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Cost-Effective Strategies For Last-Mile Internet Connectivity By ISPs In Nigeria

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***Abstract* - Access to reliable and affordable internet connectivity remains a major challenge in many rural and semi-urban regions of Nigeria due to limited terrestrial infrastructure, high deployment costs, and challenging terrain conditions. This study investigates cost-effective strategies for last-mile broadband connectivity by Internet Service Providers (ISPs) using Mile One, Eleme, Ahoada, and Ogoloma in Rivers State as case study locations. Engineering simulations and analytical tools including Ubiquiti ISP Design Centre, Google Earth Pro, and Microsoft Excel were used for wireless coverage simulation, terrain analysis, link budget calculation, and economic evaluation. Key network parameters such as transmit power, antenna gain, propagation loss, received signal strength, coverage radius, and throughput were analyzed to assess the feasibility of different broadband access technologies. Link budget results showed received signal levels between −49 dBm and −58 dBm for link distances ranging from 2.1 km to 12.5 km, indicating reliable communication performance in the 5 GHz band. Simulation results further revealed that the Mimosa A5c access point with LiteBeam M5 customer equipment achieved coverage between 12–15 km with throughput ranging from 120–180 Mbps. Economic analysis comparing wireless-only, satellite-only, and hybrid architectures showed that a hybrid wireless–satellite model using Starlink backhaul provides the best balance between cost efficiency, scalability, and network performance. The study concludes that hybrid broadband architectures supported by optimized link budget design and propagation modeling provide a technically viable and economically sustainable solution for extending broadband connectivity in underserved regions of Nigeria.**

Keywords— Last-mile connectivity, wireless broadband networks, hybrid wireless–satellite architecture, link budget analysis, rural internet deployment, ISP network planning.

I. INTRODUCTION

Stable broadband connectivity in current societies, effective, stable broadband connectivity has been found to be a critical infrastructure to economic growth, digital inclusion, education, healthcare provision, and e-commerce. The broadband access in Nigeria is not uniformly distributed throughout the nation despite the fact that in Nigeria it has been observed that there has been serious progress in the expansion of the national backbone infrastructure in terms of use of submarine cables and metropolitan fiber networks. Cities like Lagos, Abuja, and Port Harcourt enjoy reasonably good connectivity of broadband, with much rural and semi-urban areas continuing to have a poor connection because of ineffective terrestrial links, the cost of installing hardware, and the rough geographical environment. The state of broadband penetration in Nigeria according to the Nigerian Communications Commission (NCC) is not in line with the targets of the National Broadband Plan, and most areas under-served by the current efforts do not have access to reliable last-mile connectivity.

Although the last mile that is the final part of the telecommunications network between the service providers and the end users is one of the most challenging and costly parts of broadband implementation. The cost of installing fiber based infrastructure over either sparsely populated or geographically spread locations may consume a lot of capital in regards to civil works, power supply and permits to right-of-way. Consequently, the Internet Service Providers (ISPs) often deploy their nets in and around the city full of people where the returns on the investments are predictable. This asymmetry of deployment is one of the reasons why there has always existed a digital divide between urban and rural people, making them have restricted digital access in areas like healthcare, agriculture, education, and e-commerce.

As a way to overcome these issues, the other broadband access technologies which include Fixed Wireless Access (FWA), microwave links and satellite communication have become more commonly considered as an inexpensive remedy in the provision of last-mile access. The 2.4GHz and 5 GHz unlicensed wireless technologies have flexible and scalable options of deployment at reduced cost in terms of infrastructure as compared to the traditional fiber network. Moreover, the development of Low Earth Orbit (LEO) satellite systems like Starlink has generated new possibilities in providing broadband services in remote and difficult-to-access places without necessarily having to install a large range of terrestrial infrastructure. It is then that hybrid systems, integrating both satellite backhaul and terrestrial wireless distribution networks are receiving focus as an affordable and viable means of making broadband more accessible to underserved communities.

