Addis Ababa University
Addis Ababa Institute of Technology
School of Electrical and Computer Engineering
Graduate Program in Communication Engineering

Techno-Economic Analysis of Cloud-Enabled Small Cell Networks for Video Service Delivery: A Case Study in Addis Ababa

By:
Altaseb Desalegn

Advisors:
Dr. Yihenew Wondie

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirement for the Degree of Master's Science in Communication Engineering

February, 2025
Addis Ababa, Ethiopia

Addis Ababa University
Addis Ababa Institute of Technology
School of Electrical and Computer Engineering
Graduate Program in Communication Engineering

Techno-Economic Analysis of Cloud-Enabled Small Cell Networks for Video Service Delivery: A Case Study in Addis Ababa

by:
Altaseb Desalegn
Advisor:
Dr. Yihenew Wondie

Approval by Board of Examiners

Name	**Signature**	**Date**
Dr. Yihenew Wondie: Advisor	____________________	____________________
Dr. Ephrem Teshale Bekele: Examiner	____________________	____________________
Dr. Beneyam Berehanu Haile: Examiner	____________________	____________________

Declaration

I would like to explain that this paper is my own job and does not contain content from other educational institutions without proper recognition. To our knowledge, it does not contain material previously published by others without recognition

Altaseb Desalegn
Signature
Date

This paper was submitted with my approval as an advisor to the university.

Dr. Yihenew Wondie
Signature
Date

Abstract

The demand for immersive video services, such as 360-degree live streaming, augmented reality, and virtual reality has rapidly increased, especially at crowded events, while traditional macrocellular networks often struggle when there is excessive traffic. Insufficient capacity and latency have a major impact on the capacity of a radio access network (RAN). To meet this growing demand, a robust and scalable network infrastructure is required. Cloud-enabled small cell networks hold significant promise for improving mobile network capacity and coverage challenges, at the same time improving cost, energy usage, deployment flexibility, and network management. Combining cloud infrastructure and small-cell networks, along with virtualized execution of computing resources, provides a solution. However, a full evaluation of the networks' economic viability is required prior to their implementation, as this includes a precise computation of the resources required and a thorough assessment of the expected outcomes.

This article provides a paradigm for evaluating the economic feasibility of cloud-enabled small-cell networks to deliver immersive video services during packed events. We select Meskel Square in Addis Ababa as a forecasting research location, which serves as an urban setting with concentrated hotspots. For selected scenario of implementing RAN, forecasting the required compute, storage, and radio resources and associated costs with implementing new software and hardware architecture. IST-TONIC and CELTIC-ECOSYS in MATLAB and Microsoft Excel are utilized as part of a framework that comprises marketing forecasts, network dimensioning, revenue modeling, and economic analysis. We use a 10% discount rate and a 10-year study period for a breakdown of investments value analysis. The net present value (NPV), internal rate of return (IRR), payback period (PP), operational expenditures (OpeEx), capital expenditures (CapEx) and total costs of ownership (TCO) are evaluated.

According to the results obtained, the deployment scenario with the highest return economic advantages that affect the rate of return is Open radio access network. Virtualized radio access networks come in second, centralized radio access network in third, and distributed RAN in fourth. Compared to distributed radio access networks, other architecture exhibits a better cost position. The payback periods for distributed RAN, centralized RAN, virtualized RAN, and open RAN in this scenario are 2.34, 2.048, 2.039, and 2.034 years respectively for the deployment scenario. Every architecture has a positive net present value (NPV) during the study periods and a significantly higher IRR value than the specified discounted rate. According to the findings, all scenarios are deployable and open RAN has significantly highest economic return with reduced total cost of ownership.

Keywords: Cloud-enabled Small Cell networks, Radio access network (RAN), Techno-economic analysis, Immersive video services, Economic Feasibility.

Acknowledgments

First and foremost, I would like to Express my gratitude to Almighty God for providing me with the upkeep and strength to successfully complete my thesis. I would like to sincerely thank my adviser, Dr. Eng. Yihenew Wonde, for his sustained support, tolerance, inspiration, determination, and vast expertise. His advice, during the whole research and writing process, has been quite helpful. I do extend my deep appreciation to the members of my thesis committee, Dr. Ephrem Teshale Bekele and Dr. Beneyam Berehanu Haile for their facilitation and motivating, enlightening questions and smart comments that have greatly enriched my working paper. Also, I would like to thank Ethio Telecom and my friends and colleagues for their support and important information that has enriched the value of my working paper.

I am in debt to all of the friends and colleagues with whom I have had the pleasure to work over the years; the consideration and support they have shown me have been a continuing source of motivation and stimulation. Let me conclude by expressing my profound gratitude to my family, who have been so patient and supportive over the many years I have devoted to study. Their support has been an inspiration of light in the bleakest of situations. I am grateful to everyone who participated in our journey.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

1G	1G First Generation
2G	Second Generation
3G	Third Generation
4G	Fourth Generation
5G	Fifth Generation
5G PPP	Fifth generation public partnership projuct
3GPP	Third generation partnership project
ABR	Adaptive Bit Rate
AC	Air conditioning
API	Application programing interface
AR	Augmented Reality
ARM	Advanced reduced instruction set compute machines
ARPU	Average revenue per user
BBU	Baseband unit
BFL	Backhaul and Front haul Links
BS	Base station
CAGR	compound annual growth rate
CAPEX	Capital expenditure
CDN	Content delivery network
CE	Crowed event
CESC	Cloud enabled small cell
CF	Cash flow
COTS	Commercial of the shelf
CPU	Central processing unit

DC	Datacenter
DCF	discounted cash flow
DU	Distributed unit
ETSI	European Telecommunications Standards Institute
FWA	Fixed Wireless Access
GPU	Graphical processing unit
GSM	Global System for Mobile Communications.
H2020	Horizon 2020
HD	High definition
HDD	Hard Disk Drive
HWA	Hardware accelerator
HMD	Head-Mounted Display
HP12C	financial calculator manufactured by Hewlett-Packard
ICIC	Inter-Cell Interference Coordination
IEEE	Institute of Electrical and Electronics Engineers
IMS	Immersive media service
IRR	internal rate of return
ITU	International Telecommunication Union
IVS	Immersive video service
KVM	Kernel-based Virtual Machin
LTE	Long term evolution
M2M	Machine to machine communication
eMBB	enhanced mobile broadband
MBMS	Multimedia Broadcast Multicast Services
MEC	Mobile edge computing

MIMO	Multiple Input Multiple Output
MNO	Mobile network operator
NFV	Network function virtualization
NFVI	Network function virtualization infrastracture
NPV	Netpresent value
OPEX	Operational expenditure
OPNFV	Open network function virtualization
ORAN	Open radio access network
PDU	Power distribution unit
PNF	Physical network function
RAM	Random-access memory
RAN	Radio acces network
RF	Radio frequency
ROI	Return on investment
RRC	Radio Resource Control
RRH	Remote radio head
RRM	Radio resource management
RRU	Remote radio access unit
RT	Radio transceiver
RU	Radio unit
SC	Small cell
SCNO	Small cell network operater
SDAP	Software-Defined Access Point
SDN	Software defined network
SESAME	Small cEllS coordinAtion for Multi-tenancy and Edge services

SLA	Service level agreement
SNR	Signal-to-Noise Ratio
TB	Terabyte
TCO	Total cost of ownership
TEA	Techno economic assessment
TERA	Techno-economic Result from ACTS
TONIC	TecnO-ecoNomICs of IP optimized networks and services
UDN	Ultra Dense Networks
UE	User equipment's
UMTS	Universal Mobile Telecommunications System
UWB	Ultra-Wideband
VIM	Virtual infrastructure manager
VM	Virtual machine
VNF	Virtual network function
VNFS	Virtual Network Function Software
VOD	Video on demands
VPU	Video processing unit
VR	Virtual reality
XR	Extended Reality
ZB	zettabyte

Chapter 1

Introduction

1.1 Background

5G is expected to meet the demands of multimedia applications for quality of service (QoS) and ultrahigh traffic volume density, mobility, and connection density [1] and [2]. Over the past ten years, mobile data traffic has steadily risen globally [1]. Global mobile subscriptions has already reached 6.7 billion in 2013 [1]. Due to the advancements in system performance, the introduction of new device types and applications, the global number of mobile subscriptions is expected to experience substantial growth in the coming years [1]. It was projected that the number of global mobile subscriptions could reach 13. 8 billion in 2025 and 17. 1 billion in 2030 [1].

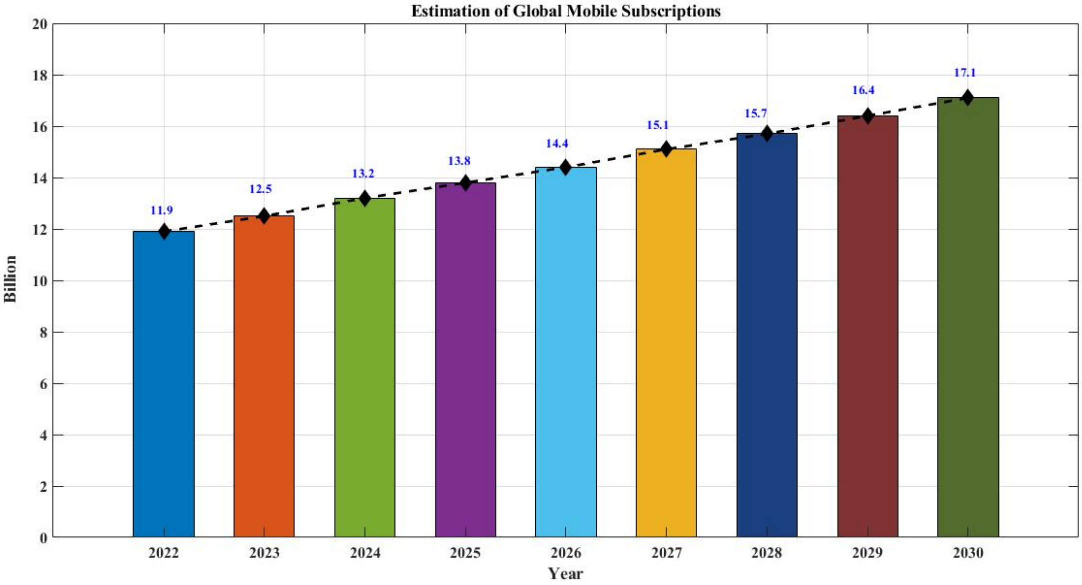


Figure 1.1: Global mobile subscription forecast by ITU [1].

A report on 5G scenarios with a goal peak rate of 10 Gbps for the uplink and 20 Gbps for the downstream was released by the European Telecommunications Standards

Institute (ETSI) (3GPP TR 38.913) [1]. This enhances for emerging massively data-intensive use cases and applications, including multiway virtual meetings, virtual and augmented reality (VAR), and so on, to name a few, show that the latency, reliability, and data rate requirements of these future applications are clearly beyond the capacity of existing 5G systems [1], [2] and [3].

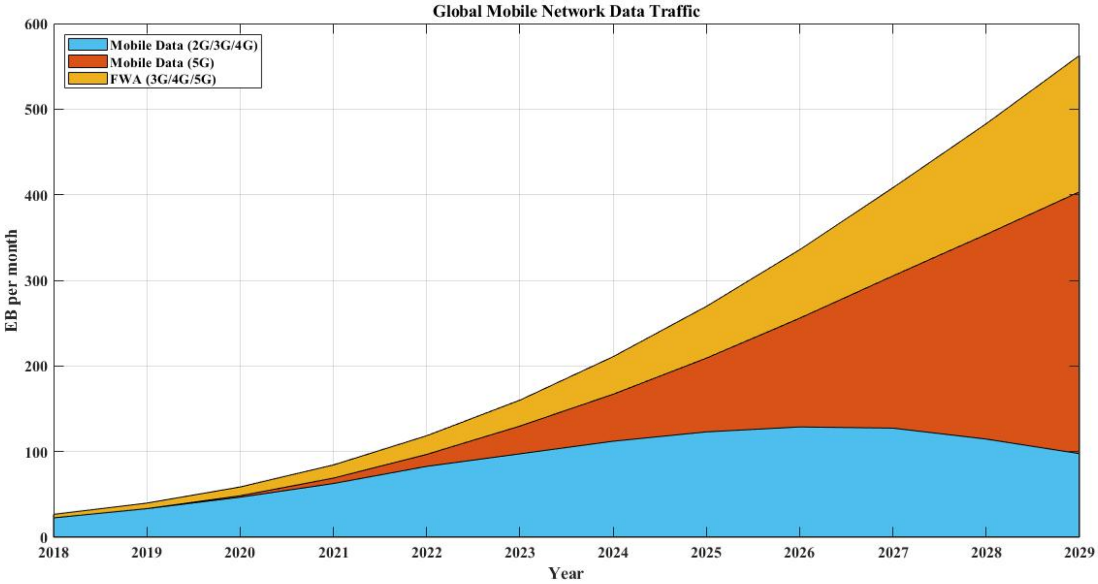


Figure 1.2: Global mobile network data traffic (EB per month) report by erricsson.

The entire amount of mobile data traffic worldwide, excluding traffic from Fixed Wireless Access (FWA), is predicted by the Ericsson 2023 research to reach 130 EB monthly by the end of 2023 [2]. This is expected to increase by around a factor of three by 2029 when it will reach 403 EB per month. After factoring in FWA, overall mobile network traffic is predicted to be approximately 160 EB per Month by the end of 2023, and 563 EB per Month by the end of 2029 [2]. The assumption underlying predicted traffic increase until 2029 is that XR-type services, such as AR, VR, and mixed reality (MR), will first become popular in the latter half of the forecast period [2]. On the other hand, if adoption is stronger than anticipated, data traffic may grow much more than currently projected at the end of the forecast period, especially in the uplink. Video traffic is predicted to make up 73% of all mobile data traffic by the end of 2023 [2] and [4]. Over the forecast period, regions with higher population density and areas with an early introduction of 5G services are likely to cause an increase in traffic demand [4]. By 2023's end, growth of 25% of 5G mobile data traffic is expected, up from 15% in 2022 and it is expected we will see an increase to 76% by 2029 as depicted in Figure 1.2 [4].

Across the globe, analysis on digital and connectivity metrics shows different progress levels across different breast areas [5]. The analysis shows that developed areas such as America, Western Europe, and some parts of Asia have managed to create strong digital ecosystems and have high levels of technology uptake, whereas many developing states are far behind [4] and [5]. No telecommunications technology and telecommunication companies are facing strong competition within themselves in this complex communication atmosphere, and this leads to new inventions.

The key market trends include the rapid deployment of 5G networks, IoT, cloud solutions, Artificial intelligence and data analysis in the business strategies. COVID-19 pandemic has indeed prompted quick progress in digital technology for health care, e-commerce and remote work businesses and these have increased the demand for reliable connectivity [4], [6] and [7]. In regard to the future outlook, it is projected that advancement of 5G, improvement of IoT, and incorporating AI innovations will be dominating the digital area [7]. This development highlights the fact that they are a major force in the construction of global economies and culture and that the nature of digital transformation is active [7].

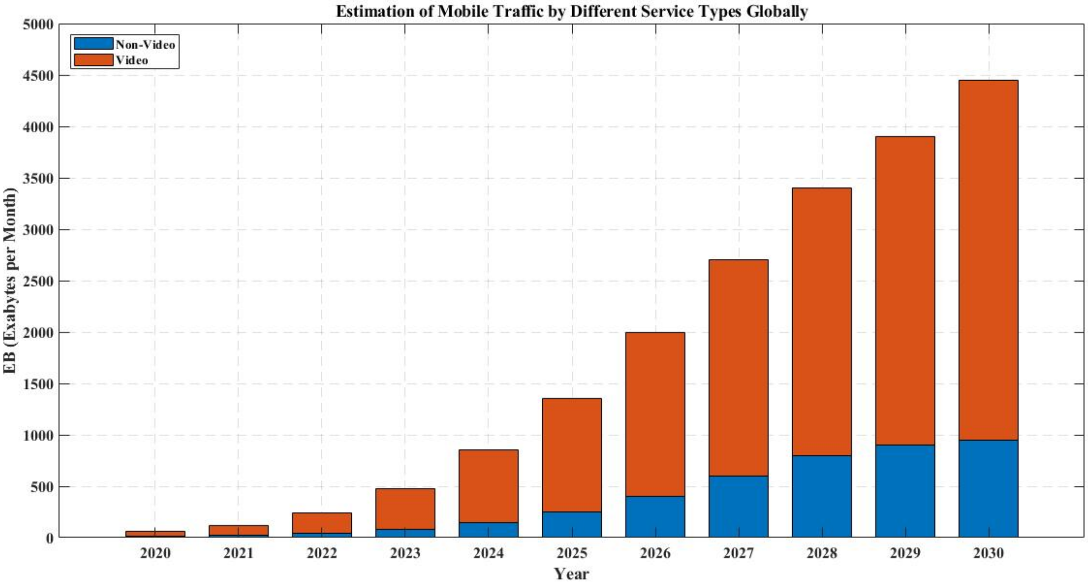


Figure 1.3: ITU forecasts the amount of mobile traffic worldwide per service type.

Mobile traffic by service type: The estimated results for mobile traffic were calculated separately for each service type and are presented in this section for the years 2020-2030 [4] and [6]. Video, non-video, and other types of services are considered. The behavior of subscribers and the characteristics of the service, particularly future new services, play a crucial role in determining the estimation of traffic volume [4] and [6]. Other information such as business model, operation model and accounting rule are also helpful [4] and [6]. The graph identifies video traffic as the primary driver of mobile traffic growth, driven by the expansion of HD and streaming services [4], [6]. While non-video traffic goes up slowly [4] and [6]. This in turn is indicative that mobile networks will have to develop in such a way as to be able to sustain the bandwidth and connectivity requirements of those services [4] and [6].

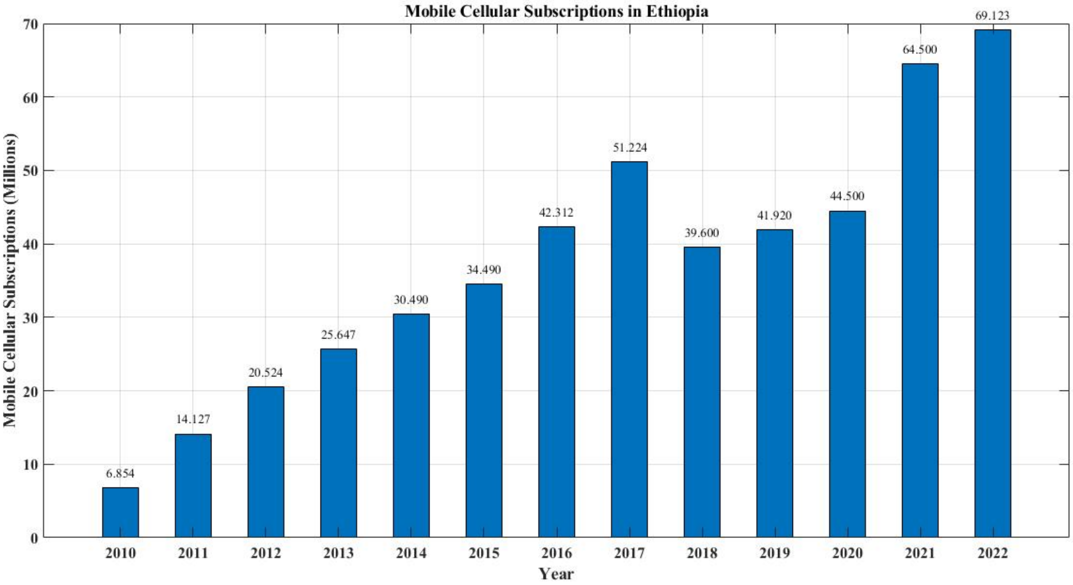


Figure 1.4: Sources: Statista Market Insights , ITU - International Telecommunication Union.

Mobile traffic in Ethipia: The research work conducted earlier and presents other statistics on internet users and internet diffusion in Ethiopia [4], [7]. Number of Mobile Subscriber was reported at 71.4 million Person in Dec. 2022 [4], [7]. This records an increase from the previous number of 64.5 Person for Dec 2021. Mobile data is updated yearly, averaging 0.000 Person from Dec 1960 to 2022, with 50 observations [7].

Mobile subscriptions in the nation for voice and internet services has increased dramatically over the previous several years to over 56 million, according to the Ethiopia Telecoms Market Report as shown in Figure 1.4 [5], [6], [7] and [8]. Capacity issues would likely persist in Ethiopia for some time to come as mobile data demand is expected to increase quickly [6], [7], [9]. In 2021, Addis Ababa's total monthly mobile data consumption will be 20.27 Petabytes (PB), which is 38.7 times the amount of traffic as shown in Figure 1.5 [9]. The operator will face significant difficulties in addressing the critical capacity given this quantity [9]. Therefore, it is crucial to investigate new technologies that may eventually provide capacity upgrades for mobile communications to meet potential capacity challenges [7], [9].

In the next decade, future mobile networks will fulfill multiple 5G requirements in terms of guaranteed user data rate, high throughput, low delay, number of User Equipments (UEs), and mobility support at high speed [3], [10]. In this context, cell densification is considered as a key solution in order to realize these enhancements [3], [10]. The basic idea is to deploy the access nodes as close as possible to the end users, in order to satisfy the required Quality of Service (QoS) and maximize the system throughput [3],

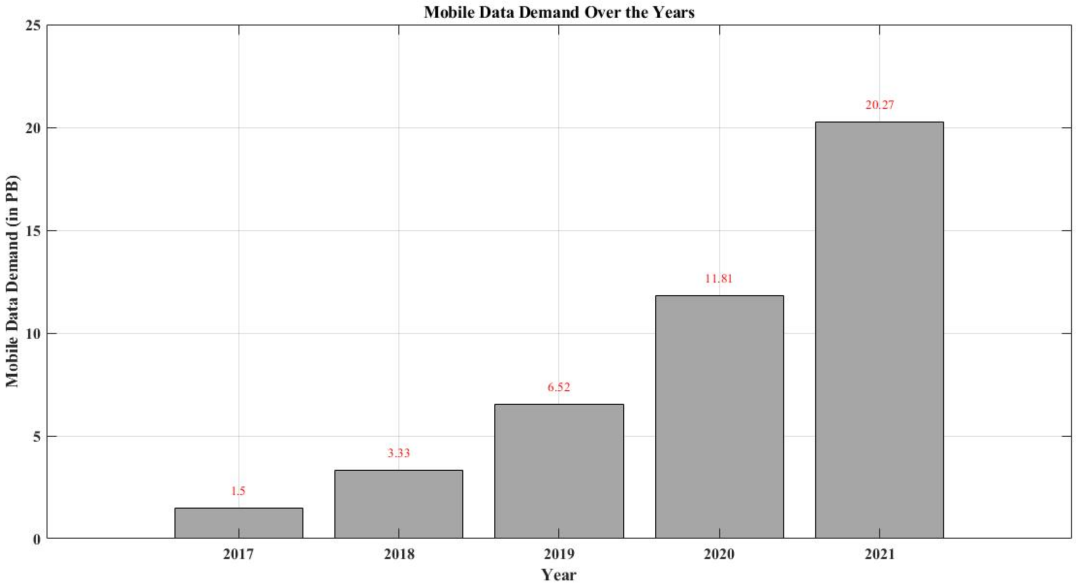


Figure 1.5: Mobile Data Demand Forecast in Addis Ababa (from 2017 to 2021).

[10]. Due to the increasing users' density, small cells become smaller and denser, leading to the ultra-dense networks concept [10], [11]. On the other side, cloud computing and service virtualization do their jobs in terms of technological investment enhancement, information management, and cost reduction [3], [12]. Virtualization in telecommunications decouples the implementation of network functions from hardware, allowing for dynamic resource setup [3], [12]. For example, CESC and Light DC are innovative infrastructures that are going to empower MEC to support advanced services like caching and video transcoding, and this enables AR/VR in 5G [3], [12].

Both SDN and NFV make user experiences frictionless with immersive media services [13]. The infrastructure of 5G guarantees low latency and high performance through the enforcement of SLA for ensuring high QoS, with ensured monitoring of compliance and cost optimization [11], [13]. With the deployment of Small Cells and Edge Computing, latency is reduced while scalability is increased with virtual and physical functions, including SC VNF and SC PNF [11], [13]. Automation of provisioning and management, the virtualization of networks and functions provides a set of benefits that includes effective hardware management, rapid introduction of new services, ease of upgrades, and reductions in both CAPEX and OPEX [12], [13], [14]. Light DCs are built by clustering CESC to make the edge more powerful; thus, high-value mobile edge services can be provided [12], [13], [14]. The 5G infrastructure will enable immersive AR/VR and high-fidelity video-both changing user experiences [12], [13], [14].

While the integration efforts with SDN and NFV guarantee the QoS for video services, monitoring frameworks track service level agreement (SLA) compliance continuously [14], [15]. Small Cell and edge computing deployments bring services closer to users, contributing to latency reduction [14], [15]. Network virtualization assists in the decoupling of Small Cell functions, which is important for scalability, manageability, and coordination [14], [15].

These advances would enable 5G infrastructure to provide better video services, improving user experiences with various innovative applications [14], [15]. The key benefits of cloud-enabled small networks are as follows: Dynamic Power Management is one technique under which the power state of the small cell components would change based on the workload requirements [16]. For instance, the small cell can power off either the RF (Radio Frequency) amplifiers or baseband processors to save power when the traffic is low [16]. (i) Small cells can be made to sleep at low-power active levels during periods of inactivity or off-peak, a factor that cloud make energy consumption drop appreciably [16], [17]. (ii) Installation of cooling systems, more efficient than air conditioning, such as liquid cooling or natural convection, saves energy consumed by the small cell [16]. (iv) Optimizing resource allocation in the cloud reduces both the amount of computational work and energy consumption in the edge [16].

1.2 Statement of the Problem

Mobile network subscribers start to shift from traditional services (voice call or text message) to heavy data- and CPU-intensive services (e.g., gaming, social networking, or immersive video service) [14]. Recently, immersive video service (IVS) in a user-dense environment like a festival, concert, or major sports event has attracted the attention of network operators and device manufacturers [14]. The developments in 5G mobile networks support higher data rates with better reliability and lower latency, enabling the deployment of a diverse range of virtual reality applications [10], [11], [13], [14], and [15].

The need for enhanced network capacity for Immersive video Services in densely populated settings increases cellular data traffic, forcing the need for more flexible, cost-effective RAN architectures with higher data rates and greater capacity [10], [11] and [13]. Several technologies have been proposed to fulfill these requirements, including massive MIMO, mmWave transmission, SDN, C-RAN, vRAN, and open RAN, which are some of the solutions [10], [11] and [13]. The thesis focuses on finding the most cost-effective Radio Access Network (RAN) implementations that deliver IVS in densely populated areas through modern cellular network configuration. Exploring Cloud RAN deployment prospects through techno-economic analysis to determine their practicality. Experts have introduced different networking concepts as well as technological solutions to handle elevated RAN network capacity needs [14] and [15].

The proliferation of immersive video services, such as augmented reality (AR) and virtual reality (VR), is so significantly changing the way individuals engage with digital content that new and unprecedented levels of demand are being placed on the underlying network infrastructure [3], [10], [16]. However, the current telecommunications infrastructure has a hard time supporting these defined key requirements of the modern applications in terms of high bandwidth, low latency and reliability [14],[17],[18]. Existing network solutions tend to compromise and result in unsatisfactory user experience or restrict the provision of immersive video services [14], [17]. Small cell networks powered by cloud have a great solution to that issue as they improve network capacity and capability locally [14], [17]. Nonetheless, the implementation of these networks is a significant technical and economical dilemma [14], [17]. These include heavy infrastructure investment and unpredictable return on investments[14], [17]. Thus the need of exhaustive investigation to find out the implementation mechanism of cloud-enabled small cell networks. Small cell equipment might consume noticeably less power, cutting OpEx [14], [15]. These advanced algorithms can optimize resource allocation, thereby improving performance and efficiency [14], [15]. IoT devices can be combined with small cells to deliver advanced services and gain insights from better data [14], [15]. Network upgrades may be required with the advance of augmented and virtual reality (AR/VR), which will need higher-bandwidth, lower-latency networks [10], [16]. AR, VR and MR will intersect AR markers, and will have different use cases and network infrastructure requirements [10], [16]. Cloud and edge computing when combined can squeeze the best of network performance, reducing the latencies of immersive video services [10], [16].

This study addresses the following key issues [10], [14], [19]:

(i) What are the technical requirements and challenges of deploying cloud-enabled small cell networks?

(ii) What are the economic costs involved in the deployment, and what income could be derived from immersive video services [14]?

(iv) What benefits will service providers, event organizers, and participants gain from using these networks?

Solutions to these problems will reveal much about the feasibility of this technological innovation and its capacity to reshape the media landscapes [14]

1.3 Objective

1.3.1 General objective

The objective of this study is to assess the technical and economic feasibility of deploying CESCN for delivering immersive video services at crowded events, with a focus on cost models to compare various RAN deployment scenarios.

1.3.2 Specific Objective

1. To identify the best area in Addis Ababa for implementing IVS through network densification.

2. To perform network dimensioning and assessments for cloud-enabled small cell network requirements.

3. To evaluate the performance metrics necessary to support IVS, such as latency, bandwidth, and reliability.

4. To evaluate various TEA frameworks select a suitable one, and adjust for local requirements.

5. To conduct a cost-benefit analysis to determine economic soundness.

6. To calculate CAPEX, OPEX, and TCO during deployment and operation

7. To explore the benefits for service providers, such as market growth, competitive edge, and improved customer satisfaction

8. To understand financial viability about the deployment from the cost-benefit analysis perspective.

1.4 Methodology

Conduct a comprehensive survey of the literature on Cloud Computing [9], Immersive video Services [11], Small Cell Networks [5], and related implementations [14]. Acknowledge any existing frameworks or approaches that might be adopted or adapted for this study, and the current state of the art in the field. Such as, Ethio Telecom infrastructure data, Addis Ababa Meskel Squire event count and attendee behavior analysis, and the associated network capacity requirements to name but a few. Determining where and how many small cells are required, estimating the amount of network bandwidth necessary in order to deliver rich Media Experiences, and also RF planning considerations, such as frequency selection to avoid interference [10]. Analyze small cell hardware cost, cloud computing services, networks and other structures cost, energy cost, maintenance, and all other related expenses. One must consider the costs associated with the installation and acquisition of a system plus or minus other considerations, and the operating cost considered over a given period [3]. Analyze the provided network coverage, throughput, delay and quality of service for the use in immersive video [3].

Determine about possible charging from the consumers of the immersive video services, for example through subscription for its use or even advertising revenue when evaluating the economic feasibility of the deployment [20]. In order to assess the effectiveness of the deployment in terms of business case, forecast the pay back period, NPV and ROI [3]. To check and compare the impact of some key parameters or assumptions on the techno economic feasibility, perform sensitivity analysis [3]. It was easier to understand how accurate the analysis is and even identify significant variables which exert considerable influence on the results. Summarize the results and conclusions of the analysis, discuss the consequences, shortcoming or potential further development.

1.4.1 Data Collection

Both primary and secondary data sources were used as the foundation for this research paper. Ethio telecom live network has been used as the primary data source [18]. Ethio telecom documentation and project reports, data from cell sites, network configuration information, and hardware and software data are all included [5]. The secondary data are based on TEA-focused dissertations, ITU publications, IEEE papers and journals, Next Generation Mobile Network (NGMN) literature, 3GPP documentation, C-RAN-related books, and 3GPP documentation [11], [19]. The relevant information for Addis Ababa was gathered, including details about the current site, spatial traffic distributions, and a digital map [18]. The target deployment region is chosen after data collection is finished [5].

1.5 Literature Review

Literature research involves examining a wide variety of publications, including standards, white papers, and research work. As related work is newly published, we look into the last version of the standard and focus on the latest academic and industry-wide work.

The numerous research on cost effectiveness in RANs demonstrates to the criticality of this factor for mobile network operaters and cloud providers [10], [13], [14], [15]. Ioannis Neokosmidis, et al, (2019) implemented "Assessment of CAPEX and OPEX for Media Services in Cloud Enabled 5G Networks" This document discusses the 5G-ESSENCE project's cloud-enabled small cell design for 5G networks [17]. Additionally, this study shows how the suggested design complies with the emerging 5G radio resource management architecture [17]. It also looks at the use of an edge enabler in 5G networks to support various virtual network tasks [17]. The improvement of particular key performance indicators in a use case for public safety is then assessed [17]. The performance of an upgraded multimedia broadcast multicast service that is 5G enabled is then assessed [17]. In a scenario including the distribution of media content, the article investigated the performance of a virtualized eMBMS network service deployed at the edge [17]. Investigations were done into how effective eMBMS is in comparison to the unicast approach [17]. Future steps will examine the notion of cSON small cells to determine how it relates to RRM and whether it has the ability to improve 5G in terms of performance and efficiency [17].

Pietro Paglierani et al, (2020) wrote an article on "Techno-economic Analysis of 5G Immersive Media Services in Cloud Enabled Small Cell Networks: The Neutral Host Business Model", This study examines the delivery of immersive video services in crowded events using a cloud-enabled small cell network owned by a neutral host and made available to several mobile network operators in multi-tenancy [14]. The author creates a planning model to forecast the needed radio, storage, and compute resources and then conduct several economic indices, such as net present value, internal rate of return, and expected payback period, to evaluate the viability of a potential investment in a 5G infrastructure for Immersive Media Services During the ten-year study period, the SCNO have to invest in equipment including racks, switches, servers, micro-servers, small cells, etc [14]. The outcomes include network investments, operational costs, and income [14]. The cumulative discounted cash flow, also referred to as the cash balance, provides an overview of the business case's overall economics and financial development [14].

Michail-Alexandros Kourtis et al (2019) "A Cloud-Enabled Small Cell Architecture in 5G Networks for Broadcast/Multicast Services", the selected study period is set to 10 years beginning in 2020 (the expected year of 5G introduction) and ending in 2029 [10]. The analysis shows that investments for an IVS in CE relying on edge cloud resources are viable with an expected payback period of 6.5 years [10].

Pouria Sayyad Khodashenas et al (2017) "The role of Edge Computing in future 5G mobile networks: concept and challenges", The paper provides an overview of edge computing technologies, from supporting heterogeneous infrastructure up to service provisioning methodologies related to the application-specific requirements [13]. This chapter highlights the most relevant subsequent challenges, including multi-tenancy, and wireless backhaul implementation [13]. Furthermore, it gathers different ideas and proposals for innovative architectures as potential approaches to address some of the identified 5G requirements [13].

Ioannis Giannoulakis, et al (2016) wrote an article on "System architecture and deployment scenarios for SESAME: Small cEllS coordinAtion for Multi-tenancy and Edge services", This paper were presented the innovative system design, concepts and visions developed by the 5G PPP H2020 project SESAME (Small cEllS coordinAtion for Multi-tenancy and Edge services) [11]. The innovation of SESAME is manifold: i) combine the key 5G small cells with cloud technology, ii) promote and develop the concept of Small Cells as-a-Service (SCaaS), iii) bring computing and storage power at the mobile network edge through the development of nonx86 ARM technology enabled micro-servers, and iv) address a large number of scenarios and use cases applying mobile edge computing [11]. To that end, SESAME envisages to virtualize and to partition Small Cell capacity, while at the same time it aims to support enhanced edge cloud services by enriching Small Cells with micro servers [11].

The research we present so far emphasized deployment for wireless networks mostly for next-generation mobile networks, introducing the concept of Cloud-RAN, cloud based media service provisinining, its deployment, and associated opportunities. In the survey on C-RAN, after a general overview of the concept of centralization and virtualization, and main enabling technologies-like compression techniques for C-RAN-based testbeds-harnessed, attention was paid to the usage of SDN and NFV technologies in C-RAN, along with challenges preceding the 5G rollout. Investigations on functional splits, throughput enhancement, interference management, energy efficiency, security, and system cost reduction have kept pace with C-RAN. Open RAN is based on the basics of C-RAN and gives much attention to the advantages and business opportunities presented by Open RAN. RAN virtualization was hardly addressed; by the name of Network Virtualization, a solution demonstrated the feasibility of the future requirements of virtualized mobile carrier networks. Most studies considered only geographical scenarios, while technology comparison mainly focused on input data assumption. No comprehensive survey was found in the literature on DRAN, C-RAN, vRAN, and open RAN comparison in the given scenario listed here Geographical location. The paper presents a study on the adoption of Cloud Radio Access Networks in the telecommunications environment, with a bias towards how such a shift is capable of transforming mobile network operations in light of next-generation, cloud-based media services. How MNOs with existing network infrastructure-including but not limited to LTE/LTE-A, 5G NR networks, transport networks, and site locations among others more easily migrate to the Cloud RAN architecture without losing those infrastructure resources at minimum TCO.

It can deploy Cloud RAN using the existing network infrastructure, thereby saving many costs for MNOs. From the above literature review, it would be inevitable that any new technology viability must be assessed both from the technical and economic standpoint. TCO was used as a basis for cost position analysis in most of the reviewed literature on Cloud RAN and assessed the cost savings obtained.

However, to evaluate the economic viability of complex technical systems aside from TCO, the revenue generated and economic decision-making criteria such as NPV, PP, and internal rate of return should be quantified, which is the main task of this study. Furthermore, this thesis presents a detailed techno-economic evaluation of the Cloud RAN to show the differences in the costs of the different architectures based on the developed scenarios. By considering real baseband module hardware specifications and future RAN solutions, the network dimensioning by the TEA model can give a more realistic estimate for the cost of the Cloud RAN.

1.6 Scopes and Limitation

The use of cloud based multi small cell network for provisioning of IVS during events with massive attendance [11]. This analysis focuses on the delivery of rich media services offered in crowded situations such as events, especially, AR and VR services [14]. It reviews the engineering requirements, availability and proficiency required to deliver these services [14]. The case study is also done in Addis Ababa Ethiopia hence establishing a clear geographical background [6]. It provides information on the environment of this city, network topology, user's behavior and possible difficulties of cloud-enabled small cell deployment [6]. In assessing the impact of the deployment scenario, the study uses a techno-economic analysis technique [6]. It takes into account, network requirements, number of users per area, data speed, bandwidth, cost for rollout, income and profitability.

From a technological point of view, the focus of the thesis is limited to the 5G CESC RAN network dimensioning at 28 GHz MMWave and follows the 3GPP TR 38.901 (Urban Micro) propagation model. From a service perspective, the study's focus is solely on IVS data services for AR/VR event users; voice service users are not taken into account. From the network operator's perspective, most OPEX and CAPEX cost estimations are based on Ethio-Telecom and vendor data in the case of Ethiopia, Addis Ababa, around an area called Meskel Square.

The research findings can be outdated over time due to the accelerated development of telecommunication and cloud computing, and thus they would need constant revising. Deployment of video services may be subject to differences in users' behavior and preference. Maintenance, technical complexity, and cost may not be well dealt with in cloud-enabled small cell networks. Scalability continues to be an important issue because scaling up from small pilots to urban-wide implementations comes with large resource and infrastructure constraints. This limitation arises from research constraints that affect data collection and from obtaining inadequate or non-recent data.

1.7 Thesis Contributions

A flexible technological and economic approach is suggested for evaluating the use of a cloud-enabled small cell network to provide immersive video services at events with a lot of people. In the provided framework, the analysis of the structure is aimed at giving a methodical approach to consider the technical and economic determinants of the deployment scenario. It performs a comprehensive feasibility analysis of the deployment scenario based on various key indicators, such as the network limit, the traffic intensity of the population, data throughput, data rate, and latency. Offers an understanding of the technological features and issues concerning the delivery of digital video services for popular occasions [3], [19]. We analyze CESCN deployment limitations, solve IVS access problems, and foresee new telecom business opportunities with 5G. We also provide necessary business model changes, capacity problems, and potential overlaps with existing solutions.

The thesis also delivers the calculation of all the costs, starting with infrastructure investment and equipment, to operation costs, and the area of economic feasibility of the deployment scenario by offering information for the probable cost and revenue models related to the issue of immersive video services. Analyzes various deployment architectures of the small cell network supported by the cloud, such as D-RAN, C-RAN, Cloud-RAN, vRAN, and O-RAN [24]. Evaluate the applications' compliance, costs, and capabilities regarding fulfilling the requirements of the deployment scheme, and compute the return on investment (ROI) of the deployment scenario with the actual expected costs and the hypothetical values of possible revenues [3], [25]. It enables one to analyze the economic effects of the cloud and contribute to decision-making on investment in cloud-enabled small cell networks [3]. From these analyses and conclusions, a thesis of the optimal deployment plan containing the recommended deployment architecture, network setup, and possible partnerships or affiliations [20]. It provides a possibility to analyze risks for the user experience, network tendencies, and the reflection of the revenues.

1.8 Thesis Layout

There are nine chapters in this work. The first chapter explains the introduction, statement of the problem, objective, methodology, scope, limitation, reviews of literature and work contributions. The second chapter deals with a general 5G network overview, AR/VR use with Edge Computing Technology and network architecture. The third chapter discusses the development and architecture of the network (D-RAN, C-RAN, V-RAN and O-RAN). The fourth chapter explains methods of techno-economic modeling and evaluation, cost modeling, income modeling and tools for investment decision-making in their mathematical approach. Chapter five represents an analysis of case studies and scenarios, network architecture and demand forecasting.

In the sixth chapter, general principles and methods for CESC network dimensions with small cells and basic approaches introduced. Discusses the selection of the path loss models, general capacity, coverage and the principles of frequency planning to estimate the required number of gNode B, implemented TEA frameworks, network dimensioning, cost and revenue modeling are explained in chapter six. Chapter Seven explains the implemented techno-economic module and techno-economic analysis. Chapter eight explains the results of techno-economic modeling and interpretation for the feasibility of each scenario. Finally, the conclusions and future works are explained in chapter nine.

Chapter 2

5G and AR/VR: Innovations and Technological Framework

2.1 AR/VR Transformative Use Cases with Edge Computing

5G is aiming to provide all-over connectivity for any kind of device and application that can benefit from being connected [37], [38], [39]. 5G network is not based on single Radio Access Technology (RAT), but rather a collection of different access and connectivity technologies used together to meet the demands of future mobile networks [37], [38] and [39].

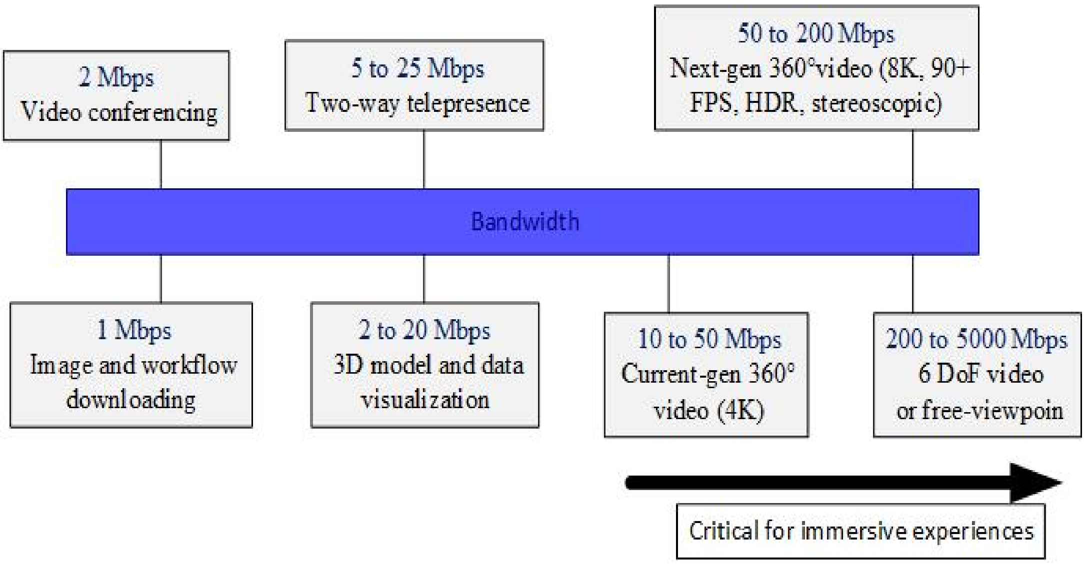


Figure 2.1: Richer visual content.

5G and edge computing enable AR/VR in many new applications [37], [38], [39]. The higher bandwidth and lower latency, which they enable, are particularly important for AR/VR, as depicted in Figure 2.1. The ability to render 3D images really takes AR/VR applications to the next level [37], [38], [39]. The lower latency that edge brings is also crucial in ensuring that the applications are comfortable for the end-user and that they can execute tasks effectively [37], [38], [39].

In order to achieve these higher speeds, 5G operates at higher radio frequencies combined with a new network architecture, thereby making it ideal for applications such as high-definition video streaming, AR, VR, and IoT [37], [38], [39]. Mobile Edge Computing (MEC) also aims to position computing and storage resources on the RAN edge to improve content and application delivery for 4G and 5G network users [37], [38], [39]. The MEC environment is characterized by very low latency, high bandwidth, and real-time access to radio network information, which can enable the deployment of new applications and services such as IoT, video analytics, and connected cars [37], [38], [39].

Deploying distributed data centers capable of content caching and processing is key for achieving low latency in mobile networks, which is also one of the defining characteristics of 5G [37], [38], [39]. AR applies digital information to real-world settings. Brands utilize AR to create interactive and engaging experiences for customers through mobile apps or intelligent eyewear [37], [38], [39]. With AR, virtual try-ons can be enabled for clothes, accessories, or even furniture to help customers see what merchandise will look or feel like before making a purchase [37], [38], [39]. Interactive product demos, 3D visualizations, and gamification experiences that AR offers enhance brand interaction [37], [38], [39]. VR embeds customers into a virtual environment run by machines [37], [38], [39]. Brands create immersive experiences through VR by taking customers on virtual tours of their stores, services, or products. Product launches, fashion shows, and events are also possible through VR [37], [38], [39]. It also provides the opportunity for brands to create virtual showrooms where customers can browse through a large portfolio of products in a simulated environment [37], [38], [39].

2.2 Enhancing AR/VR Experiences with CDN and Cloud-Enabled Small Cells

CDN and cloud-enabled small cells combine to deliver immersive experiences [37], [38]. A content delivery network (CDN), AR/VR streaming, and cloud-enabled small cell are all in some way or another related and interconnected to each other in the aspect of providing an immersive AR/VR experience over a high-speed network [37], [38]. The combination of these two technologies allows for seamless, immersive, and responsive AR/VR experiences because of the power of 5G networks, CDN infrastructure, and cloud-enabled small cells [38], [39]. CDN and 5G cloud-enabled small cells are somewhat related in the sense that they are both there to help improve network performance and to deliver content efficiently to the end user [37], [38], [39]. This is referred to as CDN, which places the content on the edge servers where the users are located to improve latency and allow for more scalability [37],[38],[39]. 5G enables small cell integration by the use of small and low-powered cell base stations that increase coverage and capacity either by offloading or providing localized base stations [37], [38], [39].

The advent of 5G networks will come with increased bandwidth and reduced latency, thus allowing CDN to deliver better and faster content [37], [38], [39]. Content delivery to the user can also be further enhanced by the inclusion of small cells in congested places or those with poor coverage, as shown in Figure 2.3 [37], [38], [39]. The small cells incorporated with cloud technology can ease some operational stresses from the core network by handling certain processes like CDN-related activities at the network's edge [37] [38] [39]. This is done by shifting content caching and delivery operations to the neighborhood of the users, connected through small cells, which relieves the backhaul traffic in the core network, hence enhancing performance [37], [38]. Content-driven networks augmented with the 5G cloud-enabled small cell framework ensure satisfaction among users accessing content over the internet [38], [39]. Users, on the other hand, would have short loading times and less buffering while viewing images and videos, as in the cases of streaming applications [37], [38], and [39].

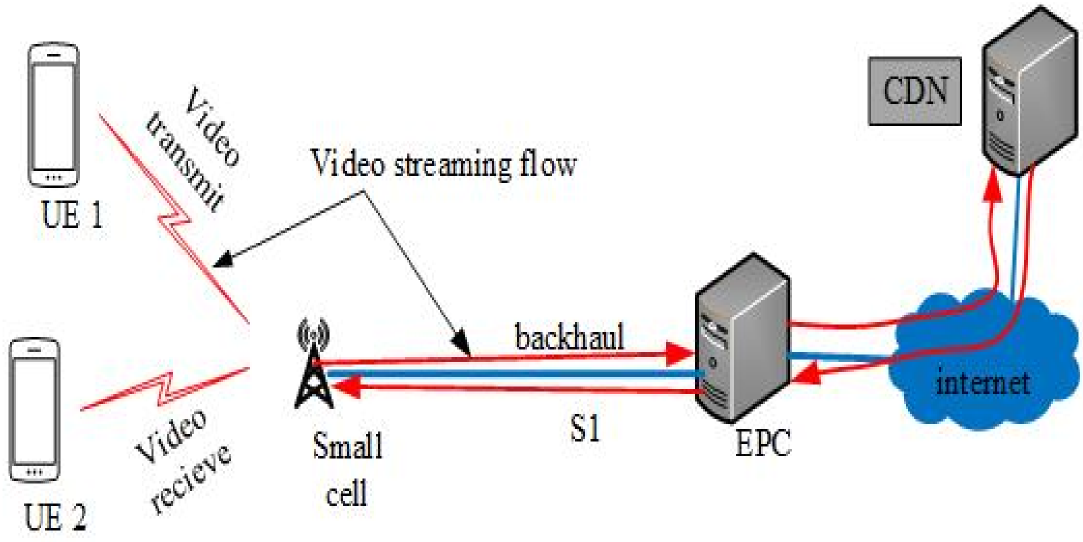


Figure 2.2: AR or VR services are hosted at the long-delayed remote DC

To deliver smooth and immersive experiences, AR/VR systems need to meet specific end-to-end latency standards [39]. The total end-to-end latency, also called Motion-to-Photo (MTP) latency, plays a key role [37], [38]. VR systems often aim for about 20 ms of latency. However, Augmented Reality (AR) has even stricter requirements [37], [38], and [39]. AR needs less delay because human movement and other factors like lighting changes can affect what users see [37], [38], [39]. 5G's enhanced mobile broadband (eMBB) offers more bandwidth than 4G [38]. But it doesn't improve low-latency performance without cutting bandwidth [37], [38]. To solve this problem, we need wireless technologies with ultra-wideband (UWB) capabilities [37], [38], and [39]. UWB allows timely transmission

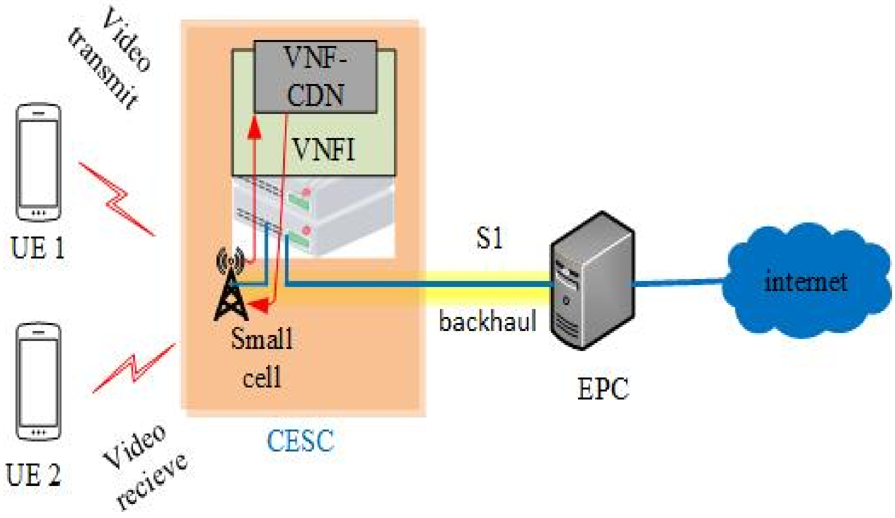


Figure 2.3: A light datacenter can host AR or VR services when the latency is minimized.

with higher capacity, making low-latency systems possible for high-quality audio and new AR/VR applications [37], [38], [39].

Latency Factors in AR/VR: We need new ideas to make regular AR/VR systems better: We can cut down lag with smart network designs; ultra-wideband (UWB) wireless tech allows for quick data sending; good data handling and display methods; top-notch hardware bits (screens, GPUs, etc.) [37], [38].

VR Cloud Services: MTP lag should be less than 20 ms. Too long may make users sick or uncomfortable [37], [38], [39].

Transmission Delays (Cloud-Based AR/VR): The cloud-based AR/VR systems may send the processed data to a remote server for rendering the virtual world [37], [38], [39]. Network communication adds extra delay [37], [38], [39]. To overcome this, improvement in network speed, such as using 5G or fiber optic connections, along with reducing the size of data transfer is required [37], [38], [39].

MTP Latency Limits: We observe that a below-7-ms MTP latency is required for complete immersion in the HMD users of VR experience [39]. From studies, both AR and VR, it was concluded that having a 5-ms-or-below latency helps in minimizing motion sickness and increases user comfort [39]. A hosted AR/VR can have a very minimized latency when operating on a lightweight datacenter.

2.3 Augmented Reality (AR) and Virtual Reality (VR) Applications Across Various Domains

Virtual reality (VR) can radically transform various sectors by enabling immersive and interactive experiences [39]. The following showcases as shown in Figure 2.4 some real-world VR applications from different sectors. At this point in time, one can only expect more creative, groundbreaking innovative and revolutionary applications in many fields of work as virtual reality technology advances [39].

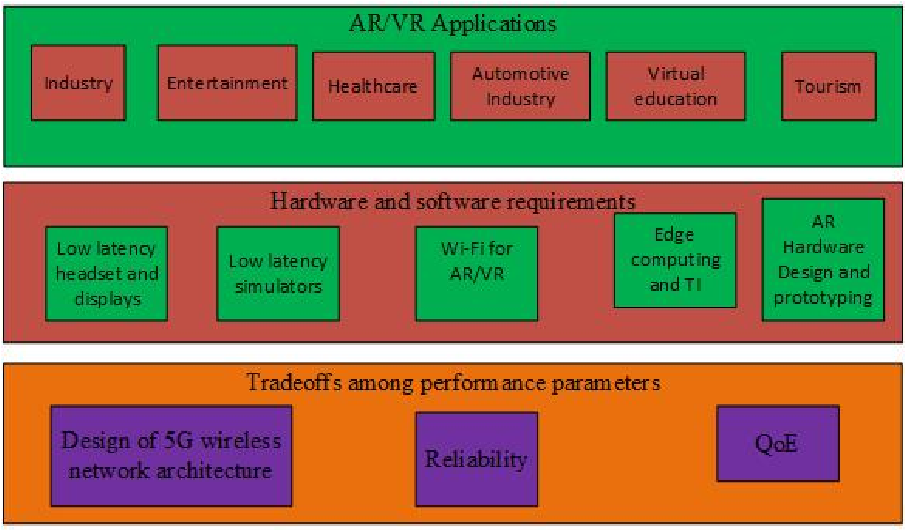


Figure 2.4: Major AR and VR applicaton area.

Industry: Such technologies boost safety processes, enhance assembly process, and provide better training simulators [24], [40]. Using AR, such as overlaying the real-time information in machines during maintenance tasks, or training factory workers by recreating difficult scenarios using VR [24], [40]. Entertainment is evolving with Augmented Reality (AR) and Virtual Reality (VR); changing the game of the entertainment industry. Imagine, walking into a virtual concert, with your Favorite band, in your surrounding [24], [40]. Virtual reality gaming places users in realistic environments, leading to increased thrill of experiences [40]. Augmented reality also influences viewers through interactive storytelling and interactive storytelling movies [24], [40].

Healthcare Innovations: AR/VR technology has a potential application in healthcare. Surgeons can use VR simulations to prepare elaborate procedures [40]. More specifically, AR superimposes patient data to enhance accuracy in surgery [40]. Moreover, Virtual Reality treatment, also aid in recovery, pain and anxiety management among patients [40].

Automotive Industry Contributions: AR/VR technology can play a great role in healthcare [25]. VR is also used to prepare and plan complex operations, where surgeons use virtual reality simulations [25]. AR during surgery helps overlay patient data, thereby increasing precision. VR therapy helps patients manage pain, anxiety, and rehabilitation [25].

Travel and Tourism Enhancement: Impact of VR and AR: VR and AR will be changing travel for people [25]. Visitors can navigate historical sites and augment today scene with historical context through the use of augmented reality guides [25]. Users can virtually travel to different exotic places such as futuristic cities and ancient ruins all from the comfort of home [25].

Virtual Education for Personalized Learning: Virtual reality creates customized learning experiences [32]. Learners may explore digital organisms, and experience science, as well as a civilization in the past. Textbooks that include AR components are designed as enhancements over traditional learning materials [32].

