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Design and Implementation of a Quick ODN Deployment in FTTH Ring Topology

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Abstract

Frequent disruptions in fiber-to-the-home (FTTH) networks, particularly in the optical distribution network (ODN) deployed by Sonatel-Senegal, can affect up to thirty customers per cable. Delays in resolving these outages can significantly impact the safety, health, and operations of businesses that rely on these connections. To address this challenge, innovative deployment and maintenance strategies are needed. This study proposes replacing the traditional fast ODN topology with a ring-based quick ODN topology that supports self-healing. This looped design utilizes new bidirectional sub-boxes and remote nodes (RNs) to enable automatic self-repair in the event of disruptions. This work presents the theoretical framework for these new sub-box configurations and describes the signal pathways in both direct and indirect directions. These pathways ensure service continuity, even in isolated sections of the network. Using OptiSystem version 17 for simulation, we identified a threshold power of −23 dBm, which aligns with acceptable telecommunications bit error rate (BER) standards. The analysis shows that in the ring ODN model, the power delivered to the customer drops to −29 dBm, with each sub-box in the loop introducing a 13.5 dB insertion loss. In comparison, the quick ODN model exhibits a 3 dB loss per line. The implementation of this new deployment technique would require an increase in transmission power at the optical line terminal (OLT) simply by replacing the optical module without modifying the physical infrastructure at the central office in order to compensate for the insertion losses associated with each sub-box.

Keywords

Deployment, Fiber-to-the-Home, Quick and Ring ODN

1. Introduction

The growing demand for faster and more reliable internet services has driven the development of various fiber-to-the-x (FTTX) technologies, including fiber-to-the-building (FTTB) and fiber-to-the-home (FTTH) in Parca *et al.* [1]. These technologies deliver communication services closer to the end user, utilizing passive optical network (PON) standards such as X gigabit passive optical network (XGPON), gigabit PON (GPON), and ethernet PON (EPON) Parca *et al.* [1]. Among the various solutions for last-mile data transmission, PON has emerged as the preferred choice in Guo *et al.* [2] and Yeh *et al.* [3]. Two primary PON technologies, time division multiplexing-PON (TDM-PON) and wavelength division multiplexing-PON (WDM-PON), are commonly used in point-to-multipoint (PTMP) and point-to-point (PTP) configurations Barzaq *et al.* [4]; Li *et al.* [5]. TDM-PON, in particular, has seen widespread adoption, with standards such as ethernet-PON (EPON, IEEE 802.3ah), gigabit-PON (GPON, ITU-T G.984), next-generation PON (NG-PON1, ITU-T G.987), and NG-PON2 (ITU-T G.989) Chung *et al.* [6]; Kaneda *et al.* [7]; Yeh *et al.* [8]; Yeh *et al.* [9]. In a star topology, each ONU is connected directly to the OLT via individual fiber-optic links. However, deployment and implementation costs are high because a fiber must be laid for each subscriber, resulting in significant technical resources required for each new connection. The star topology requires a greater number of connections and fiber-optic resources. Furthermore, it has limitations in terms of scalability compared to other topological configurations, which can make its deployment more complex on a large scale [10]. The tree topology is a point-to-multipoint (P2MP) architecture. It requires the use of one or more optical splitters and results in reduced user throughput due to media sharing. However, it remains the preferred solution because it helps reduce deployment costs [11]. The tree topology is ideal for deployments requiring efficient resource allocation while offering the capacity to serve a large number of end users [10].

Traditional fiber optic network architecture is primarily based on tree topology due to cost considerations in Sarr *et al.* [12]. One of the key challenges for operators is minimizing the costs associated with deploying and maintaining optical networks. Achieving this goal requires the development of new infrastructure and equipment to ensure the deployment of a future-proof access network. To assist network planners in reducing planning time and investment costs, scenario sets combining eye-tree topologies, home-run configurations, and GPON architectures have been proposed in Naeem *et al.* [13].

To reduce deployment and maintenance costs in traditional networks, as discussed in the works of Sarr *et al.* [12], Senegal's FTTH network replaced the traditional quick ODN optical fibers (FO) 12 FO and 6 FO with a single FO cable as part of a quick ODN deployment, as shown in **Figure 1**.

In this configuration, the optical line terminal (OLT) output ports are routed through a local loop head and transmitted via a transport cable to the zone breakpoint (ZBP) and splice protection box (SPB). Here, the signal is split by a C1 coupler

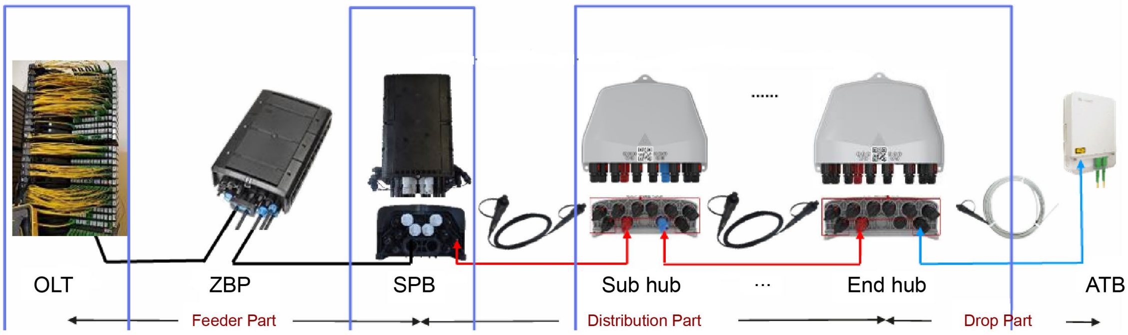

Figure 1. Quick ODN network deployment diagram.

