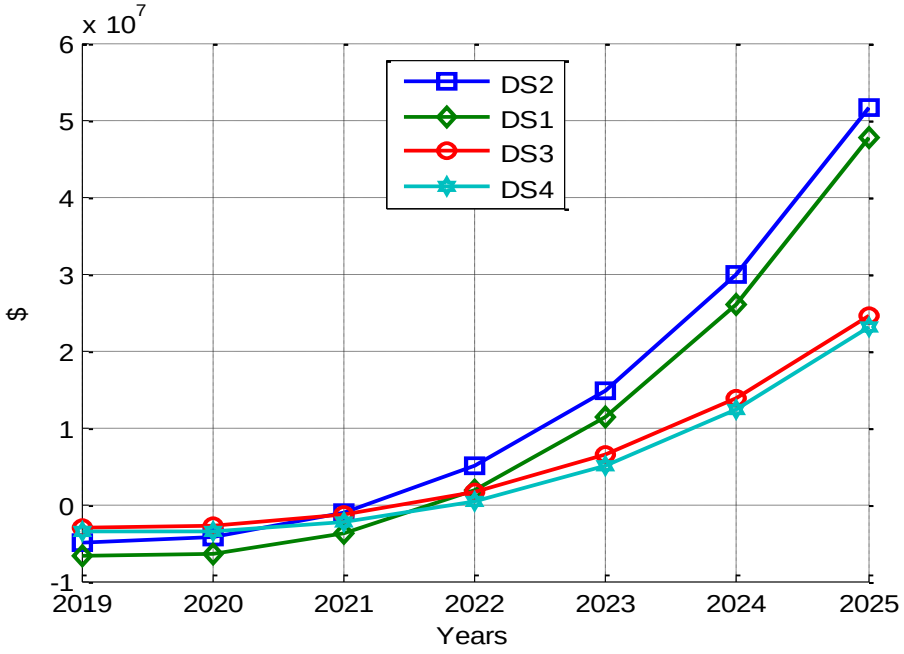


Figure 5.15.Net present Value.

The next most important economic indicators parameter was the internal rate of return (IRR). The IRR is the discount rate(factor) which makes the value of net present value to zero. The IRR results for each deployment scenarios depicted in Figure 5.16.

It also noticed that the investment was profitable and feasible if the internal rate of return value was a higher percentage (i.e. greater than defined discount factor). Consequently, as shown in the Figure 5.16, the obtained internal rate of return for all deployment scenarios are greater than 13% (value defined initially).

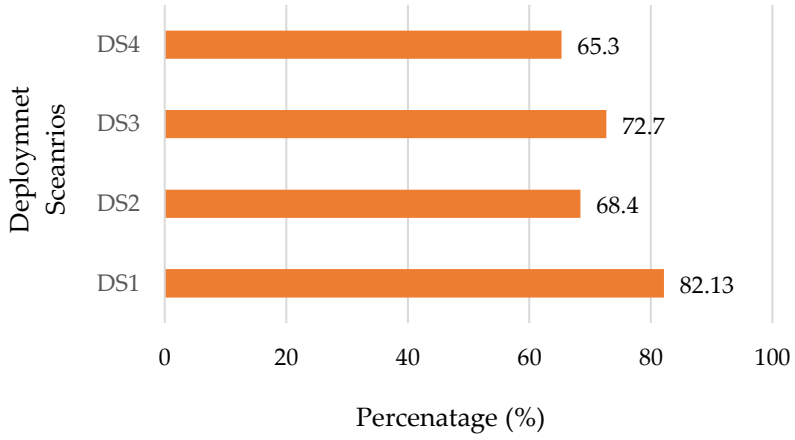


Figure 5.16.Internal rate of return (IRR).

Based on calculated net cumulative cash flow and net discounted cumulative cash flow, the payback period (a period in which the cumulative incomes equal to the initial investments) and discounted payback period is calculated and depicted in Figure 5.17.