2.4 Cloud-Enabled Small Cell Network Concept and Architecture

It is a widely accepted fact that small cells are going to be at the epicenter of 5G network deployments on a cost-effective solution that can rapidly and effectively deliver the additional radio sites required to meet the exponential growth in demand for available spectrum [32]. To provide coverage in regions with low signal or high user density, a compact low-power radio access node is employed [6], [24], [33]. In any case, the traffic is often transmitted over a fiber-optic or wireless network from the small cells to a cloud-based controller [6], [10], [24], [33]. A cloud-based controller through the backhaul network component [10]. Usually, a fiber-optic or wireless network transports the traffic from the small cells to the cloud-based controller [6], [10], [24], [33]. Actual physical antennas placed at cell sites and linked to central baseband units through fibers [6], [24], [33]. RRHs are used to transmit and receive radio signals from/ to mobile devices placed in the network. Baseband Units (BBUs) are centralized processing entities that are used to baseband process, more than one RRH [6], [24], [33]. BBUs are mostly in a centralized data center or cloud, perform call processing functions like encoding/decoding radio signals, handing over of calls between cells, and controlling network resources [6], [10], [24], [33]. Fronthaul fiber optics solutions connect the RRHs to the BBUs as they are the medium through which digitally transmitted radio signals are transported [33]. Fronthaul is one of the key aspects of RAN since extensive data transfer is required at very low latency and with high reliability and quality of service as depicted in figure 2.5 [6], [10], [24], [33].

A cloud-enabled small cell is understood as a small base station consisting of a cloud computing environment. These microcells are mounted outdoors to provide hotspots that typically have coverage areas of 100-250 meters [6], [10], [24]. They are small in dimensions and inconspicuous in shape which allows to mount them on the lamp posts, on the side walls of buildings and etc. As the number of users is growing and people expect the signal quality to be higher, small cells have grown smaller and denser [10], [24].

Small Cell Radio: Integral to the functioning of a small cell network, the small cell radio enables supply of wireless coverage to users in a given area [6], [33]. It includes a radio system that it uses in establishing contacts with the user devices antenna and base

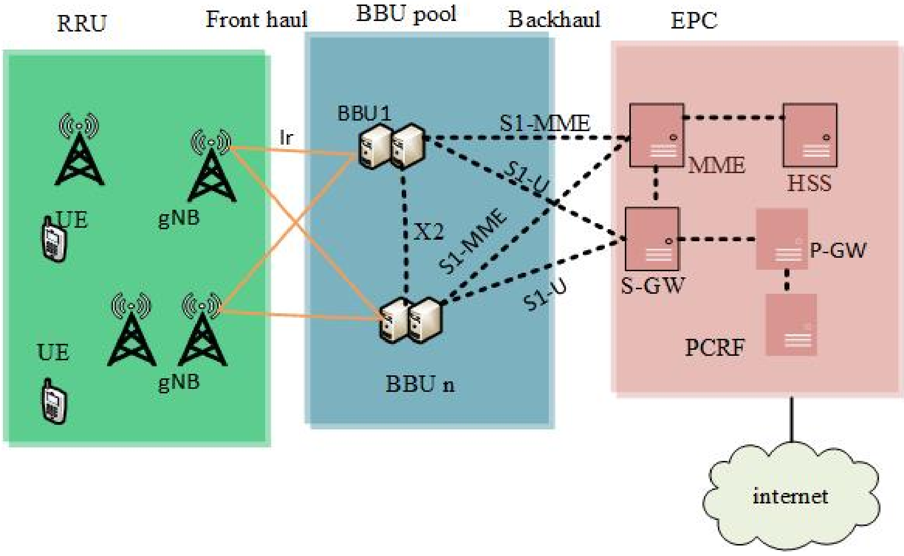


Figure 2.5: The general architecture of Cloud RAN .

station [6] [33].

Cloud radio access network: Cloud base architecture is where the radio access network tasks are processed centrally [30], [33]. Baseband processor and radio unit are therefore separate; this means that several small-cell radios can utilize the same cloud processing assets [30] [33]. The network is made more efficient and economical in terms of usage as a consequence [30], [33].

Cloud management and orchestration: Cloud management and orchestration relates to a software level that monitors and controls the cloud resources [14], [34]. Its components are network slicing, security management, and load balancing is among the features considered [10], [34]. Due to the above characteristics, the small cell network is therefore specialized, safe, and manageable [34].

The cloud-enabled small cell network architecture developed from the baseband centralized network architecture and was first implemented in 5G networks [10][24][34]. In 5G networks, the cloud-based controller replaced the BBU, and small cells were implemented at the cell site [10], [24], [34]. This architecture also enhanced high network performance, expanded network capacity and coverage in areas of interest, and optimized how network assets were utilized, as shown in Figure 2.6 [10], [24], [34].

2.5 NFV and SDN in Cloud RAN

Network function virtualization (NFV) and software-defined networking (SDN) are seen as key enabling technologies [27], [28]. Decoupling the control and data planes will enable fully programmable networks, which is the goal of SDN technology [27], [28]. However, the NFV technology enables virtualization to execute software-based network functions on general-purpose hardware [27], [28].

The advantages above mean that SDN/NFV will be crucial in the 5th generation

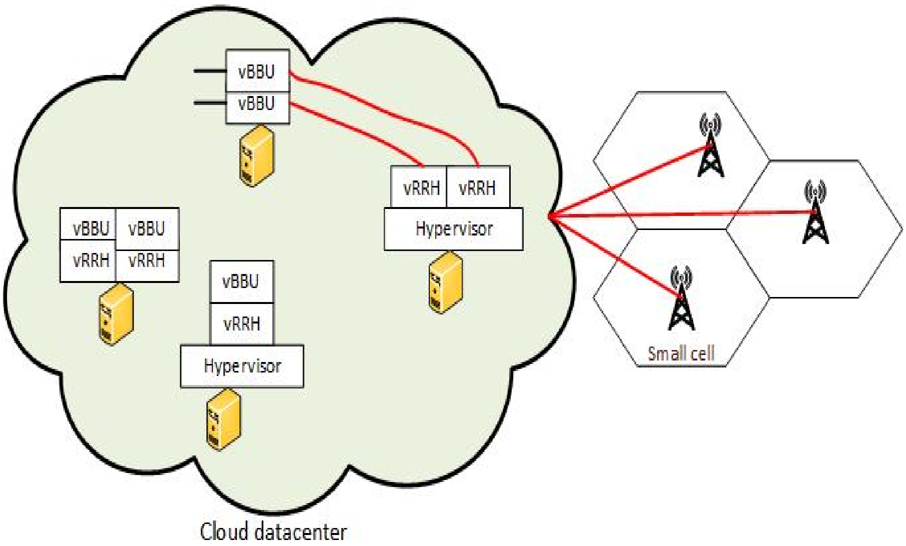


Figure 2.6: Cloud-enabled small cell network architecture.

(5G) systems [27], [28]. The SDN and NFV technologies significantly aid in developing an intelligent RAN. SDN allows the RAN-level network functions to be abstracted and modularized [27], [28]. As a result, it is possible to design a hierarchical control architecture, in which the high control layer governs lower layers by defining procedures without needing access to the details of their implementation [27], [28]. NFV-based BS might implement some network functions as physical network functions (PNFs) and others as virtual network functions (VNFs) [27], [28]. Since VNFs operate on shared NFV infrastructure (NFVI), the underlying hardware can be used effectively, which is a benefit [27], [28].

The connections between Cloud-RAN, NFV, and SDN provide information on how Cloud-RAN integrates the other two technologies to achieve many layers of centralized management in the BBU pool [28].

A new architecture called SDN (Software Defined Network) decouples the network control and forwarding functions, enabling the network control to be directly programmable, and abstracts the underlying infrastructure to allow for dynamic adjustment of applications and network services [28] . These three ideas are related, but they each serve a different purpose as shown in Figure 2.7 [28]. While NFV is focused on implementing network functions in software on common IT platforms, SDN is concerned with separating the network control layer from its forwarding layer [28]. A concept of baseband processing unification through NFV implementation in RAN results in identifying Cloud-RAN as an NFV application [28]. Hypervisor-created virtual RAN layers get managed through the same process which hardware virtualization uses to manage RAN hardware components [28]. Network operating systems control network virtualization pools which include switches alongside routers and edge caching storage components and transport

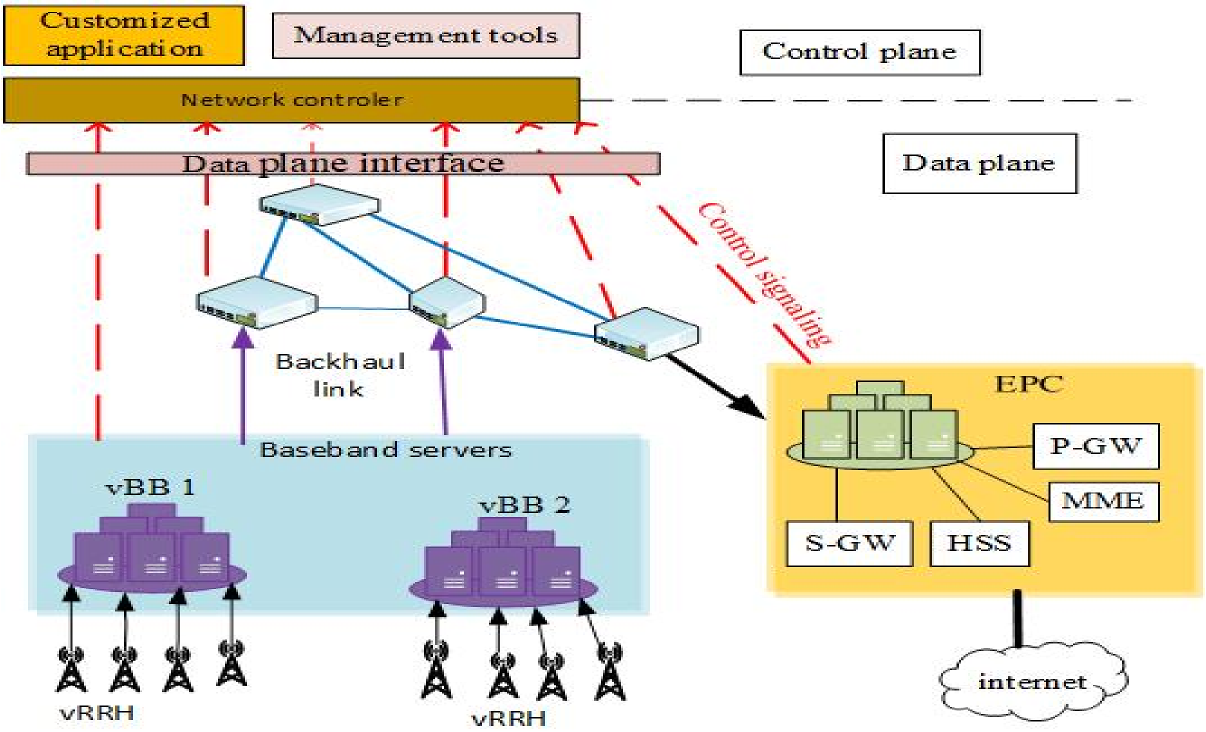


Figure 2.7: Software-Defined Networking for Radio Access Networks architecture.

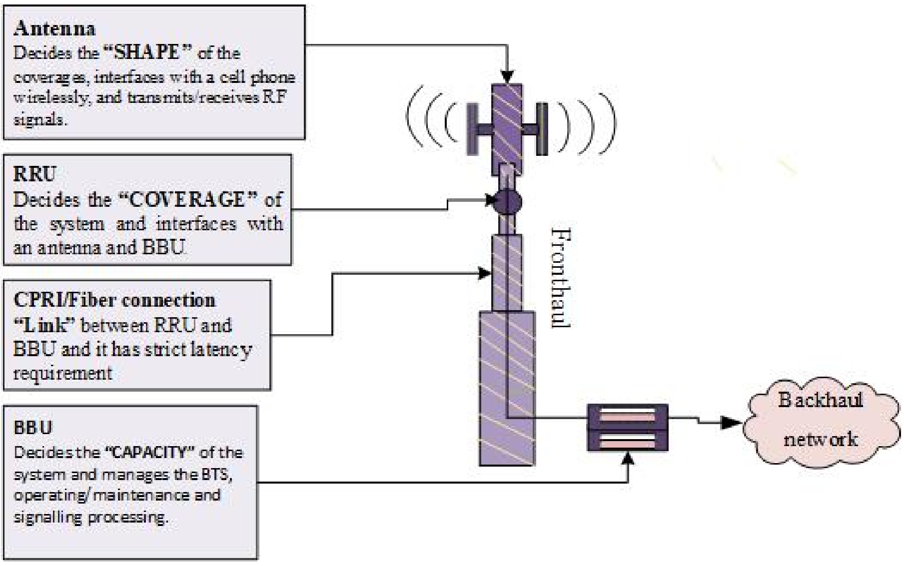
resources according to [28].

Through Cloud-RAN, various baseband processing resources are centralized to create a single resource pool, allowing for resource management and demand-driven dynamic resource allocation [28]. Compared to standard base-station architecture, Cloud-RAN has several benefits, including better resource use and reduced energy use [28]. Cloud-RAN mainly comprises three components, namely BBU pool with centralized processors, RRHs (remote radio head) provided with antennas located at the remote sites, and Fronthaul network requires high bandwidth and low latency and connects the RRHs to the BBU pool [28].

Chapter 3

An Overview of RAN Network Evolution and Architecture (D-RAN, C-RAN, V-RAN, and O-RAN)

Now within the 5G technology, a extensive range of new technologies and services is being introduced [26], [27]. these consists of LTE-NR dual Connectivity (EN-DC), NR-NR dual Connectivity (NR-DC), millimeter wave (mmWave) spectrum, network function Virtualisation (NFV), Containerised network functions, massive Machine type Communications (mMTC), Ultra Low Latency communication (URLLC), Multi-Access Edge Computing (MEC), network slicing and Vertical offerings, just to call some [26], [27].



Antenna
Decides the "SHAPE" of the coverages, interfaces with a cell phone wirelessly, and transmits/receives RF signals.

RRU
Decides the "COVERAGE" of the system and interfaces with an antenna and BBU

CPRI/Fiber connection
"Link" between RRU and BBU and it has strict latency requirement

BBU
Decides the "CAPACITY" of the system and manages the BTS, operating/maintenance and signalling processing.

Figure 3.1: Architecture of RAN.

This article explains these technologies related to RAN architecture [26], [27]. Conceptually, the RAN links user equipment, such as a cellphone, computer or any remotely controlled machine, over a fibre or wireless backhaul connection [26], [27]. That link goes to the core network, which manages subscriber information, location and more [26], [27]. Radio Access Network has evolved quite a bit, from D-RAN to C-RAN and then to vRAN and now to the hottest topic in telecom, which is Open RAN as shown in Figure 3.2 [26], [27].

Figure 3.2: RAN evolution

The Third-Generation Partnership Program (3GPP) has enabled new network elements and applications across mobile communications generations by extending the capabilities of the RAN and core networks [21], [22]. One major change that enabled higher traffic rates and had an impact on the 2G RAN was the introduction of packet-switched data into the core network [21], [22]. 3G's reduced redundancy and enhanced spectrum efficiency techniques boosted mobile broadband and RAN data ranges [21], [22].

Research indicates that RAN architecture demands restructures beyond what current LTE version upgrades recognized [22]. 5G will introduce new use cases, services, and traffic kinds, hence the RAN will require a new approach, particularly about reconfigurability and adaptability [22]. By 2020, the RAN will need to be substantially more advanced and diverse, leveraging millimeter wave (mmWave) frequency bands along with a range of enabling technologies like SDN and NFV. Today's RAN will leverage cloud (C-RAN) and virtualization (RAN) technologies to accomplish these goals [22].

In general improvements have been made, on each generations basis, especially with regard to data rates, latency, and capacity. More specifically, options and usages for spectrum have been significant to the change of RAN networks over the years [24], [26]. New wave bands have also been incorporated in the 5G concept thereby improving on the frequency range by operating at higher rate such as the millimeter-wave (mmWave) [26]. Further; features like carrier aggregation and dynamic spectrum sharing enables the operators to better utilize the limited spectrum [26]. Due to a growing need in capacity in highly populated regions, small cells have become part of RAN networks [24]. Low output transmitters known as small cells that are capable of deployment in areas of high demand for the network likely areas which include cities[26]. They assist to ease the commonly faced problem of traffic congestion in macro cells and also enhance the general capacity and coverage of the network [24].

D-RAN (Distributed RAN), whose distributed architecture requires the RRU (Remote

Radio Unit) and BBU (Base Band Unit) to be collocated [24], [27]. The cellular connects to the core through the backhaul [24], [27]. C-RAN (Centralized RAN/Cloud RAN), where RRUs are disbursed and BBUs are centralized [24], [27]. RRUs and BBUs connect through the fronthaul, and BBUs and the middle connect via the backhaul [24], [27]. C-RAN is frequently additionally referred to as Cloud-RAN because of the software of Cloud technology within the telecommunications environment [24], [27]. V-RAN (virtual RAN), wherein maximum features are processed in virtually, even in proprietary solution. O-RAN (Open RAN), a solution that emerged as part of 5G [24], [27].

3.1 D-RAN (Distributed-RAN)

One of the first form of radio access networks was the D-RAN as shown in Figure 3.3. Each cell site in this type of network has a remote radio head (RRH, also known as RRU) and a base-band unit (BBU) [22]. BBU was normally mounted in a room right below BS. RU will be set up in the room or at the top of a tower, enabling the RU to support connectivity in a large area. In this context, the RU can also be called the remote RU (RRU) [22]. Implementing D-RAN is straightforward as it does not require a high-speed interface between RU and BBU. The network densifies as the number of UEs increases and more BS are built [22],[23], [25].

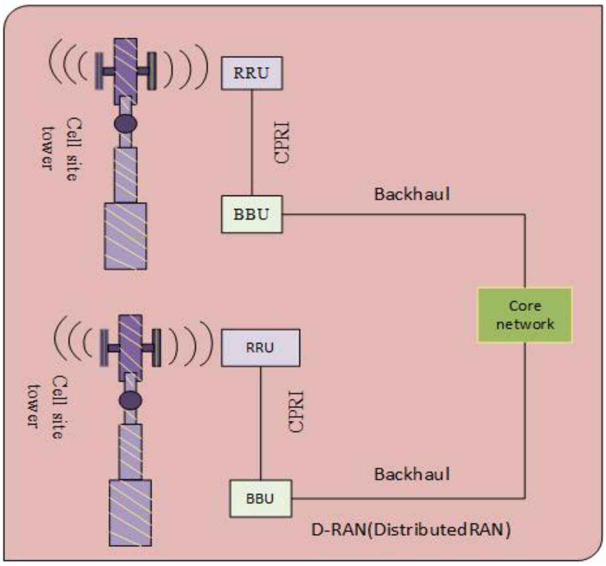


Figure 3.3: D-RAN (Distributed RAN) Architecture.

Disadvantages: The requirement for software and hardware RRH/BBU to come from the same vendor leads to vendor lock-in and inadequate resource sharing. RAN capacity will not be fully utilized in low-traffic regions. high costs of operating. Field maintenance engineers ought to visit every site, as this has an immediate effect on OPEX [23], [24].

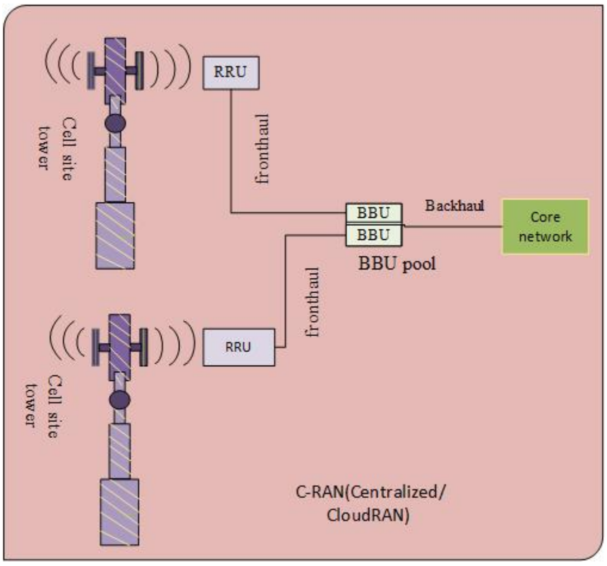


Figure 3.4: C-RAN architecture: the BBU and RRH are connected through the fronthaul while BBU and core network are connected through backhaul [26].

3.2 C-RAN (Centralized-RAN)

The advanced version of D-RAN appears as Centralized RAN or cloud RAN according to Figure 3.4 [24]. The BBU and RRH locate separately after the split since this split remains the main explanation for this arrangement. The BBU from multiple cell sites will fit into a single physical location which is known as a BBU Pool or BBU Hotel [24]. The radio unit is situated at a cell site, while the baseband unit is centrally located. Software and hardware must be purchased from the same vendor [24]. Centralized RAN is proposed to reduce the space rental cost and the power consumption of the air conditioner of the BBU by pooling BBUs from different BS into a single physical location [24]. Despite reducing the overall OpEx, Centralized RAN requires the FH to have high bandwidth and low time latency requirement [24]. The fundamental difference between Centralized RAN and Cloud RAN is the cloud system [24. In Centralized RAN, the BBUs are pooled in a physical location [24]. In Cloud RAN,BBUs from each BS were pooled in a cloud server. Control in Cloud RAN made it easier for the number of BBUs to be changed with time [24]. The cloud also increased the baseband processing by exploiting general-purpose processors [24]. Cloud RAN further reduced energy consumption, increased network throughput, improved network scalability, reduced Capital Expenditure (CapEx), and reduced OpEx [24].

Placing various sites at a single physical location helps cut down operational expenses. The co-location of RRH and BBU would necessitate rent savings because a bigger space is needed. EICIC operates more efficiently through low-latency communications that connect different sites according to inter-cell coordination requirements[26] [22].

The major drawback of fronthaul occurs due to massive data processing between

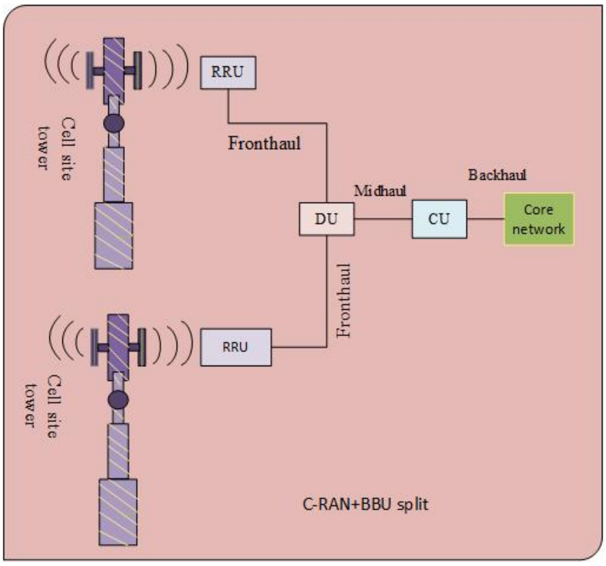


Figure 3.5: 5G NR gNodeB functional split(BBU split)

RRH and BBU while maintaining vendor lock-in properties equivalent to those in D-RAN systems. However, to further solve this problem, the 3GPP suggested that the radio unit, distributed unit (DU), and central unit (CU) be functionally separated from one another as shown in Figure 3.5 [22]. In this instance, DU (e.g., RLC, MAC, PHY) and CU (e.g., RRC, PDCP, and SDAP in the 5G scenario) can handle some substantial processing [22].

3.3 vRAN (Virtualized-RAN)

C-RAN still has limitation, such as the huge FH overhead, trust problems, security problems, and single-point failure [26], [23]. The problems forced the C-RAN framework to shift its focus to advanced computing technologies. Some of these advanced technologies were virtualization and edge computing. Virtualization is the key to the shifting from C-RAN to vRAN [26], [23].

With the exception of some important RAN architectural elements that are no longer hardware dependent, it is almost exactly the same as C-RAN. The BBU software package is placed on top of COTS servers [26], [23], [24]. This suggests that BBU which may also be split into vDU and vCU is really just a software package that is provided by the manufacturer. It can be located on the COTS server as a VNF or CNF [26], [23], [24], [56]. It proves easy to acquire COTS servers commercially and novice consumers can purchase them easily from COTS server vendors and run BBU software on top of them [26] [23] [24]. At the BBU level theoretical software-hardware separation exists yet it brings two main disadvantages including inaccessible APIs and vendor-proprietary exits [26, 23, 24]. The RRU and BBU (vDU and vCU) vendors have to be the same. The baseband unit can be separated into DU and CU, or it can be found in a single, functional location radio unit located in a cell site [26], [23], [24], [56]. Even though the BBU operates virtually atop a

COTS server with another provider the BBU-RRU pair should stem from one provider only [26] [24]. C-RAN keeps an almost identical structure compared to its preceding version except for the elimination of hardware dependence from key RAN elements. This suggests that BBU which may also be split into vDU and vCU is really just a software package that is provided by the manufacturer. It can be located on the COTS server as a VNF [26], [23]. Since COTS servers are easily obtained commercially off the shelf, purchasing COTS servers from a COTS server vendor and installing the BBU software on top of them is straightforward [26], [23], [56]. While theoretical dualization of software from hardware operations at BBUs brings potential disadvantages such as inaccessible APIs and persistent vendor-proprietary exclusions [26], [23]. The vendors for RRU and BBU must align [26] as well as [24]. Several reports indicate that baseband units can exist as a standalone DU and CU combination but also as a single functional block [26], [24], [56]. A BBU must obtain its RRU hardware from its original vendor even when this baseband unit operates on a COTS server for which it runs virtualized software [26], [24] and [56].

3.4 Open RAN

This is the RAN solution's most recent and enhanced iteration as shown in Figure 3.6. It opens interfaces between RRH, vDU, and vCU and retains all of the benefits of both C-RAN and vRAN systems in addition to bringing intelligence to the radio access network [23], [24]. There won't be any vendor lock-in in this case, and the MNO is free to select several vendors to develop the RAN network [24]. As the name implies, the interfaces between the Radio Unit, DU, and CU will be accessible [23], [24]. Every organization does not have to rely on a single supplier to provide it; goods can be obtained from several sellers.

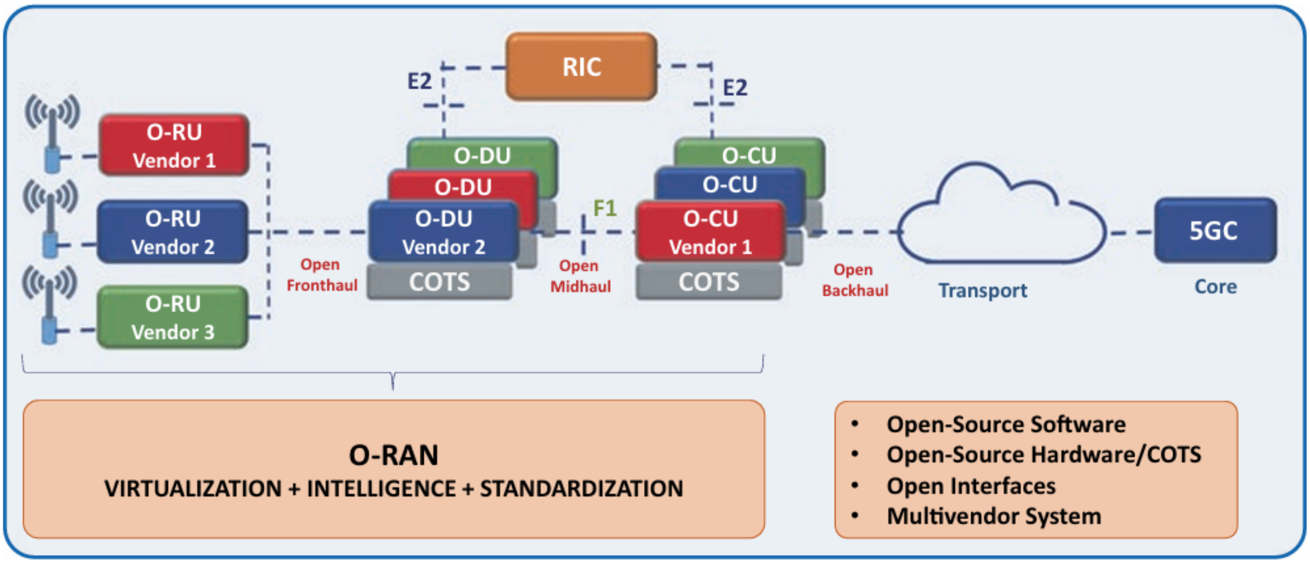


Figure 3.6: Open RAN (O-RAN) Architecture [23].

D-RAN is different from C-RAN, and vRAN is not Open RAN, even if Open RAN is intelligent with RIC and incorporates components from all previous RAN systems [23], [24]. vRAN is, in fact, a type of C-RAN . It uses virtualization technologies such as NFV or receptacles to deploy CU and DU over the x86 server (or virtual BBU on a server) [23], [24]. There is no difference between vRAN and C-RAN except that traditionally C-RAN uses proprietary hardware while vRAN uses Network Functions on the server platform [23], [24]. As explained in tabl 3.1, the most important to understand is that the Cloud RAN solution is available in C-RAN, vRAN and O-RAN to avoid miss understanding the cloud RAN solution that can be founded in C-RAN only, Because of vRAN HW/SW decoupling flexibility, we can gain scalability [23], [24]. This can decrease hardware costs and application agility as the application can be upgraded easily or swapped altogether (which is not more manageable with traditional hardware) [23], [24]. However, vRAN puts servers to new boundaries because of the performance anticipation [23], [24]. There has been quite an innovation in improving the server platform to fulfil the performance needs of vRAN [23], [24],[56].

Requirements	C-RAN (Centralized)	V-RAN (Virtualized)	O-RAN (Disaggregated)
Baseband Hardware	Proprietary Technology	COTS	COTS
Baseband Software	Proprietary Software	Proprietary Software	Software Open Interface
Radio (RRU)	Proprietary Hardware	Proprietary Hardware	COTS
BBU/RRU Interface	Proprietary Interface	Proprietary Interface	Open Interface
Integrability	Radio + BBU (HW + SW single supplier)	Radio + BBU (SW single supplier)	Radio + BBU (HW + SW various suppliers)

Table 3.1: Comparison of Cloud RAN Architectures

3.5 The 5G gNB Functional Splits

In 5G access system architecture, referred to as 'Disaggregated RAN', aims to overcome many of these challenges by breaking up monolithic network features into smaller components that can be individually relocated as needed without hindering their ability to work together to provide network services [23], [24]. Virtualisation, alternatively, transitions each of these functions from dedicated hardware to software components, enhancing for scaling, as well as rapid and continuous evolution, so that networks can meet the evolving demands of new and existing services with minimal impact to CAPEX and OPEX [23], [24].

The new 5G access system architecture has four distinct characteristics which will be described in the following section along with the benefitsts provided in comparison with legacy hardware solutions. I.e., CU (Central Unit) / DU (Distributed Unit) split, CU-CP (Control Plane) / CU-UP (User Plane) split, CU virtualisation and DU virtualization [23], [24].

Vertical and horizontal RAN disaggregation is also known as functional splits [23],

[24]. Horizontal functional split is a selection process of the appropriate centralization level in RAN framework [23], [24]. Horizontal functional split also refers to the BBU and RRU separation. It separates the integrated BBU into two separate units: Central Unit (CU) and Distributed Unit (DU). The degree of centralization in the horizontal functional split is flexible [23], [24]. However, trade-offs should be considered when choosing these functional split options. On the other hand, the vertical split is the separation between the CP and UP of the RAN. The CP and UP splitting (CUPS) is the extension of the SDN concept [23], [24].

Virtualization enhance the softwarized RAN to be sub-divided into smaller parts within single hardware that enhances softwarization [23], [24]. Virtualization technologies, which are hypervisor-based and container-based virtualization used in NFV [23], [24]. Virtualization enables hardware to host functions of multiple virtualized units, leading to a term called NFV, which virtualizes all network services, such as virtual CU or virtual DU [23], [24]. These virtualized functionalities are called Virtual Network Functions (VNFs) and they run on top of VMs. NFV uses hypervisors named Virtual Machine Monitor (VMM) or virtualizer [23], [24]. The VMM hosts and runs Virtual Machines (VMs) that host VNFs [23], [24].

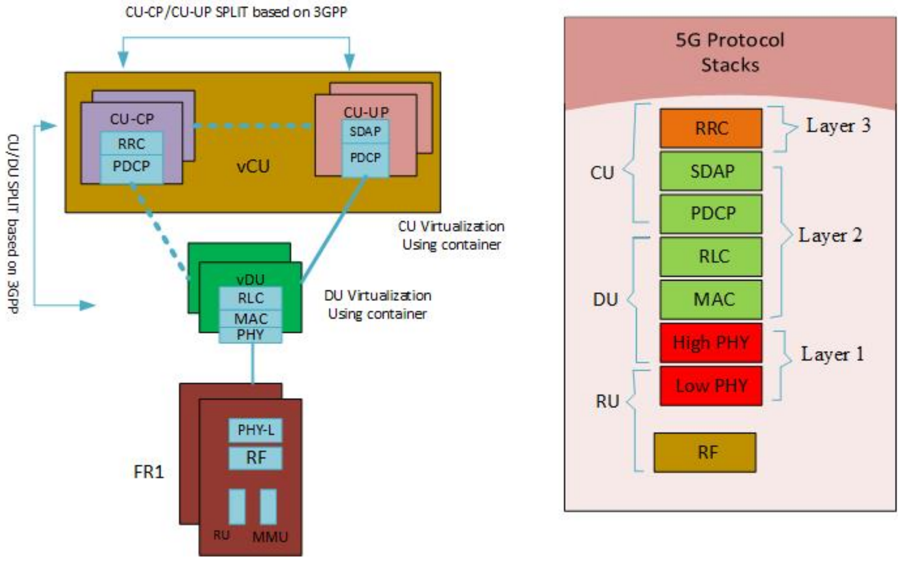


Figure 3.7: BBU split and 5G Protocol Stacks

Non-real time processing such as RRC, PDCP is off-loaded to the central site and the RRC, PDCP resource pool is shared between multiple DUs [23], [24]. CU can accommodate multiple DUs to build a large scale gNB [23], [24]. CU is virtualised on a COTS server for the scalability and flexibility. Real time processing such as RLC, MAC, PHY, RF need to remain close to the local site. DU is also virtualised on a COTS server for business agility [23], [24]. In particular, as Network Slicing and MEC are introduced, the UP should be divisible into multiple entities and allocated wherever needed for optimization of each specific services [23], [24]. Along withthe CU/DU split and CU-CP/CU-UP split, container technology can further enhance scalability, flexibility and resource efficiency [23], [24].

3.6 The Current Network Challenges

Ethio Telecom also faces some network challenges, especially in high-demand areas such as stadiums and Meskel square. Some of the key ones are listed below:

High User Density: The events held at the Meskel Square, stadiums generally are very crowded, and therefore their surroundings always contain a huge amount of mobile subscribers in a very small area [8]. This can easily increase the congestion of the network and degrade the quality of service [8].

Capacity Limitations: The events involving large crowds could lead to more than the capacity of current infrastructure resulting in slow speeds and losses of connectivity [8], [32].

Interference: There is much interference around the place due to a lot of electronic devices and physical structures in the environment, which can interfere with the signal and impede network performance [8], [32].

Latency: High latency affects real-time applications such as video streaming and online gaming, particularly when the people who gather at the Meskel Square are more in number [8].

Scalability: Scaling up network resources during events to meet peak demand is quite a task; hence, it requires advanced planning and investment [8], [24].

This may result in places lacking good or even any signal necessary having challenges in the necessary connection. The question the case study seeks to address is how these network concerns can be overcome to offer reliable immersive media experiences in technically demanding large events. It provided a potential solution and this is the small cell network which is supported on the cloud. small cells are portable wireless cells with low power output which can be deployed to enhance broadband's capability and provide localized coverage. Small cells can essentially be controlled and integrated simply through cloud technologies to ensure the likelihood of efficient resource utilization maximizes the efficiency of small cell infrastructure as a whole [24].

Chapter 4

Techno-Economic Modeling and Evaluation Mothed

Techno-economic modeling means the methodology of complex technical systems for evaluating the economic viability [36]. The steps include modeling, analysis, evaluation, and finally assessment. According to revenues and costs calculated, several indicators that assess profitability is calculated. Typical indicators may be pay-back period, NPV, and IRR [36], [37].

The most important phase in figuring out if the deployment is feasible and reducing the possibility that the investment will not be profitable [36], [37]. Even when a technology is mature enough to be deployed, the market may not be ready for its deployment. For instance, there may not be enough users, or the potential customers may be unwilling to pay a premium for a particular service [36]. Each of these factors must be analyzed using a detailed techno-economic and risk analysis methodology if a new deployment is ever to be economically viable [36]. More precisely, all the income and cash flows that are forecast, and also the sum of expenditure to be needed over the system lifetime, should be estimated [36], [37]. From this, an estimation of the payback period-that is, the time the investment needs to pay off-should be made. A project with a long payback period or the sum of cash flow is negative, is not economically viable to proceed with indicates. Since the late 90s, many European research projects have used and extended the methodology below [36], [37].

Tool for Introduction Scenario and Techno-economic Evaluation of Access Network (TITAN): TITAN is an economic model developed in the time frame from 1900- 1994. The economic analysis is made based on different scenarios that try to resemble the worst-case, average, and best economic conditions of the market for the access network only [36], [37]. **OPTImised architectures for MUltiMedia networks and services (OPTIMUM):** is an economic tool that includes various services in economic analysis that TITAN's project has not reached [36], [37].

TechnO-ecoNomics of IP optimized networks and services (TONIC): The TONIC model uses access to a business case study to assess new broadband and IP scenarios [36], [37]. It brings quantitative economic results and identifies and quantifies related risk factors. The main objectives of TONIC rely on the service definition and impact on operation [36], [37]. It defines sets of services and formulas for the purpose of determining the transport load on the network and the provision of resources for predicting demand [36], [37].

Techno-ECOnomics of integrated communication Systems services (ECOSYS): In one of the outputs generated by the EU Ecosys project, it was stated that "the business model consists of service and information flows, including a description of various business players, their roles and relationships, their relative positions in the network of value and descriptions of their cost and revenue resources" [36], [37].

Techno-Economic Results from ACTS (TERA):

TERA is the most popular and widely used techno-economic tool. It has been developed within the European Union Advanced Communications and Services (ACTS) program during the Fourth Framework Science Research and Development Program [36], [37]. The TERA tool allows techno-economic evaluation and strategic analyzes that combine high level parameters, such as subscriber density and service penetration, with the appropriate low-level parameters such as key network components. The inputs of this tool are also used in the network dimensioning of the technology [36], [37].

4.1 Analysis of IST-TONIC and CELTIC-ECOSYS Model

Research projects IST-TONIC and CELTIC-ECOSYS, both sponsored by the European Union, are centered on the creation of novel communication technologies and the evaluation of their potential economic effects [29]. The project IST-TONIC (TecnO-ecoNomICs of IP optimized networks and services) had a EUR12.5 million budget and operated from 2004 to 2007 [29]. Its goal was to investigate and develop new technologies for optimized IP-based networks and services [29]. Among other things, the initiative sought to make progress in Quality of Service (QoS), mobility, security, and service provisioning [29]. Several European universities, research centers, and business partners worked together on IST-TONIC. With a focus on Internet Protocol (IP)-based technologies, its goal was to provide new approaches, instruments, and architectures for the design and optimization of next-generation communication networks and services [29]. The project's goal was to solve the problems associated with boosting IP-based networks' capacity, performance, and efficiency while maintaining their financial sustainability as shown in figure 4.1 [29].

The project CELTIC-ECOSYS (techno-ECOnomics of integrated communication SYStems and services) had a EUR14.7 million budget and operated from 2013 to 2016 [29]. With an emphasis on the rollout of 5G networks, its goal was to examine the technolog-

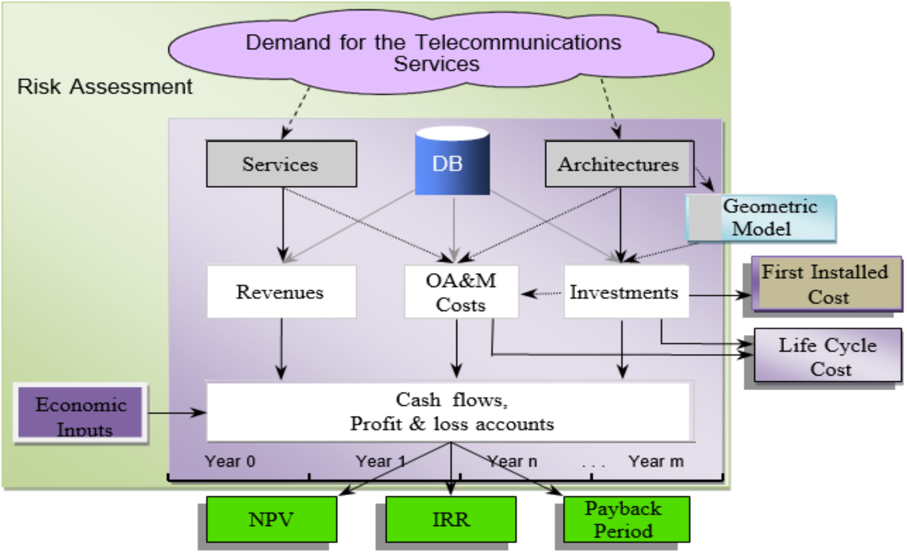


Figure 4.1: Structure of the techno-economic methodology used by TONIC .

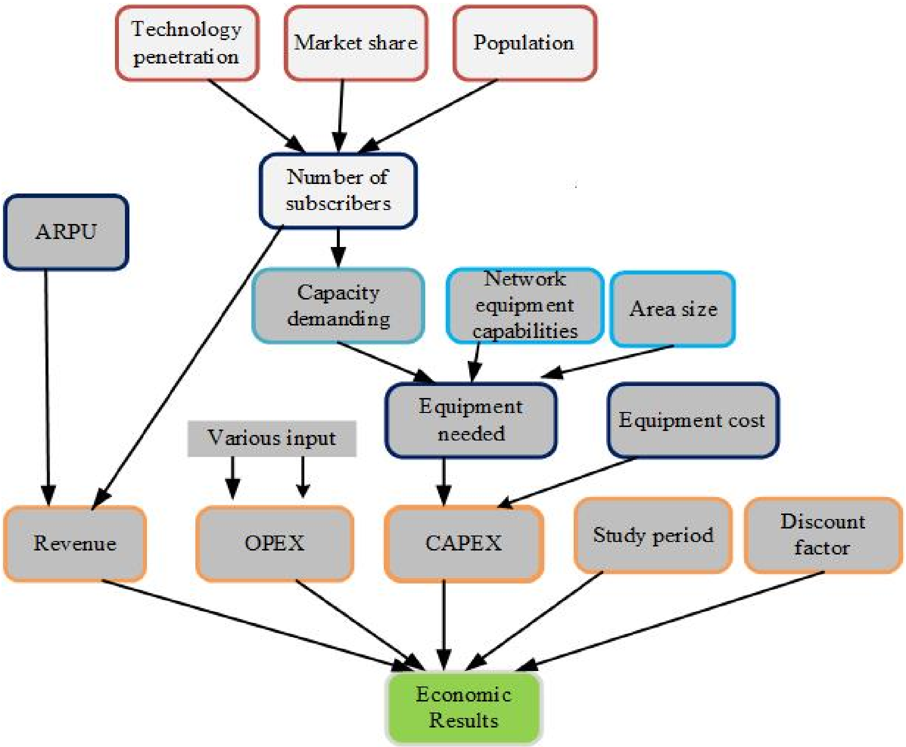


Figure 4.2: Model revenues and cost flows based on the ECOSYS project.

ical and economic elements of integrated communication systems and services [29]. The project's goal was to look at how emerging technologies, such as Software-Defined Networking (SDN) and Network Functions Virtualization (NFV), might affect the economy and open up new revenue streams and business models [30].

The project CELTIC-ECOSYS (techno-ECOnomics of integrated communication SYStems and services) had a EUR14.7 million budget and operated from 2013 to 2016. With an emphasis on the convergence of fixed and mobile networks, the Internet of Things (IoT), and 5G technologies, its goal is to examine the techno-economic elements of integrated communication systems and services as depicted in figure 4.2 [30]. The project intends to address the difficulties in creating and implementing integrated communication services and systems that are socially conscious, sustainable, and profitable [30].

While both IST-TONIC and CELTIC-ECOSYS are research projects that concentrate on the techno-economic elements of communication networks and services, their goals and areas of interest differ [30]. While CELTIC-ECOSYS is focused on examining the techno-economic aspects of integrated communication systems and services, with a particular emphasis on the convergence of fixed and mobile networks, the Internet of Things, and 5G technologies, IST-TONIC is focused on developing new methodologies, tools, and architectures for the design and optimization of IP-based networks [3]. They are a part of greater initiatives to push the boundaries of communication system design and optimization, with a focus on the systems' sustainability and economic viability [31]. Despite having distinct areas of interest, they can collaborate within the same model to accomplish the overarching objective of developing communication systems that are both economically and environmentally sustainable as explained in table 4.1 [31].

Project	Description	Responsibilities
IST-TONIC	Provides a cost model for the deployment of CESC network for AR and VR	Estimates the cost of the small cells, the cloud-based platform, and the cost of operating and maintaining the system.
CELTIC-ECOSYS	Provides data and information on the demand for AR and VR in crowded events.	Can be used to estimate the number of users who would be using the AR and VR applications and the amount of bandwidth that would be needed.

Table 4.1: IST-TONIC and CELTIC-ECOSYS Project Roles

4.2 Economic Models

Understanding a cost module is very important, as it allows a view of how the various cost parameters change in a TCO module. For example, the price of a certain component will normally come down directly with the amount bought on the market, the degree of technological maturity, and the (growing) volume of production. Inverse to this development, human resources costs, such as technical salary costs, are likely to grow yearly. The network costs, therefore, have to be estimated considering price volatility too [43].

4.2.1 Cost Modelling

The network cost is one of the major factors that determine the viability of Cloud RAN deployment scenarios [17], [35],[44]. The construction and operational costs of a radio access network can be divided into two classes, which include capital expenditures, CAPEX, and operational expenditures, OPEX [17], [35], [44]. The computations of the costs use the network components that are needed, network configuration data, and cost data for each year [17], [35], [44]. In Cloud RAN, the estimated cost for CAPEX and OPEX deals with its implementation and operational expenses, respectively, according to [17,35,44].

A. Capital Expenditure (CAPEX)

In this approach, the terms "CAPEX" refer to the initial investment expenditures related to the deployment of network infrastructure and equipment [17], [36], [45]. It covers charges for things like buying software and hardware, finding a location, setting it up, and configuring it [17], [36], [45]. The cost of small cell base stations (SCBs) and associated equipment required for network coverage and capacity inside event venues is included in the small cell hardware (SCH) category [17], [36], [45]. The cost of cloud servers used to process and provide immersive video content at central or edge cloud facilities is covered by cloud server hardware (CSH) [17], [36], [45]. Licensing for immersive video service platforms, network management software, and operating systems [17], [36], [45]. This accounts for the cost of backhaul connections to the core network and fronthaul links connecting SCBs to cloud servers [17], [36], [45].

$$\text{CAPEX} = \sum_{i=1}^{T} \sum_{j=1}^{N_i} N_j^i \cdot (c_{\text{SCH}} + c_{\text{SSW}} + c_{\text{SL}} + c_{\text{CSH}} + c_{\text{CSW}} + c_{\text{FLF}}) \cdot (1 + I_j)^{(i-1)} \tag{4.1}$$

where:

i = Year in the study period, ranging from 1 to T

j = CAPEX item (SCH, SSW, SL, CSH, CSW, BFL), ranging from 1 to N_i, where N_i is the number of items (investments) in year i

N_j^i = Number of item j required in year i

c_{SCH} = Cost of a Small Cell Basestation unit

c_{SSW} = Cost of Small Cell software

c_{SL} = Cost of Small Cell license

c_{CSH} = Cost of a cloud server unit

c_{CSW} = Cost of cloud server software

c_{FLF} = Cost of fiber optic cable and related infrastructure per item j in year i

I_j = Yearly price inflation for item j

T = Total study period

B. Operational Expenditure

Every year, the Operating Expenditure (OPEX) is computed. The OPEX expenditure for each year is added to determine the total accumulated OPEX [17], [36], [45]. Among the OPEX elements taken into account in the analysis are:Every year, the Operating Expenditure (OPEX) is computed. The OPEX expenditure for each year is added to determine the total accumulated OPEX [17], [36], [45]. Among the OPEX elements taken into account in the analysis are [17], [36], [45]:

i. OAM (operations, administration, and maintenance) cost

This covers all of the costs related to overseeing and preserving the network infrastructure, such as employee wages, training, supplies, and software programs for network administration, monitoring, and troubleshooting [36], [45].

ii. Annual Energy Cost

This includes the cost of powering the network equipment, such as small cell base stations, cloud servers, and associated infrastructure [36], [46]. It takes into account electricity consumption, utility charges, and any backup power solutions [36], [46].

1. Compute the total power consumption of all power-consuming network elements:
    - Create a list of power-consuming network elements, denoted by i [6].
    - For each network element i, multiply its power consumption P_i by the number of such elements n_i.
    - Sum up all these individual power consumptions to obtain the total power consumption P_T [6].
2. Calculate the annual energy consumption:
    - Divide the total power consumption P_T by 1000 to convert it from watts to kilowatts.
    - Multiply the result by the number of hours per day ($Hrs/Days$) and the number of days per year ($Days/Years$) to get the annual energy consumption E_T in kilowatt-hours (kWh).
3. Determine the annual energy cost:
    - Multiply the annual energy consumption E_T by the cost of energy per kilowatt-hour (C_KWH) to obtain the annual energy cost C_E.

The formulas involved are as follows:

$$P_T = \sum_i (P_i \cdot n_i) \tag{4.2}$$

$$E_T = \left(\frac{P_T}{1000}\right) \cdot \left(\frac{Hrs}{Days}\right) \cdot \left(\frac{Days}{Years}\right) \tag{4.3}$$

$$C_E = E_T \cdot C_K WH \tag{4.4}$$

Make sure to substitute the appropriate values for P_i, n_i, $Hrs/Days$, $Days/Years$, and C_KWH in the actual calculations to obtain the accurate annual energy cost [6].

iii. Annual Site Rental Costs

This refers to the cost of leasing or renting physical locations for deploying small cell base stations or other network infrastructure. It includes fees paid to property owners or authorities for site access and usage [6].

$$C_{SR} = \sum_{i=1}^{T} (N_j^i \cdot C_{SC} \cdot C_{CS}) \tag{4.5}$$

Where:

- j is a list of rental items, such as cell sites or radio towers, and cloud server racks.

- N_j^i is the number of item j in year i.
- C_{SC} is the rental cost of a cell site.
- C_{CS} is the rental cost of the server rack per cabinet in year i.
- T is the study period, indicating the number of years under consideration.

To calculate the annual site rental costs, you need to sum up the product of the number of rental items, the rental cost of a cell site, and the rental cost of the server rack per cabinet for each year [6].

Make sure to substitute the appropriate values for N_j^i, C_{SC}, C_{CS}, and T in the actual calculations to obtain the accurate annual site rental costs.

iv. Capacity Upgrade Costs

This includes the costs associated with scaling up the capacity of the network to meet increasing demand. It covers expenses such as upgrading hardware, adding small cell units, or expanding network resources.

The cost of upgrading the baseband capacity (C_{UP}) of the network per year is calculated as follows:

$$C_{UP} = \sum_{i=1}^{T} \left(N_j^i \cdot C_{Up}^i \right) \tag{4.6}$$

Where:

- j is a list of the small cell hardware items required to be installed, such as small cell units and cloud servers.
- N_j^i is the number of small cell processing hardware items j required to be installed.
- C_{Up}^i is the cost of the upgrade for item j in year i.
- T is the study period, indicating the number of years under consideration.

To calculate the capacity upgrade costs, you need to sum up the product of the number of small cell hardware items, the cost of the upgrade for each item, for each year [3], [6].

Make sure to substitute the appropriate values for N_j^i, C_{Up}^i, and T in the actual calculations to obtain the accurate capacity upgrade costs.

v. Annual Fiber Lease Cost

If the network deployment involves leasing fiber optic infrastructure for backhaul or connectivity purposes, the annual fiber lease cost (C_{FL}) can be calculated as follows:

$$C_{FL} = \sum_{i=1}^{T} \left(N_i \cdot C_{FL}^{i} \right) \tag{4.7}$$

Where:

- N_i is the number of sites in year i.
- C_{FL}^{i} is the annual fiber lease in year i.
- T is the study period, indicating the number of years under consideration [6].

To calculate the annual fiber lease cost, you need to sum up the product of the number of sites and the annual fiber lease cost for each year.

Make sure to substitute the appropriate values for N_i, C_{FL}^{i}, and T in the actual calculations to obtain the accurate annual fiber lease cost.

vi. HW & SW Maintenance Cost

This encompasses the expenses related to hardware and software maintenance. It includes costs for repairing or replacing faulty equipment, software licenses, updates, and patches [5].

The HW & SW maintenance cost (C_{HWi} and C_{SWi}) can be calculated as follows:

$$C_{HWi} = \sum_{i=1}^{T} (N_{HW}^{i} \cdot C_{HW}^{i}) \tag{4.8}$$

$$C_{SWi} = \sum_{i=1}^{T} (N_{SW}^{i} \cdot C_{SW}^{i}) \tag{4.9}$$

Where:

- N_{HW}^{i} is the number of hardware items in need of maintenance in year i.
- C_{HW}^{i} is the cost of hardware maintenance per item in year i.
- N_{SW}^{i} is the number of software licenses or instances in need of maintenance in year i.
- C_{SW}^{i} is the cost of software maintenance per license or instance in year i.
- T is the study period, indicating the number of years under consideration [3].

vii. Calculating Total OPEX

The specific values and calculations for each OPEX component would require detailed cost data, market prices, and information specific to the case study. To estimate the OPEX for each year and calculate the total accumulated OPEX over the study period, you can use the following formula:

$$OPEX = \sum_{i=1}^{T} \left((c_{\mathrm{OMA}i} + c_{\mathrm{E}i} + c_{\mathrm{SR}i} + c_{\mathrm{HW}i} + c_{\mathrm{SW}i} + c_{\mathrm{UP}i} + c_{\mathrm{FL}i}) \cdot (1 + P_i)^{(i-1)} \right) \tag{4.10}$$

Where:

- i represents the year in the study period.
- T represents the total study period.
- c_{OMAi} is the cost of operation, administration, and maintenance in year i.
- c_{Ei} is the cost of energy in year i.
- c_{SRi} is the cost of site rent in year i.
- c_{HWi} is the cost of hardware maintenance in year i.
- c_{SWi} is the cost of software maintenance in year i.
- c_{UPi} is the cost of capacity upgrade in year i.
- c_{FLi} is the cost of fiber lease in year i.
- P_i is the yearly price inflation rate for item i.

C. Total Cost of Owenership (TCO)

The Total Cost of Ownership (TCO) covers both the Capital Expenditure (CAPEX) and Operating Expenditure (OPEX) [5]. The formula for TCO is given by:

$$\mathrm{TCO} = \sum_{i}^{T} \mathrm{CAPEX}_i + \mathrm{OPEX}_i \tag{4.11}$$

Where:

CAPEX_i is the total CAPEX in year i,
OPEX_i is the total OPEX in year i,
T is the study period.

4.2.2 Revenue Model Analysis

Developing a revenue model for immersive video access involves considering various factors such as user subscriptions, content partnerships, service packages, pricing strategies, and their impact on user adoption [3], [6], [12], [14]. User subscriptions offer a recurring revenue stream based on regular payments from subscribers. Pricing strategies can include tiered subscription plans (e.g., basic, standard, premium) with different levels of access and features. Discounts or incentives for longer subscription commitments can encourage user retention [12]. Content partnerships involve collaborations with content creators or providers to offer exclusive or premium content. Revenue can be generated through revenue-sharing agreements or licensing fees. High-quality and unique content can attract more subscribers and differentiate the platform in the market [12].

Service packages bundle different services or features together for users to choose from. This can include access to additional content, premium features, or personalized experiences. Tiered pricing for service packages allows catering to different user segments and maximizing revenue potential [3].

Various pricing strategies can be employed to optimize revenue and user adoption [14]:

- **Freemium Model:** Offering a basic version of the service for free with the option to upgrade to a premium subscription for access to advanced features or content.
- **Tiered Pricing:** Offering multiple subscription tiers with different pricing and features to appeal to different user segments.
- **Usage-Based Pricing:** Charging users based on their usage of the service, such as pay-per-view or pay-per-download models.
- **Discounts and Promotions:** Offering discounts, promotions, or bundle deals to attract new subscribers or encourage existing ones to upgrade their subscription.

Average Revenue Per User (ARPU) is calculated as the total revenue generated divided by the number of subscribers. ARPU provides insights into the average spending or contribution of each user to the overall revenue of the service. It can be monitored over time to track revenue trends and evaluate the effectiveness of pricing strategies and revenue models [3], [6], [14].

$$\text{ARPU} = \frac{\text{Total Revenue}}{\text{Number of Subscribers}} \tag{4.12}$$

Market Share (MS) represents the portion or percentage of the total market that a specific provider holds. It can be calculated based on revenue or other relevant metrics such as the number of subscribers. Monitoring market share helps assess the competitive position and relative size of the platform compared to its competitors [6].

$$\text{Market Share (\%)} = \left(\frac{\text{Revenue of the Provider}}{\text{Total Market Revenue}} \right) \times 100 \tag{4.13}$$

Alternatively, market share can be calculated based on the number of subscribers or other relevant metrics [6], [14].

In conclusion, developing a revenue model for immersive media access requires careful consideration of user subscriptions, content partnerships, service packages, pricing strategies, ARPU, and market share. By analyzing these factors and continuously monitoring performance metrics, the platform can optimize revenue generation and enhance user adoption [6].

