World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

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Design and Simulation of a GPON-based FTTH Access Network in a Dense Urban District of Kinshasa: Case Study of Salongo District

TAWABA TANZEY Sugar [1], KINYOKA KABALUMUNA God'El [2] and TANGENYI OKITO Marcien [3,*]

[1] *Electronics, Higher Institute of Applied Techniques of Kinshasa, Democratic Republic of the Congo.*
[2] *Department of Physics and Applied Sciences, Faculty of Science, National Pedagogical University, Kinshasa, Democratic Republic of the Congo.*
[3] *Electricity, Higher Institute of Applied Techniques of Gombe-Matadi, Democratic Republic of the Congo.*

World Journal of Advanced Research and Reviews, 2026, 30(03), 1087-1092

Publication history: Received on 03 May 2026; revised on 13 June 2026; accepted on 16 June 2026

Article DOI: https://doi.org/10.30574/wjarr.2026.30.3.1654

Abstract

The explosion of digital uses (video on demand, teleworking, distance learning) demands bandwidths that 4G mobile infrastructures can no longer guarantee in the Democratic Republic of Congo. This paper presents the design and simulation of an FTTH (Fiber To The Home) access network based on GPON (Gigabit Passive Optical Network) technology in the Salongo district of Kinshasa. A field survey identified 4,000 potential households. The technical sizing resulted in an overall splitting ratio of 1:128 (1:16 at optical branch points and 1:8 at zone distribution points), requiring 1 ODF, 32 ZDPs, 250 OBPs, and 4,000 OTUs. The optical link budget, validated by OptiSystem simulation, estimated a total attenuation of 27.95 dB, which is within the Class B+ optical budget (28 dB), with a safety margin of 3.05 dB. The results confirm the technical feasibility of the deployment and its ability to provide downstream speeds up to 2.5 Gbit/s, thus meeting the requirements of Triple play services.

Keywords: FTTH; GPON; Optical fiber; Optical budget; Simulation; Kinshasa; Access network

1. Introduction

The Democratic Republic of Congo (DRC) is experiencing a progressive but uneven digital transformation. Kinshasa, its capital with more than 17 million inhabitants, concentrates most of the telecommunications infrastructure but suffers from a glaring internal digital divide. While mobile operators (Vodacom, Orange, Airtel) provide satisfactory coverage for mobile telephony and Internet, these solutions remain limited in terms of speed (2 to 15 Mbit/s actual), stability, and capacity to support emerging uses [1].

In parallel, the Congolese Postal and Telecommunications Company (SCPT) has made major strategic investments in the national fiber optic infrastructure: the landing of the WACS (West African Cable System) submarine cable in Moanda (initial capacity of 120 Gbit/s) and the deployment of a national backbone connecting Kinshasa to Moanda (633 km) with equipment supporting 10 Gbit/s [2]. However, this transport infrastructure remains underutilized because it is not connected to end users. The missing link is precisely the access network.

The Salongo district, located in the commune of Limete, presents characteristics that make it a relevant candidate for a pilot FTTH deployment: high population density (approximately 4,000 households for 1.2 km^2), socio-economic diversity (presence of commercial activities, schools, and health centers), and potential proximity to existing SCPT infrastructure.

* Corresponding author: TANGENYI OKITO Marcien

The objective of this study is to design, size, and simulate a GPON-based FTTH access network in the Salongo district, in order to validate its technical feasibility to provide Triple play services (high-speed Internet, IP telephony, high-definition television) to residents.

2. Material and Methods

2.1. Study Area Description

The Salongo district is located in the commune of Limete, one of the 24 communes of Kinshasa. It is bounded to the south by Boulevard Lumumba, to the east by the Ndjili River, to the north by the Matete River, and to the west by Rue des Poids lourds. Its area is approximately 1.2 km^2. The district officially has 16 main avenues and an estimated population of about 40,000 inhabitants.

2.2. Field Survey

A field measurement campaign was conducted from March 1 to 15, 2026 to assess the state of existing connectivity. Twelve measurement points distributed across all avenues were tested for the three main mobile operators (Vodacom, Orange, Airtel). Measurements were performed using an Android smartphone (4G/LTE) with the nPerf v5.2 application. A satisfaction survey was also conducted among 32 heads of households.