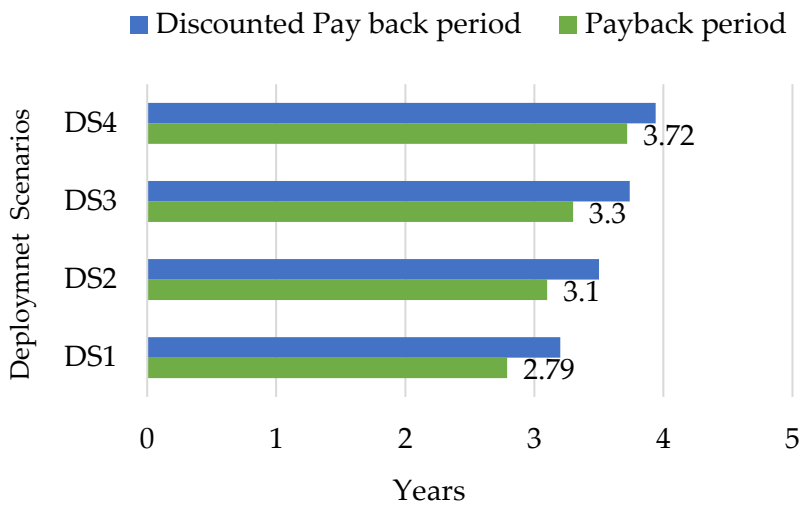


Figure 5.17.Payback period and discounted payback period.

Hence, payback period recorded for all DS1, DS2, DS3 and DS4 are 2.79, 3.1, 3.3 and 3.72 years respectively. That means, if LTE deployed in an emerging city under DS1, the time needed to return the investment was 2.79 (extra minima value). In the same way, for the rest of the deployment scenarios the return on investments achieved in 3.1,3.3 and 3.72 for DS2, DS3 and DS4 respectively.

Further, as noted from several studies, the investment is profitable and feasible if the payback period was in between 3 and 4 years (less than 3.5 years) in span 7 years.

Generally, based on network requirements, defined market potential, considered environmental and propagation mode; the deployment of LTE under all deployment scenarios except to DS4 is feasible (in terms of technical and economic) for an emerging city with the payback period of less than 3.5 years. On contemporary, deployment of LTE under DS4 slightly delayed for return on investment with 0.22 years compared to recommended value.

The aforementioned results recorded due to the considered parameters in techno economic analysis modeling of each LTE deployment scenarios and the factors considered to formulate the deployment scenarios in an emerging city. With this, to deploy LTE in emerging city, the minimum years recorded to return of investment (ROI) is 2.79 years under DS1. Whereas, the maximum years recorded to return the investment is 3.72 years under DS4.

5.5. Special Deployment Scenarios

Based on four major formulated deployment scenarios and their characteristics, special LTE deployment scenarios are articulated for an emerging city. Specially considered deployment scenarios are a function of coverage and capacity and derived from four major deployment scenarios. Namely, optimistic, coverage favored and hotspot focused LTE deployment scenarios.

Accordingly, the optimistic deployment scenario formulated with 1800/2100Mhz system frequency band and under high capacity demand (80% market potential definition). Similarly, coverage favored, and hotspot focused deployment scenario also formulated with 1800/2100Mhz under low capacity demand (50% and 30% market potential definition respectively).

Optimistic and coverage favored deployment scenarios are special form of DS1 and DS2. Whereas, hotspot focused deployment scenario is special form of DS3 and DS4. During the special deployment scenarios formulation; target area, propagation and environment model are tuned based on the characteristics of each formulated special deployment scenarios.

Summary of techno economic results of specially formulated LTE deployment scenarios is illustrated in Table 5.6. In the table, MP represent Market potential and defined in percentage with respect to population of the city. Whereas, DS represent the deployment scenario.

Table 5.6.Techno economic results of special formulated LTE deployment scenarios.