(1 input, 4 outputs). Each output of the C1 coupler supplies four cascaded sub-boxes in sequence. Sub-boxes use a single-input coupler that divides the signal into two outputs (30% and 70%). The 30% output is routed to a coupler (1 input, 8 outputs) that serves 8 customers connected to the first sub-box, while the 70% output continues to the next sub-box in the series. For the final sub-box, the input is directly connected to a coupler (1 input, 8 outputs) to serve another 8 customers in BwnFiber [14]. This quick ODN deployment strategy significantly reduces the amount of fiber required, as it deploys four boxes each serving 8 customers on a single fiber optic line, compared to Sonatel's traditional FTTH architecture in Sarr *et al.* [12]. The passive FTTH (Fiber To The Home) optical network is currently one of the most cost-effective communication architectures, while also being very easy to plan and deploy. By using only passive components for optical signal distribution, it offers low operating costs, high reliability, and minimal maintenance, making it the preferred solution for broadband access networks. However, despite its many advantages, FTTH also has certain limitations, particularly when it comes to monitoring and managing outages. Without active components, it becomes difficult to directly identify disruptions or outages in a branch of the network. The ability to precisely locate the faulty section is, however, of crucial importance, as it determines the speed of response and the effective restoration of service. An effective monitoring mechanism is therefore essential for detecting anomalies, diagnosing their cause, and implementing appropriate corrective measures [15].

However, this topology is limited by the fact that any interruption in the line results in the isolation of all downstream boxes. To address this issue, ring topologies have been proposed as an efficient and cost-effective solution. Ring topologies guarantee minimal fiber link lengths and offer enhanced survivability; if one of the connecting links is interrupted, communication can be rerouted in the opposite direction. There is an urgent need to adopt fault detection and diagnostic techniques to effectively monitor the ODN, reducing the burden on network maintenance personnel and improving network efficiency in [16].

Optical transport systems based on optical add-drop multiplexers (OADMs), which support only unidirectional transmission, limit the possibilities for bidirectional communication Klinkowski *et al.* [17]. To mitigate network traffic disconnections caused by fiber link failures, a ring topology is suggested by Sarr *et al.* [18]. A hybrid tree-ring network architecture could also be a viable alternative in Li *et al.* [19]. To enable bidirectional transmission and prevent disconnections, while reducing complexity and costs, various types of bidirectional single-line optical insertion multiplexers (SBOADM) have been proposed, depending on the number of Bragg filters and optical circulators used in Chang *et al.* [20]; Hu *et al.* [21]; Li *et al.* [22]; Tsai *et al.* [23].

To enable self-healing capabilities in quick ODN network deployments, a new approach is needed, which involves replacing the traditional quick ODN setup with a bidirectional ring quick ODN topology. The design of this new quick ODN ring model includes the introduction of new bidirectional sub box types, based on a new SBOADM configuration. This configuration consists of 3 remote nodes (RNs), 4 optical circulators (OCs), 2 C1/2 couplers, and a 1/8 coupler. Two OCs and one C1/2 coupler are kept in reserve to provide reverse supply in the event of box isolation.

This article builds on the evolution of SBOADMs for radio-over-fiber (RoF) transmission, as discussed in Chang *et al.* [20]; Hu *et al.* [21]; Li *et al.* [22]; Tsai *et al.* [23], to replace FTTH quick ODN network boxes with bidirectional hub-type SBOADMs in the ring quick ODN network.

This study proposes replacing the conventional fast Optical Distribution Network (ODN) topology with a ring-based quick ODN architecture that incorporates self-healing capabilities. The proposed loop topology employs newly designed bidirectional sub-boxes and Remote Nodes (RNs) to provide automatic network restoration in the event of link failures or disruptions. The study establishes the theoretical framework for these novel sub-box configurations and details the signal transmission mechanisms in both the primary (downstream/upstream) and protection (downstream/upstream) directions. By enabling bidirectional communication and alternative routing paths, the proposed architecture ensures uninterrupted service continuity, even when portions of the network become isolated due to failures.

The structure of this article is as follows: Section 2 outlines the configurations for both quick ODN deployment and the ring quick ODN model. Section 3 presents simulation results for the quick ODN deployment and provides a link assessment of the ring quick ODN model. Finally, Section 4 concludes the study and discusses potential future work.

2. Materials and Methods

This part consists of reproducing and evaluating Sonatel Senegal's FTTH Quick ODN network from the OLT to the customer modem on OptiSystem version 17 software. Despite this, the Quick ODN's advantage of deploying four sub boxes in series on a single line reduces the cost of fiber optic deployment. In the event of a line break or malfunction, all sub boxes located after the point of impact will be isolated. To solve this problem, we have proposed the new Ring Quick ODN deployment model, *i.e.*, looped Quick ODN deployment. This requires new bidirectional sub boxes consisting of an RN, a C1/2 coupler, a three-port optical circulator, and a C1/8 coupler. Our new Ring Quick ODN model is evaluated by comparing the downlink power assessment at the input and output of these different bidirectional sub boxes with the existing Quick ODN model.

2.1. FTTH Network Quick ODN Deployment

OptiSystem version 17 was used to configure the deployment of the FTTH quick ODN network. The quick ODN deployment, shown in Figure 2, represents a modification of the distribution segment of Sonatel's traditional FTTH architecture in Sarr *et al*. [12]. The central office (CO) houses the active components of the network, including data generators, optical transmitters, and receivers, and the GPON wavelength multiplexer. The downlink and uplink transmission wavelengths are 1490 nm and 1310 nm, respectively, both using the non-return-to-zero (NRZ) format.