In spite of these technical innovations, technical and economic viability of various last-mile deployment models is not yet a thoroughly investigated issue on the Nigerian picture. Large ISP implementations do not have a systematic analysis of the engineering that includes both link budget analysis and propagation analysis as well as coverage analysis and cost analysis. This paper hence examines cost-effective solutions to the last-mile broadband connectivity in the chosen communities in rivers state, Nigeria, such as Mile One, Eleme, Ahoada, and which comprise Ogoloma. The research assesses wireless propagation, throughput capacity, maximum coverage, and deployability cost of wireless, only satellite, and hybrid wireless-satellite deployment using engineering simulation software, including Ubiquiti ISP Design Centre, Google Earth Pro, and Microsoft Excel. The goal is to come up with an engineering framework that facilitates network planning optimization and it offers viable guidance to the Internet Service Providers who intend to increase their broadband connectivity in underserved areas.

II. RELATED WORKS

A. Last-Mile Wireless Technologies.

The adoption of wireless communication technologies in the provision of last-mile broadband connectivity has a high adoption potential because it offers a rapid deployment option, flexibility, and it does not entail a high cost of infrastructure. Internet Services Providers (ISPs) frequently use the Fixed Wireless Access (FWA). FWA operates with unlicensed frequencies like 2.4 GHz and 5 GHz to provide broadband to underexploited communities where fiber optic connectivity is scarce or missing [1].

Recent research indicates that wireless broadband technologies are very effective in eliminating deployment cost and at the same time offering reasonable throughput performance to residential users and small enterprise users. It has been established that under clear line-of-sight conditions, high-gain directional antennas can be used to implement point-to-multipoint wireless systems which have coverage distances extending beyond 10km with minimal investment in infrastructure by the service provider [2].

Nevertheless, wireless systems are prone to terrain blockage, interference, and loss of propagation especially in places where vegetation is very thick or where there are irregular surfaces. They may compromise signal quality as well as decrease the maximum throughput, and consequently, interfere with the nobility of wireless-only broadband deployment methods in some geographic circumstances [3].

B. Broadband Access by Satellite Communication

Another option to broadband connectivity is the satellite communication systems in the regions with no availability of terrestrial infrastructure or economic feasibility. Compared with traditional geostationary satellite systems, modern Low Earth Orbit (LEO) satellite systems can support much lower latency or much higher throughput as compromises, and are appropriate to support broadband internet access [4].

Research has indicated that satellite broadband may be used to achieve a geographic distribution and high speed deployment especially in the rural and remote regions. Satellite communications do not require a large mileage terrestrial backhaul infrastructure required to support services at geographically demanding locations and, as a result, the network operator is able to provide broadband services in such locations [5].

Satellite-only systems have various limitations such as shared bandwidth capacity, service subscription fee and inability to serve huge users in the same area of coverage despite these benefits. These limitations can lower the quality of the services when required on a high demand basis as well as restrict viability of satellite-only broadband implementation prototypes in dense societies [4].

C. Hybrid-wireless-satellite Architectures.

In order to get past the shortcomings of the single-technology deployment models, recent developments have suggested the study of hybrid broadband architecture that integrates the use of terrestrial wireless distribution network with satellite backhaul connections. In these types of architecture, the satellite systems offer upstream access to the internet where the wireless access points broadcast broadband networks to various users within a community [6].

Proper scalability of the network, lower cost of infrastructure and greater compatibility with the deployment are some of the benefits that hybrid architectures have. It has been found that the combination of wireless access networks with satellite backhaul can help decrease the cost per subscriber dramatically and achieve a sufficient throughput performance [6].

Nonetheless, the practical implementation of hybrid architectures may assume the delicate engineering study whose calculations may include link-budget, propagation modelling, coverage planning, and network-capacity analysis. In the absence of systematic network design and performance analysis, the hybrid networks have their poor performance owing to interference, inadequate antenna gain, and ineffective sites location [3].

D. Network Planning and Techno-Economic Review

Broadband implementation needs technical network planning on one hand, as well as economic feasibility analysis on the other. Some researches have focused on the significance of considering such engineering models as link-budget analysis, propagation modelling, and coverage simulation and establishing them in the context of techno-economic evaluation frameworks [7].

