Chijioke Ejiogu

THE ROLE OF SATELLITE INTERNET IN BRIDGING THE DIGITAL DIVIDE

Bachelor’s thesis

Bachelor of Engineering

Information Technology

2025

South-Eastern Finland
University of Applied Sciences

South-Eastern Finland University of Applied Sciences

Degree title	Bachelor of Engineering
Author	Chijioke Ejiogu
Thesis title	The role of Satellite internet in bridging the digital divide
Year	2025
Pages	60
Supervisor	Ville Kauppi

ABSTRACT

The digital divide, which is attributed to uneven access to information and communication technologies (ICTs), remains a topical issue, particularly in remote and underdeveloped regions. This paper aimed to explore the ground-breaking role satellite internet is playing in narrowing this divide, focusing on its promise to enhance accessibility, boost economic growth and improve the general quality of life for disenfranchised individuals. By addressing essential technological, economic and social factors, the objective of this study was to provide an extensive analysis of satellite internet's contributions and constraints.

The conceptual basis of this study rises from the disparity in digital access between developed and underdeveloped regions, with a look at key definitions, dimensions, and underlying causes of these differences. Furthermore, the effects of the digital divide on the economy, education, and healthcare were examined. The essentials, evolution, and advantages of satellite internet technology were studied, along with the difficulties in achieving its broad acceptance.

With a focus on connections in rural locations, this thesis explored satellite internet as a solution to the digital divide. While certain challenges were emphasized, including cost, technological constraints, and policy restrictions, case studies showed successful implementations. In this paper, the speed, performance, cost-effectiveness, and socioeconomic effects of satellite internet were evaluated in comparison to other technologies, such as fibre optics and cellular networks.

In conclusion, the study presents a summary of shortcomings in Satellite internet technology and offers stakeholders and legislators practical solutions. It highlights the necessity of teamwork and urges more study to improve satellite internet regulations and technology, to provide long-term solutions to the digital gap and advance worldwide digital inclusion.

Keywords: ICT, cellular networks, satellite, internet

CONTENTS

1 INTRODUCTION 6

1.1 Background and Significance of the Study 6

1.2 Objectives and Purpose of the Study.. 7

1.3 Scope and Limitations 7

1.4 Thesis Structure.. 8

2 SATELLITE INTERNET TECHNOLOGY 9

2.1 Key Fundamentals of Satellite internet 9

2.1.1 Basic Concept of Satellite Internet 9

2.1.2 Components of a Satellite Internet System 10

2.1.3 Basic Mechanism of Operation 11

2.2 Evolution and Innovations in Satellite Internet 11

2.2.1 Early Developments and Milestones 11

2.2.2 Transition to LEO and MEO Satellites 12

2.2.3 Emergence of High Throughput Satellites (HTS) 12

2.2.4 Satellite Constellations and NewSpace Era 12

2.2.5 Future Trends and Innovations 13

2.3 Advantages of Satellite Internet... 13

2.4 Challenges and Limitations of Satellite Internet 14

3 A GENERAL OVERVIEW OF THE DIGITAL DIVIDE 16

3.1 Definitions and Dimensions of the Digital Divide.................................... 16

3.1.1 The First-Level Digital Divide (Access Divide) 17

3.1.2 The Second-Level Digital Divide (Skills and Usage Divide) 17

3.1.3 The Third-Level Digital Divide (Benefits Divide)................................. 18

3.2 Factors Contributing to the Digital Divide... 19

3.2.1 Economic Disparities 19

3.2.2 Geographic and Infrastructure Limitations 19
3.2.3 Educational Attainment and Digital Literacy 19
3.2.4 Age and Generational Difference 20
3.2.5 Social and Cultural Barriers 20
3.3 Economic Impacts of the Digital Divide 20
3.3.1 Employment and Income Inequality 21
3.3.2 Business and Entrepreneurship Challenges 21
3.3.3 National Economic Growth and Competitiveness 21
3.4 Satellite Internet as a Panacea to the Digital Divide 22
3.5 Accessibility and Connectivity in Remote Areas 22
4 RESEARCH METHODOLOGY 25
4.1 Research Design and Approach 25
4.2 Data Collection Methods 26
4.2.1 Field Testing 26
4.2.2 Semi-structured Surveys and Interviews 27
4.2.3 Secondary Data 27
4.3 Data Analysis Techniques 33
4.3.1 Quantitative Data Analysis (Network Performance) 33
4.3.2 Qualitative Data Analysis (Socio-economic Impact) 34
4.4 Ethical Considerations 35
4.4.1 Confidentiality and Data Protection 35
4.4.2 Voluntary Participation and Right to Withdraw 35
4.4.3 Conflicts of Interest and Research Integrity 35
5 COMPARATIVE ANALYSIS AND IMPACT ASSESSMENT 37
5.1 Speed and Performance Comparisons 37
5.1.1 Throughput 40
5.1.2 Latency (Ping) 42

5.1.3 Jitter 46
5.1.4 Packet Loss 47
5.1.5 Environmental Influences 47
5.2 Cost-Benefit Analysis 48
5.3 Socio-Economic Impact 50
5.3.1 Effect on Education and Healthcare Delivery 50
5.3.2 Environmental and Policy Considerations 51
6 CONCLUSION 52
6.1 Main Findings 52
6.2 Contributions to the Field 52
6.3 Practical Recommendations 53
6.4 Limitations 53
6.4.1 Scope and Generalizability 53
6.4.2 Data Collection Limitations 54
6.4.3 Methodological Limitations 54
6.4.4 External Factors 54
6.5 Research Course 55
REFERENCES 56

1 INTRODUCTION

The digital divide remains a massive global concern, restricting access to digital resources, opportunities, communication and information for underprivileged populations. As technology advances, internet connectivity is becoming a key factor in healthcare, education, economic growth, and general societal advancement. However, the socioeconomic gap between connected and unconnected populations is widening due to the lack of dependable internet services in many rural and isolated areas. This thesis analyzes the potential, benefits, drawbacks, and relative performance of satellite internet in relation to other internet technologies to investigate its role in closing the digital divide.

1.1 Background and Significance of the Study

In the twenty-first century, internet connection is crucial for governance, healthcare, education, and economic progress. However, because of poor infrastructure, exorbitant costs, and geographic constraints, a huge percentage of the world's population, especially in rural and developing areas, remain isolated. Conventional broadband options, such mobile networks and fiber optics, are very costly and difficult to set up in rural locations. This prevailing situation, which has led to an unequal distribution of access to digital resources and opportunities, is generally referred to as the digital divide (Van Dijk 2020).

A promising answer to this problem is satellite internet, which provides connectivity and worldwide coverage to places that traditional broadband infrastructure cannot reach. As technology develops, satellite-based internet services are getting more dependable, accessible, and reasonably priced (CircleID 2024). Technological giants such as OneWeb, Amazon's Project Kuiper, and SpaceX's Starlink are at the forefront of ideas that have the potential to completely transform the digital space (Skyora 2024). This study investigates the potential of satellite internet as a functional agent to close the digital divide and support socioeconomic advancement.

1.2 Objectives and Purpose of the Study

The main purpose of this study is to investigate how satellite internet could help close the digital divide, especially in underdeveloped and isolated areas. Given the growing importance of internet connection for social inclusion, healthcare, education, and economic growth, it is critical to comprehend how effective satellite technology can be in providing connectivity. This study aims to analyze the causes of the digital divide, evaluate how satellite internet tackles these issues, and assess its possible influence on digital accessibility. In order to illustrate the benefits, drawbacks, and viability of satellite internet as a sustainable solution, the study will also contrast it with alternative connectivity options including fiber optics and mobile broadband. Also, the paper aims to give policymakers, stakeholders, and industry leaders insights into means that could improve digital inclusivity by providing a comprehensive analysis of the potential of satellite internet.

1.3 Scope and Limitations

With a particular interest in rural and underdeveloped areas where standard broadband infrastructure is either unavailable or insufficient, this study examines the contributions of satellite internet in addressing the digital divide. The study discusses the main technological facets of satellite internet, including its development and advantages, as well as obstacles to its implementation and use. Additionally, the paper also assesses the social and economic effects of satellite internet, especially in fields such as healthcare and education where digital connectivity can be deemed revolutionary.

Despite its extensive reach, the study has a few limitations. Firstly, it does not offer a detailed description of the technical engineering aspects of satellite systems, even though it provides a general overview of satellite internet technology. Secondly, low-income populations may still find the initial setup expenses and subscription fees excessive, making satellite internet access sometimes a practical impossibility. The study also recognizes performance limitations such as latency and bandwidth restrictions, which can reduce its effectiveness for high-speed applications. Lastly, regional differences in regulations and policies impact the rollout and growth of satellite internet services. Although these factors present difficulties, they also offer opportunities for further study and policy suggestions to improve the efficacy of satellite internet as a panacea for the digital divide.

1.4 Thesis Structure

This thesis comprises of seven sections, each focusing on a different facet of the study. The introductory section presents the historical framework, objective, scope, and general structure of the study. The succeeding section discusses internet technologies, with a keen interest in satellite internet, outlining its basic operational principle, development across time, and most recent advancements. While taking into consideration the obstacles to its widespread adoption, such as cost, latency, and infrastructure requirements, the study also emphasizes the benefits of satellite internet, such as its capacity to offer worldwide coverage.

A broad review of the digital divide is given in the third section, covering the essential definitions, dimensions, and the main causes of inequalities in digital access. This section also examines the social and economic effects of digital exclusion, highlighting the need for creative solutions. By examining how satellite internet affects isolated and underprivileged regions, the fourth section addresses satellite as a solution to the digital divide, providing case studies of successful satellite internet deployments. The fifth section addresses the research methods, discussing research design, as well as collection and analysis of data.

A comparative study is presented in the sixth section, where satellite internet is compared to other broadband options such as fiber optics and mobile networks. In that section, socioeconomic effects, cost-benefit analysis, performance indicators, and policy-related difficulties are discussed. This section also evaluates the effects of satellite internet on environmental sustainability, healthcare, and education. The final section summarizes the study by highlighting the main conclusions, stating the recognized shortcomings, and making suggestions for further study.

2 SATELLITE INTERNET TECHNOLOGY

The development of satellite internet technology represents an essential advancement within the telecommunications circle and has improved worldwide network connectivity by including remote areas that had previously been without digital coverage. Satellite internet functions differently from traditional terrestrial networks which depend on fiber optic cables and cell towers since it uses satellites orbiting the earth to connect to the internet. This technology has advanced substantially to deliver higher speeds together with lower latency, as well as improved accessibility. The fast-growing space-based internet services offered by Starlink, OneWeb and Viasat are defining the evolution of global digital communication (Skyora 2024).

Over the years, satellite internet has developed to address previous limitations which now allows it to serve as a legitimate substitute for traditional broadband networks. The growing dependence on internet services for educational, health care, business and social purposes makes it critical to have accessible and reliable internet services. This section discusses the basic concepts of satellite internet, as well as the major components of this technology. This paper also looks at major advancements and technological developments in satellite internet over the years. This internet service has the ability to connect remote locations and offer emergency connectivity during natural disasters. However, satellite internet comes with its own set of problems: latency, high costs, and weather interference. Also, this section provides a comprehensive overview of satellite internet technology and its functionality within current digital communication systems.

2.1 Key Fundamentals of Satellite internet

2.1.1 Basic Concept of Satellite Internet

Satellite internet functions by using a network of satellites that are placed in orbits around the earth to convey data from ground stations to end users. The wireless connection between the user’s terminal and an orbiting satellite differs satellite internet from conventional broadband networks that utilize underground cables.

The satellites function as relay stations sending data to and from the ISPs (Internet service providers) through a ground station serving as the network operations centre (NOC). (CircleID 2024).

