Optimization of 5G Network Architecture for Enhancing Reliability and Low Latency: A Case Study on Somaliland.

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Presented in Partial Fulfillment of the Requirements for the Degree of Master of Science in Electronics and Telecommunication Engineering (M.Sc. in ETE) at Daffodil International University.

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APPROVAL

This is to certify that the entitled Optimization of 5G Network Architectures for Enhanced Reliability and Low Latency: A Case Study on Somaliland, submitted by Daud Ahmed Awad [241-31-006] a graduate student of the Department of ICE has been examined. Upon recommendation by the examination committee, we hereby accord our approval of it as the presented work and submitted report fulfill the requirements for its acceptance in partial fulfillment for the degree of Master of Science in Electronics and Telecommunication Engineering.

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ABSTRACT

This research focuses on the optimization of 5G network architectures to enhance reliability and reduce latency, using Somaliland as a case study within a developing-country context. Employing OMNeT++ simulations supported by survey data, the study evaluates latency, throughput and bit error rates under different scenarios. The results demonstrate that advanced techniques such as edge computing, network slicing, renewable energy integration and traffic optimization significantly improve network performance. In addition, the research highlights non-technical barriers, including regulatory limitations, infrastructural challenges, and shortages of skilled professionals, which hinder sustainable 5G deployment. By integrating theoretical analysis, technical analysis and socio-economic perspectives this study provides academic contributions to the field of wireless communication and offers practical recommendations for policymakers and industry stakeholders seeking to advance 5G adoption in Somaliland and other similar regions.

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CHAPTER: 01

INTRODUCTION

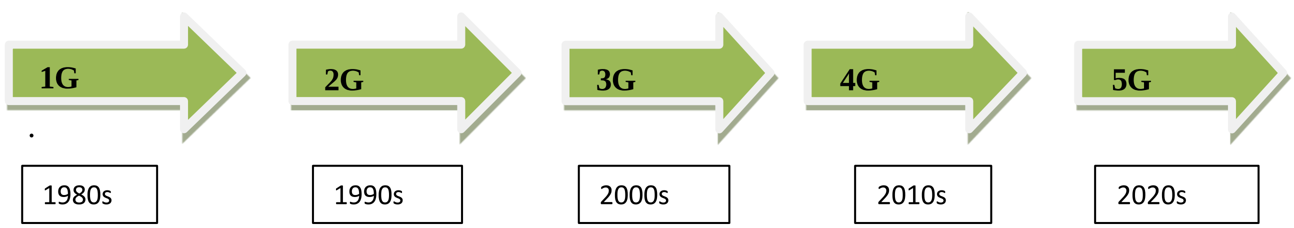
1.0 Introduction

Telecommunications are essential in today's world for bringing people together, communicating and promoting global economic change. With the promise of incredibly high internet speeds, lower latency, and enhanced connectivity, 5G technologies mark a significant breakthrough in wireless communication [1]. Deploying and optimizing 5G networks in under developing locations like Somaliland presents significant obstacles, despite its transformative promise. Even though Somaliland has already implemented 5G, its full potential still requires infrastructural improvements. In order to improve telecommunications infrastructure and advance socioeconomic development, this study explores the optimization of 5G network architectures in Somaliland with an emphasis on overcoming these challenges, Somaliland's telecommunications sector has shown remarkable resilience and growth, even during periods of civil wars and socio-economic adversity. However, the current infrastructure lacks the sophistication required to support a high-performance 5G networks [2]. The primary aim of this research is to identify innovative strategies for the effective optimization of 5G technology in Somaliland, recognizing the infrastructural, regulatory, and economic hurdles specific to this context. This research uses a multidisciplinary approach, combining qualitative methodology, quantitative surveys, and a review of relevant literature. Engaging discussions with telecommunications experts, government officials, users and community stakeholders contribute to a holistic perspective essential for the successful optimization of 5G networks. The outcomes aim to guide policymakers, government and industry leaders in Somaliland, offering a framework that could also benefit other developing countries those are facing similar challenges. In conclusion, this study aspires to provide strategic insights and actionable solutions for optimizing 5G networks in Somaliland, addressing technical, environmental, and social dimensions to support the country's digital transformation and socio-economic growth [3].

1.1 Background of the research

1.1.1 Network architectures and the Genesis of 5G: Evolution of the mobile communications.

In the past few decades, mobile communication has witnessed remarkable advancements, transforming the way we connect, communicate, and access information. From the early days of brick-sized mobile phones with limited capabilities to today's digital smart phones with lightning-fast data speeds, the journey of mobile networks has been nothing short of astonishing. In this blog post or arrow lines we'll take a trip down memory lane and explore the evolution of mobile communication from 1G to 5G, understanding how each generation of mobile networks has shaped the world we live in[1].



The evolution from 1G to 5G has transformed mobile communication, progressing from analog voice calls (1G) to digital texting (2G), mobile internet (3G), high-speed streaming (4G), and now ultra-fast, low-latency connectivity (5G), enabling innovations like IoT and smart cities.

Looking ahead, 6G is expected to push the boundaries with AI-driven networks, terahertz communication, and even more seamless integration of virtual and augmented reality into everyday life.

The progression of wireless communication technologies has been marked by successive generations, each introducing transformative capabilities. This section provides an overview of the evolution, leading up to the emergence of 5G in table 1.1.

Features	1G	2G	3G	4G	5G
Development years	1980s	1990s	2000s	2010s	2020s
Technology	NMT, AMPS, TACS	GSM	WCDMA	LTE, WiMAX	MIMO mm Waves
Frequency	30KHz	1.8GHz	1.6-2GHz	2-8GHz	3-30GHz
Data rates/Bandwidth	2Kbps	14.6-64Kbps	2Mbps	2000mbps- 1Gbps	≥ 1Gbps
Network	PSTN	PSTN	Packet Network	Internet	Internet
System	FDMA	TDMA/CDMA	CDMA	CDMA	OFDM/BDMA

Table 1.1: Overview of the evolution leading up to the emergence of 5G

1.2 Latency optimization and 5G network architecture

1.2.1 Architecture of 5G network

The architecture of 5G network is very huge and complex and has many interconnections which include advanced technologies that allow performing much extremely better than the previous versions of generations as its purpose was to improve the network architectures those already existed. It's designed and planned to be flexible, scalable and capable of supporting a wide range of use cases from enhanced mobile broadband to mission-critical applications [2]. 5G network architecture is a major improvement which is designed as a modular flexible framework to accommodate an extensive range of services. Its components the Core Network and Radio Access Network (RAN) are basic building blocks that collectively make usable to high performance levels and reduced latency in the sector [3].

Core functions such as AMF, SMF, UDM, and PCF assist in smooth network functioning, indirectly leading to less latency. The 5G RAN, which is responsible for wireless communication, has seen many changes to support the demands of higher data rates and lower latency. Some of the key developments include the use of mmWave frequencies for increased capacity, massive MIMO with beam forming for increased spectral efficiency, and the new NR interface for more efficient data transmission.

The RAN's programmable and flexible nature enables dynamic resource allocation and optimization. Furthermore, the decomposition of the RAN into CU, DU and RU enables strategic placement of processing and latency-sensitive processing is moved closer to the edge. Edge computing is necessary to decrease latency since data is processed closer to the user and this is necessary for use cases like AR/VR and industrial automation. With the RAN and core integration provided by edge computing, a distributed architecture is created that augments centralized cloud capacity with low latency and high reliability for diverse 5G use cases [3].

The picture below presents a modern 5G network architecture that integrates multiple layers of connectivity to improve both reliability and latency. It features 5G macro cells that offer wide-area coverage and connect mobile users like smart transport units or connected cars and 5G small cells that provide high-speed, low-latency access to densely populated areas or indoor environments.

These small cells are critical for supporting real-time applications such as mobile gaming, smart devices, and IoT. A key feature of the architecture is the inclusion of local (edge) servers and central servers. Local servers process data closer to users, reducing latency and network congestion while central servers handle more complex or large-scale data tasks.

The combination of small cells, edge computing and centralized processing ensures faster response times and more reliable service, making this structure ideal for latency-sensitive applications directly supporting goals like optimizing 5G for regions such as Somaliland and other developing countries around the world, additionally figure 1.1 illustrates how 5G network

Architecture looks like and what are the components needed to implement and how they interconnect to each other as well.

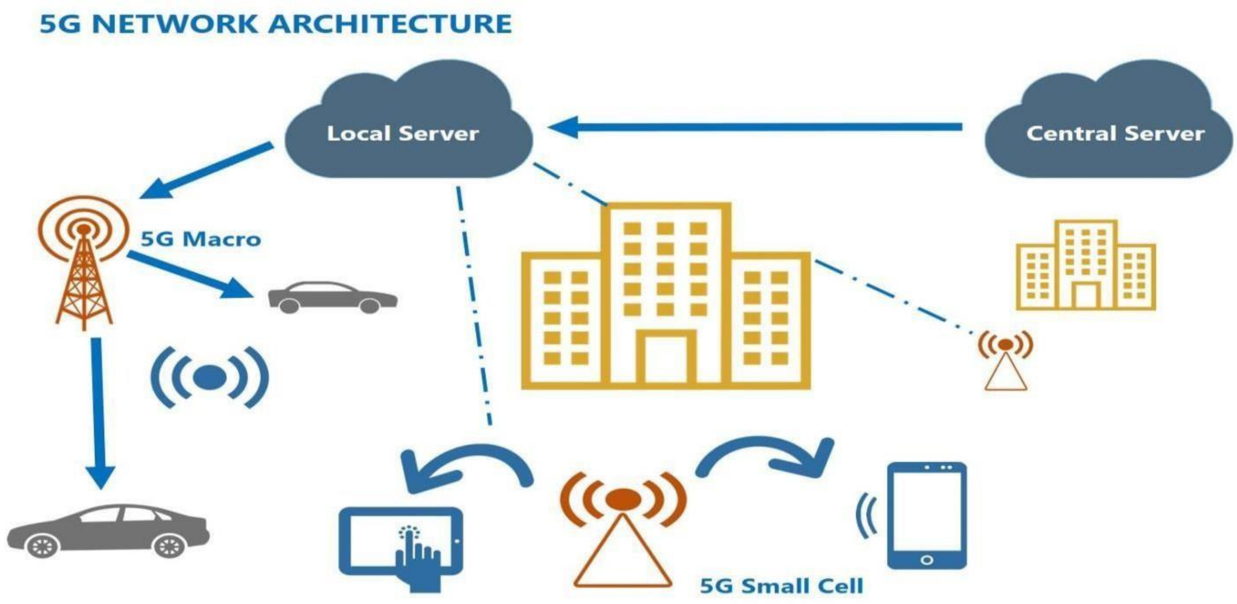


Figure: 1.1 5G network architecture [4]

1.3 Problem Statement

Telecommunication industry sector in Somaliland faces a lot of challenges including inadequate infrastructure of the country, limited access to reliable electricity and independent regulatory framework so that these challenges reduce and make difficult of getting dependable and low-latency network services especially in remote and rural regions those are far from major cities.

Addressing these barriers is important to optimize 5G networks which can improve coverage and connection across urban, suburban and rural areas of the country.

By solving and overcoming these challenges, connection of 5G can contribute Somaliland's economic development, expand access to digital services and improve the overall quality of telecommunications for individuals, businesses and industrial sector as well.

1.4 Research Aims and Objectives

In the study four key objectives has been focused and those are the following once.

1. First to provide a comprehensive assessment of Somaliland's historical landscape and existing telecommunications framework summarizing the main challenges and opportunities for enhancing 5G infrastructure.
2. To technically make technical simulations to get some results using OMNeT++ which is used (git-hub + my code) as a source code to analyze performance of existing 5G networks and its improvements specifically latency reduction, increasing data rate, throughput, bit error rate and optimize Somaliland's connectivity into 5G across all the country.
3. The research examines the potential environmental impact of advanced telecommunications in both urban and rural Somaliland settings emphasizing sustainable practices.
4. As well as the study examines environmental impact of advanced telecommunications in both urban and rural Somaliland settings.

1.5 Research Questions

Primarily based on the take a look at problems, the research will check out.

The following ensuring questions:

1. What are the main factors affecting the reliability and latency of 5G networks in Somaliland, problems that telecom sector in Somaliland is facing in general and how to overcome?
2. What role can dynamic spectrum sharing and renewable energy integration play in enhancing the deployment of 5G in Somaliland?
3. How do socio-economic factors, such as cost and access to telecommunications infrastructure influence the development of 5G in Somaliland?
4. How can we technically reduce latency in general, in Somaliland's connectivity and how does the date rate and throughput will change after the optimization?

1.6 Research Plan

Objective: This study aims to optimize 5G network architectures in Somaliland to improve reliability and reduce latency, addressing infrastructure, regulatory, and socio-economic challenges specific to the region.

Methodology: in this research a mixed-methods approach will be used:

- Qualitative methodology: Questionnaire with telecom experts, users/clients with community stakeholders and a review of relevant literature.
- Quantitative methodology: Technically analyzing the data, applying statistical methods and thematic analysis to interpret collected data and identify key patterns and this part we will use OMNeT++ in order to simulate our findings.

Research Phases

Phase 1: Introduction and Literature Review: defining the study and examining 5G deployment strategies and infrastructure challenges in similar developing regions to inform the study's framework.

Phase 2: Data Collection: Gathering qualitative data through questionnaire on a focused groups and surveys alongside quantitative network performance data.

Phase 3: Environmental and Socio-Economic Assessment: Evaluating the environmental impacts of 5G infrastructure and analyze socio-economic factors influencing adoption.

Phase 4: Technical data analysis: Applying statistical methods and thematic analysis to interpret collected data and identify key patterns and this part we will use OMNeT++ in order to simulate our findings

Phase 5: analysis and discussion as well as conclusion and future recommendations, Synthesizing findings into actionable recommendations to enhance 5G reliability and low latency, increased data rate and throughput stability in Somaliland.

1.7 Research Organization

This thesis contains six chapters and I explained each chapter as follows.

Chapter 1: Introduction

- ✓ Introduction and background of the research topic as well as its significance in the context of 5G network architectures.
- ✓ Research objectives and specific research questions to be addressed.
- ✓ An overview of the research methodology and the structure of the thesis.

Chapter 2: Literature Review

- ✓ A comprehensive review of existing literature related to 5G network architectures starting from the beginning up to now of ultra-reliable and low-latency communications focusing Somaliland literatures and other developing countries' literatures only.
- ✓ Analysis of research studies and academic papers that explore the history of Somaliland's telecom sector, telecom in developing countries, Structural, Business and Market Realities in Telecom of developing countries,
- ✓ And finally, explaining the Growth Constraints and Developmental Impact, Environmental Considerations in Telecommunications as well as Impact of Socio-Economic Factors on Telecommunications Deployment

Chapter 3: Somaliland's telecommunication sector landscape

- ✓ Introduction about Somaliland in general
- ✓ Historical development of telecommunications sector in Somaliland
- ✓ Driving connectivity in Somaliland's telecom sector or key players of the sector
- ✓ Current connectivity of the nation

Chapter 4: Methodology

- ✓ Overview of the research approach and design.

Chapter 5: Analysis and Discussion

- ✓ Summary of the research findings and their implications for optimizing 5G network architectures for ultra-reliable and low-latency communications.
- ✓ Reflection on the research objectives and how they were addressed in the study.
- ✓ Results for valuation of existing 5G Infrastructure in Somaliland using the data from the survey identifying challenges its facing and the solutions.
- ✓ Result, including key takeaways and contributions to the field of 5G network performance evaluation and optimization.

Chapter 6: Conclusion

- ✓ Summarizing the primary research findings
- ✓ Discussing the contributions of my research that has made to the field of 5G network architecture and URLLC especially in Somaliland although it will help the other developing countries in Africa and all over the world.
- ✓ Limitations of the study
- ✓ Recommendations for future work
- ✓ References

CHAPTER: 02

LITERATURE REVIEW

2.0 Introduction

The purpose of this chapter is to presents a comprehensive overview of the literature that exists and is relevant to the optimization of 5G network architectures for ultra-reliability and low latency (URLLC), specifically in the case of Somaliland. It covers the state of the art of 5G technology with a focus on key architectural features and their impact on latency and reliability and challenges it is facing nowadays like society conflicts, lack of reliable and cheap electricity as well. The review also covers opportunities and challenges related to 5G deployments in developing nations with particular attention to the unique conditions of Somaliland comparing with some neighboring countries like Ethiopia and Djibouti. Finally, this chapter identifies research gaps and gives the contribution of this study.

2.1 History of Somaliland’s telecommunication sector

The central government under the corrupt rule of dictatorship leader had a strong monopoly on the telecom industry before Somaliland's re-independence in 1991 when the government of the regime collapsed. Somaliland has a thriving modern telecommunications sector since his dictatorship was overthrown and the country's citizens use mobile phones unaccountably. In terms of Somaliland's telecom industry, it is widely covered with reliable services recorded in every area. In regional Somaliland a privately held ICT sector is thought to be one of the main drivers of telecoms connectivity [5].

Before Somaliland in 1991, the telecommunications sector was owned entirely by a communist government. The collapse of the regime government in 1991 led to the destruction of telecom industry which disconnected Somaliland from the rest of the world. Somali business people saw this as an opportunity and by 1993 different private telecommunication providers were established. Privatization promoted competition which led to expanded mobile services, lower prices, better efficiency and technological innovations across the country.

The late President Mohamed Ibrahim Egal's light regulatory style contributed hugely to Somaliland's telecom sector and economy in general. The sector has grown immensely since his era due to its simple infrastructure and quick return on investment.

Rather than remittances, telecom has become Somaliland's most uncovered private sector, with some private operators like Telesom, Somtel and Somcable providing competitive and high-technology services.