It has been found that decisions made regarding deployment can either be poor in terms of network performance when they are made based on infrastructure cost alone or even become economical in case the decisions are made based on technical performance alone. Thus, Internet Service Providers need balanced techno-economic modelling in order to guarantee reliability of the services and financial sustainability [7].

Accessibility Simulation systems have become popular in testing the network performance prior to physical implementation like wireless coverage-planning systems, and geographic analysis systems. These tools enable the network engineers to determine the coverage radius, signal strength, and maximized interference conditions based on various deployment conditions.

III METHODOLOGY

This experiment will take a simulation based approach in the engineering discipline to analyse cost effective approaches towards last mile internet connectivity in Internet Service Providers (ISPs) in Nigeria. Google Earth Pro was used to plan the network and analyze the terrain and Ubiquiti ISP Design Center was used to simulate wireless network coverage and signal propagation. The link-budget calculations and comparative cost analysis were done by use of spreadsheet models created in Microsoft Excel.

The paper assesses three last mile architectures of connectivity:

1. PtMP network Wireless Pt Multipoint network.
2. Connection to satellite broadband.
3. Hybrid satellite wireless architecture.

In the case of the wireless network simulation, some of the radio equipment considered as access points were Mimosa radios, LiteBeam, Rocket Prism 5AC, and NanoStation devices. To study the coverage capacity, the overall signal-propagation characteristics and the throughput performance of these radios, these radios were made to work as base-station transmitters in the simulation environment.

Because the power of Mimosa access radios is close to Ubiquiti devices that can be found in the simulation platform and the gain of the antenna is similar along with operating frequency, Rocket Prism 5AC was employed to model the operation of Mimosa radios inside the simulation platform. This modeling methodology allowed to assess the high-capacity wireless access performance that is adequate in the sphere of last-mile distribution of broadband.

The NanoStation devices were set to the Customer Premises Equipment (CPE) that in this case is the subscriber terminals to the access points in the simulated coverage area. This setup represents a common PtMP wireless access network architecture that is being extensively used by Internet Service Providers to deliver last-mile broadband services.

The wireless communication links received signal strength of wireless communication links were estimated by the use of the link-budget model:

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$$P_r = P_t + G_t + G_r - L_p - L_s \quad (1)$$

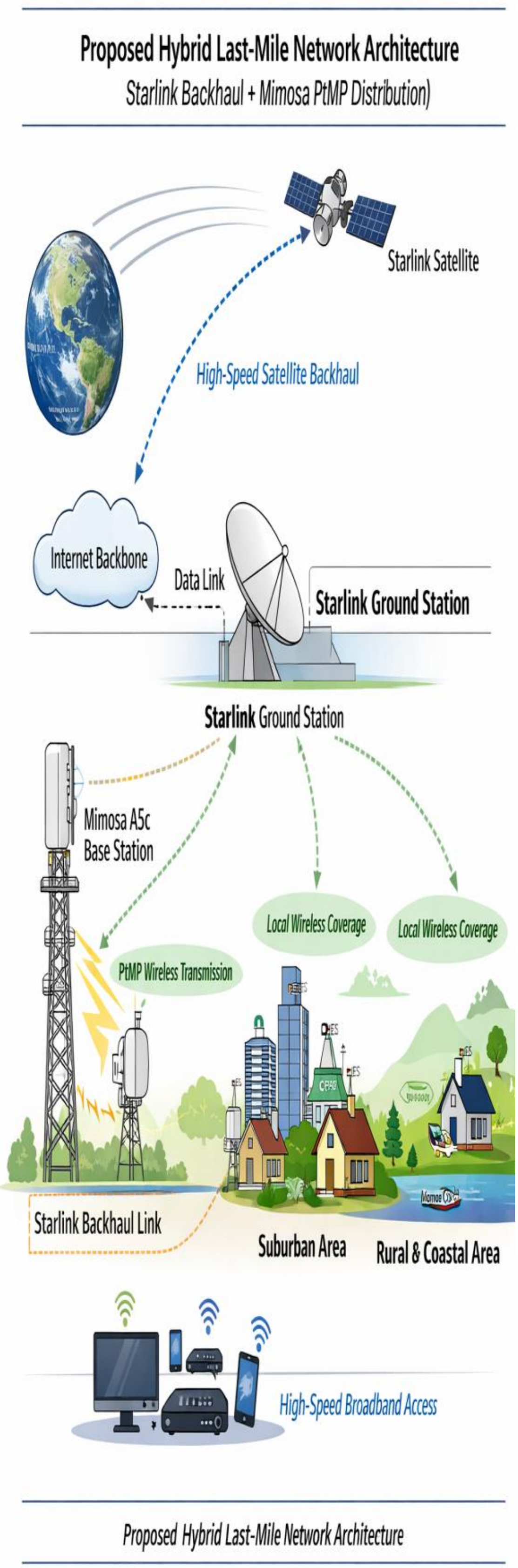
Where:
P_r= Received power (dBm), P_t= Transmit power (dBm), G_t= Transmitter antenna gain (dBi), G_r= Receiver antenna gain (dBi), L_P= = Path loss (dB), L_S=System losses (cable loss, connector loss, fading margin) (dB)