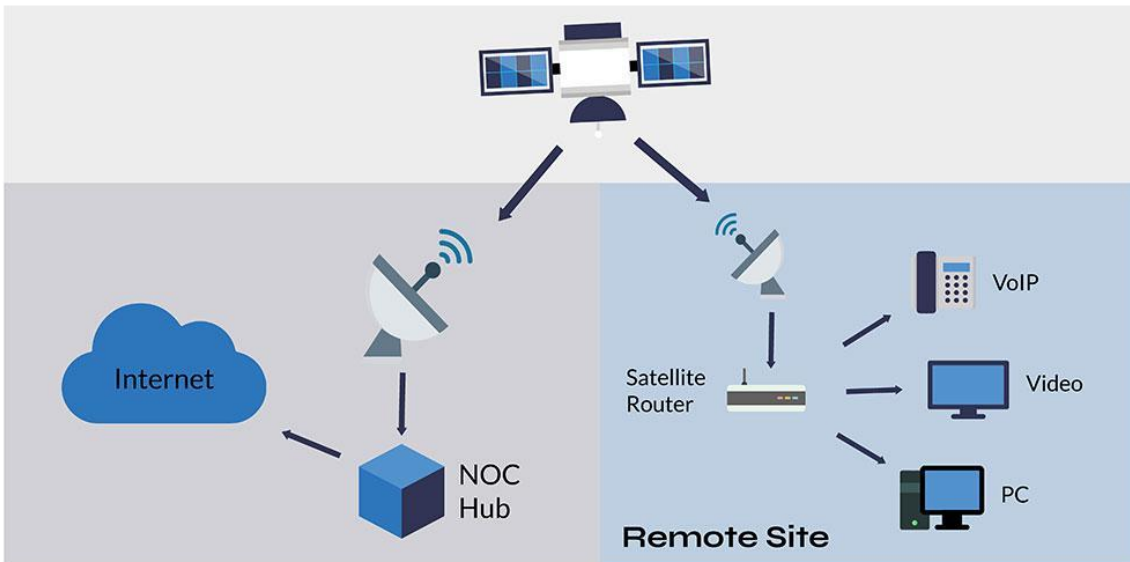

Figure 1: Basic concept of satellite internet (groundcontrol)

2.1.2 Components of a Satellite Internet System

A typical satellite internet system is divided into the following basic components:
Satellite: The satellite has the primary responsibility of switching the signal from the ISP to the end user and vice versa. The location of the satellite can be geostationary earth orbit (GEO), medium earth orbit (MEO), or low earth orbit (LEO), each having different characteristics in terms of latency and coverage (Lutz, Werner, & Jahn 2020).

Ground Station (Gateway): A satellite system is connected to the internet backbone via a ground station and data transmission and reception is managed by this terrestrial hub (Maral & Bousquet 2010).

User Terminal (Dish and Modem): The end user needs a satellite dish and a modem to gain access to the network, and this dish communicates with the satellite in orbit (Pelton 2017).

2.1.3 Basic Mechanism of Operation

Below is a step-by-step explanation of how satellite internet communication works:

- A user makes a request to access a website or watch a video.
- The request is sent from the user’s dish to an orbiting satellite.
- The ground station linked to the ISP’s internet backbone receives the request from the satellite.
- The ISP then handles the request and sends the desired information back to earth via the satellite.
- The satellite receives information from the modem, which then get it to the user’s dish, and then to the user’s device (Anil & Varsha 2011).

2.2 Evolution and Innovations in Satellite Internet

The idea of Satellite internet was introduced many decades ago in the middle of the 20th century (GroundControl 2022). Since then, satellite internet has come a long way from being a niche communication tool to facilitating global connectivity especially in remote and disadvantaged areas. The evolution of satellite internet can be traced back to the improvement of satellite technology, attitude control and communication protocols. This section discusses the historical evolution of the technology, the shift to contemporary satellite constellations, as well as the technological developments that have enhanced the performance, capacity and accessibility of the technology.

2.2.1 Early Developments and Milestones

Satellite-based communications were first proposed by Arthur C. Clarke in 1945 when he described geostationary satellites as providers of global telecommunications coverage (Clarke 1945). This idea brought about the modern satellite communication system. AT&T made history in 1962 when Telstar 1 became the first communication satellite to cross the Atlantic to broadcast videos and convey data. The Intelsat 1, known as Early Bird when it was launched in 1965, started the first commercial satellite communication system which provided global real time telecommunication services. The use of satellite communication changed in the 1970s and 1980s with the creation of Very Small Aperture

Terminals (VSATs) which allowed businesses to build private networks with small ground terminals. (Maral & Bousquet 2010.) Satellite internet services adopted geostationary Earth orbit (GEO) satellites as the main architecture during this period although their 35,786 km altitude produced high latency (ReliaSat 2024).

2.2.2 Transition to LEO and MEO Satellites

Low Earth orbit (LEO) and medium Earth orbit (MEO) satellites saw rising interest during the late 1990s and early 2000s to address the latency problems characteristic of GEO satellites. Ranging from 500 to 2,000 km above Earth, LEO satellites showed reduced latency and enhanced real-time capabilities making them suitable for video conferencing and online gaming. (Lutz et al. 2020.) Although Iridium and Globalstar, the first LEO ventures experienced financial issues initially, they established the fundamental infrastructure for contemporary satellite constellations. MEO satellites, typically placed at around 20,000 km, gained traction with systems such as O3b Networks, delivering high-throughput internet services to remote regions. (Ruble 2012.)

2.2.3 Emergence of High Throughput Satellites (HTS)

High Throughput Satellites (HTS) brought spot beam technology into the satellite internet industry. High Throughput Satellites employ numerous small spot beams to increase network capacity and data throughput instead of traditional satellites that create wide beams to serve extensive areas. Viasat-1 showcased HTS potential in 2011 through unparalleled broadband speeds delivered by satellite. (Ruble 2012.)

2.2.4 Satellite Constellations and NewSpace Era

Presently, the next iteration of satellite internet is being witnessed through the development of satellite mega constellations. It is the aim of companies such as SpaceX, Amazon and OneWeb to create high speed, low latency internet globally through the launch of thousands of LEO satellites. The aim of SpaceX’s Starlink, launched in 2019, is to create a network of over 40,000 satellites to offer broadband internet services globally especially to areas with limited access. (Lutz et al. 2020.) These constellations have been made more efficient in their network performance and scalability by the use of such advanced technologies as phased-array antennas, and inter-satellite laser links. The deployment of LEO constellations has also been propelled by advancements in reusable rocket technology, especially the Falcon 9 rocket of SpaceX. (Falcon 9 2019.) Features such as software defined satellites that can change the coverage and bandwidth according to the need are also enhancing the satellite internet services (Nilesat 2024).

2.2.5 Future Trends and Innovations

The future promises increased development in communication protocols along with satellite miniaturization and AI optimization of networks. Very Low Earth Orbit (VLEO) satellites along with quantum communication technologies investigated at Research level can provide improved connectivity and security to global internet services. The integration of satellite internet with terrestrial 5G and future 6G networks will provide seamless and ubiquitous internet access worldwide as satellite internet continues its evolution. (VLEO 2021.)

2.3 Advantages of Satellite Internet

Satellite internet technology provides benefits by connecting people and closing the digital gap in remote and underdeveloped areas. Unlike broadband methods that depend on land-based structures such as fiber optic cables and mobile towers, satellite internet uses satellites in space to deliver services making it available even in isolated and geographically challenging areas (Anil & Varsha 2011).

Furthermore, satellite internet allows for internet accessibility in locations such as islands or regions affected by disasters where conventional networks may not reach (Lutz, Werner & Jahn 2020). This is especially valuable for maritime and aviation industries.

Satellite internet services have the benefit of a simpler setup, in contrast to fiber optic networks that need thorough groundwork and installation processes. Satellite internet can be rapidly established using a satellite dish and modem, making it a great option for emergency communication and in times of natural disasters or humanitarian emergencies. In addition, the latest generation of satellites orbiting the earth at low altitudes (LEOs) has greatly enhanced internet speed and decreased delays thus making satellite internet a feasible choice for immediate applications such as video calls and online gaming. With progress in satellite technology, satellite internet is emerging as a potent substitute for conventional broadband services. (BroadbandNow 2025.)

2.4 Challenges and Limitations of Satellite Internet

While satellite internet technology offers numerous benefits, it also encounters obstacles and restrictions affecting its performance, cost and availability. A vital issue is latency in relation to geostationary (GEO) satellites placed 35,786 km above the earth. The extended signal travel distance leads to increased latency that hampers the performance of real time activities, such as gaming and video conferencing when compared to fiber optic or land-based networks. (Lutz, Werner, & Jahn 2020.)

Although LEO satellites considerably lessen latency, it is worth noting that they have their fair share of challenges such as the need to occasionally increase the number of satellites in orbit and regular replacements which can add to the overall operational intricacies and expenses involved (TelecomReview 2025).

Another challenge is the expenses associated with setting up and managing satellite internet infrastructure. The development and operation of satellite networks demand substantial financial investment, leading to higher costs for end consumers (Anil & Varsha, 2011). Although efforts are being made by companies such as SpaceX's Starlink to reduce costs, satellite internet services continue to be more expensive than conventional broadband in various locations (CircleID 2024).

Furthermore, the performance of satellite internet is influenced by weather conditions. Inclement weather such as rainfall and snowstorms can diminish satellite signals, causing brief service interruptions. This scenario is known as ‘rain fade’ and it predominantly affects high frequency satellite communication. Additionally, bandwidth limitations and data caps enforced by satellite internet companies can hinder users from engaging in tasks like streaming and downloading large files. (Berezhkova 2023.) These limitations make satellite internet less ideal for heavy data usage when compared to fiber optic broadband options. Exceeding these limits can result in throttled speeds or additional charges, adversely affecting the user’s ability to freely use the internet.

3 A GENERAL OVERVIEW OF THE DIGITAL DIVIDE

The digital divide is the distance between people, households, businesses and geographic regions with respect to modern information and communication technology (ICT). The divide refers to factors such as socio-economic status, education, geography and technological infrastructure. As digital technologies are gradually becoming an essential part of education, employment, healthcare and even social inclusion, the effects of digital exclusion are more severe than ever. The digital divide is one of the most serious problems of the modern world, which can be solved only with the concerted efforts of the governments, private sector and international organizations. Despite the fact that there has been a significant improvement in the coverage of the internet, differences in digital literacy, cost, and quality of service continue to widen the social gap. (Norris 2001.)

3.1 Definitions and Dimensions of the Digital Divide

The digital divide as defined earlier incorporates differences in access to digital devices and the internet connection. It also refers to individuals' skills and the capacity to apply technology for work, social, and learning purposes (Van Dijk, 2020). The digital divide is not an endpoint but a dynamic and multifaceted phenomenon that is influenced by technological development, socioeconomic status, as well as policy making.

According to Norris (2001), the digital divide is distinguished on various levels, between countries, in urban and rural areas, and between population subgroups. It is not only the lack of physical contact with technology, but also the differences in usage frequency and the impact of digital engagement. As digital technologies are progressively encompassing education, employment, healthcare and governance, the distance between the digitally empowered and the disadvantaged is expanding, thus exacerbating social and economic inequalities (Helsper 2021).

As pointed out by Van Dijk (2020), there are three main axes of the digital divide: the first-level digital divide (the access divide), the second-level digital divide (the skills and usage divide) and the third-level digital divide (the benefits divide). These dimensions aim to emphasize that digital inequality is not a simple issue but requires multifaceted approaches.

3.1.1 The First-Level Digital Divide (Access Divide)

The first-level digital divide is explained as the gap in access to digital devices and internet connection. It is the most basic and most apparent digital divide that relates to the possibility of people or countries to participate in the global digital society. Access to ICTs is a function of income, region, and government policies; city dwellers and high-income earners connect more frequently and have access to more digital services. (Hargittai 2002.)

Rural and remote areas are likely to suffer from the digital divide because of the non-existing, or limited broadband infrastructure and the high costs of internet services. Mobile internet and satellite technologies have expanded the coverage but accessing high-speed broadband is unfeasible for many in the low-income regions. The first-level digital divide has been the concern of policy makers, with governments and other stakeholders focusing on the expansion of digital infrastructure to hard-to-reach areas. (Helsper 2021.)

3.1.2 The Second-Level Digital Divide (Skills and Usage Divide)

Beyond network and device accessibility, the digital divide also refers to differences in digital skills and usage of devices and applications. The second-level digital divide is concerned with inequalities in the capacity of individuals to comprehend, use, and manage digital technologies and online resources (Van Deursen and Helsper, 2015). Even when people are equally connected to the internet, they differ in their capacity to comprehend, analyze and use information obtained from online sources. This can be attributed to differences in the level of education, experience, and motivation. (Helsper 2021)

This assertion is supported by Hargittai (2002) who states that digital literacy is one of the factors of the second-level digital divide since people with higher levels of education and exposure to technology most likely possess better digital skills. These skills include basic internet skills, skills in using online communication tools, skills in retrieving information from different sources and the skill of critically examining the information that is posted online. In other words, the ability to use digital technologies and online resources is a key factor that determines an individual's level of participation in the digital economy and for example, their readiness for online learning, and e-government services.