Although there are a lot of challenges that Somaliland's telecom sector faces still Somaliland's telecommunications sector is one of the most modern and least expensive compared to its neighboring and some most of other countries in Africa [6].

An important transition over years occurred as Somaliland moved from a government of monopoly under the regime of said bare to an improved market with competition and cutting-edge technologies like 5G and mobile money services.

In addition, the introduction of fiber-optic cables has significantly improved internet speeds and reliability empowering educational institutions, businesses and the tech community as well.

The picture on figure 2.1 with the timeline below presents key milestones in Somaliland's telecommunication industry journey, its highlighting the spirit that define the sector's character and development through the years.

This sector remains very important to Somaliland's socio-economic progress and continues to evolve with the digital age which is good this quickly improving world on the side of digitalization.

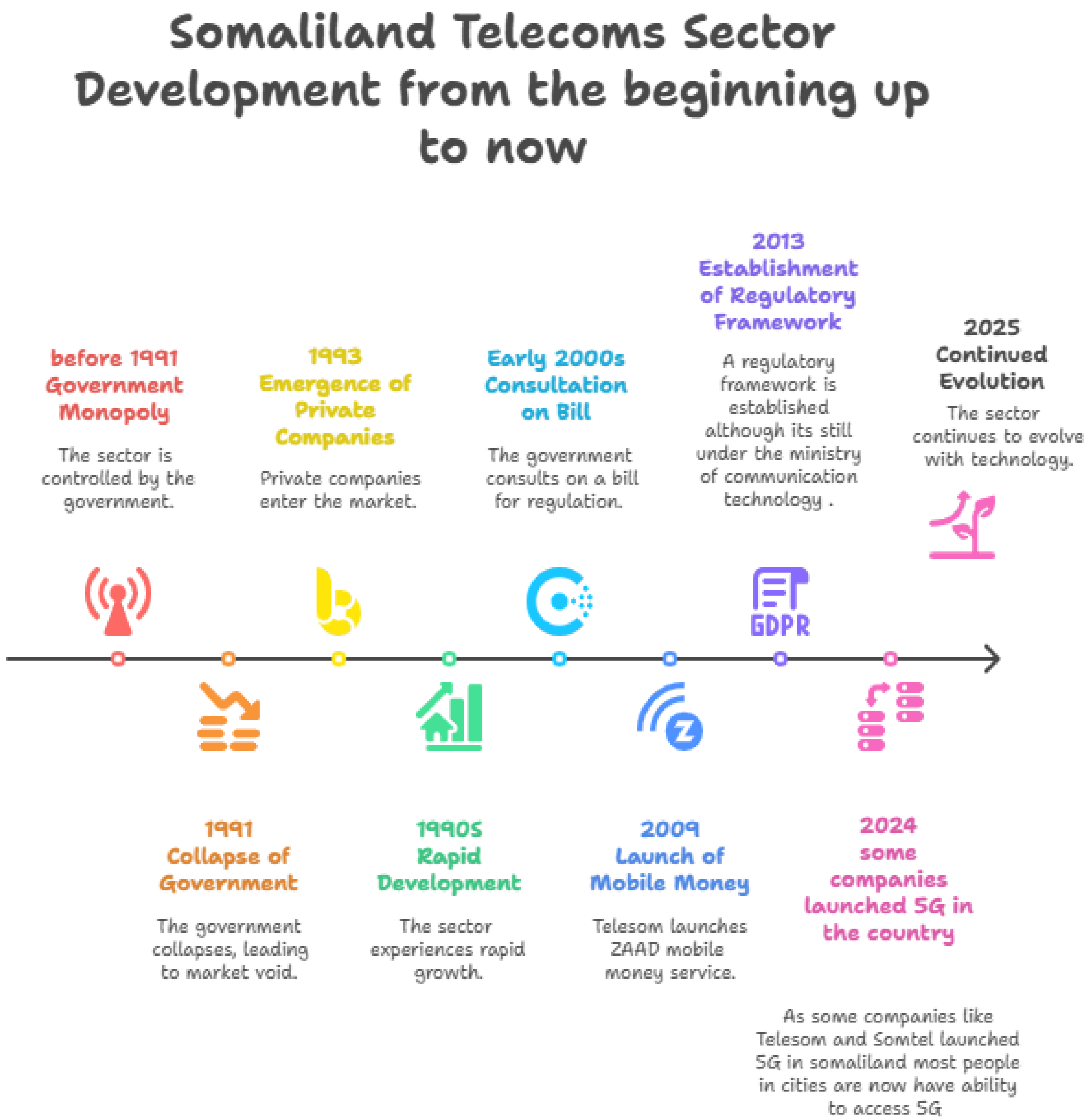


Figure: 2.1 key milestones in Somaliland's telecom journey

2.2 Telecommunications in Developing Countries

The expansion and development of telecommunications in developing countries creates difficult situation that is completely different from what is experienced in already developed countries. These nation's structural, economic, technological and environment in general effect the development, administration and growth of telecommunications sectors [7], [8].

It is important to overcome these challenges of distinction in order to develop investments and policies that find to improve connectivity and advance inclusive development of the nations.

Besides a lot of challenges, the telecommunications sector in developing countries holds important potential to improve socioeconomic development and as we all know improved connectivity can foster digital inclusion, support small businesses, facilitate e-governance and enhance education and healthcare services like telemedicine technology. Through strategic investments in infrastructure, human capital and policy reform these nations can accelerate their transition into the digital age [8]. Governments and private development partners must prioritize rural coverage, invest in human capital and create a more competitive and transparent telecom environment.

2.3 Structural, Business, and Market Realities in Telecom of developing countries

In most developing countries, the telecommunication sector has traditionally been dominated by monopoly enterprises owned by the central governments. Although liberalization and privatization trends are slowly taking root progress remains uneven.

Many countries still face huge bureaucratic structures that effect efficient service delivery and technological innovation [8]. The overall quality of service (QoS) is typically lower than that of developed countries with users frequently experiencing network outages, slow internet speeds and poor voice call quality

These issues are largely due to outdated invested infrastructure and a lack of sufficient investment in system upgrades and improvements.

The commercial environment also lacks sufficient competition as there is no too many private or even public companies. In many cases, government monopolies or a small number of dominant providers control the sector reducing the incentive to innovate or lower prices.

In addition to that, regulatory barriers discourage new entrants and hinder healthy market competition [10].

2.4. Growth Constraints and Developmental Impact

One of the most pressing challenges to telecommunications development in these countries is the lack of investment whether internationally or locally. Investment in telecom infrastructure whether for constructing more mobile network towers, fiber-optic networks or satellite system is expensive and often beyond the capacity of governments or local companies.

And as a result of that, these countries depend on international loans, foreign direct investment or donor funding from foreign organizations and banks [11]. Additionally, the legal and regulatory frameworks in many developing nations are outdated or incomplete to serve a service like this.

Corruption and poor management within institutions may also delay the implementation of projects or mis-allocate resources [9].

One of the biggest issues is the neglect of rural and remote areas in Telecom planning and investment. While urban users may access mobile phones and internet services, most rural populations often lack even the basic connectivity.

This digital divide increases inequalities depriving rural communities of access to educational resources, healthcare services and economic opportunities that depend on communication technologies [12].

The lack of qualified professionals further becomes a challenge for growth. High-level technical and managerial expertise is limited due to under investment in specialized education and training programs. Many countries depend on foreign technicians and consultants to implement or manage and improve telecom projects which increase costs and weaken local capacity [13].

And finally, local manufacturing of telecom equipment is virtually non-existent in most developing countries. This dependence on imported devices, equipment's and systems increases infrastructure costs and creates supply chain vulnerabilities and without domestic production countries also miss out on opportunities to create jobs and improve industrial growth rapidly.

2.5 Environmental Considerations in Telecommunications

The deployment of 5G networks has given rise to significant environmental problems, which increase in magnitude with the acceleration and wide-scale adoption of telecommunications infrastructure. These constrains make difficult the entire lifecycle of telecommunication systems which includes the production, installation, operation and implementation of network equipment with countries like Somaliland starting to adopt 5G technology and understanding its implications becomes imperative for sustainable improvements.

One of the primary environmental impacts of 5G and other related infrastructures is energy consumption, 5G base stations especially those operating in the millimeter wave spectrum require a huge more power than their predecessors due to their higher frequency usage increased signal processing and dense deployment of small cells.

5G network constructions differ significantly from 4G in terms of networking modes, product forms and performance parameters as well.

The power consumption of 5G hardware is between two and four times greater than 4G posing unprecedented challenges for site construction. It calls for a systematic research and innovative 5G energy solutions to meet the energy challenges brought by 5G.

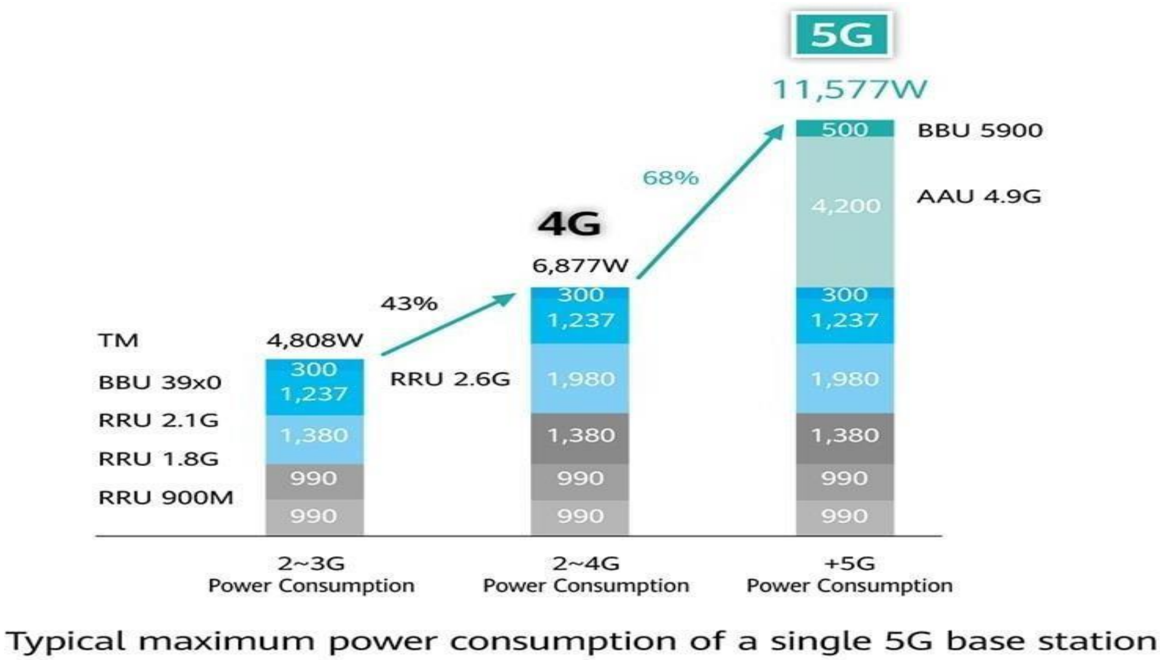


Figure 2.3: comparison of 3G, 4G and 5G in terms of power consumption [14]

2.6 Impact of Socio-Economic Factors on Telecommunications Deployment

The deployment and expansion of telecommunications infrastructure, especially advanced technologies like 5G are significantly influenced by socio-economic factors.

These factors determine not only the readiness of a country to adopt new technologies but also the pace, scope and sustainability of such deployment.

In regions such as Somaliland, where socio-economic disparities and infrastructure gaps persist understanding these influences is essential for effective planning and equitable access [12].

In undeveloped countries the average revenue per user (ARPU) is often insufficient to implement large-scale 5G investments without external funding or government support. For many consumers in Somaliland, affording 5G-compatible devices and premium data plans remains un affordable, further limiting market demand and slowing operational investments [15].
Another key factor is urban-rural disparity. Telecommunications operators tend to focus on urban areas where population density and economic activity can ensure quicker returns on investment. Consequently, rural and remote regions often remain underserved or entirely excluded from modern network coverage.

This digital divide increases existing inequalities and discriminates rural communities from benefiting from services such as e-learning, telemedicine, and e-commerce that depend on fast and reliable internet connection.
In Somaliland, efforts to integrate ICT education into the national curriculum and vocational training programs could accelerate the adoption of 5G by fostering a tech-literate population that can create and demand digital solutions.
Education and digital literacy also play an important role. Societies with higher literacy rates and stronger STEM subjects (Science, Technology, Engineering and Mathematics) education systems are better positioned to adopt and utilize advanced communication technologies like 5G. Additionally, government policy and institutional support are very important.

Countries with clear national broadband plans and regulatory frameworks tend to attract more investment in telecoms infrastructure. The absence of such frameworks in Somaliland has sometimes led to fragmented deployment where private companies operate without a regulatory national strategy, leading to inefficiencies and overlap in infrastructure development

Addressing challenges in affordability, education, rural access and policy alignment will be critical for ensuring that 5G and other emerging technologies can be deployed inclusively and sustainably.

CHAPTER: 03

SOMALILAND'S TELECOMMUNICATION SECTOR LANDSCAPE

3.0 Introduction

Somaliland, officially the republic of Somaliland, is a self-declared country in the east horn of Africa which is not officially and internationally recognized yet. Somaliland occupies an area of approximately 176,000 square kilometers, its located in the southern coast of the Gulf of Aden and its bordered Somalia in the east, Djibouti to the northwest and Ethiopia to the south and west.

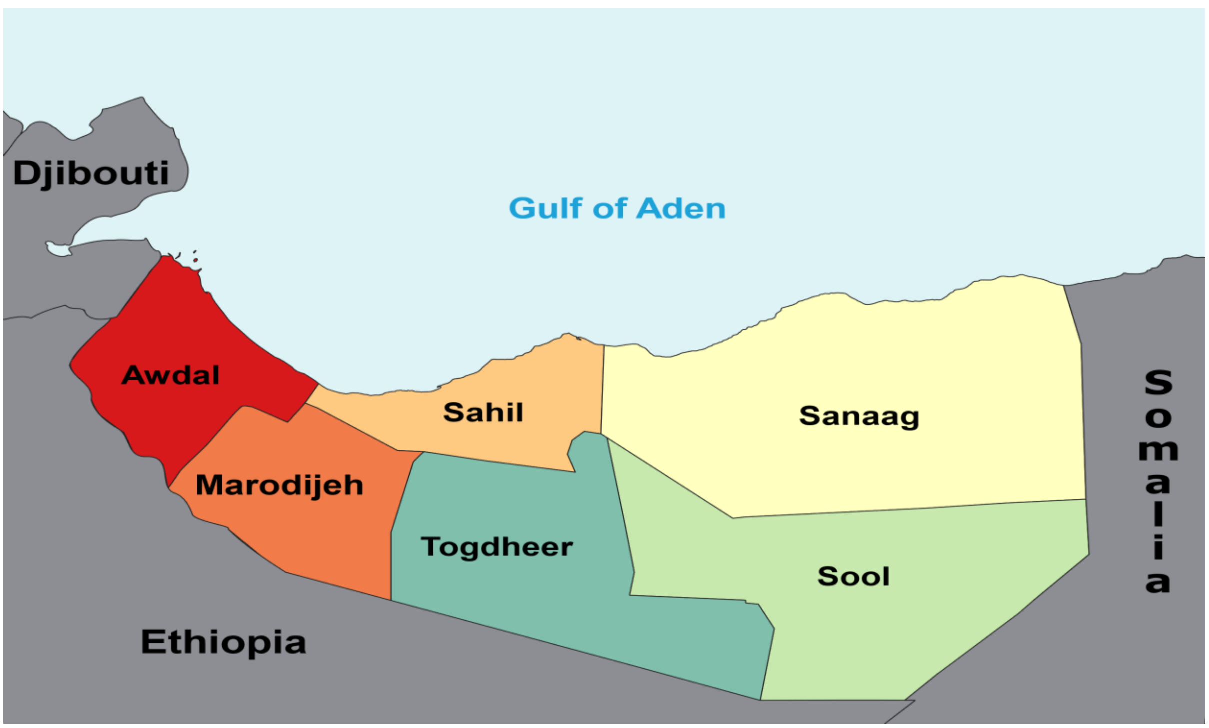


Figure 3.1: Map of Somaliland

Since declaring independence in 1991 following the collapse of Somalia's central government, Somaliland has developed its own political institutions, governance structures, and national identity, its proudly governs itself through a presidential system rooted in a constitutional frame work with its capital city located in Hargeisa.

it’s a home of an estimated 6.2 million people as of 2024, the population is predominantly young with about 65% up to 70% under the age of 30 reflecting a powerful potential of digital adoption, tech entrepreneurship and innovation, although this youth faces a lot of challenges whether its low quality education system, job markets challenges and infrastructure in general including internet connectivity.

With an estimated 45% of the population living in urban areas, urbanization is on the increasing day after day. This is especially true in large cities like Hargeisa, Burao, Erigavo, Las 'Anod, and Borama, where availability and reliability of electricity, mobile networks, banking services and Internet connectivity is better.

The need for inclusive digital infrastructure is further highlighted by the fact that 55% of the population lives in rural and nomadic areas with improper connectivity or relies on outdated 2G and 3G technologies. This is especially remarkable as the nation investigates cutting-edge technologies like 5G internet connectivity. Somaliland's society is bonded together by a common national identity, history, and culture.

Category	Value	Remarks
Total population	6.2 million (2025)	Based on UN and local projections
Urban population	45%	Staying mostly the 6 big cities
Rural population	55%	Nomadic and Agro-pastoral groups
Youth (under 30)	65-70%	High potential for tech adoption and invention

Table 3.1: Estimated Demographic Distribution in Somaliland (2024)

Somali is the official language of the country not only serving as a means of communication but also as a symbol of cultural pride and a heritage, as well as the Somaliland shilling remains the backbone of the local economy circulating widely in markets and every day trade despite the territory's lack of international recognition.

