Addis Ababa University

Addis Ababa Institute of Technology

School of Electrical and Computer Engineering Telecommunication Engineering Graduate Program

Techno-Economic analysis of 5G in case of Addis Ababa, Ethiopia

By

Yemisrach Ayenew

Advisor

Dr. Sosina Mengistu

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Thesis Title

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By:

Yemisrach Ayenew Mengistu

Dr. Sosina Mengistu	___________
Advisor	Signature
Dr.Bisrat Derebssa	___________
Examiner	Signature
Dr. Murad Ridwan	___________
Examiner	Signature

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.

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Signature

Yemisrach Ayenew Mengistu

September, 2023

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

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Signature

Dr. Sosina Mengistu

September, 2023

Abstract

In wireless networks, data consumption is increasing exponentially because new applications demand high-quality and high data rates. 5G was created to have more capacity and faster data speeds than Long-Term Evolution (LTE) technology. The ultra-low latency and ultra-high reliability that 5G technology promises will enable cutting-edge services in a variety of business sectors. However, given the fact that the transition period from the adoption of 4G to the introduction of 5G is short relative to industry standards, this introduction of new technology comes with its own challenges in terms of cost, awareness, and compatibility with existing systems.

The techno-economic analysis method refers to techniques that are used to evaluate the technical and financial performance of a service or a product. The analysis includes market forecasting, network dimensioning, cost and revenue modeling, and economic feasibility analysis for a five-year study period with in ethio telecom case uses a modified TERA model.

The nature of 5G application services offered, and the operating frequency bands all play a significant role in determining network capacity, coverage, and the number of sites required. This nature of 5G network have a great impact on network capacity, coverage, and the number of sites in the area, which influence the NPV value 1,812,120,611.60 and payback period 3 months.

Keywords: 5G, Techno-economic analysis, Deployment options, NSA, eMBB, TERA model

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List of Acronyms

1G	First Generation
2.5G	Second and a Half Generation
2G	Second Generation
3G	Third Generation
4G	Fourth Generation
5G	Fifth Generation
5GC	5G core
ACTS	Advanced Communication Telecom services
ARPU	Average revenue per user
BH	Busy hour
BS	Base Station
CAPEX	Capital expenditure
CDMA	Code Division Multiple Access
CF	Cash flow
CS	Circuit switched
DCF	Discounted Cash Flow
DL	Down link
EDGE	Enhanced Data Rates for GSM Evolution
EIRP	Effective Isotropic Radiated Power
eMBB	Enhanced Mobile Broadband
EPC	Enhanced Packet Core
ETB	Ethiopian Birr

FDD	Frequency division duplex
FDMA	Frequency division multiple access
FR1	Frequency Range 1
FR2	Frequency Range 2
GB	Giga Byte
Gbps	Giga Bits per Second
GHz	Giga Hertz
GHz	Giga Hertz
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
GTx	Transmitter antenna gain
IM	Interference Margin
IoT	Internet of Things
IRR	Internal Rate of Return
ITU	International Telecommunication Union
Kbps	Kilo bit per second
KM/hr	Kilometer per Hour
km2	Kilometer square
LDCs	Least developed countries
MAPL	Maximum of Allowable Path Loss
MATLAB	Matrix Laboratory
NPV	Internal rate of return
NR	New Radio

NSA	Non-standalone
OPEX	Operating expenditure
PBP	Payback period.
PDSCH	Physical Downlink Shared Channel.
PEST	Political Economical Social Technological
PTx	Transmitter power
PUSCH	Physical Uplink Shared Channe1
RLB	Radio Link Budget
SA	Standalone
SBA	Next-Generation Service-Based Architecture
SINR	Signal interference Noise Ratio
SMS.	Text messaging
TCO	Total cost of ownership
TDD	Time Division Duplex
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
UL	Uplink

1. Introduction

1.1 Background

In wireless networks, data traffic consumption has increased exponentially because of new applications' demands for high-quality services, high data rates, and cutting-edge user terminals over the previous ten years. To keep up with the increase in data traffic and distribute bits more efficiently, ethio-telecom, a service provider, is providing data services for users using 2G, 3G, and 4G mobile technologies[1]. And ethio-telecom has been updating its network infrastructure with cutting-edge technology like long-term evolution (LTE), and now it is starting the 5G network[2].

The next-generation mobile communication technology, known as 5G, was created to have more capacity and faster data speeds than LTE technology. The ultra-low latency and ultra-high reliability that 5G technology promises will enable cutting-edge services in a variety of business sectors [3].

The International Telecommunication Union (ITU) specifications define 5G application services as enhanced mobile broadband (eMBB), massive machine-type communication (mMTC), ultra-reliable low latency communication (URLLC), and fixed fiber-like wireless access [3]. Several design objectives for 5G systems can be identified based on three potential applications: increased downlink capacity of up to 20 Gbps, reduced latency to 1 millisecond (ms), increased user mobility of up to 500 kilometers per hour (KM/hr.), and increased connection density of up to 1 million devices per (kilometer squared (km2) [3]. There are also two 5G deployment scenario options: the "Non-Standalone" (NSA) solution, which combines LTE and 5G NR access with a 4G Enhanced Packet Core (EPC), and the "Standalone" (SA) approach, which is based on 5G New Radio (NR) access. Ethio-telecom uses the non-standalone (NSA)-based solution.

According to Ericson [4] report more than 210 service providers have launched commercial 5G services globally in 2022. Deployment of 5G standalone (SA) networks is also increasing, with more than 20 commercial launches at the end of 2021 and by the end of 2027, 5G subscriptions are expected to reach 4.4 billion. After its launch in 2019, 5G subscription growth outpaced that of 4G, reaching 1 billion subscribers 2 years earlier than 4G[4].

We can see that the 5G subscription is exponentially increasing compared to 4G and other technologies, as shown in the Figure1.

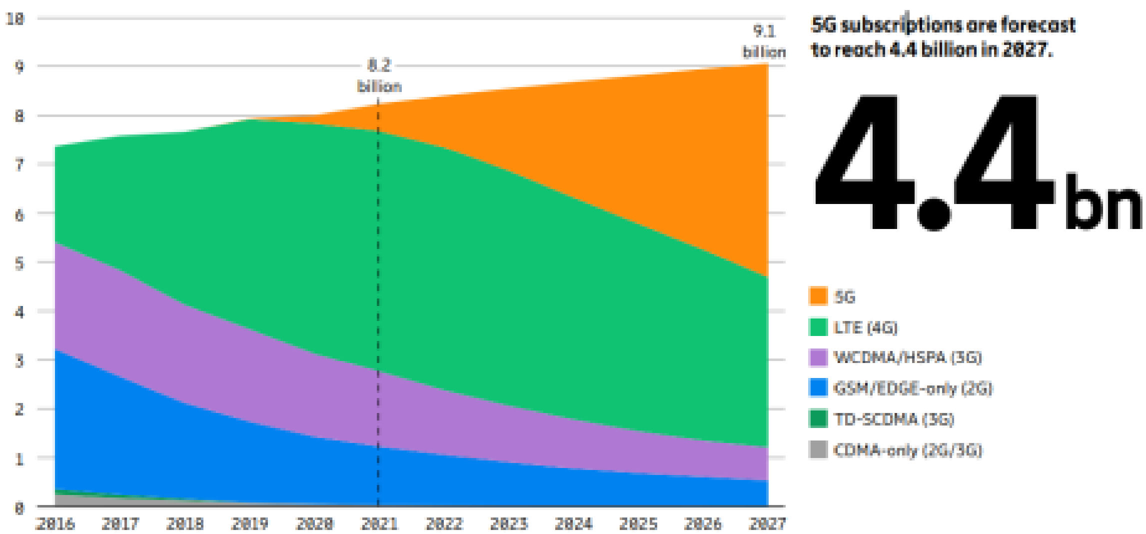

Figure 1 Mobile Subscriptions By Technology (Billion)

In January 2022, there were 29.83 million internet users in Ethiopia. At the beginning of 2022, 25.0% of the entire population had access to the internet. Internet users in Ethiopia increased by 731 thousand (+2.5%) between 2021 and 2022 [4].

Given the annual increase in internet data, 5G technology should be considered to meet customer demand for data consumption.

Introducing new technologies requires a thorough assessment of their significance from both economic and technological standpoints. Conducting a techno-economic analysis before their adoption in the telecommunications industry is critical to ensuring these technologies' cost-effectiveness.

The term "techno-economic analysis" (TEA) refers to techniques for evaluating the technical and financial performance of a service or a product. Techno-economic models can also be used to determine which type of technologies and deployment strategies are the most efficient and affordable available technology based on technical, economic, environmental, and social factors[5, 6]. TEA is done using TERA (Techno-Economic Analysis Model). Ethio-telecom is starting 5G network deployments the capital city of Ethiopia, it is essential to analyze 5G deployment options in techno-economic perspective to help the network operator to decide the optimum strategy towards 5G, optimize their network with an evolution of networks and maximize its benefit.

1.2 Problem Statement

In the context of Ethiopia, an emerging economy in Africa, this study centers upon the challenge and potential benefits that may arise from the implementation of 5G technology. Despite being home to a population of 100 million, only 46.5 million individuals utilize mobile phones, and 26.4 million access data and internet services. Notably, the telecommunications provider, ethio-telecom, swiftly transitioned from deploying 4G to 5G networks within a short timeframe, raising concerns about the adequacy of return on investment for the former. 5G technology provides services with high data transfer rates, ultra-low latency, and M2M. This services primarily benefiting sectors like manufacturing, autonomous vehicles, and smart agriculture. However, these advanced applications are currently limited in Ethiopia due to factors including the affordability of 5G-capable devices. Considering these complexities, the primary challenge revolves around assessing the potential customer base capable of adopting 5G technology over the next few years. This assessment is crucial for estimating the time required to realize a return on investment for the 5G deployment. Moreover, this study examines the significance of 5G within the Addis Ababa technological landscape, accounting for both economic considerations and the state of technological readiness. While deploying new technology entails capital and operational costs, it's essential to conduct the rationale behind introducing 5G in Addis Ababa.

This study aims to systematically model and forecast the capital and operational expenditures associated with 5G technology. By analyzing the potential user base and their readiness, this research seeks to formulate strategic deployment approaches that optimize costs while aligning with market needs. This study attempts to determine whether 5G deployment is economically and technologically viable within the Addis Ababa context. It aims to provide insights that balance the benefits of advanced technology with the real-world challenges of an underdeveloped economy, guiding decisions that will shape the future of telecom industry in Addis Ababa.

1.3 Objective

1.3.1 General Objective

The general objective of this research is to conduct the techno-economic analysis of 5G technology in Addis Ababa, Ethiopia.

1.3.2 Specific objective

- To analysis of 5G technology requirements and use cases
- To forecast the number of potential 5G customers ethio-telecom will have for the next five years
- To Analysis of the economic benefit ethio-telecom gets from 5G
- To Analysis of the technological advantage ethio-telecom gets from 5G technology

1.4 Methodology

The following techniques are used to accomplish the goals indicated above. An extensive literature review will be undertaken by referring to standards, publications, renowned company reports, and similar works.

- Primary and secondary data will be collected.
- The primary sources of data source for this research work will be collected from ethio telecom.
- The secondary data will be collected by reviewing 5G related books, 3GPP documentation, Next Generation Mobile Network (NGMN) documentations, IEEE articles and journals, International Telecommunications Union (ITU) publications, and TEA focused dissertations.
- The number of future subscribers, deployment options technology selection will be forecasted and selected.
- The costs of CAPEX and OPEX are computed.
- The cash flow (CF) and discounted cash flow (DCF) analyses were carried out using cost and revenue modeling results as well as economic inputs performed in MS Excel. As an input to the system model, a five-year research period and a discounted rate of 11.5% were assumed.
- Economic evaluation indicators for selected deployment options include net prese nt value (NPV), internal rate of return (IRR), and payback period (PP).

1.4 Related works

Different studies conducted the importance of 5G technology in terms of techno economic perspective.

In a study led by Beneyam Berehanu Haile et al [7], the authors emphasize the substantial surge in mobile data usage attributed to innovative services like high-definition (HD) video, augmented reality, virtual reality, and interactive HD TV. The authors highlight that this trend will grow exponentially in the coming years. The authors specifically investigate into the global and Ethiopian mobile growth scenarios, tracing back to the era of 1G technology.

The study predicts that data demand in Ethiopia will pose challenges within the next five years. Factors influencing this demand increase include mobile data demand itself, user usage behavior, mobile data pricing, and user income levels. The authors forecast that mobile data demand in Addis Ababa alone will rise to an astounding 20.27 petabytes per month by 2021. They further stress that expanding the current LTE infrastructure nationwide will fall short of meeting this demand. To tackle this capacity challenge, the authors propose adopting 5G technology and recommend capacity enhancement methods such as Millimeter wave communication, Massive MIMO (Multiple-Input Multiple-Output), and Ultra-dense networks

The authors also recommend future work to involve detailed analyses that consider real-world mobile traffic data and accurate modeling and forecasting parameters. By aligning with the conclusions of the authors regarding the growth of mobile communication and the increasing demand for network capacity in Ethiopia, this research highlights the necessity of implementing 5G technology to meet these capacity requirements.

In a study conducted by Rahman et al.[8], the authors motivated the challenges faced by least developed countries (LDCs) during the deployment and operational phases of 5G technology. The authors highlight that 5G technology requires specific frequency bands, including those below 1 GHz for coverage, mid-frequency bands (2.3 - 3.5 GHz range) for macro cells, and high-frequency bands (mmWave in 26 - 100 GHz range) for micro cells. However, these frequency bands have legal issues and are challenging to negotiate with governments in LDC countries. Additionally, the spectrum cost in these countries is significantly higher, often three times more than in developed nations. This difference in cost is a major obstacle to deploying 5G networks in LDCs.

Another challenge identified by the authors is the limited availability of backhaul fiber and microwave communication infrastructure, which are essential for supporting the high-speed and high-capacity requirements of 5G networks. LDC countries often lack the necessary infrastructure for seamless 5G deployment.

Furthermore, the authors point out that the absence of specific applications and use cases such as autonomous vehicles and robotic surgery in LDC countries hinders the motivation for deploying 5G networks. The lack of security experts, weak infrastructure, limited sector-specific research and development (R&D), and resistance to change are additional challenges faced by LDCs in deploying 5G technology. Based on their findings, the authors conclude that the rollout of 5G networks in LDCs will likely take a longer time than anticipated. This situation is particularly challenging in Africa, where most countries still heavily rely on 3G technology. However, it is noteworthy that Ethiopia, being an LDC country in Africa, has already made strides in installing both 4G and 5G networks. Consequently, it becomes crucial to research and explore the technological and economic benefits that 5G technology brings to Ethiopia, as well as to identify the potential areas and users who can benefit from this advanced technology.

Edward J. Oughton et al. [9], motivated by the limited number of techno-economic assessments on 5G, quantifiable evaluations of cost savings through infrastructure sharing techniques, and the scarcity of open-source analytical frameworks for this purpose, conducted their research. Their study took place at Crystal Palace in South London, United Kingdom. They aimed to integrate technology and economics to assess both the capacity and cost of 5G deployment strategies.

The researchers utilized an open-source Python simulator, pysim5G, to conduct experiments regarding 5G network deployment strategies. Their findings indicate that three specific ways can significantly lower costs for mobile network operators (MNOs) throughout the 5G implementation. Firstly, passive site sharing, where MNOs share physical cell sites while maintaining separate network resources, could independently cut costs by 30% compared to a dedicated network. Secondly, passive backhaul sharing, involving the shared use of infrastructure connecting cell sites to the core network, also showed a 30% cost reduction potential. Lastly, a multi-operator Radio Access Network (RAN) that includes sharing radio access components demonstrated the most significant cost-saving potential, with potential reductions of approximately 50% compared to standalone network deployment. These findings emphasize the value of collaborative network sharing strategies to enhance the cost-effectiveness of 5G deployment, benefiting both MNOs and potentially consumers through more affordable services.

Ghoul Smail et al [9] performed financial and economic analysis for the implementation of 5G mobile for six (6) years from 2020 to 2025, and a mathematical model is designed to describe revenue and predict costs to demonstrates if migration to 5G is cost-effective in Shanghai, China, with 6,340.5 km2 and 25 million people at a very high density of 3,854 per km2.

The researchers predicted future user numbers based on population potential, growth rate, innovation, and imitation coefficients. These variables were estimated through mathematical relations considering churn rates. The impact of these factors is initially low but gains significance over time. The expenditure to acquire users becomes especially crucial. A proposed pricing strategy analysis and a novel model were introduced. The study further delved into a comparison of capital expenditure (CAPEX) and operational expenditure (OPEX) for various base station (BS) classes under diverse scenarios.

Simulations demonstrated the competitive advantage that thorough price elasticity of volume examination can offer.

According to the paper, Shanghai, China, has a total area of 6,340.5 km2, a population of 25 million, and a very high population density of 3,854/km2. Approximately 128 mobile phones are owned by every 100 people, and 95% of the population lives in urban areas. It attracted 30 million users, far more than the whole population (25 million). In contrast, Ethiopia, spanning 1,100,000 km^2, features 46.5 million mobile users and 26.4 million data and internet service users among a population estimated to exceed 117 million [2, 10]. It's important to note the differing customer base and technological demand between ethio-telecom and Shanghai, China. These differences raise the pivotal question: Can ethio-telecom cultivate a dense 5G user population, considering the unique demands of 5G technology? Furthermore, an analysis of potential 5G technology customers and the techno-economic benefits for ethio-telecom becomes imperative.