A. Performance Evaluation Metrics

Applying the principles of cash flow (CF) and discounted cash flow (DCF) provide valuable insights into the financial feasibility of deploying cloud-enabled small cell networks for immersive media services at crowded events in Addis Ababa [6], [14].

I. Cash Flow (CF) Formula (adjusted for immersive media revenue): The CF formula adjusted for immersive media revenue is given by:

$$\text{CF} = \sum_{i}^{T} (\text{Immersive Media Rev}_i - \text{Network TCO}_i) \tag{4.14}$$

Where:

T : Represents the time period or year in consideration.

Immersive Media Rev_i : generated from immersive media services at events in year i.

Network TCO_i : Total Cost of Ownership for the network infrastructure in year i.

II. Discounted Cash Flow (DCF): The discount rate represents the rate of return or the cost of capital required for an investment. To incorporate the discount rate into your formula, you would discount each cash flow from each year (CF_i) using the appropriate discount rate (r) [6], [14].

The discounted cash flows can be calculated using the formula [14]:

$$\text{DCF}_i = \frac{CF_i}{(1+r)^i} \tag{4.15}$$

Where:

DCF_i represents the discounted cash flow in year i,

CF_i represents the cash flow in year i,

r represents the discount rate,

i represents the time period or year[14].

Once you have calculated the discounted cash flows for each year, you can sum them up to determine the net present value (NPV) of the cash flows over the given time period. Alternatively, if you want to calculate the discounted cash flow (DCF) for the entire cash flow series, you can apply the discount rate to the total cash flow (CF) rather than individual cash flows [6], [14]:

$$\text{DCF} = \frac{CF}{(1+r)^n} \tag{4.16}$$

Where:

DCF represents the discounted cash flow for the entire cash flow series,

CF represents the total cash flow,

r represents the discount rate,

n represents the number of years or time periods[6], [14].

4.2.3 Netpresent Value (NPV), Internal Rate of Return (IRR), Payback Period (PP) and Return on Investment (ROI) for a Cloud-Enabled Small Cell

Calculating NPV, IRR, PP, and ROI for a cloud-enabled small cell project involves several steps [14], [33]. The first step is to gather all the relevant data, including the investment required, the expected cash flows over the project's life, and the cost of capital [14], [33]. The second step is to use a planning model that incorporates the IST-TONIC and CELTIC-ECOSYS methodologies to estimate the project's cash flows and cost of capital [14], [33].

A. Net Present Value (NPV)

The NPV is the difference between the present value of all the project's cash inflows and the present value of all the project's cash outflows [14], [33]. It helps to determine the project's profitability and whether it is worth investing in or not. To calculate NPV, you can use the following formula [14], [33]:

$$\text{NPV} = \sum_{t=1}^{T} \frac{CF_t}{(1+r)^t} - C \tag{4.17}$$

Where CF_t is the expected cash flow in period t, r is the cost of capital, and C is the initial investment.

B. Internal Rate of Return (IRR)

IRR is the discount rate at which the present value of the project cash inflows becomes equal to the present value of the project's cash outflows [45]. It helps in judging the profitability of the project, which is compared with the required rate of return [14], [45]. One can compute IRR as:

$$\text{NPV} = \sum_{t=1}^{T} \frac{CF_t}{(1+\text{IRR})^t} - C = 0 \tag{4.18}$$

Where CF_t is the expected cash flow in period t, and C is the initial investment [14], [46].

C. Payback Period (PP)

The PP is the time required for the project to generate enough cash flow to recover the initial investment [33]. It helps to determine the project's risk and liquidity. To calculate PP, you can use the following formula [14], [33]:

$$\text{PP} = \frac{\text{Initial Investment}}{\text{Annual Cash Flow}} \tag{4.19}$$

D. Return on Investment (ROI)

The ROI is the ratio of the project's net profit to its initial investment. It helps to determine the project's profitability and efficiency. To calculate ROI, you can use the following formula [14], [33]:

$$\text{ROI} = \frac{\text{NPV} + C}{C} \tag{4.20}$$

Where NPV is the net present value and C is the initial investment.

Chapter 5

Case Study and Scenario Analysis

Ethiotelecom is the leading operator, according to Ethio telecom 2023/2024 Annual Business Performance Report with over 78.3 million subscribers [8]. The technologies used include 3G, 4G, and, in some places, limited 5G coverage [8]. Because of the growth in smartphone penetration and consumption of mobile data, data traffic has grown rapidly.

This section discusses a case study that utilises the proposed business feasibility framework. In the case study, we estimate the overall cost of building up and maintaining a mobile network with a 10-year network lifecycle using cloud-enabled small cell networks to deliver immersive media services at crowded events. Meskel Square and suruonding is a 4-km-square (2 km x 2 km) service area in Addis Ababa, Ethiopia, and is considered for this case study. A case study on various strategies of deployment and different approaches toward immersion media service network planning using cloud-enabled small cells in Meskel Square in Addis Ababa, Ethiopia is considered here. The areas such as Ghion Hotel, Stadium, Exhibition Centre, Meskel Square, and busy streets around Meskel Square [21].

Meskel Square is in practice, it is uses for exhibitions, bazaars, markets or vendors offering everything from fresh produce, household items, to souvenirs and second-hand goods. Events also include religious and public outdoor events, among others, such as the Meskel-Demera Religious Festival, which has been recognized by UNESCO as part of the world's intangible heritage [21].

There is an already deployed LTE network in the area. An LTE advanced 10-site, 30-macro cell network has also been deployed in that area; their locations are shown in purple color below Figure. It shows the position of the current site within the study area, there are 10 macro base stations in the research region, each having three sectored antennas [21].

5.1 An Influential Video Use Case Scenarios for Immersive Media Services

1. **Big Concerts**:

   Density and Movement: High density around the stage, with occasional users moving for refreshments, restrooms, or merchandise. In the case of video broadcasting or AR overlay applications, during large performances, traffic peaks are around 5–10 Mbps per user [14].

   Traffic Spikes: For high-quality video streaming or AR overlays, traffic spikes happen during major performances and peak at roughly 5–10 Mbps per user.

2. **Sports Events**:

   Distribution of Users: The users will be more uniformly distributed across the square. Hotspots near concession stands or entryways. The traffic patterns are expected to increase during plays and goals by as much as 1–5 Mbps per user for interactive gaming or live video streaming during spikes in activity [14].

   Traffic Patterns: During plays and goals, traffic patterns are expected to see spikes in activity that could approach 1–5 Mbps per user for interactive gaming or live video streaming [14].

3. **Religious Gatherings**:

   Crowd Densities and Focus Points: Crowd density at specific rituals or congregations may be highest, and the traffic would be concentrated around the religious altars or hotspots. For text updates and low-level communication, data rates may be as low as 0.5–1 Mbps, while for live sermons or religious education programs, it could go as high as 1–10 Mbps [14].

   Data Rate Requirements: For text updates and simple communication, data rate requirements could be as low as 0.5-1 Mbps, or as high as 1–10 Mbps for live sermons or educational programs [14].

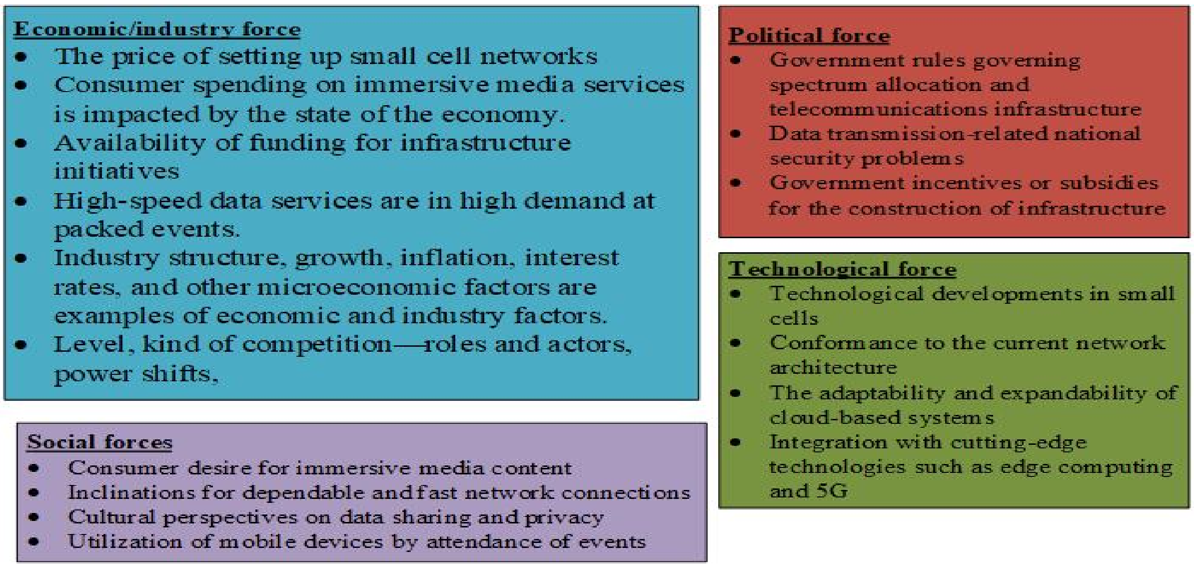
Besides, it is possible for the organizers to project on the big central screen a collage of live movies captured by the audience. In these situations, there is great demand for services that enable customers to watch movies on their smartphones or tablets at any time, such as those offered for instance by Stadium. Another creative aspect that sets apart users from a usual video content context is the urge to share their creations with other users since they are creators and consumers of the video content [3]. Technically, this kind of service needs a networking infrastructure capable of uploading and downloading big-sized files, such as HD films, extremely fast. Moreover, it should handle video streams with remarkable efficacy in order to provide good services.

5.1.1 Scenario Planning Process

One of the ways to look into, assess, and manage the uncertainties along with the disruptive impact of future technology is through the process called scenario planning [32], [48]. The telecom industry has identified and applied a strategic method for scenario planning successfully [32], [48]. Scenario planning was a good application to integrate the trends and uncertainties to build the alternative futures because the cloud-enabled small cell networks represent a new paradigm in the network architecture [32], [48].

In relation to Addis Ababa, Ethiopia, this is to develop and analyze the deployment of cloud-enabled small cell network deployment scenario for immersive media service provisioning at crowded events, that requires a range of data sources from Ethio-telecom documents, reports and strategies, related works of literature, standards, and also expert opinions, which are assessed in [32], [48].

The PEST (political, economic, social, and technological) identified the Cloud-Enabled Small Cell Network Deployment Scenario for Immersive Media Service Provisioning at Crowded Events of the mobile network, and the forces that could affect it in the future were written on Post-it notes [32], [48]. The key phrases of each aspect of PEST framework were decided [32], [48].



Economic/industry force
- The price of setting up small cell networks
- Consumer spending on immersive media services is impacted by the state of the economy.
- Availability of funding for infrastructure initiatives
- High-speed data services are in high demand at packed events.
- Industry structure, growth, inflation, interest rates, and other microeconomic factors are examples of economic and industry factors.
- Level, kind of competition—roles and actors, power shifts,

Social forces
- Consumer desire for immersive media content
- Inclinations for dependable and fast network connections
- Cultural perspectives on data sharing and privacy
- Utilization of mobile devices by attendance of events

Political force
- Government rules governing spectrum allocation and telecommunications infrastructure
- Data transmission-related national security problems
- Government incentives or subsidies for the construction of infrastructure

Technological force
- Technological developments in small cells
- Conformance to the current network architecture
- The adaptability and expandability of cloud-based systems
- Integration with cutting-edge technologies such as edge computing and 5G

Figure 5.1: Main factors in scenario planning process

For instance, uncertainties in possible regulatory changes - such as spectrum allocation policies, data privacy laws, or government limitations on putting up telecommunications infrastructure may significantly impact the viability and cost of small cell network deployment [32]. Regulatory changes may involve changing the way data is handled, deployment schedules, and license requirements, among other business considerations, and have the potential to impact investment decisions and project timelines[32]. Regulatory uncertainty can be addressed by being updated on changing regulations, interacting with the regulating bodies, and using adaptive deployment techniques. Further, collaboration with industry groups and main stakeholders will help prepare for regulatory developments upfront and reduce potential risks from regulatory ambiguity [32], [48].

5.1.2 Hyper-Connected Event Experience

In these regards, large-scale and crowded events, like music festivals, sports competitions, and cultural events have recently become more and more frequent in large capital city [32], [48]. With the growing numbers of participants and remote spectators asking for immersive video services of high quality including live streaming, augmented and virtual reality experiences [32], [48].

A. Key Drivers:

I. Rapid Technological Advancements: The exciting development in immersive media, small cell networks, and cloud computing technologies has enabled the provisions for high-bandwidth, low-latency services today [32, 48]. Moreover, full deployment and uptake of 5G technology will ensure a change in network capabilities that could potentially further enhance the immersive video experience during an event like this one due to much lower latency and faster speeds [32, 48]. While edge computing brings the processing closer to the source, thereby reducing latency and increasing efficiency, it is useful in immersive video applications for crowded areas. The increasing number of IoT device deployments in events further stresses network infrastructure; hence, robust connectivity options are needed to support these events for seamless data transfer.

II. Growing Need for Immersive Experiences: There is an increasing need for media to provide immersive experiences, improving the way people engage in and enjoy events [48]. This change in demand for options of remote access to immersive media services due to the recent rise in working from home and virtual events caused by global catastrophes like pandemics might also influence deployment strategies [33], [48].

III. Increasing Event Attendance: Addis Ababa is growing into a hub for national and international events that attract large audiences [32], [48]. Increased utilization of AR and VR for communication and entertainment may raise demand for high-bandwidth low-latency networks in events that attract large audiences [32], [48].

B. Developed Scenarios:

I. Status Quo: High-demand application scenarios, such as poor network performance, infrequent or not-at-all connectivity, and an immersive media experience that is far from optimal, are caused by the inability of current network infrastructures to cope with spikes in data traffic of thousands of users attending concurrent events.

A cloud-enabled small cell network is deployed solely for managing massive data requirements in highly crowded events [32, 48]. To provide scalable capacity and low latency connectivity, the architecture of the network has been updated with additional numbers of small cell towers amalgamated with the capacity of cloud computing [32, 48].

C. Scenario Analysis: The techno-economic analysis then has to focus on the cost-benefit and feasibility assessment of each scenario [32]. Some of the parameters to look at would include infrastructure deployment cost, operational expenses, revenue opportunities from immersive video services, user satisfaction, and scalability of network infrastructure [32], [48].

I. Collaborative Network Partnership: Network operators can collaborate with content providers in order to offer immersive media experiences that will attract larger crowds and more revenues [32], [48]. The investment in a Cloud-Enabled Small Cell Network can be done by network operators and event organizers together for large events, which can ensure reliable and high-quality immersive video services [32], [48].

II. Monitoring and Review: Regular checks of the techno-economic analysis, network performance, user feedback, and market developments are necessary to ensure the effectiveness and adaptability of the chosen approach[32], [48]. It also makes modifications based on the evolving nature of technology, the needs of users, and the technical architecture and processes that are already in place [32], [48].

Tag	Description
T1	Differentiated QoS/QoE mobile services will become more and more necessary.
T2	In the CESC for IMS area, concept testing and development cycles can be accelerated by the use of software-defined ideas and commodity hardware.
T3	Globalization of Mobile Network Operators (MNOs) using CESC for IMS can be facilitated by the adoption of more centralized frameworks and control in the telecommunications industry.
T4	The massive capacity potential of cloud growth plays a vital role in creating a more efficient mobile market, including CESC for IMS.
T5	Real-time multiplayer gaming will be played in more games.
T6	The mobile market will be more impacted by worries about information privacy, including identification and usage patterns.
T7	There will be an increase in the number of users on the CESC network.
T8	Due to declining or nonexistent margins, all of the key players in the mobile market need to find other ways to make money.
T9	How easy it is to introduce new service.
T10	There are new, unseen players getting powerful, like NEPs. These players are not visible to end users.
T11	More and more device makers will turn into cloud integrators.

Table 5.1: Key Trends in Mobile Services

T1: As cloud enabled small cells (CESC) for immersive video services (IVS) become more common, QoS and QoE in mobile services will matter more [33], [48]. CESC makes small cell deployment more scalable and efficient which means better network coverage and capacity [33], [48]. But this also means a lot of mobile services can be offered, each with different QoS requirements [33], [48]. These services can be mission critical IoT applications, low latency gaming and high definition video streaming [33], [48]. Although the benefits are clear, don't forget the challenges, because they will impact the user experience big time [33], [48].

T2: The use of software-defined ideas and commodity hardware can reduce concept testing and development cycles in the CESC for the IMS area [33],[48]. With widely available commodity hardware, agile prototyping and testing of new services and features are enabled by combining notions of NFV and SDN. The approach is less costly and less inflexible compared to traditional solutions based on hardware [33],[48].

T3: Centralized frameworks and control in the field of telecommunications may provide a better method for globalization of MNOs using CESC for IMS [32]. Centralized frameworks allow MNOs to efficiently build up their networks and services in different geographical regions by providing standardized architectural and management systems [32]. MNOs may apply centralized control to reach economies of scale, optimization of operations, and consistently high service quality in a more and more global environment [32].

T4: What is fundamental to the development of an effective mobile market, inclusive of CESC for IMS [32], is the huge capacity potential of cloud growth. Cloud technologies provide effective use of network resources, scalability, and dynamic resource allocation. With the huge capacity, MNOs can provide high-quality services that cut costs and network utilization, improving general performance and efficiency in mobile networks [32], [48].

T5: The use of real-time multi-player gaming would, in relation to CESC for IVS, increase. When applied together with other technologies, such as 5G, which enhance the performance of the network, the low latency and high bandwidth capabilities of CESC create an ideal context for mobile multi-player gaming. This follows the rising demand for immersive and interactive gaming experience and also the increasing popularity of mobile gaming [32], [48].

T6: The information privacy issues related to identity and usage habits will continue to impact the mobile market including CESC for IMS. Sensitive user data handling by mobile networks has brought increased concentration on user consent, data security, and privacy laws [33], [48]. In order to overcome such issues and retain customer confidence, safe data processing, open privacy policies, and firm security measures on the part of mobile operators and service providers should be given a high priority [33], [48].

T7: The number of users on the 5G network is probably going to increase as CESC for IMS is adopted more widely [33]. CESC makes it possible to deploy small cells more effectively, increasing network capacity and coverage. IMS user numbers are growing as a result of this expansion as well as the growing need for mobile connectivity, the emergence of IoT applications, and the increased use of smartphones [33], [48].

T8: Main companies in the mobile market, like those in CESC for IMS, must look into other revenue streams because traditional mobile service margins are either dropping or nonexistent. This entails broadening the range of services they provide, including enterprise solutions, content partnerships, value-added services, and data insights monetization [33]. It becomes imperative to identify novel revenue streams in order to maintain profitability in the highly competitive and dynamic mobile market [33], [48].

T9: The ease with which new services can be brought on board in the context of IMS for CESC will depend upon a few factors, including but not limited to the rate of consumer uptake, market competitiveness, technological maturity, and legal restrictions [48]. While aspects of compatibility, interoperability, and integration with existing networks and systems during new service introductions remain valid, the infrastructure provided by CESC is better equipped to adapt and scale [48].

T10: Network Equipment Providers (NEPs) are an example of an emerging player who is becoming increasingly important in the mobile business, most especially when CESC for IMS is considered [48]. While they may be invisible to end users, they do play a very important role in providing tools, equipment, and infrastructure that are necessary in the deployment of CESC. NEPs are pivotal to the growth and development of the mobile market by working with MNOs and other industry players in the installation of reliable and efficient mobile networks [48].

T11: Regarding CESC for IMS, with the advancement of cloud technologies, it is expected that more device manufacturers will finally turn into cloud integrators. Cloud platforms and services will allow device manufacturers to embed features like cloud-based, remote management, and synchronization operations into their devices [33], [48]. It will also provide consumers with more connected and seamless [33], [48].

U1: Market rules, number of companies that constitute the market, speed of technological improvement. It is difficult to forecast the level of competition without knowledge of market dynamic specifically [32] and [48].

U2: Virtualization of CESCs brings enormous cost benefits for the mobile operators. An operator can achieve more operational effectiveness with virtualization and cloud technologies: a reduction in hardware costs and better utilization of resources. However, actual cost-savings depend on parameters such as deployment size, network design, and utilization of the technology [32], [48].

U3: Virtualization of CESC mobile networks can facilitate entry into the industry from new players, such as software developers and CloudSPs. Owing to the elasticity and scalability of virtualized networks, it is relatively easy to create and deploy new services and applications, which will in turn promote competition and entry of new firms in the

Question ID	Question
U1	Will there be a high or low level of competition in the mobile market?
U2	Will the virtualization of CESC result in significant cost savings?
U3	Will new businesses like software developers and CloudSPs be able to enter the market as a result of the virtualization of CESC mobile networks?
U4	How many NEPs, software developers, or IT suppliers would be left in the future to provide mobile infrastructure and technical support?
U5	Will the IMS mobile sector be dominated by a small number of MNOs?
U6	Who will invest in the newest virtualization technologies: MNOs or NEPs?
U7	Will the MNOs stick to providing mobile services or expand into offering Internet service that is largely provided internally?
U8	Will MNOs have the freedom to easily swap frequencies as needed?
U9	Who will rule the mobile industry?
U10	Do NEPs stand a better chance of creating CESC?

Table 5.2: User Questions about the Mobile Market

ecosystem that supports the mobile market [32], [48].

U4: The positioning of NEP, software engineers, and IT vendors in the future mobile infrastructure and technical support cannot be forecasted. The industry would wear a different look in case of advancement or any other form of technological evolution; there could be mergers, consolidation, and even new entrants into this industry. The number of participants will vary depending upon varying market demands, technology development, and chosen commercial strategies by the industry participants [32], [48].

U5: Depending on the IMS mobile market and region, this could be dominated by just a few MNOs. The market share totally depends on the choice of consumers, the rivalry, or the boundaries in the market regarding MNOs [33].

U6: Network equipment providers (NEPs) NEPs want to, and MNOs need the latest virtualization technology [32]. To extend the mobile networks services and capabilities, MNOs have to implement new technology. Due to the emerging demands of MNO and the market, the NEPs invest in their research and development activities to provide state-ofthe-art virtualization technology as a network equipment and solution providers [32], [48].

U7: The regulatory environment, together with market conditions and strategic business decisions, may be the controlling factors that determine whether MNOs can expand their business into the provision of internet services. Some MNOs may choose to operate mainly in the mobile platform, whereas some may choose to expand and venture into the industry of internet service provision [32]. Their decision will depend upon the different MNO strategies and the market situation of the area in question [48].

U8: The regulatory framework, availability of the spectrum, and agreements among operators may be critical in determining how easily the frequencies can be switched by an MNO. While the MNO might be allowed to change frequency freely in a given situation, other situations could have restrictions or legal implications to be considered [32], [48].

U9: Owing to the dependence on a set of variables such as customer preference, strategies of competition, technical breakthroughs, and dynamics of the market, it is hard to say who will be the achiever of this, whether which company will dominate the mobile industry in future. Since the nature of the mobile market is quite dynamic, subject to sudden changes, identification of single player which would rule the whole sector is quite tough [32], [48].

U10: The NEPs are likely to develop CESC solutions if they employ knowledge about technologies and network architecture [33]. They can develop and provide hardware, software, and integration skills needed for CESC deployment [33]. Marketplace performance will be influenced, though, by a set of factors like competition, market demand, technology advancement, or the attitude followed towards collaboration with the other participants [33].

D. Correlation Matrix

A correlation matrix is an instrument for identifying the interaction between each of the uncertainties. Since it is necessary to construct the final scenario matrix with two independent uncertainties, the correlation matrix is handy to verify conformance of the chosen uncertainties [33]. As shown in Table , a “yes” answer of an uncertainty (for example U2) increased the chance of a “yes” answer for the other uncertainty (for example U10) [33]. Furthermore, the selection of the former viewpoint of an uncertainty (for example U1) increased the happening chance of the former viewpoint of the other uncertainty (for example U10) [33], [48]. In both cases, the symbol “+” will be filled in the form and the correlation is identified to be positive between the chosen pair of uncertainties. The symbol “0” indicates two of uncertainties are independent with each other [48]. Symbol “?” is used to represent the indeterminate relationship between the chosen pair of uncertainties [33], [48]. The negative correlation (-) exists between two uncertainties in other situations. The independent uncertainties such as U1 and U2 can be formed as a pair and be used to build final scenario matrices [33], [48]. Final key uncertainties U1 and U2 are chosen to construct the final scenario matrix, while other important uncertainties will support the analysis of each scenario based on the results in correlation matrix as follows [33], [48].

	$U1$	$U2$	$U3$	$U4$	$U5$	$U6$	$U7$	$U8$	$U9$	$U10$
$U1$	X	0	+	−	?	−	?	−	0	0
$U2$		X	?	−	0	?	0	0	0	+
$U3$			X	−	0	−	+	−	0	+
$U4$				X	0	0	0	0	0	0
$U5$					X	0	0	0	+	0
$U6$						X	−	+	0	−
$U7$							X	0	0	0
$U8$								X	0	−
$U9$									X	0
$U10$										X

5.2 Network Architecture for the Use Cases

The concept of Cloud Enabled Small Cells (CESC) is a unit that combines SC and micro server in one entity but can also be extended to support other access network types [14], [17]. Mobile edge computing workloads might not be served with all RAM, CPU and storage on one micro server [14], [17]. A Light DC is, therefore, a large set of micro-scale execution infrastructure based on distributed data center design built on CESC clustering, which can significantly improve both the virtualization ability and the executing ability at the edge [14], [17]. Like any other DC, Light DC is a collection of resources (computational, storage, and network) tied together through a communication network [14].

A wired or wireless method could be applied and CESCs will be connected to a Light DC [14], [13]. There are sufficient IT resources available in the Light DC, including the necessary SC Virtual Network Function (VNF) [13]. This study is the one in Meskel Square, since this is one of the biggest and most capacious places to accommodate people, [14], [40]. There, a specific CESC infrastructure was deployed, combining connectivity with edge cloud computing functions, [11]. Aiming to carry the analysis one step further, we will present the adopted model of the CESC and the services offered to the customers during occasional CEs [11]. The CESC is a virtualized execution platform integrated with the IT resources [14], [17]. The SC forwards the SC PNF by using a dedicated interface, which is often a standard Gigabit Ethernet connection [14], [40]. The combined capabilities provided by the SC PNF and VNFs are where one can find the combined capabilities [14]. PNFs and SC VNFs are two kinds of SC functionalities that exist according to [14]. The design and features of the microserver will be for the MEC environment; it will host both SC VNFs and serviceVNFS [14]. For instance, service VNFs like virtual firewalls and caching will be instantiated in the CESC microserver to meet the identified 5G needs,

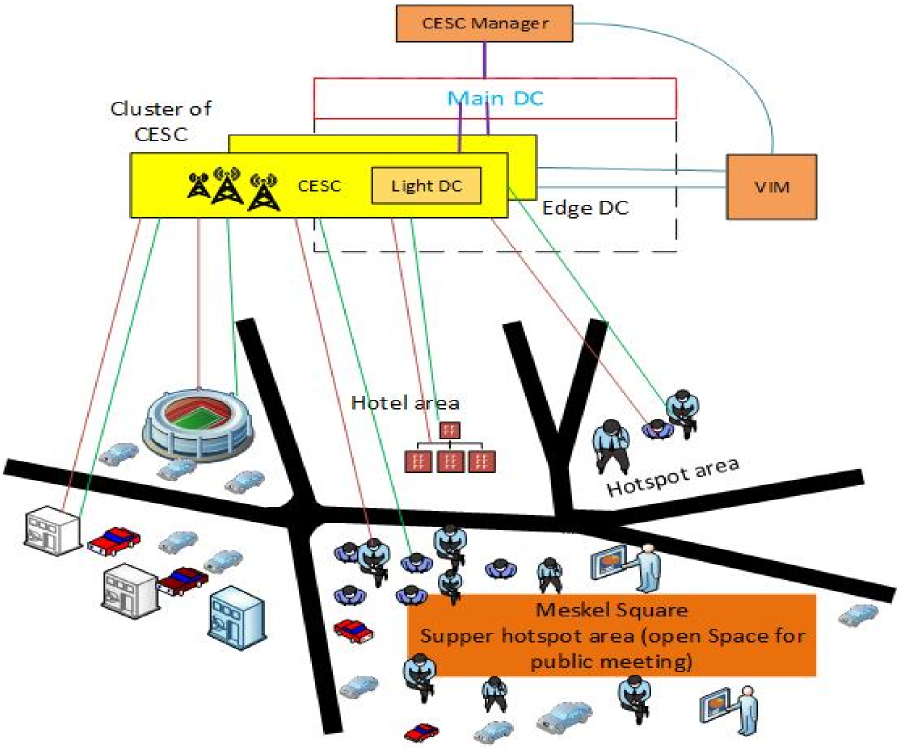


Figure 5.2: Overview of Use Cases in the Communication Ecosystem

such as low latency[14].

5.3 Demand Forecasting

Depending on the level of detail and data availability, demand forecasting can be performed using several methods, models, and frameworks [3]. One or more of these approaches can be applied based on the available data-historical trends, consumer preference, network expansion, etc.-for demand forecasting in immersive media services [3]. Other than this, immersive media services demand in Addis Ababa can be forecasted based on the growth of telecom infrastructure, event-driven opportunities, economic conditions, and consumer behavior of the city [3]. This enables a more accurate and local forecast that incorporates data from Addis Ababa's urban growth, technological readiness, and unique economic factors [3]. To do an Immersive video forecast, we need the following data and considerations [3].

1. Telecom and Internet Infrastructure.
2. Mobile and Internet Penetration .
3. Consumer Demographics and Behaviour.
4. Increased Urban Population and Smart City Initiatives.
5. Technological Readiness and Market Surveys.

6. Economic Factors and Price Sensitivity.
7. Use Cases of Immersive Media.

Addis Ababa is far more developed in terms of the infrastructure of telecommunication compared to other areas in the nation of Ethiopia. Immersive video services that call for high bandwidth with low latency are most likely to increase in growth much quicker in the metropolis than in rural regions, with better 4G coverage and an introduction of 5G in place (Ethio Telecom annual reports). Addis Ababa has a relatively high smartphone penetration rate and internet access compared to other cities in Ethiopia. These factors are critical for immersive video service demand because AR/VR and other immersive content are typically consumed through smartphones or high-end devices. Data on device ownership in Addis would improve the accuracy of your demand forecasts (National planning and development reports, reports from the Ministry of Innovation and Technology (MInT)). Addis Ababa's population is younger and more tech-savvy, with higher levels of disposable income compared to rural areas. This would imply a stronger potential demand for immersive video services. Conducting surveys or using consumer studies in Addis to measure interest in immersive experiences, like AR/VR for education, entertainment, or tourism, would provide valuable insights for demand forecasting (Central Statistical Agency (CSA) of Ethiopia, Addis Ababa urban demographic surveys, and consumer behavior studies). Addis Ababa is rapidly urbanizing, and the government is rolling out smart city initiatives that involve digitalization and the implementation of advanced ICT infrastructures. Forecasting immersive video demand should account for expected growth in urban population, infrastructure improvements, and smart city applications, which will likely accelerate the adoption of immersive services (Addis Ababa City Administration reports, UN Urbanization Reports, World Bank reports on urbanization in Ethiopia). Addis Ababa's readiness for new technologies, such as immersive media, depends on local adoption rates for technologies like 4G/5G and VR/AR-capable devices. Technology readiness indices and local market surveys focusing on Addis could provide a clear indicator of demand growth in these areas (Market research firms (e.g., Euromonitor, Deloitte reports on Africa's ICT market), tech adoption surveys from local organizations). The disposable income of Addis Ababa residents will directly affect how much they can spend on immersive media services. Economic reports can help model demand by factoring in price sensitivity and income levels specific to Addis Ababa. This paper utilizes a four-parameter logistic model for forecasting both the demand for subscriptions and the penetration of IMS (Immersive video Service). The logistic model is recommended for long-term forecasts and new services and is commonly used for fixed and mobile networks. (Economic reports from the National Bank of Ethiopia, Addis Ababa's household income and expenditure surveys). Addis Ababa frequently hosts large events that draw international audiences, which could drive short-term spikes in immersive media demand. For instance, immersive media services could be used for live-streaming in VR or AR-enhanced conference experiences. Consider using event data to model demand spikes during these periods (Government events calendar, tech and innovation fairs in Addis, large-scale events (e.g., international conferences, cultural festivals)).

Time series models like ARIMA (Auto-Regressive Integrated Moving Average) or Exponential Smoothing are used to forecast based on historical data of similar services, such as mobile internet usage and broadband adoption trends. This approach requires data over a period to predict future demand based on past patterns

The Bass Diffusion Model assumes that new users of a technology (such as immersive media services) are influenced both by innovators (early adopters) and imitators (those influenced by others' adoption). This model is commonly used for forecasting the adoption of new technologies. This model is valuable for predicting the growth rate of a new service like immersive media.

Econometric models link variables such as income levels, pricing, and demographic factors to forecast demand. These models are useful for demand forecasting of immersive media services by considering factors like consumer income and telecom prices.

Discrete choice models are particularly useful for immersive media demand forecasting by studying how consumers choose between various media services based on price, quality, and features. These models analyze consumer preferences and choices when they are faced with multiple service options.

Diffusion models are often developed for long-term subscription forecasts [14]. The models describe an S – shaped evolution with a long-term saturation level. Some relevant models are Logistic models, Bass models, Gompertz model, Fisher-Pry and Richard's model [14]. The two last one are special variants of the Logistic models. In the Fisher-Pry models are applied for long-term forecasting of many different telecommunication services [14]. The Logistic models are applied for long-term broadband forecasts [14]. The models are suitable for long-term forecasting and forecasting when the number of observations is limited [14]. Mobile broadband was introduced in the European market 2006/2007 [14]. Hence, number of yearly observations is limited [14]. A natural choice has been to apply diffusion models [14]. A suggestion here will be a four-parameter Logistic model [14].

The four-parameter logistic model is expressed as follows:

$$Y_t = \frac{M}{(1 + e^{\alpha+\beta t})^{\gamma}} \tag{5.1}$$

Where:

- Y_t: Accumulated demand at time t (as a percentage of the population)

- M: Saturation level (as a percentage of the population)
- t: Time (in years)
- α: Growth parameter (intercept term in the logistic growth equation)
- β: Growth rate parameter
- γ: Shape parameter affecting the curve's steepness

The four-parameter logistic model is commonly used to forecast long-term demand for new services and technologies. The model predicts the actual or forecasted demand, Y_t, at a given time, t, as a percentage of the total population.

The parameters α, β, and γ can be estimated using regression analysis based on historical market data.

The model works by assuming that the demand for a new service or technology will grow rapidly at first, an d then gradually slow down as it reaches saturation. The diffusion parameters control the shape of the growth curve. Estimate the demand saturation level (M) for the new service.

Estimate the diffusion parameters (α, β, and γ) using a regression analysis. This can be done using existing market data on the adoption of other new services. Use the model to forecast the demand for the new service at different time points in the future. Suppose, for example, an ethio-telecom intends to introduce a new IMS service in Meskel Square. It would want to forecast the subscription demand for this service over the next decade. Perform regression analysis using the collected market data to estimate parameters α, β, and γ. Use the logistic model equation with the estimated parameters to forecast the demand for subscriptions for each year over the next 10 years.

Chapter 6

Network Dimensioning

In the dimensioning of the 5G CESCN described in this paper, for every given deployment scenario, the number of small cells relies on several aspects such as coverage area and maximum data rate supported by a single small cell [12], [37]. The appropriate propagation model, frequency bands, user density, traffic demand bands, and network resources need to be cautiously selected in order to reach the optimum solution [12], [37], [62].

It includes cell range calculation, sector throughput calculation, and estimating network equipment quantity [12], [37], [62]. The output obtained in this phase will act as an input to TEA. It uses it for resource estimation and the cost of the network. The values obtained during this stage were two: one from coverage dimensioning, the other from capacity dimensioning [12], [37]. From the two outputs, the larger of the two numbers is used as the final output according to the dimensioning rule [12], [37]. The overall flow chart of the network dimensioning approach applied in this thesis is shown in Figure 6.1 [12], [37].

According to the radio planning strategy, the calculation of minimum number of small cells follows a worst-case planning approach [12], [36]. In other words, this strategy will take the largest figure obtained after considering the aggregate data rate of users in the area and the coverage area per small cell. It considers the worst case for a planning strategy that the capacity should be enough to handle the expected data rates and provide adequate coverage for the users inside the deployment area [12], [36]. Note that the detailed calculation method and parameters to come up with the number of SCs may be different based on the specifics of the planning study and the particular deployment scenario under investigation [12] [36], [62].

Coverage analysis: : This includes the estimation of the area that would be covered by the network of the CESC along with possible coverage holes or poor signal strength [12], [37]. The study lets the case in determining how many and where small cells are needed to create good coverage [12], [37]. It includes the number of the users to be expected along with types of applications that may be used such as voice, video, data, etc., and QoS expectations [12], [37].

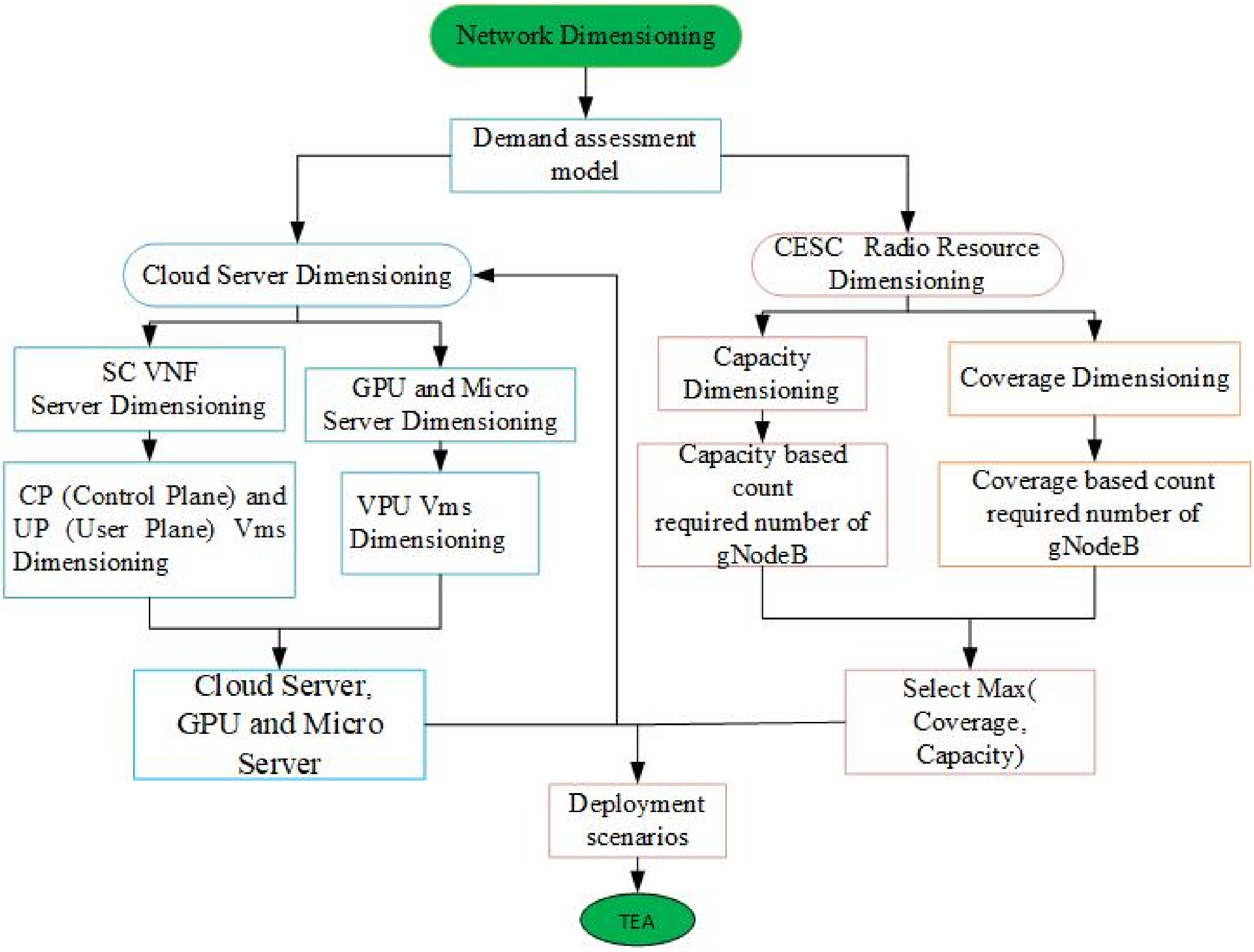


Figure 6.1: Cloud-enabled small cell Network Dimensioning Approach.

Capacity estimation: It determines the level of anticipated traffic demand within a network area. This will involve taking into account variables including population density, user behavior, and expected patterns in data usage [42]. The capacity estimation provides an indication of the number of small cells that will be needed to handle the amount of expected traffic. The elements involved include user density, traffic patterns, and interference levels [42].

Frequency planning: This involves the analysis of the available spectrum resources and proper selection of frequency bands for deployment. Proper frequency planning guarantees that the available frequencies are utilized efficiently while avoiding interference from neighboring cells [6]. Interference analysis: This includes analyzing the possible interference between small cells when these are in proximity to other cells or neighboring macrocells. Interference analysis allows for adjustments in the placement of cells and the configurations of antennas to minimize levels of interference [6].

Cloud and Virtualization Overhead: Consider the overhead introduced by the cloud and virtualization technologies while deploying the small cell functions in the cloud.

This shall include resource requirements for VMs, containers, and NFV components [6].

6.1 Cloud Enabled Small Cell Network Coverage Dimensioning

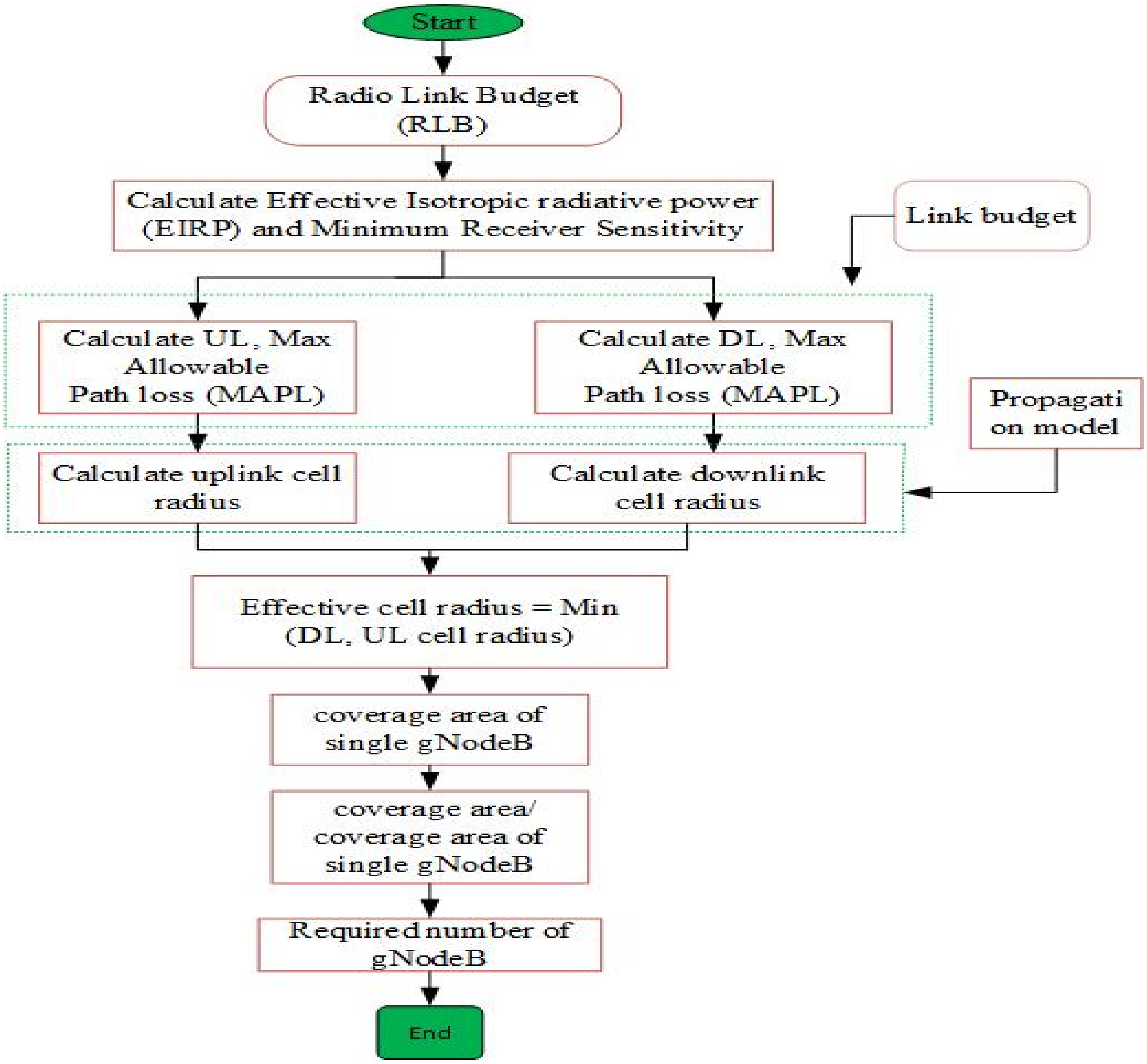


Figure 6.2: Cloud enabled small cell network coverage dimensioning flow chart.

The dimensioning of coverage begins with the calculations of the Radio Link Budget (RLB) as shown in Figure 6.2, which is in turn used to estimate the loss of the path for budgets for the radio connection DL and UL [6], [20], [42], [62]. By calculating the connection link budget, it is possible to estimate the maximum allowance of signal (loss of path) between UE and gNodeB antennas [20].

6.1.1 Propagation Model and Frequency Bands

Propagation models are usually mathematical algorithms that can predict real effective coverage area of a transmitter and its possible overlap with other transmitters, characterizing the propagation of radio waves as a function of frequency, distance, and other conditions [53], [54], [55]. Calculation of the data rate of uplink and downlink, in the context of 5G networks, involves parameters such as maximum bandwidth, number of PRBs, modulation scheme, and MIMO scheme [53], [54], [55].

A. Modeling Approaches

I. Ray-tracing models: The ray-tracing models are a propagation model that approximates the propagation of radio waves by tracing out the paths that rays take while traveling through an environment. They include reflection, diffraction, and scattering. They are quite accurate but, at the same time computationally intensive.

II. Empirical models: Created based on the measurement and statistical analysis of real-world scenarios. They are not as accurate as the ray-tracing models but are considerably faster to compute. Examples include the Okumura-Hata model and the COST 231 model [57].

III. Stochastic Models: These models describe random processes for the variation in signal strength across space and time. They are useful in predicting wireless network performance in highly dynamic environments [57], [58] .

MMWave communication stands as an essential technology for 5G systems operation. In urban Microcell (UMi) deployments, service providers utilize both LOS and NLOS conditions to assist coverage needs of urban streets [57], [58]. The 3GPP TR 38.901 technical standard defines mmWave frequency coverage from 0.5 GHz to 100 GHz. Through its framework, 3GPP TR 38.901 enables the simulation along with an assessment of mmWave channel properties under different environmental situations for optimized 5G network design. The combination of deterministic and stochastic simulation approaches enables engineers to maintain ideal performance and computational speed in their 5G system research [57], [58].

3GPP TR 38.901 defines the overall path loss, propagation, and channel modeling for 5G networks. Among the most important scenarios considered in the above recommendation is the Urban Micro model, UMi, relevant to very densely populated urban areas with street-level small-cell deployment [57]. In particular, this model has become of paramount importance for 5G deployments in cities where signal propagation is severely affected by buildings, vehicles, and pedestrians [57]. UMi targets very dense urban areas, considering small cells deployed at an average height of 10 meters or less above ground, below the rooftop level of the adjacent buildings. It shall cater to deployment scenarios including city centres, business districts, and crowded urban areas where the coverage for the small cells has to be extended for offering high-capacity, with congestion reduction

[57], [58] .

UMi includes both Line-of-Sight and Non-Line-of-Sight conditions [57], [58] . It is somewhat of a more modern model, better suited for higher frequencies and smaller cell sizes, especially for 5G.

LoS Path Loss: LoS is common within an urban microcell between the small cell base station gNB and the mobile device, especially in open streets. Path loss in LoS was modeled as a function of distance and frequency, taking both free space propagation and reflections from buildings and other urban structures into account.

For accurate design and comparison of wireless networks and/or their deployments, the wireless channel models are necessary, which will simulate the signal propagation accurately and efficiently. In this paper, we evaluated four path loss models that are introduced by the four major organizations: 5GCM (5G Communication Model), 3GPP, METIS (Mobile and Wireless Communications Enablers for the 2020 Information Society), and mmMAGIC (Millimetre-wave Mobile Access for Gigabit Communications). Based on this, the UMi environment, the propagation path is divided into two types: street canyon (SC) and open square (OS).In this case the height of base station(BS), height of User terminal (UT), and height of equipment(UE) is 10m, 1.5m and 1.0m respectively [57], [58] .

Street canyon (SC):

$$PL_{\text{UMi-LOS}} = \begin{cases} PL_1, & 10\text{m} \le d_{2D} \le d'_{BP} \\ PL_2, & d'_{BP} \le d_{2D} \le 5\text{km} \end{cases} \tag{6.1}$$

$$PL_{\text{LOS-1}} = 32.4 + 21\log_{10}(d_{2D}) + 20\log_{10}(f_c) \tag{6.2}$$

$$PL_{\text{LOS-2}} = 32.4 + 40\log_{10}(d_{3D}) + 20\log_{10}(f_c) - 9.5\log_{10}(d'^2_{BP} + (h_{BS} - h_{UT})^2) \tag{6.3}$$

$$d_{3D} = \sqrt{d_{2D}^2 + (h_{BS} - h_{UT})^2} \tag{6.4}$$

$$d'_{BP} = \frac{4(h'_{BS}h'_{UT}f_c)}{c} \tag{6.5}$$

$$c = 3.0 \times 10^8 \text{ m/s}$$
$$h'_{BS} = h_{BS} - h_E$$
$$h'_{UT} = h_{UT} - h_E$$

NLoS Path Loss: In urban environments, NLoS conditions arise when there are obstacles (e.g., buildings, vehicles) blocking the direct path between the transmitter and receiver. NLoS path loss is significantly higher than LoS and is influenced by reflections, diffraction, and scattering. The NLOS path loss model for the UMi scenario is given by: The additional loss accounts for diffraction, reflection, and scattering effects due to buildings and other obstacles. For NLoS, add the typical additional loss, which can range from 10 to 20 dB depending on the environment. The typical value of additional loss for the urban micro is 13.5 dB.

$$PL_{\text{NLOS}} = 22.4 + 35.3\log_{10}(d_{3D}) + 21\log_{10}(f_c) - 0.3(h_{\text{UT}} - 1.5) \tag{6.6}$$

where:

$$h_{BS} = 10 \text{ m}$$
$$1.5 \text{ m} \leq h_{\text{UT}} \leq 22 \text{ m}$$

$$d_{3D} = \sqrt{(h_{BS} - h_{\text{UT}})^2 + d_{2D}^2} \tag{6.7}$$

h_{BS} is the base station antenna height in meters.

h_{UT} is the user terminal antenna height in meters.

Open square (OS):

$$L_{\text{LOS}} = 32.4 + 18.5\log_{10}(d_{3D}) + 20\log_{10}(f_c) \tag{6.8}$$

$$L_{\text{NLOS}} = 32.4 + 28.9\log_{10}(d_{3D}) + 20\log_{10}(f_c) \tag{6.9}$$

6.1.2 Operating Frequency and Bandwidth

Immersive video services, such as Virtual Reality, Augmented Reality, or 360-degree video streaming require appropriate operating frequency and bandwidth so that the quality of such experiences would not be degraded with low latency. Immersive AR/VR applications for small areas,lets say a stadium, would require a demand for 5G frequency bands that offer high throughput and low latency, with the capacity to serve a dense population of users. Frequency bands usually fall within mid-band, that is, Sub-6 GHz, and high-band spectrum, mmWave, since both have their advantages depending on deployment requirements.

Frequency Range: 3.3 GHz to 4.2 GHz, for example, n77, n78, or 4.4 GHz to 5 GHz for example, n79. This band is all about moderate range and very good capacity. Suitable for a stadium with moderate users and good in-depth penetration through obstructions like stands and walls. Examples include Band n78 (3.5 GHz), one of the most deployed 5G bands around the world, hence striking a great balance between capacity and coverage; Band n79 (4.8 GHz) higher in throughput at slightly reduced coverage compared to n78 [53], [54], [55].

High-Band (mmWave), Frequency Range: 24 GHz to 40 GHz (e.g., n257, n258, n260, and n261) Very high throughput-suitable for immersive AR/VR streaming. Low latency, which is critical to real-time interactions. The limited range makes it suitable for small area deployments like stadiums. Examples include Band n260 (37–40 GHz). It is highly popular when it comes to the delivery of gigabit speeds in small dense areas. Band n261 (28 GHz) One of the highly popular mmWave deployments has very good adoptions in North America and Asia [53], [54], [55].

In edge computing, high-band mmWave takes a lot from massive MIMO and beamforming in order to channel signals in places where the user density could be very high. Frequency combination 26 GHz, 28 GHz in the 24-28 GHz mmWave bands, and 3.5 GHz used in immersive AR/VR experience [53], [54], [55]. In mmWave, the system bandwidth may go up to 1000 MHz owing to wide frequency bands and small wavelengths. Here are some examples of the channel bandwidth: Band n257: 50, 100, 200, or 400 MHz at 28 GHz frequency. Band n258: 50, 100, 200, or 400 MHz at 26 GHz frequency. Band n259: 50, 100, 200, or 400 MHz at 42 GHz frequency. Band n260: 50, 100, 200 or 400 MHz at a frequency of 39 GHz [53], [54], [55].

That is a reason why 26 GHz, 28 GHz, and 39 GHz bands are considered for immersive services, given their high-capacity usage. The required bandwidth is related to the kind of immersive media service delivered: Standard 360-degree video streaming in HD: It takes about 25-50 Mbps per user in bandwidth for a smooth experience. 4K 360-degree video or VR streaming: This normally requires 80-100 Mbps per user to ensure high-quality resolution with low latency [59].

A combination of the 3GPP TR 38.901 propagation model with Urban Micro-UMi and in the frequency band of 28 GHz (Band n257) is recommended as shown in table 6.1. This combination gives more realistic urban environments with high capacity, hence it is suitable for the deployment of small cells in densely populated urban areas [59].

Propagation Scenario	Frequency Band (GHz)	Propagation Model	Bandwidth	Mode
Urban Micro (UMi)	28 GHz (Band n257)	3GPP TR 38.901 (Urban Micro)	400 MHz	TDD (Time Division Duplex)

Table 6.1: Urban Micro (UMi) Propagation Parameters

This approach ensures that the network can handle the unique challenges of an urban environment, providing robust coverage and high capacity to meet the demands of users in a dense metropolitan area. TDD (Time Division Duplex), is a duplexing method used in 5G that allows dynamic allocation of uplink and downlink resources.

This is very important for providing immersive experiences, especially in highly interactive virtual and augmented reality environments, among others. Low latency, less than 20ms, is important to provide immersive experiences, particularly in highly interactive environments such as those involving virtual and augmented reality. That's why these types of services are mostly hosted on 5G networks, which provide the necessary bandwidth with low latency [59]. Small cells are deployed with cloud or edge computing resources for every few tens to hundreds of meters in densely populated areas, effectively delivering the service while keeping data processing closer to the user to cut down on latency [59].

If your use case involves immersive media users attending events en-masse, then 5G at 28GHz or mmWave with high bandwidths of up to 500 Mbps for advanced immersive services would be much better [59].

In immersive video services, such as Virtual Reality and 360-degree video streaming, the requirements for operating frequency and bandwidth are quite high, as high-resolution content with low latency has to be delivered as explained in table 6.2.

