Design Techniques of FTTH-GPON Networks for Segmentation and Data Traffic Relief

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Abstract. Today, the exponential increase in subscriber data usage, in short time frames, is causing Internet Service Providers (ISPs) to deploy or migrate their networks to Fiber to the Home (Gigabit) passive optical network technology to meet growing subscriber demand. However, in Ecuador, due to a lack of technical knowledge to reduce implementation costs, many of these ISPs deploy their fiber networks without Quality of Service (QoS) designs or subscriber growth. In this document, we propose specific and sequential sizing techniques for the ISP’s core equipment. This article can serve as a guide for future studies related to FTTH-GPON network design for segmentation and data traffic.

Keywords: Data traffic · FTTH · GPON · Subscriber’s growth · QoS

1 Introduction

At present, the technological progress in the telecommunications field is advancing with significant leaps. The average day for many individuals, in their personal and professional lives, require the use of technological tools for communication and information. Moreover, for these tools to be more effective, they depend on faster and reliable interchange of data frames [1].

In response to this growth, the Telecommunications Control and Regulation Agency (ARCOTEL, by its Spanish acronym) has issued permits to many small ISPs nationwide to satisfy the increased demand.

However, many of these ISPs deploy their Fiber To The Home – Gigabit Passive Optical Network (FTTH-GPON) networks with designs focusing solely on revenue rather than QoS, or even worse, preceding any method whatsoever. For these types of ISPs, their primary goal is to add more subscribers, in the short term, with minimal capital investment. Due to the absence of QoS design, this model jeopardizes the availability and speed of the service, over time, because the data traffic increases with the growth of subscribers and associated bandwidth [1].

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The rest of this article is created as follows: in Sect. 2, we present a review of the related work to previous studies of FTTH-GPON’s designing methods; in Sect. 3, we referred to a case study and the applied approach; in Sect. 4, we offer the results and discussion, and in Sect. 5 we present the conclusions and future work.

2 Related Work

We found several previous studies on the optimization of telecommunications networks that are related to fiber-optic network designs. Poon, K. et al. (2006) article: “Designing optimal FTTH and PON networks using new automatic methods”; described a hybrid method called: Expert System and Evolutionary Computing techniques; which was used to produce ‘most fit’ PON designs taking account the planning process, design factors and optimization goals.

Al-Quzwini, M. (2014) article: “Design and implementation of a Fiber To The Home FTTH access network based on GPON”; described a step-by-step design method of a protected GPON FTTH access network for 1,000 subscribers. Lokhande, M. & Singh, A. (2017) article: “Design and implementation of FTTH”; described a field implementation design for a GPON Network using computing tools such as GIS and AutoCAD.

And lastly, we used the core resulting data of a case study of one of our previous articles: “Data gathering methodological guide for designing FTTH-GPON networks with QoS” [7]; into the equipment sizing methodology of this article.

2.1 Architecture, Access Mode, and Encapsulation

The most used type of architecture in FTTH networks is Point to Multipoint (P2MP) using a tree topology and, within the network, passive optic elements (with no need of electrical source) to help distribute data frames to its subscribers [3].

FTTH-GPON adopts Time Division Multiplex (TDM) and Time Division Multiple Access (TDMA) technology for access mode to download and upload data, respectively [4].

Data encapsulation is done in two stages: the first one via GPON Encapsulation Method (GEM mode) to encapsulate Ethernet data frames, and the second by GPON Transmission Convergence (GTC) mode to encapsulate GEM, ATM, and TDM traffic [5].

2.2 Data Frame Download Operation

The Optical Line Terminal (OLT) encapsulates Ethernet, ATM, and TDM data, through GEM and GTC, to later on broadcast them in a chain of data frames to all Optical Network Terminal (ONT) units connected to the Optical Distribution Network (ODN) [3]. The chain of data frames is transmitted through fiber-optic threads, of the feeder cable, within the correspondent download wavelength following the ITU-T G.984 standard.

Once the chain of data frames reaches the first optic passive element (i.e., coupler or splitter), they are all distributed, alike, to all ONTs; meaning that the same information will receive the ONT1 like the ONTn. Downloaded data frames are structured by Physical
Control Block downstream (PCBd) and Payload (GEM Header and GEM/GTC data) [4]. In the chain of data frames, PCBd is used by each ONT to extract its corresponding Payload by TDM access mode.