A.A. Kusuma et al.[11], worked tecno-economic analysis of 5G network for Indonesia. By focused on estimating the data requirements within major Indonesian cities: Jakarta, Surabaya, and Medan for a six-year plan for the years from 2020-2025. The These cities were chosen due to their substantial data demands. The research employed a modeling approach to predict several crucial factors, including customer numbers, traffic need, technology requirement, and subsequently, the selection of suitable technologies. Furthermore, the study investigated into the simulation of both capital expenditures (CAPEX) and operating expenditures (OPEX) necessitated by the networking infrastructure. By single network operator.

In terms of technological choices, the research opted for the deployment of 5G technology. This selection involved the utilization of different frequency bands to accommodate varying needs. The low-band frequency of 700 MHz with a bandwidth of 40 MHz, the mid-band frequency of 3.5 GHz with a bandwidth of 400 MHz, and the high-band frequencies of 26 GHz and 28 GHz with a bandwidth of 400 MHz each were identified as the suitable options for implementation.

This investigation sheds light on the intricate process of estimating data needs and making strategic technology choices to provide to the rising data demands within significant urban centers. The study's findings could potentially contribute to optimizing resource allocation, enhancing network efficiency, and addressing the challenges associated with increasing data requirements.

Mako Gizachew et al.[12], motivated by the evolution of mobile telecommunication, highlighting the transition from voice-focused traffic to data-dominated services, new features are integrated while ensuring backward compatibility with earlier devices and reducing end-to-end delay or latency within the network. To solve this challenge, a techno-economic analysis of 4G network development in Addis Ababa was conducted. It utilized scenario planning methods and the TERA techno-economic analysis framework to evaluate potential LTE-advanced deployment scenarios. With a six-year study period and employed a discount rate of 10% to assess the economic viability of the proposed network deployment.

According to this research, the deployment of LTE-Advanced technology would be feasible, particularly in densely populated urban and urban areas. In their findings, they showed the potential benefit of an advanced network in meeting the demands of modern communication and data consumption patterns. With The deployment of LTE-A using without-band small cells shows feasibility in both dense urban (DU) and urban (U) areas for coverage and capacity enhancements. With the payback periods (PP) of 3.29 and 4.70 years, respectively, and the positive value of the NPV, the investment is feasible.

Negash et al [6], conducted their research in Adma City, Ethiopia. which is one of the emerging cities next to Addis Ababa. They used modified TERA model to did techno-economic analysis using MATLAB. The authors show the benefit techno-economic analysis in the context of deploying new technology and present their modified TERA model. According to this study marketing analysis and frequency selection had major impact on the deployment of 4G network on emerging city Adam.

The authors have illustrated the practicality of implementing LTE within the 1800Mhz and 2100Mhz frequencies, while accounting for low and high-capacity demands.in this deployment scenarios and techno-economic analysis, they showed that LTE deployment in the 1800Mhz band under low demand capacity is both technically and economically viable for Adama city in Ethiopia, with a payback period of 3.25 years. These findings are particularly to ethio-telecom market.

In summary, a range of authors have shown the feasibility of implementing the techno-economic analysis when implementing new technologies.in the context of 5G technology, the literature evaluated the technical and financial aspects of 5G technology, about RAN deployment, the 5G transport component, MIMO integration, capacity, and coverage. These evaluations include various countries, including India, China, England, Bangladesh, and more. These comprehensive analyses highlight the crucial significance of TEA models. These examinations underline the dynamic role of TEA models as crucial instruments for telecommunications operators when introducing new and advanced technologies[13-16].

Given these considerations, conducting a techno-economic study of 5G technology within the framework of ethio-telecom becomes crucial. The behavioral patterns of customers and the unique technological requisites in this context distinguish it from regions like London, China, India, or Indonesia. Furthermore, Ethiopia's distinct economic needs and market conditions set it apart from these nations. Therefore, a comprehensive exploration of the technological and financial advantages that 5G technology can offer to ethio-telecom is essential. This work also calls for a thorough assessment of capacity and coverage, all while taking into account the unique demand factors.

This thesis is centered around technology, specifically the realm of 5G. It employs a customized TERA model, adapted to suit the context of the study. The model is implemented using EXCEL, resulting in a novel techno-economic evaluation approach. Through this approach, various 5G deployment scenarios are assessed from both technological and economic standpoints, all within the scope of potential future network configurations.

1.6 Scope and Limitation

1.6.1 Scopes

This thesis primary goal is to conduct a five-year techno-economic analysis of 5G technology in Addis Ababa. This is based on data taken from ethio-telecom's current customer base, which uses 4G-LTE services. Furthermore, the report integrates findings from an ongoing pilot project employing 5G technology in Addis Ababa.

1.6.2 Limitation

- The recent pricing method was considered to calculate ARPU and total revenue. Different pricing methods is not considered
- OPEX cost are considered using existing 4G network and by conducting literatures.
- Cell deployment rather than macro cell deployment is not considering.

1.7 Contribution

This thesis important for network operators to identify the effect of 5G on local economy.

This makes to understand the contribution of 5G technology for the development of the countries by analyzing the cost and potential growth opportunities associated with 5G deployment.

Furthermore, this study thoroughly conducts how the techno-economic evaluation of the 5G network is conduct. It closely examines the important factors to take into account when implementing 5G technology, considering its unique attributes compared to other technologies. These factors include frequency bands, new services, and emerging technologies.

This study also provides valuable insights for various operators currently investing or considering investments in Addis Ababa. It investigates the city's potential customer base and economic requirements, guiding operators on where to invest and what technology perspectives to prioritize.

1.8 Thesis layout

The research is structured into six chapters:

• Chapter One: Background, Motivation, Problem Statement, Objectives, Methodologies, Contribution, Scope and Limitations, and Selected Related Literature Review.

• Chapter Two: Introduction to Mobile Technology Evolution and Comprehensive Exploration of 5G Technology.

• Chapter Three: Presentation of the Techno-Economic Analysis (TEA) Framework and Detailed Modeling.

- Chapter Four: In-depth Examination of 5G Deployment Scenarios and Thorough Network Dimensioning.
- Chapter Five: Presentation of Results and Discussion.
- Chapter Six: Comprehensive Conclusion of the Overall Thesis, and future work

2. Introduction to 5G Technology

2.1 History of mobile communication

1G mobile wireless technology, was introduced in the 1980s. It was analog technology used for voice communication and providing basic voice service. This service supports circuit switched (CS) connections and was developed based on frequency division duplex (FDD) to separate downlink and uplink transmissions and the frequency division multiple access (FDMA) technique to accommodate multiple simultaneous transmissions. This 1G mobile technology is not deployed in Ethiopia [7]. In the early 1990s, 2G was introduced. It was a shift from analog to digital communication.

Digital technologies such as the global system for mobile communications (GSM) and code division multiple Access (CDMA) were introduced. 2G allowed for better voice quality, increased capacity, and added support for text messaging (SMS). The next 2.5G (Second and a half generation) was introduced. This phase represented an intermediate step between 2G and 3G technologies. During this period, significant advancements were made, particularly in data services, resulting in the introduction of limited internet connectivity and the early capability of mobile web browsing. Key technologies driving this evolution included GPRS (General Packet Radio Service) and EDGE (Enhanced Data Rates for GSM Evolution). In 1999, Ethiopia launched GSM mobile service in Addis Ababa using the Ericsson network [7].

3G made its debut in the early 2000s, offering significant enhancements in data transmission speeds and capabilities. This generation revolutionized mobile usage by enabling faster internet access, video calling, and a wide range of multimedia services on handheld devices. Key technologies such as UMTS and CDMA2000 played pivotal roles in defining the 3G standard. 4G and 3G made its debut in the early 2000s, offering significant enhancements in data transmission speeds and capabilities. This generation revolutionized mobile usage by enabling faster internet access, video calling, and a wide range of multimedia services on handheld devices. Key technologies such as and CDMA2000 played pivotal roles in defining the 3G standard. 4G marked a significant leap in technology when it was introduced around 2009–2010. This transformative phase brought about substantially faster data rates, empowering users to enjoy seamless video streaming, engage in online gaming, and utilize advanced mobile applications with ease. The advent of LTE played a central role in the dominance of 4G technology worldwide, providing high data throughput and remarkably low latency, making it a game-changer in the realm of wireless communication [13].

2.2 Fifth Generation Network (5G)

The 5G network stands at the forefront of modern communication technology, leading an era of unprecedented connectivity and possibilities. As 5G represents a groundbreaking leap from its predecessors, promising enhanced data speeds, incredibly low latency, and exceptional device capacity.

Because of the data rates that reach levels in the multi-gigabit-per-second range, the advent of 5G has enabled seamless streaming of high-definition content, online gaming that occurs without interruption, and real-time interactions. Its ultra-low latency guarantees instantaneous responsiveness, rendering it the optimal platform for cutting-edge applications such as augmented reality, virtual reality, and autonomous vehicles[14]. The capacity to simultaneously interconnect enormous number o of devices is a fundamental characteristic of 5G technology, which facilitates the expansion of the Internet of Things (IoT) and enables interconnected global system. This increased device capacity empowers a wide range of industries, including healthcare, transportation, manufacturing, and more, to embrace innovative solutions and automation. With enhanced network coverage and the use of advanced antenna technologies, 5G expands connectivity to previously underserved areas and ensures a robust and reliable network experience [15].

5G also leverages a diverse spectrum range, utilizing higher-frequency bands like mmWave for ultra-fast data rates in urban environments, while lower-frequency bands offer wider coverage in suburban and rural areas. Network slicing, a novel concept introduced by 5G, enables the creation of virtual networks tailored to specific applications and user needs, optimizing network resources and providing customized services [16].

As 5G continues to evolve, ongoing research and development efforts address challenges like infrastructure deployment, spectrum allocation, and seamless integration with existing technologies [15].

2.1.1 5G Radio Network Architecture

The 5G new radio network configuration can be categorized as standalone (SA) or non-standalone (NSA). These options differ in terms of their network architecture and deployment strategy. NSA 5G is an early deployment approach that builds upon existing 4G LTE infrastructure.

In NSA 5G, 5G radio access is supported by the existing 4G core network. In the scenario of NR NSA operation, the NR base station, known as en-gNB, establishes a connection with the LTE base station, referred to as eNB, via an X2 interface [16].

While the X2 interface was traditionally limited to connecting eNBs, Release 15 broadens its functions to enable the linkage of both eNB and en-gNB within the RAN. For NR non-standalone operation, the 5G radio nodes are deployed alongside existing 4G base stations.

Furthermore, in NR non-standalone operation, the RAN employs an S1 interface to establish a connection with the EPC network. In contrast, the RAN for NR Standalone operation facilitates exclusive service delivery via the gNB, which interfaces with the novel 5G core (5GC) network. The visual representation of the 5G RAN setup can be seen in Figure 2 below [16].

This deployment option allows for faster implementation and quicker access to some 5G benefits without the need to replace the entire network infrastructure. However, the full potential of 5G, such as ultra-low latency and some advanced services, may not be fully realized in NSA mode. SA 5G is the ultimate vision of a fully independent 5G network architecture.

In SA 5G, both the radio access network and the core network are based entirely on 5G specifications, without relying on any previous-generation networks. SA 5G unlocks the full capabilities of 5G, including ultra-low latency, network slicing, and other advanced features, offering the highest performance and improved efficiency. Deploying SA 5G requires a more extensive upgrade of the entire network infrastructure, but it enables the realization of the complete 5G vision [17].

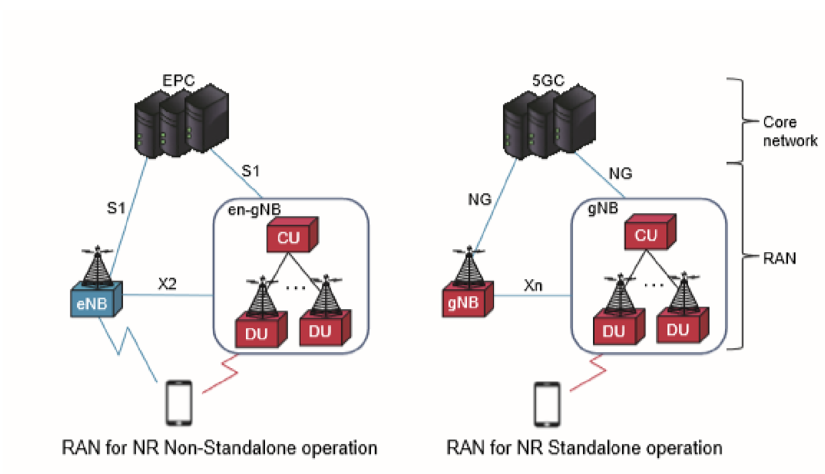

Figure 2 5G RAN configuration [16]

2.2.2 Next-Generation Service-Based Architecture (SBA)

There are two components to this architecture presentation: the control plane function is on the upper part, and the user plane is on the lower part.

The control planes were linked via a service-based interface. To manage subscriber attachment, sessions, and mobility, the Access Management Function and the Session Management Function link to the user plane node via N1, N2, and N4. The N2 and N3 interfaces are dictated by how 5G presents itself to the core and are hence reliant on the 5G RAN architecture. Figure 3 shows, SBA of 5G NR [18].

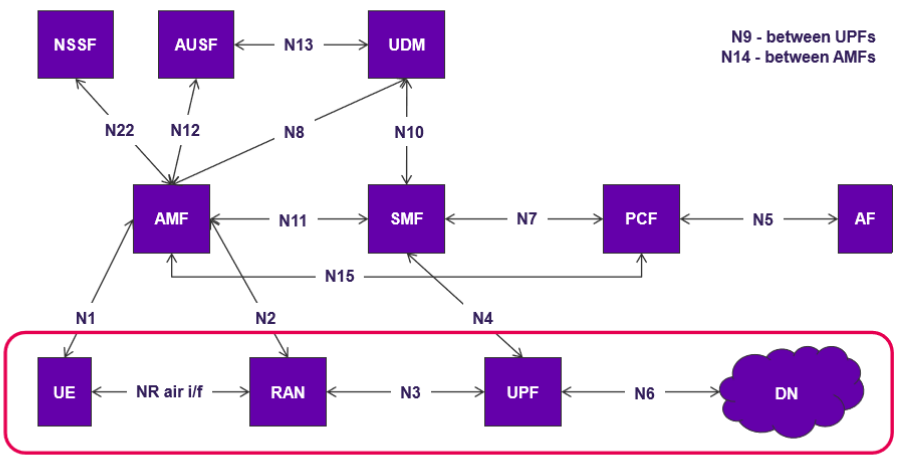

Figure 3 Next-Generation Service-Based Architecture [17]

1. User Equipment (UE): is a physical device that is attached to the RAN module and can be associated with an individual or a network of devices.
2. User Plane Function (UPF): The User Plane Function is a vital part of 5G's architecture. It handles the data traffic between the User Equipment (UE) and the rest of the network. This function is responsible for routing and forwarding data packets efficiently while maintaining a high level of performance and low latency. The UPF is designed to manage various types of data traffic, ensuring smooth communication and a seamless user experience.

3. Radio Access Network (RAN): The Radio Access Network is the part of the network that connects devices (like your smartphone) to the network infrastructure through wireless signals. It includes base stations (or cell towers) and other equipment that transmit and receive radio waves.

   In 5G, RAN includes new technologies like Massive MIMO (Multiple-Input Multiple-Output) to improve data rates, coverage, and overall network performance.
4. Data Network (DN): The Data Network, often referred to as DN, encompasses the entire data communication system that allows devices to exchange information. This includes the core network, which manages data transmission and routing, as well as various network nodes that ensure data reaches its intended destination. In 5G network, the Data Network facilitating the flow of data between different parts of the network, including the core and edge components Access and Mobility.
5. Management Function (AMF): - A Network Slice Selection Function (NSSF) has been included in the AMF. Session Management Function (SMF): - This sets up and manages sessions, according to network policy. SMFs are used to assign resources and set the system up for multicast or broadcast [17].

2.2.3 5G Application services

1. The Enhanced Mobile Broadband (eMBB)

This service has a primary providing ultra-fast data speeds and high-capacity connectivity to densely populated urban areas. It aims to provide seamless streaming of 4K/8K videos, online gaming, and other data-intensive applications.

2. Massive Machine-Type Communications (mMTC)

It refers a service wherein 5G networks extend their support to an immense number of interconnected devices within the IoT (Internet of Things) ecosystem. It facilitates smart city applications, industrial automation, and various sensor networks.

3. Ultra-Reliable Low-Latency Communications (URLLC)

This technology is applicable for applications that demand ultra-low latency and high reliability. Such as remote surgery, autonomous vehicles, and industrial control systems.

4. Fixed Wireless Access (FWA)

5G can be deployed as an alternative to traditional fixed-line broadband in areas lacking adequate wired infrastructure. Using wireless technology FAW offers high-speed internet connectivity to homes and businesses [16, 18].

2.2.4 5G Frequency band

The 5G standard specifies two carrier frequency ranges: FR1 (6GHz with TDD & FDD) and FR2 (23-53GHz with TDD). These two ranges are defined based on their respective frequency bands and have distinct characteristics that impact the way they propagate signals and the physical layer settings they employ.