Service Type	Operating Frequency	Bandwidth Requirement (Mbps)
SD Video (480p)	2.4 GHz, 5 GHz, 3.5 GHz	1.5 - 2.5
HD Video (720p)	2.4 GHz, 5 GHz, 3.5 GHz	3 - 5
Full HD Video (1080p)	2.4 GHz, 5 GHz, 3.5 GHz	5 - 8
2K Video (1440p)	2.4 GHz, 5 GHz, 3.5 GHz	10 - 16
4K Video (2160p)	2.4 GHz, 5 GHz, 3.5 GHz	20 - 35
8K Video (4320p)	2.4 GHz, 5 GHz, 3.5 GHz	50 - 100
360-Degree Video (VR, 6K)	2.4 GHz, 5 GHz, 3.5 GHz	60 - 100
360-Degree Video (VR, 8K)	24 GHz, 28 GHz, 39 GHz	100 - 200
360-Degree Video (VR, 12K)	24 GHz, 28 GHz, 39 GHz	200 - 400
Interactive AR/VR	2.4 GHz, 5 GHz, 6 GHz, 3.5 GHz	50 - 100

Table 6.2: Operating frequency and Bandwidth Requirements for Different Video and Interactive Services [53], [54], [55]

6.1.3 Modeling of Radio Link Budget Parameters

Radio Link Budget analysis is one of the most interesting processes in designing a wireless communication system. The concept is to take into account the total gain and losses from transmitter to receiver so that reliable communication can be possible [57]. RLB will estimate MAPL between the transmitter and the receiver in the DL and UL transmission directions [57], [58]. This can be estimated on different topography by comparing MAPL with the loss of the path from the appropriate spread model. RLB is taken into account by a number of factors that affect the final cell coverage. When these factors are achieved, the calculation of all profits and losses, loss of building penetration, loss of feeder, antenna gain and radio interference [57], [58]. Some of the key elements of the Radio Link Budget enlisted below are used for calculating the radio link budget:

i. **Transmitter Power of gNodeB:** This is the total power transmitted from BS/small cell. The unit of the value is generally in dBm or Watt. Higher power can extend the range but may cause interference.

ii. **gNodeB Transmit Antenna Gain (G_{Tx}):** It is an ability of antenna to focus energy in one direction, having only the motive of improving the signal strength in that direction. The antenna gain has a direct relationship with the size of the antenna and the width of the horizontal or vertical antenna patterns. Here, the profits and width of the beam are selected in relation to the requirements for the type and coverage of the clutter. The low profit antenna, 15-17dbi, is usable in dense urban and urban overcasts, while high-profit antenna, 18-20 dBi, are useful in the extension of the radio frequency, RF, coverage in rural areas and highways typical of 17 DBi [46], [57], [58].

iii. **EIRP (Effective Isotropic Radiated Power):** The total power radiated by the antenna, a combination of transmitter power and antenna gain. It is used to determine how much transmission power is emitted in the desired direction and includes the gain of the transmitter antenna with losses in transmission cables and connectors [57]. It can be determined using the following formula [62].

$$\mathrm{EIRP} = P_{\mathrm{Tx}} + G_{\mathrm{Tx}} - \sum \text{Total Tx Losses} \tag{6.10}$$

where P_{Tx} is the transmitter power (dBm), G_{Tx} is the transmitter antenna gain (dBi), and Total Tx losses are cable and other losses (dB).

iv. **Cell Edge User Throughput:** It is the lowest clean individual target permeability of the UE required on the edge of the cell. The network operator usually provides this parameter based on the necessary services on the cell edge [57], [58] [62].

v. **Thermal Noise:** Expressed as:

$$N = KBT \tag{6.11}$$

where $k = 1.38066 \times 10^{-23}\,\mathrm{J/K}$ is Boltzmann's constant, $T = 290\,\mathrm{K}$ is absolute temperature, $B = 100\,\mathrm{MHz}$ is channel bandwidth, and N is the thermal noise (dB).

vi. **UE Maximum Total Transmitter Power:** Indicates the UE transmission energy that depends on the UE performance class

vii. **Loss:** It includes loss of cable and body in gNodeB and UE. The cable loss value is determined by the cable length, it varies from 1-6 dB for gNodeB. Body loss occurs when the UE is held close to the user's head, and it is nearly 2-3 dB in practical planning.

viii. Noise Figure: It is the ratio of SINR when entering the receiver to SINR at the end of the receiver output and used to evaluate the power of the receiver. The typical value of noise number is between 6 and 8 dB [62].

ix. Signal to Interference Noise Ratio (SINR): SINR depends on the design of the receiver, which is derived from the results of the system level simulation. The SINR parameter is therefore based on the specifics of the supplier.

x. Receiver Sensitivity: Indicates the minimum signal strength needed for gNodeB decoding or UE receiver in the absence of interference and is expressed as:

$$R_S = N_F + SINR + N \tag{6.12}$$

where R_{S} is receiver sensitivity (dBm), NF is the noise figure (dB), SINR is the signal-to-interference-noise ratio (dB), and N is thermal noise (dB).

xi. Slow/Shadow Fading Margin: It is a fading caused by blocking the natural element. The difference with slow fading is determined by the standard deviation of slow fading and the fading of the shadows is caused by changes in location. Depending on the nature of the clutter, the standard deviation of slow fading ranges from 5 to 12 dB.

xii. Body Loss: It is a loss of results from signal delay and immersion when the terminal antenna is close to the body [62].

xiii. Feeder Loss: It is a loss caused by various devices located along the antenna path to the receiver [62].

xiv. Penetration Loss: It is the fading of radio signals caused by a building obstruction from an indoor terminal to the gNodeB and vice versa. This is determined by the nature of the buildings and the category of clutter in the targeted coverage area [62].

Clutter Type	Penetration Loss (dB)	Typical Values (dB)	Standard Deviation of Slow Fading (dB)
Dense Urban	19-25	19	10
Urban	15-18	15	8
Suburban	10-14	11	6
Rural	5-8	8	6

Table 6.3: Clutter Types and Their Penetration Loss Parameters [57], [58], [62]

System Bandwidth: The amount of frequency spectrum available for communication. Higher bandwidth allows for higher data rates but might increase noise [57].

Maximum Allowable Path Loss (MAPL): The MAPL determines the maximum cell range and evaluates the required number of gNodeB sites to cover the target area [57]. It is calculated as follows:

$$\mathrm{MAPL} = \mathrm{EIRP} - R_S - p_L - S_M - I_M + G_{\mathrm{RX}} \tag{6.13}$$

Where:

- EIRP: Effective Isotropic Radiated Power (dBm)
- R_S: Receiver Sensitivity (dBm)
- p_L: Penetration Loss (dB)
- S_M: Shadow-Fading Margin (dB)
- I_M: Interference Margin (dB)
- G_{RX}: Receive Antenna Gain (dBi)

This provides a clear overview of the link budget parameters for both downlink and uplink in a 5G network environment.

Approximately Link budget can be calculated using the formula:

$$\begin{aligned} P_{\text{received}}\,(\text{dBm}) = {} & P_{\text{transmitter}}\,(\text{dBm}) - \text{Pathloss}\,(\text{dB}) - \text{Miscellaneous Loss}\,(\text{dB}) + \\ & G_{\text{Tx Antenna}}\,(\text{dB}) + G_{\text{Rx Antenna}}\,(\text{dB}) - L_{\text{Tx}}\,(\text{dB}) - L_{\text{Rx}}\,(\text{dB}). \end{aligned}$$

Pathloss (dBm) = gNodeB transmit power (dBm)–10 log10 (subcarrier quantity) +gN odeB antenna gain (dBi)– gNodeB cable loss (dB)– penetration loss (dB)– foliage loss (dB)– body block loss (dB)– interference margin (dB)– rain/ice margin (dB)–slow fad ing margin (dB) + UT antenna gain (dB)–thermal noise figure (dBm)– UT noise figure.

6.1.4 Cell Area and Site Count

In most of the network planning studies, the area coverage area is modeled as hexagonal and we assume that the web configuration is also hexagonal. Depending on the web layout, the site configuration may be versatile, bi-sector or trick [57], [58].

I. Omnidirectional Site Coverage Area

The inter-site distance, denoted as D, is calculated as:

$$D = 1.732 \times R \tag{6.14}$$

The site coverage area A_{sc} is given by:

$$A_{\mathrm{sc}} = 2.949 \times R^2 \tag{6.15}$$

Where R represents the radius. This formula calculates the coverage area of a single omnidirectional cell site. The area covered by a circular antenna in a hexagonal layout, which is a common representation in cellular network planning [57], [58].

II. 2-Sector Site Coverage Area

The inter-site distance, D, is:

$$D = 1.732 \times R \tag{6.16}$$

The site coverage area A_{sc} for the 2-sector configuration is:

$$A_{\mathrm{sc}} = 1.732 \times R^2 \tag{6.17}$$

III. 3-Sector Site Coverage Area

The inter-site distance, D, is:

$$D = 1.5 \times R \tag{6.18}$$

The site coverage area A_{sc} for the 3-sector configuration is:

$$A_{\mathrm{sc}} = 1.949 \times R^2 \tag{6.19}$$

Based on the coverage area of a single SC (Asc), the number of needed SCs based on coverage area (NSCa) is the bare minimum of SCs needed to cover the entire area (A).

Coverage-Based Site Count

Finally, the coverage-based site count is calculated as:

$$N_{\mathrm{sc}_a} = \mathrm{round}\left(\frac{A}{A_{\mathrm{sc}}}\right) \tag{6.20}$$

Where:

- A: Total area to be covered
- A_{sc}: Area covered by a single small cell

6.2 Cloud Enabled Small Cell Network Capacity Dimensioning

In telecommunications, capacity-based dimensioning covers a systematic process that analyzes the number of network elements that would be needed in view of meeting the expected user demand for the efficient and effective delivery of services [59]. Equally important, designing small cell networks involves going through this very process, with increased deployment aimed at improving coverage and enhancing capacity in urban areas as depicted in figure 6.3. Capacity dimensioning makes an estimate of the amount of resources needed to carry a given offered traffic with some given Quality of Service, throughput or blocking probability [59].

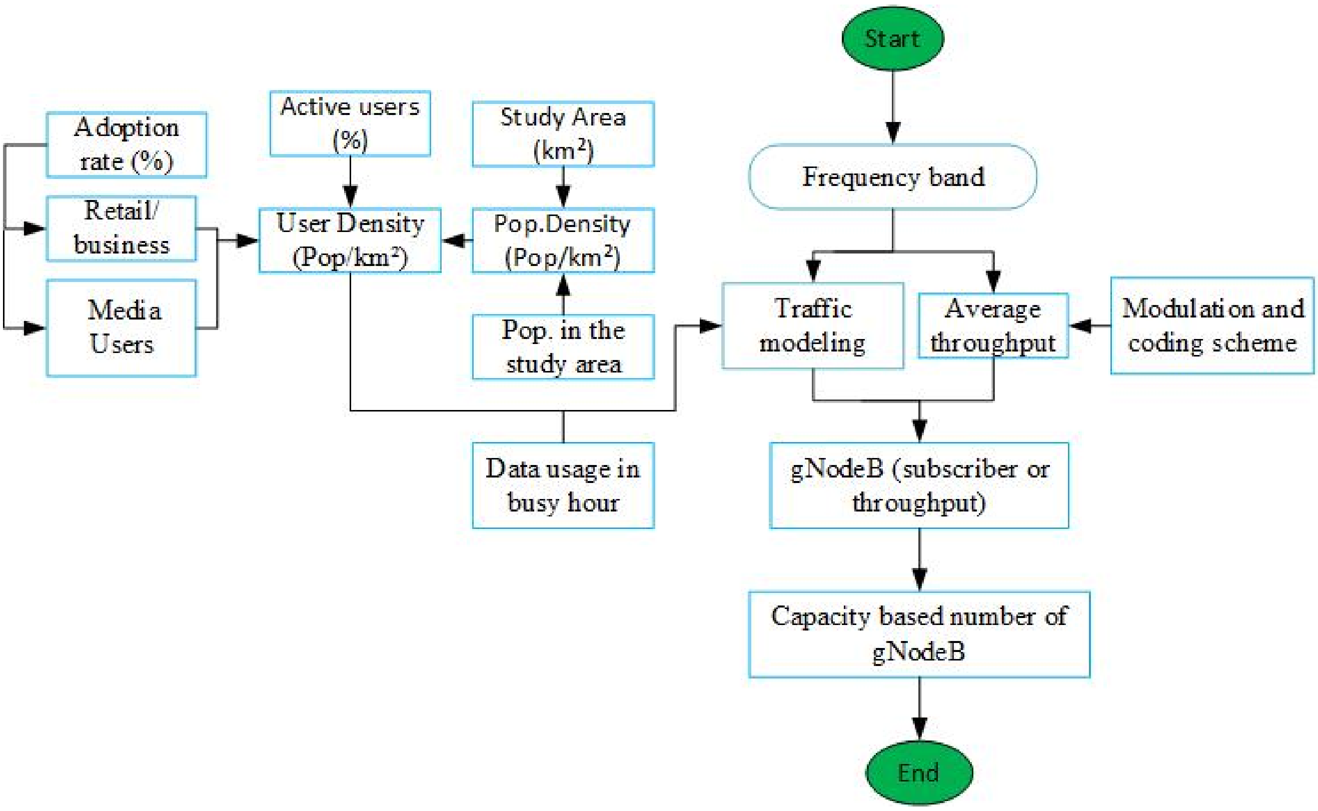


Figure 6.3: Cloud enabled small cell network capacity dimensioning flow chart.

6.2.1 Data Rate Modeling

Throughput, in general, is the maximum possible data rate that a communication system can transmit [59]. It is defined as a quality indicator expressed in terms of the data transfer rate of usual and non-redundant information [59]. The primary objective of the capacity planning exercise will be to arrive at an estimate of the site count based on the capacity requirements [59]. Wherein network operators define capacity needs according to forecasted traffic and average cell throughput required to determine the capacity-based site count [59]. The maximum data rate of DL and UL that can be supported by the UE shall be determined per band or band combinations supported by the UE [59]. For NR, the approximate data rate for a given number of aggregated carriers in a band or band combination is computed as follows [59].

5G NR Throughput Formula

$$\text{5G NR Throughput (DL and UL) (Mbps)} = 10^{-6} \sum_{j=1}^{J} \left(V_{\text{Layers}}^{(j)} \cdot Q_m^{(j)} \cdot f^{(j)} \cdot R_{\max} \cdot \frac{N_{\text{PRB}}^{(\text{BW}(j),\mu)} \cdot 12}{T_s^{\mu}} \cdot \left(1 - \text{OH}^{(j)}\right) \right) \tag{6.21}$$

Where:

- 10^{-6}: Constant for Mbps conversion.
- j: Represents the number of aggregated component carriers in a band or band combination ($1 \leq j \leq 16$).
- $V_{\text{Layers}}^{(j)}$: Maximum number of MIMO layers (≤ 8 in DL and ≤ 4 in UL).
- $Q_m^{(j)}$: Modulation order (QPSK = 2, 16QAM = 4, 64QAM = 6, 256QAM = 8).
- $f^{(j)}$: Scaling factor for mobility ($f^{(j)} \in \{0.4, 0.75, 0.8, 1\}$).
- $R_{\max}$: Coding rate ($R_{\max} = \frac{948}{1024}$ for LDPC).
- $N_{\text{PRB}}^{(\text{BW}(j),\mu)}$: Maximum number of allocated Physical Resource Blocks (e.g., 264 PRB for 400 MHz and 120 kHz subcarrier spacing).
- T_s^{μ}: Average OFDM symbol duration ($T_s^{\mu} = \frac{10^{-3}}{14 \cdot 2^{\mu}}$ for normal cyclic prefix).
- $\text{OH}^{(j)}$: Control channel overhead. Typical values:
  - FR1: 0.14 (DL), 0.08 (UL).
  - FR2: 0.18 (DL), 0.10 (UL).

6.2.2 Traffic Modelling

The basic objective of the operation is to describe the average behavior of subscribers during the busiest day of the event.To calculate the Single-UE Busy Hour Rate required for immersive media services, calculate how much data a single user consumes during the busiest hour of network activity [59]. This depends on the kind of immersive media (such as AR, VR, 4K/8K video streaming), resolution, frame rate, and user experience [59]. Among these, each immersive service has its bitrate:

Throughput per User Category:

Each service type will have different average throughput requirements based on video resolution, frame rate, and bit rate, as shown in the table 6.4.

Network bandwidth and latency requirements:

Currently, 4K panoramic video only requires 20 to 40 Mbps data rate and 50 ms latency. As 5G networks contribute to considerable improvement in data rate (more than 100 Mbps) and latency (less than 10 ms), users will enjoy more comfortable viewing experiences.

Network Data Rate and Latency Requirements for 360° Cloud VR and CG Cloud VR

CG Cloud VR delivers 2K services in its infancy. For better visual experience, the image resolution has to be 4K or 8K. In addition, the feature of strong interaction turns the CG Cloud VR services to be more latency-sensitive [59].

360° Video Resolution	Frame Rates (fps)	Coding	Transmission	Data rate (Mbps)	Latency (ms)
4K (3840x2160)	60	H.265	Sphere	20-40	≤ 50
8K (7680x4320)	90	H.265	Sphere Field of view (FOV)	90-130 30-50	≤ 20
12K 3D (11520x6480)	120	H.266	Sphere Field of view (FOV)	500-700 200-300	≤ 10

Table 6.4: Network data rate and latency requirements of 360° Cloud VR video

CG VR Resolution	Frame Rates (fps)	Coding	Data rate (Mbps)	Latency (ms)
2K (2560x1440)	70	H.265	30-50	≤ 20
4k (3840x1920)	90	H.265	50-200	≤ 16
8K 3D (7680x3840)	120	H.266	200-800	≤ 10

Table 6.5: Network data rate and latency requirements for CG VR video

Latency Requirements and Capabilities of 360° VR and CG VR Services

The latency values in the table represent the round trip time (RTT) latency requirements on the RAN side. Operators can selectively launch 360° VR or CG VR services based on their own service and network capabilities as shown in table 6.4 and 6.5.

Since 360° VR video is a derivative of video services, operators equipped with traditional video platforms can swiftly run such VR services at low cost. In order to deploy CG VR services, which have high requirements for GPU rendering and streaming, operators must add GPU resource pools to further supplement their existing cloud platforms and data centers [59].

360° VR

360° VR involves real-world scenes captured using 360° cameras. The viewer can look around but cannot interact with the environment. Common applications include immersive videos or storytelling, virtual tours (real estate, museums, travel), and training based on real-world scenarios, such as safety procedures.

CG VR (Computer-Generated VR)

CG VR represents a fully computer-generated environment or scene where users can freely interact and roam, often powered by game engines such as Unity or Unreal Engine. Common applications include gaming and entertainment, training and simulations (medical, military, and industrial), interactive storytelling, and architecture or product design visualization.

Capacity-Based Site Count (DL/UL)

The formula for the maximum number of subscribers per gNodeB for each service type based on the average throughput requirements is as follows:

Average Throughput at Busy Hour (BH)

The average throughput at the busiest hour (BH) for immersive video services can be calculated using the following formula:

$$\text{Bitrate} = \frac{\text{Resolution} \times \text{Frame Rate (fps)} \times \text{Color Depth (bits/pixel)}}{\text{Compression Ratio}} \tag{6.22}$$

$$\text{Data Volume (Bytes)} = \frac{\text{Bitrate (bps)} \times \text{Streaming Duration (seconds)}}{8} \tag{6.23}$$

$$\text{Avg. Throughput per Subscriber (Mbps)} = \frac{\text{Total Data Volume}}{\text{BH Duration} \times 30} \tag{6.24}$$

Maximum Users per gNodeB (DL, UL)

$$U_{\text{max (DL, UL)}} = \text{round}\left(\frac{\text{5G NR Throughput (Mbps)}}{\text{Average Throughput per Subscriber in a Month (Mbps)}}\right) \tag{6.25}$$

Total Number of Sites (gNodeBs) Required

$$N_{\text{sc (DL and UL)}} = \text{round}\left(\frac{U}{U_{\text{max}}}\right) \tag{6.26}$$

Where:

- U: Total number of users
- U_{max}: maximum number of users per a single small cell

6.3 Cloud Server Dimensioning

To accomplish the desired data rates and maintain adequate radio coverage, the CESC cluster exploits the use of SC VNF in the bridge between radio and cloud domains. The intercepted S1 radio encapsulation/decapsulation process by the SC VNF close to the end users enables data processing. This allows CPU and data-intensive applications to run closer to the end users, resulting in better performance with increased latency. Light DC plays a key role in executing the SC VNF and additional Service VNFs to support the computations and services demanded [3], [49], [50]. The control plane VMs have management and control-related responsibilities inside the VNF. This typically encompasses multiple tasks at a time, like signaling, routing, and also configuration management [3], [49], [50].

In general, Cloud RAN architectures virtualize part of the baseband processing to VNFs, so-called virtualized BBU pools, operating on top of COTS cloud servers [3]. The purpose of the cloud server dimensioning is to calculate the number of cloud servers needed by the VNFs for virtualized baseband processing. Cloud RAN VNFs can consist of different VMs that handle different parts of the virtualized baseband processing. In this model, it is assumed that the following VMs are deployed to handle the NRT baseband function processing in the cloud. The deployed VMs are User VM (UE VM), Cell VM, Central gNB VM (CVM) and Operation and Management VM (OAM VM) [3]. VMs need resources of processor cores of the cloud server for their processes, and hence, calculating the total number of VMs required in the network will calculate the number of required cloud servers for Cloud RAN [3].

First, we assign control plane (CP) and user plane (UP) VMs per VNF. UP VMs handle data plane-related tasks, thus processing actual user data, while CP VMs handle control and administrative tasks, including signaling, resource allocation, and network management. The amount of VMs to be assigned to each VNF depends on the needs of each network and the task each VNF executes [3].

Number of CP VMs per VNF ($V_{\mathbf{NFCP}}$):

$$\mathrm{VNF}_{\mathrm{CP}} = \frac{N_{\mathrm{CPVM}}}{\mathrm{VNF}_T} \tag{6.27}$$

Where:

- V_{NFCP} is the total number of CP VMs in the network.
- VNF_T is the total number of VNFs required in the network.

Number of UP VMs per VNF ($V_{\mathbf{NFUP}}$):

$$\mathrm{VNF}_{\mathrm{UP}} = \frac{N_{\mathrm{UPVM}}}{\mathrm{VNF}_T} \tag{6.28}$$

Where:

- V_{NFUP} is the total number of UP VMs in the network.
- N_{UPVM} is the total number of UP VMs in the network.
- VNF_T is the total number of VNFs required in the network.

Cloud Server Requirements per VNF ($S_{\mathbf{VNF}}$):

$$S_{\mathrm{VNF}} = \frac{(\mathrm{VNF}_{\mathrm{CP}} \times C_{\mathrm{CP}}) \times (\mathrm{VNF}_{\mathrm{UP}} \times C_{\mathrm{UP}}) + C_{\mathrm{CgNB}} + C_{\mathrm{OAM}}}{C_{\mathrm{server}}} \tag{6.29}$$

Where:

- C_{CP} is the required number of CPU cores per CP VM.
- C_{UP} is the required number of CPU cores per UP VM.
- C_{CgNB} is the required number of CPU cores for the gNB (base station).
- C_{OAM} is the required number of CPU cores for other auxiliary modules.
- C_{server} is the number of CPUs per server.

Total Number of Cloud Servers in the Network (N_S):

$$N_S = S_{\mathrm{VNF}} \times \mathrm{VNF}_T \tag{6.30}$$

Where:

- N_S is the total number of servers required in the network.

- S_{VNF} is the number of cloud servers per VNF.
- VNF_T is the total number of VNFs in the network.

6.4 GPU and Micro Server Dimensioning

In doing so, some additional IT resources and hardware accelerators like GPUs and micro servers must be provided in the Light DC [3]. The enriched Light DC can thus offer, thanks to the additional IT resources and hardware accelerators, compute-intensive video processing during Crowded Events (CEs) which is an extended basic service usually provided by mobile radio networks [14].

Cloud Video Transcoding and Service Bundles: With such high computational load in order to handle demand for video streaming, SSPs use cloud services to do video transcoding [36], [37], [38] . It will turn a single stream of a video into several bit rates for adaptive bitrate streaming of that particular video [35]. Transcoding can be either offline, such as pre-conversion, or online, meaning real-time during streaming [14].

Transcoding Policies: Scheduling policies for the video fragments are explained that maintain when to transcode in order to observe SLA with CDNs [14],[20] as shown in table 6.6. Pre-conversion of videos to multiple bit rates and storing them may be done offline. Online transcoding does this conversion in real time and adaptively considers devices and network conditions [14],[20].

Service Bundles:

Service Bundle	SLA	Initial bundle Share	Bundle Share after 5 years
Bronze	Basic connectivity	85%	10%
Silver	IMS with medium resolution video content	10%	15%
Gold	IMS with high resolution video content	5%	75%

Table 6.6: SLA for Service Bundles

From the ten-year study period, over the first five years, customer preferences and adoption rates evolve as users get familiarized with features offered by both Silver and Gold bundles, inclusive of immersive media service (IMS) services powered by the Video Processing Unit [14]. Such a VPU allows for the real-time sharing of video content at high resolution and allows content creation and distribution within predetermined peer groups [14]. IMS can be accessed via browsers or mobile apps, enabling live streaming, uploading of videos, and offline access [14].

Key capabilities of the VPU are as follows: Real-time interaction-Communication of live or prerecorded video content amongst group members

Content Adaptation: This involves adapting video resolution and format to match the medial capabilities of users' devices for optimum QoE.

Flash events: Delivering event-related information or ads quickly, bypassing group constraints.

Distributed storage: It will store the transcoded video for current or future use.

VPU-Based Video Transcoding and Resource Estimation

An unlimited population of customers uses c identical servers ("channels"). There are several ways of implementing an M/M/c system. The main two are channel divisions with no multiplexing: the C channels are separate each with its input queue. They are used in Telecommunications as TDMA and FDMA. Statistical multiplexing: arrivals join a single queue and enter the first available channel (including the Internet, by efficiently utilizing shared resources and dynamically allocating bandwidth as needed) [52].

For example, 4K and 8K video resolutions the GPU server and micro-server provision for delivering AR or VR services through edge computing, we can examine different hypotheses using key performance indicators like VPU, service time, arrival rate, and system capacity [52],[64], [65].

Arrival Rate (λ): The flow of AR/VR requests in the system; that is, the frequency at which requests arrive. This could be based on the traffic of users, the number of devices, and the number of users at any one time [52], [64], [65] .

Service Rate (µ): How fast the server can handle AR or VR requests. Specifically, how much power is consumed in the case of GPUs and micro servers in the above equation would depend on the amount of processing integrated into these machines and the kind of AR or VR content being processed [52].

Service Time (T): Processing time per request or the time required to process the request for a particular AR or VR application, which will depend on the complexity of the requested application. For instance, the video resolution of the application, the latency required for the application, and the interactivity of the application [51], [52].

System Capacity (C): The number of GPU servers in the system. To find the minimum number of servers (C) in the system, we aim for a system utilization rate (ρ) between 70% - 80% per server [51], [52].

Queueing Model: The above models will be followed by developing Queueing models to represent the thus-made system using M/M/c models depending on constraints like the system capacity.

This depends on the kind of AR/VR application to implement. For example, when streaming 4K VR content, the GPU's processing is going to be different as well as the related service rate compared to simple AR applications. For ease of calculation, one may assume µ (requests processed per second by each server) can be obtained from the system specification of the GPU or micro server [3],[51], [52].

$$\mu = \frac{1}{T} \tag{6.31}$$

In a queueing model for m/m/c, c is the number of servers such as GPU or micro server, the system assumes that requests arrive according to the Poisson process, service times follow an exponential distribution and there are c servers [3], [49], [50],[51], [52].

$$\rho = \frac{\lambda}{C\mu} \tag{6.32}$$

Where C is the number of servers

$$L = C\rho + \frac{(C\rho)^{(C+1)} P_0}{C!(1-\rho)^2} \tag{6.33}$$

L (Average number of customers in the system)

$$W = \frac{L}{\lambda} \tag{6.34}$$

W (Average waiting time in the system):

$$L_q = L - C\rho \tag{6.35}$$

Lq (Average number of customers in the queue):

$$P_0 = \frac{1}{\sum_{K=0}^{C-1} \frac{\rho^K}{K!} + \frac{\rho^C}{C!} \times \frac{1}{1-\rho}} \tag{6.36}$$

P0 (Probability of no customers in the system)

To estimate the amount of RAM required per VPU instance, we can use a statistical model based on the properties of EPS (Egalitarian Processor Sharing) systems [3].

The steady-state probability that a VPU instance processes i video files concurrently is given by:

$$\pi_i = i(1-\rho) \tag{6.37}$$

where ρ represents the CPU usage, and the variable i represents the number of video files being processed concurrently by a VPU instance in a steady-state condition. By setting π_i to an arbitrarily low value, such as 10^{-5}, we can determine the corresponding number of concurrently processed files i using the equation:

$$i = \frac{\log(\pi_i) - \log(1-\rho)}{\log(\rho)} \tag{6.38}$$

In experimental research, it has been verified that one instance of the VPU without any active transcoding sessions requires approximately 6 GB of RAM. Additionally, each multiple transcoding session requires an additional 0.5 GB of RAM [3].

Therefore, the minimum quantity of RAM required to process i files can be calculated as:

$$\text{RAM (GB)} = 0.5i + 6 \tag{6.39}$$

To estimate the overall storage capacity required for the IMS system, we need to consider several factors [3], [49], [50].

Stream Generation Rate (γ^0): The rate at which participants generate new live streams (in streams per unit time).

Average Duration of Video Sequences (T): Denoted as T (in seconds).

Data Rates for Silver and Gold Users: Denoted as D_s and D_g (in bits per second, bps) respectively.

CE Duration ($\mathrm{T_E}$): Denoted as T_E (in seconds).

Considering that transcoding processes generate both medium and high-resolution content for Gold users, and only medium-resolution content for Silver users, the storage capacity C (in bits) can be calculated using the following formula [3], [49], [50]:

$$C = T_E \cdot (\lambda_0 + \gamma^0) \cdot (U_g \cdot D_g + U_g \cdot D_s + U_s \cdot D_s) \cdot T \tag{6.40}$$

where:

λ_0 is the arrival rate of video files from off-line transcoding,
γ^0 is the rate at which live streams are generated by participants in a CE,
U_g is the percentage of Gold bundle users,
U_s is the percentage of Silver bundle users,
D_g is the data rate for Gold users,
D_s is the data rate for Silver users.

Chapter 7

Economic Analysis of the Applied Techno-Economic Model

7.1 Implemented TEA Model

In the fourth chapter we saw different models of techno-economic evaluation and their application area. The technical model is a systematic framework for analysis of economic feasibility of technology, including all system parameters. Based on the derived framework from the model, this work has modified the model to include input parameters as shown in Figure 7. 1, is based on the explained model in Chapter 4, Section 4.1. The model comprises marketing, technical, and economic parts. Modified IST-TONIC and CELTIC-ECOSYS Techno-economics of integrated communication systems and services in MATLAB and MS-Excel for the economic component was selected for this research because it can be applied to the wireless telecommunication industry and seamless mobile IP service provision [14], [17], [41].

Using the TEA model provides an understanding to network planners and decision-makers on a cost-effective approach that can be formulated based on capital and operating expenditure together with the revenue generated by deploying different types of RAN technology, such as D-RAN, C-RAN, vRAN, and O-RAN. This also guarantees the best returns on the investment while establishing the future for the network. This model would facilitate providing commonly used financial criteria, such as the payback period and IRR, to enable the network operators to determine the financial viability of the project.

The inputs taken for this system model were a 10-year study period, a 10% discount rate, and a 15% tax rate [17], [41]. The outputs of the models in each architecture will be some economic evaluation measures like NPV, IRR, and PP [17], [41].

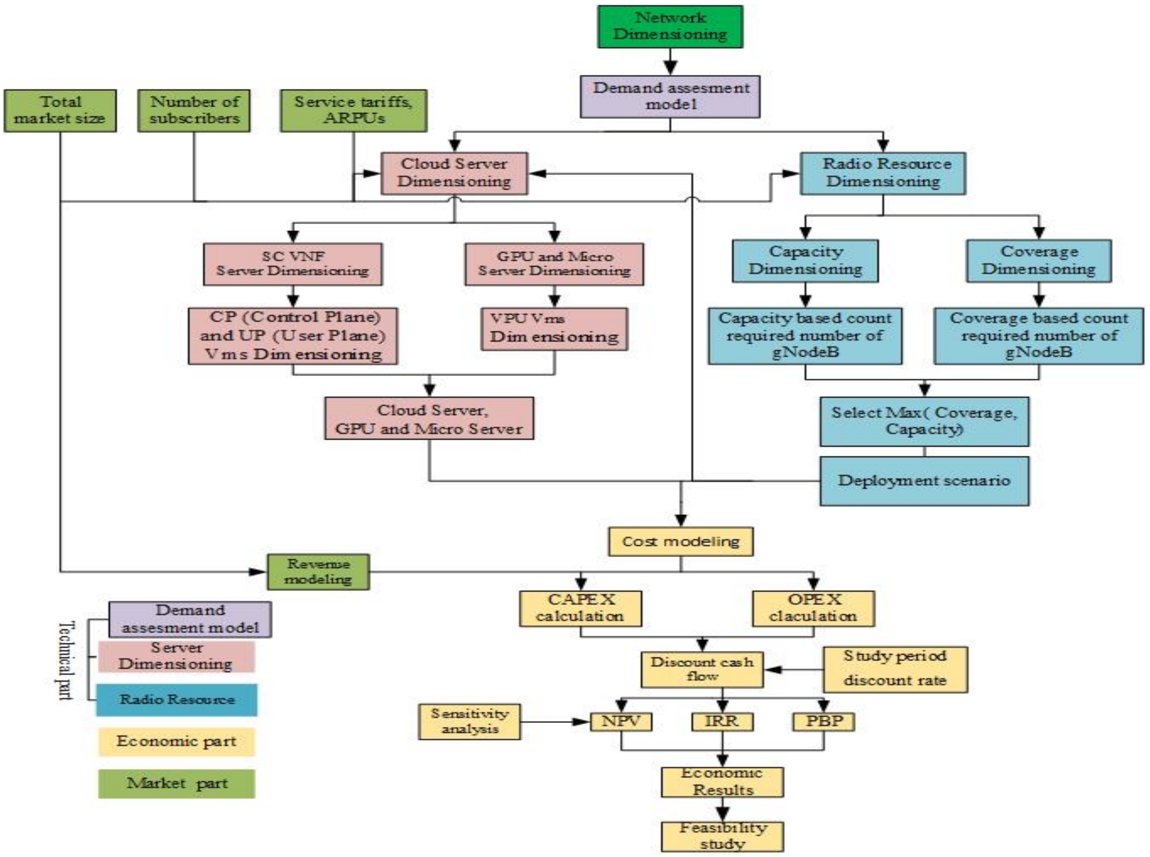


Figure 7.1: Modified and implemented techno-economic analysis model.

7.2 Deployment Site Selection for Cloud-Enabled Small Cell Networks.

This section discusses a case study that utilizes the proposed business feasibility framework. In the case study, we estimate the overall cost of building up and maintaining a mobile network with a 10-year network lifecycle using cloud-enabled small cell networks to deliver immersive media services at crowded events. Meskel Square and its surroundings is a 4-km-square (2 km x 2 km) service area in Addis Ababa and is considered for this case study. The area includes the Ghion Hotel, Stadium, Exhibition Centre, Meskel Square, and busy streets around Meskel Square as shown in Figure 7.2 [21], [61].

Meskel Square is, in practice, used for exhibitions, bazaars, markets, or vendors offering everything from fresh products and household items to advertising boards showcasing various goods and products to events. Events also include religious and public outdoor events, among others, such as the Meskel-Demera Religious Festival, which UNESCO has recognized as part of the world's intangible heritage [21], [61].

The research data from Ethio-Telecom demonstrates that an LTE advanced network already functions presently across 10-site operations within this study area. The current site serves as a study area because it operates 10 macro base stations with antennas split

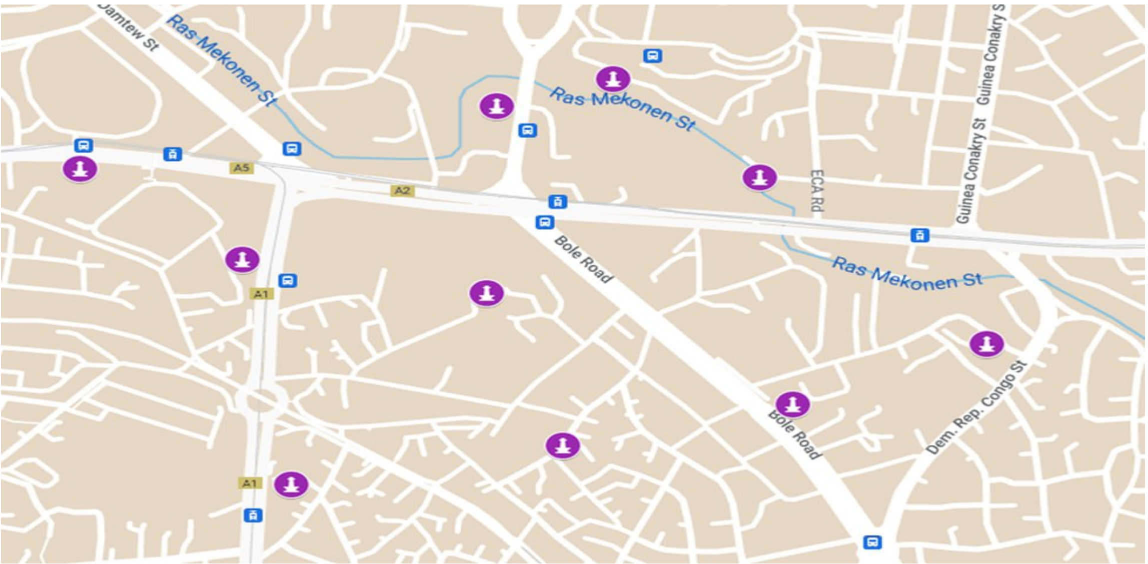


Figure 7.2: An LTE network in the area of Meskel Square in the city center of AA.

across three sectors [21]. 5G services operated by Ethio-Telecom are active on multiple sites throughout Addis Ababa [21]. Ethio-Telecom installs 5G active antenna units (AAUs) in Meskel Square inside its already deployed infrastructure. The 5G technology is implemented through dual connectivity with LTE and other generations by adding a 5G active antenna unit to the existing resource.

7.3 Immersive Media Service User Demand Forecast Analysis.

Immersive media solutions represent a series of tools, methodologies, and services intended to offer users some form of experience that is engaging and interactive [64], [65], [66]. The main focus of such solutions is to sink the user into a virtual environment totally so that they can engage with content or come across it in a more dynamic and realistic manner [64], [65], [66], [71]. One of the key factors driving demand for immersive media solutions in the market is rapid technological advancement. Advancements in VR, AR, MR, and 360-degree video have created the potential for even more realistic and immersive experiences. This allows users to be fully involved in the virtual environment, creating an interactive and engaging feeling that was not previously possible [64], [65], [66],[71].

Perform regression analysis using the collected market data to estimate parameters α, β, and γ based on the collected historical data and formula in chapter five in section 5.5.

Use the logistic model equation with the estimated parameters to forecast the demand for subscriptions for each year over the next 10 years.

Historical Data and Market Assumptions

According to Ethio-telecom 2022/23 Annual Business Performance report as shown in table 7.1 [63].

No.	Metric	Value
1	Total Subscribers	72 Million
2	Subscriber Growth	8%
3	Mobile Voice Subscribers	69.5 Million
4	Data and Internet Users	33.9 Million
5	Fixed Services Subscribers	853.6 K
6	Fixed Broadband Subscribers	618.3 K
7	Telecom Density	66.8%
8	New Mobile Sites	3,251
9	Additional Mobile Network Capacity	9.5 Million
10	2G Population Coverage	99.19%
11	3G Population Coverage	98.4%
12	4G/LTE Population Coverage	33%
13	5G Capacity	440 Thousand Customers
14	Fixed Broadband Capacity	228 Thousand Additional Customers
15	Tele-birr Subscribers	34.3 Million

Table 7.1: Historical Data from annual business performance report of Ethio-Telecom [63],

Suppose that we have to forecast the demand for a new technology AR/VR service in a market over 10 years. The service market usually starts small, grows at an increasingly rapid rate, and eventually saturates as most potential customers adopt it. Suppose we have historical demand data for the first 5 years, and we wish to forecast for the next 5 years. We also know that the total market saturation point, or maximum demand, is forecasted at about 31,875 users in the selected deployment area.

Initial guess for parameters form historical data

Suppose we have the following demand data (in units) for the first 5 years as shown in table 7.2:

Year (t)	Demand (Y)
1	1,000
2	3,000
3	8,000
4	12,000
5	15,000

Table 7.2: Demand Data Over Years (1 to 5)

Use the extended learning curve model to predict the price evolution of network components. Let's say, for example, the estimated parameters from regression analysis are α =1.5, β =0.5, and γ =1.5 , and the demand saturation level M is projected to be 31,875 (maximum market capacity in the area). We can then use the logistic model equation to forecast the demand for subscriptions for each year t over the next 10 years.

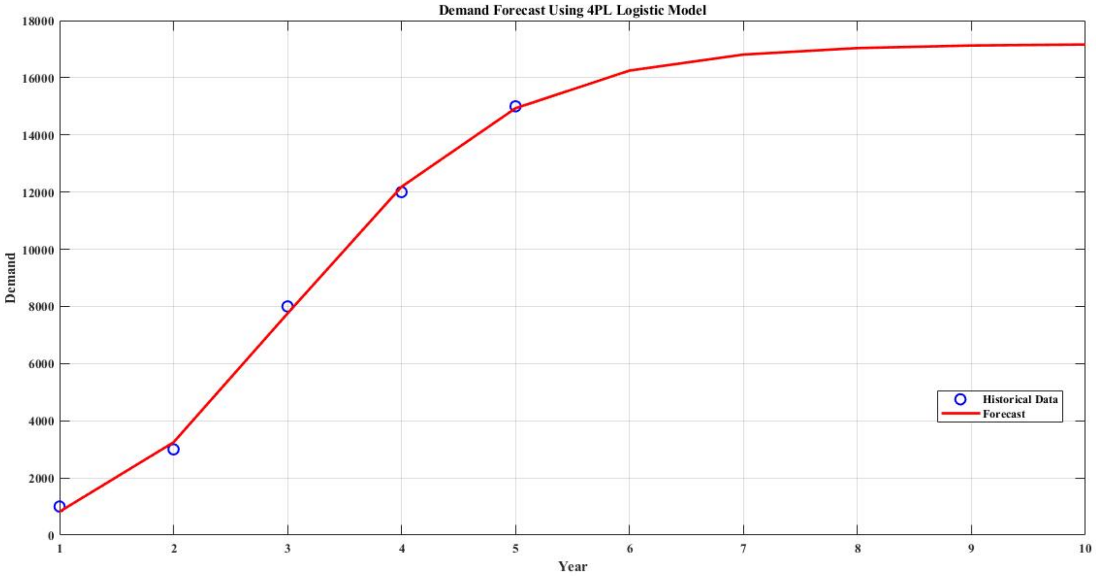


Figure 7.3: Extended learning curve model.

Using the optimized logistic model, the forecasted demand for the next 5 years (years 6 to 10) the following table

Year (t)	Demand (Y)
1	1,000
2	3,000
3	8,000
4	12,000
5	15,000
6	16,249
7	16,810
8	17,037
9	17,127
10	17,162

Table 7.3: Demand Data Over Years

After forcasting, let's say the optimized parameters M=17185.7101, $\alpha = 1.8932$, $\beta =$ -0.93823, γ =2.3757. This will provide an estimation of the percentage adoption at any given time t helping in planning and resource allocation for the forecasted demand [64].

From this graph, the demand for this new Immersive media service increases rapidly [64]. Initial production estimates are based on analysis of market demand, capacity, and historical data. Market research focuses on market size, adoption rate, and competitive landscape, all driven by economic factors of GDP growth and disposable income [64].

During big events, like the annual Meskel Festival, hundreds of thousands of people reportedly congregate around the area. Some put the figure between 255,000 and 320,000 per gathering, depending on the event and crowd density.Assuming Meskel Square's

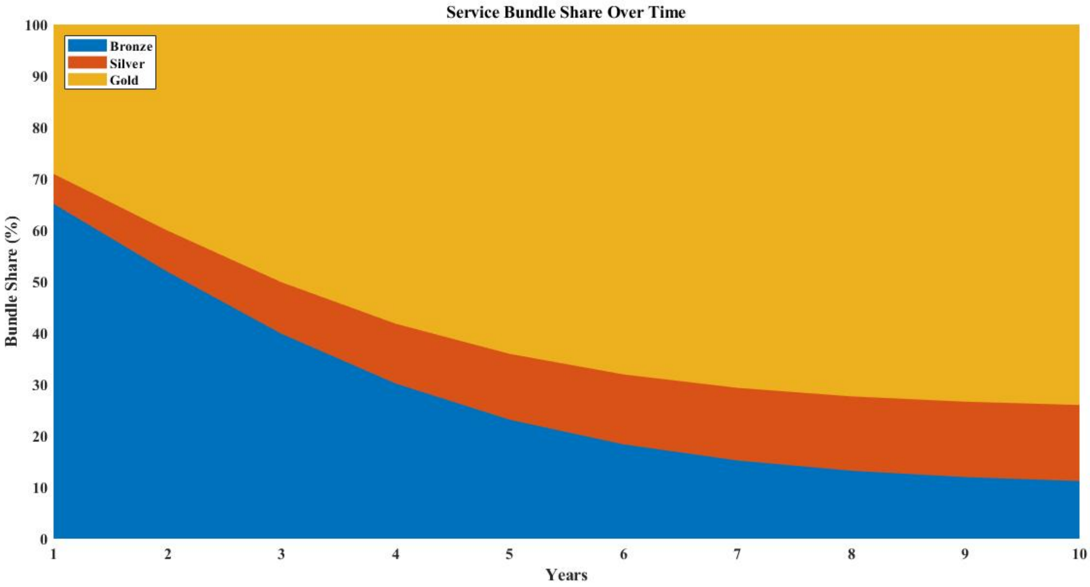


Figure 7.4: Service bundles with different SLAs.

255,000 attendees, among them, 31, 875 uses the AR/VR service for the following SLA [61]. It is mentioned that the initial bundle share should be 85% Bronze, 10% Silver, and 5% Gold. Over five years, it evolves to 10% Bronze, 15% Silver, and 75% Gold, as the capabilities of 5G push demand for high-resolution video [61], [64].

Because 5G technology will enable high-resolution video content, consumer preference is likely to move toward the higher-tiered Gold bundle over time as shown in figure 7.4. This means that the usage of the Bronze bundle will drop as users move on to Silver or Gold bundles [64], [71]. As demand increases, so will the load on the network, which requires additional 5G infrastructure and investments in new technologies such as edge computing [64], [71].

Year	Gold Share (%)	Silver Share (%)	Bronze Share (%)	Gold Users	Silver Users	Bronze Users
1	11.72	2.34	85.94	3733	747	27395
2	30.37	4.88	64.75	9681	1554	20640
3	53.72	8.52	37.76	17108	2715	12052
4	67.02	11.90	21.08	21361	3792	6719
5	72.84	13.70	13.46	23222	4368	4285
6	74.67	14.29	11.03	23820	4547	3508
7	75.23	14.47	10.31	23995	4610	3270
8	75.41	14.53	10.07	24052	4628	3195
9	75.48	14.55	9.97	24074	4634	3170
10	75.51	14.56	9.93	24083	4637	3155

Table 7.4: Share and User Data by Year

7.4 Deployment Scenarios

Following the discussed RAN Network Evolution and Architecture in chapter three and Network Deployment Scenario analysis for Immersive Media Service Provisioning at

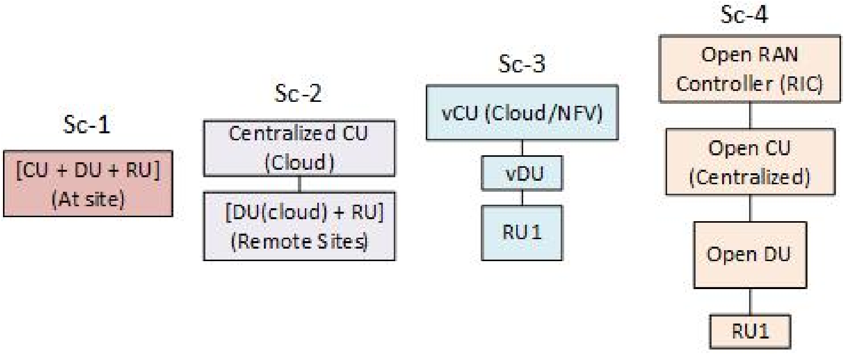


Figure 7.5: Deployment Schematic of each scenario

Crowded Events of the mobile network in chapter five, the formulated deployment scenarios for the Cloud RAN are presented below for further analysis as shown in table 7.5 . In this regard, four deployment scenarios have been formulated based on selected uncertainty extreme values. The formulated deployment options are also known as D-RAN (Distributed RAN) (Sc1), Cloud or C-RAN (Centralized RAN) (Sc2), vRAN (Virtualized RAN) Scenario 3 (Sc-3), and Open RAN Scenario 4 (Sc-4).

I. Scenario 1 (Sc-1) Distributed RAN (D-RAN):

Traditional RAN with Distributed BBU infrastructure using existing sites and densify with new additional site. In a distributed RAN, the BBUs and RRHs are co-located at each cell site. This traditional setup allows each cell site to operate independently, which might ease initial deployment but usually results in higher operation costs and multiple site management complexities. A single BBU or (CU and DU) components must be deployed in every site, which results in increased initial capital outlay and requires exclusive radio units for each location. The costs for site acquisition, along with power supply system installation, cooling technology, and site maintenance expenses fall under Site Infrastructure Costs.

II. Scenario 2 (Sc-2) Centralized RAN (C-RAN):

All BBU related assets will be Centralized and it enables resource pooling, through which efficiency and operation costs can significantly decrease. This is due to the centralization of the BBUs from the RRHs, remaining at cell sites in a centralized RAN. Further, it also allows much easier upgrades and better cell coordination.

Establishing a single BBU (CU and DU) pool provides the opportunity to decrease BBU infrastructure requirements. Deployment of RRHs at remote sites. Strong funding must be allocated to build high-speed fiber optic technology between remote radio units and their centralized baseband unit pool. The construction expenses for data center facilities that will contain clustered BBUs represent one type of cost.

III. Scenario 3 (Sc-3) Virtualized RAN(vRAN):

All BBU related assets will be deployed with Centralized and Virtual, Virtualized

RAN is one step further virtualizing the BBUs themselves onto generic hardware, not necessarily special equipment. This further allows for better flexibility, scalability, and cost savings; network functions would be deployed as software on commercial off-the-shelf servers.

Baseband Unit operations can be performed by virtual machines and containers through their software codes. The implementation of network function virtualization utilizes commercial off-the shelf hardware products which are named COTS. The implementation needs financial backing to integrate virtualization platforms with software license fees. To establish NFV infrastructure public organizations must allocate funding toward servers and storage systems together with networking equipment. Standard commercial hardware vRAN deployments enable operators to obtain operational gains and financial benefits by providing simple control of their network function deployments.

IV. Scenario 4 (Sc-4) Open RAN (O-RAN):

All RAN related assets will be Centralized, Virtual, and Open, is developed on the merit of centralized and virtualized RAN with the addition of open interfaces and interoperability between the equipment of different vendors. It will further provide an architectural road map toward higher flexibility and cost efficiency, thus encouraging innovation while decreasing dependency on single-vendor solutions. It finds its place as a future-proof solution for increasing network demands. These are scenes demonstrating the development of RAN deployment from traditional hardware-dependent setups to more flexible, cost-effective, future-ready network architectures.

Network infrastructure implementation requiring open interfaces generates expenses, while testing for vendor equipment compatibility leads to additional costs, and deployment of modular hardware components increases expenses similarly as the implementation of RIC platforms for real-time network optimization.

Deployment Scenario	scenario	Abbreviations	Description of Scenarios
D-RAN (Traditional RAN)	Scenario 1	Sc-1	Distributed
Cloud (C-RAN)	Scenario 2	Sc-2	Centralized
vRAN	Scenario 3	Sc-3	Centralized and Virtual
Open RAN	Scenario 4	Sc-4	Centralized, Virtual, and Open

Table 7.5: Deployment Scenarios of Various RAN Technologies

7.5 Technical Analysis

7.5.1 5G CESCN Coverage Dimensioning Analysis

The key coverage-related parameters needed to predict the MAPL are RLB inputs namely, transmitter and receiver characteristics, the propagation model, geographical information, and the coverage probability desired. Selection of the propagation model is one of the most decisive steps of this study. This thesis mostly relies on an empirical propagation model. Because it is a relatively simplistic model, it does not need accurate geographical data on the deployment area, such as the street width, the height of the building and the distance of the building separation. This makes it easier to use and more accurate for the selected area. Moreover, based on our information source of thesis, the operators also utilize this propagation model.

Parameter	Downlink	Uplink
Frequency (MHz)	28000	28000
Bandwidth (MHz)	400	400
UE to gNB Distance (m)	150	150
Average Building Height (m)	5	5
Average Street Width (m)	500	500
MIMO Scheme	4X4	4X4
Duplex Mode	TDD	TDD
Sub Carrier	12	12
Max Number of Resource Blocks	264	264
Sub Carrier Spacing (kHz)	120	120
Boltzmann Constant	1.38×10^{-23} mWs/K	1.38×10^{-23} mWs/K
Temperature (°K)	290	290
Cell Edge Reliability	85% (Power outage = 0.15)	85% (Power outage = 0.15)
User Environment	Outdoor	Outdoor
Cell Edge Data Rate (Mbps)	80 Mbps	80 Mbps
Shannon Capacity Scaling Factor (α)	0.6	0.6
Planning Area (km^2)	$4\,\text{km}^2$	$4\,\text{km}^2$

Table 7.6: Downlink and Uplink Parameters

These essential components describe millimeter-wave (28GHz) wireless link behavior in the table 7.6 through downlink and uplink focus. Wireless network design depends on the attributes that directly affect throughput rates and coverage areas both for dependable mobile signal reception and for transmission.

Parameter	Notation	Downlink	Uplink
gNB TX Power (dBm)	A	46	46
gNB TX Antenna Gain (dBi)	B	16	16
gNB RX Antenna Gain (dBi)	C	0	0
gNB TX Cable Loss (dB)	D	0	0
gNB RX Cable Loss (dB)	E	2	2
gNB Noise Figure (dB)	F	10	10
gNB Height (m)	-	10	10

Table 7.7: gNB Parameters

The parameters shown in table 7.7 and table 7.8 assists in describing critical features of gNB Parameters and UE Parameters (user devices) for wireless communication. We use these data points to work out signal power levels and network performance across all digital connections. According to wireless communication standards UE refers to the device on the user side that connects to base station gNB in 5G and eNB in 4G.

Parameter	Notation	Downlink	Uplink
UE TX Power (dBm)	G	23	0
UE TX Antenna Gain (dBi)	H	0	0
UE RX Antenna Gain (dBi)	I	0	0
UE TX Cable Loss (dB)	J	0	0
UE RX Cable Loss (dB)	K	0	0
UE Noise Figure (dB)	L	10	10
UE Height (m)	M	1.5	1.5

Table 7.8: UE Parameters

Various connectivity factors in Table 7.9 impact wireless link performance especially for mobile networks. These issues weaken wireless signal fidelity and lower the network's area and data transmission capability. All these parameters create mathematical models to handle the actual issues that wireless systems deal with in practice to deliver dependable network performance.

Parameter	Notation	Downlink	Uplink
Penetration loss (dB)	N	15	15
Foliage loss (dB)	O	2	2
Body block loss (dB)	P	3	3
Interference margin (dB)	Q	6	3
Rain/Ice margin (dB)	R	1	1
Slow fading margin (dB)	S	7	7
Thermal Noise Power (dBm)	T	-117.96	-117.96
Control channel overhead (dB)	U	2	2

Table 7.9: Loss Parameters

$$\text{Subcarrier Quantity} = \text{Subcarrier} \times \text{Max number of resource block} = 264 \times 12 = 3,168$$

$$N_{\text{thermal}} = 10 \times \log\left(K \times T \times B\right) = 10 \times \log\Big(1.38 \times 10^{-23} \times 290 \times 400\,\text{MHz}\Big) = -117.96\,\text{dBm}$$

$$\text{Receiver noise-floor} = \text{Thermal noise} + \text{UE noise figure} = -117.96\,\text{dBm} + 10\,\text{dB} = -107.96\,\text{dBm}$$

$$\text{Receiver Sensitivity} = N_{\text{thermal}} + \text{NF} + \text{SINR} = -117.96\,\text{dBm} + (-8.3\,\text{dB}) + 10\,\text{dB} = -116.26\,\text{dB}$$

$$\text{NF is the noise figure of the receiver (in dB)}, \quad \text{Noise Figure (dB)} = 10\,\text{dB}$$

$$\text{SNR is the minimum signal-to-noise ratio required (in dB) for proper detection.}$$

$$\text{SINR} = 10 \times \log_{10}(\text{SINR}_{\text{linear}})$$

where SINR_{dB} is the SINR value in decibels and $\text{SINR}_{\text{linear}}$ is the SINR value in linear scale.

