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Performance Evaluation of Gigabit Passive Optical Network (GPON) for Fiber to the Home Applications Using OptiSystem Software: A Case Study in Tripoli, Libya

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Abstract:

Gigabit Passive Optical Network (GPON), a cost-effective solution for triple-play services, is favored for its flexibility in accommodating future technologies. GPON networks theoretically can support up to 64 users within a 20 km reach, operating at 2.488 Gbps downstream and 1.244 Gbps upstream [1], [2]. Utilizing OptiSystem software, this paper focuses on a comprehensive performance evaluation of a GPON Fiber to the Home (FTTH) network in Tripoli, Libya. Through practical implementation in the national FTTH project by Hatif Libya Telecom, it was determined that service delivery via the Optical Line Terminal (OLT) to areas approximately 20 km away from the Central Office (CO) was not viable. Based on this principle, we conducted a performance analysis of a GPON network over feeder cable lengths ranging from 5 km to 30 km, evaluating key parameters such as received power, Bit Error Rate (BER), and Q-factor. The results indicate that as the distance increases and the number of users serviced on a single fiber strand approaches 32, both the error rate and the likelihood of transmission failures rise significantly. The simulation results provided critical insights into the performance evaluation of GPON for Fiber to the Home (FTTH) networks using OptiSystem software. Notably, the Bit Error Rate (BER) analysis demonstrated a direct correlation between increasing feeder cable lengths within the 5-30 km range and rising BER values. Additionally, the Q-factor analysis highlighted the network's performance, indicating that lower Q-factor values corresponded with higher BER levels and potential transmission challenges.

Keywords: Fiber to the Home (FTTH), Gigabit Passive Optical Network (GPON), Optical Line Terminal (OLT), Optical Network Terminal (ONT), Splitter

1. Introduction

The twenty-first century has seen countless changes in the telecommunications networks (the means to deliver services to residential and business consumers). The phenomenon is underpinned by two technologies: Internet Protocol (IP) and Optical Fiber. The technology provides triple play (voice, video, and data services) over a common protocol—IP. Operators are quickly moving to maximize the number of services offered to a single customer via a bundled offering. Technologies such as IP telephony, IP Television (IPTV), and broadband will become a common requirement [3]. As bundled services and technologies are deployed, the

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legacy networks designed to efficiently deliver a single service are stressed, and in many cases incapable of offering the desired services.

The aging copper access infrastructure in residential and business locations is unable to meet the demand of increase in bandwidth for several applications. These demands can only be met by the deeper penetration of optical fiber in Access Networks and increasing deployment of Fiber-to-the-Home (FTTH). As a result, FTTH is the fastest-growing global broadband technology with significant deployments.

OptiSystem, a leading software tool in the field of optical communication systems, plays a pivotal role in the design, simulation, and analysis of optical networks. By providing a comprehensive platform for modeling optical components, signal propagation, and network architectures, OptiSystem enables engineers to simulate real-world scenarios and assess the performance of optical communication systems with precision [4], [5].

In this paper, we delve into the design and performance evaluation of GPON FTTH networks using OptiSystem. The performance metrics, including eye diagrams, minimum BER values, and Q-factor, are thoroughly examined to ascertain network robustness and reliability.

1.1 Gigabit Passive Optical Network (GPON)

GPON family of specifications has been released by the International Telecommunication Union (ITU) in the ITU-T G-984.x series of documents starting from 2003 [6]. All Passive Optical Network (PON) technologies are based on the same principal layout of a Passive Optical Network as shown in Fig. 1. A number of terminals at the customer side communicate with the same port of the Optical Line Terminal (OLT) in the Central Office (CO). The full bandwidth of this port is shared between the connected Optical Network Terminals (ONT ‘s) [6].