FR1 - Frequency range: This range covers carrier frequencies that are below 6 GHz and includes both Time Division Duplex (TDD) and Frequency Division Duplex (FDD) modes. Frequencies within this range are commonly used for a variety of wireless communications and have relatively good propagation properties. They can penetrate obstacles and cover larger distances, making them suitable for providing wide area coverage and serving both urban and rural environments.

FR2 - Frequency range 2 This range comprises carrier frequencies between 23 GHz and 53 GHz and exclusively operates in the TDD mode. Frequencies in this higher range exhibit significantly different propagation characteristics compared to FR1. They are often referred to as mmWave frequencies and are characterized by shorter wavelengths. While they offer very high data rates and capacity, they have limited range and are more susceptible to attenuation due to atmospheric absorption and obstacles like buildings and foliage.[19, 20].In Table 1 and Table 2,the frequency ranges and band are show for both FR1 and FR2.

Table 1 5G NR operating frequencies in FR1 [19]

Band	Range of frequencies in FR1			
	Uplink [GHz]	Downlink [GHz]	Bandwidth [MHz]	Duplex Mode
n1	1.92- 1.989	2.11-2.17	60	FDD
n2	1.85- 1.91	1.93-1.99	60	FDD
N3	1.171- 1.785	1.805-1.88	75	FDD
N5	0.824-0.849	0.869-0.894	25	FDD
N7	2.5-2.67	2.62-2.69	70	FDD
N8	0.88-0.915	0.925-0.96	35	FDD
N20	0.832-0.862	0.791-0.821	30	FDD
N28	0.703-0.748	0.758-0.803	45	FDD
N66	1.71-1.78	2.11-2.2	90	FDD
N70	1.695-1.71	1.995-2.02	15/25	FDD
N71	0.663-0.698	0.617-0.652	35	FDD
N74	1.427-1.47	1.475-1.518	43	FDD
N38	2.57-2.62	2.57-2.62	50	TDD
N41	2.469-2.69	2.469-2.69	194	TDD
N50	1.431-1.517	1.431-1.517	85	TDD
N51	1.427-1.432	1.427-1.432	5	TDD
N77	3.3-4.2	3.3-4.2	900	TDD
N78	3.3-3.8	3.3-3.8	500	TDD
N79	4.4-5	4.4-5	600	TDD

Table 2 5G NR operating frequencies in FR1 [19]

Band	Range of frequencies in FR1			
	Uplink [GHz]	Downlink [GHz]	Bandwidth [MHz]	Duplex Mode
n257	26.5- 29.5	26.5- 29.5	50-400	TDD
n258	24.25- 27.5	24.25- 27.5	50-400	TDD
n259	39.5- 43.5	39.5- 43.5	50-400	TDD
n260	37.0- 40.0	37.0- 40.0	50-400	TDD
n261	27.5-28.35	27.5-28.35	50-400	TDD

3. Techno economic modeling and evaluation method

3.1 Introduction to Techno-economic Analysis (TEA)

TEA is a comprehensive methodology used to assess the feasibility and economic viability of a technology or project. It involves analyzing the total costs, potential revenues, and performance metrics of the technology or system under consideration, enabling informed decisions about its implementation or adoption.

It involves evaluating the total costs, technical performance, revenue potential, and risk factors associated with adopting the technology or implementing the project. TEA allows stakeholders to make informed decisions by comparing different alternatives, expert opinions, understanding the financial implications, and ensuring that resources are allocated efficiently to achieve the desired objectives [12, 21].

3.2 Modified TERA Model

The term techno-economics was announced in the European research program called Research in Advanced Communications in Europe (RACE) in 1985-1995 the context of telecommunication. Later, a methodology and a tool for the techno-economic evaluation of new narrow band and broadband services and access networks were developed (1990–1994) as part of the RACE 2087 Tool for Introduction Scenarios and Techno Economic Studies for the Access Network (TITAN) project [21].

Many European research projects have expanded and exploited the methodology and tools developed in the early programs since the late 1990s for various application areas. OPTIMUM (Optimized Architectures for Multimedia Networks and Services) from 1994 to 1998; TERA (Techno-economic Results from ACTS) from 1994 to 1998; TONIC (Techno-economics of IP Optimized Networks and Services) from 1998 to 2002; and ECOSYS (Techno-economics of Integrated Communication Systems and Services) from 2004 to

2007 were all introduced for various purposes and application areas based on the projects [6, 21]. The TEA models used in the TERA framework as well as the project year are shown in Table 3.

Table 3 TEA models drawn from TERA framework[21]

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

The Techno Economic Results from ACTS (Advanced Communication Telecom services) framework (TERA) is a well-liked techno-economic analytical methodology in the telecom sector. TERA combines technical, market, economic, and costs of important network components to enable techno-economic analyses[6].

The framework depicted in Figure 4, the traditional techno-economic modeling process involves two primary starting points: services and technical architectures. The models use forecasts and assumptions related to these elements, along with a few general economic inputs like the discount factor, study period duration, and residual value of investments at the end of the period.

By considering these factors, the models calculate various financial aspects such as revenues, operational costs, and investments, as well as cumulative cash flows. Moreover, they determine important decision-making criteria like net present value (NPV), internal rate of return (IRR), and payback period (PBP).

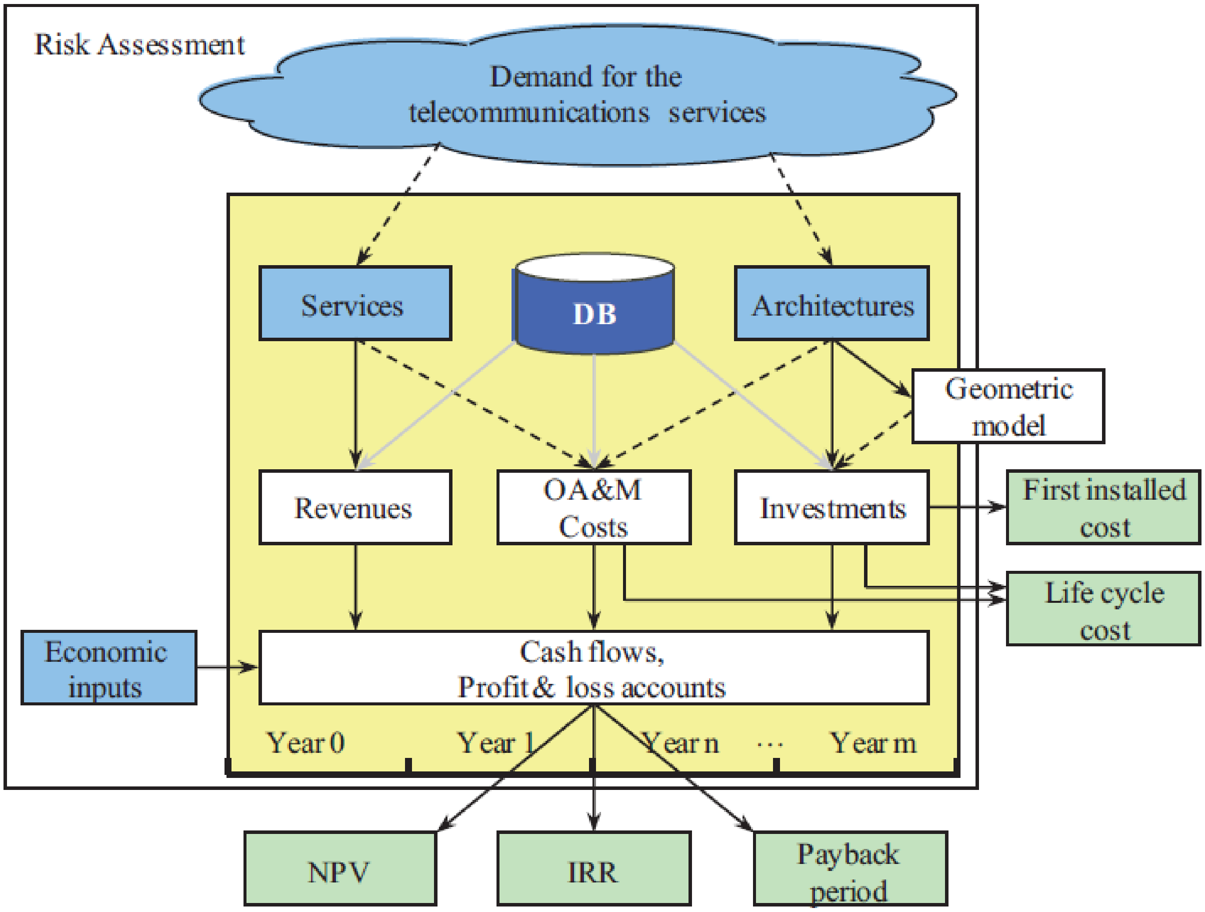

Figure 4 TERA Framework [23]

The modeling methods created for techno-economic analysis are well-suited for assessing different technology architectures [22]. Modeling becomes more challenging when analyzing future time frames and dealing with increased technology uncertainty. To handle these situations, scenario planning is used, allowing the creation of alternative approaches and addressing uncertainty effectively [6],[21]

For this reason, the TERA model is modified in this study to handle the 5G network deployment scenarios formulation as input. The modified TER framework used in this study is shown in the Figure 5.

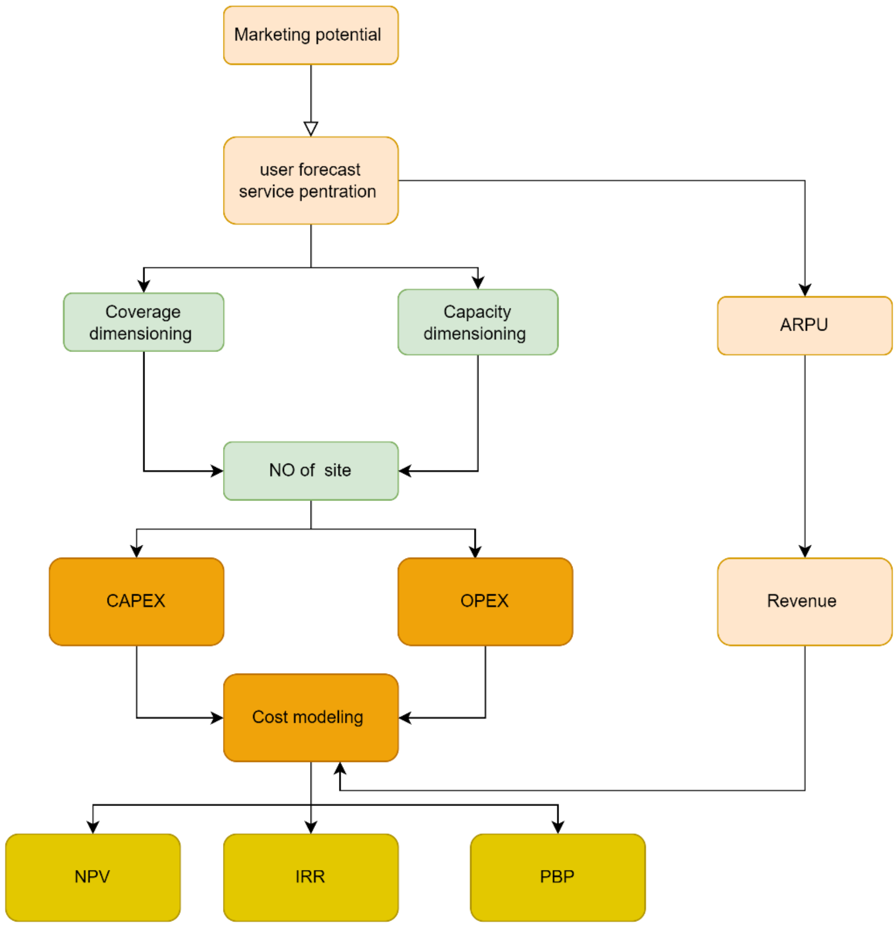

Figure 5 Modified TERA framework for TEA

3.3 5G NR Network Dimensioning

Network dimensioning is the procedure of determining the optimal capacity and resources necessary for a telecom network to function in an efficient and effective manner. Network dimensioning considers various factors, such as the number of users, service types, traffic patterns, expected expansion, and technological breakthroughs. The aim is to guarantee that the network can manage the expected load without experiencing any congestion and service interruptions [11].

The process of network dimensioning involves the identification of requisite resources to satisfy the minimal requirements of the services intended to be rendered at a specified location [11]. Dimensioning a radio cellular network involves considering essential components such as the coverage area, frequency band, allocated bandwidth, MIMO configuration, population density, and the distribution of network traffic.

Coverage and capacity planning are fundamental stages of the network dimensioning process, which ascertain the number of radio stations necessary to meet the criteria for coverage and capacity. The network dimensioning process also entails the evaluation of the traffic profile, including data rates and coverage parameters, for network loading purposes [23]. Figure 6 shows the overall network dimensioning process using flow chart.

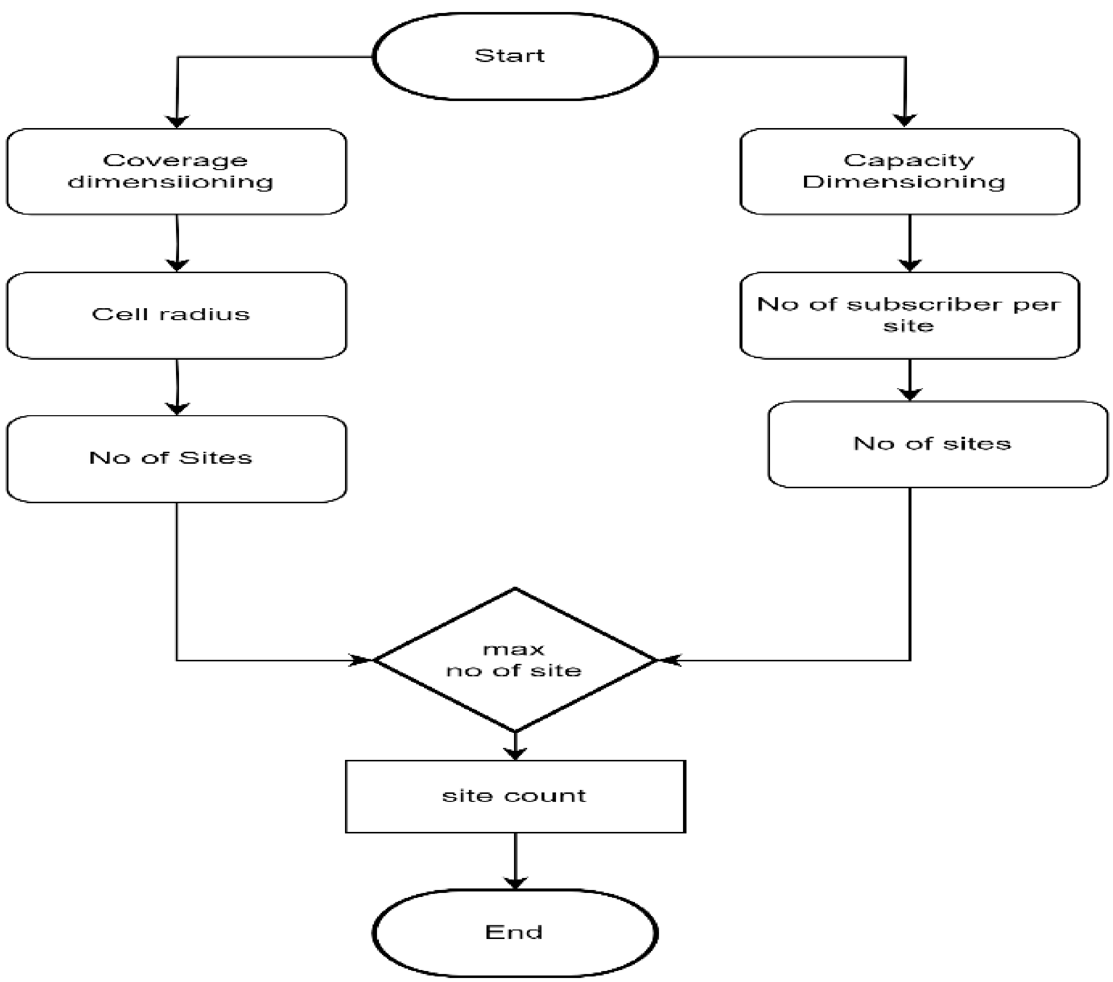

Figure 6 5G NR network dimensioning flow chart [24]

3.3.1 Coverage Dimensioning

Coverage dimensioning is a crucial stage in deploying a 5G NR network. It entails calculating the resources needed for sufficient signal coverage in a designated area and prioritizing coverage over capacity. This process ensures the accurate placement of 5G base stations according to specific requirements and determines the coverage range of each station [25].

4G coverage dimensioning is primarily focused on maximizing coverage range and maintaining consistent signal strength, 5G coverage dimensioning is more intricate, considering factors like frequency bands, advanced antenna technologies, small cells, and network densification to optimize coverage and capacity for diverse usage scenarios.

The main inputs considered in coverage dimensioning are geographical information, frequency band and bandwidth, transmitter power, antenna characteristics, propagation model, receiver sensitivity, interference, obstacles and interference, path loss models, multipath and shadow fading, and penetration loss [25]. Figure 7 shows the process and steps that we follow during the determination of the number of sites based on the selected site area to cover the range.