3.1.3 The Third-Level Digital Divide (Benefits Divide)

The third-level digital divide is concerned with the extent to which people and communities are digitally included and whether they are able to benefit from digital engagement. This level of the digital divide is interested in the capacity of people to embrace the digital society to change their lives for the better (Van Dijk, 2020). This dimension aims to determine whether digital inclusion can result in real social, educational, and economic value.

Van Deursen and Helsper (2015) states that the use of digital technology is not equally beneficial. They went further to assert that individuals with better digital literacy and better access to technology receive more benefits from the digital economy, land better jobs, perform better in school, and have better access to financial services. Similarly, people with low digital engagement may not be able to use online resources to achieve their personal or professional goals.

The third-level digital divide emphasizes the fact that in order to close the digital gap, more effort must be made than simply to give people smartphones and computers. It is also important to address the issue of how people can effectively use digital tools to enhance their lives and become active citizens. There is a need for digital literacy programs, affordable access to technology, and policy measures that support people's ability to benefit from the digital economy.

3.2 Factors Contributing to the Digital Divide

The digital divide is affected by different interrelated factors that determine the availability, adoption, and impact of digital technologies. These factors include economic and geographical barriers, as well as differences in education, age, and social status. These barriers must be removed in order to develop a digital society where everyone can access and engage equally in the digital services and economy. (Van Dijk 2020.)

3.2.1 Economic Disparities

A key factor leading to the digital divide is the inequality in income. Digital technologies such as computers, smartphones, and broadband internet are an expensive proposition, which low-income households may not be able to bear. People from lower socio-economic status are unlikely to own digital devices or sign up for high-speed internet connection. Even in the countries with near universal access to the Internet, affordability is the main reason for the exclusion. (Helsper 2021.)

3.2.2 Geographic and Infrastructure Limitations

Location is an important factor in the availability of digital access. This accounts for why rural and remote areas are characterized by poor or no access to high-speed internet infrastructure. (Hargittai 2002.) While the majority of the population in urban centers has access to extensive broadband networks, many rural populations still rely on outdated technologies, which are often slow and unreliable (Van Deursen & Helsper 2015). Broadband infrastructure is continually expanded by governments and private companies, but the rate of expansion is riddled with inconsistencies across different regions.

3.2.3 Educational Attainment and Digital Literacy

Education is a significant predictor of both access to and usage of digital resources. Individuals with higher levels of education are more likely to acquire the necessary digital skills that enable them easily navigate on different online platforms. In contrast, those with a lower level of education may not be able to handle digital tasks at all, which exacerbates the divide. Educational institutions are an important agent in the promotion of digital literacy through the inclusion of technology and digital skills into the learning process. (Selwyn 2004.)

3.2.4 Age and Generational Difference

Age is also a factor that defines digital ability and activeness. Those who have been raised in the digital era are likely to be more comfortable using online resources than the more elderly citizens who find it difficult to navigate through new digital platforms. The aversion to digital technology among the elderly is due to technofear, skepticism and/or reluctance towards new matters, or physical impairments, such as deterioration of vision and mobility. This issue can be addressed by targeted training programs which can enhance the digital skills of the older population. (Van Dijk, 2020.)

3.2.5 Social and Cultural Barriers

Social and cultural factors are also determinants of digital inclusion. For example, gender inequalities can hinder the availability of digital resources since in some societies women are denied access to certain activities. Moreover, factors such as language and disability can limit people’s participation in the digital world. Concerted efforts to make digital resources more inclusive include providing content in different languages and making designs easily accessible to people with disabilities. (Helsper 2021.)

3.3 Economic Impacts of the Digital Divide

The economic implications of the digital divide are clearly defined and rather comprehensive, especially regarding the consequences for people, companies, and countries. In a world where digital technologies are gradually integrating into all aspects of the economy, the excluded population is likely to have difficulties in finding employment, starting a business and by extension, achieving economic development. The economic effects of the digital divide are evident in employment rate, business competitiveness, and national productivity. (Van Dijk 2020.)

3.3.1 Employment and Income Inequality

A direct economic consequence of the digital divide is illustrated by employment opportunities. Nowadays most jobs require digital skills, be it basic computer literacy or advanced technical expertise. This puts those without digital access or skills at a disadvantage in the labor market, limiting job prospects and earning potential. (Helsper 2021.) As stated by Van Deursen and Helsper (2015), digital skills have become essential for career. Hence, the digital divide also leads to income inequality since the digitally literate are better placed to land well-paying jobs while those who lack digital skills are trapped in low-income employment.

3.3.2 Business and Entrepreneurship Challenges

The digital divide has an important implication for small and medium sized enterprises (SMEs). Those that do not possess digital tools cannot effectively operate in the modern economy which is based on e-commerce, digital marketing, and online financial services (Norris 2001). This paper also established that entrepreneurs in digitally excluded areas have a difficult time attracting a large customer base, raising capital, and incorporating technology into their businesses. Digital technologies help businesses improve performance, decrease costs, and increase market coverage. Not being able to join the digital economy may lead to business stagnation and economic differences between the digitally included and the digitally excluded areas. (Selwyn 2004.)

3.3.3 National Economic Growth and Competitiveness

At the national level, the digital divide impacts productivity and global competitiveness and, therefore, forms a barrier to the digital inclusion of countries. Faster economic growth is experienced by those countries with high levels of digital access because of improved productivity, new innovations, and efficient communication and access to public services. (Van Dijk 2020.) Digital exclusion prevents many nations from participating in the new global digital economy and thus, limits the means for economic growth. It also undermines the attempts of governments to shift towards e-governance, digital taxation and online service delivery, deepening the existing wealth gaps between the developed and developing nations. (Hargittai 2002.)

3.4 Satellite Internet as a Panacea to the Digital Divide

In the continued quest for digital inclusion, satellite internet has emerged as a promising alternative for bridging the digital divide, particularly in remote, rural, and underserved areas. In sparsely inhabited or geographically difficult places, traditional broadband technologies such as fiber-optics or Digital subscriber line (DSL) are either too expensive or logistically unfeasible to implement. On the other hand, satellite internet provides wide-area coverage, making it possible to access the internet almost anywhere in the world. Compared to previous geostationary systems, the technology promises lower latency, faster speeds, and more reliability with the introduction of new-generation low Earth orbit (LEO) satellite constellations like Starlink and OneWeb. Consequently, satellite internet may significantly enhance digital connection and guarantee equal access to online education, healthcare, e-commerce, and governmental services. In order to realize its promise as a solution to the digital divide, issues of affordability, infrastructure investment, and supportive legislative frameworks must be addressed. (Van Dijk 2020.)

3.5 Accessibility and Connectivity in Remote Areas

A primary advantage of satellite internet is its capacity to deliver access in remote and underserved areas where terrestrial infrastructure is deficient or absent. Conventional broadband solutions depend significantly on terrestrial infrastructure, including fiber-optic cables and cellular towers, which are economically impractical to deploy in rural or inaccessible regions due to low population density and challenging topography. Conversely, satellite internet systems convey data using orbiting satellites, enabling the provision of internet services across extensive geographic regions, including hilly terrain, deserts, islands, and remote settlements. (Lutz, Werner & Jahn 2020.)

This feature is especially important in underdeveloped countries where rural communities often lack access to basic communication services. According to the International Telecommunication Union (ITU 2021), approximately 2.7 billion people throughout the world were still offline in 2020, with the vast majority living in rural and remote areas. Satellite internet can provide a rapid deployment paradigm in these places, eliminating the need for major terrestrial infrastructure construction. Modern LEO satellite systems, such as SpaceX's Starlink, operate at altitudes ranging from 500 to 2,000 kilometers, resulting in much lower latency compared to classic geostationary satellites at 35,786 kilometers. This upgrade makes LEO-based satellite internet more appropriate for real-time applications such as video conferencing, online learning, and telemedicine. (CircleID 2024.)

In Finland, for example, satellite internet has been investigated as a feasible method for improving rural broadband coverage, particularly in northern Lapland, where extreme weather conditions and low population density make terrestrial expansion difficult. According to the Finnish Transport and Communications Agency (Traficom, 2023), satellite services are increasingly being included in national broadband policies to supplement fixed and mobile networks and ensure complete territory coverage.

Additionally, satellite internet aids in disaster recovery and emergency response. Satellite systems can provide a durable and quickly deployable communication backbone in instances where traditional networks are damaged or overburdened, such as natural catastrophes or conflict zones (Berezhkova, 2023). This ensures that critical services and coordination efforts can continue even under the most difficult conditions.

While satellite internet shows great promise for increasing accessibility, its potential is dependent on the affordability of user terminals, long-term service pricing and supporting regulatory conditions. Without these, the technology may remain out of reach for many of the communities it is intended to connect.

Nonetheless, satellite internet is a transformative instrument for closing the digital divide and promoting global digital inclusion.

4 RESEARCH METHODOLOGY

4.1 Research Design and Approach

This study is particularly focused on the potential of satellite internet in bridging the technological gap and inequality. In order to thoroughly examine the function of satellite internet, more specifically Starlink, in bridging the connectivity gap between telecommunication networks, this study employs a mixed-method research design, primarily integrating quantitative analysis and qualitative methodologies. Additionally, by gathering and examining important network performance metrics, such as speed, latency, and reliability, quantitative methods are used to evaluate the performance of Starlink against other cellular networks that are present within the Nigerian borders. The qualitative approaches utilized here largely concentrate on document analysis and interviews with users in less urban and underserved regions, offering insights into the socio-economic implications of satellite internet utilization and the viewpoints of stakeholders.

The mixed-methods design allows for the triangulation of results, which improves validity and dependability (Creswell & Clark, 2017). Specifically, the quantitative data on network performance serves as a foundation for understanding satellite internet's technological capabilities, whilst the qualitative data aids in explaining users' experiences and the wider societal implications.

Overall, the study uses an exploratory-comparative approach to evaluate how Starlink compares to traditional cellular networks (4G/5G) in Nigeria, in terms of affordability, performance, and accessibility. This method provides empirical data to evaluate how well satellite internet (Starlink) fills connectivity gaps, offering a competitive alternative and complementing traditional mobile network operators, particularly in remote and underserved areas. By increasing internet accessibility, satellite internet has the potential to improve digital inclusion while coexisting with current mobile networks.

4.2 Data Collection Methods

In this thesis, data was primarily collected via live field-testing methods over a 10-day period. Other means were informal interviews and document analysis.

4.2.1 Field Testing

Direct speed testing was performed in a specified area in Port Harcourt City in Rivers State, Nigeria, where terrestrial internet service is commonly accessible. The download speed, upload speed, latency, and jitter for both Starlink and the main cellular networks in the test area were measured using 'Speedtest by Ookla' and 'Fast.com by Netflix'. Tests were carried out at certain times of day between 9 a.m. and 12 p.m., as these are peak usage hours.

Fast.com is a simple internet speed test offered by Netflix whose main objective is to rapidly determine the user's current download speed. A more thorough and popular tool for assessing internet performance is Speedtest by Ookla (Speedtest.net), which provides measurements of upload and download speeds as well as latency (ping) and jitter. (Lutu & Vdovichenko, 2017.)

Table 1. Comparison between Speedtest and Fast.com (Lutu & Vdovichenko)

Feature	**fast.com (Netflix)**	**Speedtest by Ookla**
Provider	Netflix	Ookla
Metrics	Primarily Download Speed	Download Speed, Upload Speed, Latency (Ping), Jitter, Packet Loss (in some versions)
Complexity	Very Simple, Minimal User Interface	More Advanced Interface, Server Selection, Detailed Results
Advertising	No Ads	Contains Advertisements (unless they use a paid version)

Feature	**fast.com (Netflix)**	**Speedtest by Ookla**
Data Usage	Designed to use less data for testing (Netflix focus)	Can use more data, especially with longer tests
Server Network	Netflix's Content Delivery Network (CDN).	Global Network of Test Servers. Allows the user to select from a list of test servers (with more options) to more accuratley reflect their network's condition.
Data Access	Limited Public Data	Extensive Public Data Available (Speedtest Global Index, Speedtest Intelligence - paid service)

4.2.2 Semi-structured Surveys and Interviews

In addition to the extensive field testing, a few semi-structured interviews were carried out with local business owners and residents of the zones that were chosen within the test area. Their opinions of satellite internet, their experiences with internet access (or lack thereof), and the possible effects of increased connectivity on their lives and means of subsistence were all examined in the interviews. Interviewees were picked using a purposive sampling strategy to ensure inclusion from different demographic groups and sectors.