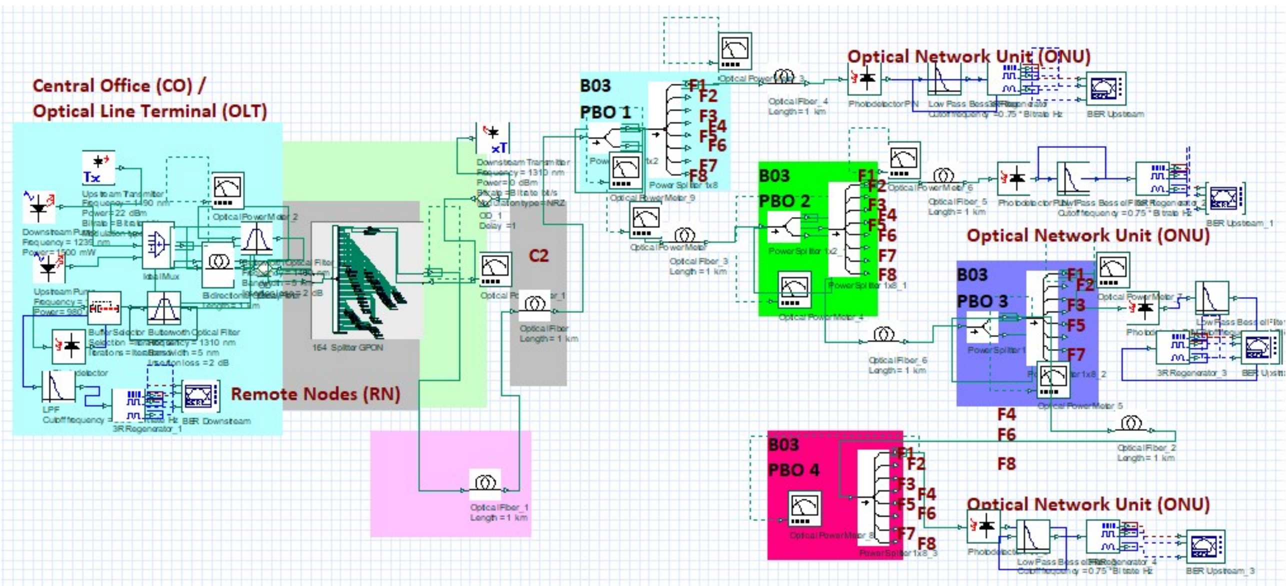

Figure 2. Experimental configuration of Quick ODN deployment.

The optical line terminal (OLT) and optical network terminals (ONTs) support a downstream data rate of 2.5 Gbit/s and an upstream data rate of 1.25 Gbit/s. To ensure high signal quality, each OLT port serves four sub-boxes, each supporting 8 customers: Sub-box 1, Sub-box 2, Sub-box 3, and the end box. Photometric measurements are performed at these boxes to assess both input and output signal powers. Each customer modem, specifically the optical network unit (ONU), includes a photodetector that converts the optical signal into an electrical signal, which is then filtered by a Bessel low-pass filter to reduce noise. A 3R generator is used as a bit error rate (BER) upstream adapter to assess signal quality at the customer's site.

2.2. Ring Quick ODN Deployment of the FTTH Network

The new ring quick ODN model provides a self-healing solution for the FTTH quick ODN network in the event of a line break or malfunction. It features a looped deployment of the quick ODN network over a single line. Figure 3 illustrates the network deployment of a ring quick ODN topology, which consists of four boxes interconnected by a remote node (RN) via a single bidirectional fiber.

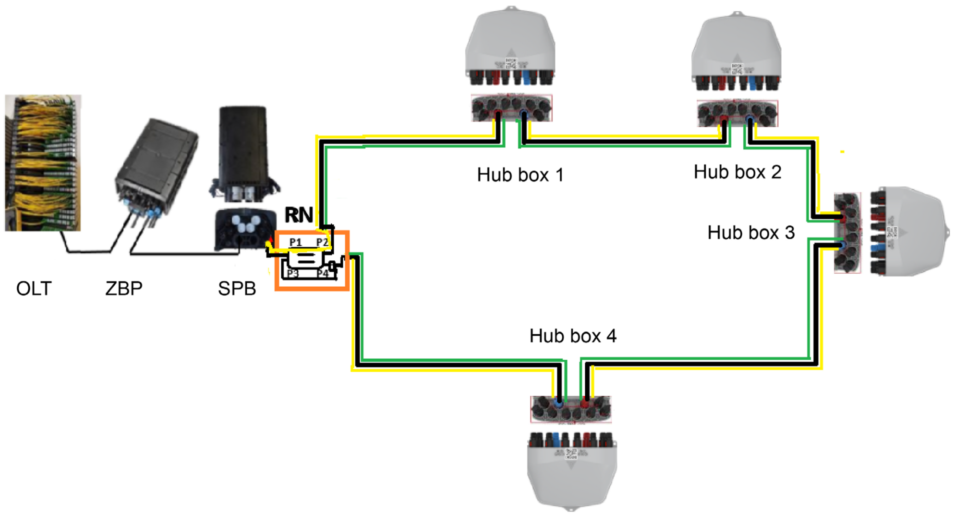

Figure 3. Ring Quick ODN deployment diagram.

This configuration modifies the quick ODN deployment shown in Figure 1, transitioning to a ring topology that incorporates new bidirectional sub-boxes and an RN to enable self-repair in case of a line cut or malfunction. The new model requires changes to the structure of the quick ODN sub-boxes, incorporating RNs, optical circulators, and Bragg filters.

In the ring quick ODN deployment, a remote node (RN) is introduced into the loop to ensure self-protection of the line in the event of a cable break. A network node (RN) comprises a 2 × 2 optical switch and a 1 × 2 optical splitter, used to connect the control unit (CO) to the main fiber optic ring. The optical signals emitted by the OLT can be transmitted via the main fiber to the RN, then circulate within the main ring in a clockwise (CW) direction or in both clockwise (CW) and counterclockwise (CCW) directions, depending on the status of the optical switch located in the RN. If there is no malfunction in the loop, the switch (SW) on the RN is set to parallel mode [input port 1, output port 3], as shown in Figure 4(a) below. This allows the downstream optical signals to be directed sequentially to the first sub box (forward direction). To detect a malfunction in the loop, the SW is equipped with a light sensor. Under normal conditions, a portion of the downlink signal passing through all the sub-boxes is converted into an electric current by the SW's photodetector. This current is used to keep the SW in parallel mode. The absence of this current indicates a malfunction in the ring line, causing the SW to switch to cross-connect mode.

Figure 4. RN in different states: (a) parallel state and (b) crossed state.