Deployment Scenarios	Optimistic		Coverage favored		Hotspot focused	
Description	1800Mhz-80%MP	2100Mhz-80%MP	1800Mhz-50%MP	2100Mhz-50%MP	1800Mhz-30%MP	2100 Mhz-30%MP
Name	DS1_1	DS2_1	DS1_2	DS2_2	DS3_1	DS4_1
Forecasted Users at end of 7th year	257040		160650		96390	
Cell radius (Km)	0.8	0.7	0.8	0.7	0.8	0.7
Number of eNodeB's Via Coverage	61	82	43	73	27	36
Number of eNodeB's Via Coverage	60		34		21	21
Total CAPEX cost (M$)	5.44	9.27	2.83	7.63	2.78	2.82
Total OPEX cost (M$)	16.2	21.77	11.42	19.38	07.17	09.56
TCO (M$)	21.64	31.04	14.25	27.01	9.95	12.38
Total Revenue ($)	119.28		74.551		74.551	
NPV(M$)	40.11	34.17	42.04	16.31	15.07	14.04
IRR (%)	76.1	61.5	74.3	48.23	66.4	61.5
PP(Years)	3.01	3.72	3.25	4.4	3.54	3.82

As shown in Table 5.6, the main techno economic results illustrated in summary form and the interpretation of each results is almost the same as that of earlier described results. The only difference basically found on the category of specially formulated deployment scenarios derived from the major formulated deployment scenarios.

To highlight some of the techno economic results of specially formulated deployment scenarios, in all specially considered deployment scenarios positive net present value was recorded. The minimum payback period recorded to deploy LTE in an emerging city achieved under DS1_1(Optimistic) and it is 3.01 years.

Chapter 6 : Conclusion and Future work

6.1. Conclusion

The exponential growth of innovative data service demand in emerging cities of developing countries has been pushing deployment of state-of-the art mobile technologies including LTE. However, deployment of mobile technologies is commonly vendor driven without backed by localized techno-economic assessments. This leads to underutilization and wastage of resource, low performance of network and quality of service when the investments start the operation.

In this thesis work, techno-economic analysis modeling approach has been considered and techno-economic evaluation of formulated LTE deployment scenarios are undertaken. Potential LTE deployment scenarios were formulated through scenario planning method for emerging city. Mathematical approach is proposed for marketing forecast in consideration of the future market in the city. LTE radio access network dimensioning also performed for the 7 years study period in the monopoly operator (ethio telecom) for exemplary emerging city of Ethiopia (Adama city) based on stated network requirements.

Both CAPEX and OPEX costs were modeled for each formulated LTE deployment scenarios based on an overlay network deployment strategy of existing 2G/3G technology for an emerging city. Economic feasibility of each formulated deployment scenario was done using popular economic feasibility indicators. Further, techno-economic evaluation approach implemented in MATLAB based on modified TERA model and supported with a graphical user interface for easily analyzing the formulated potential LTE deployment scenarios in technical and economic aspects.

From the results of the study; it can be concluded that:

- Market potential and operating frequency have a great impact on network capacity, coverage and number of eNodeB's which in turn influences the rate of return on investments in all LTE deployment scenarios (DSs).
- In urban environmental conditions a high number of eNodeB's required (almost twice) to keep the targeted cell edge data rate requirement and to mitigate the loss due to a multipath effect of the transmission system.
- In most of the DSs, the LTE RAN is coverage limited which in turn indicates low user's area density and capability to serve a high user in the future.
- Roll out plan is a key parameter to avoid underutilization of network capacity in tuning the deployment of network elements with demand capacity.
- In all formulated DSs, the total operational cost is greater than twice that of the total investment cost which indicates to focus on OPEX driven costs.
- High share of CAPEX cost taken by eNodeB related cost for the deployment of LTE in result of overlay network deployment strategy (60-67%).
- The operational cost is increasing linearly with the number of service users and sites. A high share of the OPEX cost taken by network driven cost (60%).
- Operator revenue is increasing exponentially with time due to an exponential incremental of the number of service users and data service usage level.
- Deployment of LTE in 1800Mhz band under high and low demand capacity (DS 1 and DS 3) and in 2100Mhz band under high demand capacity (DS 2) is feasible for an emerging city with the payback period (PP) of less than recommended years (3.5 years) within span of 7 years operation duration.
- From specially formulated DS, the optimistic and coverage favored LTE DSs (in 1800Mhz band under high and low demand capacity) are the most feasible LTE DSs for an emerging with payback period of less than 3.5 years for ROI.
- Based on existing technology service users' trends, coverage favored DS is the recommended DS to deploy LTE in Adama city of Ethiopia in technical and economically feasible way with PP of 3.25 years in monopoly operator.