2.3. Architecture Selection

After comparative analysis of possible architectures (P2P, EPON, GPON, XGS-PON, WDM-PON), GPON (Gigabit Passive Optical Network) was selected for the following reasons: high splitting ratio (1:128), suitable optical budget (Class B+, 28 dB), native Triple play support, mature and available equipment, and lowest cost per subscriber among standard PON solutions.

2.4. Network Sizing

The sizing was carried out according to the following formulas:

- Transport cable capacity = Subscriber base / Overall splitting ratio
- Number of OBPs (Optical Branch Points) = Subscriber base / OBP splitting ratio
- Number of ZDPs (Zone Distribution Points) = (Number of OBPs) / (ZDP splitting ratio × Number of cassettes)
- Number of transceiver ports = Subscriber base / Overall splitting ratio

2.5. Optical Link Budget

The total attenuation was calculated using the formula:

$$A_{total} = (L_{fiber} \times \alpha_{fiber}) + (N_{connectors} \times \alpha_{conn}) + (N_{splices} \times \alpha_{splice}) + A_{splitter1} + A_{splitter2} + \text{Margin}$$

Where:

- α_fiber = 0.27 dB/km at 1490 nm (downlink)
- α_conn = 0.25 dB per SC/APC connector
- α_splice = 0.1 dB per splice
- A_splitter (1:8) = 10.5 dB
- A_splitter (1:16) = 13.5 dB

2.6. Simulation

The optical budget simulation was performed using OptiSystem software (Optiwave Systems) with an OLT laser source of 3 dBm at 1490 nm, a G.652 single-mode optical fiber of 5 km, two attenuators modeling the splitters (10.5 dB each), and a PIN photodiode optical detector.

3. Results

3.1. Field Survey Results

The results of mobile broadband (4G/LTE) measurements are presented in Table 1.

Table 1 Summary of results by operator

Operator	Average Downstream (Mbit/s)	Average Upstream (Mbit/s)	Average Latency (ms)
Vodacom	8.0	3.2	87
Orange	6.3	2.6	95
Airtel	4.3	1.9	115
Average	**6.8**	**2.6**	**96**

No measurement point reached 20 Mbit/s downstream, the minimum recommended threshold for a satisfactory Triple play experience. The satisfaction survey revealed that 84% of residents use the Internet at home, but only 16% are satisfied with their current speed. Furthermore, 90% of respondents said they were ready to switch to fiber optic if the offer is reasonably priced.

3.2. Network Sizing Results

The technical sizing results are presented in Table 2.

Table 2 Summary of network sizing

Equipment	Symbol	Quantity
Optical Distribution Frame	ODF	1
Zone Distribution Points	ZDP	32
Optical Branch Points	OBP	250
Optical Termination Units	OUT	4,000
Transceiver ports	-	32
GPON cards (16 ports)	-	2
ODF (12 fibers)	-	3

The overall splitting ratio adopted is 1:128, broken down into two levels: 1:16 at OBPs and 1:8 at ZDPs.

3.3. Optical Link Budget Results

The attenuation calculation results are presented in Table 3.

Table 3 Optical link budget calculation (1:64 configuration)

Element	Calculation Formula	Result (dB)
Fiber loss (5 km)	5 km × 0.27 dB/km	1.35
Connector loss (8)	8 × 0.25 dB	2.00
Splice loss (6)	6 × 0.1 dB	0.60
ZDP splitter (1:8)	-	10.50
OBP splitter (1:8)	-	10.50

Safety margin	-	3.00
Total attenuation	**Sum**	**27.95 dB**

The power received by the ONT is:

$$P_{received} = P_{transmitted} - A_{total} = +3 \text{ dBm} - 27.95 \text{ dB} = -24.95 \text{ dBm}$$

This value is higher than the receiver sensitivity (-28 dBm), with a safety margin of 3.05 dB, thus validating the technical feasibility.

3.4. Simulation Results

OptiSystem simulation confirmed the theoretical calculations (Table 4).

Table 4 Comparison of theoretical calculation and simulation

Parameter	**Theoretical Calculation**	**OptiSystem Simulation**	**Difference**
Total attenuation (dB)	27.95	28.03	0.08
Received power (dBm)	-24.95	-25.03	0.08
Margin (dB)	3.05	2.97	0.08
BER	-	2.8×10^{-12}	-

The measured Bit Error Rate (BER) of 2.8×10^{-12} is well below the acceptable threshold of 10^{-9}, ensuring error-free transmission.