$\text{SINR}_{\text{linear}}$ Shannon-Hartley theorem, maximum data rate Rbandwidth B and SINR as:

$$R = B\log_2(1 + \text{SINR})$$

$$\text{Thus, SINR} = 2^{\frac{R}{B}} - 1$$

$$R = B\log_2(1 + \text{SINR})$$

$$\text{Thus, SINR} = 2^{\frac{R}{B}} - 1$$

$$\text{Given the value of SINR: SINR} = 0.1487$$

$$\text{Maximum data rate} = 80\,\text{Mbps} \quad \text{and bandwidth is} \quad 400\,\text{MHz}$$

$$\text{SINR} = 10 \times \log_{10}(0.1487) = -8.3\,\text{dB}$$

$$\text{Subcarrier or processing gain loss} = 10\log(\text{subcarrier quantity}) = 10{\times}\log(3168) = 35\,\text{dB}$$

$$\text{EIRP} = A + B + C - E$$

Where:

$$A = \text{Tx output power} = 46\,\text{dBm}$$

$$B = \text{Tx antenna gain} = 16\,\text{dBi}$$

$$E = \text{Tx cable and connector loss} = 2\,\text{dB}$$

$$\text{Thus, EIRP} = 46 + 16 - 2 = 60\,\text{dBm}$$

MAPL = EIRP − Receiver sensitivity − control channel overhead + gNB TX Antenna Gain (dBi) - Penetration Loss - processing gain loss - Foliage loss (dB) - Body block loss (dB) - Interference margin (dB) - Rain/Ice margin (dB) - Slow fading margin (dB)

$$\text{PL} = 32.4 + 21 \cdot \log_{10}(d_{\text{3D}}) + 20 \cdot \log_{10}(f_c)$$

$$d_{\text{3D}} = \sqrt{d_{\text{2D}}^2 + (h_{\text{BS}} - h_{\text{UT}})^2}$$

$$\text{PL} = 32.4 + 10.5 \cdot \log_{10}(d_{\text{2D}}^2 + (h_{\text{BS}} - h_{\text{UT}})^2) + 20 \cdot \log_{10}(f_c)$$

$$d_{\text{2D}}^2 = 10^{\frac{\text{PL}-32.4-20\cdot\log_{10}(f_c)}{10.5}} - (h_{\text{BS}} - h_{\text{UT}})^2$$

$$d_{\text{2D}} = \sqrt{10^{\frac{\text{PL}-32.4-20\cdot\log_{10}(f_c)}{10.5}} - (h_{\text{BS}} - h_{\text{UT}})^2}$$

$$\text{DL: } \frac{107.26\,\text{dB} - 32.4 - 28.94}{21} = 2.2$$

$$d_{\text{3D}} = 10^{2.2} = 158.5\,\text{m}$$

$$d_{\text{2D}} = \sqrt{d_{\text{3D}}^2 - (h_{\text{BS}} - h_{\text{UT}})^2} = 158.3\,\text{m}$$

$$\text{UL: } \frac{110.26\,\text{dB} - 32.4 - 28.94}{21} = 2.3$$

$$d_{3\text{D}} = 10^{2.3} = 199.5\,\text{m}$$

$$d_{2\text{D}} = \sqrt{d_{3\text{D}}^2 - (h_{\text{BS}} - h_{\text{UT}})^2} = 199.3\,\text{m}$$

Parameter	**DL**	**UL**
MAPL (dB)	105.26	108.26
Cell radius range (m)	158.3	199.3

Table 7.10: Parameters for DL and UL

The MAPL and cell radius ranges are computed for both DL and UL respectively, based on the defined coverage input parameters. The obtained results for both cases are displayed below.

The coverage area for a 3-sector configuration with three directional antennas is:

$$A_{\text{sc}} = 1.949 \cdot R^2$$

$$A_{\text{scDL}} = 1.949 \cdot 158.3^2 = 48,839.8\,\text{m}^2$$

$$A_{\text{scUL}} = 1.949 \cdot 199.3^2 = 77,415.24\,\text{m}^2$$

SCs based on coverage area (N_{sc_a}) cover the entire area (A) of 4 square kilometers.

$$N_{sc_aDL} = \text{round}\left(\frac{4,000,000}{48,839.8}\right) = 82\,\text{gNodeB}$$

$$N_{sc_aUL} = \text{round}\left(\frac{4,000,000}{77,415.24}\right) = 52\,\text{gNodeB}$$

7.5.2 5G CESCN Capacity Dimensioning Analysis

In addition to the basic parameters and the mathematical approach described in the Chapter fourth part 4.2, the input parameters used for the capacity dimension are explained as follows in Table 7.11:

Aggregate Throughput

Aggregated throughput was calculated using the 3GPP TS 38,306 5G NR and the main parameters used to calculate the unit permeability summarized in Table 7.11.

$$T_S^{\mu} = \frac{10^{-3}}{14 \cdot 2^{\mu}} = \frac{10^{-3}}{14 \cdot 2^2} = \frac{10^{-3}}{56} = 17.857\,\mu\text{s}$$

$$\text{Throughput}_{\text{DL}} = 10^{-6} \cdot 8 \cdot \left(\frac{4 \cdot 8 \cdot 1 \cdot 948}{1024} \cdot 264 \cdot 12 \cdot \frac{1}{17.857 \cdot 10^{-6}} \cdot 0.86\right)$$

$$\text{Throughput}_{\text{DL}} = 10^{-6} \cdot \left(4 \cdot 8 \cdot 1 \cdot 0.92578125 \cdot 3,168 \cdot \frac{1}{17.857 \cdot 10^{-6}} \cdot 0.86\right) = 36,159.298\,\text{Mbps}$$

Parameter	DL	UL
Frequency	28GHz	28GHz
Bandwidth (MHz)	400 MHz	400 MHz
Overhead (OH)	0.14 (DL)	0.08 (UL)
Max. code rate (Rmax)	948/1024	948/1024
Number of carriers (J)	8	6
Number of Layers (V)	4	4
Scaling factor/signaled per band (f)	1	1
Max. number of Resource blocks	264	264
Sub-carrier per Resource block	12	12
Sub-carrier spacing	120 kHz	120 kHz
Symbol duration, T_s^μ (µs)	$T_s^\mu = \frac{10^{-3}}{14\cdot 2^\mu}$	$T_s^\mu = \frac{10^{-3}}{14\cdot 2^\mu}$
Numerology (μ)	2	2
Bits per Symbol from the modulation scheme	8	8

Table 7.11: DL and UL Parameters

$$\text{Throughput}_{\text{UL}} = 10^{-6} \cdot 6 \cdot \left(\frac{4 \cdot 8 \cdot 1 \cdot 948}{1024} \cdot 264 \cdot 12 \cdot \frac{1}{17.857} \cdot 0.92 \right)$$

$$\text{Throughput}_{\text{UL}} = 10^{-6} \cdot 6 \cdot \left(4 \cdot 8 \cdot 1 \cdot 0.92578125 \cdot 3,168 \cdot \frac{1}{17.857 \cdot 10^{-6}} \cdot 0.92 \right) = 29,011.53\,\text{Mbps}$$

Data Plan, User Category and Traffic modeling

User Category	Video resolution	Frames per Second	Bits per Pixel	Compression Ratio
Bronze	2K (2560x1440)	70	8	10
Silver	4K (3840x1920)	90	10	20
Gold	8K 3D (7680x3840)	120	8	15

Table 7.12: User Categories and Service Types

$$\text{Bitrate} = \frac{\text{Resolution width} \times \text{Resolution height} \times \text{Frame per second} \times \text{Bits per pixel}}{\text{Compression ratio}}$$

$$\text{Bronze bundle (2K)} = \frac{7680 \times 3840 \times 120 \times 8}{15} = 206.4\,\text{Mbps}$$

$$\text{Silver bundle (4K)} = \frac{3840 \times 1920 \times 90 \times 10}{20} = 331.776\,\text{Mbps}$$

$$\text{Gold bundle (8K)} = \frac{2560 \times 1440 \times 70 \times 8}{10} = 1,887.44\,\text{Mbps}$$

$$\text{Bronze (2K) data volume} = \text{Bitrate} \times \text{BH duration} = 206.4 \times 10,800\,\text{s} = 2,229,660\,\text{Mbits}$$

$$\text{Silver (4K) data volume} = \text{Bitrate} \times \text{BH duration} = 331.776 \times 10,800\,\text{s} = 3,583,180\,\text{Mbits}$$

$$\text{Gold (8K) data volume} = \text{Bitrate} \times \text{BH duration} = 1,887.44 \times 10,800\,\text{s} = 20,384,317\,\text{Mbits}$$

$$\text{Avg. Throughput per Subscriber (Mbps)} = \frac{\text{Total data volume}}{\text{BH duration} \times 30} = \frac{2,229,660\,\text{Mbits}}{10,800 \times 30} = 6.88\,\text{Mbps}$$

$$\text{Avg. Throughput per Subscriber (Mbps)} = \frac{\text{Total data volume}}{\text{BH duration} \times 30} = \frac{3,583,180\,\text{Mbits}}{10,800 \times 30} = 11.1\,\text{Mbps}$$

$$\text{Avg. Throughput per Subscriber (Mbps)} = \frac{\text{Total data volume}}{\text{BH duration} \times 30} = \frac{20,384,317\,\text{Mbits}}{10,800 \times 30} = 62.9\,\text{Mbps}$$

$$D_{\text{agg per gNodeB}} = D_g + D_s + D_b = 6.88\,\text{Mbps} + 11.1\,\text{Mbps} + 62.9\,\text{Mbps} = 80.86\,\text{Mbps}$$

Number of Subscribers

During big events, like the annual Meskel Festival at Meskel Square, hundreds of thousands of people reportedly congregate around the area. Some put the figure between 255,000 and 320,000 per gathering, depending on the event and crowd density [61]. Another source says that between 200,000-500,000 people, during the largest gatherings [61].

Normally, not everybody in the crowd is using their device at the same time. Based on several case studies, estimates are that 20-30% of the crowd may be active users during major events who utilize mobile data for streaming, social media, and communications. This number, however, may be higher depending upon the nature of the event [53], [55]:

Concerts/Sports: As high as 40% higher engagement.

Religious ceremonies: Fewer participants, at about 20% of the population.

This essentially means that with the use of immersive media, such as virtual and augmented reality, a large fraction of attendees participating in any event are successfully entertained [53], [55], [61]. Though the actual percentage may vary according to the event and the technology used, research on immersive media points out that it can enhance the experience for up to 70-80% of participants [53], [55], [61]. Let's take, for instance, 255,000 of which the crowd event participant 25% might be active users during major events, and from that, 50% of the population estimated that to be entertained using immersive technologies like virtual reality and augmented reality [53], [55], [61]. For this thesis by calculating the above assumed percentages the total users are 31,875.

Maximum Users per gNodeB (DL, UL)

$$U_{\max\,(\text{DL})} = \text{round}\left(\frac{36,159.298\,\text{Mbps}}{80.86\,\text{Mbps}}\right) = 447\,\text{users}$$

$$U_{\max\,(\text{UL})} = \text{round}\left(\frac{29,011.53\,\text{Mbps}}{80.86\,\text{Mbps}}\right) = 359\,\text{users}$$

Total Number of Sites (gNodeBs) required

$$N_{sc_u(\text{DL})} = \text{round}\left(\frac{U}{U_{\max}}\right) = \text{round}\left(\frac{31,875}{447}\right) = 72\,\text{gNodeBs}$$

$$N_{sc_u(\text{UL})} = \text{round}\left(\frac{U}{U_{\max}}\right) = \text{round}\left(\frac{31,875}{359}\right) = 89\,\text{gNodeBs}$$

From coverage-based site count (DL/UL) and Capacity-based site count (DL/UL), the former refers to the number of sites required to provide adequate signal coverage (geographical area) for the users to ensure they have reliable connectivity, regardless of traffic volume. The key goal here is to ensure that users can connect to the network in all areas. The latter, on the other hand, pertains to the number of sites that would be necessary to process the network's traffic demand-the number of users and the amount of data being transmitted. In this case, it is to make sure that the network has adequate capacity to carry peak traffic loads without congestion. Thus, for optimal network design and performance, 89 sites would be selected based on the best option for both download and upload requirements in the deployment area as depicted in table 7.13.

Category	Coverage Based Site Count	Capacity Based Site Count
Downlink (DL)	82	72
Uplink (UL)	52	89
Best Selected		**89**

Table 7.13: Required Number of gNB for coverage and capacity based site counts

Distribut and Centralized Unit Quantity The DU performs real-time baseband processing, which is latency-sensitive, and it needs to process data from multiple RRUs. Depending on processing capacity, load, geographical distance, and real-time load balancing, one DU can handle several RRUs. In this thesis, the typical ratio for DU to RRU is 1:10.

The CU, which handles high-layer processing, manages non-real-time processing and high-level functions such as mobility and session management. It can support a large number of DUs. In this thesis, the CU to DU ratio is 1:5.

$$\text{DU} : \text{RRU} = 1 : 10$$

$$\text{CU} : \text{DU} = 1 : 5$$

$$\text{DUs} = \text{round}\left(\frac{\text{Estimated total required cell}}{\text{Cells per DU}}\right) = \text{round}\left(\frac{89}{10}\right) = 9$$

$$\text{CUs} = \text{round}\left(\frac{\text{Estimated total required DU}}{\text{CUs per DU}}\right) = \text{round}\left(\frac{9}{5}\right) = 2$$

Cloud Server Dimensioning Analysis

Total Workload: The total number of tasks or resources required to manage a particular type of VNF at a specific time. Examples include a count nUE VMs of Media Streaming VNFs and count ncell VMs of Traffic Management VNFs.

VNF Capacity: The maximum of the total tasks or resources that one VNF is able to manage.

$$\text{Number of VNFs} = \frac{\text{Total Workload}}{\text{VNF Capacity}}$$

Media Streaming VNFs: Media Streaming VNFs are engaged in the reception, processing and delivery of multimedia content including audio or video to end user equipment commonly referred to as UEs. These functions usually include transcoding, adaptive streaming, buffering and managing of media session.

Traffic Management VNFs: Traffic Management VNFs enhance the data traffic flow in the network: maximizing resource usage sent over the network and enhancing as well managing the data traffic flow. They are so important in the management of the network issues such as load, congestion and quality of service parameters previously noted.

Session Handling VNFs: Session Handling VNFs are involved in creating, managing and also tearing down communication sessions between the UE and the network. This pertains to issues of user identities, services; duration of various sessions; and management of user requests.

Control VNFs: The Control VNFs are responsible for performing the control plane of the network. These are used for signaling, granting resources, managing connections and overseeing the running of the network. Control VNFs play a role of ensuring that data pertaining to the user is well dispatched while at the same time, ensuring that the resources in the network are optimally exploited.

OAM VNFs (Operations, Administration, and Maintenance): Specifically, Traditional OAM VNFs are used for purpose of network management, monitoring and maintenance. It offers compelling functions like, network health check, fault detection and correction services, network performance check and configuration services.

$$\text{Media Streaming VNFs} = \frac{\text{Total UE VMs}}{\text{Cell VM capacity per Traffic Management VNF}} = \frac{31,875}{10,000} = 4$$

$$\text{Traffic Management VNFs} = \frac{\text{Total Cell VMs}}{\text{UE VM capacity per Traffic Management VNFs}} = \frac{96}{100} = 1$$

$$\text{Session Handling VNFs} = \frac{\text{Total UE VMs}}{\text{UE VM capacity per Session Handling VNF}} = \frac{31,875}{11,000} = 3$$

$$\text{Control Plane VNFs} = \frac{\text{Total Cell VMs}}{\text{Cell VM capacity per Control VNF}} = \frac{96}{100} = 1$$

$$\text{Number of VNFs for OAM} = \frac{\text{Total UE VMs}}{\text{UE VM capacity per OAM VNF}} = \frac{31875}{31875} = 1$$

Number of CP VMs per VNF

$$VNF_{CP} = \frac{N_{CPVM}}{VNF_T} = \frac{50}{10} = 5$$

$$VNF_{UP} = \frac{N_{UPVM}}{VNF_T} = \frac{100}{10} = 10$$

Parameter	Value
Total number of virtual network functions (VNF_T)	10
Number of Control Plane VMs (N_CPVM)	50
Number of User Plane VMs (N_UPVM)	100
Required CPU cores per CP_VM (C_CP)	4
Required CPU cores per UP_VM (C_UP)	8
Required CPU cores for the gNB (C_gNB)	16
Required CPU cores for other auxiliary modules (C_OAM)	10
Number of CPUs per server (C_server)	32

Table 7.14: Virtual Network Function (VNF) and CPU Requirements

Cloud Server Requirements per VNF (SVNF)

$$S_{VNF} = \frac{((VNF_{CP} \times C_{CP}) \times (VNF_{UP} \times C_{UP}) + C_{CgNB} + C_{OAM})}{C_{server}} = \frac{(5 \times 4 + 10 \times 8 + 16 + 10)}{32} = 4$$

$$N_S = S_{VNF} \times VNF_T = 4 \times 10 = 40$$

GPU and Micro Server Dimensioning

$$\text{Arrival Rate}\, \lambda = 4,782\, \text{requests/sec (AR/VR requests arriving at the system).}$$

$$\text{Service Time per request}\, T = 0.001\, \text{seconds.}$$

$$\text{CPU usage}\, \rho = 0.75$$

$$\text{Service Rate}\, \mu = \frac{1}{T} = \frac{1}{0.001\, \text{sec}} = 1000\, \text{requests per second.}$$

$$C = \frac{\lambda}{\rho\mu} = \frac{4782}{0.75 \times 1000} = 7\, \text{GPU servers}$$

$$P_0\, \text{(Probability of no customers in the system)} = 0.472$$

$$L\, \text{(Average number of customers in the system)} = 870$$

$$W\, \text{(Average waiting time in the system)} = 0.18\, \text{seconds}$$

$$L_q\, \text{(Average number of customers in the queue)} = 865$$

$$\text{CPU usage}\, \rho = 0.75$$

$$\pi_i = 10^{-1}, \quad i = \frac{\log(\pi_i) - \log(1-\rho)}{\log(\rho)} = \frac{\log(10^{-1}) - \log(1-0.75)}{\log(0.75)} = 3$$

Therefore, the minimum quantity of RAM required to process i files can be calculated as:

$$\text{RAM (GB)} = 0.5 \times 3 + 6 = 8\, \text{GB}$$

Stream Generation Rate

We have a system where 4782 participants are streaming, and each participant generates a stream at an average rate of 0.001 streams per second, then the overall stream generation rate would be:

Parameter	Value
Average duration of video sequences (T)	60 seconds
Data rate for Silver users (D_s)	1 Mbps
Data rate for Gold users (D_g)	5 Mbps
Crowded Event duration (T_E)	3,600 seconds
Arrival rate of video files (λ)	4,782 files/s
Gold bundle users (U_g)	60%
Silver bundle users (U_s)	40%

Table 7.15: Video Streaming Event Data

$$\gamma^0 = 4782 \times 0.001\,\text{streams/sec} = 4.782\,\text{streams/second.}$$

$$C = T_E \times (\lambda_0 + \gamma^0) \times (U_g \times D_g + U_g \times D_s + U_s \times D_s) \times T$$

Since the gold users can uses both the gold bundle and the silver bundle in the above formula

$$C = 10,800\,\text{sec}\times(4782\,\text{files/sec}+4.782\,\text{streams/sec})\times(0.6\times5\,\text{Mbps}+0.6\times1\,\text{Mbps}+0.4\times1\,\text{Mbps})\times60\,\text{sec}$$

$$C = 3,600\,\text{sec} \times (4786.782\,\text{items/sec}) \times (4\,\text{Mbps}) \times 60\,\text{sec} = 4,135,779,648\,\text{Megabit}$$

$$1\,\text{Megabit} = 0.000125\,\text{Gigabytes}$$

$$C = 516.97\,\text{TB}$$

7.6 Market Analysis

7.6.1 Cloud Enabled Small Cell Network Dimensioning Result and Comparative Analysis

Depending on the prognosis of the user's growth, the user determines the maximum number of users to the cell space and is assumed that the load on the control plane on the connected device is believed to be constant. As a result, the number of devices is expected to continue to grow, but the signaling frequencies on the connected devices will not change in the network.

The device growth rate for this scenario is 2% CAGR (Compound Annual Growth Rate). This rate is minimal, since 5G and other disruptive technologies like IoT would be developed during this era. The number of cell sites for each year can be calculated using the compound annual growth formula based on this growth rate. This growth rate represents the expected increase in the number of devices or subscribers in the network during this period.

$$F_V = P_v \times (1 + r)^n$$

Where:

- F_V is the Future Value (number of cell sites in the future year),
- P_v is the Present Value (number of cell sites in the initial year),
- r is the growth rate per period (expressed as a decimal),
- n is the number of periods (number of years from 2026 to the future year).

For this scenario, $r = 0.02$ and n is the number of years from 2026 to the future year. This formula provides the projected number of cell sites for each year, which can then be used for network dimensioning and planning purposes [60], [67], [68], [69], [70], [73].

Year	Number of Cell Sites	RUs/RRU	DU	**CU**	No. of Servers
2025	89	267	9	2	40
2026	91	6	9	2	41
2027	95	12	9	2	43
2028	101	18	10	2	46
2029	109	24	11	2	50
2030	120	33	12	3	55
2031	135	45	13	3	62
2032	155	60	15	3	71
2033	182	81	18	4	83
2034	218	108	22	5	99
2035	266	144	27	6	120

Table 7.16: Year-wise Growth of Network Components (2025-2035) [60],[67], [68], [69], [70], [73].

Parameter Name	Variable Name	Cost per Unit (k$)
CAPEX		
Acquisition and installation cost of small cell mast on the site	C_{mast}	5
Single RU cost	C_{RU}	2
Cost of single DU/CU in terms of one physical server	$C_{\text{CU/DU}}$	6
DU/CU SW cost	C_{SW}	0.2
DU/CU SW License	C_{SWL}	0.2
Cabinet DU/CU	$C_{\text{Cabinet DU/CU}}$	1.5
Cost of a single CPRI	C_{CPRI}	0.08
Cooling unit cost for DU/CU	C_{cooling}	1.5
OPEX		
Annual renting cost of cell site (per site)	$C_{\text{site rent}}$	0.06
Software update, % of cost of software	$C_{\text{Software update}}$	5%
HW & SW maintenance (2% & 10% of equipment)	$C_{\text{maintenance}}$	2% & 10%
The power consumption of a single RU Power, W/h	$C_{\text{power RU}}$	500
Power consumption of a single DU/CU module, W/h	$C_{\text{power DU/CU}}$	400
Power consumption of the cooling unit, W/h	$C_{\text{power cooling}}$	500
Cost of energy W/h	$C_{\text{W/h}}$	0.0002
Annual OAM per site	C_{OAM}	0.075

Table 7.17: CAPEX and OPEX Cost Parameters of D-RAN [60], [67], [68], [69], [70], [73].

D-RAN is traditional RAN where each cell site has its own baseband unit (BBU) and remote radio unit (RRU). Simple to deploy, suitable for smaller networks, high CAPEX

Parameter Name	Variable Name	Cost per Unit (k$)
CAPEX		
Acquisition and installation cost of the small cell mast on the site	C_{mast}	5
Single RRU cost	C_{RU}	2
Cost of single DU/ virtual DU in terms of one physical server	C_{DU}	3
Cost of single CU / virtual CU in terms of one physical server	C_{CU}	5
Fronthaul and midhaul link cost	C_{FMhual}	0.1
DU/CU SW cost	$C_{(\text{DU/CUsw})}$	0.4
DU/CU SW License	$C_{(\text{DU/CUswl})}$	0.2
Cooling unit cost for DU/CU	C_{cooling}	5
Cabinet DU	$C_{\text{Cabinet DU}}$	0.5
Cabinet CU	$C_{\text{Cabinet CU}}$	1
OPEX		
Annual renting cost of cell site (per site)	$C_{\text{site rent}}$	0.06
Software update, % of cost of software	$C_{\text{Software update}}$	5%
HW & SW maintenance (2% & 10% of equipment)	$C_{\text{maintenance}}$	2% & 10%
Power consumption of a single RU Power, Wh	$C_{\text{power RU}}$	500
Power consumption DU, Wh	C_{DU}	200
Power consumption CU, Wh	C_{CU}	400
Power consumption of the cooling unit, W/h	$C_{\text{power cooling}}$	200
Cost of Energy W/h	$C_{\text{W/h}}$	0.0002
Annual OAM	C_{OAM}	0.05

Table 7.18: CAPEX and OPEX Cost Parameters of C-RAN [60],[67], [68], [69], [70], [73].

Parameter Name	Variable Name	Cost per Unit (k$)
CAPEX		
Acquisition and installation cost of the mast on the site	C_{mast}	5
Single RRU cost	C_{RU}	2
COTS HW Cost for vDU	$C_{(\text{COTS vDU})}$	0.4
COTS HW Cost for vCU	$C_{(\text{COTS vCU})}$	0.7
Fronthaul and Midhaul link cost	C_{FL}	0.1
DU/CU SW cost	C_{SW}	0.4
DU/CU SW License	C_{SWL}	0.2
Cooling unit cost for vDU/vCU	C_{cooling}	5
Cabinet DU	$C_{\text{Cabinet DU}}$	0.5
Cabinet CU	$C_{\text{Cabinet CU}}$	1
OPEX		
Annual renting cost of cell site	$C_{\text{site rent}}$	0.06
Software update, % of cost of software	$C_{\text{Software update}}$	5%
HW & SW maintenance (2% & 10% of equipment)	$C_{\text{maintenance}}$	2% & 10%
Power consumption of a single RU Power, Wh	$C_{\text{power RU}}$	500
Power consumption DU, Wh	C_{DU}	200
Power consumption CU, Wh	C_{CU}	400
Power consumption of the cooling unit, W/h	C_{cooling}	200
Cost of energy W/h	$C_{\text{power cooling}}$	0.0002
Annual OAM	C_{OAM}	0.05

Table 7.19: CAPEX and OPEX Cost Parameters of vRAN [60], [67], [68], [69], [70], [73].

and OPEX due to the need for separate BBUs at each site. Less interms of resource utilization [60]. C-RAN centralized the BBUs at the central location (BBU pool) while the RRUs remained distributed at the cell site. Due to shared infrastructure, improved resource utilization, and maintenance, CAPEX and OPEX were lower. Requires high-speed fronthaul links (e.g., fiber optics cables) to connect the BBUs to RRUs, which can be costly and complex to deploy [60]. vRAN is similar to C-RAN but uses virtualization technologies to run BBUs on generic (COTS) hardware rather than dedicated hardware. Flexibility in resource allocation, reduced hardware costs, and the ability to leverage cloud computing [60], [67], [68], [69], [70], [73]. Open RAN promotes interoperability and standardization by using different vendors' open interfaces and modular components. Reduce

Parameter Name	Variable Name	Cost per Unit (k$)
CAPEX		
Acquisition and installation cost of the mast on the site	C_{mast}	5
Single RRU cost	C_{RU}	1.5
DU (Distributed Unit) (O-DU)	C_{DU}	1.6
CU (Centralized Unit) (O-CU)	C_{CU}	2.8
Cabinet DU	$C_{\text{Cabinet DU}}$	0.5
Cabinet CU	$C_{\text{Cabinet CU}}$	1
DU/CU Software cost	$C_{(\text{softwareDU/CU})}$	0.4
DU/CU Software license cost	$C_{(\text{software license})}$	0.2
RAN Intelligent Controller (RIC)	C_{RIC}	3.5
Fronthaul and Midhaul	$C_{\text{fronthual}}$	0.1
5G NR Open RAN License	C_{license}	0.4
Cooling unit cost for vDU/vCU	C_{cooling}	5
OPEX		
Annual renting cost of cell site	$C_{\text{site rent}}$	0.06
Software update, % cost of software	$C_{\text{Software update}}$	5%
HW & SW maintenance (2% & 10% of equipment)	$C_{\text{maintenance}}$	2% & 10%
Power consumption of a single RU Power, Wh	$C_{\text{power RU}}$	700
Power consumption DU, Wh	C_{DU}	200
Power consumption CU, Wh	C_{CU}	400
Power consumption of the cooling unit, W/h	C_{cooling}	200
Cost of energy W/h	$C_{\text{power cooling}}$	0.0002
Annual OAM	C_{OAM}	0.05

Table 7.20: CAPEX and OPEX Cost Parameters of Open RAN [60],[67], [68], [69], [70], [73].

vendor lock-in, encourage innovation, and potentially lower costs through competition and the use of best-of-breed components [60], [67], [68], [69], [70], [73].

In a three-sector site, the number of RUs per BS is 3. Fronthaul, midhaul, and backhaul are all part of 5G transport networks, connecting cell sites to each other, then the core, and to data centers. The BBU in 5G is disaggregated into a CU and a DU. The fronthaul transport network in 5G interconnects the RRU or AAU with DU. Midhaul in 5G interconnects the CU to the DU and 5G backhaul to core is not be part of this study. In some instances, fronthaul and midhaul optical lines can be immediate distance to one another. Shorter distances are sometimes seen in very dense urban areas or in network topologies where the base station and distant radio heads or other network components are in closer proximity to one another. ITU forecasts mobile traffic by various service kinds' worldwide. Low values for such distances, like between the CU and DU in campus networks or data centers, allow the facilitation of much lower latency and, therefore, much better network performance in high-density locations. Assume the fronthaul and midhaul optical line length is 0.1 km for DRAN and 0.2 km for the other [60], [67], [68], [69], [70], [73].

RAN Architectures	CAPEX (k$)	OPEX (k$)	TCO (k$)
D-RAN	1,822.72	424.645	2,247.365
C-RAN	1,085.2	275.53	1,360.37
v-RAN	1,053.2	270.442	1,323.642
Open RAN	947.94	361.45	1,309.39

Table 7.21: RAN Architectures and Their TCO Costs

The first-year Radio Access Network (RAN) architecture cost analysis appears in Table 7.21 for 2025. The monetary values displayed show the necessary budget requirements for installing and supporting various RAN networks in a specific period.

7.7 Target Data Rates and Its Tariffs

The table 7.22, shows the different user classes, target data rates, and tariffs for IMS services: Ethio-Telecom changes the tariffs as may be required and usually reacts in response to alterations in operational cost, changes in the foreign exchange rate, and other economic considerations. Such tariff changes can occur any number of times. This thesis assumes that Ethio-Telecom typically revises the tariff once during the study period, considering inflation, the rise in operational costs, and the evolution of the economy. To maintain reasonably low-value packages on average, an upraise of 18% in data packages is expected.

Bundle	**User**	Data Rate (Mbps)	Tariff (Price per Event $)
Gold	Interactive VR, gaming, AR	5 Mbps	29.9
Silver	Immersive VR experiences	1 Mbps	7.5
Bronze	Streaming, movies	0.5 Mbps	4.2

Table 7.22: Service Bundles and Its Tariffs

Throughout this thesis, we assume that the current tariff has a long-standing existence for the upcoming five years, and the revision year will be 2031, continuing until the end of the study period in 2035. We can calculate the new tariff, which is an increase of 18%, by using the following formula:

$$\text{New Tariff} = \text{Original Tariff} \times \left(1 + \frac{\text{Percentage Increase}}{100}\right)$$

The crowded event service provider, on average, hosts six events annually, including the following: Meskel festival, Irreecha, Eid Al-Fitr, exhibitions, music festivals, and sports events.

The annual total cost can be calculated as:

$$\text{Annual Total Cost} = \text{Number of Events} \times \text{Service Bundle Tariff}$$

The annual revenue per service bundle ($) can be calculated as:

$$\text{Annual Revenue per Service Bundle} = \text{Service Bundle Users} \times \text{Service Tariff}\,(\$/\text{User})$$

To calculate the net revenue after a 15% tax deduction for each of these total revenues, we use the following formula:

$$\text{Net Revenue} = \text{Total Revenue} \times (1 - \text{Tax Rate})$$

where the Tax Rate is 0.15.

$$\text{ARPU} = \frac{\text{Total Revenue}}{\text{Number of Subscribers}} = \frac{36,218,864.65}{31,875} = 1,136.278\,\$$$

Chapter 8

Results and Discussion

This chapter presents the techno-economic analysis of results from various deployment scenarios for different RAN Architectures. Targeted to assess costs associated deployment Scenario listed in chapter seven in section 7.3, the data obtained from Ethiotelecom covers existing 4G and the current rollout 5G traffic data. In this case study, a ten-year study period starting from the year 2025 was considered. Currently, Ethiotelecom is operating with D-RAN architecture. Given all the available options for the most economic RAN architecture in this use case, based on TCO and economic metrics. The following sections will present the inputs used within the model in order to conduct the analysis, the chosen deployment option for the use case, results on network dimensioning in Chapter Seven, Section 7.4 and market analysis in Chapter Seven, Section 7.5. Discussion of the techno-economic aspects evaluation will be provided and some observations on the obtained results are presented.

8.1 Infrastructure Expansion Over the Course of the Project's Duration

Techno-economic model results for the network investments, operational expenditures, and revenues will be presented in this section based on chapter seven, section 7.1. It will also present the financial outcome, expressed by the financial indices discussed before.

The wholesale access would require investment in new cell sites, cloud servers, racks, switches, GPU servers, microservers, small cells, etc. A detailed interpretation of the quantities of these investments throughout the study is provided in figure 8.1. The network operator will deploy the network in steps, according to the development and deployment pace of 5G and IMS.

The investment components, configurations as shown in Figurethe 8.1, illustrates the growth of each component and shows the trends, patterns, and amount of investment in different components over time. The small cell network rollout's capacity planning, infrastructure construction, and resource allocation may all be better understood and

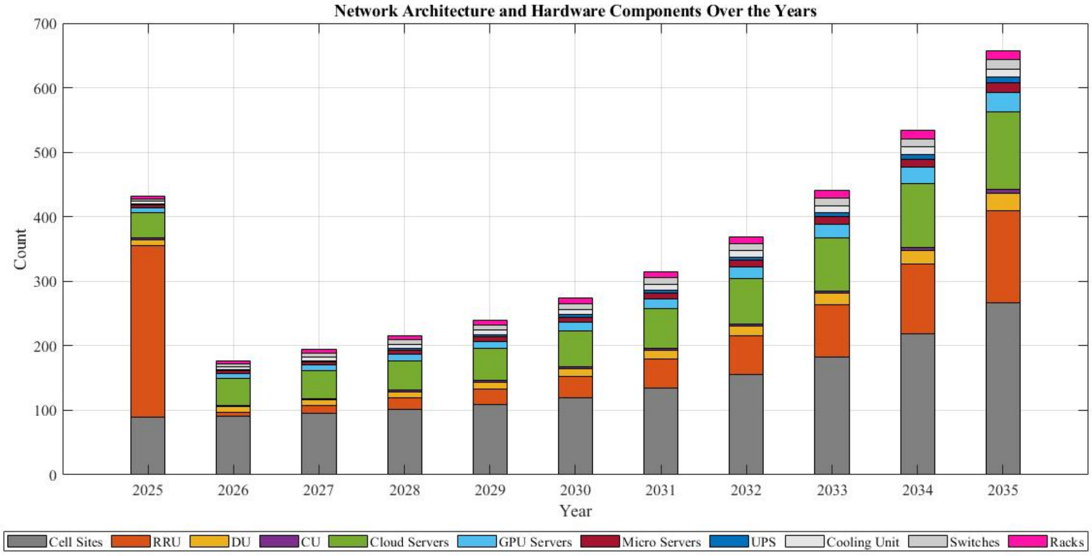


Figure 8.1: Required number of components during the lifetime of the project

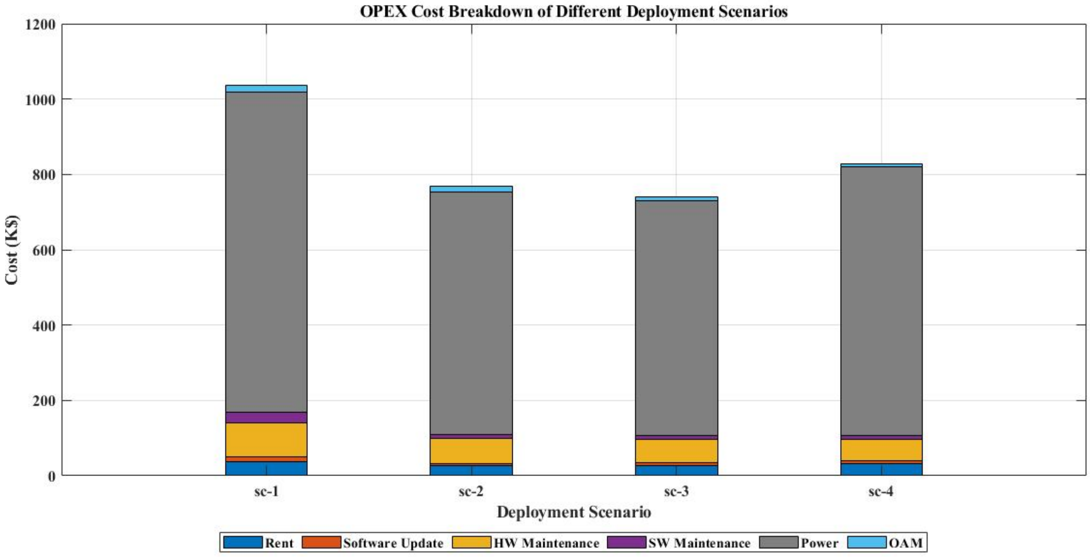


Figure 8.2: Opex cost breakdown over the deployment period.

decided with the aid of this figure.

The majority of OPEX is contributed by maintenance, site rent, OAM, power consumption cost, and Software update costs. D-RAN (Sc-1) has the highest overall OPEX, since the distributed nature of the network will make hardware maintenance more expensive and increase power consumption, and higher OAM costs due to managing a larger number of distributed units. C-RAN (Sc-2) thus, shows a reduction in HW Maintenance and Power costs compared to D-RAN, as it centralizes some of the functions so that the quantity of distributed units and associated costs are reduced. These are all due to a more centralized resource allocation, thus easier to reach, fewer sites, and cost-effective in operation. vRAN(Sc-3) By virtualizing some of the network functionalities, which would decrease HW Maintenance and Power costs, hardware is not that much needed. Since vRAN contains some more expensive software, the SW maintenance cost of vRAN is higher when compared to the other architectures. O-RAN (Sc-4) Offers further possibilities for OPEX optimization. As is, openness and the unbundling may provide more options for vendor flexibility or optimize elements, which is eventually better for HW Maintenance, SW Maintenance, and probably even OAM costs. As depicted in figure 8.2 of all the OPEX components, power consumption throughout the deployment period is the highest for all scenarios.

8.2 Economic Analysis Result

This section develops the economic analysis of CAPEX, OPEX, TCO, and revenues for each scenario. The outcome of the network dimensioning in chaper seven section 7.4 is a starting point to calculate the total cost of equipment required for each architecture. Based on assumptions made in each, this outcome gives the CAPEX and OPEX. Adding these amounts together provides the total Ccost of ownership (TCO) for the initial year investment.

8.2.1 Results of the CAPEX and OPEX Evaluation

The capital expenditure (CAPEX) and operational expenditure (OPEX) of four different deployment scenarios labeled "Sc-1," "Sc-2," "Sc-3," and "Sc-4.". The total estimated CAPEX ($k\$$) for the scenarios are as follows: Sc-1: 2,247.3, Sc-2: 1,085.2, Sc-3: 1,053.2, Sc-4: 947.94. Similarly, the total estimated OPEX ($k\$$) for the scenarios during the study period are as follows: Sc-1: 424.645, Sc-2: 275.53, Sc-3: 270.442, Sc-4: 361.45.

The initial year investment for each architecture are depicted in Figure 8.3, CAPEX apparently is the highest for Sc-1 and goes on decreasing in Sc-2, Sc-3, and Sc-4. That would mean the initial investment in Sc-1 is way higher compared to the other scenarios. OPEX also shows a decreasing trend from Sc-1 to Sc-3, while increase in Sc-4, some increase is due to the fact that power consumption is larger as compared to others. That

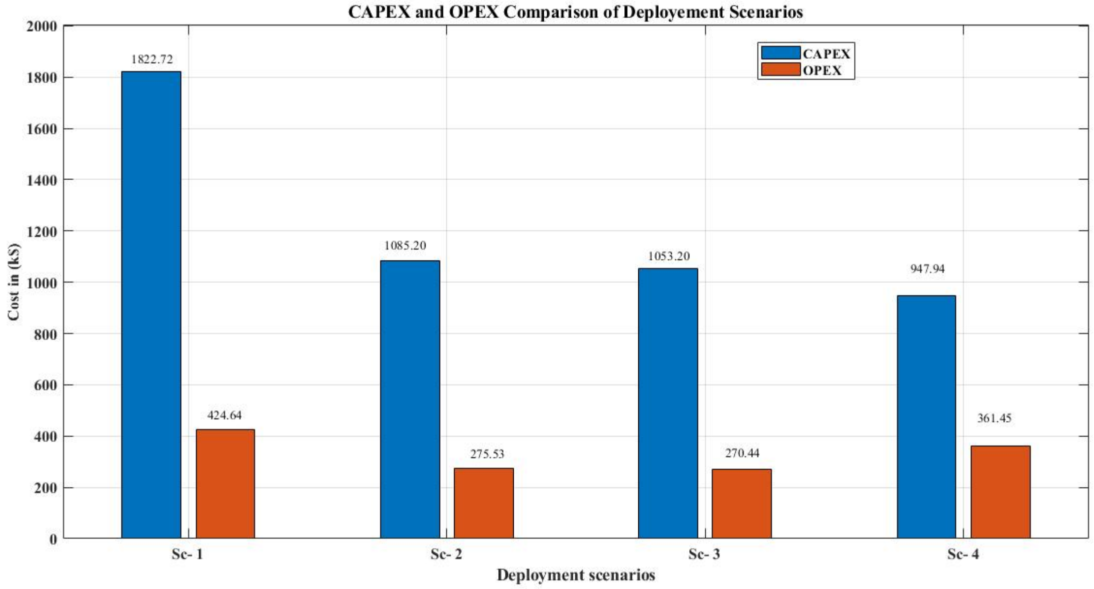


Figure 8.3: CAPEX and OPEX estimations for each deployment scenario.

means the operational costs that continue to be incurred are lower for the latter scenarios. Reductions in CAPEX and OPEX from Sc-1 to Sc-4 could be an indication that further optimization may be realized by the use of different approaches to deployment or the deployment of other technologies. These allows for easy comparison of total costs and the breakdown of CAPEX and OPEX for each scenario, useful during decision-making and planning.

I. Comparison of Percentage-Based CAPEX and OPEX Evaluation Results

Figure 8.4 depicted that, Sc-2 (C-RAN) has much lower CAPEX compared to Sc-1, which could be because of expected outcomes of cost reductions for infrastructure since there is centralization within the C-RAN. Sc-3 (vRAN) Further reduction of CAPEX is realized from the Sc-2 scenario to exhibit that virtualization can offer much more significant CAPEX saving. Sc-4 (O-RAN) much more CAPEX reduction possibly as a result of disaggregation in both hardware and software of O-RAN. This would enable further cost efficiency in component choice. OPEX of Sc-2 (C-RAN), presents a moderate OPEX reduction in connection with Sc-1; this was expected since C-RAN can reduce the operations' complexity and hence maintenance costs. Sc-3, presents a further reduction in OPEX due to reduced hardware maintenance and power consumption. Sc-4 based on O-RAN shows high OPEX reduction as compared Sc-1 and minimally increased in comparison to Sc-2 and Sc-3. This probably happens due to the opening of interfaces that will provide more advanced support of effective operations, software updates, and integration with third-party solutions. Among all those, v-RAN has the greatest potential to lower both CAPEX and OPEX compared to D-RAN. The enabling role is played by virtualization decreasing the cost of both CAPEX and OPEX.

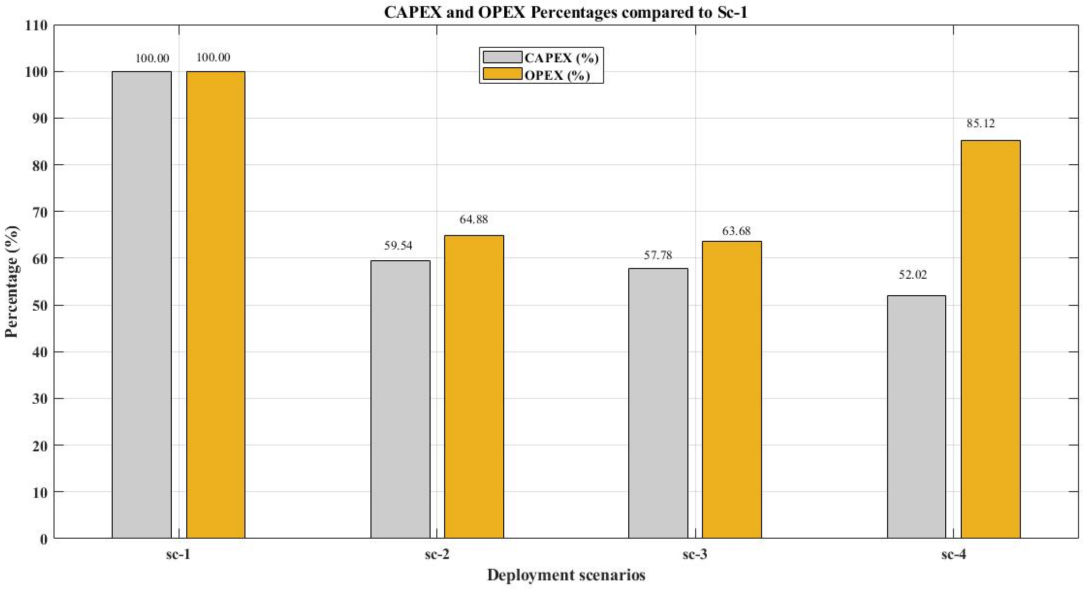


Figure 8.4: CAPEX and OPEX percentage comparison.

II. CAPEX Trends

All the scenarios increase at a gradual rate over the years. However, the increase itself is different in each scenario. Sc-1 increases faster initially, while Sc-4 increases much more gradually. Sc-1 has always stayed at the top in CAPEX over the years, indicating a higher initial investment and possibly continuing infrastructure costs. The CAPEX is the lowest in Sc-4 among all the scenarios, which means that this scenario has the lowest upfront costs associated with the deployment. The gradual growth of CAPEX in all scenarios indicates that ongoing investments are needed for network expansion based on new trafic increament as explained in chaper seven section 7.2 demand forecast analysis. The different trends of CAPEX in scenarios indicate that different deployment strategies may affect the overall investment as depicted in figure 8.5.

The CAPEX annual trend of each architecture is illustrated individually in the figure 8.5. Due to the fact that the D-RAN entails a fairly expansive hardwar investment in the first year of implementation, the start up costs are considerably higher to other types of structures. In the same manner, it as illustrated that the investment cost for all architectures decreases and gradualy grows in the study period. This pattern is expected as most new technologies are capital intensive and decrease in the subsequent years in the study period. The D-RAN got the higher share of the total investments for all the architectures. The rest is most cost effective in CAPEX relative to D-RAN, which is cheaper respectively in the scenario. In particular, the potential cost saving in hardware configuration as proposed by the D-RAN concept were counterbalanced by higher CAPEX costs.

III. OPEX Trends

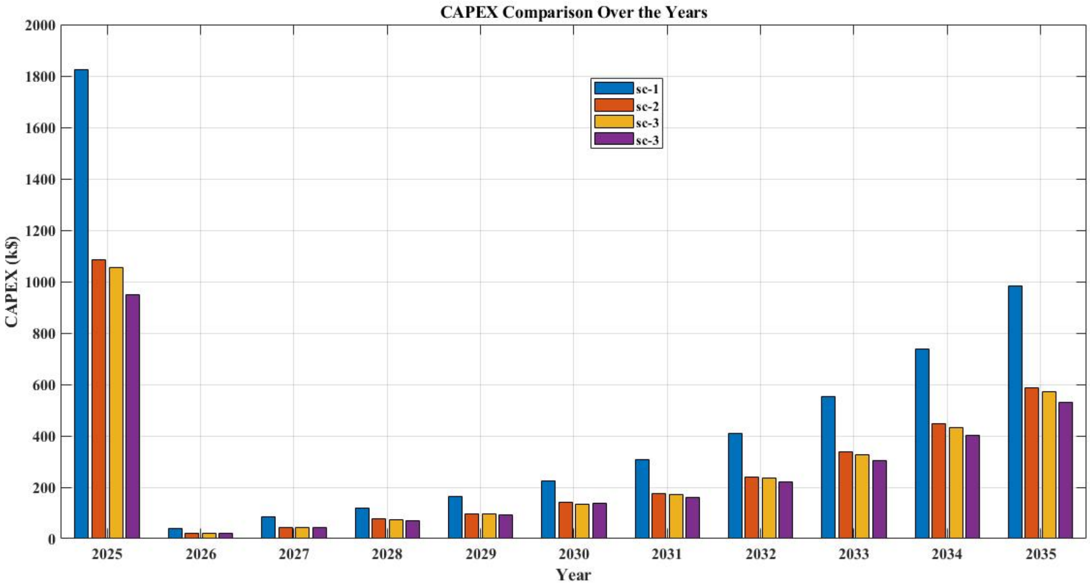


Figure 8.5: CAPEX cost trends for each architecture.

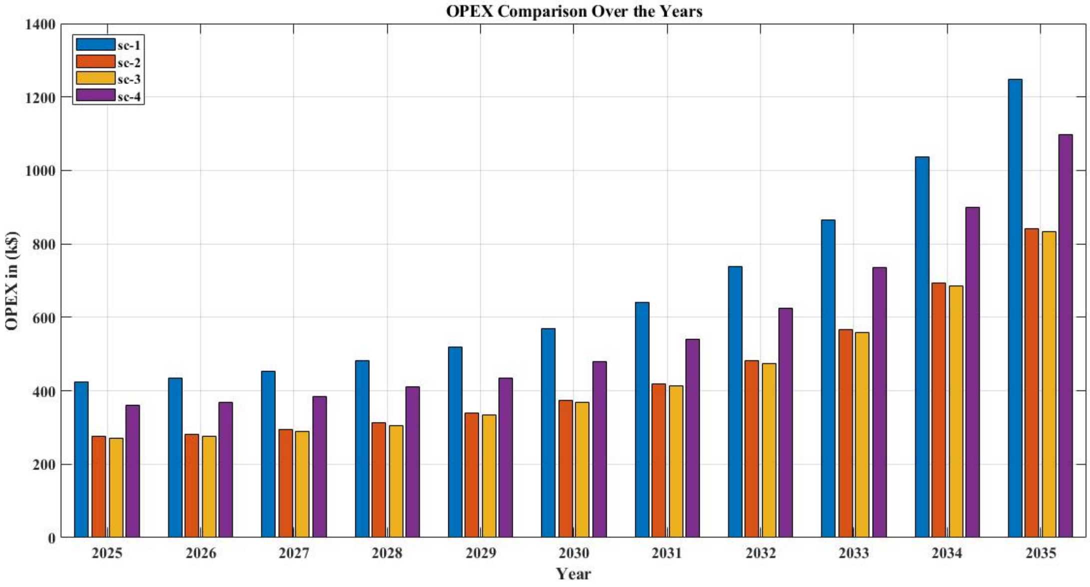


Figure 8.6: OPEX trends over the study period .

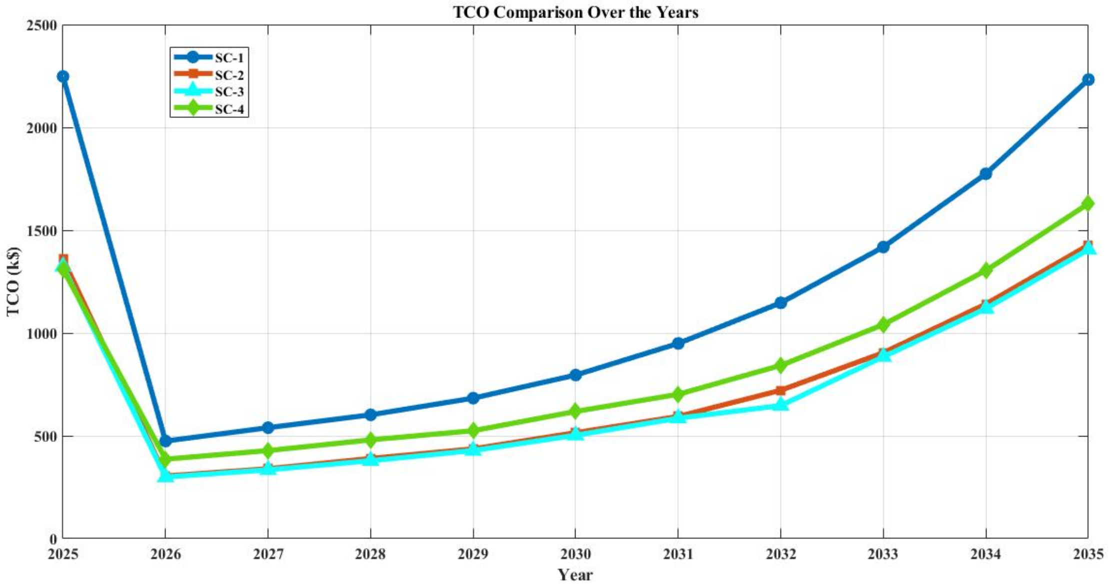


Figure 8.7: TCO trends for the architectures over the study period.

It has been realized that OPEX cost is a continuous cost and keeps on increasing with time, this is due to the reason that more and more network elements are added each year in order to meet the capacity demand of the network equipments that need to be installed. The cost of running a distributed architecture is worse than that of centrally designed architectures. This is very centralizing to the BBU split (CU/DU) as costs arising from site visit are greatly minimized. Based on the OPEX analysis of SC-2, better OPEX savings are obtained with the centralized architecture because of low maintenance, site rent, energy, and operation costs.

The figure 8.6 represents the cost breakdown of a service bundle with different service level agreements (SLAs). This plot represents the operating expenses trend over a period of ten years, starting from 2025 to 2034. The trend in these steadily growing operating expenses over the decade is very helpful in visualizing trends in the data, for instance, constant growth of the expenses perhaps due to many other factors related to inflation, expansion of services, or increasing operation activities.

IV . TCO trends

TCO of four different deployment scenarios over the years starting from 2025 to 2035 is depicted in figure 8.7. Sc-1 (D-RAN) it indicates high initial TCO and a gradual increase afterward. This reflects that there is high initial and expansion investment and as well as continuous operational expenses. Sc-2 has a lower initial TCO compared to Sc-1 and has a moderate increase with time. It reflects lower initial investment but possibly higher operational costs compared to Sc-3. Sc-3 (vRAN) Presents a lowest initial TCO than Sc-1, Sc-2 and Sc-4 and increases gradually over time. This indicates a lowest initial investment and possibly lower operational costs compared to Sc-1, Sc-2 and Sc-4. Sc-3 consistently

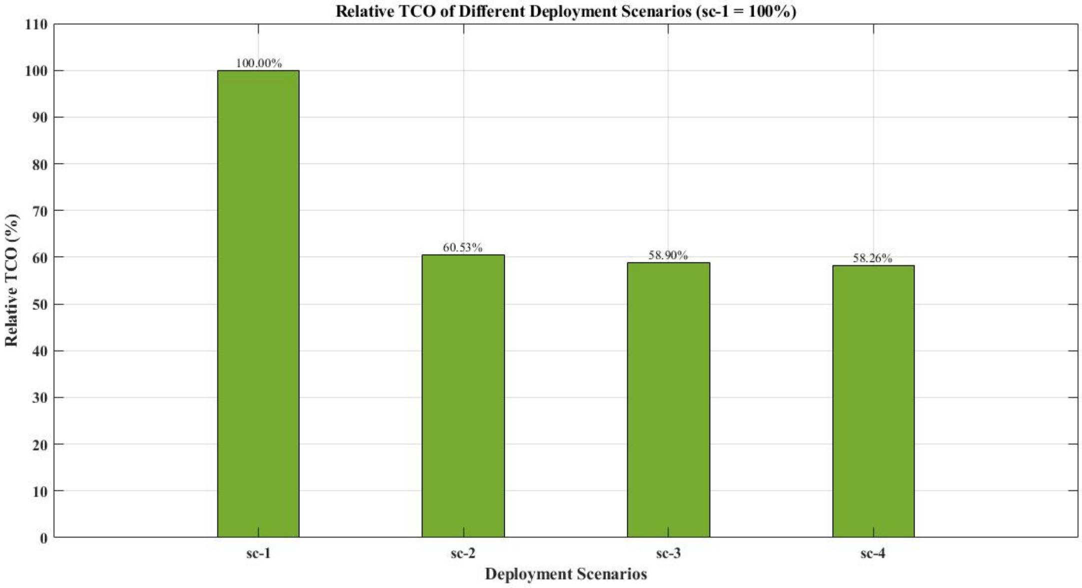


Figure 8.8: TCO change comparison for the deployment scenario.

has the lowest TCO across all years, which may indicate some cost advantages associated with this deployment scenario. SC-4 (O-RAN) has the lower initial TCO and maintains a relatively low and steady growth rate over the years as compaired with Sc-1. This is due to that Sc-4 has higher OPEX than Sc-2 and Sc-3. Sc-1 has the highest TCO for all cases, reflecting perhaps the potential cost implication of a D-RAN deployment. Sc-2 and Sc-4 present TCO values that fall in between Sc-1 and Sc-3, with generally lower TCOs for Sc-3 than for Sc-2. Figure 8.7 generaly illustrates the different TCO profiles that different deployment scenarios can have. Sc-3, vRAN, seems to provide the most promising TCO trajectory. The growing TCO over time for all scenarios testifies to the importance of long-term operational costs and possible further investments when strategies of deployment are considered. The differences in TCO trends likely reflect the cost implications of different technologies as explained in chaper three D-RAN, C-RAN, vRAN, O-RAN-in terms of infrastructure, expansion, maintenance, and operational expenses. CRAN, vRAN and open RAN each of these approaches advantages cloud technology in different ways, offering distinct advantages in terms of flexibility, cost efficiency, and performance. DRAN provides more traditional, localized network architecture, while still benefiting from improvements in coverage and capacity management. However, it tends to be more hardware-intensive than C-RAN or vRAN.