In the event of an outage, it is possible to restore interrupted connections by changing the status of the switch (SW) in the RN, switching it from parallel to cross-over mode. In Figure 4(b), in a cross configuration, the downstream signals are redirected from port 1 to port 4 of the SW. The integrated optical splitter then divides these signals into two paths (yellow and red): one is routed in the opposite direction to restore interrupted connections (indirect direction in red), while the other is sent back to port 2 of the SW, exits through port 3, and is then re-injected into the main ring in the direct direction (yellow).

The new Ring Quick ODN deployment model for the FTTH network requires the creation of a new type of bidirectional sub box, shown in Figure 5 below. The new sub box consists of 3RN, 4OC, 2C1/2, 2FBG, and 1C1/8. Among these components, 2OC, 1C1/2, and 1 FBG are reserved to ensure self-repair in the event of a loop malfunction. This new sub box is a type of bidirectional OADM that allows signals to be added and extracted on each sub box on the line. In the event of a malfunction, the input ports of these isolated sub boxes become output ports and vice versa. As a result, the components that were in reserve become active to switch the output port to an input port.

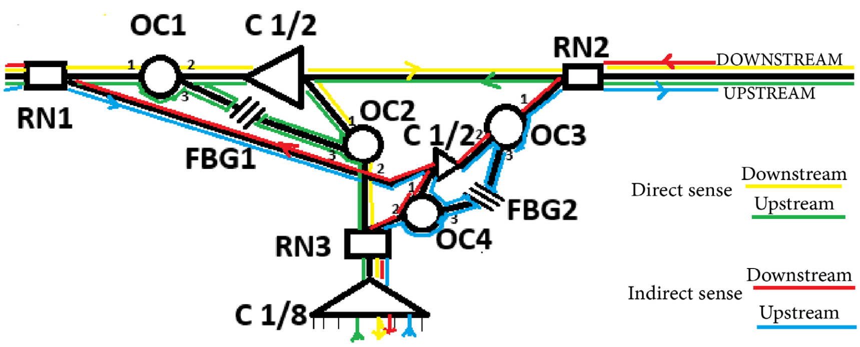

Figure 5. Structure of a sub box Ring Quick ODN.

The downstream signal enters the sub box via the RN1, passes through the first circulator (OC1) with three ports [input 1, output 2], and then passes through a coupler [1 input, 2 outputs]. One of the outputs of this coupler feeds the next sub box via another RN2. The second output of C1/2 is directed to a second circulator OC2, also with three ports [input 1, output 2], followed by another RN3 and then a coupler [1 input, 8 outputs], which serves the 8 clients of this sub box. The 1310 nm wavelength upstream signals consist of those from customers connected to this sub box and those from other sub boxes on the line. The upstream signal, transmitted by customer modems, enters the C1/8 coupler through these outputs [1 input, 8 outputs], passes through the RN, and flows into the OC2 circulator [Input Port 2, Output Port 3]. It is then reflected by the Bragg filter configured only for the 1310 nm upstream wavelength. This Bragg filter only reflects the 1310 nm wavelength. The reflected signal re-enters the OC2 circulator [Input port 3, Output port 1], passes through the coupler [1 input, 2 outputs] via one of its outputs, and enters the OC1 circulator [Input port 2, Output port 3]. It is reflected again by the Bragg filter before re-entering the OC1 circulator [input port 3, output port 1] and passing through the RN to return to the OLT. At the same time, the upward signals from the other sub boxes enter the sub-box via RN2 and enter coupler 1/2 via these outputs before entering circulator OC1 [Input port 2, Output port 3]. It is then reflected by the same Bragg filter configured at 1310 nm. The reflected signal re-enters the OC1 circulator [Input Port 3, Output Port 1] and passes through the RN1 to return to the OLT. As described above, the paths of the descending (yellow) and ascending (green) signals are identical in the four sub-boxes in series on the ring deployment shown in Figure 6.

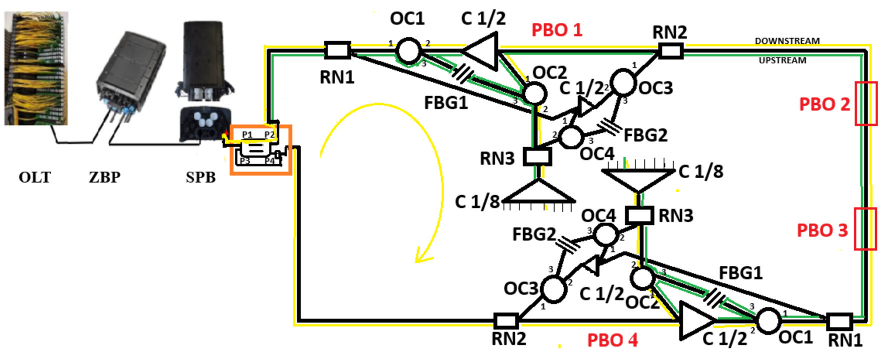

Figure 6. Ring Quick ODN deployment configuration.

Downstream signals enter each sub box through its RN1 and exit through the RN2 to feed the next sub box up to the central RN. The incorporation of an additional coupler [1 Input, 2 Outputs] and two indirect circulators, held in reserve, within the new sub box design enables bidirectional functionality. This feature allows the system, in the event of a cable break or box malfunction, to switch the output port to function as an input port, as illustrated in Figure 7.

In the event of a malfunction anywhere along the line, the RN becomes active (cross state). The OLT signal enters the RN at port P1 and exits at port P4, where it is duplicated by a splitter. One output from the splitter re-enters the RN through port 2 and exits at port 3, maintaining continuity in the non-isolated portion of the line. The other output feeds the isolated segment of the line in the reverse direction.