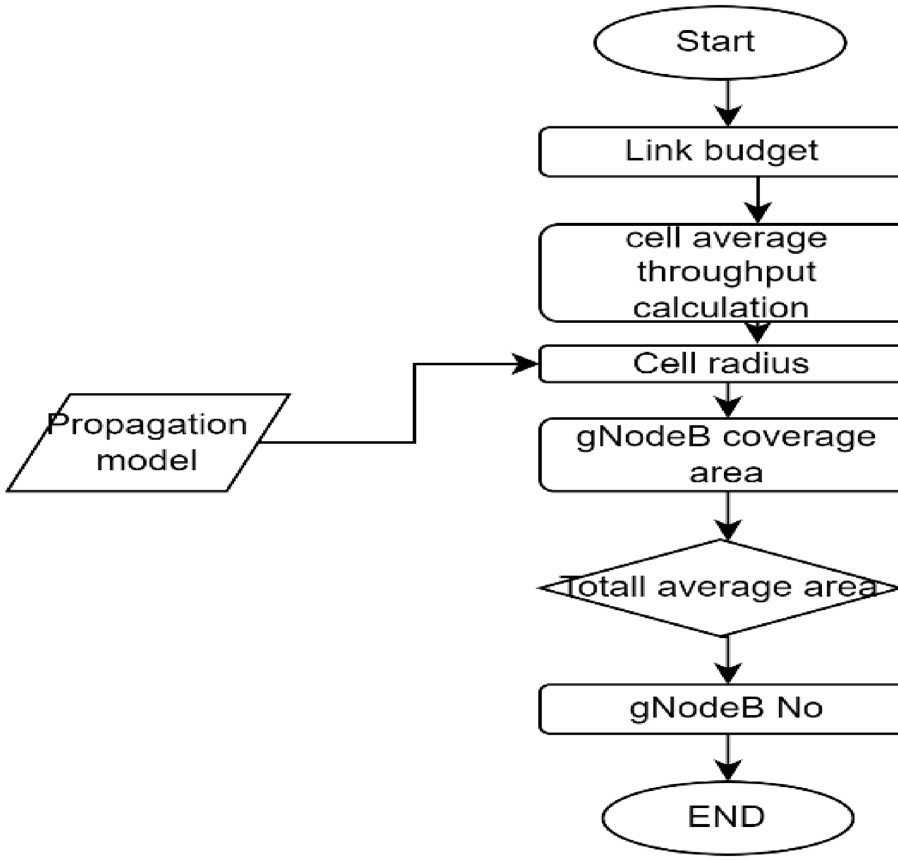

Figure 7 coverage planning flow chart [29]

i. **Link budget**

A radio link budget in coverage dimensioning for a 5G network is a comprehensive calculation that accounts for all gains and losses in a communication link. It helps determine if the received signal strength is sufficient for reliable communication [25].

The calculation of the link budget tries to estimate the maximum value of Allowable Path Loss (MAPL) or the weakening signal received between the mobile antenna and the mobile station antenna on the downlink and uplink sides.

What often leads to poor performance in initial 5G networks is an overestimation of the radio link budget. This means that the expected cell coverage and the strength of the downlink signal from the base station turn out to be higher than the actual situation on the ground. This result in a lower signal quality for users, affecting things like download speeds. This overestimation can be caused by various factors, but a common reason is using a too simplistic method for calculating link budgets that worked for older cellular systems.

Unlike previous systems, 5G NR employs advanced antenna arrays that match the spread of radio channels more precisely, especially in higher frequency bands. These frequencies open up new opportunities for 5G, but they also come with challenges in signal propagation. To deal with this, 5G uses more focused antennas to overcome the increased signal loss. This distinction is a key feature of 5G, allowing it to work in new radio bands beyond what LTE could handle [26].

Uplink and downlink radio link budgets help assess the possible path loss between sender and receiver in planned areas. The link budget estimation sets the limit for max MAPL. When using an accurate propagation model, the MAPL gives an estimate of the farthest reach of a cell [27].

ii. Parameters used in 5G NR link budget

The main parameters used in this study link budget are Transmit Power (in dBm), Antenna Gain, Receiver Sensitivity, Margin, interference margin, Effective Isotropic Radiated Power (EIRP) and other Loss.

1. Transmitter power (in dBm)

Transmitter power is a critical parameter that determines the strength of the signal transmitted, impacting the signal's coverage range and quality o manage interference between various network components, improve network performance, and guarantee reliable communication, transmitter power must be adjusted.

2. Interference margin

Interference Margin (IM) is determined based on the targeted Signal-to-Interference-plus-Noise Ratio (SINR) and the workload present in neighboring cells. This equation is applied to calculate the interference margin for the downlink.

$$IM_{DL} = -10\log(1 - Load_{DL} I_N 10^{0.1SINRPDSCH}) \quad (3.1)$$

Where, IM_{DL} is DL interference margin, $Load_{DL}$ is the DL load, I_N is the adjacent cells interference factor, and SINR PDSCH is the required SINR for PDSCH detection.

3. Effective Isotropic Radiated Power (EIRP)

EIRP refers to the precise amount of power that a hypothetical isotropic antenna would require to produce identical signal strength in a specific direction as the present antenna in use.

EIRP considers both the antennas transmit power and its gain. This metric plays a pivotal role in determining the strength of the transmitted signal, signal coverage, and quality,

all of which constitute critical aspects of wireless communication systems, including 5G.

$$EIRP = P_{TX} - G_{TX} - \sum Total\ TX_{loss} \quad (3.2)$$

Where: PTx is the transmitter power (dBm) and GTx is the transmitter antenna gain (dBi)

EIRP for Downlink

$$EIRP_{DL} = TX_{power} - L_{feeder} - L_{Jumpers} - L_{connectors} - ILTMA + G_{TXAntenna} \quad (3.3)$$

EIRP for Uplink

EIRP = $Tx_{Powe} + UETx_{Antenaa\ gain}$ (3.4)

4. Propagation models

A propagation model is a tool utilized to show the average signal propagation and transform the maximum allowable propagation loss into the maximum cell range[28]. This model is contingent on various factors such as demography, distance, frequency, atmospheric conditions, and indoor and outdoor settings. Examples of this model include free space, Empirical COST 231 Model (Walfisch-Ikegami), Okumura-Hata, Longley-Rice, Lee, and Young's models [28].

A propagation model is a tool utilized to show the average signal propagation and transform the maximum allowable propagation loss into the maximum cell range [43]. This model is contingent on various factors such as demography, distance, frequency, atmospheric conditions, and indoor/outdoor settings. Numerous examples of this model include free space, Walfish-Ikegami, Okumura-Hata, Longley-Rice, Lee, and Young's models[28].

5. Okumura-Hata Model:

The Okumura model was constructed in three different settings: urban, suburban, and open spaces. The Okumura-Hata model is an empirical representation of the graphical path loss data. between source and destination, between 1 and 20 kilometers[27, 28].

3.3.2 Capacity Dimensioning

Capacity dimensioning involves estimating the resources needed to handle a specific amount of user traffic while maintaining a certain quality of service (QoS). This helps decide how many network sites are necessary to cover an area. This estimation considers factors like the market's size, potential subscribers based on numbers, sizes, and market share and also the basic needs for capacity dimensioning are cell capacity, subscriber density, and subscriber traffic profile. [25].

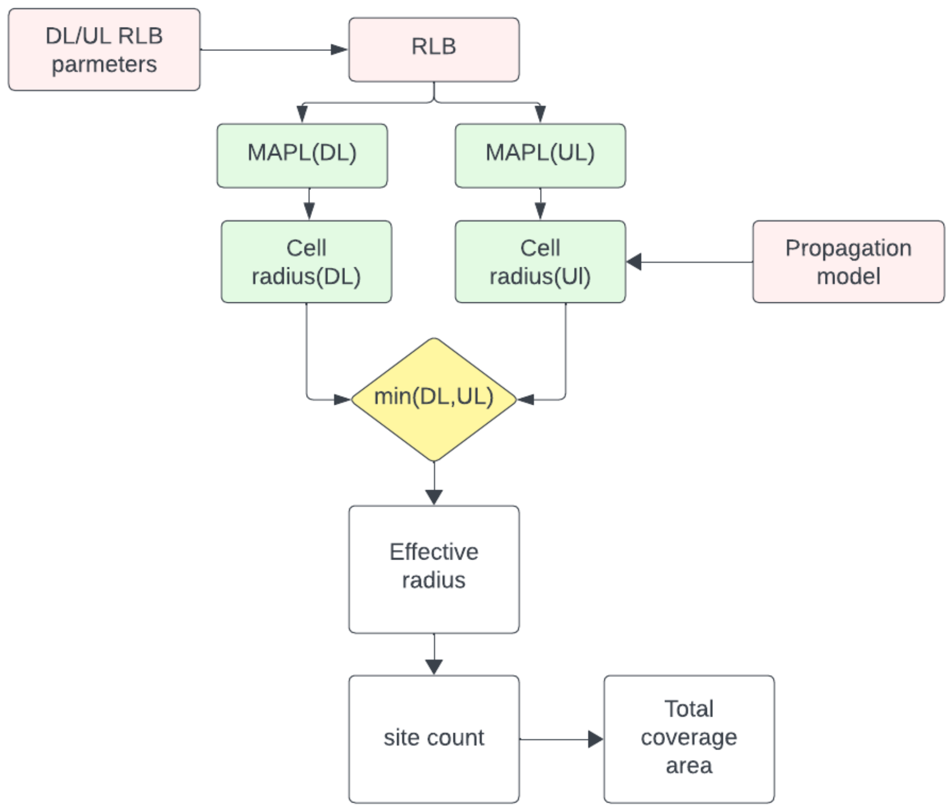

Figure 8 Capacity planning flow chart [6]

3.4 Cost Modelling

Cost can generally be defined as the value of resources, material or financial, used or consumed in the process of production or service provision. As such, costs can be classified into two groups: capital expenditure (CAPEX) and operating expenditure (OPEX). Operating expenditure is incurred in order to cover the cost of day-to-day operations such as stationary costs, salaries and benefits, power consumption, and other fixed expenditures of immaterial amount.

On the other hand, capital expenditures refer to resources consumed to acquire assets that are expected to benefit the organization for more than one budget year. The costs of buildings, equipment and furniture, research and development are categorized in this group. These types of costs are allocated to each year of operation or service life of the asset in a systematic manner called depreciation[21].

Cost modeling is creating a mathematical representation of costs. The two main approaches used in cost modeling are top-down and bottom-up approaches. The first step in the bottom-up approach is forecasting the demand for the new service. Then, the existing network infrastructure is analyzed. In the top-down approach, the process used in the top-down approach is reversed. The existing network infrastructure is analyzed first, and based on it, a cost is modeled for the new system [22]. Bottom-up and hybrid approaches are preferable in techno-economic modeling.

In this study, a hybrid approaches were employed to evaluate the expenses related to various network components. The anticipated demand was used as a guide to identify the necessary elements. Using this information, a cost model, similar to the one shown in Equation 3.5, was developed. However, it's important to note that while the current network has the potential to handle 5G traffic, the expenses related to core and backhaul are not considered in this cost assessment. These methods are often selected for investment calculations due to the changing costs of network components over time [29].

$$C_{T} = N_M C_M + N_S C_S + C_{spectrum} + C_{BH} + C_{core} + OPEX \tag{3.5}$$

Where $NMCM+NSCS+Cspecrum+CBH+CCore = CAPEX$, CT is total cost, NM and NS are number of macro and small cells, CM macro cell, CS small cell, Cspectrum spectrum, CBH backhaul and Ccore core and OPEX cost to run the network.

The sum of CAPEX and OPEX cost is considered as total cost of ownership (TCO). And its network deployment cost in telecom industry. It’s obtained using the following formula

$$TCO = CAPEX + OPEX \tag{3.6}$$

3.5 Revenue modeling

Revenue modeling refers to a systematic process that determines how a business generates its income over a specific period of time. The total number of subscribers, average revenue per user, and market share of the technology or service are the three major factors considered in revenue modeling for techno-economic analysis. Though sometimes it is important to consider other indirect revenue sources, the projection of expected revenue from such services is primarily determined by the total number of subscribers and average revenue per user or tariffs [22]. This calculation allows us to model the expected revenue outcome, which can be expressed as:

$$RT = ARPU * SP * PMS * IR \tag{3.6}$$

Where, RT is the generated revenue, SP is predicted number of subscribers, PMS is predicted market share of 5G and IR is indirect revenue from for example roaming, sale of SIM.

3.6 TEA Evaluation

3.6.1 Cash flow (CF)

Cash flow shows cash used by the project, cash outflow, and cash generated by the business, or cash inflows. Cash flow is an important measure of the viability of a project. The success of every project depends on its cash flow pattern. So, understanding the cash generating capacity of projects helps to select the most profitable venture. If the cash flow generated by a project is over and above all its costs and expenses, it will have a positive net cash inflow[30, 31].

$$CF = \sum_{i=1}^{5} (R_{T-C_T})i \tag{3.7}$$

Where R_T is revenue modeling, C_T is cost modeling and i is the study period.

3.6.2 Discounted Cash Flow (DCF):

Discounted cash flow is a valuation method used to calculate the present value of future cash flows. The idea underlying discounted cash flow is the time value of money; money today is worth more than money tomorrow due to inflation. Discounted cash flow is determined by calculating the present value of all cash flows at the company's cost of capital. In DCF analysis, future cash flows are "discounted" back to their present value using a discount rate. If the present value of projected cash flows is greater than the initial investment, the project is considered financially viable [12].

$$DCF = \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \cdots + \frac{CF_i}{(1+r)^i} \tag{3.3}$$

Where CF is cash flow, r is discount rate and i is the study period

3.6.3 NPV, Internal Rate of Return and Payback Period

Net Present Value (NPV):

Net present value is calculated by deducting the initial investment from the present value of cash inflows over a specific period of time. Since time value of money is considered, NPV is a better means of determining viability of a project. A positive NPV suggests that the project is expected to generate more cash inflows than outflows, indicating a potentially profitable venture. The NPV of a project is determined as the difference between the discounted value of future earnings and the initial investment amount[6, 21].

$$NPV = \sum_{i=0}^{i} \frac{CF_i}{(1+r)^i} \tag{3.4}$$

Where CF is cash flow, r is discount rate and i is the length study period

Internal Rate of Return (IRR):

The internal rate of return is the rate at which the NPV of the project equals zero. IRR doesn't convey any meaning by itself. It has to be compared with the company's cost of capital or other suitable measures set by the management. If the IRR is greater than the cost of capital, then the project is expected to produce a favorable return. In addition, IRR can also be used to choose among mutually exclusive projects. Projects are ranked based on their respective IRRs, and the project with the highest IRR is selected.

$$NPV = \sum_{t=0}^{T} \frac{CF_t}{(1 + IRR)^t} = 0 \tag{3.5}$$

Where, t= Period, t is a positive Integer, T is total number of periods, NPV is Net Present Value, IRR is Internal Rate of Return and CF is cash flow.

Payback period

The payback period is one of the easiest metrics used in project analysis. It is the number of periods or the time it takes for net cash inflows to return the initial investment. It is computed by adding the annual net cash inflows until the sum equals the initial investment. If a uniform cash inflow is assumed, then the payback period is simply calculated by dividing the initial investment by the annual cash inflow[22].

Net Income

Net income, or net profit, of a project or business is computed by dividing all periodic costs and expenses by the total revenue generated during a specific period. Net income is determined using the matching principle. The matching principle states that revenue generated during a specific period must be matched with the costs and expenses incurred to generate it. Unlike cash flow, net income includes the allocation of non-cash expenses such as depreciations and amortizations. Due to this, cash flows are more important measures in project selection than cash flows[22].

Depreciation

As stated above, the determination of net income involves the allocation of non-cash expenses such as depreciation over the project's life or the life of the asset. A project's cost structure can broadly be classified as capital expenditure and operating expenditure. Operating expenditures are recognized as expenses during the period in which they are incurred. On the other hand, capital expenditures, for the purpose of determining net income, are allocated over the project's life. The rationale behind this is the matching principle. The initial capital expenditure is incurred to enable the company to generate revenue over the life of the project. Hence, this outlay must be allocated accordingly to adhere to the matching principle. The systematic allocation of capital expenditure over the life of the projects is what we call depreciation[22].

4. Deployment scenarios and Techno-economic analysis of 5G network

In this chapter 5G deployment analysis scenarios using Scenario planning tools to run the business are discussed.by considering these options, areas selected in this deployment, marketing analysis of the research and things that are consider and need to be analyzes during the deployment of 5G in discussed.

4.1 Deployment Scenarios Analysis

Scenario planning is a commonly utilized approach for engaging in strategic business planning and arriving at decisions in the presence of notable uncertainties over an extended duration. Recently, scenario planning tool is used to wireless industry [22].

Addis Ababa has a population of more than 5 million, and almost all the federal government offices, different international organizations, embassies, and private and non-private organizations are located there. It's a city where potential customers are together, hosting lots of international government and non-government conferences and playing a key role in trade within Ethiopia and Africa [32].

Throughout the history of ethio telecom, Addis Ababa has been at the forefront of adopting new telecommunications technologies. Currently Addis Ababa uses 2G,3G and 4G technologies. As shown the Figure 9, the number of 4G subscribers increase exponentially for the past years. This increase in 4G subscribers suggests that the city's population is open to adopting advanced technologies. This could be due to factors like increasing familiarity with digital tools, changing communication habits, and the appeal of the enhanced services that 4G provides.