V. Relative TCO of Various Deployment Scenarios (sc-1 = 100%)

TCO of three deployment scenarios - sc-2, sc-3, and sc-4 - against a base line scenario, sc-1 =100%. The computed Relative TCO sc-2 is around 60.53%, which means its TCO is roughly 60.53% of the TCO of sc-1. This would therefore be a substantial cost reduction compared to the baseline scenario Sc-1. Relative TCO of Sc-3 about 58.90%, which further reduces the TCO compared to sc-2. Relative TCO of sc-4 is about 58.26%, similar to sc-3, which postulates that the TCO levels are about the same due to that Sc-4 has higher OPEX as compared to Sc-2 and Sc-3 as shown above section in OPEX comparison figure. Figure 8.8 shows how TCO costs can be drastically reduced compared to the baseline scenario (sc-1). This spread in Relative TCO values would likely reflect cost implications for various technologies represented by these scenarios. Sc-4 representing O-RAN, shows a dramatic reduction in TCO from the baseline-a possible indication of the cost benefits of O-RAN deployments in the inial year investment.

8.3 Analysis of Techno-Economic Evaluation Results

8.3.1 Analysis of Cash Flow and Revenue Results

A breakdown of investments (CAPEX) and running costs (OPEX) for the IMS-capable CESC (Cloud-Enabled Small Cell) infrastructure. Major contributors to costs are identified in chapter seven section 7.5. On the other hand, depending on industry norms and accessible data, revenue can be computed using the number of subscribers or other pertinent measures. Through the implementation of these pricing strategies and an analysis of their effects on user uptake, immersive media access services can maximize revenue creation in section 7.6. We must take into account the quantity of users subscribing to each bundle and the associated tariff prices in order to determine the income generation for the IMS (Immersive media service) based on the offered user bundles and tariff rates.

When evaluating investment prospects and their possible economic impact, financial measures are essential. Through the application of IRR, NPV, ROI, and PP to project evaluation, decision-makers can make well-informed choices that promote efficiency, sustainability, and economic growth.

Techno -economic analysis is used to evaluate the economic feasibility of any architecture. Techno-economic analysis was included in the outcome of the technical and costumed model and the defined discount rate (10 %) for the purpose of providing economic metrics such as NPV, IRR and return time. The method used is the analysis of cash flows (CF) and cumulative cash flow (CCF) and is discussed below.

I. Immersive media service netrevenue

To predict the revenue for immersive media in 2035 time period (T) 10 years, discount rate 10% per year and a 15% tax rate [17], [41]. The outputs of the models in each architecture will be some economic evaluation measures like NPV, IRR and PP [17], [41].

From 2026 through 2035 figure 8.9 reveals yearly revenue increasing steadily. Our total revenue keeps growing every year and jumps significantly from 2030 to 2031. The revenue is divided into four categories. The graph displays our business performance breakdown into Gold Revenue, Silver Revenue, Bronze Revenue, and Net Revenue. The bottom part presents Gold Revenue since it produces the largest portion of income. The

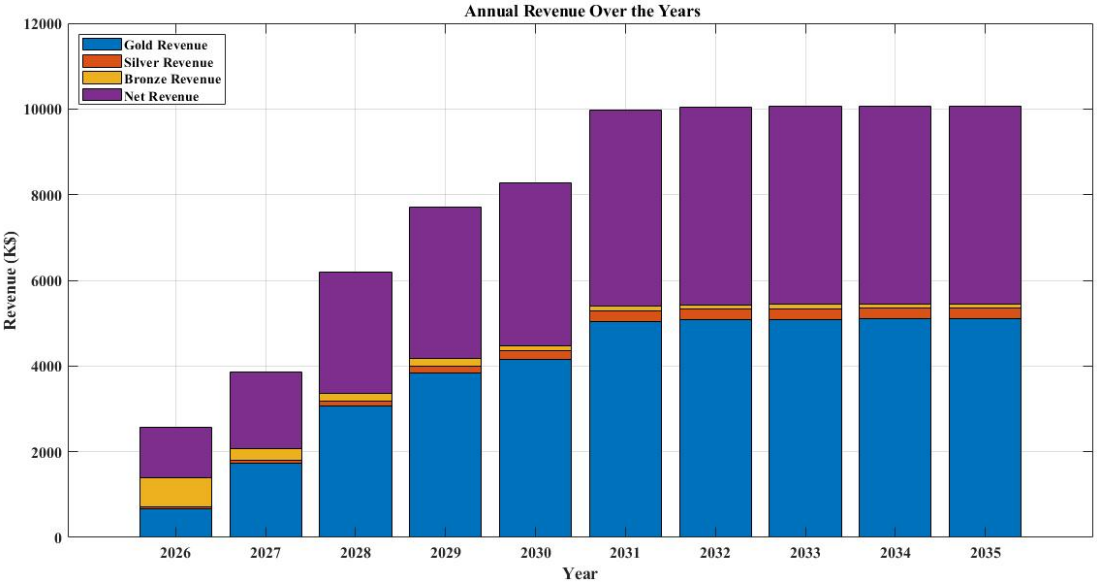


Figure 8.9: Annual Revenue Over the Years

total revenue line maintains its steady upward trajectory from 2026 through 2035. Silver Revenue is the second-largest component. Both economic segments show steady growth patterns throughout the studied periods. Bronze Revenue shows minimal change like the other parts yet generates less revenue than in other business segments. Over time, the gap between the revenue categories widens, demonstrating that gold generates more revenue than silver. While the revenue from bronze bundles is initially high, it steadily declines as people switch to silver and gold bundles as explained in chapter 7 section 7.2.

II. ARPU

Over nine years starting in 2026, figure 8.10 shows average net revenue (ARPU) growing strongly. A fast rise from 2026 to 2028 leads to steady growth up to 2031. ARPU plateaus at just 144.70 once the market reaches 2031. During 2026-2031 the graph shows quick revenue increases. After 2031 the graph shows its market growth is leveling off because it has reached market maturity according to these results.

III. Cash Flow Trends

All the scenarios are slightly negative during the earliest years of 2025-2026 to clearly depict significant CAPEX. Sc-1 (D-RAN) the time period, in which negative cash flow is observed may suggest that this option has higher initial costs compare to others. Sc-4 (O-RAN) this is the least negative of initial cash flow that makes it an indication that initial investments could be low. All the scenarios are positive after a few initial investment years, showing that revenues grow above costs. Cash flow for all scenarios increases in general with time, reflecting the growing revenue streams associated with network operations. As compared to Sc-4, the cash flow of Sc-1 is lower, which can be interpreted as a higher initial investment cost. Sc-4 presents faster transition into positive cash flow

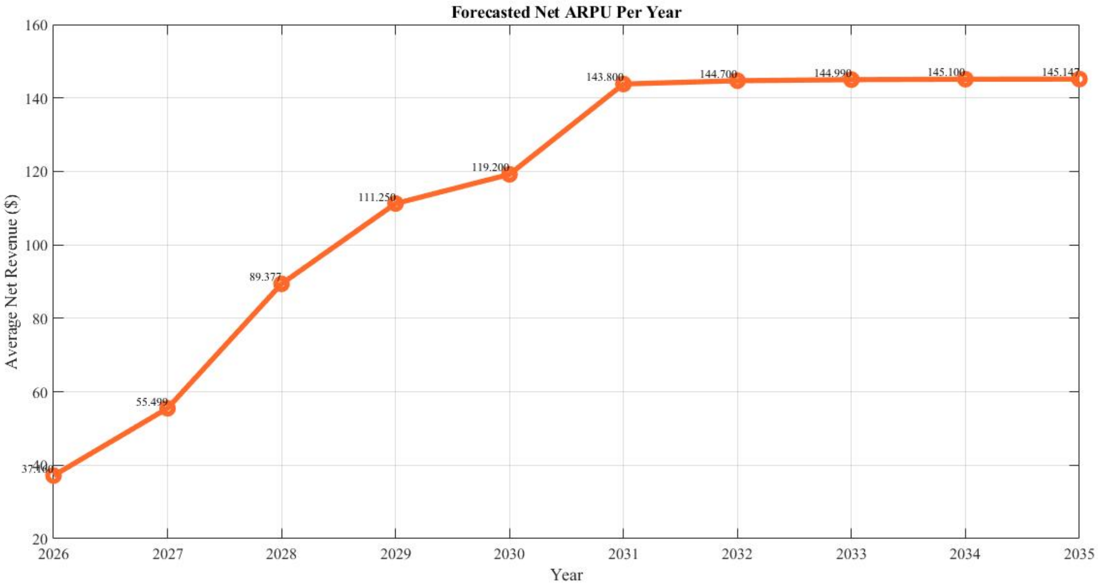


Figure 8.10: Forecasted Net ARPU Per Year

and higher cash flow generation along time . While Sc-2 (C-RAN) and Sc-3 (vRAN) present intermediate cash flow trends, Sc-4 could have faster ROIs given the low initial investment and higher revenues it generates as shown in figure 8.11. This increased cash flow, over time, emphasizes possibilities for long-term profitability and revenue growth in the sector of telecommunications.

a. Discounted Cash Flow (DCF)

Figure 8.12 displays how different RAN deployment plans called "sc-1," "sc-2," "sc-3," and "sc-4" generate Discounted Cash Flow (DCF) during the period from 2025 through 2035. The illustration (Figure 8.12) demonstrates how different RAN deployment methods generate cash flow through 2035 when the 10

Scenario Comparison:Deployment of D-RAN technology in Sc-1 demands greater upfront expenses than O-RAN in Sc-4. O-RAN technology reaches positive DCF results earlier than other technologies and produces more DCF over time. The DCF performance results for Sc-2 and Sc-3 lie between the other scenarios. Figure 8.12 reveals that all RAN deployment plans need major capital investment at their start. Sc-4 (O-RAN) reveals faster return on investment possibilities due to smaller upfront costs and stronger potential to generate more revenue.

b. Cumulative Cash Flows trend

Figure 8.13 provides an overview of the accumulated cash flow trend for various deployment scenarios. The information is of utmost importance to the decision makers in order to assess the financial viability and long-term profitability of each deployment scenarios. In Sc-1 (D-RAN) shows an initial negative steeper slope, representing higher initial investment costs. For the subsequent years, the slope gets flatter while the cash

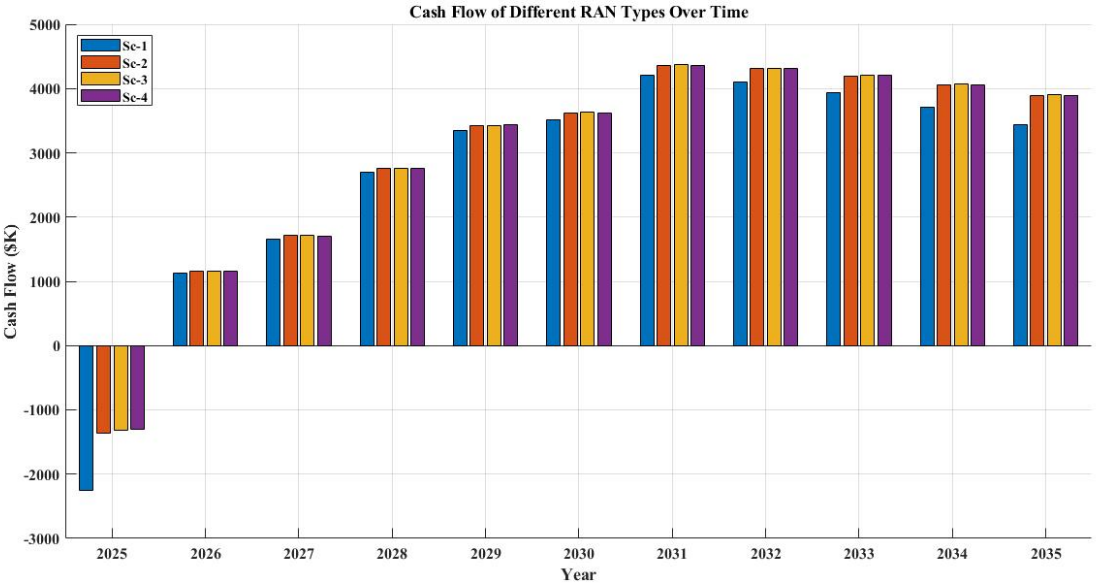


Figure 8.11: Cash flow analysis of the deployment architectures.

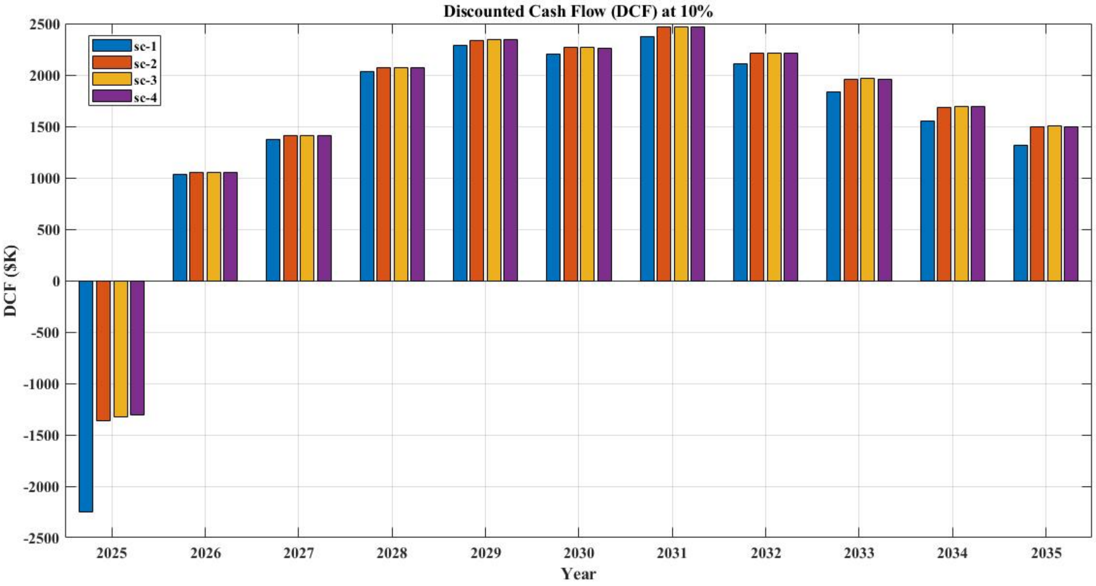


Figure 8.12: Discounted Cash Flow analysis of SC.

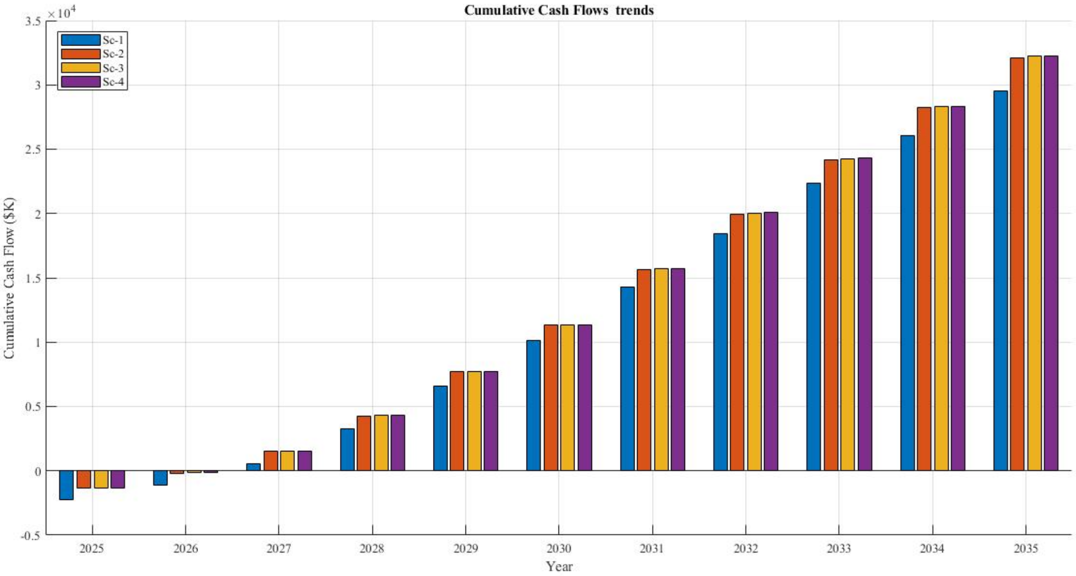


Figure 8.13: Cumulative cash flow analysis of SC.

flow increases gradually. Sc-2 (C-RAN) has a less steep initial negative cash flow slope, showing lower initial investment costs than Sc-1. Its cash flow keeps increasing over the years. Meanwhile, Sc-3(vRAN) depicts the lowest initial negative cumulative cash flow, which means the lowest initial investment costs. The cumulative cash flow will increase steadily over time. Sc-4 (O-RAN) has both the minimum initial negative cumulative cash flow in the early years and the maximum in later years, which indicates a faster return on investment and higher overall profitability. This figure represents the time taken by each case to recover the initial investment and start showing a positive cumulative cash flow. The fastest recovery can be shown by scenario Sc-4. Increasing cumulative cash flow with time for all scenarios gives proof of the possibility of long-term profitability and growth of revenue in the field of telecommunication. In all scenarios, Sc-4 has higher cumulative cash flow than other scenarios, which proves a potential for higher profitability and faster return on investment.

IV. Net Present Value (NPV)

Figure 8.14 allows the view of a comprehensive NPV of different scenarios for deployment, which is key for the decision-makers to gauge on the financial attractiveness of the different options available. This indicates that, at a discount rate of 10%, the project is financially feasible as it generates positive net cash inflows over the 10-year period as shown infigure 8.14. Therefore, the net present value (NPV) of the cash flows over the 10-year period indicates the present value of the project's future cash flows after accounting for the time value of money. The NPV is a computation made in finance to determine the present value of a stream of future cash flows. It is a means of comparing investments with various timings of cash flows. The logic of it all is that a dollar today

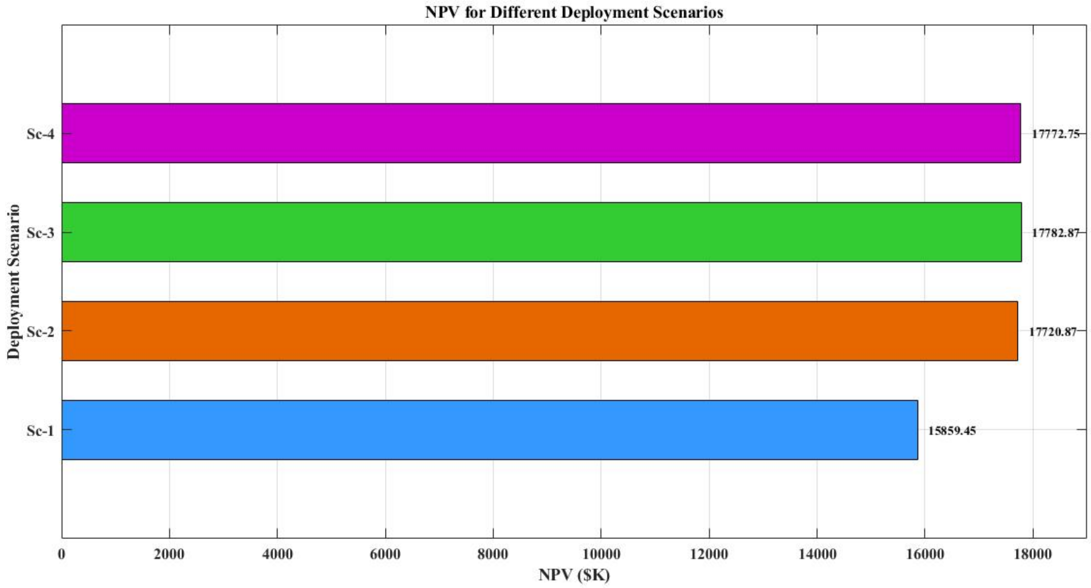


Figure 8.14: Net present value (NPV) of the deployment scenario.

is more than a dollar tomorrow, because of time value of money and the possibility of inflation.

Scenario Comparison: Sc-4 (O-RAN): Exhibits the highest NPV, meaning the highest NPV represents the maximum financial gain that the project can produce during its entire life cycle. Sc-3 (vRAN): Indicates the second-high NPV, indicating a good financial performance. Sc-2 (C-RAN): Shows a moderate NPV. Sc-1 (D-RAN): Demonstrates the lowest level of NPV and highlights consequent, fewer financial profits as compared to other situations. Financial Performance: NPV outcome of every deployed scenario in the context of financial profitability. Taking into account the financial metrics O-RAN's Sc-4 is projected to generate the greatest returns. Investment Decision-Making: NPV as the main tool for assessing the financial profitability of investment projects. The higher the NPV, the superior investment opportunity is described by figure 8.14. Technology Impact: It seems that the NPV fluctuation is due to the differences in NPV between technologies such as D-RAN, C-RAN, vRAN, and O-RAN according to their investment cost, operating cost and revenue.

V. Internal Rate of Return (IRR)

The other economic metric used is the internal rate of return (IRR). IRR is a discount rate that is used for project analysis or capital budgeting which makes the net present value (NPV) of future cash flows equal to zero. Investments with higher IRR and NPV values are assumed to be better investments. If two systems have equal ROI periods, IRR and then NPV will be used for comparison. Thus, all architectures would be financially viable in the future. Open-RAN achieved higher IRR value than the other architectures. We can use Microsoft Excel or any financial calculator to calculate the

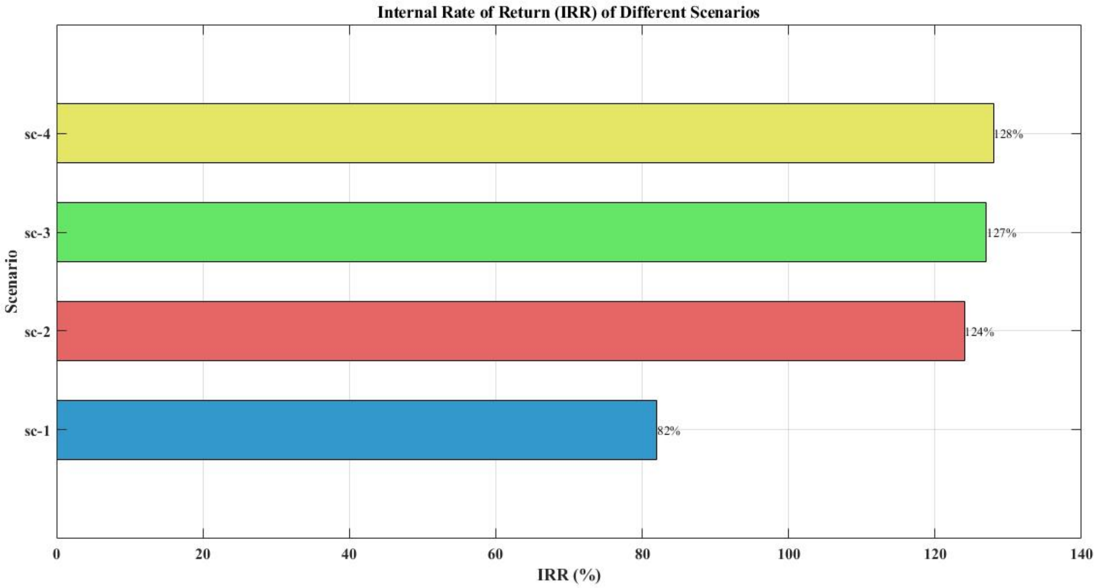


Figure 8.15: Internal rate of return (IRR) of the deployment scenario.

IRR of the cloud-enabled small cell. Note that the IRR calculation requires numerical methods or financial software to find the exact value. Uning HP12C Financial Calculator. Using initial investment value and each discount DCF mentioned above we can calculate it. The different IRR values as shown in figure 8.15 likely reflect the financial implications of various technologies-D-RAN, C-RAN, vRAN, and O-RAN-pertaining to initial investment, operational expenses, and revenue generation.

Scenario Comparison: Sc-4 (O-RAN): Present the highest IRR which means that this business plan will get the highest return of investment. Sc-3 (vRAN): Shows the second-highest IRR. Sc-2 (C-RAN): Shows a moderate IRR. Sc-1 (D-RAN): Demonstrates the lowest IRR that symbolizes lower rate on investment. Financial Performance: The IRR of each deployment scenario is indicated on the chart as a descriptor of the firms' financial results. Again, it is with regard to the payback that O-RAN shows the most promising of all, notably Sc-4. Investment Decision-Making: The concept of IRR is used in the assessment of the economic profitability of investment investment projects. It is the management's belief that projects with a higher IRR offer greater investment prospects. Technology Impact: This is probably due to the fact that profitable IRR values may represent the cost of a particular technology (D-RAN, C-RAN, vRAN, O-RAN) in the short term, the cost of operating with this technology, and the revenues obtained from it in the long term.

Generally, high IRR value (82%, 124%, 127%, and 128%) points to the project or investment earning considerable returns, as set against the cost. High IRR value will depend on a number of variables related to the nature of the investment, market circumstances, risk considerations, and time limit. However, with the increasing demand for interactive and engaging content, investment in immersive media services, such as virtual reality, augmented reality, and mixed reality, can be profitable.

VI. Payback Period (PP)

The return time is the time when cumulative income equals the initial investment. It is one way to evaluate the effectiveness of investment and evaluate how quickly the system and the purchased equipment will return its investment. PP is the time required for the inflow of cash from the project to equal the initial investment costs. Figure 8.16 provides an overview of the Payback Period relating to different deployment scenarios. Such information is very basic for the decision-maker, who has to assess the speed of recovery of investment and financial attractiveness of each option with respect to deployment scenarios. These values represent the payback period for each year. This indicates how many years it takes for the initial investment to be recouped based on the annual cash flows. The payback period obtained for D-RAN, C-RAN, vRAN and open RAN are 2.34, 2.048, 2.039 and 2.034 respec tively. This means, O-RAN achieved the lowest return on investment period, which is 2.034 years.

Scenario Comparison: Sc-4 (O-RAN): This one reveals the shortest Payback Period evidencing the shortest time needed to recover the initial investment. Sc-3 (vRAN): Demonstrates Payback Period of slightly longer than Sc-4. Sc-2 (C-RAN): Demonstrates a longer Payback Period than in Sc-4 and Sc-3. Sc-1 (D-RAN): Indicates the longest Payback Period to show a slow pace in regaining on the initial investment. Investment Recovery: SC-4 (O-RAN) reveal the shortest pay back period among all the options presented in the table. Financial Performance: Payback period which is calculated in terms of months is suggestive of the fact that smaller the number, the better is the prospects of the investment proposition. Technology Impact: The fluctuating Payback Periods may be attributed to how this approach-such as D-RAN, C-RAN, vRAN, and O-RAN- may incur in terms of initial cost, operating expenses, and profitability.

VII. Return on Investment (ROI)

ROI is a metric used to evaluate the profitability of an investment by comparing the gain or loss to the cost of the investment. It is typically expressed as a percentage. ROI (Return on Investment) and IRR are two different financial metrics used to assess investments. ROI measures the net gain or return on an investment relative to the cost. Figure 8.17 depicts the financial performance for each deployment scenario based on ROI. The Sc-4 O-RAN appears to offer the most interesting return on investment.

Sc-4 (O-RAN): Results in the highest ROI of 73.14%, hence revealing the most important aspect of return on investment. Sc-3 (vRAN): Demonstrates the second highest 68.92% of ROI. Sc-2 (C-RAN): Returns a relatively average of 66.85% of the amount invested. Sc-1 (D-RAN): Demonstrates the least outcome of the ROI test at 45.68%, thus meaning lower achievement and investment returns. Financial Performance: The chart also shows the total Return on Investment for each of the deployment scenarios. Taken

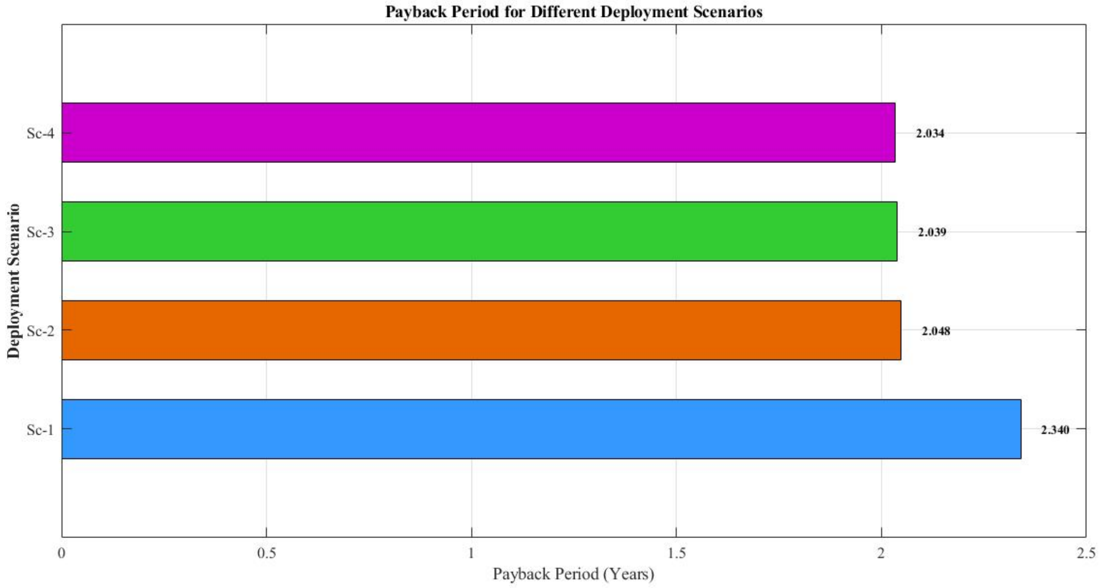


Figure 8.16: Payback period (PP) of the deployment scenario .

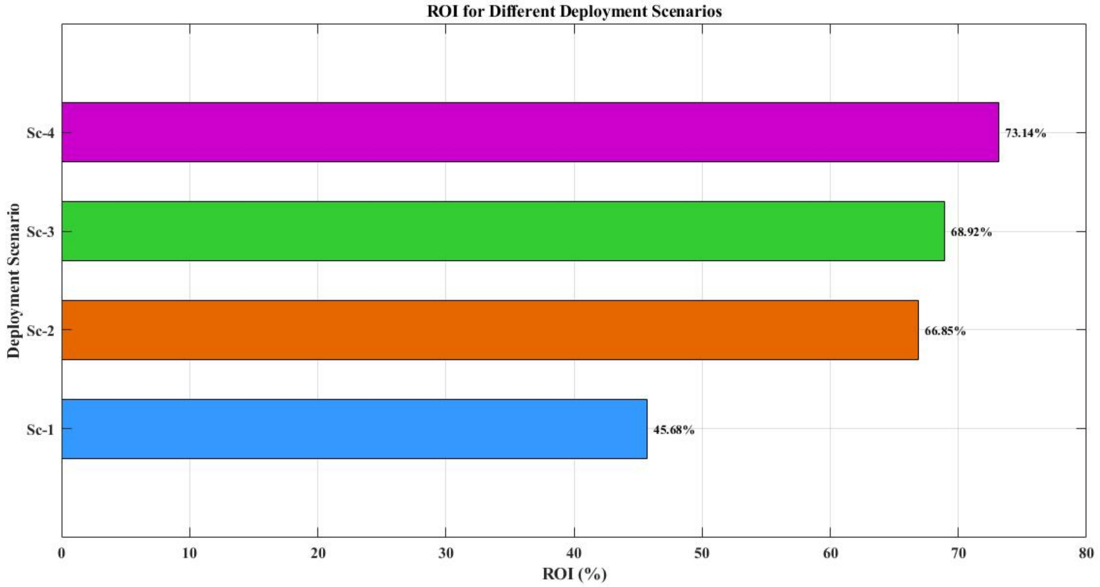


Figure 8.17: ROI of the deployment scenario.

in such a view, Sc-4 (O-RAN) seems to provide the highest potential for return on investments. Investment Decision-Making: ROI is and effective measure used for assessing profitability of investments on projects. More attractive is equal to a higher ROE Since this measures the rate of return on investment, a higher figure means the investment is more attractive.

Architecture	NPV ($)	IRR (%)	Payback Period (pp)	ROI (%)
D-RAN	15,859,453.8	82%	2.34 years	45.68%
C-RAN	17,720,867	124%	2.048 years	66.85%
V-RAN	17,782,868.7	127%	2.039 years	68.92%
O-RAN	17,772,754.5	128%	2.034 years	73.14%

Table 8.1: Comparison of architectures with financial performance indicators

8.4 Sensitivity Analysis

Sensitivity analyses were performed to assess the impact of altering input parameters on the project's NPV. Parameters considered include service fees (tariffs), stadium capacity, CAPEX, and OPEX. Services' fees are identified as the most sensitive parameter, with NPV showing improvement with tariff increases and potential marginal negativity with tariff reductions.

Various scenarios were run to determine the effect of changing the assumptions used in the input variables for calculating the NPV of the project. Variables are tariffs which are also described as service fees, the number of spectators the area can hold, fixed capital investments (CAPEX), and operating expenses (OPEX). Fees of services are found to be the most sensitive element in which NPV is likely to gain from tariff hike and likely to turn marginal negative with tariff cut. The results of sensitivity analysis reveal that particular attention should be paid to the rates of user adoption and the pricing of the new services. The user adoption leads to better NPV, IRR, and ROI of the service in addition, the result of service price escalation is a declining payback period, making it clear that they are pivotal to the project.

User Adoption

When user adoption is increased by 10%, the impact on NPV, IRR, payback period (pp), and ROI for each architecture is as follows: When user adoption is high, the NPV and ROI are great across the four architectures but especially so in the O-RAN. The periods of payback are also reasonably short suggesting early returns on investment.

By reducing the user adoption rate by 10% we get that the NPV and ROI are both reduced for all the architectures and D-RAN suffers the worst as for both metrics are concerned. we also find that payback periods and IRR are lower across the board, illustrating the cost of lower user adoption.

Service Pricing

Architectures	NPV ($)	IRR (%)	pp	ROI (%)
D-RAN	17,445,399.18	90.2	2.574 year	50.248%
C-RAN	19,492,953.7	136.4	2.478 year	73.535%
V-RAN	19,561,155.57	139.7	2.2429 year	75.8%
O-RAN	19,550,029.95	140.8	2.2374 year	80.45%

Table 8.2: Comparison of various architectures based on user adoption assumptions

Architectures	NPV ($)	IRR (%)	pp	ROI (%)
D-RAN	14,273,508.4	73.8	2.106 year	41.112%
C-RAN	15,948,780.3	111.6	1.8432 year	60.165%
V-RAN	16,004,581.83	114.3	1.8351 year	62.028%
O-RAN	15,995,479	115.2	1.8306 year	65.826%

Table 8.3: Comparing various architectures based on input assumptions

The result demonstrates that the increase of service prices by 5% eventually raises the NPV and ROI in all the examined architectures, with the highest improvement achieved by O-RAN. It also results in shorter payback periods hence pointing to rapid recovery of the investments made.

Architectures	NPV ($)	IRR (%)	pp	ROI (%)
D-RAN	16,652,426.49	86.1	2.457 year	47.964%
C-RAN	18,606,910.35	130.2	2.1504 year	70.1925%
V-RAN	18,672,012.135	133.35	2.14095 year	72.366%
O-RAN	18,661,392.225	134.4	2.1357 year	76.797%

Table 8.4: Evaluation of various designs' underlying assumptions based on service pricing

When service prices are lowered by 5% the results are In decreasing the price of services all the architectures experience a lower NPV and ROI. Nevertheless, the architectures have high financials even when the price has been cut down; O-RAN leading all the architectures in the panel.

Architectures	NPV ($)	IRR (%)	pp	ROI (%)
D-RAN	15,066,481.11	77.9	2.223 year	43.396%
C-RAN	16,834,823.65	117.8	1.9456 year	63.5075%
V-RAN	16,893,725.265	120.65	1.93705 year	65.474%
O-RAN	16,884,116.775	121.6	1.9323 year	69.483%

Table 8.5: Different architectures are compared using input assumptions.

Chapter 9

Conclusion and Future Work

9.1 Conclusion

Due to rapid increase of traffic load and further increase in demand for data rate on the mobile communication and low latency connectivity which are beginning to exert pressure on available network bandwidth and also entail. Innovations that can enhance the value of cost effective as well as energy effective answers. This requires a radical type of thinking and revolution on the design of mobile network and couple of it on the RAN architecture. In light of the fact that performs much better and cost significantly less than D-RAN, C-RAN, virtualized (vRAN) and open RAN is a basic building block new generation of mobile communications networks including 5G. The networks represented by Cloud RAN embrace the application of the concept of NFV based on the IT management tendency of cloud environment, virtualization, and automation. To investigate the feasibility of deploying the CESCN for serving immersive video service during CE, we conducted a technoeconomic analysisof DRAN, CRAN, and Open RAN, as presented in this paper.

For CAPEX, the largest components are cell sites, small cells RRU and cloud servers , and all of them have to be deployed in the edge infrastructure. Two major aggregates of OPEX are the power and hardware maintance costs. The investment will pay itself out after about 2.34, 2.048 , 2.039 and 2.034 years respctively for DRAN ,CRAN vRAN and open RAN according to our analysis. The techno-economic analysis used here in for identifying and describing the ‘ideal’ planning and economic models constituting is original and innovative in its own right; the results are drawn from results from funded research initiatives, including ISTTONIC and CELTICECOSYS. These tools have been applied successfully in several initial experiments carried out within the project. But limited validation of the overall model with testbed experiments in a real network operating in a real Crowded Event still poses research challenges and is outside the purview of this paper. The implementation and validation of the proposed technoe-conomic analysis for DRAN, CRAN, vRAN and Open RAN architectures is subject of ongoing research and results will be discussed in future work.

Such a use case of 5G networks is immersive video service provision at public events. The services provide real-time, high-quality media content for an enhanced user experience. The study proposes the distribution of IVS using a CESC network. The architecture leverages edge computing capabilities, thus assuring low latency and quality of user experience. Any new service must be financially viable first to cater to it. This paper assesses the viability of an investment in a 5G infrastructure for IMS. A set of financial return on investment indicators is assessed, including net present value, internal rate of return, and estimated payback period. Other miscellaneous mobile network carriers may lease capacity in the CESC network. This is an economically viable approach since it facilitates cost-sharing and optimal utilization of resources.

Our analysis focuses on four deployment scenarios using Distributed RAN and Cloud RAN networks. We tested each deployment scenario's financial success by assessing total costs of ownership while calculating financial metrics including NPV, IRR, and PBP using a 10% discount rate. We tested how adjusting CAPEX OPEX and revenue inputs affects the final outcome using extreme and optimal assumptions. Our analysis reveals that revenue impact remains high regardless of scenarios but CAPEX and OPEX exhibit minimal reaction to inputs even between extensive best and worst situations. Scenario 4 shows the fastest monetary return from investment during the study period. Our combined analysis of economic and technical factors shows we should apply scenarios that fulfill users' demands. From this study, we have concluded that the SC-4 is suitable and cost-effective for small urban areas and the SC-1 is designed if there is an existing infrastructure available to the business area where traffic data is rapidly increasing and exceeding the estimated data level; Otherwise, the SC-2 is preferred as comparable from the SC-1.

This work concludes and provides insights for small cell network operators who would like to provide state-of-the-art 5G media services at busy events. Given the techno-economic factors, the Mobile network operators can make knowledgeable decisions and affect the development of 5G networks.

9.2 Future Work

In this work, techno-economic analysis was carried out to assess the viability and competitiveness of the cloud cloud, which allows scenarios to deploy with a small cell network in providing the absorption access of video services to crowded events, as well as the techno-economic evaluation approach in this study was limited to the selected area. We can analyze rural and dense urban areas through different deployment setups that blend wireless and wired capabilities. We tested network planning only with mm-wave bands but future studies should explore low and mid bands using a distinct propagation model. Economic viability of different scenarios was determined using three financial metrics NPV IRR and PBP.

Another important dynamic involves price evolution and service penetration, which over time seriously affects IMS's ability to make money. In the future, actual deployed data will be integrated into economic models to enhance their accuracy. Observe the scalability of the proposed CESC model in supporting larger crowds and diverse event settings. This should be flexible enough to adapt to dynamically changing user demands and network conditions. Investigate techniques that can be used to ensure cost-efficiency while providing the highest QoS for IVS. A trade-off should be considered in resource allocation and QoS requirements. The laws and regulations that may influence the implementation of the CESC networks should be established. Legal and licensing matters have to be addressed if deployment is to be successful.

The techno-economic evaluation approach used in this work was restricted to the 3GPP TR 38.901 propagation model with Urban Micro-UMi and in the 28 GHz frequency band-Band n257-for immersive video service provisioning, based on the developed deployment scenarios. It can be further enhanced by taking into consideration other high-band mmWave like 39 GHz bands are considered for immersive services, given their high-capacity usage. It can also be further enhanced by the use of the common input and parameter modeling methodology to all cellular technologies.

References

[1] F. Tariq et al., "A Speculative Study on 6G," *IEEE Wirel. Commun.*, vol. 27, no. 4, pp. 118–125, 2020, doi: 10.1109/MWC.001.1900488.

[2] C. Cheevers, et al., "NGN PEC 1 - Virtual and Augmented Reality – How do they affect the current service delivery and home and network architectures?," *ARRIS Enterp. LLC*, 2016.

[3] P. Paglierani et al., "Techno-economic analysis of 5G immersive media services in cloud-enabled small cell networks: The neutral host business model," *Trans. Emerg. Telecommun. Technol.*, vol. 31, no. 2, pp. 1–20, 2020, doi: 10.1002/ett.3746.

[4] Ericsson, "Mobile Data Traffic," Ericsson Mobil. Vis., pp. 1–6, 2023, [Online]. Available: https://www.ericsson.com/en/reports-and-papers/mobility-report

[5] Internet Penetration in Ethiopia, Estimated, Available at: `https://www.google.com/search?q=Internet+penetration+in+Ethiopia+is+estimated&oq=Internet+penetration+in+Ethiopia+is+estimated&gs_lcrp=EgZjaHJvbWUyBggAEEUYOdIBBzc2MWowajeoAgCwAgA&sourceid=chrome&ie=UTF-8`

[6] Behailu Getachew Moges, "Techno-Economic Analysis of Cloud RAN Deployment Scenarios: in the Context of Ethio Telecom Addis Ababa, Ethiopia," 2022.

[7] Statista, Digital Connectivity Indicators for Ethiopia. Available at: `https://www.statista.com/outlook/co/digital-connectivity-indicators/ethiopia#internet`

[8] F. H. Tadesse and Ç. Erçin, "Assessing the user's needs in urban open space of Addis Ababa, Ethiopia," *Int. J. Adv. Appl. Sci.*, vol. 8, no. 7, pp. 106–114, 2021, doi: 10.21833/ijaas.2021.07.013.

[9] CEIC Data, Number of Mobile Subscribers in Ethiopia. Available at: `https://www.ceicdata.com/en/indicator/ethiopia/number-of-subscriber-mobile`

[10] M. Kourtis et al., "A Cloud-Enabled Small Cell Architecture in 5G Networks for Broadcast/Multicast Services," 2019.

[11] I. Giannoulakis et al., “System architecture and deployment scenarios for SESAME: Small cEllS coodinAtion for Multi-tenancy and Edge services,” in *IEEE NETSOFT 2016 - 2016 IEEE NetSoft Conf. Work. Software-Defined Infrastruct. Networks, Clouds, IoT Serv.*, pp. 447–452, 2016, doi: 10.1109/NETSOFT.2016.7502483.

[12] L. Goratti et al “The Role of Virtualization in the Small Cell Enabled Mobile Edge Computing Ecosystem,” in *Cloud Fog Comput. 5G Mob. Networks Emerg. Adv. Appl.*, vol. 1, pp. 728–733, 2017, doi: 10.1007/978-3-319-65172-9.

[13] P. S. Khodashenas et al., “The Role of Edge Computing in Future 5G Mobile Networks: Concept and Challenges,” *Cloud Fog Comput. 5G Mob. Networks Emerg. Adv. Appl.*, pp. 349–370, 2017, doi: 10.1049/pbte070e.

[14] P. Paglierani, I. Neokosmidis, T. Rokkas, and C. Meani, “Techno-economic Analysis of 5G Immersive Media Services in Cloud Enabled Small Cell Networks: The Neutral Host Business Model,” pp. 1–20.

[15] I. Neokosmidis et al., “Techno-economic Assessment of Immersive Video Services in 5G Converged Optical/Wireless Networks,” in *2018 Opt. Fiber Commun. Conf. Expo. OFC 2018 - Proc.*, pp. 1–3, 2018.

[16] Y. Shekhawat et al., “Orchestrating Live Immersive Media Services over Cloud Native Edge Infrastructure,” in *IEEE 5G World Forum, 5GWF 2019 - Conf. Proc.*, pp. 316–322, 2019, doi: 10.1109/5GWF.2019.8911681.

[17] I. Neokosmidis, P. Paglierani, and K. Moessner, “Assessment of CAPEX and OPEX for Media Services in Cloud Enabled 5G Networks,” in *2019 CTTE-FITCE Smart Cities Inf. Commun. Technol.*, pp. 1–6, 2019.

[18] J. S. Walia et al., “A Virtualization Infrastructure Cost Model for 5G Network Slice Provisioning in a Smart Factory,” *J. Sens. Actuator Networks*, vol. 10, no. 3, 2021, doi: 10.3390/jsan10030051.

[19] C. Colman-Meixner et al., “Deploying a Novel 5G-Enabled Architecture on City Infrastructure for Ultra-High Definition and Immersive Media Production and Broadcasting,” *IEEE Trans. Broadcast.*, vol. 65, no. 2, pp. 392–403, 2019, doi: 10.1109/TBC.2019.2901387.

[20] G. Smail and J. Weijia, “Techno-economic Analysis and Prediction for the Deployment of 5G Mobile Network,” in *Proc. 2017 20th Conf. Innov. Clouds, Internet Networks, ICIN 2017*, no. 2015, pp. 9–16, 2017, doi: 10.1109/ICIN.2017.7899243.

[21] S. G. Zeleke, B. B. Haile, E. T. Bekele, E. Mutafungwa, and J. Hämäläinen, “Data-Driven Multiobjective Optimization for Massive MIMO and Hyperdensification Empowered 5G Planning under Realistic Network Environment,” *Wirel. Commun. Mob. Comput.*, vol. 2023, 2023, doi: 10.1155/2023/7146912.

[22] D. Nicholson, *Ethiopia 2050.*

[23] Z. H. Chang et al “Distributed Video Transcoding on a Heterogeneous Computing Platform,” in *2016 IEEE Asia Pacific Conf. Circuits Syst. APCCAS 2016*, pp. 444–447, 2017, doi: 10.1109/APCCAS.2016.7803998.

[24] A. Checko et al., “Cloud RAN for Mobile Networks - A Technology Overview,” *IEEE Commun. Surv. Tutorials*, vol. 17, no. 1, pp. 405–426, 2015, doi: 10.1109/COMST.2014.2355255.

[25] P. Paglierani, C. Meani, A. Albanese, and P. S. Crosta, “Immersive Video Services at the Edge: an Energy-Aware Approach,” *Journal Name*, vol. 10, no. 3, pp. 145–154, 2017.

[26] SDxCentral. (n.d.). RAN Network. Retrieved from `https://www.sdxcentral.com/5g/ran/definitions/ran-network/`

[27] K. Bahram et al., “Survey on 5G Second Phase RAN Architectures and Functional Splits,” *IEEE Commun. Surv. Tutorials*, pp. 1–25, 2022. [Online]. Available: `https://ubibliorum.ubi.pt/handle/10400.6/12363`

[28] M. A. Habibi, M. Nasimi, B. Han, and H. D. Schotten, “A Comprehensive Survey of RAN Architectures Toward 5G Mobile Communication System,” *IEEE Access*, vol. 7, pp. 70371–70421, 2019. doi: `10.1109/ACCESS.2019.2919657`

[29] E. Explanation and M. Visualization, “Sign up on myMSC & Book Online D-RAN, C-RAN, vRAN and Open RAN,” pp. 1–5. [Online]

[30] L. More, “C-RAN vs Cloud RAN vs vRAN vs O-RAN vs traditional RAN - Guide!,” pp. 1–57, 2021. [Online]

[31] P. K. Thiruvasagam et al., “Open RAN: Evolution of Architecture, Deployment Aspects, and Future Directions,” pp. 1–28, 2023. [Online] Available: `http://arxiv.org/abs/2301.06713`

[32] X. Bai, “Scenario Analysis on LTE Mobile Network Virtualization,” no. July, 2013.

[33] M. A. Kourtis et al., “A Cloud-Enabled Small Cell Architecture in 5G Networks for Broadcast/Multicast Services,” *IEEE Trans. Broadcast.*, vol. 65, no. 2, pp. 414–424, 2019, doi: 10.1109/TBC.2019.2901394.

[34] M. Kist, “Radio and Baseband Unit Virtualization: Pushing the Boundaries of Future Mobile Networks,” no. August, 2020.

[35] C. Bouras, P. Ntarzanos, and A. Papazois, “Cost Modeling for SDN/NFV Based Mobile 5G Networks,” in *Int. Congr. Ultra Mod. Telecommun. Control Syst. Work.*, vol. 2016-Decem, pp. 56–61, 2016, doi: 10.1109/ICUMT.2016.7765232.

[36] M. Mahloo, J. M. Soares, and A. Roozbeh, “Techno-economic framework for cloud infrastructure: A cost study of resource disaggregation,” in *Proc. 2017 Fed. Conf. Comput. Sci. Inf. Syst. FedCSIS 2017*, vol. 11, pp. 733–742, 2017, doi: 10.15439/2017F111.

[37] A. Kostopoulos, I. P. Chochliouros, E. Sfakianakis, D. Munaretto, and C. Keuker, “Deploying a 5G Architecture for Crowd Events,” no. i, 2019.

[38] A. Albanese, “Grant Agreement No. 671596 Experimental Integration results of HW/SW modules of the overall SESAME framework,” no. 671596, pp. 1–63, 2017.

[39] I. Action, “Grant Agreement No. 671596 CESC Small Cell prototype and PoC,” no. 671596, pp. 1–63, 2017.

[40] A. Kostopoulos, I. P. Chochliouros, I. Giannoulakis, and A. Kourtis, “Small Cells-as-a-Service in 5G Networks,” in *2018 IEEE Int. Symp. Broadband Multimed. Syst. Broadcast.*, pp. 1–5, 2020.

[41] D. Dissertation, *Techno-Economic Assessment of Access Technologies*, 2015.

[42] F. Yaghoubi et al., “Techno-economic and business feasibility analysis of 5G transport networks,” in *Opt. Wirel. Converg. 5G Networks*, pp. 273–295, 2019, doi: 10.1002/9781119491590.ch13.

[43] P. H. Kobos et al., *Techno-Economic Analysis: Best Practices and Assessment Tools*, no. December, 2020.

[44] M. M. Rahman, C. Despins, and S. Affes, “Analysis of CAPEX and OPEX benefits of wireless access virtualization,” in *2013 IEEE Int. Conf. Commun. Work. ICC 2013*, pp. 436–440, 2013, doi: 10.1109/ICCW.2013.6649273.

[45] J. Harno, “Techno-Economic Analysis of Beyond 3G Mobile Technology Alternatives,” July, 2007.

[46] A. Reesom Bisrat, B. B. Haile, E. Mutafungwa, and J. Hämäläinen, “Quality Evaluation for Indoor Mobile Data Customers in Addis Ababa Business Area Using Data from Network Management System, Walk Test, Crowdsourcing and Subjective Survey,” *Journal Name*, vol. 1026, 2019, doi: 10.1007/978-3-030-26630-1.

[47] B. B. Haile, D. A. Bulti, and B. M. Zerihun, “On the relevance of capacity enhancing 5G technologies for Ethiopia,” in *10th Ethiopian ICT Annual Conference*, Addis Ababa, Ethiopia, June 2017.

[48] P. Schoemaker, “Scenario planning: a tool for strategic thinking,” *Long Range Planning*, vol. 28, no. 3, p. 117, 1995, doi: 10.1016/0024-6301(95)91604-0.

[49] F. Alvarez et al., “An Edge-to-Cloud Virtualized Multimedia Service Platform for 5G Networks,” *IEEE Transactions on Broadcast*, vol. 65, no. 2, pp. 369–380, 2019, doi: 10.1109/TBC.2019.2901400.

[50] R. Kumar, “A protocol with transcoding to support QoS over Internet for multimedia traffic,” in *Proceedings of the IEEE International Conference on Multimedia Expo*, vol. 1, no. August, pp. I465–I468, 2003, doi: 10.1109/ICME.2003.1220955.

[51] M. Zukerman, *Introduction to Queueing Theory and Stochastic Teletraffic Models*, 2022.

[52] J. L. Van Den Berg, “The M/G/1 queue with processor sharing and its relation to a feedback queue,” *Queueing Systems*, vol. 9, pp. 365–401, 1991.

[53] Y. Qi, M. Hunukumbure, M. Nekovee, J. Lorca, and V. Sgardoni, *Quantifying Data Rate and Bandwidth Requirements for Immersive 5G Experience*, in *Proc. 2016 IEEE International Conference on Communications Workshops (ICC)*, 23-27 May 2016, Kuala Lumpur, Malaysia, DOI: 10.1109/ICCW.2016.7503829, IEEE, 2016.

[54] T. Taleb, Z. Nadir, H. Flinck, and J. S. Song, *Extremely Interactive and Low-Latency Services in 5G and Beyond Mobile Systems*, *IEEE Communications Standards Magazine*, vol. 5, no. 2, pp. 114-119, June 2021, doi: 10.1109/MCOMSTD.001.2000053.

[55] A. Bujari et al., *Addressing the Bandwidth Demand of Immersive Applications Through NFV in a 5G Network*, *Springer*, vol. 25, pp. 1114-1121, Mar. 2020.

[56] 5G Networks, *Virtualised and Disaggregated 5G NR vRAN Architecture*, Available at: `https://www.5g-networks.net/virtualised-and-disaggregated-5g-nr-vran-architecture/`.

[57] R. N. Esa, A. H. Danisya, and A. R. Danisya, “5G NR planning at frequency 3.5 GHz: Study case in Indonesia industrial area,” *2020 2nd International Conference on Industrial Electrical and Electronics (ICIEE)*, Purwokerto, Indonesia, 2020.

[58] J. T. J. Penttinen, *5G Explained: Security and Deployment of Advanced Mobile Communications*, 1st ed. Atlanta, Georgia, USA: John Wiley and Sons Ltd, 2019.

[59] T. Kebebew, “Coverage, capacity, and cost performance analysis of 5G sub-band (3.5GHz) and 5G millimeter-wave (26GHz): In the context of Addis Ababa, Ethiopia,” Aug. 2023.

[60] D. Kondrashov et al., *Calculation of the Total Cost of Ownership of 5G Network for Different Types of Architecture: Distributed RAN, Centralized RAN and Open RAN*, Proceedings on Engineering Sciences, Vol. 05, No. 1 (2023), pp. 73-84, doi: 10.24874/PES05.01.007, Available at: `http://www.pesjournal.net`.

[61] Horn Affairs, *Ethiopia: Meskel Square to Accommodate a Million People*, Available at: `https://hornaffairs.com/2013/09/03/ethiopia-meskel-square-accommodate-million-people/`.

[62] Tujuma, Bayisa, *Techno-economic Comparison of Mid-band 5G Fixed Wireless Access and GPON-based Optical Distribution Networks*, Addis Ababa University, 2023-06.

[63] Ethio Telecom, *Ethio Telecom 2023/24 Semi-Annual Business Performance*, Available at: `https://www.ethiotelecom.et/ethio-telecom-2023-24-semi-annual-business-performance/`.

[64] Y. Qi, M. Hunukumbure, M. Nekovee, J. Lorca, and V. Sgardoni, “Quantifying data rate and bandwidth requirements for immersive 5G experience,” *IEEE Access*, vol. 8, pp. 129828–129836, 2020. doi: 10.1109/ACCESS.2020.2994231.

[65] Grand View Research, *Immersive Entertainment Market Report*, Available at: `https://www.grandviewresearch.com/industry-analysis/immersive-entertainment-market-report`.

[66] Mordor Intelligence, *Immersive Experiment Market*, Available at: `https://www.mordorintelligence.com/industry-reports/immersive-experiment-market`.

[67] Federal Communications Commission (FCC), "Final catalog of eligible expenses and estimated costs: Secure and trusted communications networks reimbursement program," Aug. 3, 2021.

[68] A. Teker, A. H. Ornek, and B. Canberk, "Network bandwidth usage forecast in content delivery networks," *Medianova CDN R&D Center, Şehit Ahmet Sokak No:4 Mecidiyeköy İş Mer. 15th Floor, Şişli/Istanbul/Turkey*, 2023. Email: aykut.teker@medianova.com, ahmet.ornek@medianova.com, canberk@itu.edu.tr.

[69] S. S. Lisi, A. Alabbasi, M. Tornatore and C. Cavdar, "Cost-effective migration towards C-RAN with optimal fronthaul design," in *IEEE ICC 2017 SAC Symposium Access Systems and Networks Track*, 2017.

[70] M. I. Hossain and M. A. Alzarrad, "Small-cell installation in transportation infrastructure: A literature review," *Technical Report*, Jan. 2020. DOI: 10.36501/0197-9191/20-004. Available at: `https://www.researchgate.net/publication/339150097`.

[71] Y. Shekhawat et al., "Orchestrating live immersive media services over cloud native edge infrastructure," *Conferences [IEEE 2nd 5G World Forum]*, 2019.

[72] J. L. Frauendorf and É. A. de Souza, "The architectural and technological revolution of 5G," 2023.

[73] R. P. Wicaksono, H. U. Mustakim, and A. A. F. Purnama, "Technical and economic analysis for 5G NR network non-standalone planning in Yogyakarta City using 2300 MHz frequency," 2024.