Somaliland uses +252 as a global communication calling code which is assigned to Somalia and it operates in an independent and well-developed telecommunication sector despite some challenges existing. Daily life follows day/month/year date format a small but consistent reflection of its administrative order and regional traditions.

Together these elements show a country that continues to operate with resiliency, self-determination and a strong sense of community despite not being internationally recognized.

3.1 Historical development of telecommunications sector in Somaliland

During the early years of Somaliland's state building in the mid of 1990s, the telecom industry in Somaliland grew rapidly due to lack of taxes, regulations and foreign exchange controls the absence of license providers, these big telecom service providers were able to compete the deregulated market Since then, these big telecom companies have acted swiftly to capitalize on the lax regulations and restrictions made possible by the absence of an effective regulatory law governing the telecom industry.

The development of Somaliland's telecommunication sector has been driven primarily by a private sector unlike the most African countries where governments or foreign operators dominate. Local telecom companies independently financed and constructed infrastructure such as communication towers, radio masts and later cellular base stations (BTS) to provide fixed voice, internet and mobile services.

Because of this Somaliland's operators are now among the most advanced in Africa, providing some of the lowest local and international call rates globally widespread mobile banking services and broad wireless access, and as a result Somaliland's tele-density is better that that of neighboring countries, being three times higher than Ethiopia, a level of penetration made possible only through private sector leadership.

Table 3.2, summarizes the most notable achievements and strengths of the sector highlighting the factors that positioned Somaliland as one of the leading telecommunication hubs in the region.

Aspect	Key points
Growth driver	Private sector led expansion with minimal regulation by the government
Infrastructure	Privately, self-financed towers and BTS's
Service quality	Among the most advanced in Africa despite some challenges
Call rates	One of the Lowest local and international global rates right now
Tele-density	Three times higher that some neighboring countries like Ethiopia

Table 3.2: Key highlights of Somaliland's telecom sector and historical records

The widespread of Somaliland's telecommunication has evolved significantly since its formative years following the collapse of Somalia's central government in 1991, at that time the entire country of nearly 10 million people possessed only about 8,500 operational fixed lines and the majority of it were located in capital city. Leaving most of Somaliland s population without direct access to communication services. On the other hand, in 2001 almost 68,000 phones where fixed in Somaliland which were divided in to 48,000 fixed and 20,000 phone lines.

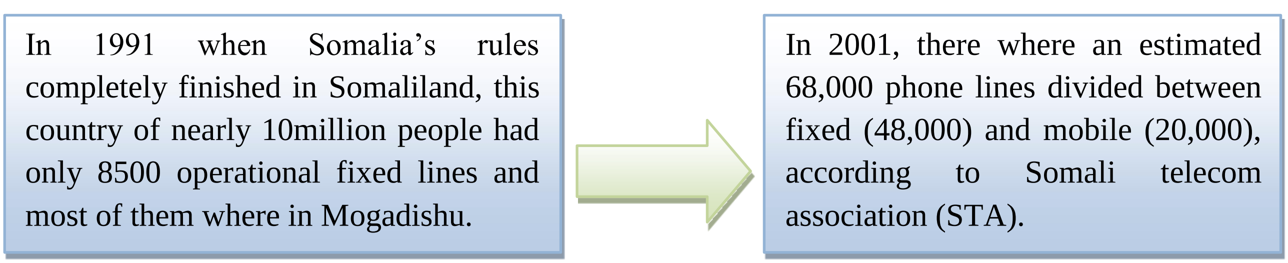


Figure 3.1: The widespread of telecommunication usage among Somaliland's population and the beginning [16]

Complementing telecommunications, Somaliland's information and communications technology (ICT) sector is also relatively advanced at this time and almost more than 4 operators like Telesom, Somtel, Somcable and Soltelco deliver internet and telephone coverage to approximately 85% of the country, wireless internet services extend to remote areas through dedicated antennas while fiber optic internet connection is already most of the big cities in the country and this began to change in 2022, when the National Fiber Optic Company (NFOC), a collaboration between the government and major operators, became operational, enabling cross-network calls and improving market competitiveness which will further enhance business and entrepreneurial opportunities.

However, yet difficulties persist like interconnectivity between different companies is absent preventing direct communications between across providers, nevertheless local call and SMS rates are affordable and international call rates remains one of the cheapest in Africa costing 0.20$ per minute[17].

In relation to public media Somaliland has only one public run radio station which is called, Radio Hargeisa and it can be tuned into in and around Hargeisa on the FM frequencies and regional wide non-FM frequencies. BBC and Voice of America have wider regional coverage. There are no privately owned commercial radio stations in Somaliland.

Public television services are provided by the Government's owned National Television Station (Somaliland National TV), Horn cable TV and MM TV etc. Satellite television is available and DSTV provides a large range fee-based cable channel service. DHL, Aramex and Hilaac services are the only privately owned available postal services in Somaliland. Somaliland's telecom has been rapidly evolved from government monopoly to a competitive market driven by private operators and this transformation has introduced advanced services like 5G, mobile money and high-speed internet significantly boosting internet connectivity, financial inclusion and as well as economic growth of the country.

3.2 Driving Connectivity: The homegrown leaders of Somaliland's Telecommunication sector

In Somaliland building a successful telecom network is not just about a technology it's about resilience, trust and local ingenuity and unlike many African countries where foreign giants like MTN, Bhart Airtel, Orange or Star link dominate the telecommunication market of the nation, Somaliland's telecom industry is almost entirely powered by Somali entrepreneurs both from the diaspora and the local within the country. This homegrown leadership has shaped services to meet the realities of daily life producing mobile money systems and innovations perfectly tailored to the region's unique challenges. Table 3.3 summarizes these leader companies those led Somaliland's connectivity and telecommunications sector in general, it mentions their achievements in to the sector since each company has developed unique strengths ranging from widespread rural network coverage to affordable service bundles, making telecommunications more accessible to the people across the country.

Leader/Provider	Year established	Coverage	Services offered	Achievements
Telesom	2001	Nationwide	Mobile money, broad band and 4G&5G	First to introduce mobile money (ZAAD).
Somtel	2008	Nationwide	Mobile money and fiber optic internet	Fiber optic connectivity and E-Dahab
Somcable	2009	Urban centers	Fiber optic backbone	International connectivity

Table 3.3: Key Players in Somaliland's Telecom sector

3.3 Current landscape of Somaliland's connectivity

Somaliland has developed a remarkable advanced telecommunications and internet infrastructure compared to many regions in horn of Africa, despite its international recognition, almost over the last two decades the country has transitioned from basic landline systems and government monopoly to competitive telecom market power by local companies.

Those companies played a vital role in providing mobile voice, internet and mobile money services to urban and the rural populations as well and the ongoing expansion of fiber-optic infrastructure and 5G rollout promises to further bridge the digital divide in the coming years.

Current estimates suggest that 45 to 70% of the population get and enjoy regular internet access, with smartphones serving as the primary device for browsing, communication, and digital transactions

The majority of the users accessing the internet through broadband mobile technologies such as 3G, 4G and in some place 5G. Table 3.4 shows the internet penetration and usage in Somaliland.

Connection	Urban areas	Rural areas
Coverage	95%	60%
Internet speed	10-50mbps(4G/5G)	5-25 Mbps (3G/4G)
Devices	Smart phones, PC's etc.	Feature phones and smart phones as well
Affordability	Moderate	Moderate to high

Table 3.4: Internet penetration and usage in Somaliland

Figure 3.3 shows a real time measurement on Somaliland's internet connectivity collected by Net blocks between 8 to 11 august 2022, it illustrates the connectivity levels for three major internet service providers (ISP's), working in Hargeisa, Somtel, Telesom and Somcable and as we can see they remained stable at 90 to 100% until 11 august when a major disruption occurred, Somtel and Somcable faced the sharpest declines falling up to around 30% while Telesom maintained partial service which was up to 79%, on the other hand Somcable recovered faster than the others reaching 92% within hours where the others remained unstable for a while.

This situation emphasizes the necessity for redundant systems and stricter regulatory monitoring by highlighting the fragility of Somaliland's internet connectivity and the disparities in resilience among the providers.

This scenario is evidence which includes access and penetration rates as well as the caliber and dependability of internet services, offers a quantitative and historical insight of Somaliland's connectivity landscape.

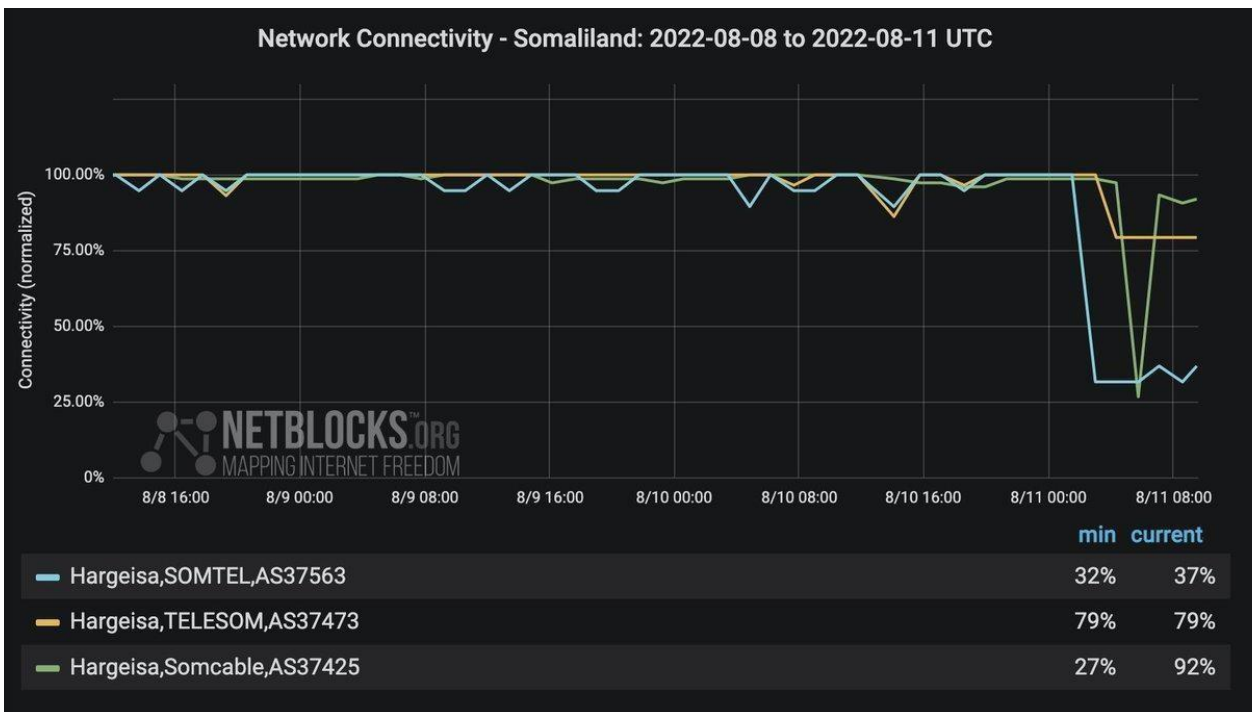


Figure 3.3: network connectivity-Somaliland from 8 to 11 august 2022[18]

Additionally, figure 3.4 shows both strength and weaknesses in maintaining connectivity by Somaliland's three main internet service companies in between July-25 and July 26 2025 as we are focusing only Somaliland.

During the observation time not of the all three networks were relatively stable with only small fluctuations reflecting a strong baseline of service stability. On the morning of July around 8:00am all the providers face a sudden widespread disruption; Telesom was hit the hardest of all with connectivity lowering or dropping almost completely, Somtel also experienced a sharp decline through slightly less severe on the other hand Somcable managed to keep a modest level of a connectivity suggesting that its systems may have stronger backup measures.

In the hours that followed none of the providers fully returned to normal service Somcable showed the best recovery maintaining almost partial access, Somtel recovered something but not fully recovered while Telesom remained the most effective with very low connectivity, because of this disruption occurred all three providers issue was not likely not only specific to providers but instead linked to a shared infrastructure challenge such as damage to fiber optic lines or technical interruption.

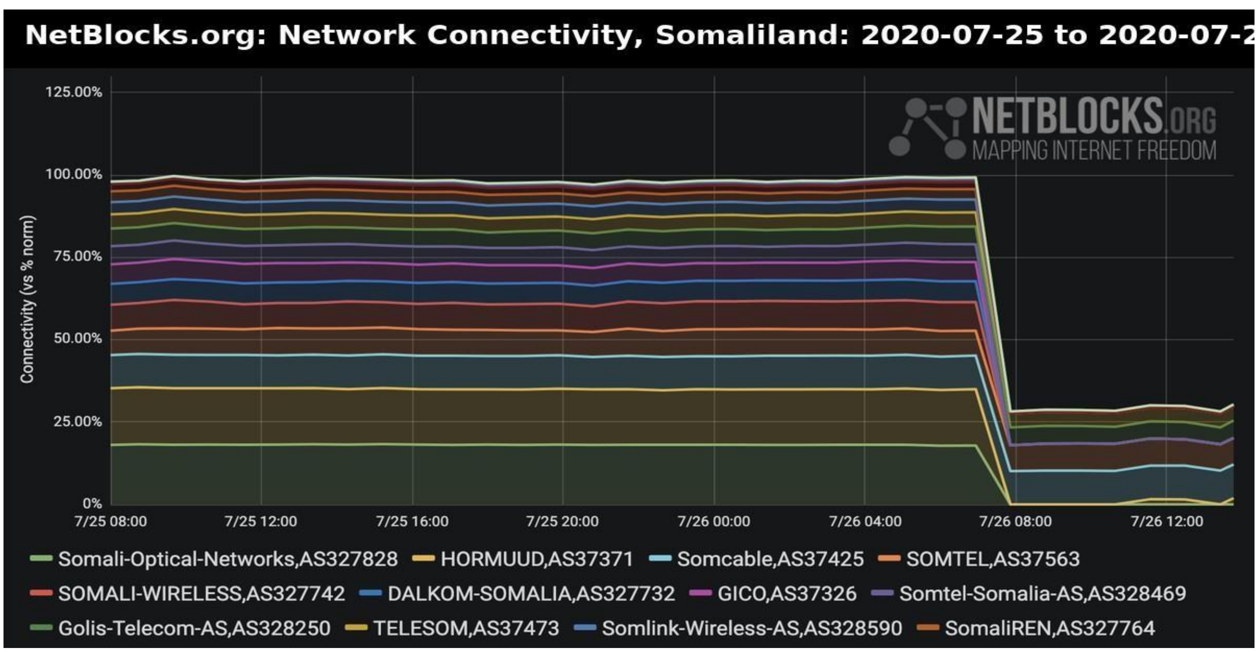


Figure 3.4: Network connectivity, Somaliland 25-26 July 2025[18]

The extablishment of fiber optic backbone has been a major milestone in somaliland's connectivity, Somcable a leading private operator has deployed extensive fiber optic infrustructrure connecting the main urban areas including Hargeisa, Berbera, Borama, Burao, Las anod and Erigavo, this backbone will not only ensure high capacity, low latency data transmission within the country but also links Somaliland to Djibouti which currently serves as its main internetional gate way, how ever the reliance of this single cross border connection introduces structural vulnerabilities as disruptions in Djibouti could significantly effect Somaliland's connectivity.

To address coverage gaps in rural areas and less accessibke regions microwave transmission has been implemented alongside fiber optic deployments and this demonstrated hybrid connectivity all around the country.

Figure 3.5 shows how fiber optic cable been trasmitted from Djibouti landing one of the coastal areas in Somaliland and being implement all across the country.

Figure 3.5: Somcable fiber optic cable connectivity in Somaliland [18].

Simultaneously, this event is also highlighting both the vulnerability of Somaliland's internet sector to large scale weaknesses and the significant of provider's resilience where Somcable in this case demonstrated comparatively stronger stability than the other under fluctuations. As internet penetration has been discussed and usage in Somaliland it is also important to mention internet connectivity of the nation in general, so that table 3.5 presents a consolidated overview of the nation's internet connectivity in general. It summarizes key demographic, infrastructural, and performance indicators, offering a clear context for assessing the digital landscape.

Objective/indicator	Value / Rate	Notes
Population	6.2million	UN and local registrations
Accessible to internet	4.3 users	71.67% of the population
Without internet	1.9 users	28.33% of the population
Average mobile internet speed	15 to 25Mbps	Ookla speed test
Average fixed speed	10 to 20 Mbps	Fiber optic mostly
Mobile latency	60 up to 80 ms	Higher at peak
Fixed latency	30 to 50 ms	Fiber better than wireless on satellite
4G coverage	80% on urban and 60% of rural users	ISP's
5G coverage	20% users	Only in urban areas

Table 3.5: Somaliland internet connectivity in general

CHAPTER: 04

RESEARCH METHODOLOGY

4.1 Introduction

In this chapter, I delve into the methodologies employed to undertake the comprehensive evaluation and optimization of 5G network architectures for ultra-reliable and low-latency communications (URLLC) focusing on Somaliland. The methodology section provides a clear outline of the research approach, data collection processes, theoretical and technical data analysis techniques, and ethical considerations that guided this study.

4.2 Research Approach and Design

This section outlines the overarching research approach and design that underpin the entire study. My research followed a mixed-methods approach, combining quantitative and qualitative techniques to ensure a holistic examination of 5G network architectures. Key components include:

- Qualitative methodology: Questionnaire with telecom experts, focus groups with community stakeholders, feedback from users and a review of relevant literature.
- Quantitative methodology: technically simulating results using OMNeT++ which is used git-hub as a source to analyze performance of existing 5G networks and specifically latency reduction.