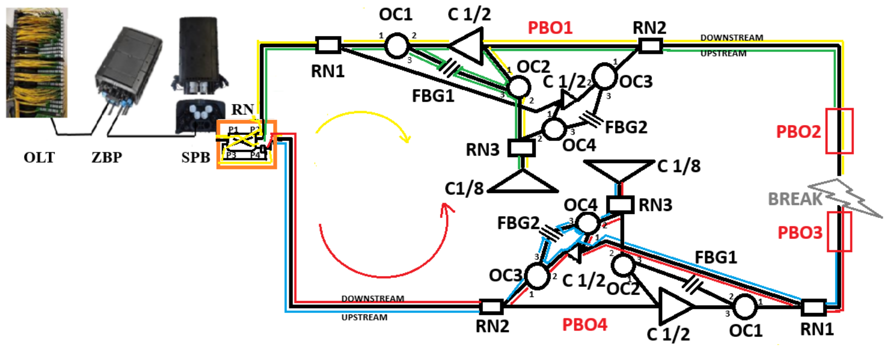

Figure 7. Self-repair configuration for Ring Quick ODN Deployment.

The signal traveling in the reverse direction passes through the RN of sub-box 4, which becomes the first sub-box in the new line, then proceeds through the first indirect circulator (OC3) [Input port 1, Output port 2] and the spare coupler [1 input, 2 outputs]. One output of the coupler, which was held in reserve, passes through RN2 to supply the other isolated sub-box, while the second output travels through the second indirect circulator (OC4) [Input port 1, Output port 2], then the RN, and finally passes through the coupler [1 input, 8 outputs] that serves the customers.

In the upstream path, the signal transmitted by the customer modems enters the coupler [1 input, 8 outputs], passes through the RN, and enters the OC4 circulator [Input port 2, Output port 3]. It is then reflected by the reserve Bragg filter before re-entering the OC4 circulator [Input port 3, Output port 1]. This reflected signal moves through the coupler [1 input, 2 outputs], enters the OC3 circulator [Input port 2, Output port 3], and is reflected again by the Bragg filter. The signal then re-enters the OC3 circulator [Input port 3, Output port 1] before passing through the RN to reach the OLT. The received power (P_r) at the 8 outputs is calculated using the following formula of [24]:

$$P_r = P_e - \alpha_T \tag{1}$$

with α_T, the total attenuation on the transmission line and P_e the transmit power.

This formula is used to calculate the received signal power at each point in the ring quick ODN network, taking into account the losses and the number of components involved. The insertion loss associated with an RN is 4.5 dB, the loss for an optical circulator (OC) is 1.5 dB, the loss for a C1/2 coupler is 3 dB, and the loss for a C1/8 coupler is 9 dB, and the maximum range of the distribution network is 20 km, which corresponds to a total line loss of 5 dB in the optical fiber.

3. Results and Discussion

The dimensioning of the quick ODN network, as shown in **Figure 2**, as well as our ring quick ODN deployment model, depends on the received signal strength and signal quality at each client modem. These parameters are measured using a photometer and analyzed through an eye diagram. The optical signal, once converted into an electrical signal, is evaluated using a bit error rate (BER) display and compared against the Kim model in Alnajjar *et al.* [25]. According to the Kim model, the minimum acceptable bit error rate in telecommunications is 10^{-9}, which corresponds to a Q factor of approximately 6 in Alnajjar *et al.* [25].

3.1. FTTH Quick ODN Network

The signal power simulation results for the quick ODN deployment, as shown in **Figure 2**, are presented in **Table 1** below. **Table 1** displays the input and output powers for customers connected to the three sub-boxes and the end-box of the quick ODN deployment. The difference in input power between two consecutive boxes ranges from 3 to 4 dBm, which corresponds to the attenuation introduced by a coupler 1/2 used in the link evaluations of our ring quick ODN deployment model. This difference represents the insertion loss of a quick ODN sub-box along the line.

Table 1. Input and output power of the four series-connected boxes in the quick ODN network.

Quick ODN	Sub box 1	Sub box 2	Sub box 3	End box
Box inpout power	−1.869	−5.08	−8.289	−11.5
Box output power to Customer	−13.911	−17.121	−20.331	−20.531

These simulation results indicate that the difference between the input power of each box and the output power delivered to the customer's cable is approximately 12 dB. This value represents the total loss for each of the three sub-boxes in the quick ODN deployment, which includes the combined losses of couplers 1/2 and 1/8. The difference between the input and output power of the end box is 9 dB, corresponding to the loss introduced by the 1/8 coupler. Therefore, the end box consists solely of a 1/8 coupler. In the Quick ODN deployment, the first three sub-boxes are identical and consist of a C1/2 coupler and a C1/8 coupler, while the end box consists of a single C1/2 coupler. The quality of the signals received from the optical network terminal (ONT) in each of the four boxes is evaluated using eye diagrams and compared to the bit error rate (BER) transmission threshold of 10^{-9}, as shown in **Figure 8**.

Signal quality is assessed using the eye diagrams in **Figure 8**, which represent the signal quality for customer modems connected to Hub 1, Hub 2, Hub 3, and the end box, respectively.

The high signal quality is confirmed by wide-open eye diagrams, with BER values of 0; 3×10^{-111}; 2×10^{-39} and 2×10^{-34}, and Q factors of 53, 22, 12.8, and 12.1 for customer modems connected to hub 1, hub 2, hub 3, and endbox, respectively. These results correspond to excellent signal quality according to Kim's standard models, where the minimum permissible bit error rate in telecommunications is 10^{-9} and the Q factor is around 6 Alnajjar *et al.* [25]. The Quick ODN network deployment shown in **Figure 2** extends 2 km between sub-hub 1 and the OLT, and these simulation results show very good signal quality. To study the coverage range of the Quick ODN deployment, the distance is increased until the BER of sub-hub 3 is close to or equal to 10^{-9}. This distance corresponds to 20 km, with output powers from the box to the customer of −16.711 dBm, −19.921 dBm, −23.131 dBm, and −23.331 dBm at sub-box 1, sub-box 2, sub-box 3, and end box, respectively, as illustrated in Table 2 below. In this deployment, the minimum power threshold at the output of the box to the customer is −23 dBm.