4.2.3 Secondary Data

In this thesis, research papers, industry reports, and regulatory documents on satellite and mobile internet deployment were used as secondary sources of data. This data supplements the field-testing data and provides a larger sample size.

Furthermore, A standard PC was connected to the Starlink user terminal to simulate real-world user interaction and data transfer scenarios while leveraging on speed test tools. The attributes of the hardware equipment used for the field testing are given in table 2.

Table 2. PC hardware specification

Feature	***Specification***
Product Name	HP Pavilion Gaming Laptop 15-dk1115TX
Product Number	296G4PA
Microprocessor	Intel® Core™ i5-10200H (2.4 GHz base frequency, up to 4.1 GHz with Intel® Turbo Boost Technology, 8 MB L3 cache, 4 cores)
Chipset	Intel® HM470
Memory	16 GB DDR4-2933 SDRAM (2 x 8 GB)
Video Graphics	NVIDIA® GeForce® GTX 1650 Ti (4 GB GDDR6 dedicated)
Display	15.6" diagonal FHD (1920 x 1080), IPS, micro-edge, anti-glare, 250 nits, 45% NTSC
Hard Drive	256 GB PCIe® NVMe™ M.2 SSD, 1TB HDD
Optical Drive	Not included
Wireless Connectivity	Intel® Wi-Fi 6 AX201 (2x2) and Bluetooth® 5 combo (Supporting Gigabit file transfer speeds)
Network Interface	Integrated 10/100/1000 GbE LAN
Expansion Slots	1 multi-format SD media card reader
External Ports	▪ 1 SuperSpeed USB Type-C® 10Gbps ▪ (USB Power Delivery, DisplayPort™ 1.4, HP Sleep and Charge) ▪ 1 SuperSpeed USB Type-A 5Gbps (HP Sleep and Charge) ▪ 2 SuperSpeed USB Type-A 5Gbps ▪ 1 HDMI 2.0 ▪ 1 RJ-45 ▪ 1 AC smart pin ▪ 1 headphone/microphone combo

Dimensions (W x D x H)	36 x 25.6 x 2.34 cm
Weight	Starting at 2.23 kg
Power Supply	150 W Smart AC power adapter
Battery	3-cell, 52.5 Wh Li-ion polymer
Webcam	HP Wide Vision HD camera with integrated dual array digital microphone
Audio Features	Audio by B&O; Dual speakers; HP Audio Boost 1.0
Operating System	Windows 10 Home 64
HP Apps	HP Audio Switch; HP Documentation; HP e-Service; HP JumpStart; HP Support Assistant; OMEN Command Center; HP Connection Optimizer; HP PC Hardware Diagnostics Windows
Software Included	McAfee LiveSafe™

In addition, the test location's pre-installed Starlink user terminal was set up to connect to Starlink's satellite network, enabling immediate testing. Following that, quantitative data from speed tests and data sources were examined using descriptive statistical methods, and appropriate conclusions were drawn to compare Starlink's performance to that of other cellular networks.

Figure 2. Installed starlink equipment at test location

Starlink is a satellite internet constellation comprised of several key components: the satellite network itself, ground stations, user terminals (often called "Dish"), and routers. As of early 2025, Starlink had approximately 5,650 satellites in Low Earth Orbit (LEO), traveling at roughly 27,000 km/hr (Pearlman, 2024). Initial projections had estimated that global coverage would require over 10,000 satellites and current deployment strategies and satellite capabilities are constantly evolving (Bello et al. 2024).

The user terminals employ phased array technology to steer beams for precise connections in the Ku and Ka bands, a necessity given the impracticality of mechanical steering. Initially, Starlink utilized a bent-pipe relay strategy, which required data to be relayed through ground stations. However, newer generations of Starlink satellites, such as the V2 and V3 versions, incorporate laser crosslinks for inter-satellite communication. This technology reduces reliance on ground stations and enables more direct data transmission pathways, especially over oceanic or remote regions. (McDowell 2023.) These laser links are a key advancement in creating a truly global and resilient network.

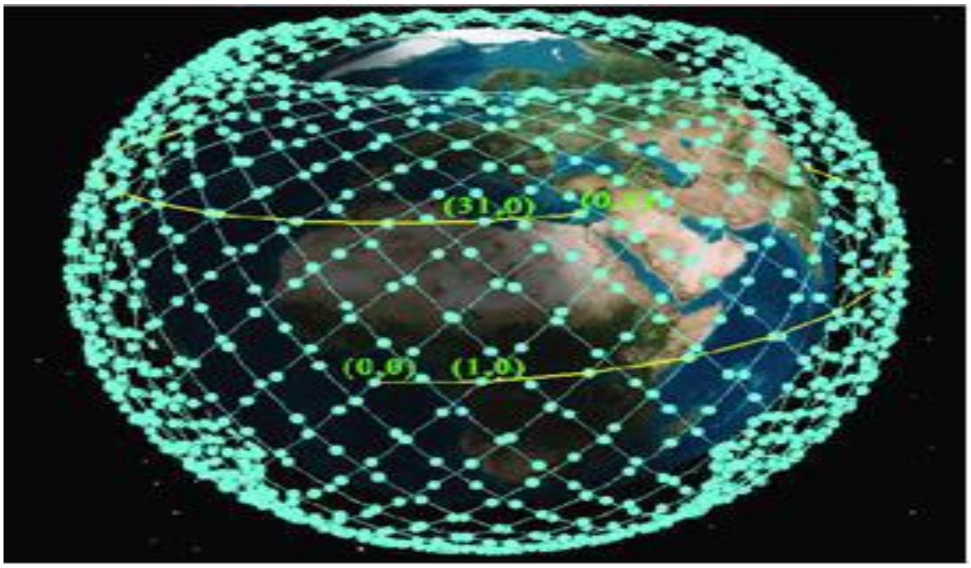

Figure 3. Starlink satellite constellations (Zhang et al. 2020)

Starlink ground stations, or gateways, provide the connection to the terrestrial internet. These stations communicate directly with satellites and connect to fiber optic networks. As of early 2025, Nigeria had two active gateways located in Lekki (Lagos State) and Osun State, with potential for expansion as the network grows. Continued expansions of ground stations have also been deployed in other areas of Africa. (Starlink Coverage Map 2025.)

Figure 4: Starlink ground station (TechWithMuchiri, 2025)

Furthermore, in this thesis, various modem/router devices were utilized to collect key network parameters for MTN and Airtel networks to be compared with

Starlink. The specifications for the MTN 4G Broadband Router and the Airtel 4G MiFi devices are presented in Table 3 and Table 4 respectively.

Table 3. MTN router specification (revenes 2025)

Specification	**Details**
Model	ZTE MF927U
Network Compatibility	4G LTE FDD B1/B3/B5/B7/B8/B20/28 3G B1 2100MHz, B8 900MHz
Download Speed	Up to 150 Mbps
Upload Speed	Up to 50 Mbps
Wi-Fi Connectivity	802.11b/g/n, 2.4GHz Connects up to 32 devices
Battery Capacity	2,000mAh Up to 7 hours usage time Up to 200 hours standby time
Additional Features	LED indicators for signal strength, battery level, Wi-Fi status, and new SMS alerts
SIM Card Slot	Yes
Supported Network	MTN 4G LTE

Table 4. Airtel 4G Mifi specification (revenes 2025)

Specification	**Details**
Model	Vida M4
Network Compatibility	4G LTE FDD B1/B3/B5/B8/B7/B20 3G B1 2100MHz, B8 900MHz
Download Speed	Up to 150 Mbps
Upload Speed	Up to 50 Mbps
Wi-Fi Connectivity	802.11b/g/n, 2.4GHz Connects up to 10 devices
Battery Capacity	2,400mAh Up to 6 hours usage time

Additional Features	1.44-inch TFT LCD display indicating battery, Wi-Fi connections, data usage, new messages, and hotspot details
SIM Card Slot	Yes
Supported Network	Airtel 4G LTE

4.3 Data Analysis Techniques

This section describes the techniques used to analyze the data collected in this study. A mixed-methods approach was employed, requiring distinct analytical strategies for the quantitative network performance data (collected as described in 4.1 and 4.2) and the qualitative data gathered from semi-structured and unstructured interviews. The results of these analyses are then integrated into section 5 to provide a comprehensive assessment of the role of satellite internet. The methods employed are described below.

4.3.1 Quantitative Data Analysis (Network Performance)

This subsection details the methods used to analyze the network performance data, including download speed, upload speed, latency, jitter, and packet loss, for both Starlink and select cellular networks available in the chosen area. The main objective of this analysis is to identify statistically significant differences in performance between the two technologies and to assess the impact of environmental factors. The data collected was analyzed using statistical analysis (network performance metrics such as Throughput, Latency and Jitter), and comparative analysis (contrasting Starlink i.e satellite network with cellular networks based on performance, cost, and impact). The core data analysis techniques applied to the collected data are presented below.

- ❖ **Outlier Removal**: Outliers were identified using (e.g., the interquartile range (IQR) method) and removed from the dataset to reduce the influence of anomalous measurements.

- ❖ **Handling Missing Data**: Missing data points were handled using listwise deletion or imputation. The rationale for this approach is that missing data can significantly impact the validity and reliability of findings. Proper handling ensures that the analysis remains accurate, unbiased, and representative of the real-world scenario.

- **Data Aggregation and Transformation**: Data was aggregated and averaged to enhance accuracy, as two different speed test tools were utilized. This approach ensured more reliable results by balancing variations between Fast.com and Speedtest by Ookla.

  Averaging parameter readings is crucial in this context, for the reasons listed below.

  - Eliminates Tool-Specific Variations: Different tools may have slight discrepancies due to their test methodologies, so averaging provides a more balanced result.
  - Ensures Fair Comparison: Averages smooth out inconsistencies across different days, allowing for a more accurate performance assessment.
  - Reflects Real-World Experience: Since network conditions fluctuate, averaging download speed, upload speed, and latency gives a more reliable picture of the overall network performance.
  - Reduces Outliers' Impact: Isolated spikes or drops in speed due to temporary network congestion or external factors would not skew the results.

4.3.2 Qualitative Data Analysis (Socio-economic Impact)

This subsection outlines the methods used to analyze the qualitative data collected from semi-structured interviews. The purpose of this analysis is to identify key themes related to the socio-economic impact of satellite internet and to understand the lived experiences of users. The methods used in this analysis are presented below.

- **Transcription and Preparation**: All interviews were audio-recorded and transcribed. Transcripts were reviewed for accuracy and completeness. The transcripts were anonymized to protect the privacy of participants. All identifying information was removed or replaced with pseudonyms.

- **Thematic Analysis**: This involved identifying key trends from qualitative responses, i.e. interviews. Interview transcripts were coded to identify recurring themes related to the challenges of digital exclusion, the perceived benefits and drawbacks of satellite internet, and the social and economic impacts of improved connectivity.

4.4 Ethical Considerations

This section outlines the ethical principles that guided the study, ensuring participant protection, confidentiality, and research integrity.

4.4.1 Confidentiality and Data Protection

All collected data were processed with strict confidentiality to safeguard participant privacy. Each participant was assigned a unique identifier, ensuring that personal details were anonymized and removed from the dataset before analysis. Interview transcripts were securely stored on a password-protected device which could only be accessed by the author. For quantitative data (e.g. speed test results), location information was aggregated at the community level, preventing the identification of specific users while still providing meaningful insights into network performance. This approach complies with standard data protection regulations and ethical research practices. The data collected will be retained for a period of six (6) months to allow for further analysis if necessary. After this period, it will be securely destroyed in accordance with established data security protocols, ensuring no unauthorized access or misuse.

4.4.2 Voluntary Participation and Right to Withdraw

Participants were explicitly informed that their involvement in the study was entirely voluntary. They had the right to withdraw at any time without facing any penalties or negative consequences. This assurance was crucial to maintaining trust and ensuring that participants engaged freely without coercion. Moreover, participants were reassured that their decision to participate (or not) would not affect any existing relationships or partnership, preventing undue pressure or ethical concerns regarding consent.

4.4.3 Conflicts of Interest and Research Integrity

The author affirms that no conflicts of interest influenced the study’s design, data collection, analysis, or reporting. The study was conducted objectively and transparently, with every effort made to ensure unbiased interpretation and presentation of results.