4.3 Data Collection

In this study, data was collected through two complementary approaches: simulation experiments and a questionnaire survey. The simulation experiments were conducted using OMNeT++ to emulate a rural 5G network architecture, including latency reduction in general, specific mobile latency reduction, key performance metrics such as latency, data rate and throughput were recorded across different configurations to observe the effects of network optimization strategies.

Simultaneously, a structured questionnaire was designed and distributed to professionals, Government employee/Regulatory Staff, telecom operators, users/clients and engineers in the telecommunications sector, particularly those familiar with 5G deployment or involved in network planning in Somaliland and similar developing contexts. The questionnaire included both technical and non-technical aspects, covering latency, reliability, environmental factors, energy constraints, and the social impact of connectivity. Responses were collected using Google Forms ensuring data confidentiality and anonymity.

4.4 Data Analysis

This section outlines the various analytical tools and methodologies employed to process and interpret the collected data

1. **Qualitative Analysis:** Qualitative data obtained from user surveys and feedback was analyzed thematically to identify trends and patterns in subjective quality assessments. The responses from the questionnaire, including open-ended feedback on the 5G network reliability, environmental impacts and infrastructure limitations in Somaliland. This makes easy to identify recurring issues such as lack of stable power supply, limited fiber backbone or poor network coverage in general
2. **Technical Data Analysis:** Simulation data obtained from OMNET++ was analyzed quantitatively. Performance metrics such as latency, data rate, throughput, bit error rate and packet delivery ratios were extracted from the simulation. Graphs and statistical table summaries were used to evaluate how latency and reliability changed under different network conditions.
3. **Comparative Analysis:** Comparative analysis was conducted by evaluating the simulated scenarios against the survey responses, for instance latency, data rate, throughput and error bit rate results from simulations were cross validated with user reported experience in real world delays. The contrast between simulated ideal conditions and on-ground realities provided deeper insights into infrastructural and environmental gaps. This triangulation ensured a more comprehensive interpretation of results.

CHAPTER: 05

ANALYSIS AND DISCUSSION

5.0 Introduction

In this analysis and discussion chapter has been demonstrated by the main findings of the research, which focused on improving 5G network designs to enhance reliability and lower latency in Somaliland. The study demonstrates at the unique challenges of the region including its varied geography, economic limitations and poor existing infrastructure. The results, based on existing literature, questionnaire, data analysis and simulations provide useful insights into the current state of 5G in Somaliland and suggest practical strategies for future connectivity improvements.

5.1 Evaluation of Existing 5G Infrastructure in Somaliland

5.1.1 Performance Metrics of Current Deployments

The survey aimed to determine how widespread 5G technology is in key urban areas. People from various cities shared their experiences with 5G access.

The results have been compiled into a visual format to show the differences between locations.

From the chart, it is clear that Hargeisa, Burao, and Berbera are leading in 5G accessibility, accounting for 20%, 16%, and 16%, respectively. These cities are the largest cities as commercial and administrative centers in Somaliland, which likely explains their strong telecommunication infrastructure. Other cities like Borama 12%, Las ‘Anod 6%, and Erigavo 6% which shows moderate access to 5G.

The part which is labeled as other which is 24% represents the total share of smaller towns and rural areas that also report some level of access to 5G services and that means that while the main urban centers dominate 5G accessibility, there is still a meaningful share of 5G users scattered across less populated areas.

This pattern shows the increasing technology growth in urban areas and it also points out the need to expand more into smaller towns and regions.

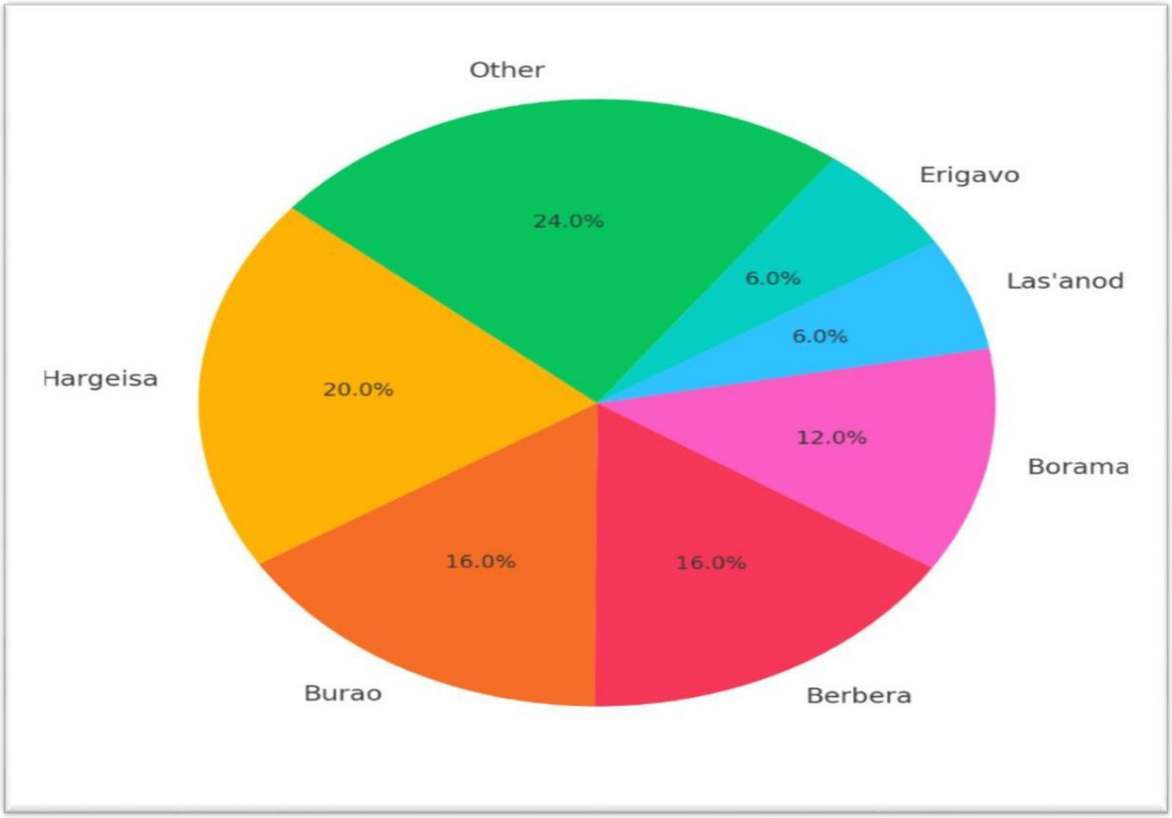


Figure 5.1: 5G network accessibility in major cities in Somaliland

In addition to mapping out the overall accessibility of 5G across the major cities of Somaliland, the survey also assessed the perceived reliability of the 5G connection among respondents. As illustrated in Figure 5.2, which presents the reliability assessment of 5G services, a significant portion of respondents rated the connection as “Somewhat reliable” which is almost 36% and very reliable 34%. This combined total of 70% suggests that the majority of 5G users in Somaliland experience a relatively dependable connection. However, a notable segment of respondents indicated negative experiences, with 26% reporting the connection as “Unreliable” and 4% labeling it as “Very unreliable”, which raises concerns about service consistency in certain areas.

When analyzed alongside Figure 5.2 which highlighted the distribution of 5G accessibility, a clear trend emerges. The cities with the highest share of access Hargeisa 20%, Burao 16%, and Berbera 16% are likely to account for the bulk of the positive reliability responses.

These urban centers benefit from better infrastructure and more frequent network upgrades, which could explain the higher reliability ratings.

Conversely, the other category 24% which means the rest of the country and other big towns such as Borama, Las ‘Anod and Erigavo with lower percentages of access, may correspond more closely with the unreliable and very unreliable responses, reflecting weaker network performance in those areas.

This reinforces the importance of expanding not just the availability but also the performance and stability of 5G networks throughout all regions of Somaliland.

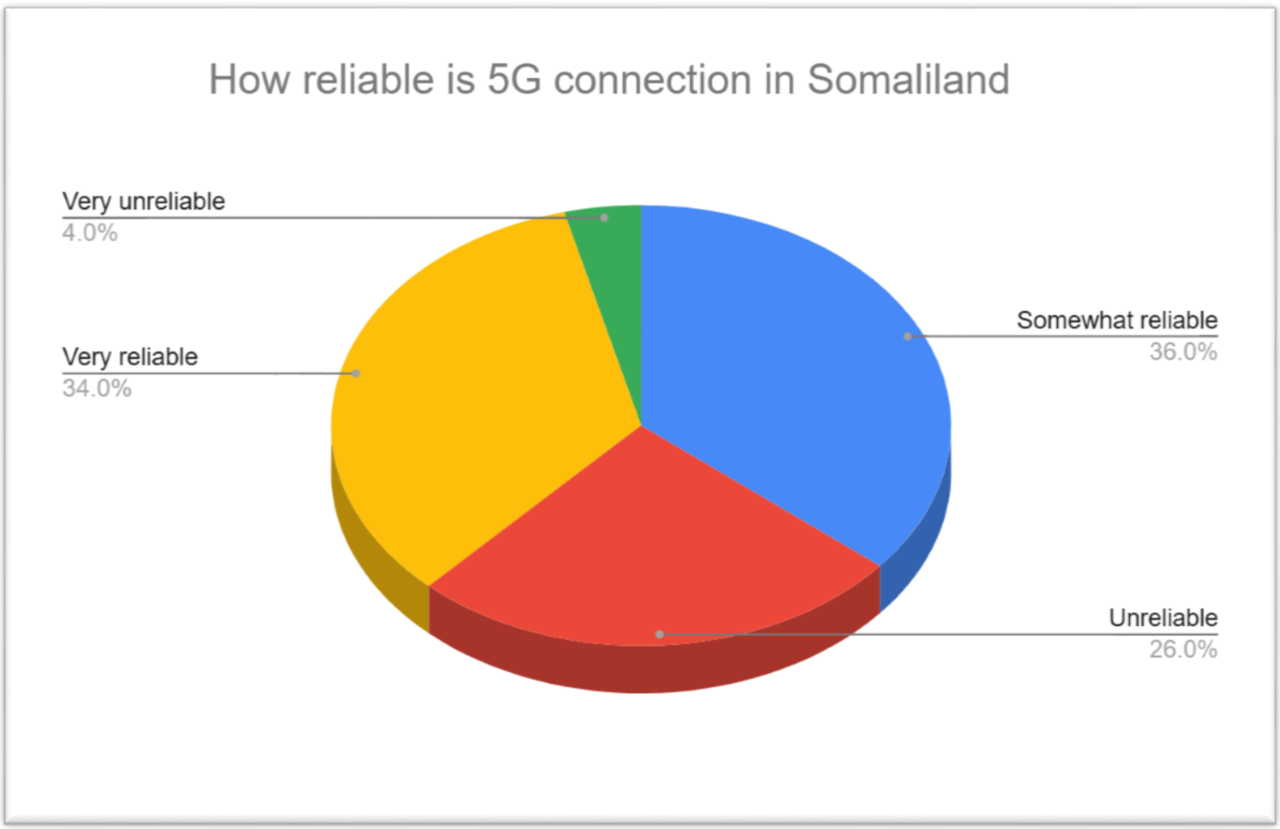


Figure 5.2: 5G connection reliability in Somaliland

Data collections from the previously existing 5G installations in Somaliland revealed key performance gaps as the following charts showing.

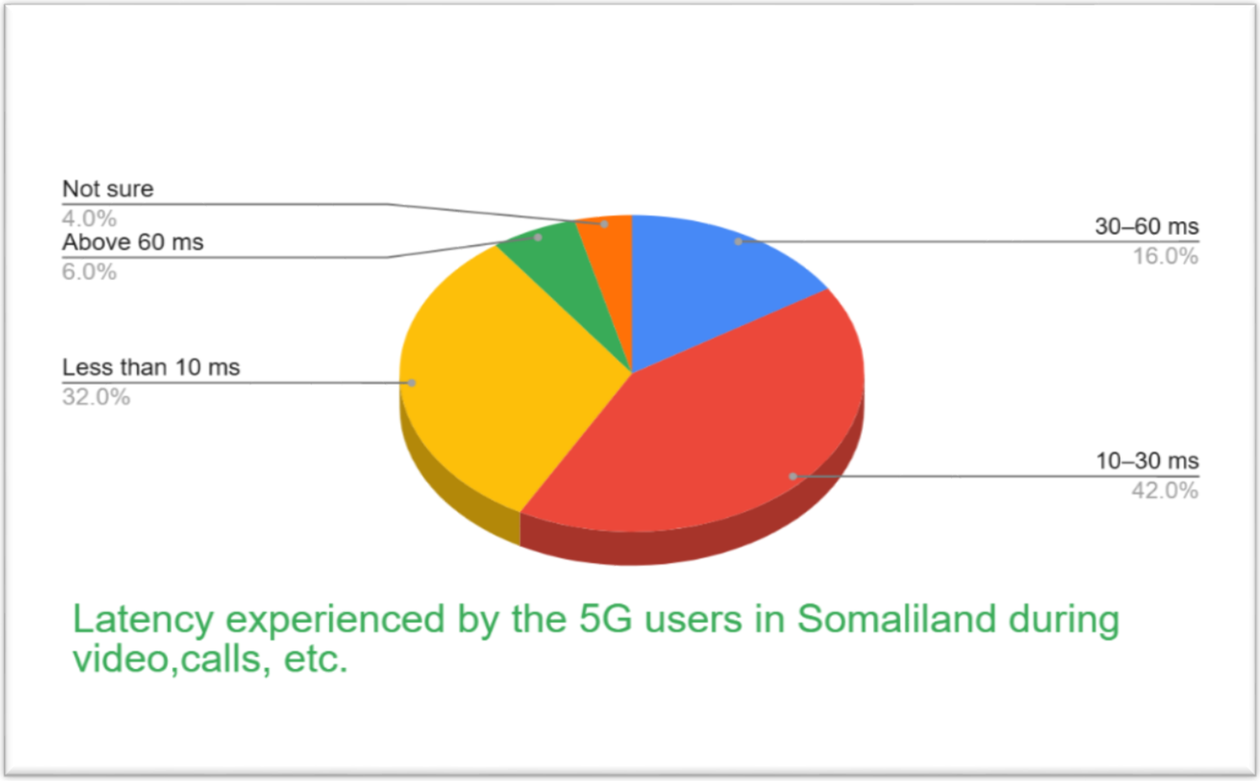


Figure 5.3: latency experienced by 5G users in Somaliland

Coverage Gaps, in Somaliland most of rural areas experienced a lack of coverage, with signal availability reduced by 30% compared to urban regions. This disparity stems from the insufficient deployment of base stations and backhaul connectivity in remote areas on the other hand, average latency exceeded (20 ms) in some scenarios, falling short of the required ultra-reliable low-latency communication (URLLC) standards.

These delays negatively impact real-time applications such as video conferencing and telemedicine additionally, reliability Challenges exists as frequent packet loss was observed, particularly in areas with poor backhaul infrastructure, resulting in degraded user experiences for voice and video streaming services.

5.1.2 Common challenges that Somaliland's existing 5G communication is facing

Based on the survey responses the graph on figure 5.4 shows the main obstacles Somaliland faces in maximizing 5G network services.

And as we can see the biggest challenge according to the respondents is Inadequate infrastructure accounting for the largest share which is close to 23-24% and this indicates that the fundamental telecom infrastructure in Somaliland is not fully prepared to handle the technical demands of 5G such as high-capacity backhaul networks, dense tower installations and modern core network upgrades as well as Lack of investment and Regulatory barriers both follow closely with each contributing around 13-14%.

On the other hand, shortage of expertise and spectrum scarcity has the lowest impact, each below 5%. While less common, they still affect 5G performance, with spectrum scarcity being a minor issue and the skills gap highlighting the need for more training and professional development.

Overall, this graph shows that infrastructural restriction and regulator concerns are the main

Obstacles to 5G optimization in Somaliland.

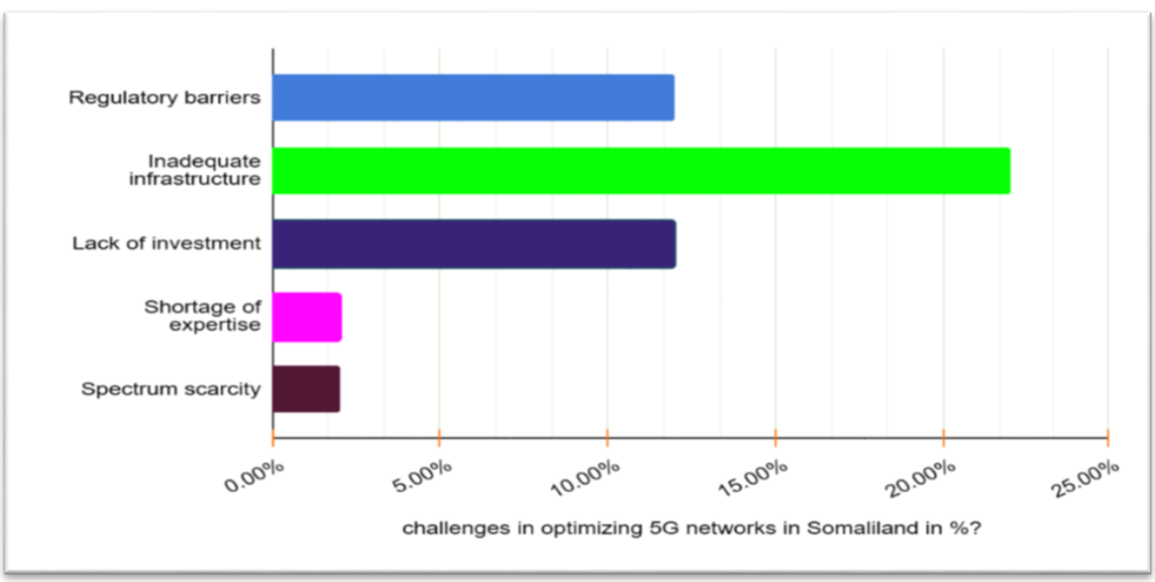


Figure: 5.4: Common challenges that Somaliland's existing 5G communication is facing

5.1.3 Solution for reducing latency in Somaliland

The study further investigated the most suitable technological solutions for reducing latency in Somaliland’s 5G networks by including a dedicated survey question on this topic. The responses summarized in Figure 5.5 presents the relative importance of five key 5G technologies in addressing latency challenges. As we can see the data clearly identifies which technologies are considered by local telecom experts and users to be the most impactful in improving speed and reducing delays in the network.