6.2. Future work

Although several studies have been made on LTE technology, the present thesis focuses on studying the LTE deployment in an emerging city under different deployment scenarios from techno-economic perspective. This thesis improved further in the future by addressing the limitation cited in limitation part and in using more accurate data modeling for each parameter considered in the study.

This study was limited to monopoly telecom operator market and can be further researched in a competitive environment and operators with currently formulated LTE deployment scenarios and other deployment scenarios. Further, in this thesis work, the modified TERA model used for techno-economic evaluation of LTE deployment scenarios. Taking this study and other related studies as inputs and TERA framework as the base, TERA model can be further improved and extended as future work for accurate techno- economic evaluation of cellular technology.

The implemented techno-economic evaluation approach in this study was limited to LTE technology based on the formulated deployment scenarios. It can be further improved in considering several parameters in the feedback loop process for accurate techno-economic evaluation. Moreover, it can be improved using the standard input and parameter modeling approach to apply for all the cellular technology.

Lastly, the implemented techno-economic evaluation approach in MATLAB can be further used as a starting point to develop in the future the portable and easily accessible techno-economic evaluation application in a project form.

References

[1] Cisco, "Global Mobile Data Traffic Forecast Update, 2016–2021," 2017. [Online]. Available: https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/mobile-white-paper-c11-520862.html. [Accessed 10/ 10/ 2018].

[2] A. Zishan, "Feasibility study of fourth generation (4G/LTE) mobile network in Bangladesh," Master Thesis,Department of Industrial and production Engineering ,Bangladesh Universtity of Engnieering and Technology, Bangladesh, 2016.

[3] T. Knoll, "LTE Network Design from a Techno-Economic Perspective," *lte-business-model*, pp. 1-68, 2012.

[4] Global Mobile Suppliers Association(GSA), "Lte-global-network-status," [Online]. Available: http://allafrica.com/stories /2017051 50752.html . [Accessed 01 07 2018].

[5] Ethio telecom, "Ethio telecom company monthly report and circulation2016-2017," Addis Ababa, Ethiopia, 2016.

[6] Ethio telecom, "Ethio telecom company profile," Addis Ababa,Ethiopia, 2016/17.

[7] C. Coletti, "Heterogeneous Deployment Analysis for Cost-effective Mobile Network Evolution," Doctoral Dissertations, Department of Electronic Systems, the Faculty of Engineering and Science, Aalborg University, 2014.

[8] T. Worku, "LTE Technology Deployment Strategy for Mobile telecom Operators; Techno Economic Prespectives," Master's thesis, KAIST,Korea, 2014.

[9] J. Harno, "Techno-economic analysis of beyond 3G mobile technology alternatives," *Emerald Group Publishing*, vol. 11, no. 3, 2009.

[10] T. Smura, "Techno-Economic Analysis of IEEE 802.16a-Based Fixed Wireless Access Networks," Master's Thesis, Aalto, School of Electrical Engineering, Helsinki, 2009.

[11] T. Smura, "Techno-economic modelling of wireless network and industry architectures," Doctoral Dissertations, Aalto University School Electrical Engineering, Helsinki, 2012.

[12] T. Smura, "Final techno-economic results on mobile services and technologies," in *EU ITS ECOSYS project*, 2006.

[13] Addis Herland, "Adama - a Suitable Town for Investment," A.A, Ethiopia, 2017.

[14] H. Desalegn, "Techno-Economic Analysis of LTE Deployment: A Case Study of Addis Ababa, EthiopiaAddis Ababa, Ethiopia, June 2014.," Master's Thesis, Addis Ababa insitute of Technology, Addis Ababa University,Addis Ababa, Ethiopia, 2014.

[15] F. Moulianitakis, " A techno-economic comparison between outdoor macro-cellular and indoor offloading solutions," Master's Degree , Stockholm, Sweden, 2015, 2015.

[16] Z. Frias and J. Pérez, "Techno-economic analysis of femtocell deployment in long-term evolution networks," *EURASIP Journal on Wireless Communications and Networking*, p. pp. 1–15, 2012.

[17] A. Jha, "Techno-economic assessment of the potential for LTE based 4G mobile services in rural India," in *IEEE International Conference* , Kolkata, India, 2015.