To uphold research integrity, the study strictly adhered to established ethical guidelines to prevent any manipulation or misrepresentation of data. The findings were reported accurately, ensuring that all conclusions were based solely on the evidence collected. Additionally, any limitations or uncertainties in the results were clearly acknowledged to maintain transparency and credibility.

5 COMPARATIVE ANALYSIS AND IMPACT ASSESSMENT

5.1 Speed and Performance Comparisons

The findings from both field tests and crowdsourced data analysis reveal notable variations in the performance of Starlink satellite network compared to other cellular networks (Airtel and MTN) across the study location. The tests were conducted over a 10-day period, from February 28, 2025, to March 13, 2025, to assess network efficiency in terms of speed and performance, reliability, and service delivery.

These differences are evident in key metrics such as download and upload speeds and latency. Table 5 provides a comprehensive summary of these performance indicators, highlighting the comparative strengths and limitations of each network type as recorded during the field tests for the 10-day period.

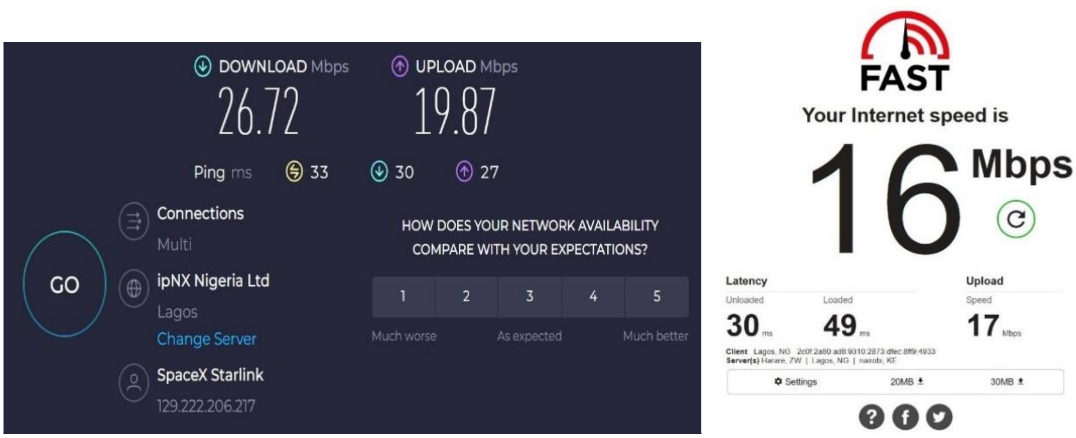

Figure 5: Sample Data throughput for Starlink

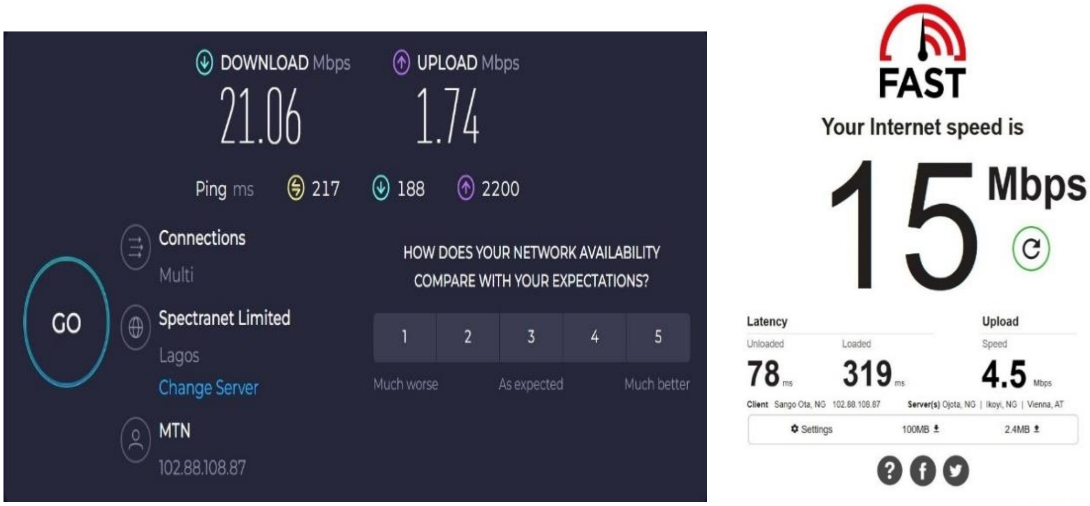

Figure 6: Sample data throughput for MTN

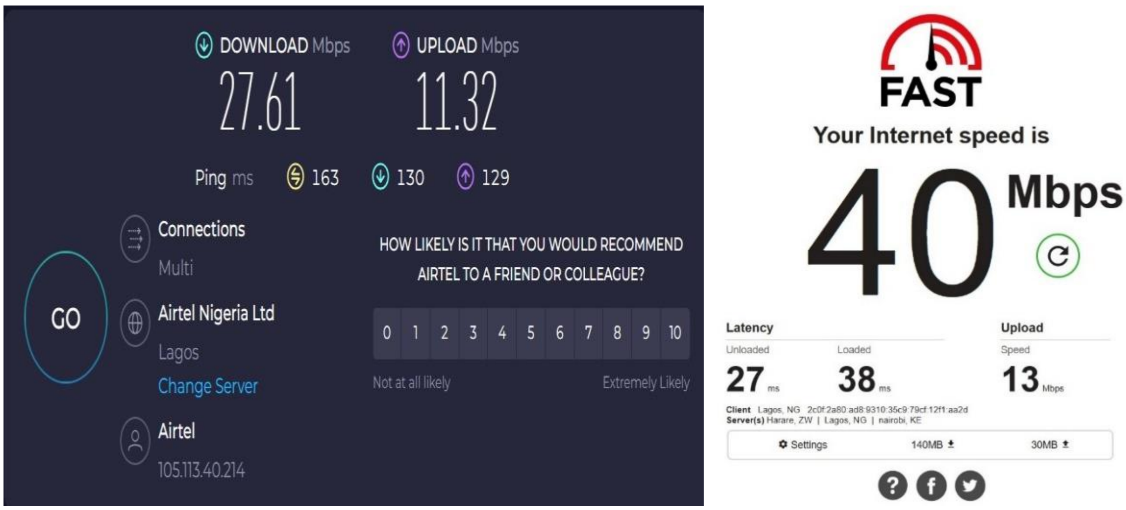

Figure 7: Sample data throughput for Airtel

Table 5: 10-day data throughput readings

Day	Network	Fast.com (Download Mbps)	Fast.com (Upload Mbps)	Fast.com Latency (Unloaded/ Loaded ms)	Speedtest.net (Download Mbps)	Speedtest. net (Upload Mbps)	Speedtest. net Ping (Idle/Download ms)
Day 1	Airtel	7.5	1.2	195/1100	12.03	5.1	1390/1795
	MTN	14	19	150/757	8.78	21.28	306/1465
	Starlink	45	19	31/37	75	20.84	26/35

Day 2	Airtel	40	13	27/38	27.61	11.32	163/130
	MTN	15	4.5	78/319	21.06	1.74	217/1880
	Starlink	16	17	30/49	26.72	19.87	33/30
Day 3	Airtel	15	3.9	293/1500	15.48	2.66	683/864
	MTN	5.1	15	80/315	15	14.57	840/311
	Starlink	15	3.2	22/120	57.46	12.66	38/31
Day 4	Airtel	7.4	3.1	111/572	11.92	4.09	88/290
	MTN	14	5	47/450	8.5	3.5	204/1460
	Starlink	36	9.3	26/47	64.95	12.23	38/32
Day 5	Airtel	16	4.1	39/1400	15.42	3.93	59/822
	MTN	9.4	2.5	89/323	9	5	75/2236
	Starlink	16	4.9	30/40	24.13	18.12	37/74
Day 6	Airtel	12	0.11	1330/1330	10.38	2.5	2686/2185
	MTN	6.6	29	37/520	8.4	12.94	205/780
	Starlink	29	7.6	29/36	66.73	11.52	44/36
Day 7	Airtel	12	7.5	125 / 850	14.76	6.5	150/1300
	MTN	1.6	5.3	64/255	22.03	13.21	212/1733
	Starlink	25	16	29/60	48.48	17.37	35/65
Day 8	Airtel	8.4	3.8	51/1700	10.75	3.34	69/232
	MTN	16	38	42/1600	15.96	7.5	48/192
	Starlink	44	16	28/40	71.54	13.65	34/37
Day 9	Airtel	6.7	3.3	126/1300	9.13	3.5	603/905
	MTN	13	2.5	38/1500	12.24	4.75	52/220
	Starlink	26	6.5	22/34	37.72	8.36	42/31
Day 10	Airtel	15	4.5	120/1005	18	5.5	150/1504
	MTN	12	5	58/950	14.3	10	180/1250
	Starlink	25	14	23/38	38	16.5	35/40

As discussed in the previous section, two speed test tools were used for better accuracy with the intent of obtaining average values for more accurate results. Table 6 shows the average throughput reading for the 10-day period.

The parameters measured are discussed in the following sections.

5.1.1 Throughput

Throughput measures the volume of data a network can handle, typically in bits per second. From the test result as shown in Table 6, recorded upload throughput ranged from 0.11Mbps to 38Mbps, while download throughput varied between 5.1Mbps and 75Mbps. Compared to most Nigerian mobile network operators, which average 1.56Mbps–18.01Mbps (download) and 4.63Mbps–17.49Mbps (upload) on 4G networks (Ekpe et al. 2022), Starlink demonstrated significantly higher performance, particularly in download speeds. Higher download speeds allow for faster loading of web pages, streaming videos, and downloading files. This is crucial for assessing the user experience, particularly for activities such as video streaming, web browsing and file downloads.

Table 6: 10-day average throughput readings

Day	Airtel (Avg. Download Speed Mbps)	MTN (Avg Download Speed Mbps)	Starlink (Avg Download Speed Mbps)	Airtel (Avg Upload Speed Mbps)	MTN (Avg Upload Speed Mbps)	Starlink (Avg Upload Speed Mbps)
Day 1	9.77	11.39	60	3.15	20.14	19.92
Day 2	33.81	18.03	21.36	6.65	1.27	11.89
Day 3	15.24	10.05	36.23	3.28	8.04	8.89
Day 4	9.66	11.25	40.48	3.6	4.25	10.77
Day 5	15.71	9.2	20.07	4.02	3.75	11.51
Day 6	11.19	7.5	47.87	1.3	20.97	9.56
Day 7	13.38	11.82	36.74	7	9.26	16.69
Day 8	9.58	15.98	57.77	3.57	36.46	14.83
Day 9	7.92	12.62	26.86	3.4	3.63	7.43
Day 10	16.5	13.15	31.5	5	7.5	15.25

From Table 6, the Mean (Average Values), Maximum and Minimum values for each network were determined using the formula below.

$$\text{Mean} = \frac{\sum \text{Xi}}{\text{N}}$$ ………………………. Equation 1

Where: Xi = Each individual value, N = Total number of values.

Table 7: Mean, min and max upload and download speeds.

Network	Download Speed (Mbps)			Upload Speed (Mbps)		
	Mean	Min	Max	Mean	Min	Max
Airtel	**14.28**	7.92	33.81	**4.1**	1.3	7
MTN	**12.1**	7.5	18.03	**11.53**	1.27	36.46
Starlink	**37.89**	20.07	60	**12.67**	7.43	19.92

Table 7 shows the mean, minimum, and maximum download and upload speeds respectively.