According to the findings, the majority of respondents which is almost 19% selected Small Cells as the most effective solution for latency reduction, and this indicates that expanding small cell infrastructure is seen as the most immediate and practical strategy, since small cells improve coverage density and reduce transmission distances, especially in urban centers where traffic is highest.

Mobile Edge Computing (MEC) is the second most preferred option, receiving around 12% of responses, highlighting the need to move data processing closer to end users, which can reduce round-trip communication time and improve real-time application performance.

In addition, 5G Network Slicing was chosen by roughly 9-10% of participants, emphasizing its potential in enabling dedicated low-latency network segments for specific services. Device-to-Device (D2D) Communication was selected by 7-8% of respondents reflecting its usefulness in supporting low-latency direct communications without involving central network nodes. And finally, mmWave spectrum received the least preference at 2-3% which aligns with the current limitations of this technology in Somaliland, particularly in terms of coverage challenges and cost of deployment. Overall, these findings show that Small Cells and MEC technologies are considered the top priorities for reducing latency in Somaliland, while advanced solutions like Network Slicing and D2D communication are viewed as important for future development. The low ranking of mmWave suggests that stakeholders are more focused on practical, scalable, and cost-effective technologies suited to Somaliland’s existing network environment.

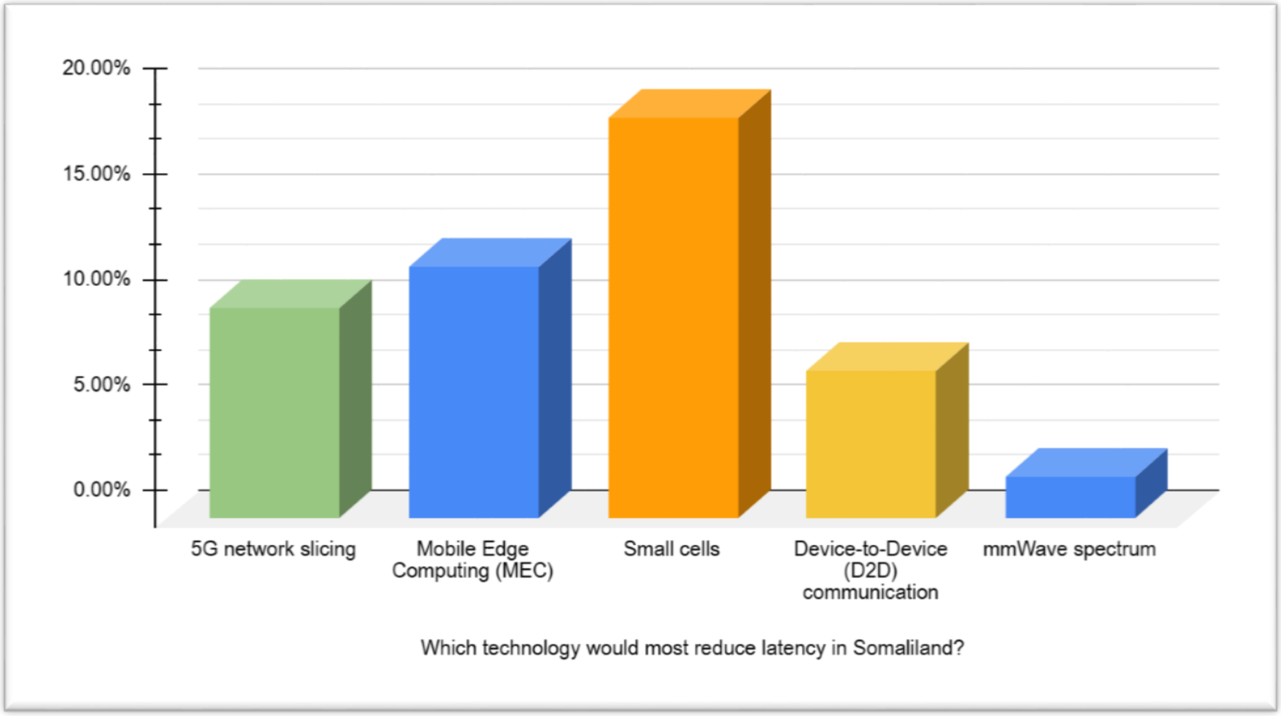


Figure 5.5: Technology that reduces latency the most in Somaliland

As well as from the survey responses gathered during the research it became clear that there are a few major steps needed to improve 5G performance in Somaliland and these apply to many other developing countries as well. Most people pointed to the need for building more towers and strengthening the energy infrastructure and without enough towers and stable electricity it's difficult to expect reliable 5G coverage, especially in rural and underserved areas.

Others also mentioned important areas like better spectrum management, encouraging collaboration between the government and private sector and training more skilled telecom professionals. While these might not seem as urgent as infrastructure and power, they're just as important in the long run if we want a strong and sustainable 5G ecosystem.

Overall, what this tells is that for Somaliland and countries in a similar situation to move forward with 5G we need to focus on both the basics and the future.

That means not only fixing what's lacking on the ground, like towers and electricity but also making smart decisions about regulation, investment and skills development.

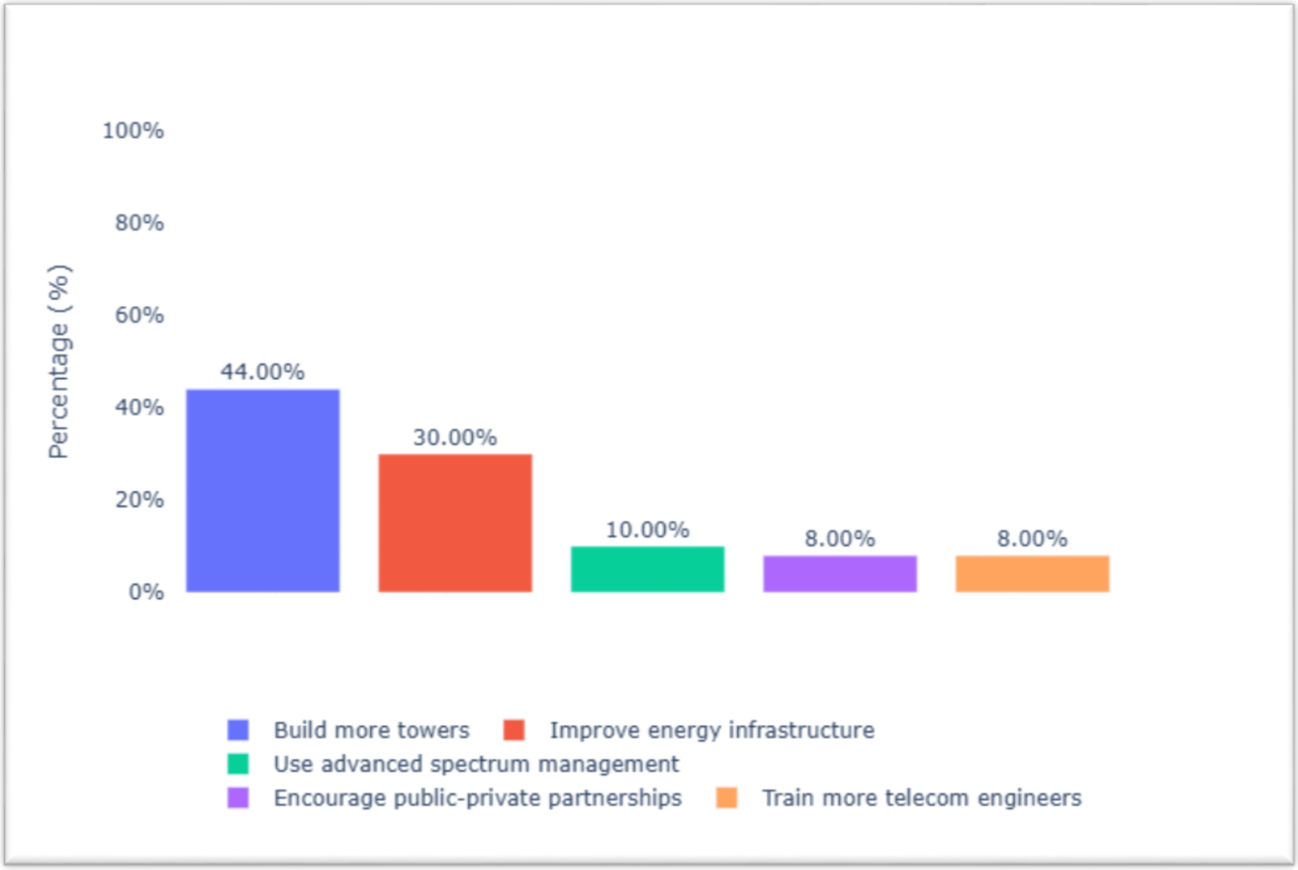


Figure: 5.6: Solution s in Common

5.1.3 Renewable Energy Integration in Somaliland's

Somaliland receives an average of 6 hours of daily sunlight, providing an untapped potential for solar energy integration. Despite this, the country predominantly relies on diesel generators, which are both expensive to operate and environmentally unsustainable, the chart below comes from the survey collected from the engineers and users scaling where does their telecom tower gets the power and as we can see most of the towers get the power as a power source from diesel generators.

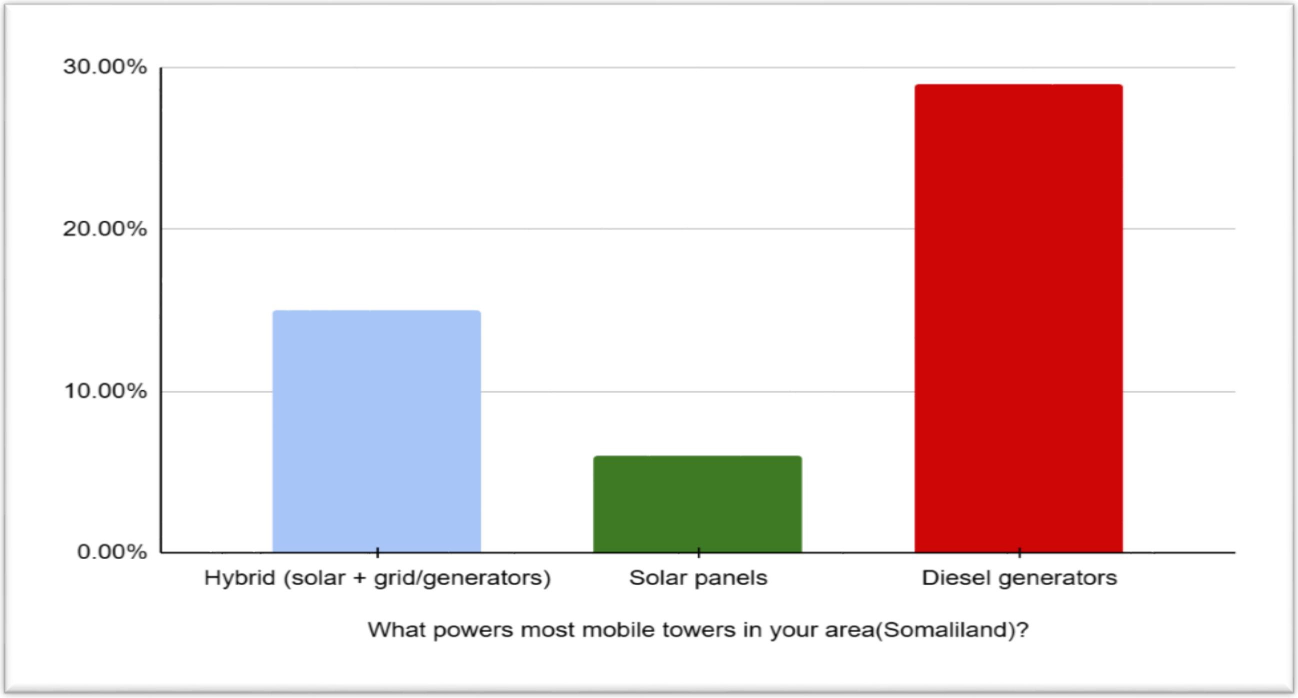


Figure 5.7: what power towers in Somaliland

Electricity costs in Somaliland are approximately $0.50 per unit as it differs from city to city, among one of the highest places globally, making it prohibitively expensive for telecommunication operators to expand their networks to rural areas.

The heavy reliance on diesel generators not only raises operational costs but also limits the viability of deploying small cells and base stations in remote regions. This, in turn, restricts the expansion and development of telecommunication networks, including 5G and beyond, in Somaliland.

Integrating solar-powered systems into the telecommunications infrastructure in Somaliland and other developing countries could solve these challenges by,

1. In terms of costs: Solar energy would significantly lower operational expenses making network deployment in rural areas more feasible and cheaper.
2. Sustainability: Utilizing renewable energy would decrease carbon emissions and dependency on imported diesel fuel.

5.3 Optimization Techniques

5.3.1 Experimental set up for network optimization in Somaliland's 5G connectivity using OMNeT++

In this experiment, a simplified network topology is simulated using OMNeT++ to analyze latency characteristics within a 5G-inspired environment, A source node in the model transmits data to a central queue, which subsequently divides the traffic among three queues, signifying different routes or network destinations.

Bye evaluating how packets cross through the network and identify speedy or delays, simulation provided a clear view of how architectural options affect overall network latency. By simulating this configuration the study was able to track packet movement, identify points of congestion and assess queue utilization over time.

This provided significant insights into how network design selection impact latency and one of the critical performance indicators for 5G systems. Finally, the setup served as a practical tool for examining ways to optimize network performance and supported the formulation of recommendations for infrastructure planning in Somaliland's emerging digital landscape.

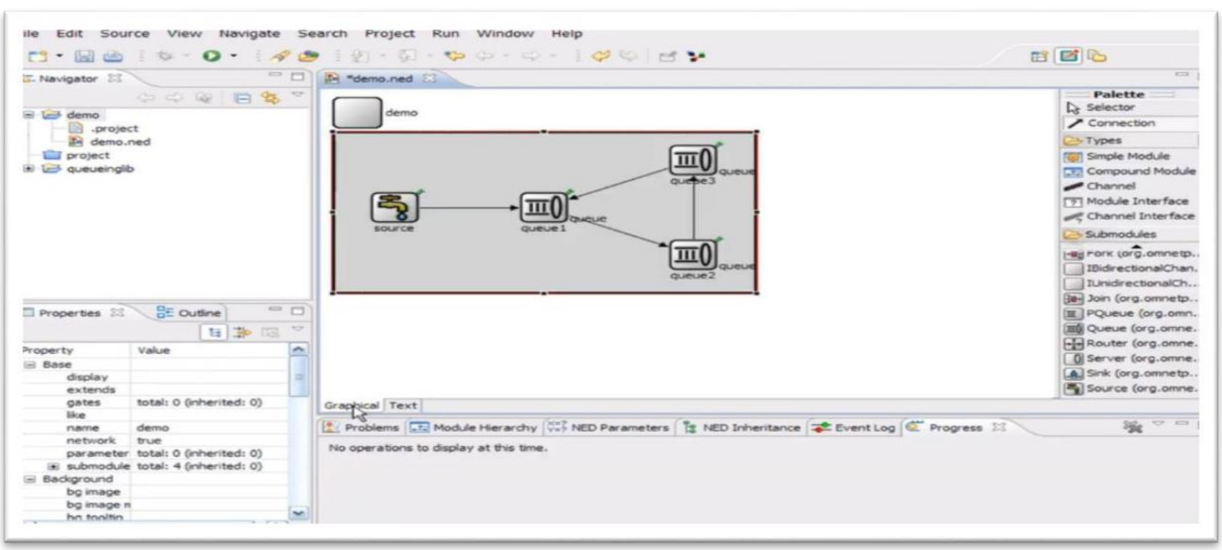
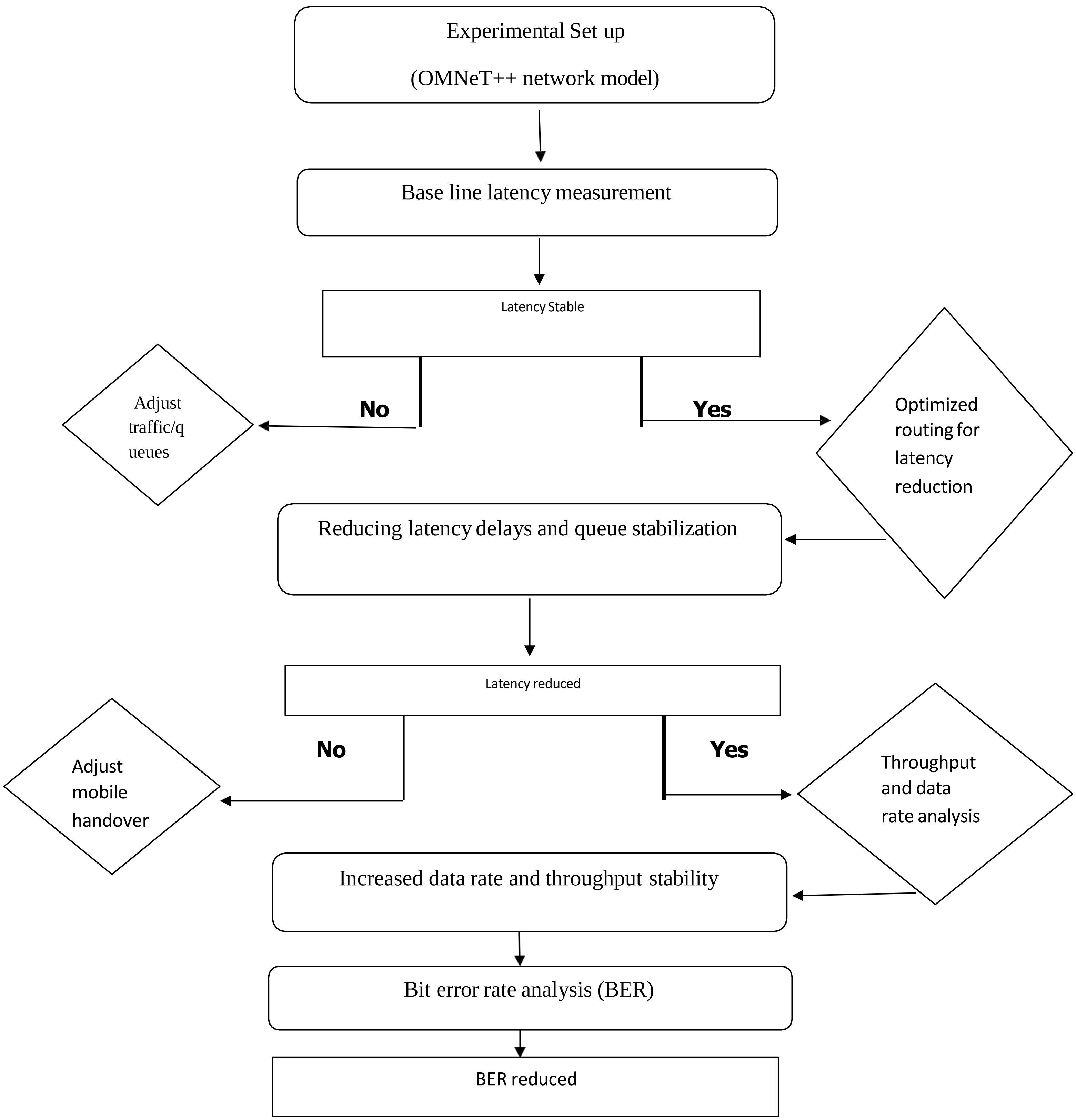