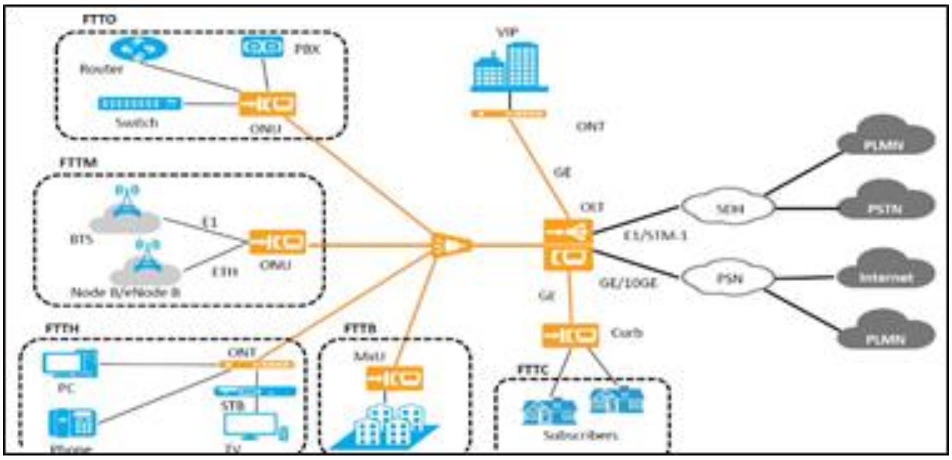

Figure 1:. FTTx network architecture

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1.2 Optical Distribution Network (ODN)

ODN refers to the network infrastructure that delivers fiber-optic communication directly to individual residences or businesses. In an FTTH ODN network, optical fibers are extended from the central office directly to the subscriber premises, providing high-speed internet, voice, and video services [7]. The FTTH ODN network typically includes passive optical components such as splitters, distribution panels, and connectors to distribute signals efficiently to end-users. These passive elements play a crucial role in ensuring reliable and high-quality transmission of data over the fiber-optic network.

ODN, an integral part of the PON system, provides the optical transmission medium for the physical connection of the ONUs to the OLTs as shown in Fig. 2.

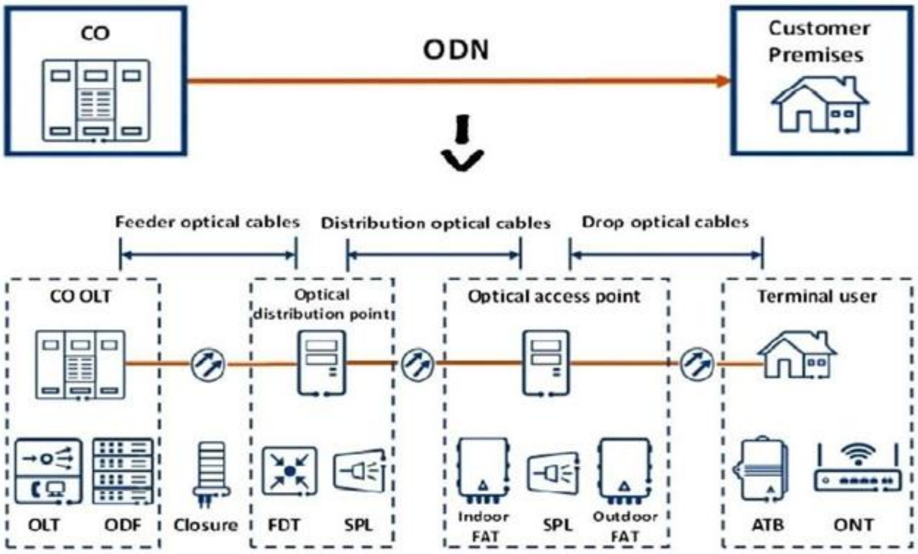

Figure 2: ODN network components

2. Proposed Methodology

Systematic block schemes of downstream and upstream configurations of the FTTH GPON Networks are designed and constructed. The simulation was conducted for several optical fiber lengths. These lengths are 5, 10, 15, 20, 25, and 30 Km. GPON provides 2.488 Gbps of bandwidth downstream shared by a maximum of 64 end-users (GPON uses 2.488 Gbps downstream and 1.244 Gbps upstream data transmission). The wavelengths used are 1490nm for voice/data and 1550 nm for video (long distance). This design assumes cascaded splitting where splitters are located close to all users that they provide the service to, so the distribution and drop sections of the cables are short. The transmission system was simulated for one transmission power value of 5 dBm. The optical fiber attenuation was set to 0.35 dB/km, and the chromatic dispersion was set to 16.75 PS/nm/km.

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2.1 Network Parameters

When simulating the downstream segment of a G-PON system, the initial step commonly centers on configuring the simulation parameters. By defining the signal wavelength at 1490 nm and bitrate, set at 2.488 Gbps, along with a sensitivity level of -28 dBm. Subsequently, these parameters are employed to model the system's performance as the signal traverses through different components, evaluating the signal quality at the receivers through diverse metrics like Bit Error Rate, Eye Diagram, Maximum Q-Factor, and attained Power. The system parameters are analyzed as shown in Table I.