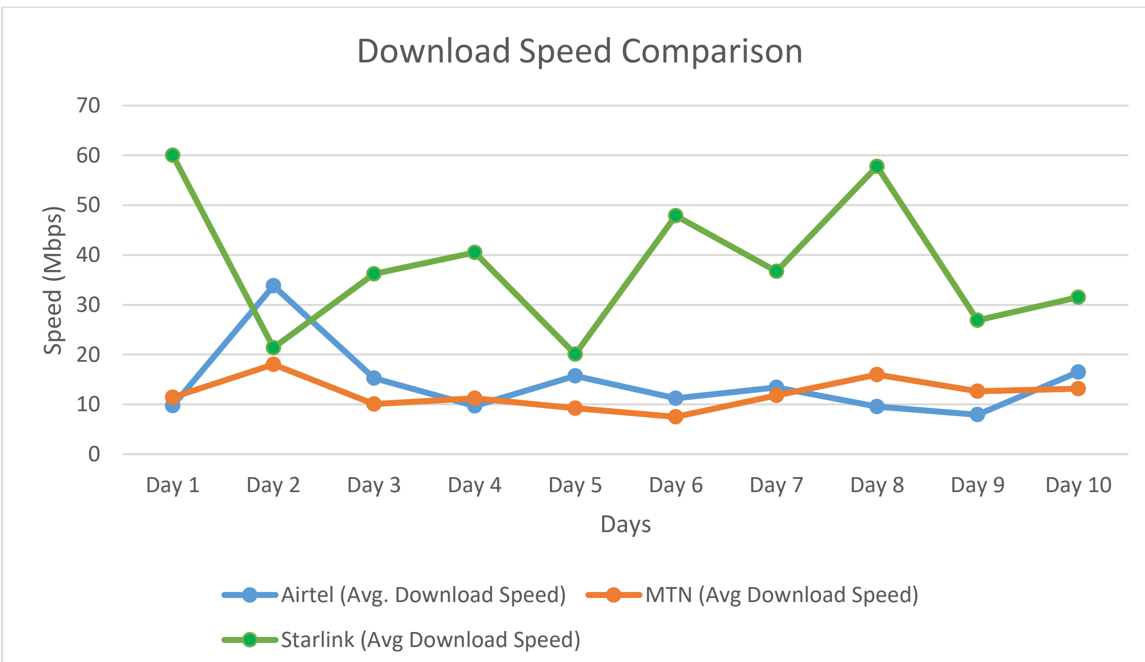

Figure 8: download speed chart

Starlink consistently outperformed MTN and Airtel, with speeds peaking at approximately 60 Mbps, while the mobile networks remained between 5-20 Mbps. Starlink's fluctuations were likely due to network congestion, weather conditions or satellite positioning (particularly on day 2 and 4). Airtel showed a brief spike on Day 2, possibly due to low congestion at the time of testing, while MTN remained stable even if slow.

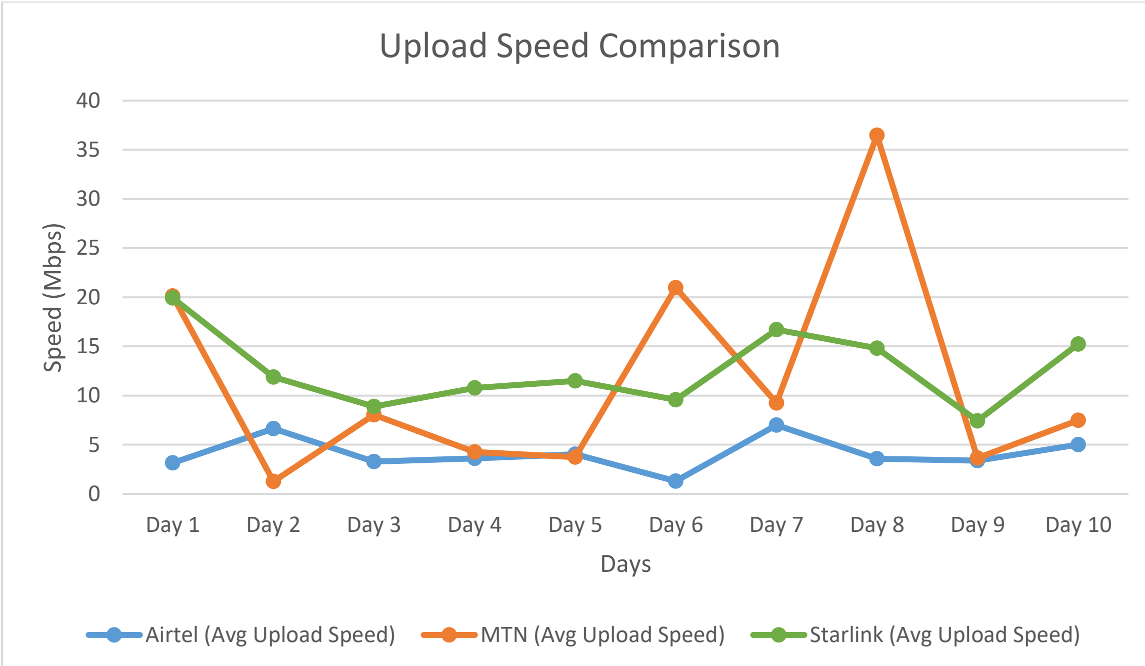

Figure 9: Upload speed chart

The upload speed results reveal a more varied performance, particularly for MTN, which exhibited unusual spikes on Days 5, 7, and 8, reaching as high as 35 Mbps on Day 8. MTN Spikes (Days 5, 7, and 8) could be attributed to temporary network optimizations, reduced congestion, or changes in tower traffic at the time of testing. Starlink maintained stable upload speeds (10–20 Mbps), while Airtel had the lowest and most consistent upload speeds, rarely exceeding 5 Mbps.

Starlink delivered the most reliable performance, making it a strong alternative for underserved areas. These results reinforce satellite internet's potential as a viable connectivity solution, particularly where traditional mobile network operators struggle to provide consistent speeds.

5.1.2 Latency (Ping)

Latency can be defined as the entire duration of travel of a data packet between a designated user device and a server, measured in milliseconds (ms) (Bandwidth Place 2025). Low latency signals a more responsive connection. This statistic is important for real-time applications such as video conferencing, online gaming and remote-control systems. High latency can result in delays and lag, rendering certain programs unusable. Table 8 shows the average latency reading for the 10-day period.

Table 8: Average Latency

Day	Airtel (Avg Idle Latency)	MTN (Avg Idle Latency)	Starlink (Avg Idle Latency)	Airtel (Avg Loaded Latency)	MTN (Avg Loaded Latency)	Starlink (Avg Loaded Latency)
Day 1	792.5	228	28.5	1447.5	1111	36
Day 2	95	147.5	31.5	84	1099.5	39.5
Day 3	488	460	30	1182	313	75.5
Day 4	99.5	125.5	32	431	955	39.5
Day 5	49	82	33.5	1111	1279.5	57
Day 6	2008	121	36.5	1757.5	650	36
Day 7	137.5	138	32	1075	994	62.5
Day 8	60	45	31	966	896	38.5
Day 9	364.5	45	32	1102.5	860	32.5
Day 10	135	119	29	1254.5	1100	39

As seen from Table 8, latency values were measured using two different speed test tools: Fast.com and Speedtest by Ookla. Since these tools categorize latency differently, a structured approach was adopted to ensure consistency in comparison. Each tool measures latency under different network conditions.

Fast.com provides two key latency measurements: unloaded latency, which reflects network performance in an idle state and is most relevant for real-time activities like gaming and video calls (with lower values, typically under 50ms, ideal), and loaded latency, which measures latency under conditions of heavy network usage.

Speed test by Ookla, on the other hand, reports three types of latency: idle latency, which corresponds to latency when the network is not under load and is comparable to Fast.com's unloaded latency; download latency, which measures latency during download activity and is equivalent to Fast.com's loaded latency; and upload latency, which measures latency during upload activity. Since

Fast.com does not provide an upload latency metric, this parameter was excluded from the study.

In order to ensure consistency and comparability between platforms, the following equivalences were established for the analysis: unloaded latency from Fast.com was treated as equivalent to idle latency from Speed test, while loaded latency from Fast.com was considered equivalent to download latency from Speed test.

A balanced representation of network performance was obtained by adopting an averaging approach across the two tools as seen in Table 8.

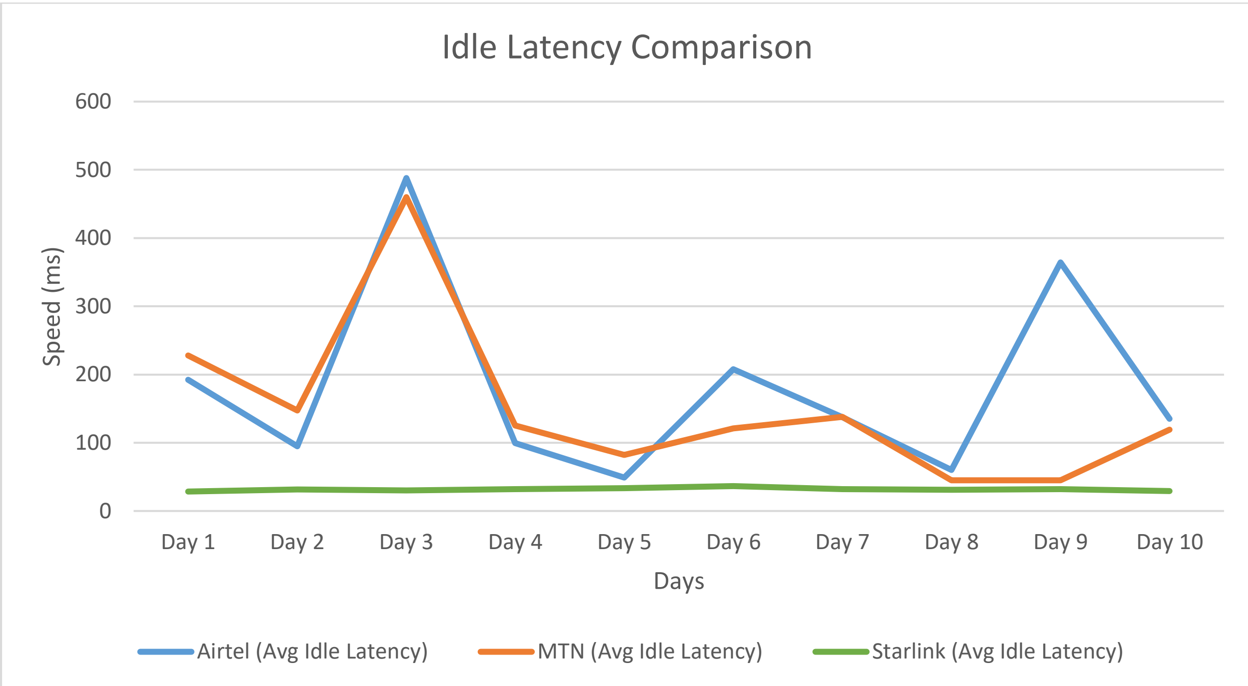

Figure 10: Idle latency comparison

Figure 10 shows the average idle latency chart measured across the 10-day period.

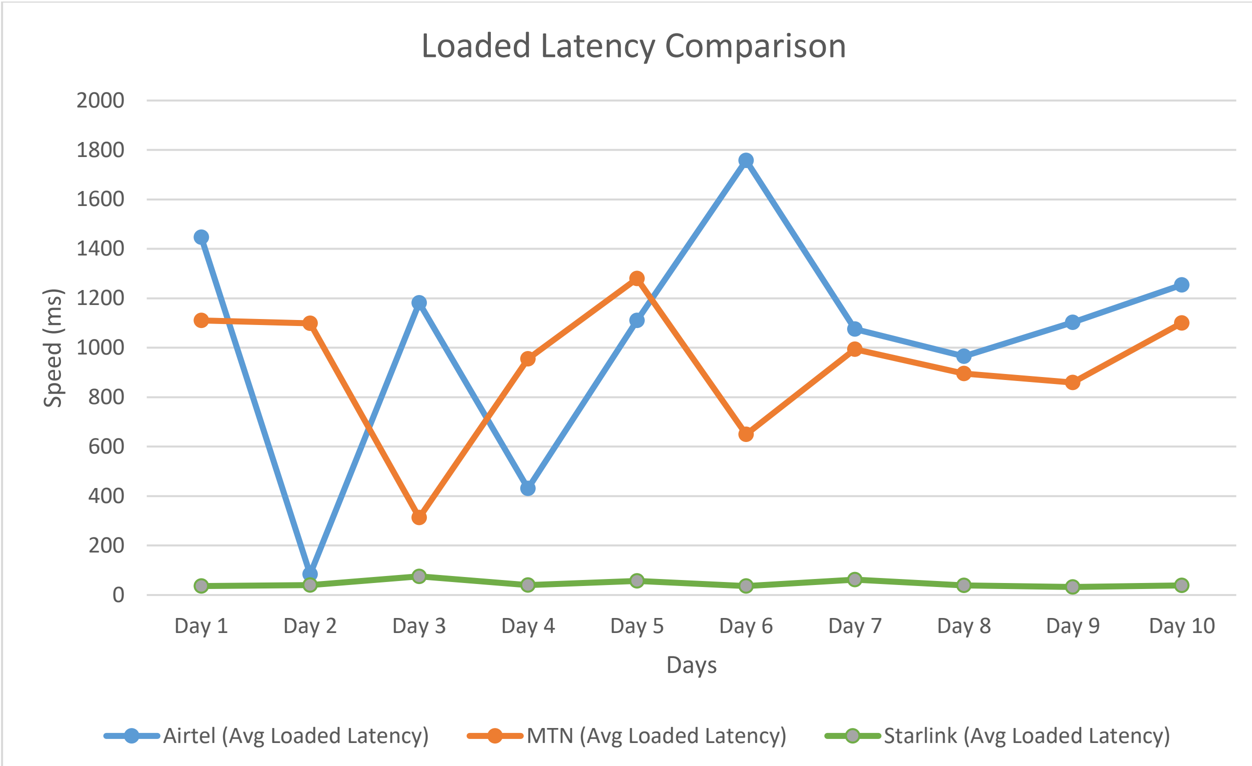

Figure 11: Loaded latency

Starlink maintained stable and low latency (idle: 28-36 ms, loaded: 32-75.5 ms), indicating a consistent performance level, efficient traffic handling and minimal congestion. MTN and Airtel experienced significant fluctuations, with high spikes in idle latency on Days 3 and 9 and loaded latency on Days 1 and 6, suggesting network congestion, routing inefficiencies and infrastructure limitations. Airtel had the highest loaded latency overall, making it less reliable under heavy usage.