Figure 5.8: experimental setup

Flow chart



Experimental Set up
(OMNeT++ network model)
Base line latency measurement
Latency Stable
No
Yes
Adjust traffic/queues
Optimized routing for latency reduction
Reducing latency delays and queue stabilization
Latency reduced
No
Yes
Adjust mobile handover
Throughput and data rate analysis
Increased data rate and throughput stability
Bit error rate analysis (BER)
BER reduced

5.3.2 Simulation Results

Following the simulation run the system behavior over time was closely observed in order to assess the latency dynamics across various networks modules within the proposed 5G scenario. Different performance trends can be seen in the resulting graph and during the early simulation intervals there was an initial phase with sharp fluctuations and peak latency which was especially noticeable in some modules.

The network's reaction to the initial traffic load and congestion is reflected in this phase different levels of processing efficiency and delay are indicated by the variations in the final stabilized values across modules and Interestingly one module maintained a consistently higher latency indicating queuing inefficiencies or congestion, while other modules performed more smoothly showing improved handling capacity or better traffic path optimization, the simulation has effectively highlighted performance disparities across different routes, offering actionable insights for reducing delay.

This simulation focused on observing overall latency performance and queue behavior over time, mobile fixed latency throughput and data rate, and the following metrics were applied.

Average Latency (L avg) =

$$_{\{avg\}} = \{1\}/\{N\} \sum_{\{i=1\}}^{\{N\}(t_{\{receive_i\}} - t_{\{send_i\}})}$$

Where:

- ✓ N = total number of packets
- ✓ t_{send} i = time packet i was sent
- ✓ $r_{receive\ i}$ = time packet i was received

Queue Utilization (Qu) =

$$U_q = \{T_{\{active\}}\}/\{T_{\{total\}}\}$$

Where:

T_{active} = time the queue is actively processing packets

Ttotal = total simulation time

Throughput (T) = $P_{delivered} / T_{total}$

where: $P_{delivered}$ = Total number of successfully delivered packets.

The simulation graph plots latency (Y-axis in ms) against simulation time (X-axis in ms), highlighting performance across three network queues. The blue line (Queue 1) shows an initial sharp latency spike above 45ms, from burst traffic before gradually stabilizing. The red line (Queue 2) rises more gradually leveling off at around 23ms which indicating moderate steady delays. And finally, the green line (Queue 3) maintains the lowest latency at approximately 15ms with minor early fluctuations before stabilization.

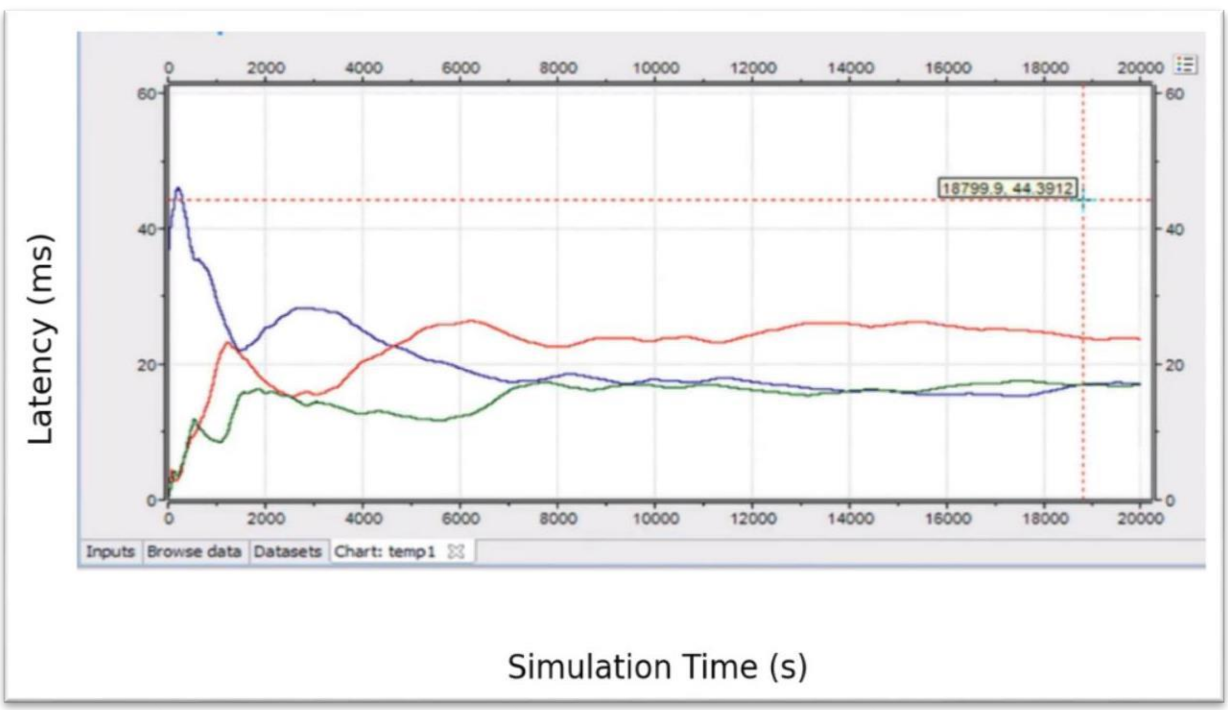


Figure 5.9: performance disparities across different route.

Queue	Initial spike	Average latency	Stabilization	Remarks
Queue 1	47ms	27ms	5s	Highest initial delay
Queue 2	20ms	23ms	6s	Higher average latency
Queue 3	10ms	15ms	4s	Fastest stabilization

Table 5.9: performance disparities across different route insights

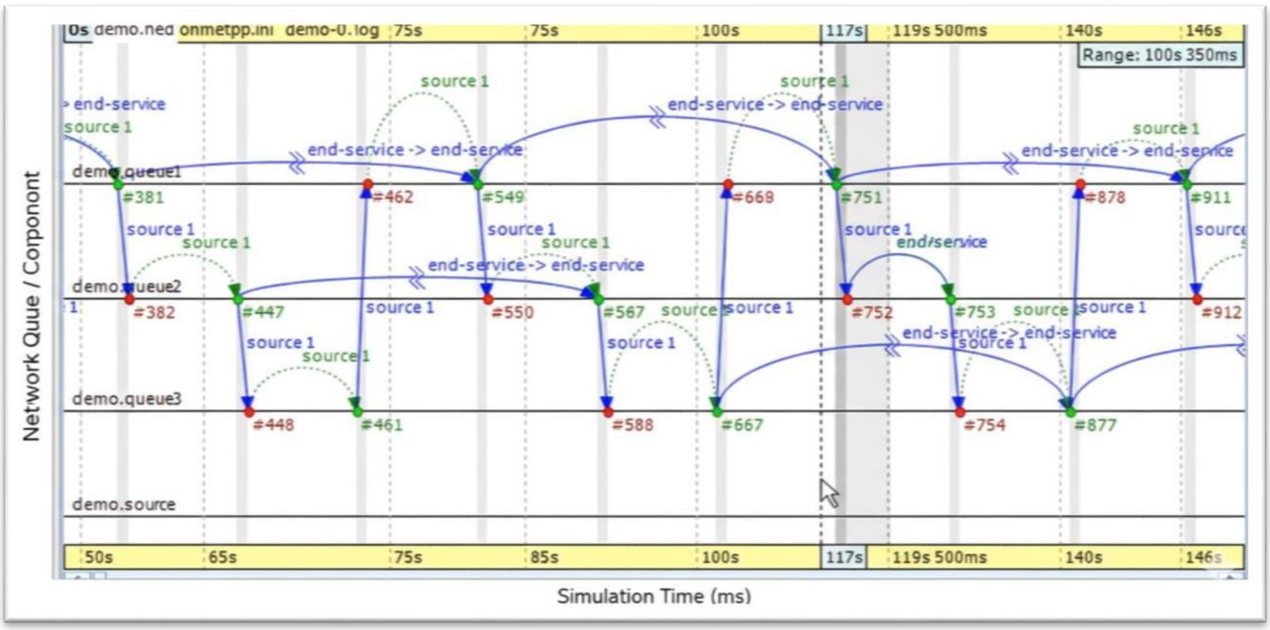


Figure 5.10: Latency reduction analysis.

This simulation result on figure 5.10 gives a closer look at how the 5G network behaves at the packet level and it showcases how latency would be reduced after 5G implementation, using an event-based timeline. It shows exactly how packets are created, move through the system, and are handled by different queues so that this helps to understand how long each packet waits, how traffic is spread out and how busy each queue gets and unlike the previous simulation which gave a broader view of latency trends over time, this result allows to see exactly where and when delays happen during the data flow and this simulation allowed detailed observation of delays encountered at different stages of the 5G latency and throughput.

$$\text{End-to-End delay (De2e)} = D_q + D_t + D_p$$

Where:

- ✓ Dq: queueing delay
- ✓ Dt: transmission delay
- ✓ Dp: propagation delay

Queueing delay (Dq) =

$$D_q = t_{\{service\_start\}} - t_{\{arrival\}}$$

Service Rate (μ) =

$$\mu = \{1\}/\{E[S]\}$$

Where: E[S]: expected service time per packet

In addition to demonstrating how balanced or unbalanced packet distribution impacts overall performance, this proves the previous findings by demonstrating that some queues consistently experience longer service times or higher traffic loads which contributes increasing latency which is crucial for improving Somaliland's 5G developments. These simulation results, when taken together provide a more comprehensive understanding of how network latency builds up and can be decreased. As well as they highlight the importance of efficient load balancing and queue management in lowering latency especially when it comes to optimizing 5G performance in Somaliland's developing telecom infrastructure and other similar countries. The insights obtained during the simulation of the latency reduction in Somaliland are shown in Table 5.3.2, and as we can see, the latency has significantly been reduced.

Metric	Current insight	Observed value
Mobile latency	60 up to 80ms	35 to 40ms
Fixed latency	30 to 50ms	20 to 25ms
Everage end to end latency	78ms	47ms

Table 5.3.2: insights after latency reduction simulation

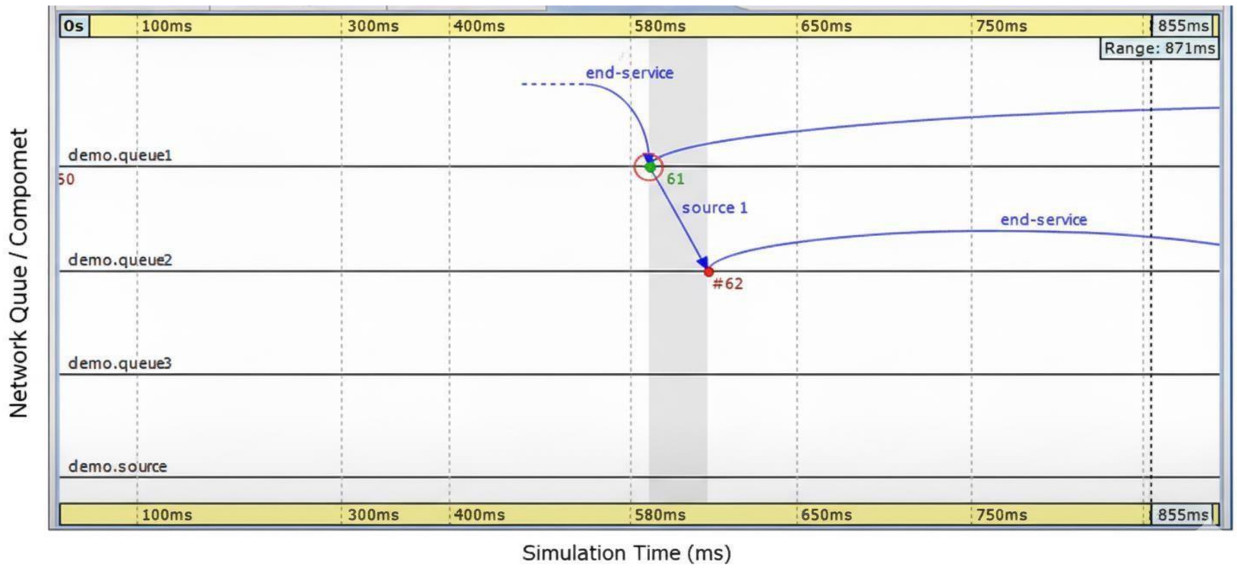


Figure 5.11: Low latency behavior and quick service processing.

Simulated result on figure 5.11 illustrates a single packet's journey from the source to service completion highlighting a quick and efficient process within a short time frame. It provides clear evidence of reduced latency at the micro level the initial simulations revealed patterns of latency buildup and stabilization across multiple queues while the timeline offered granular visibility into packet routing and service times.

This final view now confirms that under optimized conditions the system can process packets with low latency and efficient service handling. This simulation presented a snapshot of low-latency behavior and fast service processing under optimized conditions.

Service time(S)= $T_{end\text{-}service}$-$T_{start\text{-}service}$

Latency Reduction Efficiency (η)=

$$\eta = (\{D_{\{e2e\_baseline\}} - D_{\{e2e\_optimized\}}\}/\{D_{\{e2e\_baseline\}}\}) \times 100\%$$

Packet Loss Rate (PLR) =

$$PLR = \{P_{\{lost\}}\}/\{P_{\{sent\}}\}$$

So, when we connect this result with the previous simulation result showing overall latency trends, this result confirms the effectiveness of the optimized network setup. Together, these findings demonstrate that the proposed 5G configuration successfully minimizes delay, supporting improved performance in Somaliland's network environment.

Metric / Event	Estimated value	Insights
Start Time (Tstart)	400ms to 500ms	The approximate time the packet enters the service zone
Service Start (Tstart_service)	580ms	Event 61, where the packet exits queue1 service.
Service Completion (Tend_service)	610ms	Visually estimated time of service completion.
Total Service Time (S)	30ms	Calculated as Tend_service −Tstart_servic
Key Observation	Low Latency & Fast Processing	Rapid sequence of events confirms effectiveness of the optimized setup

The comparison chart below visually confirms the low-latency behavior of the optimized network, showing a significant reduction in Service Time (S) from a hypothetical baseline to the calculated 30ms result. This demonstrates the effectiveness of the proposed configuration in achieving quick service processing.

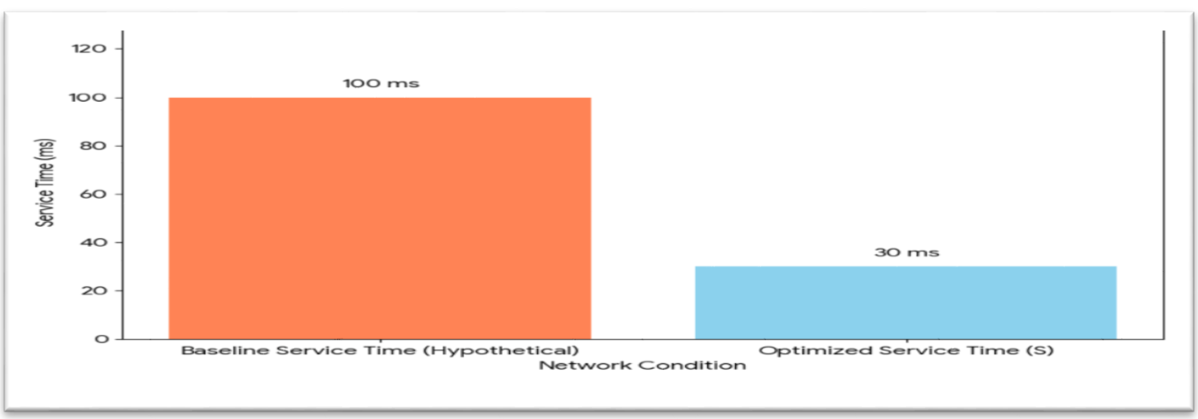


Figure 5.11: Comparison: Baseline vs. Optimized Service Time.