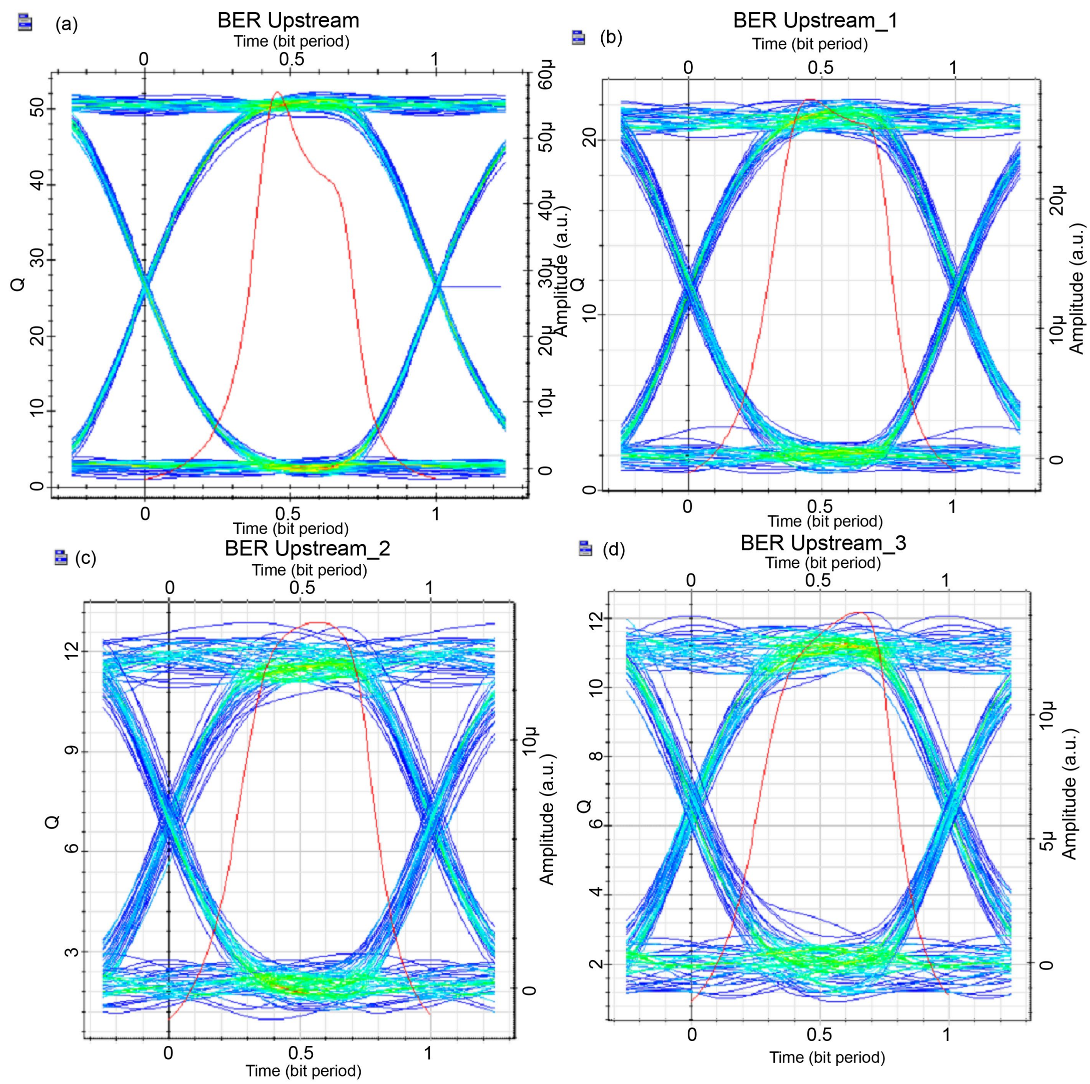

Figure 8. Output signal strength a, b, c, and d of sub-box 1, sub-box 2, sub-box 3, and the end box, respectively, at 5 km of the quick ODN network.

Table 2. Output power to customers of the four boxes in series on the 20 km quick ODN network.

Quick ODN/20Km	Sub box 1	Sub box 2	Sub box 3	End box
Box output power to Customer	−16.711	−19.921	−23.131	−23.331

Signal quality in this deployment is demonstrated by the diagrams in Figure

9(a)-(d), which show bit error rates (BER) of 8×10^{-133}; 6×10^{-37}; 10^{-9} and 3×10^{-10} and Q factors of 24, 12, 5.9, and 6.15, respectively, for customer modems connected to sub box 1, sub box 2, sub box 3, and the end box.