Starlink's stability and consistency shows its potential for a reliable low-latency internet, suitable for remote jobs, gaming, and real-time applications, while MTN and Airtel struggled with variations in performance. Well established Telcos in Nigeria such as like MTN and Airtel have measured average latencies of 122.49ms and 136.68ms, respectively, on their 4G networks (Ekpe et al. 2022). The results emphasize Starlink's potential as a stable alternative for areas with inconsistent mobile network connectivity, as well as its importance in bridging the digital divide.

5.1.3 Jitter

Jitter refers to the variation in latency over time, measured in milliseconds (ms) (Ring Central 2022). Real-time applications such as VoIP (Voice over IP) calls and video conferencing are affected by jitter, which indicates an inconsistent connection. In this paper, the jitter was determined by calculating the difference between consecutive latency readings, as represented by Equation 2.

$\text{Jitter} = |\text{Latency}_n - \text{Latency}_{n-1}|$ .... Equation 2

Where:

- Latency_n is the current latency measurement.
- Latency_{n-1} is the previous latency measurement.

High jitters can cause audio and video distortion, making communication difficult. Table 9 represents jitter values for the 10-day cycle. In scenarios such as video conferencing or VoIP calls, jitters should be below 30 - 70 milliseconds to avoid disruptions (Ring Central 2022).

Table 9: Average Jitter values

Day	Airtel Idle Jitter (ms)	MTN Idle Jitter (ms)	Starlink Idle Jitter (ms)	Airtel Loaded Jitter (ms)	MTN Loaded Jitter (ms)	Starlink Loaded Jitter (ms)
Day 1	0	0	0	0	0	0
Day 2	97.5	80.5	3	1363.5	11.5	3.5
Day 3	393	312.5	1.5	1098	786.5	36
Day 4	388.5	334.5	2	751	642	36
Day 5	50.5	43.5	1.5	680	324.5	17.5
Day 6	159	39	3	646.5	629.5	21
Day 7	70.5	17	4.5	682.5	344	26.5
Day 8	77.5	93	1	109	98	24
Day 9	304.5	0	1	136.5	36	6
Day 10	229.5	74	3	152	240	6.5

Airtel and MTN show high jitter fluctuations, especially under loaded conditions, with Airtel peaking at 1363.5 ms (Day 2) and MTN at 786.5 ms (Day 3), which is likely due to network congestion or infrastructure issues, causing choppy audio, video lag, and dropped connections. Starlink maintains a stable, low jitter, making it more suitable for real-time applications such as VoIP and video calls, and for ensuring smoother performance.

5.1.4 Packet Loss

As the name implies, packet loss refers to the percentage of data packets that fail to reach their destination. Packet loss degrades the user experience, resulting in the retransmission of the lost packets. Packet loss has several implications on network performance which include reduced throughput, increased latency as well as poor quality of service and reduced reliability. Packet loss can be inferred from high latency spikes and irregular fluctuations, as unstable latencies indicate network congestion, retransmissions, or dropped packets. (Gillis 2021.) As seen from Table 8, significant packet loss is observed on Airtel and MTN, particularly on Days 3, 6, and 9, where latency spikes indicate network instability. Airtel's loaded latency exceeds 1700 ms on Day 6, suggesting severe congestion and possible packet loss. MTN shows high latency fluctuations on Days 3 and 5, indicating packet drops due to network strain. Starlink remains stable throughout, with minimal latency variations, suggesting little to no packet loss. High packet loss on Airtel and MTN may lead to slow browsing, failed connections, and buffering, whereas Starlink's stability ensures a consistent performance.

5.1.5 Environmental Influences

The performance of the Starlink connection was monitored in different rainfall scenarios. The internet connection was steady and functioned even when there was little rain or drizzle. However, it was discovered that intense rain significantly deteriorated service, particularly on Day 2 and Day 5, resulting in network downtimes. Heavy rainfall disrupts Starlink’s connection due to signal attenuation when raindrops absorb and scatter radio signals between the satellite and the user terminal (Dish). This phenomenon, known as rain fade, weakens signal strength or can cause complete disconnection. (Rucker & Thompson, 2018.)

5.2 Cost-Benefit Analysis

While Starlink offers improved performance compared to cellular networks in terms of speed, it also comes at a relatively higher overall cost. The initial equipment costs as well as monthly subscription costs for Starlink are significantly higher than those for the cellular internet access that was considered within the scope of this paper.

On the other hand, the monthly subscription fees for Starlink might prove to be more efficient for businesses and/or large household users as the subscription offers unlimited data in contrast to “capped” cellular data plans or unlimited plans with bandwidth trade-offs provided by most of the mobile network operators such as MTN and Airtel operators in Nigeria. Even though these cellular network providers offer cheaper data plans, interviews and surveys conducted during the course of this paper show that most users complain about reliability, speed and performance.

Furthermore, the benefits of improved internet access, particularly in underserved areas, can outweigh the relatively higher costs. Access to reliable internet can provide opportunities for remote work, online education, and e-commerce, which can lead to increased income and improved quality of life (Walko P 2022). Table 10 shows a cost breakdown of the setup and recurring cost for all three internet service providers.

Table 10: Annual setup and subscription cost

Cost Component	Airtel (MNO) (₦)	MTN (MNO) (₦)	Starlink (Satellite) (₦)
Average Setup Costs			
Router/Modem/SIM Card	30,000 (4G)	30,000 (4G)	440,000 (Starlink Kit)
Installation Cost	(Self-Setup)	(Self-Setup)	(Self-Setup)
Total Setup Cost	30,000	30,000	440,000
Monthly Subscription Cost			
100GB Data Plan	30,000	30,000	N/A
200GB Data Plan	40,000	50,000	N/A

Unlimited Data	50,000	50,000	75,000
Annual Subscription Cost	360,000 – 600,000	360,000 – 600,000	900,000
Total Cost (1-Year)	630,000 (Max)	630,000 (Max)	1,340,000

From Table 10 and Figure, Airtel and MTN have relatively low setup cost (Average of ₦30,000) and lower annual subscription cost (₦600,000) when compared to a satellite internet provider such as Starlink. Lower initial setup costs and flexible data plans make them more affordable. However, they suffer from high latency, unstable speeds, and congestion issues and are more suitable for light to moderate users or areas with very strong network coverage.

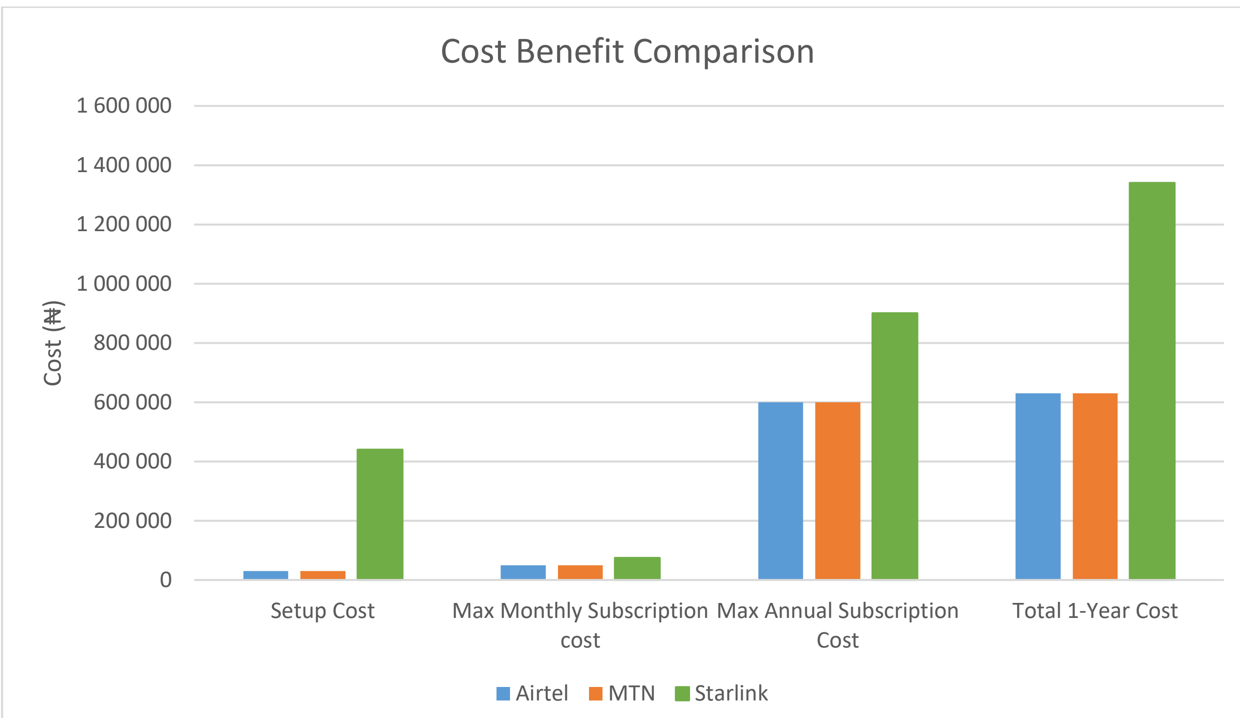

Figure 12: Airtel, MTN and Starlink cost analysis

On the other hand, Starlink has a relatively higher setup cost (₦440,000) and expensive annual subscription cost (₦900,000). However, it offers better speed, stability, availability, as well as lower latency and higher reliability, making it ideal for businesses in remote areas.

Airtel and MTN appear to be budget-friendly but less reliable. In contrast, Starlink is relatively expensive but delivers superior performance for high-demand users**.**

5.3 Socio-Economic Impact

The semi-structured surveys and interviews conducted in this paper revealed several key socio-economic impacts of satellite internet adoption in the study areas. Residents reported that improved internet access has enabled them to access online education resources and pursue online degrees, start and grow small businesses by reaching new customers online, stay connected with family and friends who live far away, and access telehealth services to improve their healthcare outcomes.

Furthermore, faster and reliable internet boosts e-commerce, remote work, and fintech services (Bertschek et al., 2020). Starlink's satellite coverage has created better rural connectivity, offering a viable solution for remote studies, businesses, and telemedicine in regions where other network providers perform poorly or are unavailable.

5.3.1 Effect on Education and Healthcare Delivery

Satellite internet has shown promise in improving education and healthcare delivery in rural communities. Teachers are able to use online resources to enhance their lessons and provide students with access to a wider range of learning materials. Telehealth services have become more accessible, allowing residents to consult with doctors remotely and receive timely medical care. However, the adoption of these technologies is still limited by several factors, including a lack of digital literacy skills among some residents, limited availability of computers and other devices, and concerns about the cost of internet access and equipment.

In addition, research has shown that, even in developed nations, limited broadband access in rural areas remains a major challenge (Rudnick et al., 2020). Addressing these barriers is essential in maximizing the benefits of satellite internet for education and healthcare access.

5.3.2 Environmental and Policy Considerations

Policy and environmental issues are also important in the implementation of satellite internet. Concerns over space debris and collision risk are heightened by the growing number of satellites in orbit. Astronomical observations may potentially be impacted by satellite-induced light pollution. From a policy standpoint, in order to guarantee fair competition and safeguard customers, governments must create explicit laws for satellite internet providers. Policies for allocating spectrum must be created to safeguard the interests of other spectrum users while simultaneously fostering the expansion of satellite internet. It might be necessary to revise universal service obligations to make sure satellite internet providers support initiatives to close the digital divide. (Lord & Urama, 2021.)