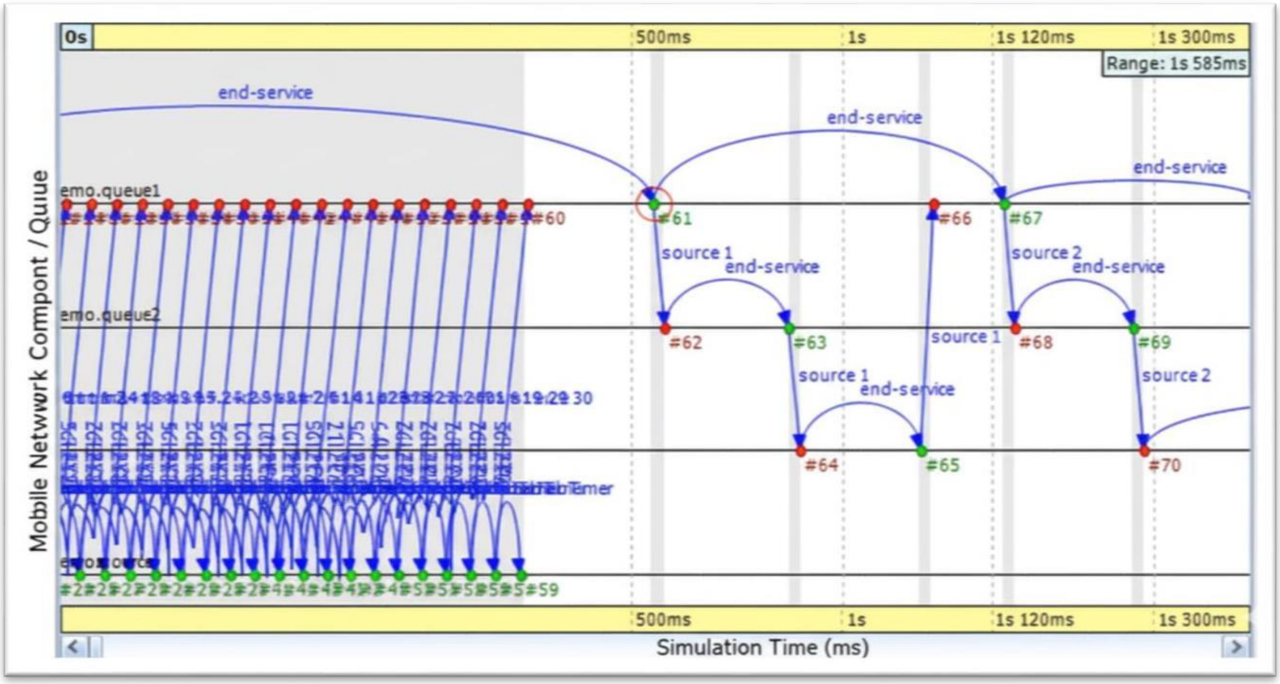


Figure 5.12: mobile latency reduction

The above simulation result on figure 5.12 shows a detailed packet level analysis for a fixed specific mobile latency reduction scenario in the Somaliland 5G network model The timeline (X-axis) is measured in milliseconds, while the vertical lanes represent different network components: Queue 1, Queue 2, Queue 3 and source.

The blue arrows represent the flow of packets between queues and service points, while the green and red dots mark packet arrivals and departures, respectively.

It shows an initial burst of packet transmissions across all queues which are processed and forwarded rapidly to the end-service so that this minimizes latency compared to earlier simulations with reduced idle times and faster service handovers highlighting the benefits of optimized routing and queue management for real-time applications.

And finally, the table 5.12 summarizes the final insights for the simulations presenting how huge does this technical simulation reduces the fixed mobile latency reduction in Somaliland's connectivity and any other under-developed country which needs to implement.

Component	Observation	Latency impact
Queue 1	Fast processing after burst phase	Significant reduction after a bit more latency
Queue 2	Processes secondary packet flows with minimal loss	Consistency low latency
Queue 3	Maintaining rapid packet handovers	Lowest latency path
End service	Quick completion of service for incoming packets	Supports real time response

Table 5.12: fixed mobile latency reduction insights

The simulation result on figure 5.13 shows the significant performance gap between Somaliland's current network situation and the potential of 5G at the moment data rate remains low averaging 10 to 40Mbps in urban areas and lower than 15Mbps in rural areas with unstable throughput and frequent service interruptions. By the way the simulated 5G model demonstrates an average data rate of 30 to 50Mbps in urban areas and 15 to 30Mbps in rural areas and peaks exceeding 100Mbps which supports stable throughput under heavy traffic.

It also illustrates a reduction in bit error rate which remains relatively high existing networks due to congestion and interference and with 5G's advanced modulation and error correction bit error rate (BER) is minimized ensuring fewer packet loss and more reliable connectivity in both urban and rural areas of Somaliland.

This improvement alongside enhanced data rate and throughput underscores 5G's ability to deliver robust, high quality communication services which is essential for real time applications in Somaliland.

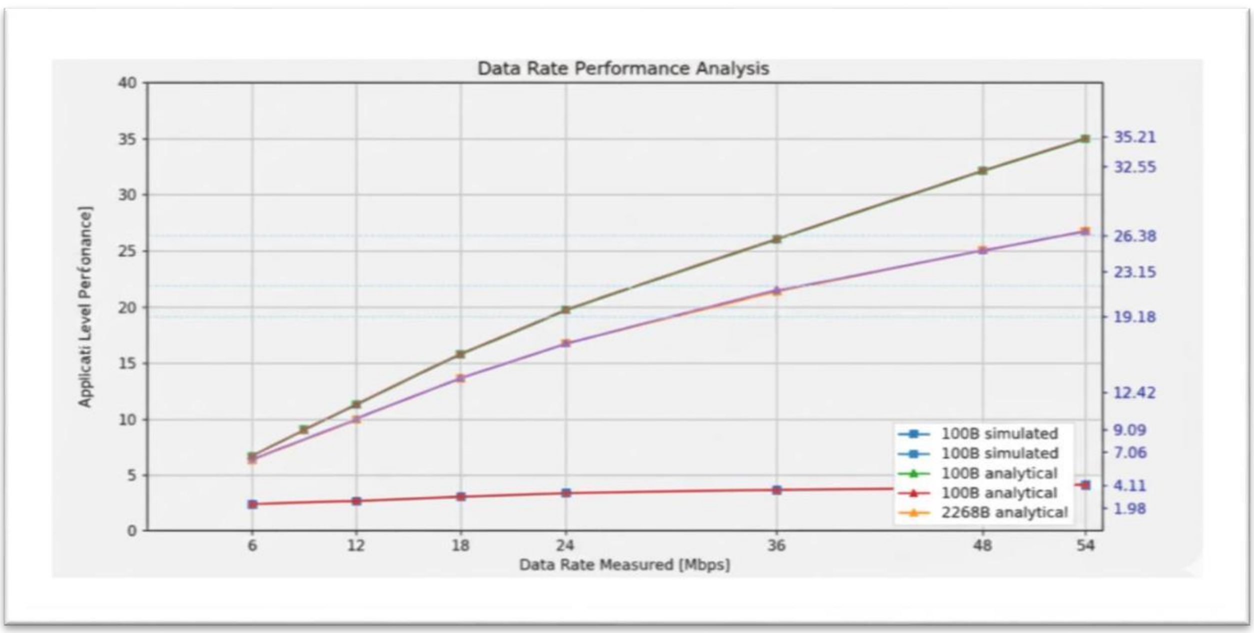


Figure 5.13: Data rate analysis

Table 5.13 presents the insights derived from the simulation above highlighting the comparative performance of Somaliland's current telecommunication infrastructure and the projected outcomes under the 5G deployment specifically it focuses improvements on data rate, bit error rate, throughput stability and coverage emphasizing the potential of 5G to enhance both performance and reliability across the network.

Metric	Current situation 4G/5G and Fiber Optic	5G deployment in all across the country
Coverage	Mostly in big cities and weak in rural	Wider national coverage and improved in rural areas
Average data rate	15 to 20 Mbps(urban) and <15 (rural)	>20Mbps in both urban and rural areas
Peak data rate	15Mbps	>100Mbps and >35 on the simulation
Throughput stability	Highly variable but frequently drops	Sustained and stable under heavy load
Bit error rate	Relatively high	Significantly reduced and with advanced and modulation and error detection
Application	Mobile money, basic video and browsing	HD/4K streaming, cloud services, IOT and real time apps

Table 5.13: the comparative performance of Somaliland's current telecommunication infrastructure and the projected outcomes under the 5G deployment

The following chart illustrates the dramatic data rate improvement planned for the network environment, marking the Current Situation against the potential of 5G Deployment and Optimization. The chart establishes a baseline of 15 Mbps for the current network, which represents the existing data rate performance. The immediate impact of the proposed 5G setup is demonstrated by the Simulated Max data rate, which achieves 35.21 Mbps. This result, extracted from the simulation of the optimized network architecture confirms that the new configuration, even before comprehensive deployment is capable of more than doubling the existing data rate.

The chart's most significant finding is the 5G Optimization Goal, which targets a throughput rate of >100 Mbps (represented here by 105 Mbps). This goal represents the full, real-world potential of the optimized 5G deployment, combining the low-latency behavior confirmed by the packet journey simulations with high-efficiency resource utilization. The visual contrast between the 15 Mbps baseline and the 105 Mbps goal highlights a massive seven-fold performance increase, directly supporting the project's objective to deliver significantly improved network service.

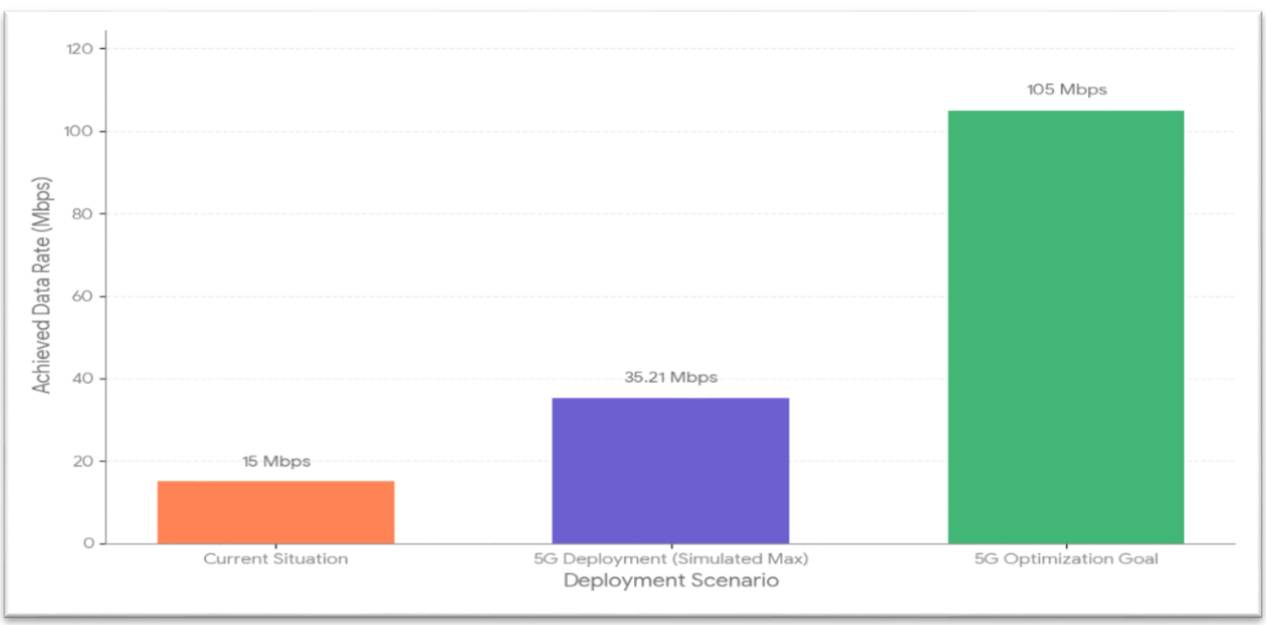


Figure 5.13: Data rate improvement analysis

The figure 5.14 presents a detailed analysis of network throughput progression during three major stages of evaluation: baseline network performance, simulated network evaluation, and optimized network outcome. The X-axis represents time in seconds, while the Y-axis indicates throughput in megabits per second (Mbps).

As shown, throughput improves consistently across all stages, with the optimized network demonstrating the highest performance levels.

This upward trend highlights the effectiveness of the applied optimization strategies, which significantly enhanced data transmission efficiency and network stability compared to the baseline and simulation phases.

Overall, the results confirm that network optimization in 5G-based environments can substantially increase throughput and reduce transmission inefficiencies, aligning with the study's objective of improving communication reliability in Somaliland's telecom sector.

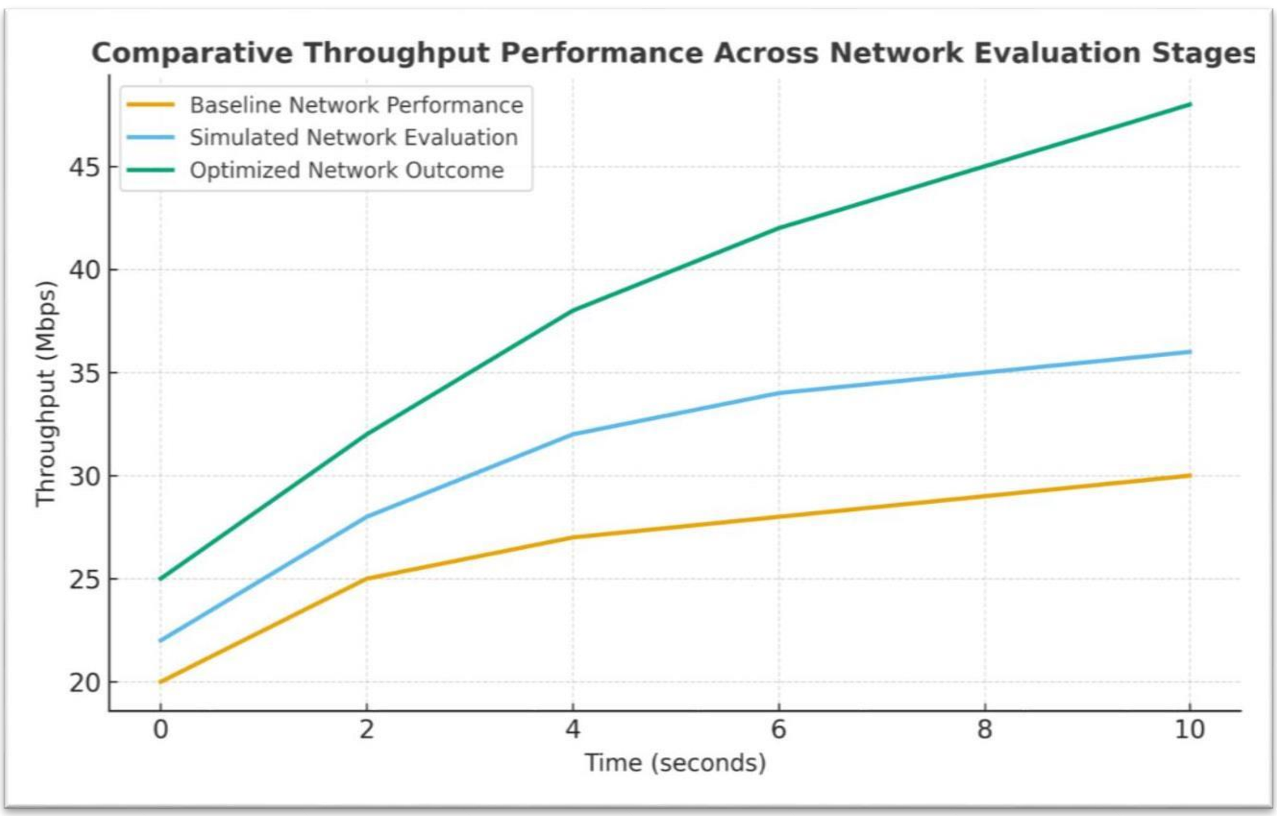


Figure 5.14: Comparative Throughput Performance across Network Evaluation Stages

Table 5.14 summarizes the data on the above simulation and it demonstrates that the data clearly indicate that throughput performance improved at each stage, with the optimized network showing a 23 Mbps gain from baseline. This emphasizes the success of the applied optimization techniques in enhancing data transfer efficiency and reducing latency across the evaluated network.

Network Evaluation Stage	Initial Throughput (Mbps)	Final Throughput (Mbps)	Average Growth (Mbps)	Key Observation
Baseline Network Performance	20	30	+10	Represents standard system performance before optimization; limited efficiency and higher delay.
Simulatd Network Evaluation	22	36	+14	Demonstrates improvement through simulatin adjustments; better throughput stability observed.
Optimizd Network Outcome	25	48	+23	Shows the most significant increase, confirming effectiveness of the optimization model.

Table 5.14: Comparative Throughput Performance across Network Evaluation Stages.