$$FSPL = 32.44 + 20log10(d) + 20log10(f) \quad (2)$$

Where:
d = distance between transmitter and receiver (km)
f = frequency (MHz), FSPL = Free Space Path Loss (dB)

The various network layouts were analysed based on coverage, the power or received signal strength, throughput and deployment cost (network simulations). It was then followed by a comparative analysis of the simulation results in order to come up with the most cost effective strategy of implementing last mile broadband in Nigeria.

Fig 1. Hybrid Last-mile Network Architecture Proposal.



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IV RESULTS AND DISCUSSION

A. Terrain and Line-of-Sight Analysis

An analysis of the terrain and line-of-sight (LOS) was carried out using Google Earth Pro, which enabled the geographical factors affecting wireless signal propagation for the identified study areas to be characterized. The analysis revealed the heterogeneity of the elevation, building density, and potential signal obstacles within the study areas. For instance, the urban environments, such as Mile One, were characterized by high building density, which can cause signal degradation and interference. However, the semi-urban environments, such as Ahoada, were characterized by open terrain with minimal obstacles, which is beneficial for wireless broadband deployment.
Table 1 has summarized the **terrain characteristics of the study areas** results

Table 1 **Terrain characteristics**

Location	Elevation	Building Density	Line-of-Sight Obstacles
Mile one	13m	High	Tall buildings
Eleme	15m	Medium	Open terrain
Ahoada	15m	Low	Open terrain
Ogoloma	7m	Medium	Water channels