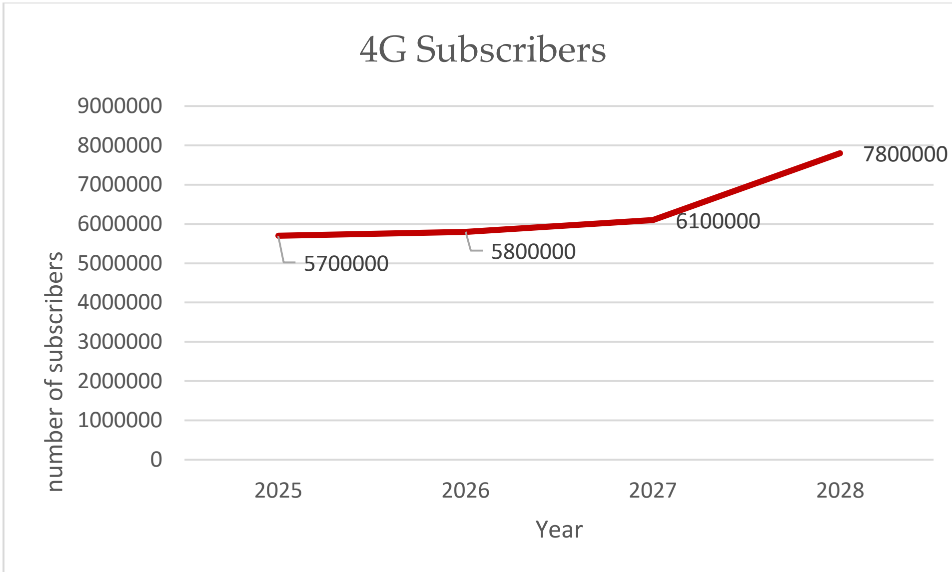

Figure 8 Previous years 4G subscribers

According to a survey done in Addis Ababa using five days of ethic telecom data, the rising availability compatible devices is favorably influencing the deployment of 5G technology. 0.94% of active devices support 5G and 62% support 4G devices, this growing trend shows that as more people obtain access to suitable 5G devices, the city will be well-positioned to benefit from the increased connection and benefits that 5G technology may provide.

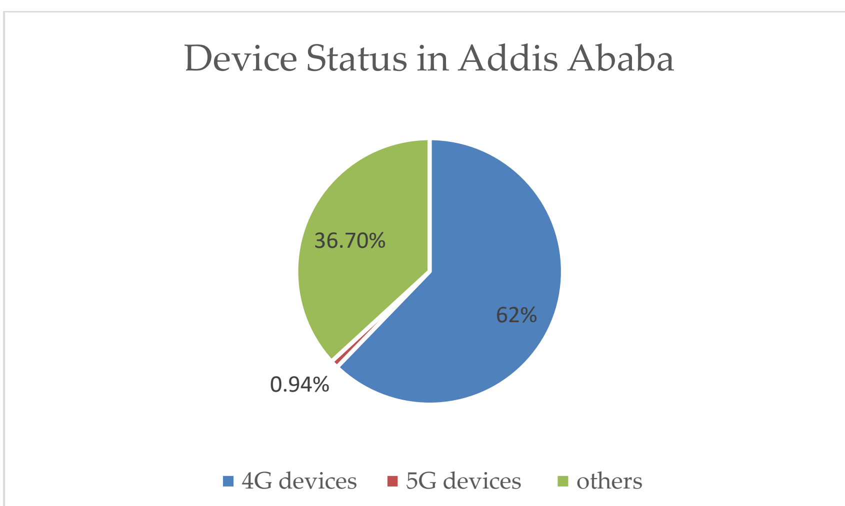

Figure 9 Devices status in Addis Ababa

Given the distinctive demands for 5G technology's applications, the introduction of 5G in Addis Ababa, requires suitable methods. The scenario planning method, a tool that has gained prominence in the wireless industry, is used for managing uncertainties, complexities, and disruptions posed by new technologies, particularly in the telecommunications sector and emerging cellular technology. To formulate 5G deployment scenario planning, different data sources are considered: ethio-telecom, literature, documentation, reports, and experts' interviews. The deployment scenario steps listed in [33] are applied. The steps for deployment scenarios are described as follows:

i. Defining the time frame, scope and stakeholders

Time frame: Based on various studies pertaining to scenario formulation, the time frame identified spans from five to ten years. With this time horizon as the input, the present study documented the status of the city and technology lifetime trends (rate) within the selected timeframe of five years.

Scope: During the deployment of 5G new radio, the scope is limited to the new radio network in Addis Ababa in the context of ethio telecom network operator.

Stakeholders: The key players involved in the 5G deployment are end users, mobile network (service) operators, and vendors or suppliers.

ii. Key factors affect 5G deployment

The analysis of factors contributing to challenges in 5G technology, as well as trends, is conducted through a review of literature, related studies, industry standards, expert viewpoints, and vendor reports. Given the various suggestions from different sources and its common usage in the telecom sector, the PEST (Political, Economic, Social, and Technological) framework was chosen for analysis.

This framework helps identify uncertainties that need careful assessment and management before making further decisions. The summary of the PEST trend analysis is shown in Table 4.

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Table 4 Factor that affect 5G deployment in PEST model [6, 27, 30]

PEST Analysis	Trend
Political	✓ Operating frequency ✓ Licensing and permits ✓ Regulation stability
Economic	✓ Charging and tariff of services, ✓ Customizing phones, high CAPEX and OPEX cost, penetration of mobile phones and affordability, ✓ Investment and operational cost ✓ Pricing policy and revenue
Social	✓ Number of customer and demand ✓ User awareness on new technologies ✓ Number of connected devices ✓ Content creation,
Technological	✓ Network Compatibility with existing network ✓ User demand

iii. Trends

From the above key factors of 5G deployment, key trends are selected in the deployment of 5G technology. These selected key trends are important for the deployment of 5G technology in Addis Ababa. The key trends are listed in the table below. Table 5, presents the trends within the PEST model, which is a strategic framework used for analyzing the external macro-environmental factors that can impact an organization.

Table 5 Trend analysis for 5G deployment scenarios

PEST	Factor trend	Description
Political	Frequency allocation	5G has a wide range of frequency bands, including low, medium, and high bands.
Economical	Increase capital and operational expenditure costs	The cost of new network deployment and operation is high
	Mobile subscribers and traffic growth	Growth of data service users in different application areas E.g., video streaming, online gaming
	Investment opportunity	The 5G network is beyond high data rates and capacity. It has new innovation services for IoT devices and massive types of machine communication
	Increase investment opportunities in the cities	Attract different investors to invest in different services and manufacturers.
Social	Device availability	Ability to buy new devices that support 5G due to the high cost of new devices
	User awareness for new technology	The awareness of users of new technologies like 5G is low
	User demand	5G demand needs higher data speeds, lower latency, and new applications

Technological	Enhance mobile cellular technology	Improved data rate, latency, QoS, and reliability
	Backward compatibility with existing technology (4G)	Designed to be backward compatible with existing networks

4.2 Techno-economic Analysis

4.2.1 Marketing Analysis

The integration of technology and economics in the deployment of 5G networks necessitates a holistic approach that extends beyond technical considerations. An integral component of this approach is marketing analysis, which plays a pivotal role in understanding how the dynamic interplay of market forces influences the feasibility and success of 5G technology implementation in Addis Ababa.

The procedure for performing marketing analysis involves thoroughly assessing industry trends, studying consumer actions, analyzing competitors, and identifying potential sources of revenue. These efforts yield valuable insights into the need for 5G services, strategies for setting prices, and the creation of viable business structures.

By investigating the intricate relationship between technology and the market, this analysis contributes crucial insights to the broader techno-economic assessment, enabling informed decisions that align with the unique needs of Addis Ababa's telecom landscape.

The data sources for marketing analysis are the census data of Addis Ababa and subscriber records and trends from ethio telecom's 4G network services.

The target city for this study is Addis Ababa. Addis Ababa is the highest population city in the country. Which is estimated more than 5 million in 562 square kilo meter .The number of populations in the city for the year of 2019, 2020, 2021 and 2022 recorded as

4,592,000, 4,794,000, 5,006,000, and 5,228,000 respectively with a yearly growth rate of 4.36, 4.40, 4.42, and 4.43 respectively [34].

i. Population Forecast

To predict the service user in the study period, first number of populations needs to forecasted. To forecast the total number population for 5-year geometric progression method using the previous 5-year data. Geometric progression method is popular method in rapid growing city. The estimated geometric mean used in the forecasting process was 4.40%. This is obtained taking the previous five years' growth rate. The forecasted population of the city illustrated in Figure 11 below.

As shown in Figure 11, the population of Addis Ababa city will increase for the next five years, with an expected growth rate of 4.40%. By the end of the study period in 2028 G.C, the city's population is estimated to reach 7,070,111. This is largely due to Addis Ababa's prominent position as the country's main urban hub, hosting numerous government and international institutions. Additionally, the city's central role as the headquarters of the African Union and various global organizations contributes to its attractiveness. Notably, Addis Ababa's reputation as the safest city in the country makes it a preferred choice for people seeking a secure living environment.

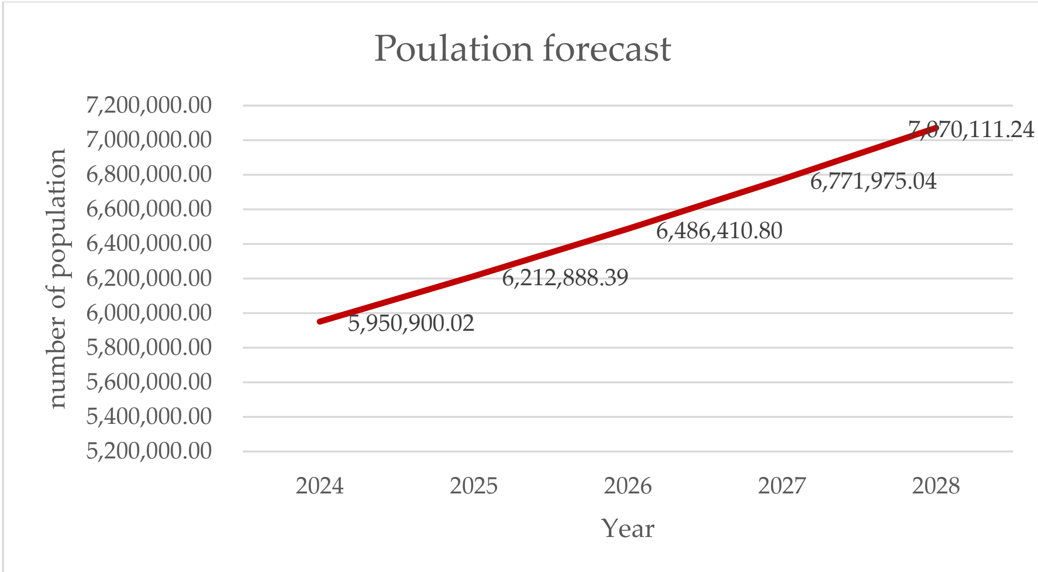

Figure 10 Forecast Population number of Addis Ababa city

ii. 5G Subscribe Forecast

The Bass model is utilized for the purpose of predicting the number of 5G subscribers over the course of the next five years. This model is widely recognized as the best approach to fully describe the initial stages and subsequent expansion of new services. It introduces a theoretically satisfying and mathematically refined framework for explaining the diffusion process of a novel technology or product within a specified population of end-users. The Bass model is highly effective in predicting market trends for products or services that exhibit diffusion-type characteristics, such as mobile telecommunications [31]. The projected number of 5G users in the future is determined by factors such as population potential, growth rate innovation (p), and imitation (q) coefficients, and can be estimated using the equation provided below:

$$N(t) = M.1 - \frac{e^{-t(q+p)}}{1 + \frac{q}{p}.e^{-t(q+p)}} \quad (4.1)$$

- where N (t) is the number of customers / subscribers in year (t)
- M is the number of existing network current customer

- p value > 0 is an innovation coefficient, which is the probability of an initial purchase at the start of the deployment of a new network.
- q≥0 is the imitation coefficient, which refers to the group size of future users

Where p=0.0267, q=3356, M=6,100,000 and t=5 years

The p and q values referenced in this study were derived from literature sources and were applied to Indonesian cities, Jakarta, Surabaya, and Medan. These cities were selected as representatives of urban areas with comparable characteristics to Addis Ababa, taking into account factors such as population size and the demand for city-specific data. It is important to note that both and Ethiopia are developing countries [11].

According to Figure 11, there are roughly 190,000 5G network subscribers at the beginning of the study period. By the end of the study period, five years later, the number of subscribers has increased exponentially to more than 1.6 million.

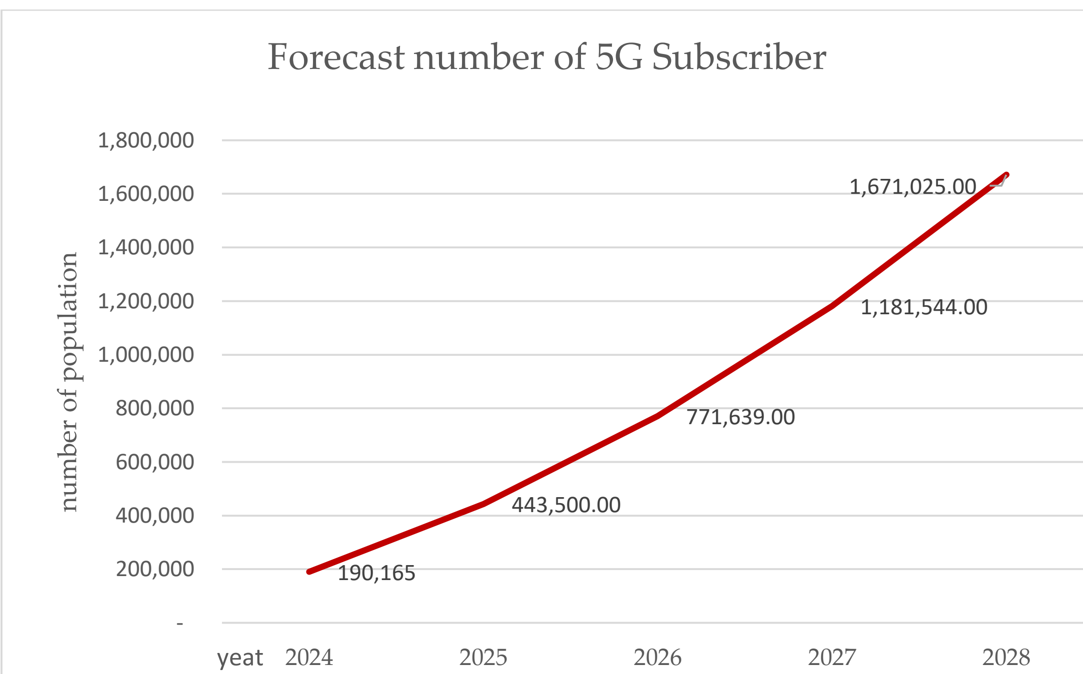

Figure 11 Forecast number of 5G subscribers

iii. Service Penetration Rate

Another crucial factor to consider in the marketing analysis is the penetration rate of service users. This rate is determined based on the defined market potential and the city's population, as illustrated in Figure 13. This is formulated using Equation 4.2. The analysis shows a gradual progression from 3% to 24% increasing rates. The increasing penetration rates indicate a growing acceptance of 5G technology.

$$\text{Service pentration rate} = \frac{Y(t)}{P(t)} \qquad (4.2)$$

Where y(t)is forecasted users at year t and P(t) forecasted population in the city

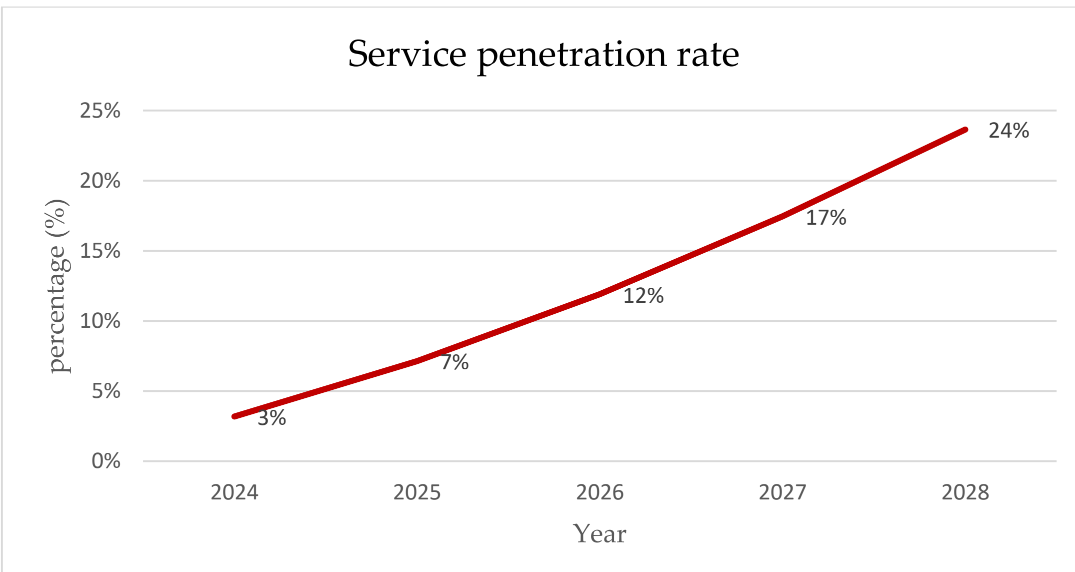

Figure 12 Service penetration rates

4.2.2 Economic Analysis

i. ARPU

In this research, ARPU is determined by analyzing the previous 4 years of ethio telecom ARPU data. By observing the historical trends in ARPU over these years, a linear regression assumption is applied to project its future path. Using linear regression method assumption suggests that the ARPU value increases in a steady and consistent manner year by year.