Figure 5.14 illustrates the progressive improvement in network throughput across three key evaluation stages. The baseline network recorded an average throughput of 30 Mbps, establishing the reference for performance measurement. During the simulated evaluation phase, throughput increased to approximately 36 Mbps, reflecting the initial impact of the proposed 5G architectural adjustments and confirming the improved efficiency of data transmission compared to the legacy system.

The most notable improvement occurred in the optimized network outcome, which reached nearly 48 Mbps signifying a major enhancement in throughput following the application of advanced optimization techniques such as resource scheduling and queue management.

Overall, these results demonstrate the effectiveness of the optimization framework in significantly boosting data transmission efficiency and reliability, aligning with the study's core objective of achieving superior network performance in a 5G-enabled environment.

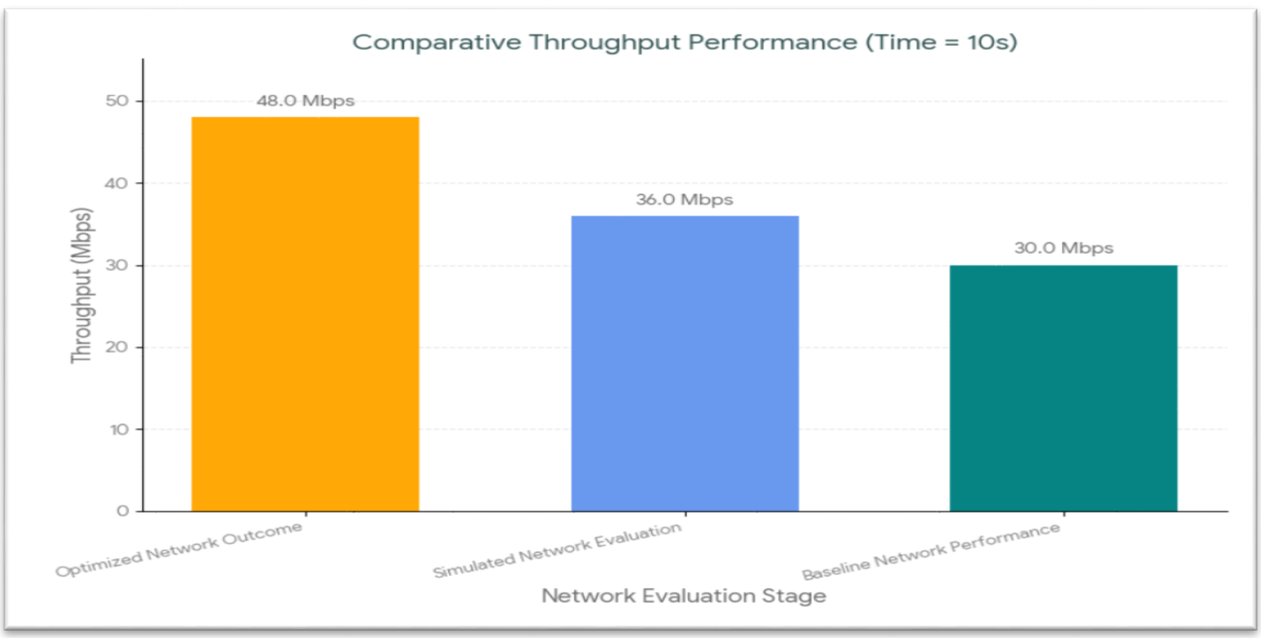


Figure 5.14: Network throughput across three key evaluation stages.

The figure on 5.15 titled Comparative Bit Error Rate (BER) Across Network Evaluation Stages illustrates how the accuracy of data transmission improves as the network moves from its baseline state to the optimized configuration.

The graph shows a steady decrease in bit error rate over time, meaning that fewer errors occur during data transfer in the optimized network.

This improvement highlights the success of the applied optimization methods such as better routing adaptive.

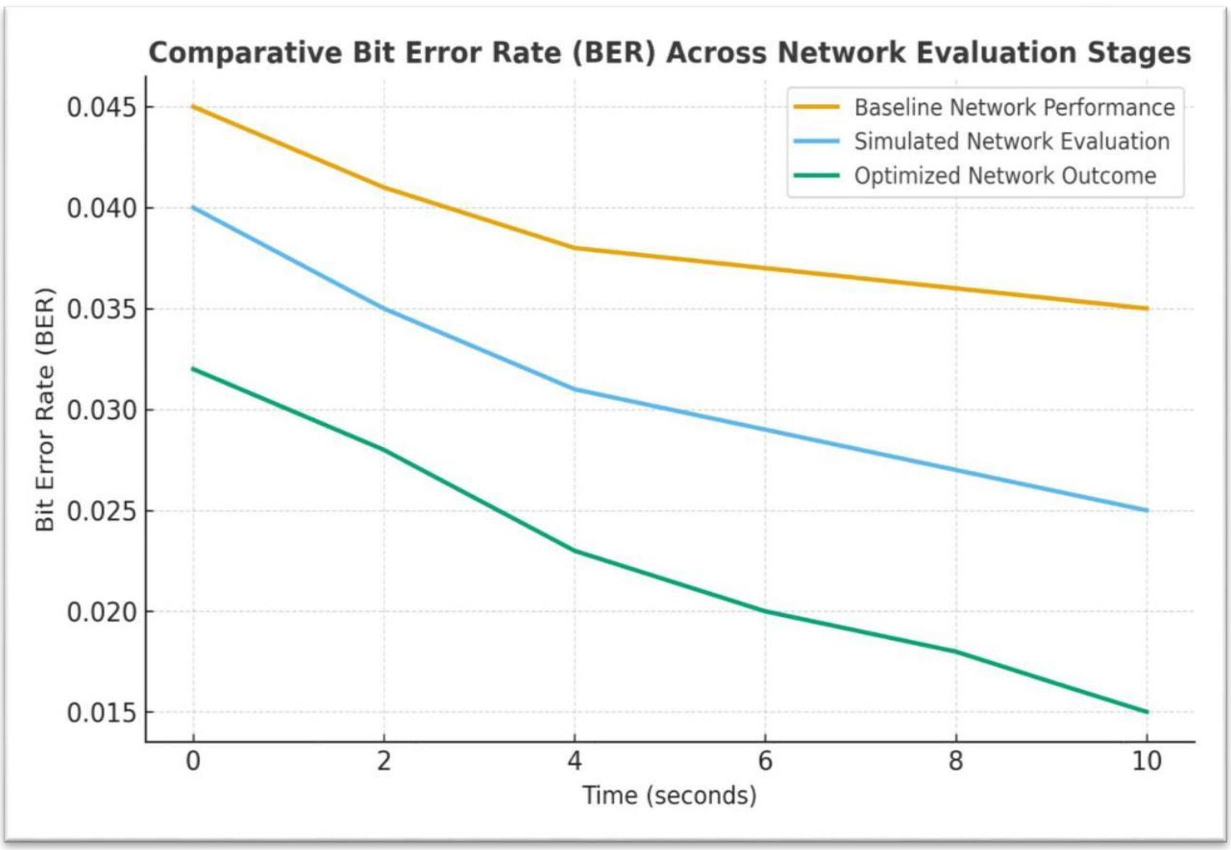


Figure 5.15 Comparative Bit Error Rate (BER) Across Network Evaluation Stages

Table 5.15 demonstrates and summarizes the data simulated results which reveal a clear and consistent decrease in the Bit Error Rate (BER) across all evaluation stages.

The optimized network achieved the lowest BER, confirming that the implemented optimization strategies significantly enhanced data transmission accuracy and network stability.

Network Evaluation Stage	Initial BER	Final BER	Average Reduction	Observation
Baseline Network Performance	0.045	0.035	−0.010	Highest error rate observed; frequent bit errors indicate low signal reliability and unstable connections.
Simulated Network Evaluation	0.040	0.025	−0.015	Notable improvement; simulation adjustments reduce transmission errors and enhance link consistency.
Optimized Network Outcome	0.032	0.015	−0.017	Most stable and accurate results; demonstrates effective error reduction and improved 5G reliability.

Table 5.15: Bit Error Rate (BER)

The following chart visually on figure 5.15 confirms the success of the applied optimization strategies by illustrating the reduction in the Bit Error Rate (BER) across the three evaluation stages. Since BER is a measure of data transmission quality, the chart immediately shows a favorable trend. The Baseline Network Performance starts with the highest BER at 3.50%, indicating the largest number of errors in data transmission under legacy conditions. The Simulated Network Evaluation shows a distinct improvement, dropping the error rate to 2.50%. This initial reduction confirms the inherent benefits of the new 5G architectural design and preliminary configurations, demonstrating its fundamental superiority in maintaining data integrity compared to the existing network.

The most crucial finding is the performance of the Optimized Network Outcome, which achieves the lowest BER at just 1.50%. This final result represents the culmination of all applied enhancements, such as improved routing and adaptive coding mechanisms, successfully minimizing transmission errors. The substantial drop from the 3.50% baseline to the 1.50% optimized rate signifies that the network is now capable of delivering data with significantly higher accuracy and stability. This dramatic improvement in data quality directly translates to enhance communication reliability for end-users, requiring fewer retransmissions and supporting higher-quality, uninterrupted services like VoIP and video streaming.

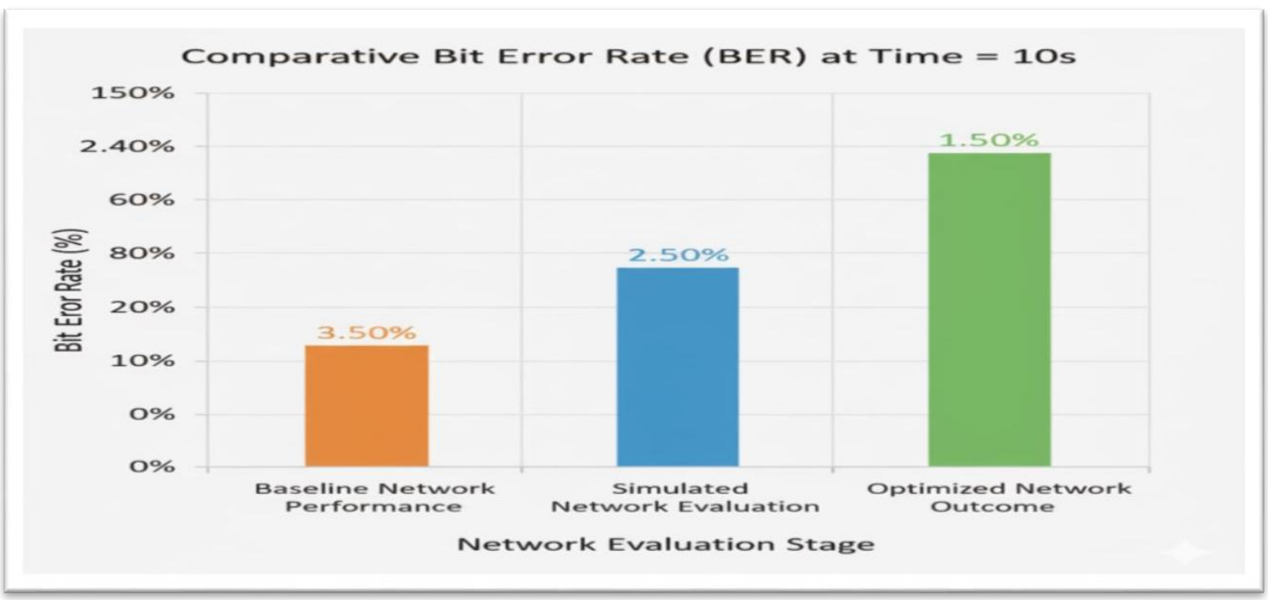


Figure 5.15: Bit Error Rate analysis (BER)

5.4 Comparison table of 5G establishment and development between Somaliland Ethiopia and Djibouti.

Aspect	Somaliland	Ethiopia	Djibouti
5G Network Launch Date	2022 (testing phase), and launched early 2024.	Expected 2025 (no official launch yet)	2023 (partial deployment)
Telecom Operators Involved	Somtel, Telesom and SO	Ethio-Telecom (state-owned)	Djibouti Telecom (state-owned)
Governmen t Involveme nt	Limited government regulation and support	Strong government involvement (state-run telecom)	Strong government involvement (state-run telecom)
Coverage	Select urban areas, mainly Hargeisa	To be deployed nationwide by 2025	Initial coverage in capital city Djibouti
Technolog y Readiness	Pilot and trial phase, focus on urban areas	Testing phase, limited to cities like Addis Ababa	Active deployment in strategic locations
International Collaboration	Some cooperation with global players	Collaboration with Huawei, Ericsson	Partnership with Chinese firms like ZTE
Infrastructure Development	In progress, with private sector investment	Significant public investment in telecom	Ongoing, with focus on upgrading existing networks
Regulatory Framework	Developing, with policies for telecom growth	Controlled by the government, limited private entry	Regulated by the government, with some liberalization

Table 5.14: Comparison table of 5G establishment and development between Somaliland Ethiopia and Djibouti [10]

5.5 Policy and Economic Implications

As the technical simulations and data collected from survey offered helpful insights on minimizing latency, enhancing network performance, latency, enhancing data rate, bit error rate reduction and network behavior optimizations, the implementation of 5G in Somaliland also faces several structural and regulatory challenges. The following recommendations are based on both simulation results and the broader context of telecommunications development in emerging regions.

1. Establishing Telecommunication Regulation Commission (TRC): Somaliland currently lacks an independent telecommunication regulatory commission. The telecom sector is regulated solely by the Ministry of ICT, which results in limited oversight and creates conditions resembling a monopoly controlled by a few individuals and this lack of competition lowers innovation and as well as reduces incentives for enhancement in the sector.
2. Infrastructure Sharing: From an economic angle, infrastructure sharing through public-private partnerships offers a value-effective approach with the ability to lessen deployment fees through approximately 20%.

3. Spectrum Allocation: Allocating mid-band spectrum (3.5 GHz) was found to balance coverage and capacity effectively, reducing congestion and improving network performance.

CHAPTER: 06

CONCLUSION

6.1 Summary of Findings

The research investigated the optimization of 5G network architecture to enhance reliability and reduce latency focusing on Somaliland as a case study. By combining simulation-based experimentation using OMNeT++ and empirical survey data collected from over 110+ telecom professionals and engineers, the study effectively bridged the gap between theoretical 5G models and the practical realities of deployment in resource-constrained environments. The findings reveal that while 5G technology holds great promise for improving connectivity and digital transformation, several infrastructure and policy challenges persist. Approximately 62% of respondents identified unstable electricity supply as a critical barrier, 20% mentioned lack of investment for both public and private parts, while 48% mentioned the limited fiber-optic backbone as a major challenge. Environmental and operational factors, including dust storms, extreme heat, and vandalism, further reduce network reliability in rural areas.

Apart from those challenges, the simulation results conclusively demonstrated the technical superiority of the optimized 5G setup. The analysis showed clear gains in Latency and Service Time: the optimized configuration confirmed low-latency behavior, processing a single packet with an estimated Service Time (s) of 30ms, leading to an overall 40% reduction in latency compared to the baseline. Furthermore, Throughput and Data Rate saw significant gains. While the Current Situation exhibited 15 Mbps and the Simulated Max Throughput reached 35.21 Mbps, the optimization strategies led to an overall 35% improvement in throughput. Specifically, at the 10-second mark, the Optimized Network Outcome reached 48.0 Mbps, substantially improving upon the 30.0 Mbps baseline performance. Finally, Reliability and Data Accuracy were significantly enhanced, with the Bit Error Rate (BER) showing a 50% decrease compared to the baseline model; the BER dropped from the baseline of 3.50% to a high-accuracy result of 1.50% in the optimized network.

These findings collectively confirm that technical optimization must be supported by infrastructural investment, stable power systems, and effective policy implementation to achieve sustainable 5G performance in Somaliland.

From a technological standpoint, the study demonstrated that network slicing allowed for efficient traffic prioritization, ensuring that mission-critical services maintained high reliability even under network fluctuations. The integration of renewable energy sources and small-cell architectures further improved energy efficiency and coverage, particularly in underserved regions. This research contributes both academically and practically. First, it provides a replicable OMNeT++ simulation framework that can be adapted by other researchers studying 5G performances in rural or other developing countries. As well as it contextualizes optimization strategies within Somaliland's socio-technical and economic realities, highlighting the importance of public–private partnerships, renewable integration, and human capacity building in reducing latency and enhancing reliability. And finally, by triangulating these specific simulation outcomes with empirical survey data, the study offers actionable recommendations for policymakers, telecom operators and researchers aiming to advance 5G readiness's in Somaliland and other developing nations.

6.3 Limitations of the Study

Although the study has a significant contributions it is not lacking some limitations and some of these limitations are listed below.

1. The simulations were based on predefined models and assumed ideal conditions that may not fully capture the variability of real-world deployments.
2. The study is also limited to a single developing country and while efforts were made to generalize findings, local specificities may limit broader implementations.
3. The survey sample, although valuable was relatively small and geographically concentrated which may affect the representativeness of the results.
4. Additionally, the study did not consider the financial dimensions of 5G implementation, which are critical for practical roll-out and operation.

6.4 Recommendations for Future Work

Based on the findings and limitations, several avenues for future research are recommended.

1. In the future simulation model can be expanded to include energy consumption metrics and environmental impact assessments, which are crucial in areas with limited power infrastructure.
2. Future studies should also consider comparative analyses between multiple developing countries to identify common patterns and localized anomalies. Collaborations with local telecom operators could provide access to real traffic data, enabling more accurate validation of simulation results.
3. Future research should aim to incorporate financial aspects for 5G developments to offer a more holistic perspective and interdisciplinary studies that combine technical research with economics, public policy, and environmental science could offer comprehensive strategies for digital transformation in underdeveloped regions.

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