Figure 2 Google Earth terrain view of Ahoada

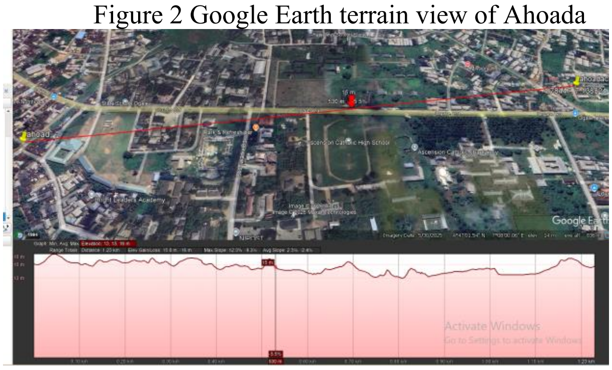


Figure 3 Google Earth terrain view of Ogloma

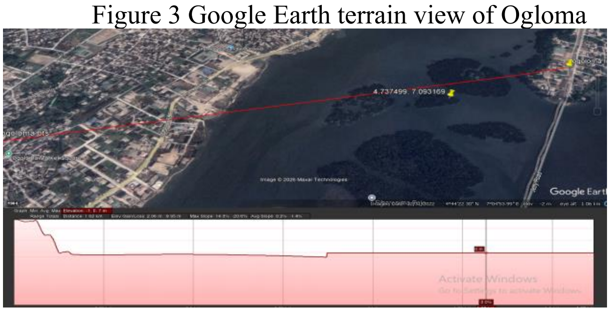


Figure 4 Google Earth terrain view of Eleme

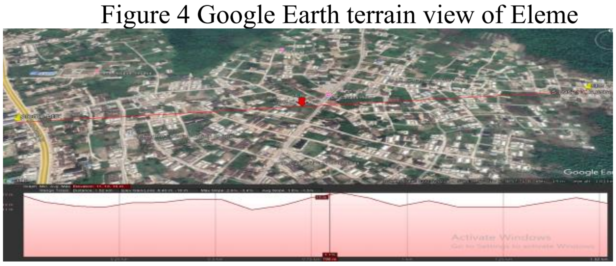
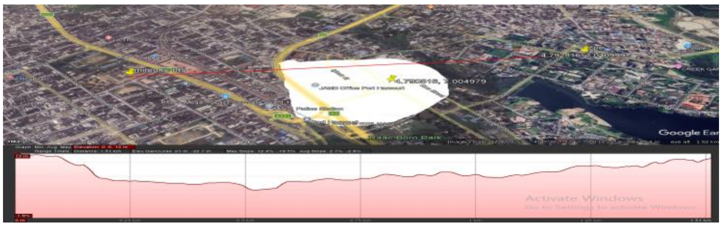


Figure 5 Google Earth terrain view of Ahoada



B. Hybrid Network Simulation Results

Simulations of wireless networks were implemented using the Ubiquiti ISP Design Centre to determine the performance features of the suggested hybrid broadband construction that comprises Mimosa radios and Starlink satellites connection. In the proposed system, the Internet backhaul of the high-capacity is Starlink, and the wireless access layer is represented by Mimosa A5c radios, which offer connectivity to several users over Point-to-Multipoint (PtMP) connections. The simulation outcomes confirm that the hybrid architecture has the capability to serve immediate communities at distances of several kilometres around a satellite in an environment that depends on the terrain circumstances and antenna configuration provided the satellite has open broadband connections. Table 2 has a summary of the equipment parameters that were used in the simulation.

Table 2 Simulation results of Devices:

Equipment	Frequency (GHz)	TX Power (dBm)	Antenna Gain (dBi)	Distances (km)	Max Throughput (mbps)	Coverage radius
Rocket Prism5 AC	5	26	19	4.08	166	Good
Lite Beam	5	25		4.08	182	Fair
Nano Station	5	2				
Mimosa A5c	5-6	26	19	4.08	200	Excellent

The result shows that the hybrid architecture being studied can successfully provide connectivity of Starlink satellites backhaul through wireless access nodes to neighboring communities. In addition, the report indicates that the Mimosa A5c radio provides better coverage, reliability and throughput, which makes it a proper choice when implementing a last-mile broadband in semi-urban and rural environments.

C. Mimosa Wireless Access Link Budget Analysis.

The link budget analysis was performed to determine the signal strength of the received signal of the Mimosa wireless access links to distribute Starlink backhaul connectivity. Table 3 shows computed received signal level at different transmission distances.

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Table3 Link Budget Result

Distance (km)	Path Loss FSPL (dB)	Received Signal (dBm)	Link Quality
0.5	100	-34	Excellent
2	112	-46	Excellent
4.08	118	-52	Good
5	120	-54	Good

The findings show that signal strength decreases as the transmission distance increases because of the propagation loss. However, Mimosa radios have a high power of transmission and gain of the antenna that can allow successful wireless communication that can be used to transfer Starlink connectivity to other locations many kilometres away.

D. Cost Analysis of Hybrid Mode Deployment.

A cost comparison was also made to determine the economic viability of other last-mile connectivity services.
Deployment models taken into consideration were three:
i. Wireless-only deployment
ii. Satellite-only deployment
iii.Starlink satellite backhaul and Mimosa wireless distribution Hybrid deployment.
The results of the cost analysis are summarized in **Table 3**

Table 4 Cost Analysis

Deployment Model	**CAPEX (USD)**	**Monthly OPEX (USD)**	**Coverage**
Wireless Only	4,500	120	Medium
Satellite Only	800	80	High
Hybrid (Mimosa + Starlink)	6,500	120	High

The results point out that, even though the hybrid architecture involves a greater upfront capital investment, it does offer a zero-sum game that balances a massive coverage level and increased scalability and service reliability. In turn, the hybrid model is particularly applicable to the implementation of last-mile broadband in the semi-urban and rural settings where fiber infrastructure is limited or unavailable.