[18] T. Estifanos, "Telecommunication in Ethiopia," 2010.

[19] G. Tadesse, G. Bahilgwa, " Mobile Phones and Farmers' Marketing Decisions in Ethiopia," Ethiopia, 2014.

[20] BuddeComm , "Ethiopia - Telecoms, Mobile and Broadband - Market Insights, Statistics and Analysis," 2016.

[21] GSMA Intelligence, "Definite data and analysis for mobile industry," [Online]. Available: https://www.gsmaintelligence.com/markets/1013/dashboard/. [05 02 2018].

[22] R.Shetty, "4G: Deployment Strategies and Operational Implications Managing Critical Decisions in Deployment of 4G/LTE Networks and their Effects on Network Operations and Business," 2014.

[23] 3GPP Webage, "LTE Specification," [Online]. Available: http://www.3gpp.org/techno logies /keywords-acronyms/98-lte. [Accessed 21 08 2018].

[24] 3GPP Website,"3GPP technologies," [Online]. Available: http://www.3gpp.org/ tech nologies. [Accessed 23 02 2018].

[25] T. Mamo, "Nominal and Detailed LTE Radio Network Planning: Case of Kirkos Sub-City in Addis Ababa," Master Thesis ,AAiT,AAU,Addis Ababa Ethiopia, 2016.

[26] Z. Gurmu, "Long Term Evolution (LTE) Radio Network Dimensioning: Case of Addis Ababa City," Master Thesis, AAiT,Addis Ababa University, Addis Ababa, Ethiopia, 2015.

[27] B. B Haile, E. Mutafungwa and J.Hämäläinen, "LTE-Advanced enhancements for self-backhauled LTE-U small cells: An Addis Ababa case study," in *AFRICON,2015*, 2015.

[28] S. Abdul Basit, "Dimensioning of LTE Network DescModels and Tool, Coverage and Capacity Estimation of 3GPP Long Term Evolution radio interface," Master Thesis, Espoo,Spain, 2009.

[29] Oslen, "Techno-Economic Evaluation of Narrowband and Broadband Access Network Alternatives and Evaluation Scenario Assessment," in *IEEE Communication,*, 1996.

[30] Oslen, "Techno-Economic Evaluation of Narrowband and Broadband Access Network Alternatives and Evaluation Scenario Assessment," in *IEEE Communication*, 1996.

[31] M. Kantor, "General framework for techno-economic analysis of next generation access networks," *Dep. of Telecomm., AGH University of Science and Technology ,* 2010.

[32] T. Wulf, P. MeiBner and S. Stubner, A Scenario-based Approach to Strategic Planning – Integrating Planning and Process Perspective of Strategy, 2010.

[33] B. B. Haile, "Development of the wi-fi offloading business concept within the African market context," Addis Ababa,Ethiopia.

[34] P. Schoemaker, "Scenario planning: A tool for strategic thinking," *Sloan Management Review,* Vols. 36-40, 1995.

[35] G.Gabner, H. Kosow and K.Robert, " Methods of Future and Scenario Analysis :Overview, assessment, and selection criteria," 2009.

[36] T. Leva, "Scenario analysis on future internet," *Espoo,* 2009.

[37] X. Bai, "Scenario Analysis on LTE mobile network virtualization," Master‟s Thesis, Aalto University, Finland, 2013.

[38] Slideshare, "Geomtric regression method," [Online]. Available: https://www.slideshare .net/PallaviBadry/poulation-forecasting. [Accessed 24 07 2018].

[39] M. Sokele, "Analytical Method for Forecasting of Telecommunications Service Life -cycle Quantitative factors," *Doctorial Dissertations , University of Zagreb, Croatia,* 2009.

[40] G.Lilien, "The Bass Model: Marketing Engineering Technical Note," 2007.

[41] D. Hurissa, "Deployment of Long Term Evolution (LTE) Femtocells in Dead Zone Areas," Master's Thesis , Addis Ababa instiute of Technology,Addis Ababa University,Addis Ababa, Ethiopia, 2014.

[42] B. Seifu, "LTE Radio Network Planning: Modeling Approaches for the Case of Addis Ababa," Master's Thesis , AAiT, Addis Ababa University,Addis Ababa,Ethiopia, 2012.