Appendix

Techno-Economic Analysis of Cloud-Enabled Small Cell Networks for Video Service Delivery: A Case Study in Addis Ababa

Altaseb Desalegn Yimer
Addis Ababa Institute of Technology
Addis Ababa University
Addis Ababa, Ethiopia
altasebd@insa.gov.et

Dr.Yihenew Wendie Marye
Addis Ababa Institute of Technology
Addis Ababa University
Addis Ababa, Ethiopia
yihenew.wondie@aait.edu.et

***Abstract*—The demand for immersive video services such as 360-degree live streaming, augmented reality, and virtual reality has rapidly increased, especially at crowded events, while traditional macrocellular networks often struggle when there is excessive traffic. Insufficient capacity and latency have all put significant strain on network capacity in the radio access network (RAN). Cloud-enabled small cell networks hold significant promise for improving mobile network capacity and coverage challenges while improving cost, energy usage, deployment flexibility, and network management. Combining cloud infrastructure and small-cell networks, along with virtualized execution of IT resources, provides a solution. However, a full evaluation of the networks' economic viability is required prior to their implementation, as this includes a precise computation of the resources required and a thorough assessment of the expected outcomes.This article provides a paradigm for evaluating the economic feasibility of cloud-enabled small-cell networks to deliver immersive video services during packed events. We select Meskel Square in Addis Ababa as a forecasting research location, which serves as an urban setting with concentrated hotspots. For selected scenario of implementing RAN, forecasting the required compute, storage, and radio resources and associated costs with implementing new software and hardware architecture. IST-TONIC and CELTIC-ECOSYS in MATLAB and Microsoft Excel are utilized as part of a framework that comprises marketing forecasts, network dimensioning, revenue modeling, and economic analysis. We use a 10% discount rate and a 10-year study period for a breakdown of investments value analysis.The net present value (NPV), internal rate of return (IRR), payback period (PP), operational expenditures (OpeEx), capital expenditures (CapEx) and total costs of ownership (TCO) are evaluated. According to the results obtained, the deployment scenario with the highest return economic advantages that affect the rate of return is Open radio access network.**

***Index Terms*—Cloud-enabled Small Cell networks, Radio access network (RAN), Techno-economic analysis, Immersive video services**

I. INTRODUCTION

A. Motivation

5G is expected to meet the demands of multimedia applications for quality of service (QoS) and ultrahigh traffic volume density, mobility, and connection density [1] and [2]. Over the past ten years, mobile data traffic has steadily risen globally [1]. Global mobile subscriptions has already reached 6.7 billion in 2013 [1]. Due to the advancements in system performance, the introduction of new device types and applications, the global number of mobile subscriptions is expected to experience substantial growth in the coming years [1]. It was projected that the number of global mobile subscriptions could reach 13. 8 billion in 2025 and 17. 1 billion in 2030 [1].

The entire amount of mobile data traffic worldwide, excluding traffic from Fixed Wireless Access (FWA), is predicted by the Ericsson 2023 research to reach 130 EB monthly by the end of 2023 [2]. This is expected to increase by around a factor of three by 2029 when it will reach 403 EB per month. After factoring in FWA, overall mobile network traffic is predicted to be approximately 160 EB per Month by the end of 2023, and 563 EB per Month by the end of 2029 [2]. The assumption underlying predicted traffic increase until 2029 is that XR-type services, such as AR, VR, and mixed reality (MR), will first become popular in the latter half of the forecast period [2]. On the other hand, if adoption is stronger than anticipated, data traffic may grow much more than currently projected at the end of the forecast period, especially in the uplink. Video traffic is predicted to make up 73% of all mobile data traffic by the end of 2023 [2], [4].

Mobile traffic in Ethipia:The number of mobile subscriptions in the nation for voice and internet services has increased dramatically over the previous several years to over 56 million, according to the Ethiopia Telecoms Market Report [5], [6], [7] and [8]. Capacity issues would likely persist in Ethiopia for some time to come as mobile data demand is expected to increase quickly [6], [7], [9]. In 2021, Addis Abeba's total monthly mobile data consumption will be 20.27 Petabytes (PB), which is 38.7 times the amount of traffic [9]. The operator will face significant difficulties in addressing the critical capacity given this quantity [9]. Therefore, it is crucial to investigate new technologies that may eventually provide capacity upgrades for mobile communications to meet potential capacity challenges [7], [9].

In the next decade, future mobile networks will fulfill multiple 5G requirements in terms of guaranteed user data rate, high throughput, low delay, number of User Equipments (UEs), and mobility support at high speed [3], [10]. In this context, cell densification is considered as a key solution in order to realize these enhancements [3], [10]. The basic idea is to deploy the access nodes as close as possible to the end users, in order to satisfy the required Quality of Service (QoS) and maximize the system throughput [3], [10]. Due to the increasing users' density, small cells become smaller and denser, leading to the ultra-dense networks concept [10], [11]. On the other side, cloud computing and service virtualization do their jobs in terms of technological investment enhancement, information management, and cost reduction [3], [12]. Virtualization in telecommunications decouples the implementation of network functions from hardware, allowing for dynamic resource setup [3], [12]. For example, CESC and Light DC are innovative infrastructures that are going to empower MEC to support advanced services like caching and video transcoding, and this enables AR/VR in 5G [3], [12].

The infrastructure of 5G guarantees low latency and high performance through the enforcement of SLA for ensuring high QoS, with ensured monitoring of compliance and cost optimization [11], [13]. With the deployment of Small Cells and Edge Compute, latency is reduced while scalability is increased with virtual and physical functions, including SC VNF and SC PNF [11], [13]. While the integration efforts with SDN and NFV guarantee the QoS for media services, monitoring frameworks track SLA compliance continuously [14], [15]. Small Cell and edge computing deployments bring services closer to users, contributing to latency reduction [14], [15]. Network virtualization assists in the decoupling of Small Cell functions, which is important for scalability, manageability, and coordination [14], [15]. These advances would enable 5G infrastructure to provide better media services, improving user experiences with various innovative applications [14], [15].

The key benefits of cloud-enabled small networks are as follows: Dynamic Power Management is one technique under which the power state of the small cell components would change based on the workload requirements [16]. For instance, the small cell can power off either the RF (Radio Frequency) amplifiers or baseband processors to save power when the traffic is low [16]. (i) Small cells can be made to sleep at low-power active levels during periods of inactivity or off-peak, a factor that could make energy consumption drop appreciably [16], [17]. (ii) Installation of cooling systems, more efficient than air conditioning, such as liquid cooling or natural convection, saves energy consumed by the small cell [16]. (iv) Optimizing resource allocation in the cloud reduces both the amount of computational work and energy consumption in the edge [16].

B. Related Works

The numerous research on cost effectiveness in RANs demonstrates to the criticality of this factor for mobile network operaters and cloud providers [10], [13], [14], [15]. Ioannis Neokosmidis, et al, (2019) implemented "Assessment of CAPEX and OPEX for Media Services in Cloud Enabled 5G Networks" This document discusses the 5G-ESSENCE project's cloud-enabled small cell design for 5G networks [17]. Additionally, this study shows how the suggested design complies with the emerging 5G radio resource management architecture [17]. It also looks at the use of an edge enabler in 5G networks to support various virtual network tasks [17]. The improvement of particular key performance indicators in a use case for public safety is then assessed [17]. The performance of an upgraded multimedia broadcast multicast service that is 5G enabled is then assessed [17]. In a scenario including the distribution of media content, the article investigated the performance of a virtualized eMBMS network service deployed at the edge [17]. Investigations were done into how effective eMBMS is in comparison to the unicast approach [17]. Future steps will examine the notion of cSON small cells to determine how it relates to RRM and whether it has the ability to improve 5G in terms of performance and efficiency [17].

Pietro Paglierani et al, (2020) wrote an article on "Techno-economic Analysis of 5G Immersive Media Services in Cloud Enabled Small Cell Networks: The Neutral Host Business Model", This study examines the delivery of immersive media services in crowded events using a cloud-enabled small cell network owned by a neutral host and made available to several mobile network operators in multi-tenancy [14]. The author creates a planning model to forecast the needed radio, storage, and compute resources and then conduct several economic indices, such as net present value, internal rate of return, and expected payback period, to evaluate the viability of a potential investment in a 5G infrastructure for Immersive Media Services During the ten-year study period, the SCNO have to invest in equipment including racks, switches, servers, micro-servers, small cells, etc [14]. The outcomes include network investments, operational costs, and income [14]. The cumulative discounted cash flow, also referred to as the cash balance, provides an overview of the business case's overall economics and financial development [14].

Michail-Alexandros Kourtis et al (2019) "A Cloud-Enabled Small Cell Architecture in 5G Networks for Broadcast/Multicast Services", the selected study period is set to 10 years beginning in 2020 (the expected year of 5G introduction) and ending in 2029 [10]. The analysis shows that investments for an IVS in CE relying on edge cloud resources are viable with an expected payback period of 6.5 years [10].

Pouria Sayyad Khodashenas et al (2017) "The role of Edge Computing in future 5G mobile networks: concept and challenges", The paper provides an overview of edge computing technologies, from supporting heterogeneous infrastructure up to service provisioning methodologies related to the application-specific requirements [13]. This chapter highlights the most relevant subsequent challenges, including multi-tenancy, and wireless backhaul implementation [13]. Furthermore, it gathers different ideas and proposals for innovative architectures as potential approaches to address some of the identified 5G requirements [13].

Ioannis Giannoulakis, et al (2016) wrote an article on “System architecture and deployment scenarios for SESAME: Small cEllS coordinAtion for Multi-tenancy and Edge services”, This paper were presented the innovative system design, concepts and visions developed by the 5G PPP H2020 project SESAME (Small cEllS coordinAtion for Multi-tenancy and Edge services) [11]. The innovation of SESAME is manifold: i) combine the key 5G small cells with cloud technology, ii) promote and develop the concept of Small Cells as-a-Service (SCaaS), iii) bring computing and storage power at the mobile network edge through the development of nonx86 ARM technology enabled micro-servers, and iv) address a large number of scenarios and use cases applying mobile edge computing [11]. To that end, SESAME envisages to virtualize and to partition Small Cell capacity, while at the same time it aims to support enhanced edge cloud services by enriching Small Cells with micro servers [11].

The research we present so far emphasized deployment for wireless networks mostly for next-generation mobile networks, introducing the concept of Cloud-RAN, cloud based media service provisinining, its deployment, and associated opportunities. In the survey on C-RAN, after a general overview of the concept of centralization and virtualization, and main enabling technologies-like compression techniques for C-RAN-based testbeds-harnessed, attention was paid to the usage of SDN and NFV technologies in C-RAN, along with challenges preceding the 5G rollout. Investigations on functional splits, throughput enhancement, interference management, energy efficiency, security, and system cost reduction have kept pace with C-RAN. Open RAN is based on the basics of C-RAN and gives much attention to the advantages and business opportunities presented by Open RAN. RAN virtualization was hardly addressed; by the name of Network Virtualization, a solution demonstrated the feasibility of the future requirements of virtualized mobile carrier networks. Most studies considered only geographical scenarios, while technology comparison mainly focused on input data assumption. No comprehensive survey was found in the literature on DRAN, C-RAN, vRAN, and open RAN comparison in the given scenario listed here Geographical location. The paper presents a study on the adoption of Cloud Radio Access Networks in the telecommunications environment, with a bias towards how such a shift is capable of transforming mobile network operations in light of next-generation, cloud-based media services. How MNOs with existing network infrastructure-including but not limited to LTE/LTE-A, 5G NR networks, transport networks, and site locations among others more easily migrate to the Cloud RAN architecture without losing those infrastructure resources at minimum TCO.

II. 5G AND AR/VR: TRANSFORMATIVE USE CASES WITH EDGE COMPUTING

5G is aiming to provide ubiquitous connectivity for any kind of device and application that can benefit from being connected [37], [38], [39]. 5G network is not based on single Radio Access Technology (RAT), but rather a collection of different access and connectivity technologies used together to meet the demands of future mobile networks [37], [38], [39].

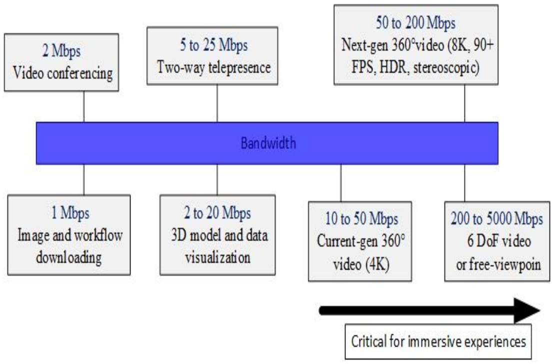


Fig. 1. Richer visual content.

5G and edge computing enable AR/VR in many new applications [37], [38], [39]. It is fair to say that some of those might have been possible previously to some degree, but their value has been unlocked [37], [38], [39]. The higher bandwidth and lower latency, which they enable, is particularly important for AR/VR as depicted in figure 1. The ability to render 3D images really takes AR/VR applications to the next level [37], [38], [39]. Lower latency that edge brings is also crucial in ensuring that the applications are comfortable for the end-user and that they can execute tasks effectively [37], [38], [39]. 5G allows for superior wireless data transfer rates, better latency, and a greater overall ability to connect devices than its predecessors, older generations like 4G and 3G [37], [38], [39]. In order to achieve these higher speeds, 5G operates at higher radio frequencies combined with a new network architecture, thereby making it ideal for applications such as high-definition video streaming, AR, VR, and IoT [37], [38], [39]. Mobile Edge Computing (MEC) also aims to position computing and storage resources on the RAN edge to improve content and application delivery for 4G and 5G network users [37], [38], [39]. MEC environment is characterized by very low latency, high bandwidth and real-time access to radio network information, which can enable deployment of new applications and services such as IoT, video analytics and connected cars [37], [38], [39]. Deploying distributed data centers capable of content caching and processing is key for achieving low latency in the mobile networks, which is also one of the defining characteristics of 5G [37], [38], [39].

AR applies digital information to real-world settings. Brands utilize AR for creating interactive and engaging experiences for customers through mobile apps or intelligent eyewear [37], [38], [39]. With AR, virtual try-ons can be enabled for clothes, accessories, or even furniture to help customers see what merchandise will look or feel like before making a purchase [37], [38], [39]. Interactive product demos, 3D visualizations, and gamification experiences that AR offers enhance brand interaction [37], [38], [39].

VR embeds customers into a virtual environment run by machines [37], [38], [39]. Brands create immersive experiences through VR by taking customers on virtual tours of their stores, services, or products. Product launching, fashion shows, and events are also possible through VR [37], [38], [39]. This way, it creates bespoke and memorable brand experiences [37], [38], [39]. It also provides the opportunity for brands to create virtual showrooms where customers can browse through a large portfolio of products in a simulated environment [37], [38], [39].

III. An Overview of RAN Network Evolution and Architecture (D-RAN, C-RAN, V-RAN, and O-RAN)

Now in the 5G era, a wide variety of new technologies and services is being introduced [26], [27]. These includes LTE-NR Dual Connectivity (EN-DC), NR-NR Dual Connectivity (NR-DC), millimeter wave (mmWave) spectrum, Network Function Virtualisation (NFV), Containerised Network Functions, massive Machine Type Communications (mMTC), Ultra Reliable Low Latency Communication (URLLC), Multi-Access Edge Computing (MEC), Network Slicing and Vertical Services, just to name a few [26], [27].

The use of Radio Access Networks (RAN) began with the very first development of cellular systems [26], [27]. The radio access network consists of the base station and the radio-aided directional antennas deployed in relation to their coverage area as shown in Figure 2 [26], [27]. The RAN, which supports the 3G and 4G networks and is anticipated to greatly contribute to 5G technology development as well, is now an indispensable part of telecommunication services [26], [27]. There have been modifications to the RAN over the years but once we evolve into the new phase of mobile communication or 4G, the changes will be more radical [27].

This article explains these technologies related to RAN architecture [26], [27]. Conceptually, the RAN links user equipment, such as a cellphone, computer or any remotely controlled machine, over a fibre or wireless backhaul connection [26], [27]. That link goes to the core network, which manages subscriber information, location and more [26], [27]. Radio Access Network has evolved quite a bit, from D-RAN to C-RAN and then to vRAN and now to the hottest topic in telecom, which is Open RAN as shown in Figure 2 [26], [27].

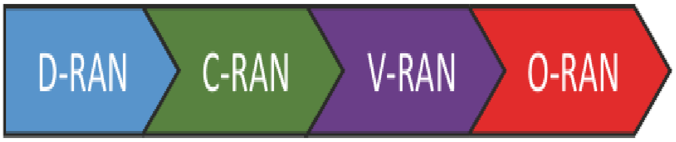


Fig. 2. RAN evolution

A. D-RAN (Distributed-RAN)

One of the first kinds of radio access networks was the distributed radio access network or D-RAN as shown in Figure 3. Each cell site in this type of network has a remote radio head (RRH, also known as RRU) and a base-band unit (BBU) [22]. BBUwas usually installed in a room right below BS. RU could be installed in the room or at the top of a tower, enabling the RU to support connectivity in a large area. In this context, the RU can also be called the remote RU (RRU) [22]. Either way, the distance between RRU and BBU is short. Implementing D-RAN is straightforward as it does not require a high-speed interface between RU and BBU. Each RAN operates independently. The network densifies as the number of UEs increases and more BS are built [22],[23], [25].

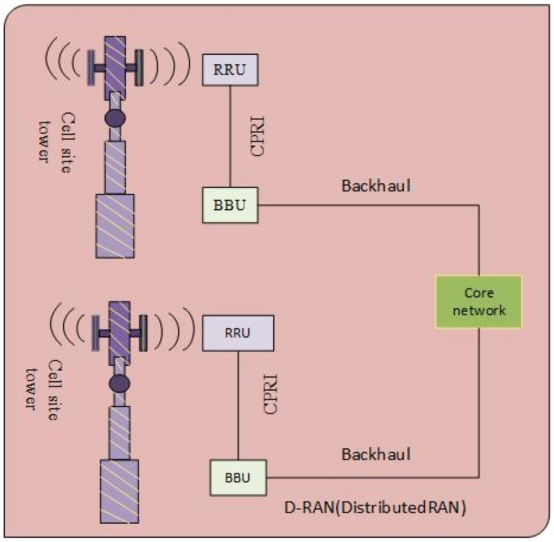


Fig. 3. D-RAN (Distributed RAN) Architecture.

Disadvantages: The requirement for software and hardware RRH/BBU to come from the same vendor leads to vendor lock-in and inadequate resource sharing. RAN capacity will not be fully utilized in low-traffic regions. high costs of operating. Field maintenance engineers ought to visit every site, as this has an immediate effect on OPEX [23], [24].

B. C-RAN (Centralized-RAN)

Centralized RAN or cloud RAN is a better version of D-RAN [24] as shown in Figure 4. The BBU and RRH will no longer be housed together at the cell site location, which is the reason behind this. Resources may be dynamically pooled, and the BBU of several cell sites will be located in the same physical location (also known as the BBU Pool or BBU Hotel) [24]. The radio unit is situated at a cell site, while the baseband unit is centrally located. Software and hardware must be purchased from the same vendor [24]. Initially, Centralized RAN is proposed to reduce the space rental cost and the power consumption of the air conditioner of the BBU by pooling BBUs from different BS into a single physical location [24]. Despite reducing the overall OpEx, Centralized RAN requires the FH to have high bandwidth and low time latency requirement [24]. The fundamental difference between Centralized RAN and Cloud RAN is the cloud system [24]. In Centralized RAN, the BBUs are pooled in a physical location [24]. In Cloud RAN,BBUs from each BS were pooled in a cloud server. Cloud RAN is superior

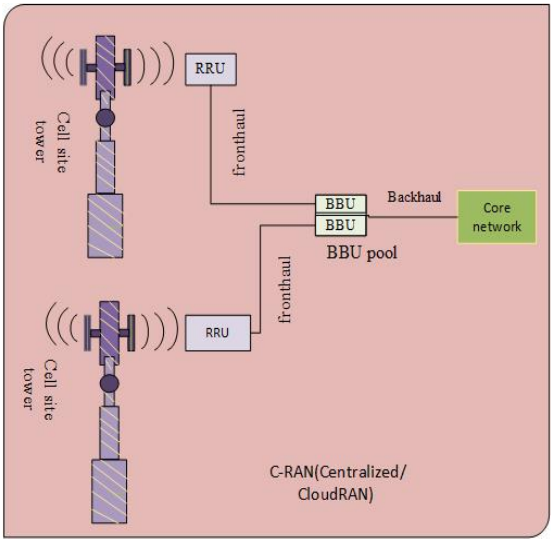


Fig. 4. C-RAN architecture: the BBU and RRH are connected through the fronthaul while BBU and core network are connected through backhaul [26].

because the cloud [24]. control in Cloud RAN made it easier for the number of BBUs to be changed with time [24]. The cloud also increased the baseband processing by exploiting general-purpose processors [24]. Cloud RAN further reduced energy consumption, increased network throughput, improved network scalability, reduced Capital Expenditure (CapEx), and reduced OpEx [24].

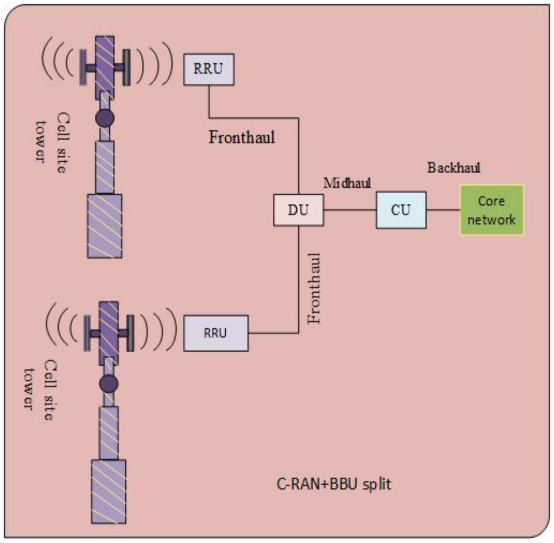


Fig. 5. 5G NR gNodeB functional split(BBU split)

Advantages: When multiple sites can be handled from a single physical location, operating expenses are reduced. Savings on rent (if RRH and BBU are co-located, a larger space is required). Improved inter-cell coordination (e.g., eICIC operates more efficiently when there is low-latency communication between sites)[26], [22] Disadvantages:The fronthaul experiences significant data pressure due to the enormous quantity of data processing from RRH to BBU, which maintains vendor dependency similar to D-RAN. However, to further solve this problem, the 3GPP suggested that the radio unit, distributed unit (DU), and central unit (CU) be functionally separated from one another as shown in Figure 5 [22]. In this instance, DU (e.g., RLC, MAC, PHY) and CU (e.g., RRC, PDCP, and SDAP in the 5G scenario) can handle some substantial processing [22].

C. vRAN (Virtualized-RAN)

C-RAN still has limitations, such as the huge FH overhead, trust problems, security problems, and single-point failure [26], [23]. The problems forced the C-RAN framework to shift its focus to advanced computing technologies. Some of these advanced technologies were virtualization and edge computing. Virtualization is the key to the shifting from C-RAN to vRAN [26], [23].

With the exception of some important RAN architectural elements that are no longer hardware dependent, it is almost exactly the same as C-RAN. The BBU software package is placed on top of COTS servers [26], [23], [24]. This suggests that BBU which may also be split into vDU and vCU is really just a software package that is provided by the manufacturer. It can be located on the COTS server as a VNF or CNF [26], [23], [24]. Since COTS servers are easily obtained commercially off the shelf, purchasing COTS servers from a COTS server vendor and installing the BBU software on top of them is straightforward [26], [23], [24]. Even though software-hardware decoupling at the BBU level is theoretically possible, there are still disadvantages, such as inaccessible APIs and persistent vendor-proprietary exits [26], [23], [24]. The RRU and BBU (vDU and vCU) vendors have to be the same. The baseband unit can be separated into DU and CU, or it can be found in a single, functional location radio unit located in a cell site [26], [23], [24]. The BBU and RRU must still originate from the same provider even though the BBU is virtualized and sits atop the COTS server [26], [24]. Except some important RAN architectural elements that are no longer hardware-dependent, it is almost exactly the same as C-RAN. This suggests that BBU which may also be split into vDU and vCU is really just a software package that is provided by the manufacturer. It can be located on the COTS server as a VNF [26], [23]. Since COTS servers are easily obtained commercially off the shelf, purchasing COTS servers from a COTS server vendor and installing the BBU software on top of them is straightforward [26], [23]. Even though software-hardware decoupling at the BBU level is theoretically possible, there are still disadvantages, such inaccessible APIs and persistent vendor-proprietary exits [26], [23]. The RRU and BBU (vDU and vCU) vendors have to be the same [26], [24]. The baseband unit can be separated into DU and CU, or it can be found in a single, functional location [26], [24]. Within a cell site is the radio unit [26]. The BBU and RRU must still originate from the same provider even though the BBU is virtualized and sits atop the COTS server [26], [24].

D. Open RAN

This is the RAN solution's most recent and enhanced iteration as shown in Figure 6. It opens interfaces between RRH, vDU, and vCU and retains all of the benefits of both C-RAN and vRAN systems in addition to bringing intelligence to the radio access network [23], [24]. There won't be any vendor lock-in in this case, and the MNO is free to select several vendors to develop the RAN network [24]. As the name implies, the interfaces between the Radio Unit, DU, and CU will be accessible [23], [24]. Every organization does not have to rely on a single supplier to provide it; goods can be obtained from several sellers.

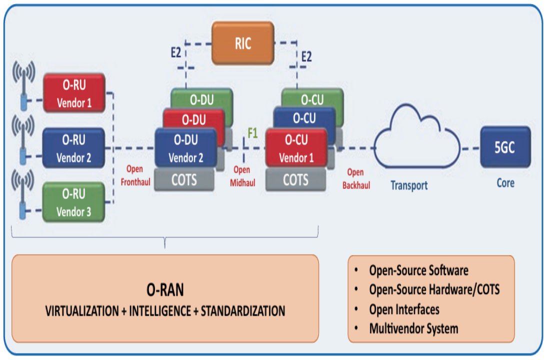


Fig. 6. Open RAN (O-RAN) Architecture [23].

D-RAN is different from C-RAN, and vRAN is not Open RAN, even if Open RAN is intelligent with RIC and incorporates components from all previous RAN systems [23], [24]. vRAN is, in fact, a type of C-RAN . It uses virtualization technologies such as NFV or receptacles to deploy CU and DU over the x86 server [23], [24]. (or virtual BBU on a server). There is no difference between vRAN and C-RAN except that traditionally C-RAN uses proprietary hardware while vRAN uses Network Functions on the server platform [23], [24]. The most important to understand is that the Cloud RAN solution is available in C-RAN, vRAN and O-RAN to avoid miss understanding the cloud RAN solution that can be founded in C-RAN only, Because of vRAN HW/SW decoupling flexibility, we can gain scalability [23], [24]. This can decrease hardware costs and application agility as the application can be upgraded easily or swapped altogether (which is not more manageable with traditional hardware) [23], [24]. However, vRAN puts servers to new boundaries because of the performance anticipation [23], [24]. There has been quite an innovation in improving the server platform to fulfil the performance needs of vRAN [23], [24].

E. The 5G gNB functional splits

The new 5G access system architecture has four distinct characteristics which will be described in the following section along with the benefitsts provided in comparison with legacy hardware solutions. I.e., CU (Central Unit) / DU (Distributed Unit) split, CU-CP (Control Plane) / CU-UP (User Plane) split, CU virtualisation and DU virtualization [23], [24].

Vertical and horizontal RAN disaggregation is also known as functional splits [23], [24]. Horizontal functional split is a selection process of the appropriate centralization level in RAN framework [23], [24]. Horizontal functional split also refers to the BBU and RRU separation. It separates the integrated BBU into two separate units: Central Unit (CU) and Distributed Unit (DU). The degree of centralization in the horizontal functional split is flexible [23], [24]. However, trade-offs should be considered when choosing these functional split options. On the other hand, the vertical split is the separation between the CP and UP of the RAN. The CP and UP splitting (CUPS) is the extension of the SDN concept [23], [24].

Virtualization enables the softwarized RAN to be subdivided into smaller parts within single hardware that enhances softwarization [23], [24]. There are two virtualization technologies, which are hypervisor-based and container-based virtualization [23], [24]. Virtualization allows hardware to host functions of multiple virtualized units, leading to a term called NFV, which virtualizes all network services, such as virtual CU or virtual DU [23], [24]. These virtualized functionalities are called Virtual Network Functions (VNFs) and they run on top of VMs. NFV uses hypervisors named Virtual Machine Monitor (VMM) or virtualizer [23], [24]. The VMM hosts and runs Virtual Machines (VMs) that host VNFs [23], [24].

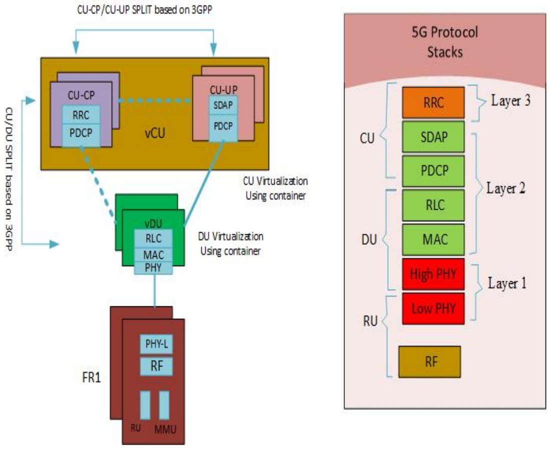


Fig. 7. BBU split and 5G Protocol Stacks

Non-Real time processing such as RRC, PDCP is off-loaded to the central site and the RRC, PDCP resource pool is shared between multiple DUs [23], [24]. CU can accommodate multiple DUs to build a large scale gNB [23], [24]. CU is typically virtualised on a COTS server for the scalability and flexibility. Real time processing such as RLC, MAC, PHY, RF need to remain close to the local site. DU is also virtualised on a COTS server for business agility [23], [24]. The Conventional DUs with fixed Control and User Plane (CU/UP) resources, which are typically designed to accommodate such 'typical mobile data services', are not well-suited to support the newer traffic patterns. Instead, a more flexible capability to dimension and scale directly in-line the traffic requirements of new types of services is needed [23], [24]. In particular, as Network Slicing and MEC are introduced, the UP should be divisible into multiple entities and allocated wherever needed for optimization of each specific services [23], [24]. Along withthe CU/DU split and CU-CP/CU-UP split, container technology can further enhance scalability, flexibility and resource efficiency [23], [24].

F. The current network challenges

Ethio Telecom also faces some network challenges, especially in high-demand areas such as stadiums and Meskel square. Some of the key ones are listed below:

High User Density: The events held at the Meskel Square, stadiums generally are very crowded, and therefore their surroundings always contain a huge amount of mobile subscribers in a very small area [8]. This can easily increase the congestion of the network and degrade the quality of service [8].

Capacity Limitations: The events involving large crowds could lead to more than the capacity of current infrastructure resulting in slow speeds and losses of connectivity [8], [32].

Interference: There is much interference around the place due to a lot of electronic devices and physical structures in the environment, which can interfere with the signal and impede network performance [8], [32].

Latency: High latency affects real-time applications such as video streaming and online gaming, particularly when the people who gather at the Meskel Square are more in number [8].

Scalability: Scaling up network resources during events to meet peak demand is quite a task; hence, it requires advanced planning and investment [8], [24].

This may result in places lacking good or even any signal necessary having challenges in the necessary connection. The question the case study seeks to address is how these network concerns can be overcome to offer reliable immersive media experiences in technically demanding large events.

IV. TECHNO-ECONOMIC MODELING AND EVALUTION MOTHED

Techno-economic modeling means the methodology of complex technical systems for evaluating the economic viability [36]. The steps include modeling, analysis, evaluation, and finally assessment. According to revenues and costs calculated, several indicators that assess profitability is calculated. Typical indicators may be pay-back period, NPV, and IRR [36], [37]. More precisely, all the income and cash flows that are forecast, and also the sum of expenditure to be needed over the system lifetime, should be estimated [36], [37]. From this, an estimation of the payback period-that is, the time the investment needs to pay off-should be made. A project with a long payback period or the sum of cash flow is negative, is not economically viable to proceed with indicates. Since the late 1990s, many European research projects have used and extended the below-mentioned methodologies [36], [37].

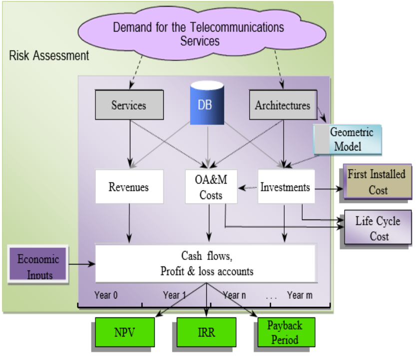


Fig. 8. Structure of the techno-economic methodology used by TONIC .

A. Analysis of IST-TONIC and CELTIC-ECOSYS Model

Research projects IST-TONIC and CELTIC-ECOSYS, both sponsored by the European Union, are centered on the creation of novel communication technologies and the evaluation of their potential economic effects [29]. The project IST-TONIC (TecnO-ecoNomICs of IP optimized networks and services) had a EUR12.5 million budget and operated from 2004 to 2007 [29]. Its goal was to investigate and develop new technologies for optimized IP-based networks and services [29]. Among other things, the initiative sought to make progress in Quality of Service (QoS), mobility, security, and service provisioning [29]. Several European universities, research centers, and business partners worked together on IST-TONIC. With a focus on Internet Protocol (IP)-based technologies, its goal was to provide new approaches, instruments, and architectures for the design and optimization of next-generation communication networks and services [29]. The project's goal was to solve the problems associated with boosting IP-based networks' capacity, performance, and efficiency while maintaining their financial sustainability [29].

The project CELTIC-ECOSYS (techno-ECOnomics of integrated communication SYStems and services) had a EUR14.7 million budget and operated from 2013 to 2016 [29]. With an emphasis on the rollout of 5G networks, its goal was to examine the technological and economic elements of integrated communication systems and services [29]. The project's goal was to look at how emerging technologies, such as Software-Defined Networking (SDN) and Network Functions Virtualization (NFV), might affect the economy and open up new revenue streams and business models [30]. The project CELTIC-ECOSYS (techno-ECOnomics of integrated communication SYStems and services) had a EUR14.7 million budget and operated from 2013 to 2016. With an emphasis on the convergence of fixed and mobile networks, the Internet of Things (IoT), and 5G technologies, its goal is to examine the techno-economic elements of integrated communication systems and services [30]. The project intends to address the difficulties in creating and implementing integrated communication services and systems that are socially conscious, sustainable, and profitable [30].

While both IST-TONIC and CELTIC-ECOSYS are research

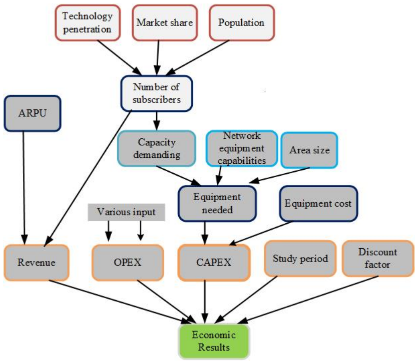


Fig. 9. Model revenues and cost flows based on the ECOSYS project.

projects that concentrate on the techno-economic elements of communication networks and services, their goals and areas of interest differ [30]. While CELTIC-ECOSYS is focused on examining the techno-economic aspects of integrated communication systems and services, with a particular emphasis on the convergence of fixed and mobile networks, the Internet of Things, and 5G technologies, IST-TONIC is focused on developing new methodologies, tools, and architectures for the design and optimization of IP-based networks [3]. They are a part of greater initiatives to push the boundaries of communication system design and optimization, with a focus on the systems' sustainability and economic viability [31]. Despite having distinct areas of interest, they can collaborate within the same model to accomplish the overarching objective of developing communication systems that are both economically and environmentally sustainable [31].

B. Cost Modelling

The network cost is one of the major factors that determine the viability of Cloud RAN deployment scenarios [17], [35],[44]. The construction and operational costs of a radio access network can be divided into two classes, which include capital expenditures, CAPEX, and operational expenditures, OPEX [17], [35], [44]. The computations of the costs use the network components that are needed, network configuration data, and cost data for each year [17], [35], [44]. In Cloud RAN, the estimated cost for CAPEX and OPEX deals with its implementation and operational expenses, respectively, according to [17,35,44].

1) Capital expenditure (CAPEX): In this approach, the terms "CAPEX" and "components" refer to the initial investment expenditures related to the deployment of network infrastructure and equipment [17], [36], [45]. It covers charges for things like buying software and hardware, finding a location, setting it up, and configuring it [17], [36], [45]. The cost of small cell base stations (SCBs) and associated equipment required for network coverage and capacity inside event venues is included in the small cell hardware (SCH) category [17], [36], [45]. The cost of cloud servers used to process and provide immersive media content at central or edge cloud facilities is covered by cloud server hardware (CSH) [17], [36], [45]. Software licensing (SL): This category covers licensing for immersive media service platforms, network management software, and operating systems [17], [36], [45]. Backhaul and Fronthaul Links (BFL): This accounts for the cost of backhaul connections to the core network and fronthaul links connecting SCBs to cloud servers [17], [36], [45].

$$\text{CAPEX} = \sum_{i=1}^{T}\sum_{j=1}^{N_i} N_j^i \cdot (c_{\text{SCH}} + c_{\text{SSW}} + c_{\text{SL}} + c_{\text{FFL}}) \cdot (1 + I_j)^{(i-1)} \tag{1}$$

where:

i = Year in the study period, ranging from 1 to T
j = CAPEX item (SCH, SSW, SL, FFL), ranging from 1 to N_i, where N_i is the number of items in a year i
N_j^i = Number of item j required in year i
c_{SCH} = Cost of a Small Cell Basestation unit
c_{SSW} = Cost of Small Cell software
c_{SL} = Cost of Small Cell license
c_{CSH} = Cost of a cloud server unit
c_{CSW} = Cost of cloud server software
c_{FBLF} = Cost of fiber optic cable j in year i
I_j = Yearly price inflation for item j
T = Total study period

2) Operational expenditure : Every year, the Operating Expenditure (OPEX) is computed. The OPEX expenditure for each year is added to determine the total accumulated OPEX [17], [36], [45]. Among the OPEX elements taken into account in the analysis are:Every year, the Operating Expenditure (OPEX) is computed. The OPEX expenditure for each year is added to determine the total accumulated OPEX [17], [36], [45]. Among the OPEX elements taken into account in the analysis are [17], [36], [45]:

OAM (OPERATIONS, ADMINISTRATION, AND MAINTENANCE) COST

This covers all of the costs related to overseeing and preserving the network infrastructure, such as employee wages, training, supplies, and software programs for network administration, monitoring, and troubleshooting [36], [45].

CALCULATING ANNUAL ENERGY COST

This includes the cost of powering the network equipment, such as small cell base stations, cloud servers, and associated infrastructure [36], [46]. It takes into account electricity consumption, utility charges, and any backup power solutions [36], [46].

In order to calculate the network's annual energy cost, the total energy consumption of all small cell base stations units and cloud servers is added up [36], [46].

1) Compute the total power consumption of all power-consuming network elements:

    - Create a list of power-consuming network elements, denoted by i [6].
    - For each network element i, multiply its power consumption P_i by the number of such elements n_i.
    - Sum up all these individual power consumptions to obtain the total power consumption P_T [6].
2) Calculate the annual energy consumption:
    - Divide the total power consumption P_T by 1000 to convert it from watts to kilowatts.
    - Multiply the result by the number of hours per day ($Hrs/Days$) and the number of days per year ($Days/Years$) to get the annual energy consumption E_T in kilowatt-hours (kWh).
3) Determine the annual energy cost:
    - Multiply the annual energy consumption E_T by the cost of energy per kilowatt-hour (C_KWH) to obtain the annual energy cost C_E.

The formulas involved are as follows:

$$P_T = \sum_i (P_i \cdot n_i) \tag{2}$$

$$E_T = \left(\frac{P_T}{1000}\right) \cdot \left(\frac{Hrs}{Days}\right) \cdot \left(\frac{Days}{Years}\right) \tag{3}$$

$$C_E = E_T \cdot C_KWH \tag{4}$$

Make sure to substitute the appropriate values for P_i, n_i, $Hrs/Days$, $Days/Years$, and C_KWH in the actual calculations to obtain the accurate annual energy cost [6].

Calculating Annual Site Rental Costs

This refers to the cost of leasing or renting physical locations for deploying small cell base stations or other network infrastructure. It includes fees paid to property owners or authorities for site access and usage [6].

For the network, the annual site rental costs (CSR) can be calculated as follows [6]:

$$C_{SR} = \sum_{i=1}^{T} (N_j^i \cdot C_{SC} \cdot C_{CS}) \tag{5}$$

Where:

- j is a list of rental items, such as cell sites or radio towers, and cloud server racks.
- N_j^i is the number of item j in year i.
- C_{SC} is the rental cost of a cell site.
- C_{CS} is the rental cost of the server rack per cabinet in year i.
- T is the study period, indicating the number of years under consideration.

To calculate the annual site rental costs, you need to sum up the product of the number of rental items, the rental cost of a cell site, and the rental cost of the server rack per cabinet for each year [6].

Make sure to substitute the appropriate values for N_j^i, C_{SC}, C_{CS}, and T in the actual calculations to obtain the accurate annual site rental costs.

Calculating Capacity Upgrade Costs

This includes the costs associated with scaling up the capacity of the network to meet increasing demand. It covers expenses such as upgrading hardware, adding small cell units, or expanding network resources.

The cost of upgrading the baseband capacity (C_{UP}) of the network per year is calculated as follows:

$$C_{UP} = \sum_{i=1}^{T} \left(N_j^i \cdot C_{Up}^i\right) \tag{6}$$

Where:

- j is a list of the small cell hardware items required to be installed, such as small cell units and cloud servers.
- N_j^i is the number of small cell processing hardware items j required to be installed.
- C_{Up}^i is the cost of the upgrade for item j in year i.
- T is the study period, indicating the number of years under consideration.

To calculate the capacity upgrade costs, you need to sum up the product of the number of small cell hardware items, the cost of the upgrade for each item, for each year [3], [6].

Make sure to substitute the appropriate values for N_j^i, C_{Up}^i, and T in the actual calculations to obtain the accurate capacity upgrade costs.

Calculating Annual Fiber Lease Cost

If the network deployment involves leasing fiber optic infrastructure for backhaul or connectivity purposes, the annual fiber lease cost (C_{FL}) can be calculated as follows:

$$C_{FL} = \sum_{i=1}^{T} \left(N_i \cdot C_{FL}^i\right) \tag{7}$$

Where:

- N_i is the number of sites in year i.
- C_{FL}^i is the annual fiber lease in year i.
- T is the study period, indicating the number of years under consideration [6].

To calculate the annual fiber lease cost, you need to sum up the product of the number of sites and the annual fiber lease cost for each year.

Make sure to substitute the appropriate values for N_i, C_{FL}^i, and T in the actual calculations to obtain the accurate annual fiber lease cost.

CALCULATING HW & SW MAINTENANCE COST

This encompasses the expenses related to hardware and software maintenance. It includes costs for repairing or replacing faulty equipment, software licenses, updates, and patches [5].

The HW & SW maintenance cost (C_{HWi} and C_{SWi}) can be calculated as follows:

$$C_{HWi} = \sum_{i=1}^{T} (N_{HW}^{i} \cdot C_{HW}^{i}) \tag{8}$$

$$C_{SWi} = \sum_{i=1}^{T} (N_{SW}^{i} \cdot C_{SW}^{i}) \tag{9}$$

Where:

- N_{HW}^{i} is the number of hardware items in need of maintenance in year i.
- C_{HW}^{i} is the cost of hardware maintenance per item in year i.
- N_{SW}^{i} is the number of software licenses or instances in need of maintenance in year i.
- C_{SW}^{i} is the cost of software maintenance per license or instance in year i.
- T is the study period, indicating the number of years under consideration [3].

The specific values and calculations for each OPEX component would require detailed cost data, market prices, and information specific to the case study. To estimate the OPEX for each year and calculate the total accumulated OPEX over the study period, you can use the following formula:

$$OPEX = \sum_{i=1}^{T} \left((c_{\text{OMA}i} + c_{\text{SR}i} + c_{\text{HW}i} + c_{\text{FL}i}) \cdot (1 + P_i)^{(i-1)} \right) \tag{10}$$

Where:

- i represents the year in the study period.
- T represents the total study period.
- c_{OMAi} is the cost of operation, administration, and maintenance in year i.
- c_{Ei} is the cost of energy in year i.
- c_{SRi} is the cost of site rent in year i.
- c_{HWi} is the cost of hardware maintenance in year i.
- c_{SWi} is the cost of software maintenance in year i.
- c_{UPi} is the cost of capacity upgrade in year i.
- c_{FLi} is the cost of fiber lease in year i.
- P_i is the yearly price inflation rate for item i.

C. Total cost of owenership (TCO)

The Total Cost of Ownership (TCO) covers both the Capital Expenditure (CAPEX) and Operating Expenditure (OPEX) [5]. The formula for TCO is given by:

$$\text{TCO} = \sum_{i}^{T} \text{CAPEX}_i + \text{OPEX}_i \tag{11}$$

Where:

CAPEX_i is the total CAPEX in year i,
OPEX_i is the total OPEX in year i,
T is the study period.

D. Revenue Model Analysis

User subscriptions offer a recurring revenue stream based on regular payments from subscribers. Pricing strategies can include tiered subscription plans (e.g., basic, standard, premium) with different levels of access and features. Discounts or incentives for longer subscription commitments can encourage user retention [12].

Service packages bundle different services or features together for users to choose from. This can include access to additional content, premium features, or personalized experiences. Tiered pricing for service packages allows catering to different user segments and maximizing revenue potential [3].

Average Revenue Per User (ARPU) is calculated as the total revenue generated divided by the number of subscribers. ARPU provides insights into the average spending or contribution of each user to the overall revenue of the service. It can be monitored over time to track revenue trends and evaluate the effectiveness of pricing strategies and revenue models [3], [6], [14].

$$\text{ARPU} = \frac{\text{Total Revenue}}{\text{Number of Subscribers}} \tag{12}$$

PERFORMANCE EVALUATION METRICS

Applying the principles of cash flow (CF) and discounted cash flow (DCF) provide valuable insights into the financial feasibility of deploying cloud-enabled small cell networks for immersive media services at crowded events in Addis Ababa [6], [14].

a) Cash Flow (CF) Formula (adjusted for immersive media revenue):: The CF formula adjusted for immersive media revenue is given by:

$$\text{CF} = \sum_{i}^{T} (\text{Immersive Media Rev}_i - \text{Network TCO}_i) \tag{13}$$

Where:

T : Represents the time period .
$\text{Immersive Media Rev}_i$: immersive media services in year i.
Network TCO_i : Total Cost of Ownership i.

DISCOUNTED CASH FLOW (DCF):

The discount rate represents the rate of return or the cost of capital required for an investment. To incorporate the discount rate into your formula, you would discount each cash flow from each year (CF_i) using the appropriate discount rate (r) [6], []14].

The discounted cash flows can be calculated using the formula [14]:

$$\text{DCF}_i = \frac{CF_i}{(1+r)^i} \tag{14}$$

Where:

DCF_idiscounted cash flow in year i,
CF_i represents the cash flow in year i,
r represents the discount rate,
i represents the time period or year[14].

Once you have calculated the discounted cash flows for each year, you can sum them up to determine the net present value (NPV) of the cash flows over the given time period. Alternatively, if you want to calculate the discounted cash flow (DCF) for the entire cash flow series, you can apply the discount rate to the total cash flow (CF) rather than individual cash flows [6], [14]:

$$\text{DCF} = \frac{CF}{(1+r)^n} \tag{15}$$

Where:

DCF discounted cash flow for the entire cash flow series,
CF total cash flow,
r discount rate,
n number of years or time periods[6], [14].

E. Netpresent value (NPV), internal rate of return (IRR), payback period (PP) and return on investment (ROI) for a cloud-enabled small cell

Calculating NPV, IRR, PP, and ROI for a cloud-enabled small cell project involves several steps [14], [33]. The first step is to gather all the relevant data, including the investment required, the expected cash flows over the project's life, and the cost of capital [14], [33]. The second step is to use a planning model that incorporates the IST-TONIC and CELTIC-ECOSYS methodologies to estimate the project's cash flows and cost of capital [14], [33].

NET PRESENT VALUE (NPV)

The NPV is the difference between the present value of all the project's cash inflows and the present value of all the project's cash outflows [14], [33]. It helps to determine the project's profitability and whether it is worth investing in or not. To calculate NPV, you can use the following formula [14], [33]:

$$\text{NPV} = \sum_{t=1}^{T} \frac{CF_t}{(1+r)^t} - C \tag{16}$$

Where CF_t is the expected cash flow in period t, r is the cost of capital, and C is the initial investment.

INTERNAL RATE OF RETURN (IRR)

IRR is the discount rate at which the present value of the project cash inflows becomes equal to the present value of the project's cash outflows [45]. It helps in judging the profitability of the project, which is compared with the required rate of return [14], [45]. One can compute IRR as:

$$\text{NPV} = \sum_{t=1}^{T} \frac{CF_t}{(1+\text{IRR})^t} - C = 0 \tag{17}$$

Where CF_t is the expected cash flow in period t, and C is the initial investment [14], [46].

PAYBACK PERIOD (PP)

The PP is the time required for the project to generate enough cash flow to recover the initial investment [33]. It helps to determine the project's risk and liquidity. To calculate PP, you can use the following formula [14], [33]:

$$\text{PP} = \frac{\text{Initial Investment}}{\text{Annual Cash Flow}} \tag{18}$$

RETURN ON INVESTMENT (ROI)

The ROI is the ratio of the project's net profit to its initial investment. It helps to determine the project's profitability and efficiency. To calculate ROI, you can use the following formula [14], [33]:

$$\text{ROI} = \frac{\text{NPV} + C}{C} \tag{19}$$

Where NPV is the net present value and C is the initial investment.

V. CASE STUDY AND SCENARIO ANALYSIS

EEthio Telecom is the leading operator, according to Ethio telecom 2023/2024 Annual Business Performance Report with over 78.3 million subscribers [8]. The technologies used include 3G, 4G, and, in some places, limited 5G coverage [8]. Because of the growth in smartphone penetration and consumption of mobile data, data traffic has grown rapidly.

This section discusses a case study that utilises the proposed business feasibility framework. In the case study, we estimate the overall cost of building up and maintaining a mobile network with a 10-year network lifecycle using cloud-enabled small cell networks to deliver immersive media services at crowded events. Meskel Square and suruonding is a 4-km-square (2 km x 2 km) service area in Addis Ababa, Ethiopia, and is considered for this case study.

Meskel Square is in practice, it is uses for exhibitions, bazaars, markets or vendors offering everything from fresh produce, household items, to souvenirs and second-hand goods. Events also include religious and public outdoor events, among others, such as the Meskel-Demera Religious Festival, which has been recognized by UNESCO as part of the world's intangible heritage [21].

A. Demand forecasting

Diffusion models are often developed for long-term subscription forecasts [14]. The models describe an S – shaped evolution with a long-term saturation level. Some relevant models are Logistic models, Bass models, Gompertz model, Fisher-Pry and Richard's model [14]. The two last one are special variants of the Logistic models. In the Fisher-Pry models are applied for long-term forecasting of many different telecommunication services [14]. The Logistic models are applied for long-term broadband forecasts [14]. The models are suitable for long-term forecasting and forecasting when the number of observations is limited [14]. Mobile broadband was introduced in the European market 2006/2007 [14]. Hence, number of yearly observations is limited [14]. A natural choice has been to apply diffusion models [14]. A suggestion here will be a four-parameter Logistic model [14].

The four-parameter logistic model is expressed as follows:

$$Y_t = \frac{M}{(1 + e^{\alpha+\beta t})^{\gamma}} \tag{20}$$

Where:

- Y_t: Accumulated demand at time t (as a percentage of the population)
- M: Saturation level (as a percentage of the population)
- t: Time (in years)
- α: Growth parameter (intercept term in the logistic growth equation)
- β: Growth rate parameter
- γ: Shape parameter affecting the curve's steepness

The four-parameter logistic model is commonly used to forecast long-term demand for new services and technologies. The model predicts the actual or forecasted demand, Y_t, at a given time, t, as a percentage of the total population.

The parameters α, β, and γ can be estimated using regression analysis based on historical market data.

The model works by assuming that the demand for a new service or technology will grow rapidly at first, and then gradually slow down as it reaches saturation. The diffusion parameters control the shape of the growth curve. Estimate the demand saturation level (M) for the new service.

Estimate the diffusion parameters (α, β, and γ) using a regression analysis. This can be done using existing market data on the adoption of other new services. Use the model to forecast the demand for the new service at different time points in the future. Suppose, for example, an ethio-telecom intends to introduce a new IMS service in Meskel Square. It would want to forecast the subscription demand for this service over the next decade. Perform regression analysis using the collected market data to estimate parameters α, β, and γ. Use the logistic model equation with the estimated parameters to forecast the demand for subscriptions for each year over the next 10 years.

VI. NETWORK DIMENSIONING

In the dimensioning of the 5G CESCN described in this paper, for every given deployment scenario, the number of SCs relies on several aspects such as coverage area and maximum data rate supported by a single small cell [12], [37]. The appropriate propagation model, frequency bands, user density, traffic demand bands, and network resources need to be cautiously selected in order to reach the optimum solution [12], [37].

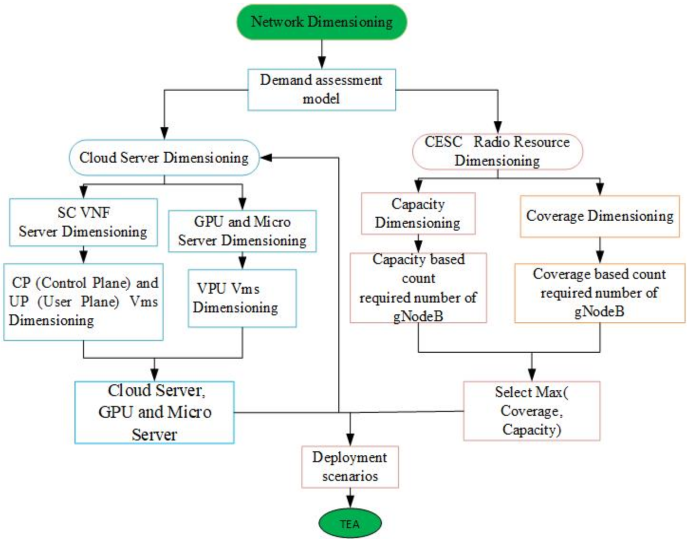


Fig. 10. Cloud-enabled small cell Network Dimensioning Approach.

It includes cell range calculation, sector throughput calculation, and estimating network equipment quantity [12], [37]. The output obtained in this phase will act as an input to TEA. It uses it for resource estimation and the cost of the network. Coverage and capacity dimensioning is the two outputs, the larger of the two numbers is used as the final output according to the dimensioning rule [12], [37]. The overall flow chart of the network dimensioning approach applied in this thesis is shown in Figure 6.1 [12], [37].

A. Cloud Enabled Small cell Network Coverage Dimensioning

The size of the coverage begins with the calculations of the radio connection (RLB) budget, which in turn are used to estimate the loss of the path for budgets for the radio connection DL and UL [6], [20], [42]. By calculating the connection budget, it is possible to estimate the maximum allowance of signal (loss of path) between UE and gNodeB antennas [20]. It also provides the required SINR level for the receiver, with regard to interference and shadow [6], [20], [42].

For accurate design and comparison of wireless networks and/or their deployments, the wireless channel models are necessary, which will simulate the signal propagation accurately and efficiently. In this paper, we evaluated four path loss models that are introduced by the four major organizations: 5GCM (5G Communication Model), 3GPP, METIS (Mobile and Wireless Communications Enablers for the 2020 Information Society), and mmMAGIC (Millimetre-wave Mobile Access for Gigabit Communications). Based on this, the UMi environment, the propagation path is divided into two types: street canyon (SC) and open square (OS).

Street canyon (SC):

$$PL_{\text{UMi-LOS}} = \begin{cases} PL_1, & 10\text{m} \leq d_{2D} \leq d'_{BP} \\ PL_2, & d'_{BP} \leq d_{2D} \leq 5\text{km} \end{cases} \tag{21}$$

$$PL_{\text{LOS-1}} = 32.4 + 21\log_{10}(d_{2D}) + 20\log_{10}(f_c) \tag{22}$$

$$d_{3D} = \sqrt{d_{2D}^2 + (h_{BS} - h_{UT})^2} \tag{23}$$

$$d'_{BP} = \frac{4(h'_{BS} h'_{UT} f_c)}{c} \tag{24}$$

$$\begin{aligned} c &= 3.0 \times 10^8 \text{ m/s} \\ h'_{BS} &= h_{BS} - h_E \\ h'_{UT} &= h_{UT} - h_E \end{aligned}$$

Open square (OS):

$$L_{\text{LOS}} = 32.4 + 18.5\log_{10}(d_{3D}) + 20\log_{10}(f_c) \tag{25}$$

$$L_{\text{NLOS}} = 32.4 + 28.9\log_{10}(d_{3D}) + 20\log_{10}(f_c) \tag{26}$$

OPERATING FREQUENCY AND BANDWIDTH

3.3 GHz to 4.2 GHz, for example, n77, n78, or 4.4 GHz to 5 GHz for example, n79. This band is all about moderate range and very good capacity. Suitable for a stadium with moderate users and good in-depth penetration through obstructions like stands and walls. Examples include Band n78 (3.5 GHz), one of the most deployed 5G bands around the world, hence striking a great balance between capacity and coverage; Band n79 (4.8 GHz) higher in throughput at slightly reduced coverage compared to n78.