E Performance Comparison of Deployment Architectures

The three deployment models were compared to determine the performance of this hybrid architecture. Table 4.5 exhibits the findings.
The results are presented in **Table 5**

Table 5 Performance Comparison

Metric	**Wireless Only**	**Satellite Only**	**Hybrid (Mimosa + Starlink)**
CAPEX	Medium	High	Medium
OPEX	Low	Very High	Low
Coverage	Medium	High	High
Scalability	Medium	Medium	High

The findings show that Mimosa Starlink hybrid architecture can provide the most optimal trade-off of network performance, coverage, and cost of deployment.

V. DISCUSSION OF RESULTS

The results of the terrain research, network simulation, link-budget analysis, and cost evaluation altogether indicate that the combination of a hybrid architecture with Starlink satellite backhaul, and Mimosa wireless distribution would work to be an effective solution to the last-mile connection in Nigeria. Although the inclusion of Mimosa wireless access networks enables the efficient allocation of high-speed internet connectivity to far fling locations, the inclusion of satellite connected ties ensures that the entire connectivity is distributed with ease to numerous users without the need to engage the use of costly fibre connections. In urban areas where the infrastructure is dense, the site layout of the antenna might need meticulous design to limit signal blockage; conversely, another feature of suburban and semi-urban zones like Eleme and Ahoada is that these areas have high potential of implementing hybrid broadband development due to favourable topography and unrestricted line of sight corridors. It is also found out during the analysis that the Mimosa hybrid architecture featuring the Starlink project and better scalability of cover, minimized the operational expenses, and increased service availability, making it a realistic approach to deployment by Internet Service Providers (ISPs) intending to broaden the prospects of broadband services in underserved regions.

VI. CONCLUSION AND FUTURE WORK

This paper analysed the cost-efficient solutions to the last-mile internet connectivity of Internet Service Providers (ISPs) in Nigeria through the evaluation of wireless, satellite and hybrid broadband deployment architecture.
The study combined terrain analysis, wireless coverage simulation, the link budget modelling and comparative cost analysis with the help of which the most appropriate network architecture to extend broadband connectivity to underserved communities was identified.
Simulations made possible by the Ubiquiti ISP Design Center of wireless networking revealed that services enabled by wireless radios operating in the 5 GHz band can give dependable broadband connections with the coverage radius of approximately 4 km under desirable line- of-sight situations.
Another analysis that confirmed the point of received signal strength decreasing with the distance of transmission was the link budget analysis.
Nevertheless, the introduction of high transmission capacity and high gain antennas provide stable communication connections that can support broadband access to a range of several kilometres.
The comparative cost analysis discerned that the satellite-only deployment was least costly in terms of its initial infrastructure cost due to the low amount of equipment maintained, but wireless-only deployment is a high capital investment but with scalability across connections of multiple users within a local coverage zone.
Alternatively, the hybrid architecture, which combines satellite backhaul and wireless point-to-multipoint distribution, provides the best balance answer in terms of the coverage area, capacity, or scalability, and reliability of the services.
The hybrid model efficiently delivers broadband to the communities that are either devoid of fiber infrastructure or economically unfeasible channels of his route by connecting to the local wireless

distribution networks, combined with the introduction of satellite connectivity as the main gateway to the internet.

Accordingly, the findings show that semi-urban and rural localities can be presented with a feasible and scalable solution to the problem of broadband connections in the last mile because of hybrid wireless-satellite infrastructure.

Future studies can focus on the practical field execution and results validation of the suggested hybrid network architecture to continue to support the previous simulation data under real-life tasks.

Further research can also be on the combination of some emerging wireless, intelligent, traffic-management and renewable energy-based base stations to increase the efficiency of the network, reduce the cost of its operation, and ensure that the broadband introduction in developing areas remains sustainable.

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