Table 1. GPON Simulation Parameters

No.	Item	Description	Specification
1	Fiber Optic Cable (G.652)	Attenuation at 1310 nm	0.35 (dB/KM)
		Attenuation at 1490 nm	0.25 (dB/KM)
2	Connecting point	Fusion splicing Loss	0.1 dB
		Connector Loss	0.25 dB
3	Splitter unit	1:8 Splitter	10.2 dB
		1:4 Splitter	7.2 dB
		1:2 Splitter	3.5 dB
4	Transmitter	Tx power	+5 dBm
5	Receiver	Rx Sensitivity	- 28 dBm
6	GPON	Data Rate	2.488/1.244 Gbps

2.1 Design Configuration in Optisystem

This design configuration scheme is simulated as per the design approved and implemented in Tripoli, Ben Ashour Area, by Hatif Libya Company, where Hatif Libya GPON Network accommodate a maximum of 32 ONTs or clients per 1 GPON port or over a single feeder fiber, so in this design, a combination of 1:4 and 1:8 cascaded splitters are used. Fig. 3, shows the design configuration scheme that has been created in the Optisystem:

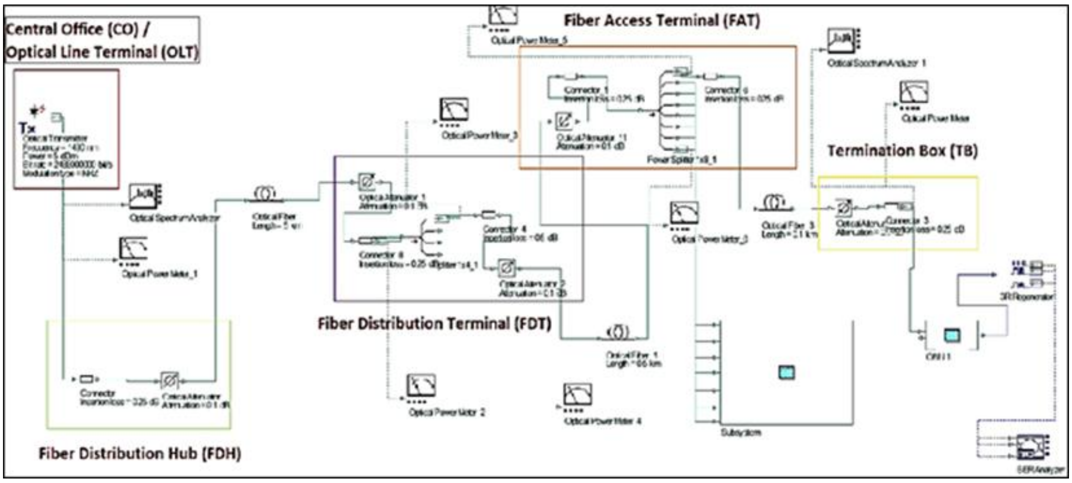

Figure 3:. OptiSystem downstream configuration

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As it shown in figure 3, the OLT or Optical Transmitter device has been set at a frequency of 1490 nm, 2.488 Gbps, and a transmitted power of +5 dBm according to the Class C+ SFP module currently used by the provider, the FDH (Fiber Distribution Hub) which is a high capacity ODF used to connect OLT with outside planet (OSP) feeder cable and has 1 connector and 1 splice as cumulative loss, and the feeder cable length will be varying in between 5-30 km away according to the distance from the CO to the FDT point based on the network, the third box is the FDT Cabinet (Fiber distribution Terminal) which connect between feeder cable and other distribution cables and contains several splitters of 1: 4 based on the calculation of the total client needs on 1 GPON port (32 end-user), and the standard attenuation on the 1: 4 splitter is 7.2 dB. FAT (Fiber Access Terminal) using a 1: 8 splitters, with a standard attenuation of 10.2 dB which is the last outdoor passive component and is directly connected to the ONT device through a drop cable, its length ranging from (100 – 500 m) and its end is spliced inside a TB (Terminal Box) located indoor and connected to the ONT with a fiber patchcord.