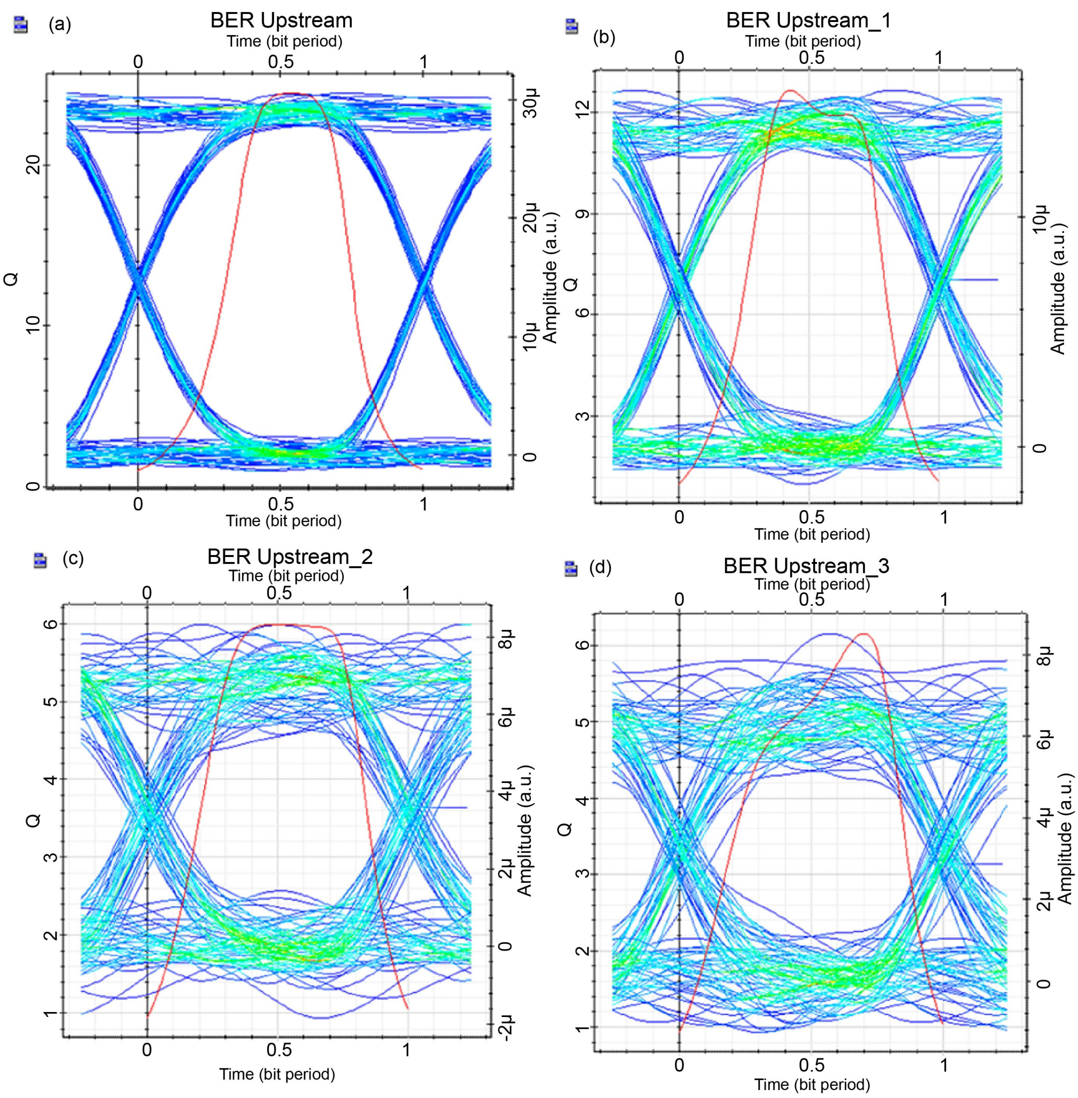

Figure 9. Output signal strength a, b, c, and d of sub-box 1, sub-box 2, sub-box 3, and the end box, respectively, at 20 km along the Quick ODN network.

These results indicate that the distribution range of the quick ODN network is limited to 20 km, as shown in [14], with a bit error rate (BER) of 10^{-9}, which is the threshold allowed in telecommunications. Beyond this distance, the signal quality at the last boxes deteriorates. Interestingly, the signal quality at the end box is superior to that of sub box 3, likely because the end box is equipped with a single C1/8 coupler, which reduces the number of components compared to sub box 3.

As part of this quick ODN rollout, signal quality varies from box to box. The signal quality for customers connected to the first two boxes is significantly better than that for customers connected to the last two boxes. To address this imbalance, Huawei-Senegal is using C1/2 couplers (30%, 70%) in the rollout of the quick ODN FTTH network in Senegal. However, the frequent occurrence of cable cuts highlights the need for a new deployment and maintenance strategy to ensure robust self-protection for this FTTH quick ODN network [14].

3.2. FTTH Ring Quick ODN

The new quick ODN ring model shown in **Figure 4** has been evaluated using a power link budget analysis. These results are compared with those of the existing quick ODN model. **Table 3** summarizes the power simulation results for the first sub-box of the existing quick ODN model and the proposed new ring quick ODN model. Simulation results for the quick ODN network indicate that the threshold power corresponding to the threshold bit error rate (BER) in telecommunications is −23 dBm. Signal quality degrades as the number of components inside a sub-box increases. However, deploying the quick ODN model in a two-way loop requires the addition of certain components to ensure line self-protection in the event of a failure. As shown in **Figure 4**, each sub-box in the quick ODN ring network consists of 3 RNs, 4 OCs, 2 C1/2 couplers, and one 1/8 coupler, with 2 OCs and one C1/2 coupler reserved for rerouting the signal in the opposite direction to feed the isolated junction box in case of a fault.

For the first sub box, the signals going down to the clients pass through 2 RNs, 2 OCs, and a C1/2, while those feeding the next sub box pass through 2 RNs and a C1/2. The insertion loss associated with an RN is 4.5 dB, the loss for an optical circulator (OC) is 1.5 dB, the loss for a C1/2 coupler is 3 dB, and the loss for a C1/8 coupler is 9 dB. To evaluate the new quick ODN ring model, the received powers and losses in the forward direction for the first sub-box are compared with those of the quick ODN network, as shown in **Table 3**. As in the quick ODN model, the same OLT output transmit power of 0.5 dBm is used. The input power at the first concentrator is −5 dBm, while the received power at the customer outputs of sub-box 1 in the quick ODN ring deployment is −29 dBm. Total losses for a sub-box in the quick ODN ring model are 24 dB, compared with 12 dB in Sonatel's quick ODN model.

Table 3. Comparative link balance between quick ODN and ring quick ODN.

	OLT output power (dBm)	Sub box Input power (dBm)	Sub box output power to customer (dBm)	Sub box output power (dBm)	Power loss output Sub box to customer (dB)	Sub box insertion power loss (dB)
quick ODN	0.5	−1.869	−13.911	−5.08	12.042	3.211
ring quick ODN	0.5	−5	−29	−18.5	24	13.5

The insertion loss of a sub-box in the ring quick ODN loop is 13.5 dB, while the insertion loss of a sub-box in a quick ODN is 3.21 dB. The significant power reduction in the new ring quick ODN model is due to the composition of these new bidirectional sub-boxes. The end-to-end pre-connected cable solution eliminates the need for splicing fiber at height and reduces the risk of failure due to tightening. In the event of a line failure, the cable can be easily replaced, ensuring quick installation and simplified troubleshooting compared to traditional deployment [26]. However, self-repairing Quick ODN ring deployment may be the best solution to avoid line interruption.