That is a reason why 26 GHz, 28 GHz, and 39 GHz bands are considered for immersive services, given their high-capacity usage. The required bandwidth is related to the kind of immersive media service delivered: Standard 360-degree video streaming in HD: It takes about 25-50 Mbps per user in bandwidth for a smooth experience. 4K 360-degree video or VR streaming: This normally requires 80-100 Mbps per user to ensure high-quality resolution with low latency.

MODELING OF RADIO LINK BUDGET PARAMETERS

The MAPL determines the maximum cell range and evaluates the required number of gNodeB sites to cover the target area. It is calculated as follows:

$$\text{MAPL} = \text{EIRP} - R_S - p_L - S_M - I_M + G_{\text{RX}} \tag{27}$$

Where:

- EIRP: Effective Isotropic Radiated Power (dBm)
- R_S: Receiver Sensitivity (dBm)
- p_L: Penetration Loss (dB)
- S_M: Shadow-Fading Margin (dB)
- I_M: Interference Margin (dB)
- G_{RX}: Receive Antenna Gain (dBi)

Pathloss (dBm) = gNodeB transmit power (dBm)–10 log10 (subcarrier quantity) +gN odeB antenna gain (dBi)– gNodeB cable loss (dB)– penetration loss (dB)– foliage loss (dB)– body block loss (dB)– interference margin (dB)– rain/ice margin (dB)–slow fad ing margin (dB) + UT antenna gain (dB)–thermal noise figure (dBm)– UT noise figure.

Cell Area and Site Count

3-Sector Site Coverage Area

The inter-site distance, D, is:

$$D = 1.5 \times R \tag{28}$$

The site coverage area A_{sc} for the 3-sector configuration is:

$$A_{\text{sc}} = 1.949 \times R^2 \tag{29}$$

$$N_{\text{sc}_a} = \text{round}\left(\frac{A}{A_{\text{sc}}}\right) \tag{30}$$

Where:

- A: Total area to be covered
- A_{sc}: Area covered by a single small cell

B. Cloud Enabled Small Cell Network Capacity Dimensioning

Throughput, in general, is the maximum possible data rate that a communication system can transmit. It is defined as a quality indicator expressed in terms of the data transfer rate of usual and non-redundant information. The primary objective of the capacity planning exercise will be to arrive at an estimate of the site count based on the capacity requirements. Wherein network operators define capacity needs according to forecasted traffic and average cell throughput required to determine the capacity-based site count. The maximum data rate of DL and UL that can be supported by the UE shall be determined per band or band combinations supported by the UE. For NR, the approximate data rate for a given number of aggregated carriers in a band or band combination is computed as follows.

5G NR THROUGHPUT FORMULA

$$\begin{aligned} (\text{Mbps}) = 10^{-6} \sum_{j=1}^{J} \Bigg(& V_{\text{Layers}}^{(j)} \cdot Q_m^{(j)} \cdot f^{(j)} \cdot R_{\max} \\ & \cdot \frac{N_{\text{PRB}}^{(\text{BW}(j),\mu)} \cdot 12}{T_s^{\mu}} \cdot \left(1 - \text{OH}^{(j)}\right) \Bigg) \end{aligned} \tag{31}$$

Where:

- 10^{-6}: Constant for Mbps conversion.
- j: Represents the number of aggregated component carriers in a band or band combination ($1 \leq j \leq 16$).
- $V_{\text{Layers}}^{(j)}$: Maximum number of MIMO layers (≤ 8 in DL and ≤ 4 in UL).
- $Q_m^{(j)}$: Modulation order (QPSK $= 2$, 16QAM $= 4$, 64QAM $= 6$, 256QAM $= 8$).

- $f^{(j)}$: Scaling factor for mobility ($f^{(j)} \in \{0.4, 0.75, 0.8, 1\}$).
- R_{max}: Coding rate ($R_{\text{max}} = \frac{948}{1024}$ for LDPC).
- $N_{\text{PRB}}^{(\text{BW}(j),\mu)}$: Maximum number of allocated Physical Resource Blocks (e.g., 264 PRB for 400 MHz and 120 kHz subcarrier spacing).
- T_s^{μ}: Average OFDM symbol duration ($T_s^{\mu} = \frac{10^{-3}}{14 \cdot 2^{\mu}}$ for normal cyclic prefix).
- $\text{OH}^{(j)}$: Control channel overhead. Typical values:
  - FR1: 0.14 (DL), 0.08 (UL).
  - FR2: 0.18 (DL), 0.10 (UL).

Capacity-Based Site Count (DL/UL)

The formula for the maximum number of subscribers per gNodeB for each service type based on the average throughput requirements is as follows:

Average Throughput at Busy Hour (BH)

The average throughput at the busiest hour (BH) for immersive video services can be calculated using the following formula:

$$\text{Bitrate} = \frac{\text{Resolution} \times \text{Frame Rate (fps)} \times \text{Color Depth (bits/pixel)}}{\text{Compression Ratio}} \tag{32}$$

$$\text{Data Volume (Bytes)} = \frac{\text{Bitrate (bps)} \times \text{Streaming in (seconds)}}{8} \tag{33}$$

$$\text{Avg. Throughput (Mbps)} = \frac{\text{Total Data Volume}}{\text{BH Duration} \times 30} \tag{34}$$

Maximum Users per gNodeB (DL, UL)

$$U_{\text{max (DL, UL)}} = \text{round}\left(\frac{\text{5G NR Throughput (Mbps)}}{\text{Av.Thr per Subscriber in a Month}}\right) \tag{35}$$

Total Number of Sites (gNodeBs) Required

$$N_{\text{sc (DL and UL)}} = \text{round}\left(\frac{U}{U_{\text{max}}}\right) \tag{36}$$

From coverage-based site count (DL/UL) and Capacity-based site count (DL/UL), the former refers to the number of sites required to provide adequate signal coverage (geographical area) for the users to ensure they have reliable connectivity, regardless of traffic volume. The key goal here is to ensure that users can connect to the network in all areas. The latter, on the other hand, pertains to the number of sites that would be necessary to process the network's traffic demand-the number of users and the amount of data being transmitted. In this case, it is to make sure that the network has adequate capacity to carry peak traffic loads without congestion. Thus, for optimal network design and performance, 89 sites would be selected based on the best option for both download and upload requirements in the deployment area.

Distribut and Centralized Unit Quantity The DU performs real-time baseband processing, which is latency-sensitive, and it needs to process data from multiple RRUs. Depending on processing capacity, load, geographical distance, and real-time load balancing, one DU can handle several RRUs. In this thesis, the typical ratio for DU to RRU is 1:10.

Category	Coverage Count	Capacity Count
Downlink (DL)	82	72
Uplink (UL)	52	89
Best Selected		**89**

TABLE I
REQUIRED NUMBER OF GNB FOR COVERAGE AND CAPACITY BASED SITE COUNTS

The CU, which handles high-layer processing, manages non-real-time processing and high-level functions such as mobility and session management. It can support a large number of DUs. In this thesis, the CU to DU ratio is 1:5.

$$\text{DU} : \text{RRU} = 1 : 10$$

$$\text{CU} : \text{DU} = 1 : 5$$

$$\text{DUs} = \text{round}\left(\frac{\text{required cell}}{\text{Cells per DU}}\right) = \text{round}\left(\frac{89}{10}\right) = 9$$

$$\text{CUs} = \text{round}\left(\frac{\text{required DU}}{\text{CUs per DU}}\right) = \text{round}\left(\frac{9}{5}\right) = 2$$

Cloud Server Dimensioning Analysis

Total Workload: The total number of tasks or resources required to manage a particular type of VNF at a specific time. Examples include a count nUE VMs of Media Streaming VNFs and count ncell VMs of Traffic Management VNFs.

VNF Capacity: The maximum of the total tasks or resources that one VNF is able to manage.

$$\text{Number of VNFs} = \frac{\text{Total Workload}}{\text{VNF Capacity}}$$

VII. IMPLEMENTED TECHNO-ECONOMIC MODEL AND TECHNO-ECONOMIC ANALYSIS

In the fourth chapter we saw different models of techno-economic evaluation and their application area. The technical model is a systematic framework of economic feasibility analysis, including all system parameters. Based on a derived frame from the model, this thesis work modified the model to comprise the input parameters is based on the explained model in chapter four section 4.1. The model comprises marketing, technical, and economic parts. Modified IST-TONIC and CELTIC-ECOSYS Techno-Economics of integrated communication systems and services in MATLAB and MS-Excel for the economic component was selected for this research because it can be applied to the wireless telecommunication industry and seamless mobile IP service provision [14], [17], [41].

DEPLOYMENT SCENARIOS

Following the discussed RAN Network Evolution and Architecture in chapter three and Network Deployment Scenario analysis for Immersive Media Service Provisioning at Crowded Events of the mobile network in chapter five, the formulated deployment scenarios for the Cloud RAN are presented below for further analysis. In this regard, four deployment scenarios have been formulated based on selected uncertainty extreme values. The formulated deployment options are also known as D-RAN (Distributed RAN) (SC1), Cloud or C-RAN (Centralized RAN) Sc2, vRAN (Virtualized RAN) Scenario 3 (Sc-3), and Open RAN Scenario 4 (Sc-4)

Scenario 1 (Sc-1) Distributed RAN (D-RAN):

In a distributed RAN, the BBUs and RRHs are co-located at each cell site. This traditional setup allows each cell site to operate independently, which might ease initial deployment but usually results in higher operation costs and multiple site management complexities.

Scenario 2 (Sc-2) Centralized RAN (C-RAN):

It enables resource pooling, through which efficiency and operation costs can significantly decrease. This is due to the centralization of the BBUs from the RRHs, remaining at cell sites in a centralized RAN. Further, it also allows much easier upgrades and better cell coordination.

Scenario 3 (Sc-3) Virtualized RAN(vRAN):

Virtualized RAN is one step further virtualizing the BBUs themselves onto generic hardware, not necessarily special equipment. This further allows for better flexibility, scalability, and cost savings; network functions would be deployed as software on commercial off-the-shelf servers.

Scenario 4 (Sc-4) Open RAN (O-RAN):

Open RAN is developed on the merit of centralized and virtualized RAN with the addition of open interfaces and interoperability between the equipment of different vendors. It will further provide an architectural road map toward higher flexibility and cost efficiency, thus encouraging innovation while decreasing dependency on single-vendor solutions. It finds its place as a future-proof solution for increasing network demands. These are scenes demonstrating the development of RAN deployment from traditional hardware-dependent setups to more flexible, cost-effective, future-ready network architectures.

VIII. Results and Discussion

This chapter presents the techno-economic analysis of results from various deployment scenarios for different RAN Architectures. Targeted to assess costs associated deployment Scenario listed in chapter seven in section 7.3, the data obtained from Ethiotelecom covers existing 4G and the current rollout 5G traffic data. In this case study, a ten-year study period starting from the year 2025 was considered. Currently, Ethiotelecom is operating with D-RAN architecture. Given all the available options for the most economic RAN architecture in this use case, based on TCO and economic metrics. The following sections will present the inputs used within the model in order to conduct the analysis, the chosen deployment option for the use case, results on network dimensioning in Chapter Seven, Section 7.4 and market analysis in Chapter Seven, Section 7.5. Discussion of the techno-economic aspects evaluation will be provided and some observations on the obtained results are presented.

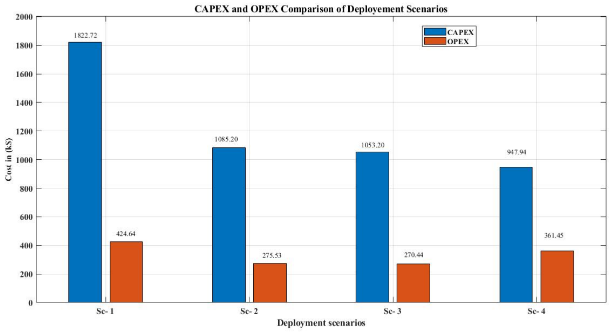


Fig. 11. CAPEX and OPEX estimations for each deployment scenario.

A. *Economic Analysis Result*

This section develops the economic analysis of CAPEX, OPEX, TCO, and revenues for each scenario. The outcome of the network dimensioning in chaper seven section 7.4 is a starting point to calculate the total cost of equipment required for each architecture. Based on assumptions made in each, this outcome gives the CAPEX and OPEX. Adding these amounts together provides the total CAPEX and OPEX for the initial year investment.

CAPEX and OPEX Evaluation

The capital expenditure (CAPEX) and operational expenditure (OPEX) of four different deployment scenarios labeled ”Sc-1,” ”Sc-2,” ”Sc-3,” and ”Sc-4.”. The total estimated CAPEX ($k\$$) for the scenarios are as follows: Sc-1: 2,247.3, Sc-2: 1,085.2, Sc-3: 1,053.2, Sc-4: 947.94. Similarly, the total estimated OPEX ($k\$$) for the scenarios during the study period are as follows: Sc-1: 424.645, Sc-2: 275.53, Sc-3: 270.442, Sc-4: 361.45.

The initial year investment for each architecture are depicted in Figure 11, CAPEX apparently is the highest for Sc-1 and goes on decreasing in Sc-2, Sc-3, and Sc-4. That would mean the initial investment in Sc-1 is way higher compared to the other scenarios. OPEX also shows a decreasing trend from Sc-1 to Sc-3, while increase in sc-4, some increase is due to the fact that power consumption is larger as compared to others. That means the operational costs that continue to be incurred are lower for the latter scenarios. Reductions in CAPEX and OPEX from Sc-1 to Sc-4 could be an indication that further optimization may be realized by the use of different approaches to deployment or the deployment of other technologies. These allows for easy comparison of total costs and the breakdown of CAPEX and OPEX for each scenario, useful during decision-making and planning.

Percentage Comparison

Figure 12 depicted that, Sc-2 (C-RAN) has much lower CAPEX compared to Sc-1, which could be because of expected outcomes of cost reductions for infrastructure since there is centralization within the C-RAN. Sc-3 (vRAN) Further reduction of CAPEX is realized from the Sc-2 scenario to exhibit that virtualization can offer much more significant CAPEX saving. Sc-4 (O-RAN) much more CAPEX reduction

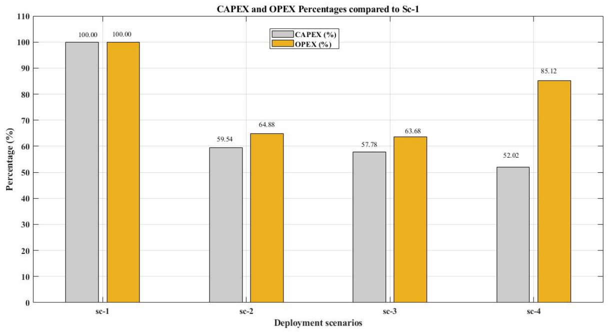


Fig. 12. CAPEX and OPEX percentage comparison.

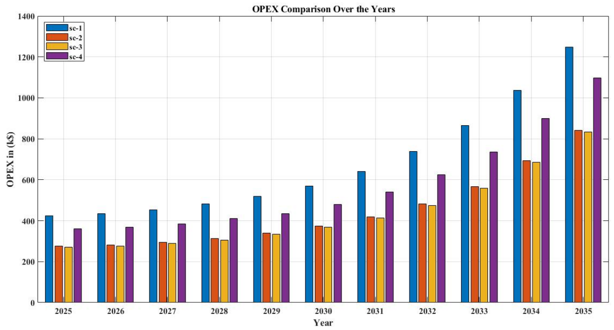


Fig. 14. OPEX trends over the study period .

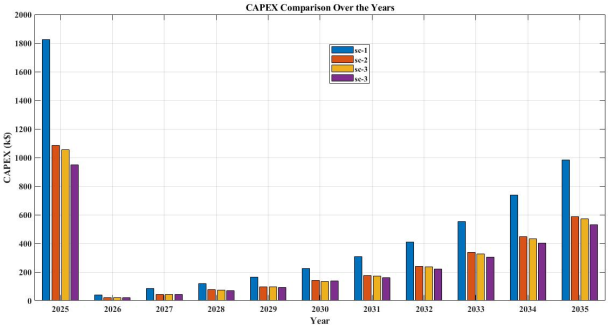


Fig. 13. CAPEX cost trends for each architecture.

possibly as a result of disaggregation in both hardware and software of O-RAN. This would enable further cost efficiency in component choice. OPEX of Sc-2, C-RAN, presents a moderate OPEX reduction concerning Sc-1; this was expected since C-RAN can reduce the operations' complexity and hence maintenance costs. Sc-3, presents a further reduction in OPEX due to reduced hardware maintenance and power consumption. Sc-4 based on O-RAN shows high OPEX reduction as compared Sc-1. This probably happens due to the opening of interfaces that will provide more advanced support of effective operations, software updates, and integration with third-party solutions. Among all those, v-RAN has the greatest potential to lower both CAPEX and OPEX compared to D-RAN. The enabling role is played by virtualization decreasing the cost of both CAPEX and OPEX.

CAPEX Trends

All the scenarios increase at a gradual rate over the years. However, the increase itself is different in each scenario. Sc-1 increases faster initially, while Sc-4 increases much more gradually. Sc-1 has always stayed at the top in CAPEX over the years, indicating a higher initial investment and possibly continuing infrastructure costs. The CAPEX is the lowest in Sc-4 among all the scenarios, which means that this scenario has the lowest upfront costs associated with the deployment. The gradual growth of CAPEX in all scenarios indicates that ongoing investments are needed for network expansion based on new trafic increament as explained in chaper seven section 7.2 demand forecast analysis. The different trends of CAPEX in scenarios indicate that different deployment strategies may affect the overall investment as depicted in figure 13.

The CAPEX annual trend of each architecture is illustrated individually in the figure above. Due to the fact that the D-RAN entails a fairly expansive hardwar investment in the first year of implementation, the start up costs are considerably higher to other types of structures. In the same manner, it as illustrated that the investment cost for all architectures decreases and gradualy grows in the study period. This pattern is expected as most new technologies are capital intensive and decrease in the subsequent years in the study period. The D-RAN got the higher share of the total investments for all the architectures. The rest is most cost effective in CAPEX relative to D-RAN, which is cheaper respectively in the scenario. In particular, the potential cost saving in hardware configuration as proposed by the D-RAN concept were counterbalanced by higher CAPEX costs.

OPEX Trends

It has been realized that OPEX cost is a continuous cost and keeps on increasing with time, this is due to the reason that more and more network elements are added each year in order to meet the capacity demand of the network equipments that need to be installed. The cost of running a distributed architecture is worse than that of centrally designed architectures. This is very centralizing to the BBU split (CU/DU) as costs arising from site visit are greatly minimized. Based on the OPEX analysis of SC-2, better OPEX savings are obtained with the centralized architecture because of low maintenance, site rent, energy, and operation costs.

The figure 14 represents the cost breakdown of a service bundle with different service level agreements (SLAs). This plot represents the operating expenses trend over a period of ten years, starting from 2025 to 2034. The trend in these steadily growing operating expenses over the decade is very helpful in visualizing trends in the data, for instance, constant growth of the expenses perhaps due to many other factors related to inflation, expansion of services, or increasing operation activities.

TCO trends

TCO of four different deployment scenarios over the years

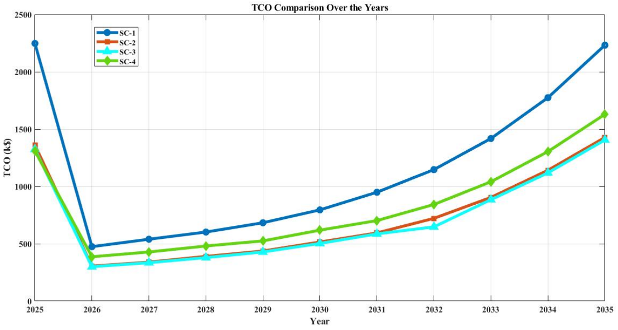


Fig. 15. TCO trends for the architectures over the study period.

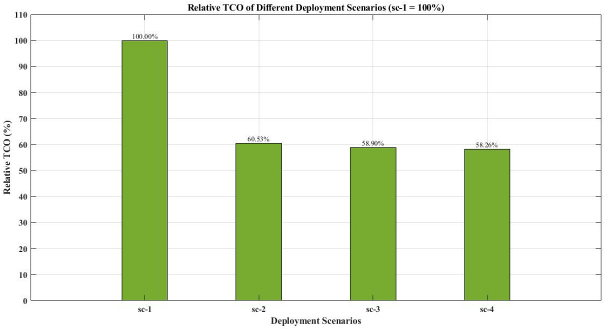


Fig. 16. TCO change comparison for the deployment scenario.

starting from 2025 to 2035 is depicted in figure 15. Sc-1 (D-RAN) it indicates high initial TCO and a gradual increase afterward. This reflects that there is high initial and expansion investment and as well as continuous operational expenses. Sc-2 has a lower initial TCO compared to Sc-1 and has a moderate increase with time. It reflects lower initial investment but possibly higher operational costs compared to Sc-3. Sc-3 (vRAN) Presents a lowest initial TCO than Sc-1, Sc-2 and Sc-4 and increases gradually over time. This indicates a lowest initial investment and possibly lower operational costs compared to Sc-1, Sc-2 and Sc-4. Sc-3 consistently has the lowest TCO across all years, which may indicate some cost advantages associated with this deployment scenario. SC-4 (O-RAN) has the lower initial TCO and maintains a relatively low and steady growth rate over the years as compaired with Sc-1. This is due to that Sc-4 has higher OPEX than Sc-2 and Sc-3. Sc-1 has the highest TCO for all cases, reflecting perhaps the potential cost implication of a D-RAN deployment. Sc-2 and Sc-4 present TCO values that fall in between Sc-1 and Sc-3, with generally lower TCOs for Sc-3 than for Sc-2. Figure 15 generaly illustrates the different TCO profiles that different deployment scenarios can have. Sc-3, vRAN, seems to provide the most promising TCO trajectory. The growing TCO over time for all scenarios testifies to the importance of long-term operational costs and possible further investments when strategies of deployment are considered. The differences in TCO trends likely reflect the cost implications of different technologies-D-RAN, C-RAN, vRAN, O-RAN-in terms of infrastructure, expansion, maintenance, and operational expenses.

TCO of three deployment scenarios - sc-2, sc-3, and sc-4 - against a base line sc-1 =100%. The computed Relative TCO sc-2 is around 60.53%, which means its TCO is roughly 60.53% of the TCO of sc-1. This would therefore be a substantial cost reduction compared to the baseline scenario Sc-1. Relative TCO of Sc-3 about 58.90%, which further reduces the TCO compared to sc-2. Relative TCO of sc-4 is about 58.26%, similar to sc-3, which postulates that the TCO levels are about the same due to that Sc-4 has higher OPEX as compared to Sc-2 and Sc-3 as shown above section in OPEX comparison figure. Figure 16 shows how TCO costs can be drastically reduced compared to the baseline scenario (sc-1). This spread in Relative TCO values would likely reflect cost implications for various technologies represented by these scenarios. Sc-4 representing O-RAN, shows a dramatic reduction in TCO from the baseline-a possible indication of the cost benefits of O-RAN deployments in the inial year investment.

Breakdown of Investments and Running Costs

A breakdown of investments (CAPEX) and running costs (OPEX) for the IMS-capable CESC (Cloud-Enabled Small Cell) infrastructure. Major contributors to costs are identified in chapter seven section 7.5. On the other hand, depending on industry norms and accessible data, revenue can be computed using the number of subscribers or other pertinent measures. Through the implementation of these pricing strategies and an analysis of their effects on user uptake, immersive media access services can maximize revenue creation in section 7.6.

Techno -economic analysis is used to evaluate the economic feasibility of any architecture. Techno-economic analysis was included in the outcome of the technical and costumed model and the defined discount rate (10 %) for the purpose of providing economic metrics such as NPV, IRR and return time. The method used is the analysis of cash flows (CF) and cumulative cash flow (CCF) and is discussed below.

Immersive video service net-revenue

To predict the revenue for immersive media in 2035 time period (T) 10 years, discount rate 10% per year and a 15% tax rate [17], [41]. The outputs of the models in each architecture will be some economic evaluation measures like NPV, IRR and PP [17], [41].

From 2026 through 2035 figure 17 reveals yearly revenue increasing steadily. Our total revenue keeps growing every year and jumps significantly from 2030 to 2031. The revenue is divided into four categories. The graph displays our business performance breakdown into Gold Revenue, Silver Revenue, Bronze Revenue, and Net Revenue. The bottom part presents Gold Revenue since it produces the largest portion of income. The total revenue line maintains its steady upward trajectory from 2026 through 2035. Silver Revenue is the second-largest component. Both economic segments show steady growth patterns throughout the studied periods. Bronze Revenue shows minimal change like the other parts

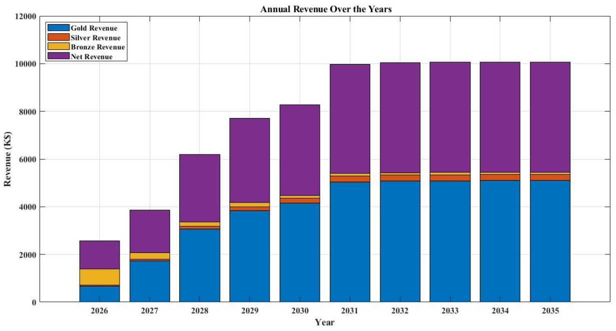


Fig. 17. Annual Revenue Over the Years

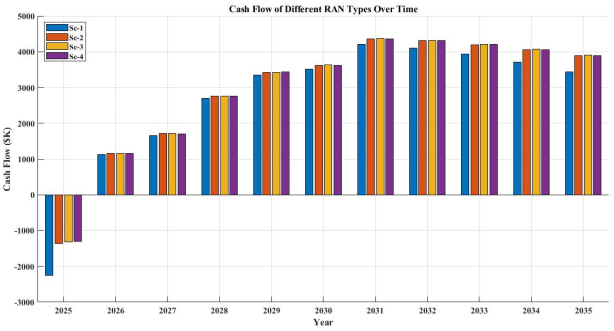


Fig. 19. Cash flow analysis of the deployment architectures.

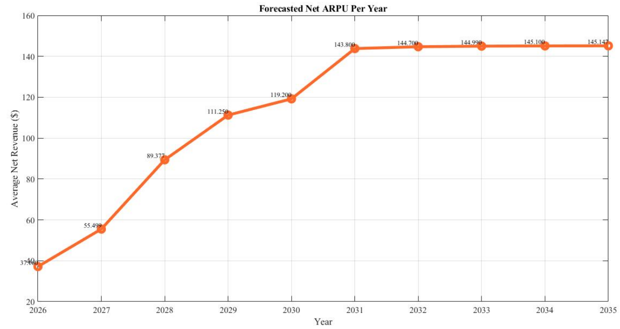


Fig. 18. Forecasted Net ARPU Per Year

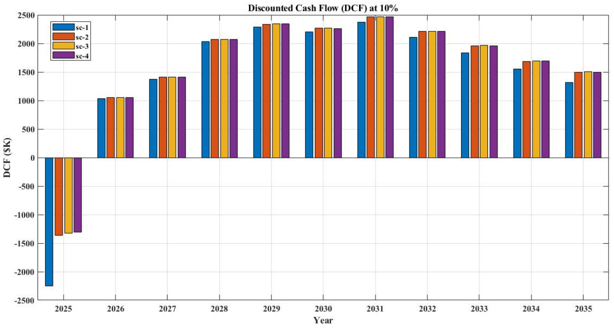


Fig. 20. Discounted Cash Flow analysis of SC.

yet generates less revenue than in other business segments. Over time, the gap between the revenue categories widens, demonstrating that gold generates more revenue than silver. While the revenue from bronze bundles is initially high, it steadily declines as people switch to silver and gold bundles as explained in chapter 7 section 7.2.

ARPU

Over nine years starting in 2026, figure 8.10 shows average net revenue (ARPU) growing strongly. A fast rise from 2026 to 2028 leads to steady growth up to 2031. ARPU plateaus at just 144.70 once the market reaches 2031. During 2026-2031 the graph shows quick revenue increases. After 2031 the graph shows its market growth is leveling off because it has reached market maturity according to these results.

Cash Flow Trends

All the scenarios are slightly negative during the earliest years of 2025-2026 to clearly depict significant CAPEX. Sc-1 (D-RAN) the time period, in which negative cash flow is observed may suggest that this option has higher initial costs compare to others. Sc-4 (O-RAN) this is the least negative of initial cash flow that makes it an indication that initial investments could be low. All the scenarios are positive after a few initial investment years, showing that revenues grow above costs. Cash flow for all scenarios increases in general with time, reflecting the growing revenue streams associated with network operations. As compared to Sc-4, the cash flow of Sc-1 is lower, which can be interpreted as a higher initial investment cost. Sc-4 presents faster transition into positive cash flow and higher cash flow generation along time . While Sc-2 (C-RAN) and Sc-3 (vRAN) present intermediate cash flow trends, Sc-4 could have faster ROIs given the low initial investment and higher revenues it generates as shown in figure 19. This increased cash flow, over time, emphasizes possibilities for long-term profitability and revenue growth in the sector of telecommunications.

Discounted Cash Flow (DCF)

Figure 8.12 displays how different RAN deployment plans called ”sc-1,” ”sc-2,” ”sc-3,” and ”sc-4” generate Discounted Cash Flow (DCF) during the period from 2025 through 2035. The illustration (Figure 20) demonstrates how different RAN deployment methods generate cash flow through 2035 when the 10

Scenario Comparison:Deployment of D-RAN technology in Sc-1 demands greater upfront expenses than O-RAN in Sc-4. O-RAN technology reaches positive DCF results earlier than other technologies and produces more DCF over time. The DCF performance results for Sc-2 and Sc-3 lie between the other scenarios. Figure 21 reveals that all RAN deployment plans need major capital investment at their start. Sc-4 (O-RAN) reveals faster return on investment possibilities due to smaller upfront costs and stronger potential to generate more revenue.

Cumulative Cash Flows Trend

Figure 22 provides an overview of the accumulated cash

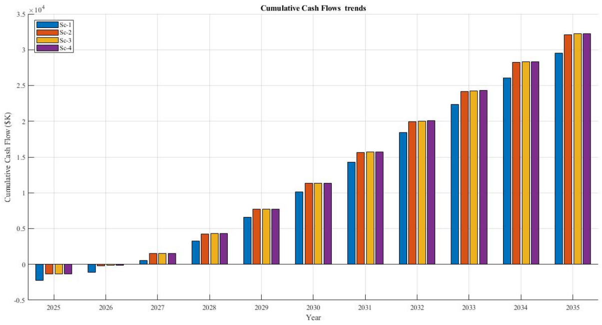


Fig. 21. Cumulative cash flow analysis of SC.

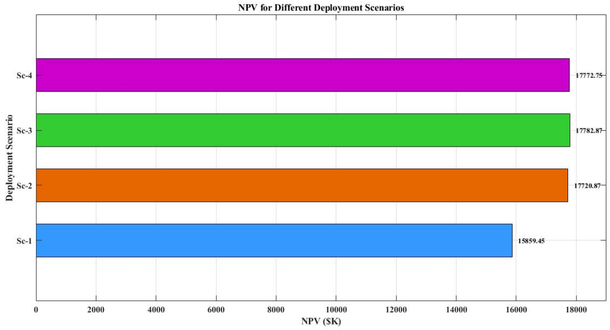


Fig. 22. Net present value (NPV) of the deployment scenario.

flow trend for various deployment scenarios. The information is of utmost importance to the decision makers in order to assess the financial viability and long-term profitability of each deployment scenarios. In Sc-1 (D-RAN) shows an initial negative steeper slope, representing higher initial investment costs. For the subsequent years, the slope gets flatter while the cash flow increases gradually. Sc-2 (C-RAN) has a less steep initial negative cash flow slope, showing lower initial investment costs than Sc-1. Its cash flow keeps increasing over the years. Meanwhile, Sc-3(vRAN) depicts the lowest initial negative cumulative cash flow, which means the lowest initial investment costs. The cumulative cash flow will increase steadily over time. Sc-4 (O-RAN) has both the minimum initial negative cumulative cash flow in the early years and the maximum in later years, which indicates a faster return on investment and higher overall profitability. This figure represents the time taken by each case to recover the initial investment and start showing a positive cumulative cash flow. The fastest recovery can be shown by scenario Sc-4. Increasing cumulative cash flow with time for all scenarios gives proof of the possibility of long-term profitability and growth of revenue in the field of telecommunication. In all scenarios, Sc-4 has higher cumulative cash flow than other scenarios, which proves a potential for higher profitability and faster return on investment.

Net Present Value (NPV)

This indicates that, at a discount rate of 10%, the project is financially feasible as it generates positive net cash inflows over the 10-year period as shown in figure 23. Therefore, the net present value (NPV) of the cash flows over the 10-year period indicates the present value of the project's future cash flows after accounting for the time value of money. The NPV is a computation made in finance to determine the present value of a stream of future cash flows. It is a means of comparing investments with various timings of cash flows. The logic of it all is that a dollar today is more than a dollar tomorrow, because of time value of money and the possibility of inflation.

Scenario Comparison: Sc-4 (O-RAN): Exhibits the highest NPV, meaning the highest NPV represents the maximum financial gain that the project can produce during its entire life cycle. Sc-3 (vRAN): Indicates the second-high NPV, indicating a good financial performance. Sc-2 (C-RAN): Shows a moderate NPV. Sc-1 (D-RAN): Demonstrates the lowest level of NPV and highlights consequent, fewer financial profits as compared to other situations. Financial Performance: NPV outcome of every deployed scenario in the context of financial profitability. Taking into account the financial metrics O-RAN's Sc-4 is projected to generate the greatest returns. Investment Decision-Making: NPV as the main tool for assessing the financial profitability of investment projects. The higher the NPV, the superior investment opportunity is described by figure 24. Technology Impact: It seems that the NPV fluctuation is due to the differences in NPV between technologies such as D-RAN, C-RAN, vRAN, and O-RAN according to their investment cost, operating cost and revenue.

Internal Rate of Return (IRR)

Another economic metric used is the internal rate of return (IRR). IRR is a discount rate that is used for project analysis or capital budgeting which makes the net present value (NPV) of future cash flows equal to zero. Investments with higher IRR and NPV values are assumed to be better investments. If two systems have equal ROI periods, IRR and then NPV will be used for comparison. Thus, all architectures would be financially viable in the future. Open-RAN achieved higher IRR value than the other architectures.

We can use Microsoft Excel or any financial calculator to calculate the IRR of the cloud-enabled small cell. Note that the IRR calculation requires numerical methods or financial software to find the exact value. Using HP12C Financial Calculator. Using initial investment value and each discount DCF mentioned above we can calculate it. The different IRR values as shown in figure 25 likely reflect the financial implications of various technologies-D-RAN, C-RAN, vRAN, and O-RAN-pertaining to initial investment, operational expenses, and revenue generation.

Scenario Comparison: Sc-4 (O-RAN): Present the highest IRR which means that this business plan will get the highest return of investment. Sc-3 (vRAN): Shows the second-highest IRR. Sc-2 (C-RAN): Shows a moderate IRR. Sc-1 (D-RAN): Demonstrates the lowest IRR that symbolizes lower rate on investment. Financial Performance: The IRR of each deployment scenario is indicated on the chart as a descriptor

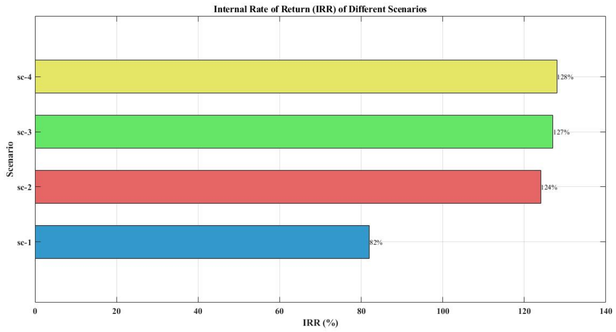


Fig. 23. Internal rate of return (IRR) of the deployment scenario.

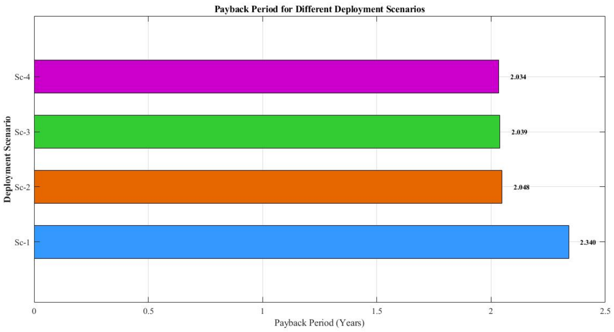


Fig. 24. Payback period (PP) of the deployment scenario .

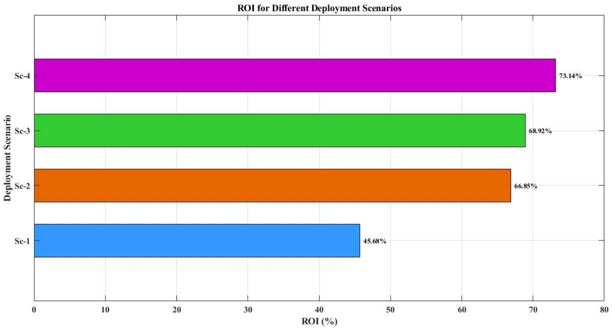


Fig. 25. ROI of the deployment scenario.

of the firms' financial results. Again, it is with regard to the payback that O-RAN shows the most promising of all, notably Sc-4. Investment Decision-Making: The concept of IRR is used in the assessment of the economic profitability of investment investment projects. It is the management's belief that projects with a higher IRR offer greater investment prospects. Technology Impact: This is probably due to the fact that profitable IRR values may represent the cost of a particular technology (D-RAN, C-RAN, vRAN, O-RAN) in the short term, the cost of operating with this technology, and the revenues obtained from it in the long term.

Payback Period (PP)

Payback period is the duration it takes for the total earnings to match the initial investments made. It is one of the methods to assess the efficiency of investments and determine how quickly the acquired systems and equipment generate a return on investment. PP is the duration of time it takes for the cash inflows generated by a project to match the initial investment cost.

Figure 26 provides an overview of the Payback Period relating to different deployment scenarios. Such information is very basic for the decision-maker, who has to assess the speed of recovery of investment and financial attractiveness of each option with respect to deployment scenarios. These values represent the payback period for each year. This indicates how many years it takes for the initial investment to be recouped based on the annual cash flows. The payback period obtained for D-RAN, C-RAN, vRAN and open RAN are 2.34, 2.048, 2.039 and 2.034 respec tively. This means, O-RAN achieved the lowest return on investment period, which is 2.034 years.

Scenario Comparison: Sc-4 (O-RAN): This one reveals the shortest Payback Period evidencing the shortest time needed to recover the initial investment. Sc-3 (vRAN): Demonstrates Payback Period of slightly longer than Sc-4. Sc-2 (C-RAN): Demonstrates a longer Payback Period than in Sc-4 and Sc-3. Sc-1 (D-RAN): Indicates the longest Payback Period to show a slow pace in regaining on the initial investment. Investment Recovery: SC-4 (O-RAN) reveal the shortest pay back period among all the options presented in the table. Financial Performance: Payback period which is calculated in terms of months is suggestive of the fact that smaller the number, the better is the prospects of the investment proposition. Technology Impact: The fluctuating Payback Periods may be attributed to how this approach-such as D-RAN, C-RAN, vRAN, and O-RAN- may incur in terms of initial cost, operating expenses, and profitability.

Return on Investment (ROI) ROI is a metric used to evaluate the profitability of an investment by comparing the gain or loss to the cost of the investment. It is typically expressed as a percentage. ROI (Return on Investment) and IRR are two different financial metrics used to assess investments. ROI measures the net gain or return on an investment relative to the cost. Figure 27 depicts the financial performance for each deployment scenario based on ROI. The Sc-4 O-RAN appears to offer the most interesting return on investment.

Sc-4 (O-RAN): Results in the highest ROI of 73.14%, hence revealing the most important aspect of return on investment. Sc-3 (vRAN): Demonstrates the second highest 68.92% of ROI. Sc-2 (C-RAN): Returns a relatively average of 66.85% of the amount invested. Sc-1 (D-RAN): Demonstrates the least outcome of the ROI test at 45.68%, thus meaning lower achievement and investment returns. Financial Performance: The chart also shows the total Return on Investment for each of the deployment scenarios. Taken in such a view, Sc-4 (O-RAN) seems to provide the highest potential for return on investments. Investment Decision-Making: ROI is and effective measure used for assessing profitability of investments on projects. More attractive is equal to a higher ROE Since this measures the rate of return on investment, a higher figure means the investment is more attractive.

IX. CONCLUSION

Due to rapid increase of traffic load and further increase in demand for data rate on the mobile communication and low latency connectivity which are beginning to exert pressure on available network bandwidth and also entail. This requires a radical type of thinking and revolution on the design of mobile network and couple of it on the RAN architecture. The networks represented by Cloud RAN embrace the application of the concept of NFV based on the IT management tendency of cloud environment, virtualization, and automation. To investigate the feasibility of deploying the CESCN for serving immersive video service during CE, we conducted a technoeconomic analysisof DRAN, CRAN, and Open RAN, as presented in this paper.

For CAPEX, the largest components are cell sites, small cells RRU and cloud servers , and all of them have to be deployed in the edge infrastructure. Two major aggregates of OPEX are the power and hardware maintance costs. The investment will pay itself out after about 2.34, 2.048 , 2.039 and 2.034 years respctively for DRAN ,CRAN vRAN and open RAN according to our analysis. Such a use case of 5G networks is immersive video service provision at public events. The services provide real-time, high-quality media content for an enhanced user experience. The study proposes the distribution of IVS using a CESC network. The architecture leverages edge computing capabilities, thus assuring low latency and quality of user experience. Any new service must be financially viable first to cater to it. This paper assesses the viability of an investment in a 5G infrastructure for IVS. A set of financial return on investment indicators is assessed, including net present value, internal rate of return, and estimated payback period. Other miscellaneous mobile network carriers may lease capacity in the CESC network. This is an economically viable approach since it facilitates cost-sharing and optimal utilization of resources.

Our analysis focuses on four deployment scenarios using Distributed RAN and Cloud RAN networks. We tested each deployment scenario's financial success by assessing total costs of ownership while calculating financial metrics including NPV, IRR, and PBP using a 10% discount rate. We tested how adjusting CAPEX, OPEX and revenue inputs affects the final outcome using extreme and optimal assumptions. Our analysis reveals that revenue impact remains high regardless of scenarios but CAPEX and OPEX exhibit minimal reaction to inputs even between extensive best and worst situations. Sc 4 shows the fastest monetary return from investment during the study period. Our combined analysis of economic and technical factors shows we should apply scenarios that fulfill users' demands. From this study, we conclude that Sc-4 is suitable and cost-effective for small urban-crowded areas and Sc-1 is suggested if there is an existing infrastructure available for the business area where traffic data usage is rapidly increasing and exceeding the estimated data rate; otherwise, Sc-2 is preferred as compaired to Sc-1.

This work concludes and provides insights for small cell network operators who would like to provide state-of-the-art 5G media services at busy events. Given the techno-economic factors, the Mobile network operators can make knowledgeable decisions and affect the development of 5G networks.

ACKNOWLEDGMENT

The study was carried out as part of the Master of Communication Engineering program, which Ethiotelecom and Addis Ababa Institute of Technology jointly implemented. To acquire the workforce of the Ethiotelecom Engineering and Marketing departments provides us with pertinent data for the study.

REFERENCES

[1] F. Tariq, M. R. A. Khandaker, K. K. Wong, M. A. Imran, M. Bennis, and M. Debbah, "A Speculative Study on 6G," *IEEE Wirel. Commun.*, vol. 27, no. 4, pp. 118–125, 2020, doi: 10.1109/MWC.001.1900488.

[2] C. Cheevers, M. Bugajski, A. Luthra, S. Mccarthy, P. Moroney, and K. Wirick, "NGN PEC 1 - Virtual and Augmented Reality – How do they affect the current service delivery and home and network architectures?," *ARRIS Enterp. LLC*, 2016.

[3] P. Paglierani et al., "Techno-economic analysis of 5G immersive media services in cloud-enabled small cell networks: The neutral host business model," *Trans. Emerg. Telecommun. Technol.*, vol. 31, no. 2, pp. 1–20, 2020, doi: 10.1002/ett.3746.

[4] Ericsson, *Ericsson Mobility Report*, 2023. Available at: https://www.ericsson.com/en/mobility-report

[5] Ethiotelecom, *Annual Report 2020*, Addis Ababa, Ethiopia.

[6] S. R. Sharma, *Cost Modeling in Mobile Networks*, IEEE Communications Magazine, vol. 56, no. 6, pp. 24-30, 2018.

[7] J. Li and H. Zhang, "Cloud RAN: A Revolutionary Technology for Mobile Networks," in *Proceedings of the IEEE 5G Conference*, 2017.

[8] B. Behailu Getachew Moges Advisor Beneyam Berehanu Haile, "Techno-Economic Analysis of Cloud RAN Deployment Scenarios: in the Context of Ethio Telecom Addis Ababa, Ethiopia," 2022.

[9] F. H. Tadesse and Ç. Erçin, "Assessing the user's needs in urban open space of Addis Ababa, Ethiopia," *Int. J. Adv. Appl. Sci.*, vol. 8, no. 7, pp. 106–114, 2021, doi: 10.21833/ijaas.2021.07.013.

[10] M. Kourtis et al., "A Cloud-Enabled Small Cell Architecture in 5G Networks for Broadcast/Multicast Services," 2019, Main Document.

[11] I. Giannoulakis et al., "System architecture and deployment scenarios for SESAME: Small cEllS coodinAtion for Multi-tenancy and Edge services," in *IEEE NETSOFT 2016 - 2016 IEEE NetSoft Conf. Work. Software-Defined Infrastruct. Networks, Clouds, IoT Serv.*, pp. 447–452, 2016, doi: 10.1109/NETSOFT.2016.7502483.

[12] L. Goratti, C. E. Costa, J. Perez-Romero, and Á. S. C. Á. V. Á., "The Role of Virtualization in the Small Cell Enabled Mobile Edge Computing Ecosystem," in *Cloud Fog Comput. 5G Mob. Networks Emerg. Adv. Appl.*, vol. 1, pp. 728–733, 2017, doi: 10.1007/978-3-319-65172-9.

[13] P. S. Khodashenas, C. Ruiz, M. S. Siddiqui, A. Betzler, and J. F. Riera, "The Role of Edge Computing in Future 5G Mobile Networks: Concept and Challenges," *Cloud Fog Comput. 5G Mob. Networks Emerg. Adv. Appl.*, pp. 349–370, 2017, doi: 10.1049/pbte070e.

[14] P. Paglierani, I. Neokosmidis, T. Rokkas, and C. Meani, "Techno-economic Analysis of 5G Immersive Media Services in Cloud Enabled Small Cell Networks: The Neutral Host Business Model," pp. 1–20.

[15] I. Neokosmidis et al., "Techno-economic Assessment of Immersive Video Services in 5G Converged Optical/Wireless Networks," in *2018 Opt. Fiber Commun. Conf. Expo. OFC 2018 - Proc.*, pp. 1–3, 2018.

[16] Y. Shekhawat et al., "Orchestrating Live Immersive Media Services over Cloud Native Edge Infrastructure," in *IEEE 5G World Forum, 5GWF 2019 - Conf. Proc.*, pp. 316–322, 2019, doi: 10.1109/5GWF.2019.8911681.

[17] I. Neokosmidis, P. Paglierani, and K. Moessner, "Assessment of CAPEX and OPEX for Media Services in Cloud Enabled 5G Networks," in *2019 CTTE-FITCE Smart Cities Inf. Commun. Technol.*, pp. 1–6, 2019.

[18] J. S. Walia, H. Hämmäinen, K. Kilkki, H. Flinck, S. Yrjölä, and M. Matinmikko-Blue, "A Virtualization Infrastructure Cost Model for 5G Network Slice Provisioning in a Smart Factory," *J. Sens. Actuator Networks*, vol. 10, no. 3, 2021, doi: 10.3390/jsan10030051.

[19] C. Colman-Meixner et al., "Deploying a Novel 5G-Enabled Architecture on City Infrastructure for Ultra-High Definition and Immersive Media Production and Broadcasting," *IEEE Trans. Broadcast.*, vol. 65, no. 2, pp. 392–403, 2019, doi: 10.1109/TBC.2019.2901387.

[20] G. Smail and J. Weijia, "Techno-economic Analysis and Prediction for the Deployment of 5G Mobile Network," in *Proc. 2017 20th Conf. Innov. Clouds, Internet Networks, ICIN 2017*, no. 2015, pp. 9–16, 2017, doi: 10.1109/ICIN.2017.7899243.

[21] S. G. Zeleke, B. B. Haile, E. T. Bekele, E. Mutafungwa, and J. Hämäläinen, "Data-Driven Multiobjective Optimization for Massive MIMO and Hyperdensification Empowered 5G Planning under Realistic Network Environment," *Wirel. Commun. Mob. Comput.*, vol. 2023, 2023, doi: 10.1155/2023/7146912.

[22] D. Nicholson, *Ethiopia 2050.*

[23] Z. H. Chang, B. F. Jong, W. J. Wong, and M. L. D. Wong, "Distributed Video Transcoding on a Heterogeneous Computing Platform," in *2016 IEEE Asia Pacific Conf. Circuits Syst. APCCAS 2016*, pp. 444–447, 2017, doi: 10.1109/APCCAS.2016.7803998.

[24] A. Checko et al., "Cloud RAN for Mobile Networks - A Technology Overview," *IEEE Commun. Surv. Tutorials*, vol. 17, no. 1, pp. 405–426, 2015, doi: 10.1109/COMST.2014.2355255.

[25] P. Paglierani, C. Meani, A. Albanese, and P. S. Crosta, "Immersive Video Services at the Edge: an Energy-Aware Approach," *Journal Name*, vol. 10, no. 3, pp. 145–154, 2017.

[26] E. Explanation and M. Visualization, "Sign up on myMSC & Book Online D-RAN, C-RAN, vRAN and Open RAN," pp. 1–5. [Online]

[27] L. More, "C-RAN vs Cloud RAN vs vRAN vs O-RAN vs traditional RAN - Guide!," pp. 1–57, 2021. [Online]

[28] X. Bai, "Scenario Analysis on LTE Mobile Network Virtualization," no. July, 2013.

[29] M. A. Kourtis et al., "A Cloud-Enabled Small Cell Architecture in 5G Networks for Broadcast/Multicast Services," *IEEE Trans. Broadcast.*, vol. 65, no. 2, pp. 414–424, 2019, doi: 10.1109/TBC.2019.2901394.

[30] M. Kist, "Radio and Baseband Unit Virtualization: Pushing the Boundaries of Future Mobile Networks," no. August, 2020.

[31] C. Bouras, P. Ntarzanos, and A. Papazois, "Cost Modeling for SDN/NFV Based Mobile 5G Networks," in *Int. Congr. Ultra Mod. Telecommun. Control Syst. Work.*, vol. 2016-Decem, pp. 56–61, 2016, doi: 10.1109/ICUMT.2016.7765232.

[32] M. Mahloo, J. M. Soares, and A. Roozbeh, "Techno-economic framework for cloud infrastructure: A cost study of resource disaggregation," in *Proc. 2017 Fed. Conf. Comput. Sci. Inf. Syst. FedCSIS 2017*, vol. 11, pp. 733–742, 2017, doi: 10.15439/2017F111.

[33] A. Kostopoulos, I. P. Chochliouros, E. Sfakianakis, D. Munaretto, and C. Keuker, "Deploying a 5G Architecture for Crowd Events," no. i, 2019.

[34] A. Albanese, "Grant Agreement No. 671596 Experimental Integration results of HW/SW modules of the overall SESAME framework," no. 671596, pp. 1–63, 2017.

[35] I. Action, "Grant Agreement No. 671596 CESC Small Cell prototype and PoC," no. 671596, pp. 1–63, 2017.

[36] A. Kostopoulos, I. P. Chochliouros, I. Giannoulakis, and A. Kourtis, "Small Cells-as-a-Service in 5G Networks," in *2018 IEEE Int. Symp. Broadband Multimed. Syst. Broadcast.*, pp. 1–5, 2020.

[37] D. Dissertation, *Techno-Economic Assessment of Access Technologies*, 2015.

[38] F. Yaghoubi et al., "Techno-economic and business feasibility analysis of 5G transport networks," in *Opt. Wirel. Converg. 5G Networks*, pp. 273–295, 2019, doi: 10.1002/9781119491590.ch13.

[39] P. H. Kobos, T. E. Drennen, A. S. Outkin, E. K. Webb, M. Scott, and S. Wiryadinata, *Techno-Economic Analysis: Best Practices and Assessment Tools*, no. December, 2020.

[40] M. M. Rahman, C. Despins, and S. Affes, "Analysis of CAPEX and OPEX benefits of wireless access virtualization," in *2013 IEEE Int. Conf. Commun. Work. ICC 2013*, pp. 436–440, 2013, doi: 10.1109/ICCW.2013.6649273.

[41] S. E. E. Profile, "Techno-Economics of Integrated Communication Systems and Services Deliverable 19: Final techno-economic results on mobile services and technologies beyond 3G," no. February, 2016.

[42] A. Reesom Bisrat, B. B. Haile, E. Mutafungwa, and J. Hämäläinen, "Quality Evaluation for Indoor Mobile Data Customers in Addis Ababa Business Area Using Data from Network Management System, Walk Test, Crowdsourcing and Subjective Survey," *Journal Name*, vol. 1026, 2019, doi: 10.1007/978-3-030-26630-1.

[43] B. B. Haile, D. A. Bulti, and B. M. Zerihun, "On the relevance of capacity enhancing 5G technologies for Ethiopia," in *10th Ethiopian ICT Annual Conference*, Addis Ababa, Ethiopia, June 2017.

[44] M. Zukerman, *Introduction to Queueing Theory and Stochastic Teletraffic Models*, 2022.

[45] J. L. Van Den Berg, "The M/G/1 queue with processor sharing and its relation to a feedback queue," *Queueing Systems*, vol. 9, pp. 365–401, 1991.

[46] Y. Qi, M. Hunukumbure, M. Nekovee, J. Lorca, and V. Sgardoni, *Quantifying Data Rate and Bandwidth Requirements for Immersive 5G Experience*, in *Proc. 2016 IEEE International Conference on Communications Workshops (ICC)*, 23-27 May 2016, Kuala Lumpur, Malaysia, DOI: 10.1109/ICCW.2016.7503829, IEEE, 2016.

[47] T. Taleb, Z. Nadir, H. Flinck, and J. S. Song, *Extremely Interactive and Low-Latency Services in 5G and Beyond Mobile Systems*, *IEEE Communications Standards Magazine*, vol. 5, no. 2, pp. 114-119, June 2021, doi: 10.1109/MCOMSTD.001.2000053.

[48] A. Bujari, O. Gaggi, M. Luglio, C. E. Palazzi, G. Quadrio, C. Roseti, and F. Zampognaro, *Addressing the Bandwidth Demand of Immersive Applications Through NFV in a 5G Network*, *Springer*, vol. 25, pp. 1114-1121, Mar. 2020.

[49] R. N. Esa, A. H. Danisya, and A. R. Danisya, "5G NR planning at frequency 3.5 GHz: Study case in Indonesia industrial area," *2020 2nd International Conference on Industrial Electrical and Electronics (ICIEE)*, Purwokerto, Indonesia, 2020.

[50] J. T. J. Penttinen, *5G Explained: Security and Deployment of Advanced Mobile Communications*, 1st ed. Atlanta, Georgia, USA: John Wiley and Sons Ltd, 2019.

[51] T. Kebebew, "Coverage, capacity, and cost performance analysis of 5G sub-band (3.5GHz) and 5G millimeter-wave (26GHz): In the context of Addis Ababa, Ethiopia," M.S. thesis, Addis Ababa Institute of Technology, Addis Ababa, Ethiopia, Aug. 2023.

[52] A. Teker, A. H. Ornek, and B. Canberk, "Network bandwidth usage forecast in content delivery networks," *Medianova CDN R&D Center, Şehit Ahmet Sokak No:4 Mecidiyeköy İş Mer. 15th Floor, Şişli/Istanbul/Turkey*, 2023. Email: aykut.teker@medianova.com, ahmet.ornek@medianova.com, canberk@itu.edu.tr.

[53] S. S. Lisi, A. Alabbasi, M. Tornatore and C. Cavdar, "Cost-effective migration towards C-RAN with optimal fronthaul design," in *IEEE ICC 2017 SAC Symposium Access Systems and Networks Track*, 2017.

[54] A. Author1, B. Author2, and C. Author3, "Orchestrating live immersive media services over cloud native edge infrastructure," *Proceedings of [Conference Name or Journal]*, 2023.

[55] J. L. Frauendorf and É. A. de Souza, "The architectural and technological revolution of 5G," 2023.

[56] R. P. Wicaksono, H. U. Mustakim, and A. A. F. Purnama, "Technical and economic analysis for 5G NR network non-standalone planning in Yogyakarta City using 2300 MHz frequency," 2024.