4. Discussion

4.1. Validation of Field Hypotheses

The field diagnosis results confirm the need for FTTH deployment in the Salongo district. The average downstream speed of 6.8 Mbit/s is far below the needs expressed by the population (30-100 Mbit/s depending on user profile). This finding is consistent with observations made in other urban areas of sub-Saharan Africa, where mobile infrastructures struggle to meet the growing demand for bandwidth [3,4].

4.2. Comparison with Other Architectures

The choice of GPON is justified by the following advantages over alternatives:

- Compared to P2P: significant reduction in civil engineering costs (32 fibers from the ODF instead of 4,000) [5];
- Compared to EPON: higher splitting ratio (1:128 vs. 1:32) and better efficiency for TDM transport [6];
- Compared to XGS-PON: lower equipment cost for current needs satisfied by 2.5 Gbit/s [7].

4.3. Interpretation of the Optical Budget

The calculated total attenuation of 27.95 dB (simulated at 28.03 dB) is lower than the Class B+ optical budget (28 dB), with a safety margin of about 3 dB. This margin complies with ITU-T G.984.2 recommendations [8], which recommend a minimum margin of 2 dB to account for component aging and environmental variations.

Parametric sensitivity analysis (Table 5) shows that the system remains robust even under degraded conditions.

Table 5 Sensitivity analysis

Adverse Scenario	Total Attenuation (dB)	Received Power (dBm)	Status
Nominal configuration	27.95	-24.95	Compliant
Distance +50% (7.5 km)	28.68	-25.68	Compliant
Laser aging (+2 dB)	29.95	-26.95	Compliant
Poor splices (0.3 dB instead of 0.1)	29.15	-26.15	Compliant
1:128 splitting ratio (non-optimized)	30.95	-27.95	Limit*

*Compliant but reduced margin (< 2 dB), requiring increased monitoring.

4.4. Study Limitations

This study has several limitations that should be mentioned:

- Lack of detailed economic analysis: Deployment costs (civil engineering, equipment, labor) were not evaluated, which is essential for project viability [9];
- Regulatory constraints not considered: Obtaining wayleave permits and rights-of-way on private land were not studied;
- Lack of power supply study: A critical issue in the DRC where power outages are frequent;
- One-dimensional simulation: Only the downstream direction (1490 nm) was simulated; the upstream direction (1310 nm) would require additional validation.

4.5. Perspectives

Future work should focus on:

- An in-depth techno-economic study integrating deployment (CAPEX) and operating (OPEX) costs;
- A field pilot on 100 households to validate the proposed design in situ;
- Evaluation of the evolution towards XGS-PON (10 Gbit/s symmetric) to anticipate bandwidth upgrades over 5-7 years [10];
- A comparative analysis with competing technologies (5G fixed, Starlink) to justify the FTTH choice;
- Integration of security aspects (theft protection of cables and equipment).

5. Conclusion

This study demonstrated the technical feasibility of deploying a GPON-based FTTH access network in the Salongo district of Kinshasa. The main results obtained are:

The field diagnosis confirmed the inadequacy of existing mobile infrastructures (average speed of 6.8 Mbit/s) and the strong public demand for very high-speed broadband (90% of respondents ready to switch to fiber);

The technical sizing resulted in an overall splitting ratio of 1:128, requiring 1 ODF, 32 ZDPs, 250 OBPs, and 4,000 OTUs to cover all 4,000 households in the district;

The optical link budget (total attenuation of 27.95 dB, received power of -24.95 dBm, margin of 3.05 dB) and OptiSystem simulation (BER = 2.8×10^{-12}) confirm that the link meets the specifications of ITU-T G.984 standard.

The proposed infrastructure will provide downstream speeds of up to 2.5 Gbit/s, far higher than current 4G speeds, with reduced latency and better stability, ensuring an optimal user experience for Triple play services.

This work provides a useful technical reference for engineers, telecommunications operators, and public decision-makers in the Democratic Republic of Congo, thus contributing to the reduction of the digital divide and the emergence of an inclusive digital economy in Kinshasa.

Compliance with ethical standards

Acknowledgments

The author thanks the Congolese Postal and Telecommunications Company (SCPT) for providing access to technical information on the national backbone, as well as the local authorities of the Salongo district for their collaboration during the field surveys.

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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