To ensure self-repair, these bidirectional sub-boxes include components that are functional only in the direct direction, with others reserved for the indirect direction in the event of an outage. This is why the input and output ports of these sub-boxes are identical, unlike the existing quick ODN model, which is unidirectional.

The power loss between the input of this sub-box and the outputs connected to the customers is 24 dB, while the insertion loss of this sub-box on the line is 13.5 dB. The insertion losses of a sub-box in the quick ODN ring network are the total losses of signals entering the sub-hub via RN1, coupler C1/2, and exiting via RN2, as opposed to the quick ODN network, where signals enter and exit the sub-box via a single coupler C1/2 with a loss of approximately 3 dB. These new sub-boxes are a type of SBOADM used in the FTTH network. The insertion losses of a bidirectional sub-box of 13.5 dB accumulate as their numbers increase on the loop. Reaching the 4 sub-boxes as in the quick ODN network requires an increase in OLT power. Amplifying the power at the source would eliminate the need for an optical amplifier in the PON network. These new sub-boxes are SBOADM types used in the FTTH network. These insertion losses are comparable to the 16.1 dB SBOADM maximum insertion loss observed in RoF transmission of five access points looped on a single line, as reported by Li *et al.* [19]. SBOADM has made it possible to move from deploying one AP per three fiber optic cables (downlink, uplink, and another for backup) to a single bidirectional fiber to deploy multiple access points using wavelength division multiplexing. WDM is used to deploy multiple access points over different wavelengths, offering better bandwidth capacity and security than TDM. WDM-PON does not reduce capital expenditures for designing a bidirectional sub-box and increases CAPEX for multiplexers that assign a wavelength to each sub-box or ONU compared to TDM-PON.

The Quick ODN has made it possible to move from a tree topology requiring a lot of cable to a single-line topology for deploying four sub-boxes. This technology is based on time division multiplexing (TDM-PON). Unlike WDM-PON, it does not require the allocation of multiple wavelengths or expensive equipment. It uses the same wavelength for both the downstream (1490 nm) and upstream (1310 nm) links. Quick ODN is fully compatible with previous topologies such as the better-known star topology, point-to-point (PtP) topology, and tree topology (point-to-multipoint). These different models use the same wavelengths, the same physical locations for sub-boxes on poles or building facades, and the same customer modems (ONTs). Quick ODN retains the same access network range (20 km) and the same capacity to serve an OLT port, including 4 sub-boxes with 8 clients. This model has minimized the number of fiber optic cables used by replacing several cables with a single line to deploy 4 sub-boxes in series. It has therefore reduced capital expenditure (Capex). The new Ring Quick ODN model is a closed-line continuation of the Quick ODN. This entails additional investment costs, in addition to the installation of new bidirectional sub-boxes, including the insertion of an RN in the ZBP and the addition of a pre-connected cable to form a ring connecting the RN to the fourth sub-box. This justifies the increase in investment costs for the Ring Quick ODN in order to ensure continuity of service for all customers in the event of a cable break, thanks to the RN's self-repair mechanism, which is capable of switching in both directions to power the ring. In the event of a completely faulty sub-box, only customers connected to that point will be affected. Maintenance is carried out by replacing the pre-connected sub-box, as in the case of Quick ODN. The new model does not require additional training for deployment and maintenance technicians, as the bidirectional sub-boxes and cables are pre-connected, as in the case of Quick ODN, and the RNs are also pre-connected. The stock of deployment and maintenance equipment consists solely of pre-connected cables of various lengths, bidirectional sub-boxes, and pre-connected RNs. However, defective sub-boxes can be reused after repair by the supplier's specialists. The migration from Quick ODN to Ring Quick ODN can preferably be carried out in areas with a high risk of failure by replacing the Quick ODN sub-boxes with bidirectional Ring Quick ODN sub-boxes, in addition to a pre-connected cable to form the ring with an RN at the ZBP. In new deployments, the rings will be designed to minimize the length of pre-connected cables used. The advantage of the new Ring Quick ODN model is that a failure of a cable or sub-box component creates an open circuit in the ring but does not affect customer connections. This model is therefore a response to requests from business customers who depend on provider connections. Due to the increased investment costs, this model can be designed specifically for customers who are sensitive to network disruptions. Implementation will consist of assembling the various components that make up the central box, as shown in **Figure 5**.

4. Conclusions

In this study, the performance of quick ODN network deployment over distances ranging from 6 to 20 km was assessed in terms of bit error rate (BER) and quality factor (Q), using simulations conducted with Optisystem software. This deployment is impacted by recurrent cable cuts, which affect multiple customers. The repair of these outages relies on the availability of cables and technicians. To enable rapid self-repair of the ODN network in the event of a line failure, a new technique for deploying the quick ODN loop network is proposed. This approach involves configuring new types of bidirectional sub-boxes within a loop architecture on the ODN. Additionally, the transmit power used in the quick ODN network was incorporated into the link budget analysis for the new quick ODN ring deployment model.

Simulation results for the quick ODN network revealed a minimum power threshold of −23 dBm, which aligns with the standard BER threshold in telecommunications. However, link budget analysis for the quick ODN ring deployment model indicated a maximum received power of −29 dBm at the customer outlets, which is significantly below the threshold defined in the quick ODN network, suggesting poor signal quality. The four bidirectional sub-boxes in the quick ODN ring deployment are identical, with insertion losses within the loop of 13.5 dB. Losses between the concentrator's input port and the customer outputs total 24 dB. The design of these new bidirectional sub-boxes requires additional costs because they contain more components than the existing quick ODN.

Implementing this new deployment technique would require an increase in transmission power at the OLT level to compensate for the insertion losses associated with each sub-box. As part of our ongoing research, we plan to implement these new types of directional boxes at Sonatel-Senegal, then conduct a practical evaluation of the link before and after loop closure.

Author Contributions

Conceptualization, Mamadou SARR and Dialo Diop; methodology, Mamadou SARR; software, Mamadou SARR; validation, Dialo Diop, and Massaer Marone; writing—original draft preparation, Mamadou Sarr; writing—review and editing, Dialo Diop; supervision, Kharouna Talla. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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