Using this linear assumption, the study then forecasts the future ARPU values. This forecast is visually represented in Figure 14, which provides a graphical representation of how the ARPU is anticipated to evolve over the coming years based on the observed linear trend.

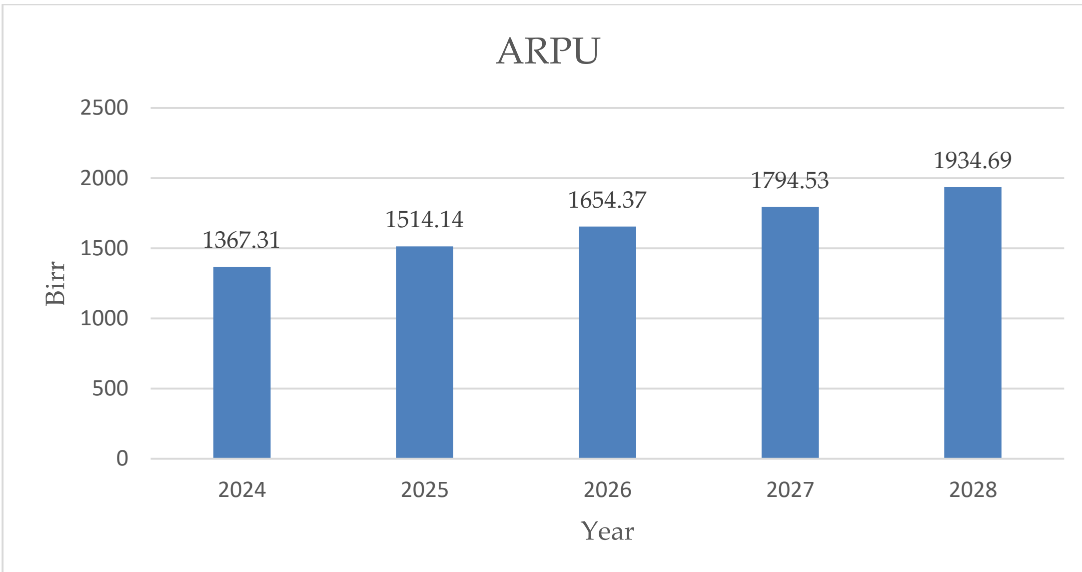

Figure 13 ARPU forecasted

ii. Revenue

As described in Section 3.4, the revenue projection relies primarily on the total number of service users and the associated tariff. Building on this idea, the study utilizes the previously forecasted numbers for both service users and the projected ARPU. By integrating these projected values, the study calculates the total revenue anticipated to be generated during the upcoming five-year study period.

This calculation factors in the expected fluctuations in user numbers and ARPU values. This approach combines the forecast user number and corresponding ARPU to provide an estimate of the cumulative revenue likely to be earned over the ensuing five years, as shown in Figure 15.

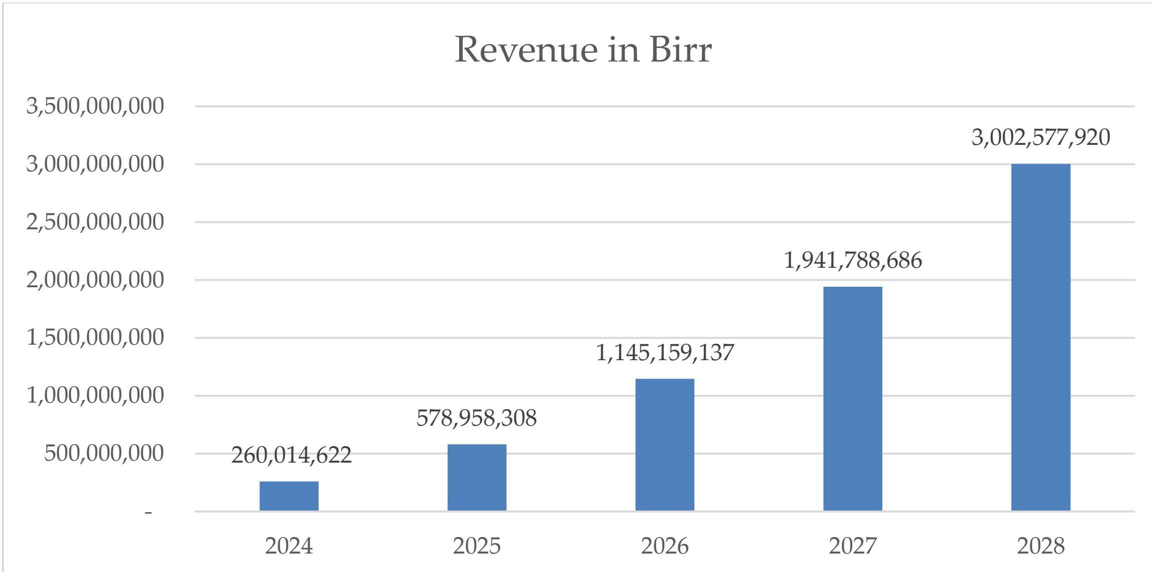

Figure 14 Forecast revenue

When the projected revenue increases over the study period, it indicates a positive growth path for ethio telecom. This upward trend suggests that the company is generating more income from its services or products over time. This increase in revenue can be attributed to various factors, such as an expanding customer base, ARPU, successful pricing strategies, increased market demand, and effective business operations.

However, to indicate the overall performance and financial health, we have to consider financial indicators like NPV, PBP, and IRR, which are described in the next section.

4.2.3 Technological deployment analysis of 5G

Unlike other technologies, 5G deployment may consider different technological considerations. In terms of application service, frequency band, and deployment option-based consultation and selection criteria, this consideration is based on the PEST model described above. By considering its political, economic, social, and technological factors.

The technological deployment options considered in this work are discussed in this section.

5G Service needs and Application area

As detailed in section 2.1.3, among the three primary 5G application areas, the enhanced Mobile Broadband (eMBB) segment is chosen within the specific context of Addis Ababa, and ethio-telecom's customer base.

The other two application services require latency of less than one millisecond (1ms), support for user mobility up to 500 kilometers per hour (KM/hr), and a connection density of up to 1 million devices per square kilometer (km^2). As these requirements are not currently met within the setting of Addis Ababa, the eMBB service is selected.

High-Speed Internet Access, Augmented Reality (AR) and Virtual Reality (VR), Cloud Services and Mobile Computing, IoT Connectivity, Mobile Video Conferencing, Online Gaming, and eSports are all part of the eMBB service.

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High-Speed Internet Access, Augmented Reality (AR) and Virtual Reality (VR), Cloud Services and Mobile Computing, IoT Connectivity, Mobile Video Conferencing, Online Gaming, and eSports are all part of the eMBB service. This choice allows us to meet rising data demands while also generating a chance to attract multinational businesses looking for services aligned with the capabilities of this 5G application.

Table 6 gives us a helpful overview of how much data different online activities usually use in a month. This information is really important when we're thinking about eMBB (enhanced mobile broadband) services. eMBB gives us faster and better internet, especially for activities that need a lot of data.

Considering this, when we watch HD videos online, make video calls on platforms like Zoom, play games, or even keep an eye on security cameras at home through the internet, we use up quite a bit of data. That's where eMBB comes in. It's designed to handle all these data-heavy activities smoothly, so our videos stream without buffering, our games don't lag, and we can check our cameras with ease.

eMBB takes these demanding activities and makes them more enjoyable because it's like having a super-fast internet connection that can keep up with all the things we love doing online. However, it's important to note that during our research, we couldn't find evidence or data indicating the usage of services beyond does eMBB services can support.

Table 6 Monthly data plan for different applications [35]

Internet activity	Minimum recommended data per month
Streaming video in HD	300GB
Making video calls on Zoom	60GB
Running home security cameras	30–300 GB (depending on video resolution)
Online gaming	30GB
Web browsing and checking email	40GB
Streaming music or podcasts	13GB

1. **Network Architecture:**

In Section 2.1.1, there are two 5G architecture deployment options. Stand-alone and non-stand alone. From the two options, the non-standalone 5G deployment option is selected. Because deploying NSA 5G has several advantages over SA, those are:

i. Cost Efficiency:

NSA 5G leverages the existing 4G core network and backhaul link for its service delivery. This inherent synergy results in enhanced cost efficiency compared to the standalone (SA) option, as it reduces the core network deployment expenses.

ii. Time to Market:

Opting for NSA 5G and deploying only the 5G gNodeB component leads to a significant time advantage. Compared to deploying the complete array of 5G network elements including the 5G core and its base station (gNodeB), NSA 5G implementation is streamlined and can be executed swiftly. This accelerated deployment timeline facilitates the introduction of a functional 5G network within a shorter span.

iii. Smooth Transition,

The deployment of NSA for 5G is designed to seamlessly integrate with the existing network, typically 4G. NSA 5G utilizes the current 4G network infrastructure, utilizing its basic network functionality while introducing additional 5G radio access capabilities. This transition minimizes disruption to existing network operations and services.

This method provides for network compatibility, effective resource sharing, and the gradual rollout of upgraded 5G services without requiring a full backhaul. In essence, a smooth transition with NSA 5G aims to offer an uninterrupted user experience while gradually capitalizing on the benefits of 5G technology.

iv. Learning and Evolution.

Deploying NSA 5G provides an opportunity to gain practical experience and knowledge about 5G technologies, network management, and operational challenges. This experience can be valuable for network operators and regulators when planning for future network upgrades and transitioning to full SA 5G deployment.

Besides this, NSA can meet the requirements through eMBB services. In our context, eMBB services were selected for the deployment of 5G in Addis Ababa. This makes NSA 5G deployment feasible in the context of Addis Ababa.

1. Frequency spectrum

This frequency band is well-suited for offering a combination of coverage and data capacity, rendering it a fitting choice for both urban and suburban regions. It offers higher speeds than lower-frequency bands like 700 MHz or 1.8 GHz while maintaining better coverage compared to mmWave frequencies. This makes it a valuable option for delivering eMBB services and supporting applications that require a good balance between speed and coverage [30].

The mid-band frequency selection is strategic considering the study's objectives. It provides an optimal platform for delivering eMBB services, which require a combination of fast data speeds and broader coverage. This frequency choice aligns well with the study's intention to offer a balanced service that meets the expectations of customers for reliable and high-speed connectivity while covering a sufficiently large area.

2. Core network of existing network

Deploying NSA 5G to the existing 4G core network emerges as a reliable and adaptable solution for managing the heightened traffic demands that come with 5G technology. The significance of this lies in the fact that the 4G core network is equipped to efficiently handle the increased data loads associated with 5G services. One key factor contributing to this capability is the incorporation of NFV technology within the 4G core [36].

NFV empowers the core network to operate in a virtualized environment, rendering it versatile and highly adaptable to changes. This means that as the network evolves to incorporate NSA 5G features, the 4G core's virtualized nature enables seamless upgrades and adjustments [37].

This inherent flexibility ensures that the network's infrastructure can be easily enhanced to accommodate the advanced functionalities of 5G without requiring substantial modifications[36, 37].

As a result, the synergy between the well-established 4G core network and NFV technology facilitates a seamless transition to NSA 5G, underscoring the network's capability to efficiently manage the anticipated surge in data traffic while providing enhanced services to user.

5 Result and Discussion

In this chapter, capacity and coverage dimensioning are used to calculate the number of base stations needed for the selected deployment area. This analysis was done using marketing analysis and the 5G technological deployment option service, which is described in Chapter 4, as the input. This deployment option involves using the NSA Enhanced Mobile Broadband service in the sub-6 GHz frequency band. Then the economic analysis is conducted by using revenue and cost modeling.

5..1 Capacity Dimensioning

The following steps show the methods used to get the number of gNodeB in capacity dimensioning. To calculate capacity, the number of busy hours in a day and the traffic usage pattern of ethio telecom customers are used. Additionally, the forecasted number of 5G subscribers and geographical deployment area of the selected area are used.

Step 1: Calculate the average total throughput per subscriber during Busy Hour (BH).

In Table 8, Ethio telecom categorizes customers as Gold, Silver, and Bronze based on their data usage. According to ethio- telecom, there are 4 busy hours in 24 hours of the day. Between 10 a.m. and 12 a.m., and 8 a.m. and 10 p.m., for a total of 4 hours per day.

Table 7 Ethio-telecom customer segmentation based on data usage level

Types of customers	Traffic Usage in GB/Month/User	Usage ratio of the services (%)	Traffic ratio of a busy hour (BH) to a whole day (%)
Gold	25	60	16.667%
Silver	20	25	
Bronze	10	15	

The average total throughput per subscriber during Busy Hour (BH) is calculated using the above data:

$$AV.thrput(Kbps) = \frac{monthly\ service\ package\ \frac{8bit}{Byte}}{no\ of\ days * time\ in\ second} * BH\ ratio$$

$Total\ Av\ thrput\ per\ subscriber\ at\ BH = \sum(average\ thrput\ per\ sub\ at\ BH(Kbps) *$
$usgae\ ratio\ of\ service\ package$

Table 8 Throughput per subscriber level

No	Customer level	Average throughput per subscriber
1	Gold customer	308.703Kbps
2	Sliver Customer	246.92kbps
3	Bronze customer	123.48Kbps
Total	Total Av throughput per subscriber	265.46Kbps

1. Calculate 5G new radio aggregate throughput per site or data rate.by using 3GPP TS 38.306 version 16.1.0 Release 16 technical specification formula.

Data rate $(Mbps) = 10^{-6}(\sum_{j=1}^{j}(V_{Layers}^{(J)}\ Q_M^{(j)} f^{(j)} R_{max} \frac{N_{PRB}^{BW(j)\mu}}{T_s^{\mu}} 12(1 - OH^{(j)}))$

Where:

- In a band or band arrangement, J is the total number of compiled elements

carriers.

- $R_{max=948/1024}$
- For the j^{-th} CC (component carrier), $V_{Layers}^{(J)}$, This is the most layers that can be used in one image
- $Q_M^{(j)}$: The Qm modulation series is 2 for QPSK, 4 for 16-QAM, 6 for 64-QAM, 8 for 256-QAM,
- $f^{(j)}$: The scaling factor between, 1/0.8/0.75/0.4,

- μ: any number between 0 and 5 can be used in 5G new radio numerology.
- T_s^{μ}:For μ value, the average OFDM symbol time in a sub frame
- $OH^{(j)}$: Overhead value
- $N_{PRB}^{BW(j)\mu}$: Maximum RB bandwidth allocation, BW (j) with numerology (μ), BW (j)

The selected 2.6 GHz bands are in frequency range 2 (FR2). Table 9 values used to calculate aggregate throughput.

Table 9 Values used to calculate aggregate throughput

Parameter	Values
Frequency range	FR1
Bandwidth (BW)	100
Number carrier	1
Bits per Symbol from modulation scheme (Q)	2
Scaling factor/ signaled per band (f)	0.8
Max. code rate ($m\ x$)	0.5
Max. number of Resource block	948/1024
Sub-carrier per Resource block	273
Sub-carrier spacing	12
Numerology(μ)	30kHz
Average OFDM symbol duration	$= 3.577 * 10^{-5}$
Overhead (OH)	0.08(UL) and 0.14(DL)

Then, we can calculate the aggregate capacity throughput per site using and the equation,

- For Uplink data rate

= Data rate $(Mbps) = 10^{-6}(\sum_{j=1}^{j}(V_{Layers}^{(J)}\ Q_M^{(j)} f^{(j)} R_{max} \frac{N_{PRB}^{BW(j)\mu}}{T_s^{\mu}} 12\left(1 - OH^{(j)}\right))$

$$Data\ rate = 625.01\ Mbps$$

- For Downlink data rate

$$Data\ rate = 584.24 Mbps$$

Both Downlink and Uplink, the maximum number of subscribers per site is now computed as follows:

$$\max no\ pf\ \ site\ subscriber\ per\ site(Ul) \frac{data\ rate_{(UL)}}{Total\ average\ throughput\ per\ subscriber\ at\ Busy\ honer}$$

$$= 2354\ \ subscriber\ per\ site\ for\ UL$$

$$\max no\ pf\ \ site\ subscriber\ per\ site(DL) \frac{data\ rate_{(DL)}}{Total\ average\ throughput\ per\ subscriber\ at\ Busy\ honer}$$

$$= 2200\ subscriber\ for\ DL$$

Therefore, both equations above can be used to compute the number of gNBs necessary.

To accommodate the target area of a given total number of projected subscribers of 1,671,025

$$Capacity\ based\ site\ count\ _{(ul)} = \frac{Total\ subscriber\ of\ target\ area}{\max no\ of\ \ subscriber\ per\ site}$$

$$= 760\ NR\ gNBs$$

$$Capacity\ based\ site\ count\ _{(dL)} = \frac{Total\ subscriber\ of\ target\ area}{\max no\ of\ \ subscriber\ per\ site}$$

$$= 710\ NR\ gNBs$$

5.2 Coverage Dimensioning

Coverage analysis of the 5G network in this study is done using the UMi (Urban Microcell) Line-of-Sight (LOS) path loss model specified in 3GPP TR 38.901, which typically employs the Okumura-Hata propagation model. The parameters used according to this model for both UL and DL are shown in Table 11 [38].