6 CONCLUSION

6.1 Main Findings

This thesis sought to study the feasibility and efficacy of satellite internet in closing the digital divide, particularly in underserved and geographically isolated places. The study discovered that satellite internet, particularly through Low Earth Orbit (LEO) constellations such as Starlink, provides significant improvements in accessibility, latency, and throughput, making it a viable alternative to terrestrial broadband and mobile networks. Field studies in Port Harcourt, Nigeria, indicated that satellite internet consistently outperformed traditional 4G services (MTN and Airtel) in terms of download/upload speed and latency. These technological characteristics were supported by qualitative findings in which users expressed great satisfaction with improved connectivity, particularly in terms of education, economic potential, and access to healthcare services.

However, the paper identified significant obstacles, including substantial initial setup and ongoing subscription expenses, weather-induced service disruptions, and infrastructural constraints such as gateway proximity and power availability. These issues hinder the wider adoption of this technology, especially among low-income and rural populations which ironically, are the very groups the technology aims to assist.

6.2 Contributions to the Field

This study highlights the potential of satellite internet in attaining digital equity. It emphasizes the necessity of assessing both the technical capabilities and the socioeconomic ramifications of connectivity solutions. This paper demonstrates through empirical testing and user feedback that satellite internet is not a luxury, but rather a necessity in situations where traditional broadband solutions are insufficient or unavailable. By combining quantitative network analysis and qualitative socioeconomic assessments, the study provides a structured approach to studying the issue.

6.3 Practical Recommendations

The findings indicate that satellite internet can play an important role in narrowing the digital divide, if certain structural and regulatory measures are undertaken. In order to enhance the accessibility and effectiveness of satellite services in remote regions, several strategic recommendations can be considered. One approach is fostering public-private partnerships, where governments and stakeholders collaborate to subsidize the cost of user equipment, thereby making satellite connectivity more affordable. Additionally, implementing digital literacy campaigns is essential to empower communities to fully benefit from internet access, especially in areas such as education, e-commerce, and telemedicine.

Reforming policies and regulations is another critical step. Establishing a favorable regulatory environment with simplified licensing procedures and efficient spectrum allocation will facilitate the deployment and expansion of satellite networks. Lastly, investing in localized infrastructure is key to ensuring uninterrupted service. This includes the provision of reliable power sources and technical support at the community level, particularly in off-grid or underserved areas.

6.4 Limitations

While the study produced useful insights, it was geographically restricted to a single urban location in Nigeria, limiting the generalizability of its findings. Furthermore, only Starlink was considered as a satellite internet provider, despite rising alternatives such as OneWeb and Amazon's Project Kuiper. These limitations can be categorized as the scope of the research, data collection methods, and generalizability of the results.

6.4.1 Scope and Generalizability

The study is limited to a specific zone in the city of Port Harcourt, Rivers state, Nigeria, and findings may not be fully generalizable to areas with different socio-economic, infrastructural, or geographical factors. Additionally, the paper focuses on Starlink as a case study for satellite internet, but other providers (e.g., Viasat) may have different performance characteristics. Variations in population density, terrain and infrastructure could also affect the applicability of findings in other regions. Future research should explore multiple satellite ISPs and broader geographic contexts to enhance generalizability.

6.4.2 Data Collection Limitations

The sample size (a 10-day reading) may limit the statistical accuracy of the quantitative analysis and depth of qualitative insights. Additionally, environmental factors such as weather conditions were not explicitly controlled, and certain metrics such as packet loss could not be properly measured as a result of tool limitations. Furthermore, the Starlink router (residential plan) was calibrated for a specific location, restricting the scope of testing to a single site. As a result, the findings may not fully represent performance across a broader geographic area.

6.4.3 Methodological Limitations

The use of semi-structured interviews provides rich qualitative insights but may be subject to interviewer bias and participant recall errors (Patton, 2015). Thematic analysis, though systematically applied, remains subjective. Despite efforts to ensure a diverse participant pool, some key demographics may have been underrepresented, potentially limiting the inclusivity of perspectives in the findings.

6.4.4 External Factors

Internet performance can vary significantly based on geographical factors such as location, existing infrastructure, and network congestion. As a result, findings related to connectivity and speed may not be universally applicable across different regions. Additionally, the rapid pace of technological advancement in systems like Starlink and cellular networks means that performance data can quickly become outdated as these technologies continue to evolve and improve.

6.5 Research Course

Future research could focus on several key areas to deepen understanding of satellite internet services. Longitudinal studies would be valuable in assessing user satisfaction and tracking the economic impact of connectivity over time. Additionally, conducting comparative analyses of multiple satellite service providers across diverse terrains could provide insights into performance variability and service reliability in different geographic contexts. Further investigation into the environmental resilience of satellite networks, such as examining signal degradation during extreme weather conditions and exploring potential mitigation strategies would also be important to enhance the reliability of these services.

REFERENCES

Anil, K., Varsha, A. 2011. Satellite Technology: Principles and Applications. Second Edition.

Bandwidth Place. Ping test. 2025. WWW Page. Available at: https://www.bandwidthplace.com/ping-test. [Accessed 21 May 2025].

Bello, N., Omorogiuwa, O. S., Akhihiero, I. V., & Akpala, E. S. 2024. Performance Test of SpaceX's Starlink: An Empirical Review. Journal of Engineering Sciences and Applications, 52(5), 73–87.

Berezhkova, A. 2023. Advantages and Disadvantages of satellite internet. WWW Document. Available at: https://nomadinternet.com/blogs/countrynomad/advantages-and-disadvantages-of-satellite-internet. [Accessed 19 Feb 2025].

Bertschek, I., Briglauer, W., Hüschelrath, K., Kauf, B., & Niebel, T. 2020. The economic impacts of broadband internet: A survey. Review of Network Economics, 19(1), 1–45.

Broadband Now. What Is Satellite Internet? Pros, Cons, and Terminology. 2025. WWW Document. Available at: https://broadbandnow.com/guides/satellite-internet-pros-and-cons. [Accessed 14 Feb 2025].

Circle ID a. Starlink Internet Service (2024 Review). 2024. WWW Document. Available at: https://circleid.com/guides/starlink-internet-service. [Accessed 27 Mar 2025].

Circle ID b. What is Satellite Internet?. 2024. WWW Document. Available at: https://circleid.com/guides/what-is-satellite-internet. [Accessed 12 Feb 2025].

Clarke, A.C. 1945. Extra-Terrestrial Relays: Can Rocket Stations Give Worldwide Radio Coverage?

Creswell, J. W., & Plano Clark, V. L. 2017. Designing and conducting mixed methods research (3rd ed.).
Ekpe U., Umoh V., and Ukommi U. 2022. A comparative study of user experienced mobile broadband performance. Nigerian Journal of Technology, vol. 41, 07 2022.

Falcon 9. SpaceX 2024. WWW Document. Available at: https://www.spacex.com/vehicles/falcon-9/. [Accessed 13 Feb 2025].

Gillis. A. S. What is Packet Loss in Networking?. 2021. BLOG. Available at: https://www.techtarget.com/searchnetworking/definition/packet-loss. [Accessed 21 May 2025].

Ground Control a. A Brief History of Satellite Communications. 2022. WWW Document. Available at: https://www.groundcontrol.com/knowledge/guides/a-brief-history-of-satellite-communications/. [Accessed 27 Mar 2025].

Ground Control b. How does satellite internet work?. WWW Document. Available at: https://www.groundcontrol.com/knowledge/guides/how-does-satellite-internet-work/. [Accessed 12 Feb 2025].

Hargittai, E. (2002). Second-Level Digital Divide: Differences in People's Online Skills. First Monday, 7(4).

Helsper, E. J. (2021). The Digital Disconnect: The Social Causes and Consequences of Digital Inequalities. SAGE Publications.

ITU. (2021). Measuring Digital Development: Facts and Figures 2021. International Telecommunication Union.

Lord, S., & Urama, K. (2021). Satellite internet and sustainable development: Overcoming regulatory and environmental challenges. Telecommunications Policy, 45(10), 102219.

Lutz, E., Werner, M., & Jahn, A. (2020). Satellite Systems for Personal and Broadband Communications. Springer.

Maral, G., & Bousquet, M. (2010). Satellite Communications Systems: Systems, Techniques, and Technology. Wiley.

McDowell, J. C. (2023). Space activities in 2023. Jonathan's Space Report.

Muchiri. Second Starlink ground station in Africa. 2025. BLOG. Available at: https://techwithmuchiri.com/starlink-ground-station-in-nairobi-kenya/. [Accessed 15 April 2025].

Nile Sat. Software Defined Satelites (SDS). 2024. WWW Document. Available at: https://nilesat.org/2024/12/17/software-defined-satellites-sds/. [Accessed 27 Mar 2025].

Norris, P. (2001). Digital Divide: Civic Engagement, Information Poverty, and the Internet Worldwide. Cambridge University Press.

Patton, M. Q. (2015). Qualitative research & evaluation methods (4th ed.). SAGE Publications.

Pearlman R. Z. (2024). Spacex launches starlink satellites on record 20th reflight of a falcon 9 rocketfirst stage. WWW Page. Available at: https://www.space.com/spacex-falcon-9-20th-launch-starlink-group-6-49. [Accessed 15 April 2025].

ReliaSat. Exploring the Evolution of Satellite Communications: from GEO to LEO. 2024. WWW Document. Available at: https://reliasat.com/satellite-communications-evolution-from-geo-to-leo/. [Accessed 27 Mar 2025].

Revenes. Airtel 4G MiFi Vida Vida M4. 2025. WWW Page. Available at: https://www.revenes.com/product/airtel-4g-mifi-vida-vida-m4/. [Accessed 17 April 2025].

Ring Central. What is jitter? How to test and reduce internet jitter. 2022. BLOG. Available at: https://www.ringcentral.com/us/en/blog/what-is-jitter/. [Accessed 15 April 2025].

Ruble, N. (2012). Market shift: HTS and 03b satellites on the rise. Satellite Spotlight.

Rucker, C. L., & Thompson, J. S. (2018). Ku-Band Satellite Communication Availability and Rain Attenuation: A Case Study. Applied Engineering Letters, 3(1), 1-7.

Rudnick, L., File, T., & Kvasny, L. (2020). Digital inclusion and exclusion in rural America: A scoping review. The Journal of Rural Studies, 78, 401-413.

Selwyn, N. (2004). Reconsidering Political and Popular Understandings of the Digital Divide. New Media & Society.

Skyora. Satellite Contributions to Global Connectivity: Bridging the Digital Divide. 2024. WWW Document. Available at: https://skyrora.com/satellite-contributions-to-global-connectivity-bridging-the-digital-divide/. [Accessed 10 Feb 2025]

Starlink Coverage Map. 2025. WWW Page. Available at: https://www.starlink.com/ng/map. [Accessed 15 April 2025].

Telecom Review. The Challenges and Limitations of LEO Satellites. 2025. WWW Document. Available at: https://www.telecomreview.com/articles/reports-and-coverage/8756-the-challenges-and-limitations-of-leo-satellites. [Accessed 27 Mar 2025].

Traficom. (2023). Broadband Coverage and Connectivity in Finland. Finnish Transport and Communications Agency.

Van Deursen, A. J., & Helsper, E. J. (2015). The Third-Level Digital Divide: Who Benefits Most from Being Online? Communication and Information Technologies Annual, 10, 29-52.

Van Dijk, J. (2020). The Digital Divide. Polity Press.

Vdovichenko, A., & Lutu, A. (2017, September). An experimental comparison of web-based speed measurement tools. In 2017 9th International Conference on Measurement (MEASUREMENT) (pp. 142-145). IEEE.

VLEO for Telecommunications. CSC 2021. WWW Document. Available at: https://connectivity.esa.int/projects/vleo-telecommunications. [Accessed 13 Feb 2025].

Walko, P. (2022). Internet access as a tool for boosting economic and social equality. BLOG. London School of Economics Blog on International Development. Available at: https://blogs.lse.ac.uk/internationaldevelopment/2022/11/29/internet-access-as-a-tool-for-boosting-economic-and-social-equality/. [Accessed 15 April 2025].

Zhang B., Qi X., and Qi Z. 2020. A Distributed Survivable Routing Algorithm for Mega-Constellations with Inclined Orbits. IEEE Access, vol. 8, pp. 219199–219213.