3. Simulation Results

3.1 Power Budget

Table II presents ONT1 received power values obtained from the simulation for different feeder cable lengths, and for 500 m distribution cable, and 100 m drop cable:

Table 2. Power Budget Results

Feeder Cable Length (KM)	Tx Power (dBm)	Rx (dBm)	Total Loss (dB)
L=5	5	-16.257	21.257
L=10	5	-17.507	22.507
L=15	5	-18.757	23.757
L=20	5	-20.007	25.007
L=25	5	-21.257	26.257
L=30	5	-22.507	27.507

According to simulation results, the received power level values are within the operating range -16 up to -23 dBm. This indicates a considerable margin from the upper limit of receiver sensitivity set at -28 dBm.

Figure 4: Receive power on the downstream configuration (L=5KM)

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3.1 Bit Error Rate (BER)

Measuring the Bit Error Rate (BER) in a simulator is a key method for evaluating the performance of fiber optic networks, complementing insights obtained from power budget analysis [8], [9]. In OptiSystem, BER is measured using a BER Analyzer, which generates an eye diagram to assess signal quality. The eye diagram offers a straightforward yet reliable way to evaluate digital transmission performance in the time domain, revealing waveform distortions similar to those observed with an oscilloscope in practical applications. To examine the effect of distance on BER in an FTTH network, simulations were carried out with feeder cable lengths ranging from 5 km to 30 km. The results, summarized in Table III, illustrate the correlation between BER values and feeder section distance.

3.2 Q-Factor Definition

The Q-factor is a signal quality metric that quantifies the signal-to-noise ratio in optical communication systems. It is related to BER by the relation:

$$BER \approx \frac{1}{2} erfc(\frac{Q}{\sqrt{2}}) \tag{1}$$

where erfc(.), is the complementary error function. As presented in Table 3, higher Q-factor values correspond to lower BER, with $Q > 6$ typically indicating error-free transmission. When BER = 1, the Q-factor is undefined and therefore reported as N/A.

Table 3. Bit Error Rate and Q-Factor values

No.	Distance (KM)	BER	Q Factor
1	5	5.206×10^{-18}	8.569
2	10	3.623×10^{-12}	6.852
3	15	8.931×10^{-07}	4.775
4	20	1	N/A
5	25	1	N/A
6	30	1	N/A

Fig. 5, presents the eye diagrams corresponding to the Bit Error Rate (BER) and Q-factor for the downstream configuration with a distance varying from 5 to 30 Km alongside the Q-Factor. The standard minimum acceptable BER for fiber optic communication systems is typically 10^{-9}, and states that within a billion transmitted bits, there should be one wrong bit. The simulation outcomes indicate that with a feeder fiber cable length (L) of less than 15 Km, the network operates nearly error-free. However, as the distance approaches 20 Km, the BER rises sharply, leading to transmission failures. Changes of BER in configuration can be seen clearly. It states that the length of fiber optic cable used has an influence on performance. The farther the ONU location, the greater the value of BER obtained and the less the received power.