We get Cell radius range (Reff) (dense urban) LOS 714m using sub-6GHz link budget excel.

Table 10 Radio link budget used

General Parameters	**DL**		**UL**	
Morphology	Urban (Dense Urban)			
Cell Edge Coverage Probability				
User environment	Outdoor			
Data channel type	PDSCH		PUSCH	
MIMO Scheme	2x64		2x64	
Duplex mode	TDD		TDD	
	Value	**Units**	**Value**	**Units**
Operation frequency	2600	MHz	2600	MHz
Operation BW	100	MHz	100	MHz
gNB Transmitter Characteristics				
Data rate	50	Mbps	10	Mbps
gNB TX power	53	dBm	23	dBm
gNB antenna gain	10	dBi	0	dBi
Cable loss	2	dB	2	dB
EIRP	61	dBm	21	dBm
UE receiver Characteristics				
UE noise figure	7.000	dB	2.000	dB
Temperature	290.000	K	290.000	K
Boltzmann constant	1.38*10^(-23)	J. K^-1	1.38*10^(-23)	J. K^-1
Max number of resource block	273.000		54.000	
Sub carrier spacing (kHz)	30.000	KHz	30.000	KHz
Sub carrier	12.000		12.000	
Sub carrier Quantity (SCQ)	3276.000	KHz	3276.000	KHz
Thermal noise	-119.591	dB	-119.444	dB
Receiver noise floor	-112.591	dBm	-117.444	dBm
Factor A	0.400		0.400	

Factor B	1.100		1.100	
SINR (Linear)	1.516		0.208	
SINR threshold	1.808	dB	-6.817	dB
Receiver sensitivity	-110.783	dBm	-124.260	dBm
Control channel overhead	0.860		0.920	
Rx antenna gain	0.000	dB	11.000	dBi
Body block loss	5.000	dB	0.000	dB
Shadowing fading loss (LOS)	9.000	dB	9.000	dB
Shadowing fading loss (NLOS)	7.800	dB	7.800	dB
foliage loss	0.000	dB	0.000	dB
Rain margin	0.000	dB	0.000	dB
Interference margin	2.000	dB	1.000	dB
Indoor penetration loss	0.000	dB	0.000	dB
Maximum allowed propagation loss (LOS)	**120.630**	**dB**	**111.107**	**dB**
Maximum allowed propagation loss(NLOS)	**121.830**	**dB**	**112.307**	**dB**
3GPP TR 38.901 UMi path loss model LOS	32.4+21*LOG10(d3D)+20*LOG10(fc)			
3GPP TR 38.901 UMi path loss model NLOS	35.3*LOG10(d3D)+22.4+21.3*LOG10(fc)-0.3(hUT-1.5)			
BS antenna height	1.500	m	30.000	m
MS antenna height	1.500	m	1.500	m
Cell radius range (dense urban) LOS	714.108		251.329	
Cell radius range (dense urban) NLOS	**0.000**	**km**	**0.000**	**km**

For Three- Sector antenna the site area (SA) is calculated

the amount of area covered is determined using A= πr² (in square kilometers) where r is the radius of the circle $A = \pi r^2$ (5-1)

$$SA = 1.601 Km^2$$

$$\text{Number of base stations} = \text{Total area} / \text{Effective coverage area}$$

And number of sites are calculated using

$$T_{CA=} \frac{T_{CA}}{SA}$$

Where SA stands for Site Area, TNS is Total number of sites, TCA is Total target coverage which is 330.

Table 11 Select number of gNodeB

Number of gNBs selected		
Dimensioning	Coverage based	Capacity based
Calculated value of gNBs	300	760
Best selected gNBs	760	

As shown in Table 13, the number of base stations for coverage-based dimensioning is 330, and for capacity-based dimensioning, there are 760 base stations. To meet both coverage and capacity requirements, a best number of base stations is chosen. Which is 796 base stations. The economic part of the thesis is done based on capacity dimensioning.

5.3 Cost and Cash flow analysis

5.3.1 CAPEX

Network costs typically consist of two main components: capital investments and operational expenses. Once the network elements are determined through RAN dimensioning, the subsequent phase involves estimating the capital investment needed for system deployment, taking into account the rollout plan. In accordance with the mathematical model for capital expenditures (CAPEX) outlined in section 3.5, the cost for each parameter in CAPEX is expressed as a per-unit value, as detailed in Table 4.17.

Table 12 CAPEX cost

	Equipment	Cost in birr
1	Spectrum	114,000,000.00
2	Site Survey and Network design	33,915,000.00
3	New eNodeB (including network elements, installation)	5,700,000.00
4	Cost related to basestation	1,299,600,000.00
5	Co site installation	4,560,000.00
6	Service related to eNodeB implementation	285,000.00
	Total	1,458,060,000.00

5.3.2 OPEX cost

Estimating operational costs for a particular project can be more uncertain compared to capital expenses. In this research, we primarily utilize annual OPEX data from the operational cost reports of the Addis Ababa LTE network currently in operation. Furthermore, we reference literature to gain insights into the operational costs associated with non-standalone 5G technology and its assumed to increase 10% each year. The estimated operational cost is shown below.

Table 13 OPEX cost

	OPEX parameters	Distribution (%)	Birr
i	**Network driven per site /year**	**60%**	235,077,519
	Network maintenance and operation	36%	1,097,250
	Site rental		14,250

	License renewal		-
	Energy consumption	15%	463,125
	Backhaul costs per site/year	9%	277,875
ii	**Business driven**	**40%**	1,235,019
	Marketing and sales (advertising)	20%	617,481
	Billing and customer care	8%	246,981
	Customer service related costs	6%	185,250
	General Administration	6%	185,250
	Total cost		239,400,000.00

5.3.4 Cost analysis

As described in Chapter 3, the cost of both capex and OPEX and the revenue are described helps to analyze the CF, DCF, net CF, depreciation, and net income of the system described in Table 15.

Table 14 Cash flow analysis

	Baseline	**2024**	**2025**	**2026**	**2027**	**2028**
Revenue in Birr		260,014,622	578,958,308	1,145,159,137	1,941,788,686	3,002,577,920
capex	(1,458,060,000)					
OPEX		(239,400,000)	(263,340,000)	(289,674,000)	(318,641,400)	(350,505,540)
TCO	(1,458,060,000)	(1,697,460,000)	(1,960,800,000)	(2,250,474,000)	(2,569,115,400)	(2,919,620,940)
Total cash outflow	(1,458,060,000)	(239,400,000)	(263,340,000)	(289,674,000)	(318,641,400)	(350,505,540)
Net cash inflow	(1,458,060,000)	20,614,622	315,618,308	855,485,137	1,623,147,286	2,652,072,380
Net cumulative cash inflow	(1,458,060,000)	(1,437,445,378)	(1,121,827,069)	(266,341,932)	1,356,805,354	4,008,877,734
Depreciation		(291,612,000)	(291,612,000)	(291,612,000)	(291,612,000)	(291,612,000)
Net Income		(270,997,378)	24,006,308	563,873,137	1,331,535,286	2,360,460,380

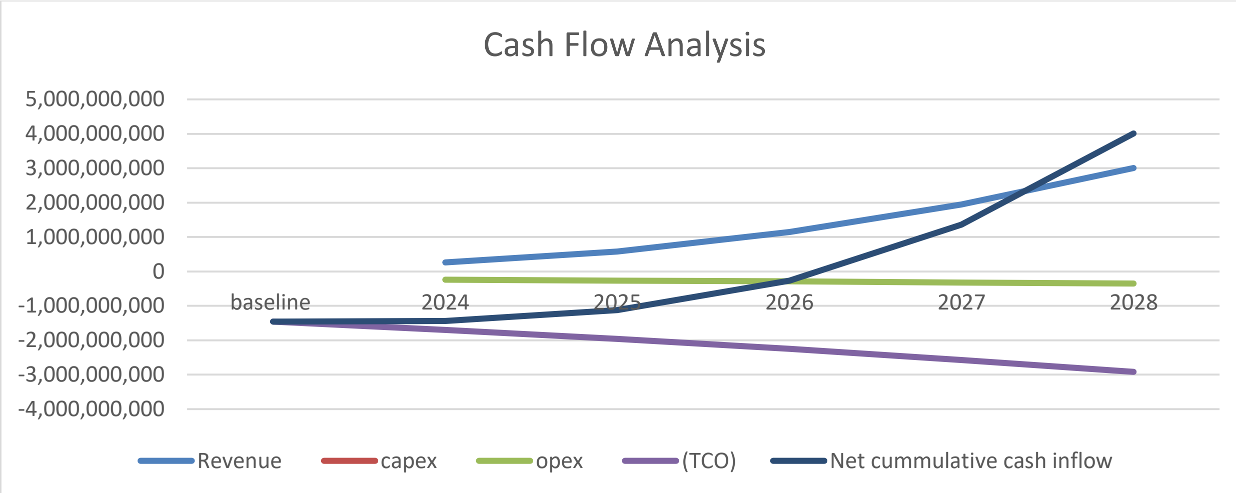

Figure 15 Cash flow analysis

Table 13 and Figure 16 shows financial trends for the 5G network from 2024 to 2028. Revenue projections indicate substantial growth, while initial Capex transition to OPEX Net cash inflow rises progressively, leading to positive cumulative cash inflow and net income by 2025. This signifies the network's potential for profitability and financial viability, showcasing revenue increases costs over the studied period.

5.4 Economic analysis

As describe in Chapter 3, the economic metrics NPV and IRR are summarized in Table 16.

Table 15 Economic analysis

NPV	1,812,120,611.60
IRR	39%
Payback period	3 years and 3 months

Cash flow statements provided paramount importance in project analysis. The cash flow statement is a summary of cash inflows and outflows during the project period. A positive net cash inflow, with cash inflows above outflows, means a project is capable of providing enough to cover all its expenses without a problem. It is vital to include the time value of money in the use of cash flows for project analysis. In this regard, discounted cash flows are more important. Other measures like NPV, IRR, and payback period solely depend on the cash flows of the project.

As can be seen from the projected cash flow statement for our project, the net cash inflow for the first three years of operations is negative. This trend is expected, given the very high initial investment. Since the initial investment cost is deducted in full at once, it pushes the net cash flow downward, but gradually it will get to the positive mark. Hence, since other metrics used show a very positive result, having negative cash inflow for the first year of operation is not worrisome. Even with three years of negative net cash inflows, the project is expected to generate a cumulative cash inflow of over Birr 4 billion at the end of the fifth year.

Another parameter used is the net income of the project. The basic difference between cash flow and income statements is the allocation of costs over the project's life. For instance, unlike cash flow statements, the initial investment outlay is systematically allocated to five years in a process called depreciation. Moreover, income statements include other arbitrary allocations and non-cash transactions such as purchases and sales on account and amortization. As a result, it doesn't show the true cash flow pattern of the project. That being said, the net income of the project is found to be attractive. Besides, a loss during the first or second year of operation is expected until the revenue generated becomes sufficient to cover expenses. As the number of users increases, it will show a positive profit. Hence, the profit of the project has been positive since the second year, and the magnitude of the profit is very attractive. The project is expected to amass over Birr 3.90 billion during the next five years.

A positive NPV indicates that a project will generate adequate cash flows to cover all initial costs, which is a sign of a profitable venture. The NPV of Birr 1.8 billion for a project with initial outlays of over Birr 1.51 billion within a period of five years is an indicator of its strong financial viability. This wider margin helps the project be less elastic for unfavorable environmental factors that could affect future cash flows.

The IRR represents the rate at which the NPV of the project is zero. In our case, the IRR of the project is 38%, which is higher than the assumed cost of capital (11.50%). This implies that the project's expected return is higher than its cost of capital by a significant margin, further indicating the project's financial viability. IRR and NPV are indicators of one another. A higher NPV indicates IRR will be significantly higher than the cost of capital, and a negative NPV indicates IRR is below the cost of capital.

Another important measure of viability is the payback period. The payback period simply measures the number of years it will take for the project to fully cover its initial investment outlay. IRR cannot be taken by itself. It has to be compared with another yardstick, such as industry averages. However, given the magnitude of the initial investment, a payback period of less than four years is generally attractive.

6 Conclusion and Future work

6.1 Conclusion

This study discovers the feasibility of implementing 5G technology in Addis Ababa using the TERA model. The study draws data from ethio-telecom to analyze trends within their 4G network and customer behavior. The data forms the basis for forecasting future subscribers and modeling revenue for 5G services.

The study examines the distinctive technological and financial implications that 5G introduces. A central consideration in 5G deployment is the careful selection and analysis of architectural components, frequency bands, and application services. The deployment strategy for Addis Ababa focuses on a non-standalone architecture (NSA) 5G service using sub-6 GHz frequency bands. This choice is driven by the data demands of the city. Coverage and capacity dimensioning calculations were performed for the 5G coverage and capacity of the city based on the forecasted number of 5G subscribers and geographical area. The capacity dimensioning number of the site is selected to meet both capacity and coverage demands.

Cost modeling was performed based on the number of 5G NR sites selected in order to show cash flow analysis. This cash flow analysis is used to conduct the economic indicators Internal Rate of Return (IRR), Net Present Value (NPR), and Pay Back Period (PBP) which help to show feasibility of implementing 5G technology.

The result of the analysis shows that deploying NSA 5G for Enhanced Massive Broad Band (eMMB) service is profitable with an IRR value of 38% and positive NPV. The PBP is 3 years and 3 months which is considered acceptable in the communications industry.5G technology also has benefits in the education and healthcare sectors. It facilitates online learning by making quality education more accessible in remote areas by means of live streaming of lectures, virtual classrooms, and interactive educational contents. It creates a level playing field for students. The technology also enhances smart agriculture by providing farmers with real-time data on weather, market conditions, and crop health.

The Ethiopian telecom market is newly opened for the private sector of domestic and foreign origin. The feasibility of 5G technology, therefore, will help attract investment in both the telecom industry and other sectors that benefit from it directly or indirectly.

6.2 Future work

This thesis focuses on the feasibility and deployment options of the 5G network in Addis Ababa. It can be a possible research area to consider the cost of the SA deployment option and different frequency ranges.

It is also another future thesis area to analyze and investigate 5G NR network dimensioning using planning tools such as WinProp and Atoll and to conduct an in-depth investigation of the planning and placement of both macro and small cell deployments in Addis Ababa.

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Appendix

Techno-Economic analysis of 5G in case of Addis Ababa, Ethiopia

Yemisrach Ayenew

School of Electrical and Computer Engineering
Addis Ababa University
Addis Ababa, Ethiopia
yemiayenew@gmail.com

Dr. Sosina Mengistu

School of Electrical and Computer Engineering
Addis Ababa University
Addis Ababa, Ethiopia
sosina.mengestu@aait.edu.et

Abstract: - *The advent of 5G technology was driven by the escalating demand for high-speed, high-quality data services in wireless networks. This next-generation technology promises ultra-low latency and exceptional reliability, paving the way for innovative services spanning various industries. However, the swift transition from 4G to 5G poses challenges in terms of cost, awareness, and compatibility with existing systems. To address these issues, a techno-economic analysis was conducted, encompassing market projections, network dimensioning, cost modeling, and a five-year economic feasibility study, utilizing a modified TERA model within the context of ethio telecom. Network capacity, coverage, and site requirements are profoundly influenced by factors such as 5G application services, deployment options, operating frequencies, and market potential. The analysis reveals a noteworthy NPV value of 1,812,120,611.60 and an impressively short payback period of only 3 months, underscoring the significant impact of these factors on the network's economic viability.*

Keywords*: *5G, Techno-economic analysis, Deployment options, NSA, eMBB, TERA model

1. Introduction

The next-generation mobile communication technology, known as 5G, was created to have more capacity and faster data speeds than LTE technology. The ultra-low latency and ultra-high reliability that 5G technology promises will enable cutting-edge services in a variety of business sectors [1].

The International Telecommunication Union (ITU) specifications define 5G application services as enhanced mobile broadband (eMBB), massive machine-type communication (mMTC), ultra-reliable low latency communication (URLLC), and fixed fiber-like wireless access [1]. Several design objectives for 5G systems can be identified based on three potential applications: increased downlink capacity of up to 20 Gbps, reduced latency to 1 millisecond (ms), increased user mobility of up to 500 kilometers per hour (KM/hr.), and increased connection density of up to 1 million devices per (kilometer squared (km2) [1]. There are also two 5G deployment scenario options: the "Non-Standalone" (NSA) solution, which combines LTE and 5G NR access with a 4G Enhanced Packet Core (EPC), and the "Standalone" (SA) approach, which is based on 5G New Radio (NR) access. Ethio-telecom uses the non-standalone (NSA)-based solution.