[43] J. Vidal, J. Pérez, A. Agustín, N. Marina, and A. Høst-Madsen, "Technoeconomic evaluation of cooperative relaying transmission techniques in OFDM cellular networks," *EURASIP Journal on Advances in Signal Processing*, vol. 11, 2012.

[44] A.Janevsk, V. Nikolikj and T.Toni, "Cost Modeling of Advanced Heterogeneous Wireless Networks under Excessive User Demand," *Member of Telekom Austria Group, Skopje, Macedonia*, p. 68–81, 2014.

[45] A.Janevskib, V. Nikolikja and T.Toni, "A Cost Modeling of High-Capacity LTE-Advanced and IEEE 802.11ac based Heterogeneous Networks, Deployed in the 700 MHz, 2.6 GHz and 5 GHz Bands," in *International conference on selected topics in Mobile and Wireless Networking*, Macedonia, 2013.

[46] R. Bhatt, R. Datta, "Cost Modelling and Studies with Different Deployment Strategies for Wireless Multimedia Sensor Network Over Flat and Elevated Terrains," *Int J Wireless Inf Networks*, 2013.

[47] Ethiotelecom, "High level Design Documentation for UMTS and LTE Network," Addis Ababa,Ethiopia, 2014.

[48] Ethio telecom, "TEP:- SER Circle HLD and LLD for UTRAN and GSM Network," Adama City, 2015.

[49] A.D., "LTE Spectrum and Network Strategies," Telecom & Media Viewpoint, 2013.

[50] Adama city size," Adama city Manecupality , Adama, Ethiopia, 2017.

[51] Ethiopian Central statistics Agency, "Adama city Population census," Addis Ababa, Ethiopia, 2015.

[52] Central Statistical Agency of Ethiopia , "Census report-2007," [Online]. Available: http://www.csa.gov.et/census-report/complete-report/census-2007. [Accessed 07 2018].

[53] City population , "Population stastics for countries," [Online]. Available: http://www.citypopulation.de/Ethiopia.html. [Accessed 28 06 2018].

[54] Ethio telecom, "Ethio telecom, 2017/18 Business Plan," Addis Ababa, 2018.

[55] M. Arif, M. Yameen, and A. Matin, "Femtocell Suburban Deployment in LTE Networks," *International Journal of Information and Electronics Engineering*, March,2013.

[56] S.F. Yunas, H. Ansari, and M.Valkama, "Technoeconomical Analysis of Macrocell and Femtocell Based HetNet under Different Deployment Constraints," Internal report, Department of Electronics and Communications Engineering, Tampere University of Technology, Finland, 2016.

[57] Ethiotelecom, "Ethiotelecom Product and Service catalogue," A.A, Ethiopia, 2016/17.

[58] "Techno economics," Techno-economic research portal, [Online]. Available: http://www.technoeconomics.ugent.be/. [Accessed 23 04 2018].

[59] D. Katsianis, "Telecommunications Network Planning and Evaluation with Techno-Economic Criteria," Department of Informatics and Telecommunications, University of Athens,Greece , 2009.

[60] U. Zareen, "LTE-Advanced: Techno Economical Perspective," *Universal Journal of Communications and Network*, 2014.

[61] Z. Zubair, "Techno-Economic Analysis of Wireless Indoor Solutions," Master of Science Thesis, KTH Information and Communication Technology, Stockholm, Sweden, 2011.

[62] R. Suhas, "WiMAX or LTE: Which Technology to Adopt?," *Communications of the IBIMA*, vol. 9, 2009.

[63] 3GPP Website, "LTE; Scenarios and requirements for small cell enhancements for E-UTRA and E-UTRAN," Technical Report, 3GPP TR 36.932 Release 12, 2014.

[64] M. Staufer and M. Knoll, "Mobile Networks Evolution for Individual Communications Experience:- CAPEX and OPEX evaluation results," CELTIC Project.

[65] J.Zander and K.Johansson, "Modelling the cost of heterogeneous wireless access networks," *Int. J. Mobile Network Design and Innovation*, vol. 2, no. 1, 2007.