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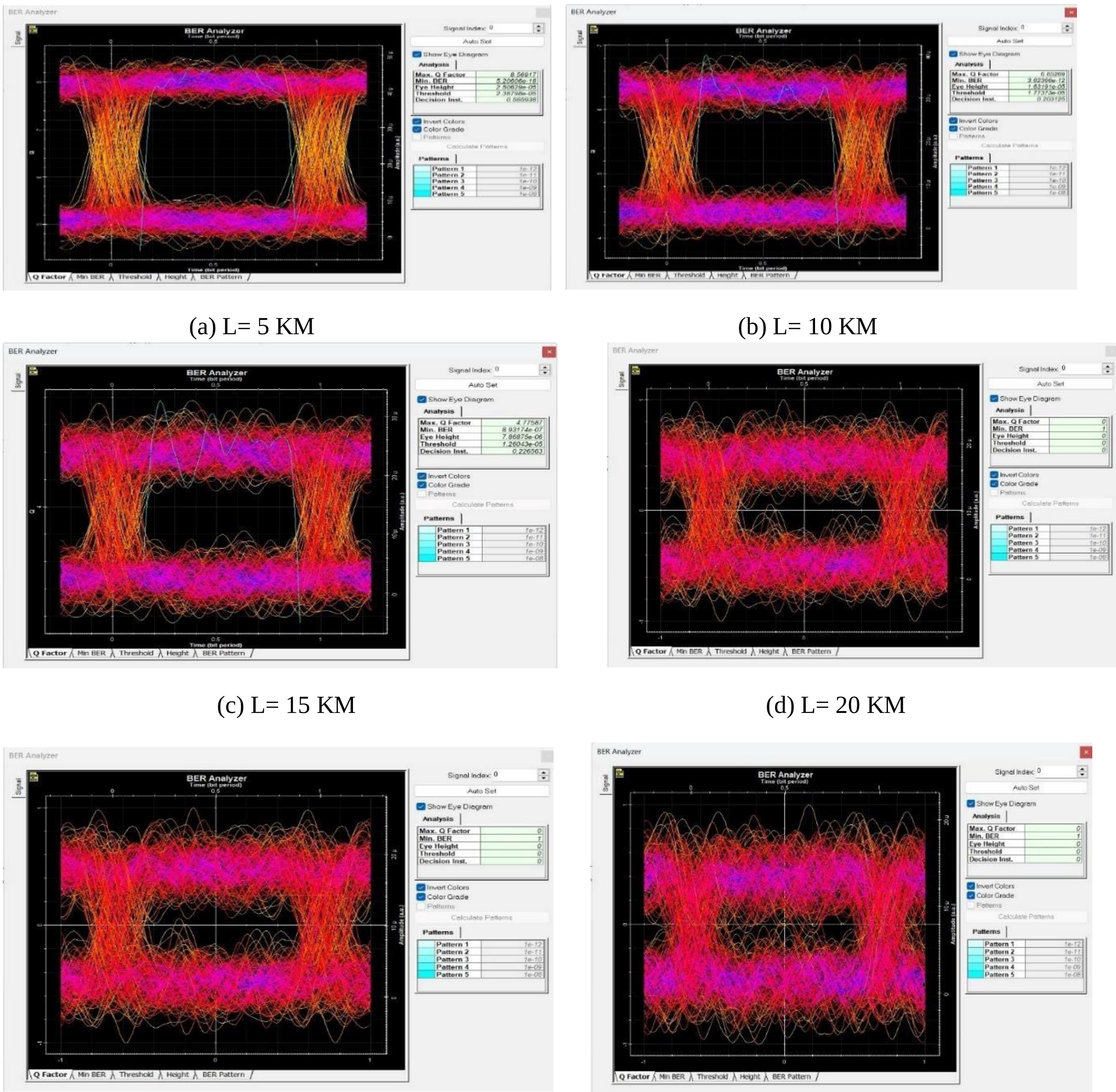

(a) L= 5 KM
(b) L= 10 KM
(c) L= 15 KM
(d) L= 20 KM
(e) L= 25 KM
(f) L= 30 KM

Figure 5: BER analyzer for downstream configuration for different feeder cable lengths

4. Conclusion

The simulation results yielded critical insights into the performance evaluation of GPON Fiber to the Home (FTTH) networks using OptiSystem. Firstly, the power budget analysis showcased received power levels comfortably within the operational range at -22 dBm, indicating a notable safety margin from the receiver sensitivity limit of -28 dBm. Secondly, the Bit Error Rate (BER) analysis revealed a direct correlation between increasing feeder cable lengths within the 5-30 Km range and escalating BER values. Notably, as the distance approached 20 Km, the BER values spiked, leading to potential transmission failures. This emphasized the

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pivotal role of optimal fiber cable lengths in maintaining low error rates and ensuring reliable network operations. Moreover, the Q-factor analysis underscored the network's performance, v with lower Q-factor values aligning with higher BER levels and potential transmission challenges. The study highlighted the necessity of meticulous network design and parameter optimization to bolster network robustness and mitigate transmission errors effectively. By leveraging OptiSystem simulations, the research provided actionable insights into the practical performance characteristics of GPON-based FTTH networks, bridging the theoretical and practical realms. These findings underscored the critical importance of maintaining optimal fiber cable lengths to uphold low error rates, guarantee dependable data transmission, and elevate overall network efficiency in GPON FTTH setups. The researcher also concluded that through the practical implementation of the national FTTH project undertaken by Hatif Libya Company in Tripoli, which will be expanded to other Libyan cities, it is not feasible to deliver the service through the OLT to areas that are approximately 20 km away from the CO. Therefore, it is necessary to design another station with an OLT to serve these locations.

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