According to Ericson [2] report more than 210 service providers have launched commercial 5G services globally in 2022. Deployment of 5G standalone (SA) networks is also increasing, with more than 20 commercial launches at the end of 2021 and by the end of 2027, 5G subscriptions are expected to reach 4.4 billion. After its launch in 2019, 5G subscription growth outpaced that of 4G, reaching 1 billion subscribers 2 years earlier than 4G[2]. In January 2022, there were 29.83 million internet users in Ethiopia. At the beginning of 2022, 25.0% of the entire population had access to the internet. Internet users in Ethiopia increased by 731 thousand (+2.5%) between 2021 and 2022

Introducing new technologies requires a thorough assessment of their significance from both economic and technological standpoints. Conducting a techno-economic analysis before their adoption in the telecommunications industry is critical to ensuring these technologies' cost-effectiveness.
The term "techno-economic analysis" (TEA) refers to techniques for evaluating the technical and financial performance of a service or a product. Techno-economic models can also be used to determine which type of technologies and deployment strategies are the most efficient and affordable available technology based on technical, economic, environmental, and social factors[3, 4]. TEA is done using TERA (Techno-Economic Analysis Model). Ethio-telecom is starting 5G network deployments the capital city of

Ethiopia, it is essential to analyze 5G deployment options in techno-economic perspective to help the network operator to decide the optimum strategy towards 5G, optimize their network with an evolution of networks and maximize its benefit.

2. Methodology

The following techniques are used to accomplish the goals indicated above. An extensive literature review will be undertaken by referring to standards, publications, renowned company reports, and similar works.

- Primary and secondary data will be collected.
- The primary sources of data source for this research work will be collected from Ethio telecom.
- The secondary data will be collected by reviewing 5G related books, 3GPP documentation, Next Generation Mobile Network (NGMN) documentations, IEEE articles and journals, International Telecommunications Union (ITU) publications, and TEA focused dissertations.
- The number of future subscribers, deployment options technology selection will be forecasted and selected.
- The costs of CAPEX and OPEX are comput ed.
- The cash flow (CF) and discounted cash flow (DCF) analyses were carried out using cost and revenue modeling results as well as economic inputs performed in MS Excel. As an input to the system model, a five-year research period and a discounted rate of 11.5% were assumed.
- Economic evaluation indicators for selected deployment options include net present value (NPV), internal rate of return (IRR), a nd payback period (PP).

3. Related Work

In a study led by Beneyam Berehanu Haile et al [5], the authors emphasize the substantial surge in mobile data usage attributed to innovative services like high-definition (HD) video, augmented reality, virtual reality, and interactive HD TV. The authors highlight that this trend will grow exponentially in the coming years. The authors specifically investigate into the global and Ethiopian mobile growth scenarios, tracing back to the era of 1G technology.

The study predicts that data demand in Ethiopia will pose challenges within the next five years. Factors influencing this demand increase include mobile data demand itself, user usage behavior, mobile data pricing, and user income levels. The authors forecast that mobile data demand in Addis Ababa alone will rise to an astounding 20.27 petabytes per month by 2021. They further stress that expanding the current LTE infrastructure nationwide will fall short of meeting this demand. To tackle this capacity challenge, the authors propose adopting 5G technology and recommend capacity enhancement methods such as Millimeter wave communication, Massive MIMO (Multiple-Input Multiple-Output), and Ultra-dense networks.

Edward J. Oughton et al. [6], motivated by the limited number of techno-economic assessments on 5G, quantifiable evaluations of cost savings through infrastructure sharing techniques, and the scarcity of open-source analytical frameworks for this purpose, conducted their research. Their study took place at Crystal Palace in South London, United Kingdom. They aimed to integrate technology and economics to assess both the capacity and cost of 5G deployment strategies.

The researchers utilized an open-source Python simulator, pysim5G, to conduct experiments regarding 5G network deployment strategies. Their findings indicate that three specific ways can significantly lower costs for mobile network operators (MNOs) throughout the 5G implementation. Firstly, passive site sharing, where MNOs share physical cell sites while maintaining separate network resources, could independently cut costs by 30% compared to a dedicated network. Secondly, passive backhaul sharing, involving the shared use of infrastructure connecting cell sites to the core network, also showed a 30% cost reduction potential. Lastly, a multi-operator Radio Access Network (RAN) that includes sharing radio access components demonstrated the most significant cost-saving potential, with potential reductions of approximately 50% compared to standalone network deployment. These findings emphasize the value of collaborative network sharing strategies to enhance the cost-effectiveness of 5G deployment, benefiting both MNOs and potentially consumers through more affordable services.

4. 5G Techno-Economic analysis

Technology Economic Assessment (TEA) is a comprehensive methodology employed to gauge the feasibility and economic viability of a given technology or project. This entails a thorough examination of various factors, including total costs, technical performance, revenue potential, and risk considerations associated with the adoption or implementation of the technology or project. TEA empowers stakeholders to make well-informed decisions by facilitating the comparison of different alternatives, leveraging expert insights, gaining a profound understanding of financial implications, and ensuring efficient resource allocation to attain the desired objectives [7, 8].

1. Marketing analysis

The deployment of 5G networks in Addis Ababa requires a comprehensive approach that encompasses both technology and economics. Marketing analysis is a critical component, involving the examination of industry trends, consumer behavior, competitor analysis, and revenue potential. By understanding the dynamic interaction between technology and the market, this analysis contributes vital insights to the broader techno-economic assessment, guiding informed decisions tailored to Addis Ababa's telecom landscape. Data sources include Addis Ababa's census data and subscriber records from ethio telecom's 4G network services, with the city boasting a population of over 5 million across 562 square kilometers and experiencing consistent annual growth [9].

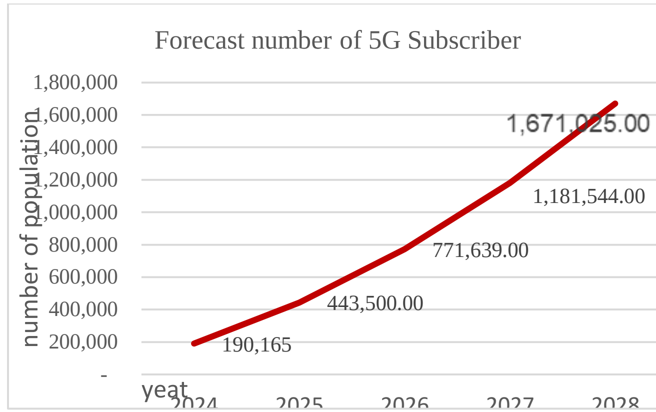
i. Population forecast

To predict service usage during the study period, we first forecast the city's population using a five-year geometric progression method based on previous data, with a geometric mean growth rate of 4.40%. As depicted in Figure below, Addis Ababa's population is expected to continue growing over the next five years, starting at 5,950,900.02, 6,212,888.39, 6,486,410.80, 6,771,957.04, and 7,071,11.24 within the 5-year' study period.

ii. Subscriber forecast

The Bass model, a well-regarded framework for predicting technology adoption, is applied here to forecast the number of 5G subscribers over the next five years. This model is particularly effective for understanding the initial stages and expansion of new services, like 5G in mobile telecommunications. The prediction considers factors such as population potential, innovation (p), and imitation (q) coefficients. Using the provided equation with p=0.0267, q=3356, M=6,100,000, and a five-year period, the study anticipates approximately 190,000 5G subscribers at the start of the period, growing exponentially to over 1.6 million by the study's end. These coefficients were adapted from literature sources and applied to cities with similarities to Addis Ababa, recognizing the common developmental context of both Ethiopia and Indonesia [10]

$$N(t) = M.1 - \frac{e^{-t(q+p)}}{1 + \frac{q}{p}.e^{-t(q+p)}}$$



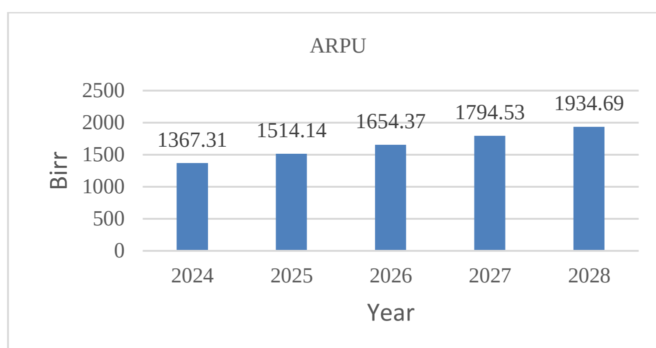
iii. Service penetration rate

The service penetration rate (SPR) is a key metric in marketing analysis, measuring the percentage of a city's population using a service, such as 5G. It's calculated by dividing the forecasted number of service users (Y(t)) by the forecasted city population (P(t)) for a specific year (t). The analysis shows a gradual increase in SPR from3%,7%,12%,17% and 24%, indicating growing acceptance of 5G technology over time. This information is valuable for marketing and planning purposes.

2.Economic analysis

i. Average revenue per user

This research uses four years of ethio telecom ARPU data to predict future ARPU trends using linear regression. It assumes a steady yearly increase and presents the forecast visually in Figure below.



ii. Revenue

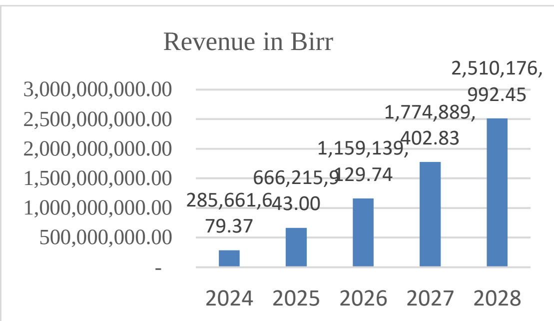
The projection of expected revenue from such services is primarily determined by the total number of subscribers and average revenue per user or tariffs

[11]. This calculation allows us to model the expected revenue outcome, which can be expressed as:

$$RT = ARPU * SP * PMS * IR$$

Where, RT is the generated revenue, SP is predicted number of subscribers, PMS is predicted market share of 5G and IR is indirect revenue from for example roaming, sale of SIM.

Revenue projection using forecasted service users and ARPU values. Total revenue over five years is calculated, considering fluctuations. Increasing revenue indicates company growth due to factors like customer base expansion, pricing strategies, and operational effectiveness. Comprehensive performance assessment includes financial indicators like NPV, PBP, and IRR, discussed next.



3.Tecnological analysis

i. Deployment analysis

In the deployment of 5G technology, critical considerations revolve around the nature of application services, the choice of frequency bands, and the selection of deployment strategies. These factors collectively shape the network's capabilities and performance, as application requirements dictate network design, frequency bands influence coverage and speed, and deployment strategies determine the network's reach and efficiency. Balancing these aspects is essential for optimizing the benefits of 5G technology across diverse use cases and geographic areas.

- Application Selection: The study focuses on Enhanced Mobile Broadband (eMBB) for Addis Ababa and ethio-telecom's customer base, as it aligns with current capabilities.
- eMBB Services: eMBB encompasses High-Speed Internet Access, AR/VR, Cloud Services, IoT Connectivity, Mobile Video Conferencing, Online Gaming, and eSports. It meets the demand for data-intensive activities.
- Network Architecture: Non-Standalone (NSA) 5G deployment is chosen for cost efficiency, faster implementation, smooth integration with existing networks, and learning opportunities.
- Frequency Spectrum: The mid-band frequency is selected for its balance between speed and coverage, crucial for eMBB services.
- Core Network Integration: Leveraging the existing 4G core network with NFV technology ensures efficient management of increased data loads, facilitating a smooth transition to NSA 5G.

  This approach caters to the needs of the region and positions it well for the future of 5G technology.

ii. Network Dimensioning

Network dimensioning is the process of determining the optimal capacity and resources needed for an efficient telecom network. It factors in user numbers, service types, traffic patterns, growth expectations, and technology advancements to ensure the network can handle loads without congestion. This involves identifying resources required for specific services at specific locations, considering factors like coverage area, frequency bands, bandwidth, MIMO configurations, population density, and traffic distribution. Key steps include coverage and capacity planning to determine the number of radio stations needed and evaluating traffic profiles for network loading.

1. Capacity Dimensioning:

Average Total Throughput per Subscriber during Busy Hour (BH):

$$Total\ Av\ thrput\ per\ subscriber\ at\ BH$$
$$= \sum(average\ thrput\ per\ sub\ at\ BH(Kbps)$$
$$*\ usgae\ ratio\ of\ service\ package$$

1. **Aggregate Throughput Calculation (Data Rate)**:

For both Uplink and Downlink data rate, you can use the formula from 3GPP TS 38.306:

$$\text{Data rate}(Mbps) = 10^{-6}\left(\sum_{j=1}^{j}\left(V_{Layers}^{(J)}\ Q_M^{(j)} f^{(j)} R_{max} \frac{N_{PRB}^{BW(j)\mu}}{T_s^{\mu}} 12\left(1 - OH^{(j)}\right)\right)\right)$$

2. **Maximum Subscribers per Site**:

For both Uplink and Downlink, the maximum number of subscribers per site is calculated as follows:

$$\max no\ pf\ site\ sub\ per\ site(Ul/DL) \frac{data\ rate_{(UL/DL)}}{Total\ av\ thrput\ per\ subs\ at\ Busy\ honer}$$

3. **Number of gNodeBs**:

To accommodate the projected number of subscribers, the number of gNodeBs necessary is calculated as follows:

$$Capacity\ based\ site\ count_{\ (UL/DL)} = \frac{Total\ subscriber\ of\ target\ area}{\max no\ of\ subscriber\ per\ site}$$

Coverage Dimensioning:

1. **Cell Radius Calculation**:

Cell radius range (dense urban) LOS is determined using the UMi Line-of-Sight (LOS) path loss model, based on Okumura-Hata propagation model or 3GPP TR 38.901 equations.

2. **Site Area Calculation**:

The area covered by each site is calculated using the formula: $A = \pi r^2$, where 'r' is the radius of the circle.

3. **Number of Base Stations**:

The number of base stations required is calculated based on the total area and effective coverage area, using the formula: Number of base stations = Total area / Effective coverage area.

From the above discussion the number of calculated base station and the selected one are described in table

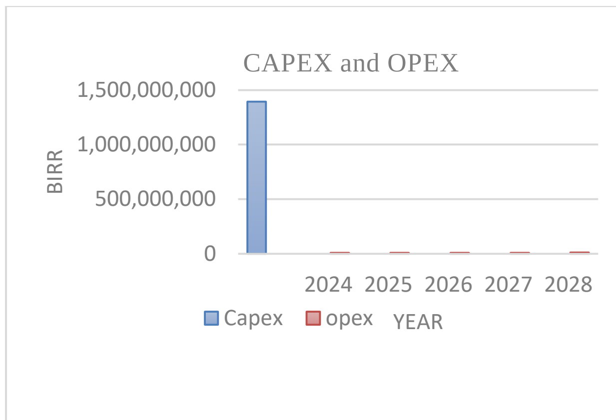
Number of base stations selected		
Dimensioning	Coverage based	Capacity based
Calculated value of base station	300	760
Best selected base station	760	

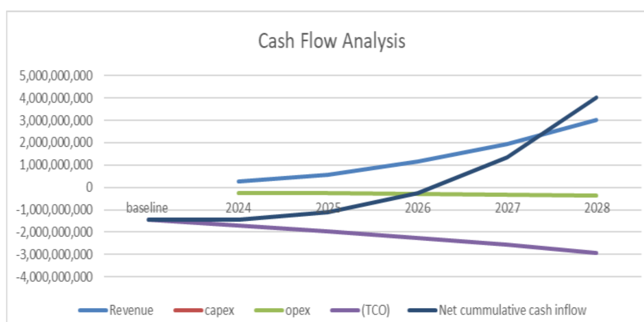
5.Result and discussion

1. Cost and Cash flow analysis

Network costs consist of capital investments and operational expenses. After determining network elements through RAN dimensioning, the next step is estimating capital investment for deployment. This is done using a mathematical model for capital expenditures (CAPEX), with costs expressed as per-unit values, which become 1,458,060,000 birr.

Estimating operational costs is more uncertain than capital expenses. We rely on annual OPEX data from the Addis Ababa LTE network and refer to literature for insights on non-standalone 5G costs, assumed to increase by 10% annually. The estimated operational costs become 239,400,000 and increase 10% each year.





The figure reveal positive financial trends for 5G from 2024 to 2028: Revenue grows, Capex shifts to OPEX, resulting in rising net cash inflow and net income by 2025, highlighting the network's profitability and sustainability.

Economic analysis

- NPV: 1.8 billion birr, indicating strong financial viability.
- IRR: 38%, significantly higher than the cost of capital (11.50%), highlighting project profitability.
- Payback period: Less than four years, which is attractive for a project of this scale.

While initial cash flows are negative due to high initial investment, the project is expected to generate over Birr 4 billion in cumulative cash inflow by the fifth year. Net income is also positive since the second year, exceeding Birr 3.90 billion over five years. These metrics collectively demonstrate the project's robust financial outlook.

6.Conclusion

This study demonstrates the feasibility of implementing 5G technology in Addis Ababa using the TERA model. It analyzes 4G network trends and customer behavior data from ethio-telecom to forecast future subscribers and model 5G revenue. The deployment strategy focuses on NSA 5G with sub-6 GHz frequency bands, catering to the city's data demands.

Coverage and capacity calculations align with forecasted 5G subscribers and geographical area. Cost modeling supports the feasibility with an IRR of 38%, positive NPV, and a 3-year and 3-month Pay Back Period.

Additionally, 5G benefits education and healthcare, enabling remote learning and smart agriculture. With Ethiopia's newly opened telecom market, this feasibility study can attract investment, benefiting various sectors directly or indirectly.

7.Future work

Future research could explore the cost of Standalone (SA) deployment and diverse frequency ranges for 5G in Addis Ababa. Additionally, an in-depth study using planning tools like WinProp and Atoll could analyze 5G NR network dimensioning and the strategic placement of both macro and small cell deployments within the city.

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