The OLT sets the data period transmission value at 125\(\mu\text{s}\) per frame. If the OLT does not need to send downstream data, the chain of frames will still be transmitted to all ONTs for synchronization purposes [4].

2.3 Data Frame Upload Operation

For upstream data, the OLT generates a bandwidth map (BM), which establishes variable slots of time for each ONT to receive data frames. The length and position of these slots, within the BM, depends on the type of data traffic, classified by Class and Quality of Service (CoS, QoS) [5]. Once the BM is established, the ONTs send bursts of data frames, within their assigned time slots, to the OLT, which are queued and processed by the TDMA access mode according to CoS and T-CONTs frame [5].

Upstream data frames are structured by (Physical Layer Overhead upstream (PLOu), Alloc-IDs, Dynamic Bandwidth Report upstream (DBRu), and Payload [5]. Additionally, it can contain Physical Layer Operation, Administration, and Management upstream (PLOAMu) and Power Level Sequence upstream (PLSu) [4].

All of the ONTs, within the ODN, are installed in different physical locations; hence there may be cases where data framing collisions may occur caused by a delay time gap [5]. To prevent this from happening, the OLT executes a scoping process; once the ONT is registered in the ODN, it calculates a delay time based on the physical distance of each unit and then transmits this information to the other units. This process is called Equalization Delay (ED) [6].

3 Case Study and Method

3.1 Case Study

In Ecuador, a country located in Latin America, the number of fiber broadband subscribers has increased considerably from 2015 to 2019 (see Fig. 1) [2].

Fig. 1. Ecuador’s fiber broadband subscribers’ growth.
To show real case dimensioning, we had to refer to a case study of one of our previous articles: “Data gathering methodological guide for designing FTTH-GPON networks with QoS” [7]. Therefore, all calculations shown in this section are based on real and reliable data.

3.2 Methodology

![Fig. 2. Sizing methodology of OLT and ONT parameters.](image1)

![Fig. 3. Sizing methodology of ODN components.](image2)
The methodology of sizing the FTTH-GPON’s equipment is executed in two processes: A. OLT and ONT technical specifications; B. ODN technical specifications; as shown in Fig. 2 and Fig. 3.

4 Results and Discussion

A. OLT and ONT Technical Specifications

OLT Technical Parameters

1. First, calculate the optimal level of division of the OLT’s PON (Passive Optical Network) ports. The GPON Optical Line Terminal equipment can be configured in three splitting levels: 1:32, 1:64, and 1:128 (each PON port can provide service to 32, 64 and 128 subscribers). This process is where most ISPs, in the absence of QoS criteria, choose to provide service to more subscribers, with a single port, without paying attention to bandwidth and subscriber’s growth.

The optimal splitting level is calculated below with the following equation:

\[ BW_{proj} \leq \frac{DS_{GPON}}{SR} \]  

Where,

- \( BW_{proj} \) = Home Projected Bandwidth
- \( DS_{GPON} \) = GPON Downstream Rate
- \( SR \) = Split Ratio

Thus,

\[ BW_{proj} = BW_{actual} \cdot CO_{BW} \]  

\[ BW_{proj} = 20.00 \text{ Mbps} \cdot 1.43; \text{ Section 4.3 [7].} \]

\[ BW_{proj} = 28.60 \text{ Mbps} \]

1:128 splitting level verification:

\[ BW_{proj} \leq \frac{DS_{GPON}}{SR} \]  

\[ 28.60 \text{ Mbps} \leq \frac{2500 \text{ Mbps}}{128} \]

28.60 Mbps \( \leq 19.53 \) Mbps; It does not comply.
Hence, if the splitting level is configured to 1:128, each port could not provide an average $BW_{proj}$ of 28.60 Mbps to each of the 128 subscribers.

1:64 splitting level verification:

$$BW_{proj} \leq \frac{DS_{GPON}}{SR}$$

$$28.60 \text{ Mbps} \leq \frac{2500 \text{ Mbps}}{64}$$

$$28.60 \text{ Mbps} \leq 39.06 \text{ Mbps}; \text{ it does comply.}$$

For the case study [7], the 1:64 splitting level is optimal because it can provide an average $BW_{proj}$ of almost 40 Mbps to each of the 64 subscribers with a single PON port.

The calculations shown above are an effective technique of data traffic congestion relief because choosing a splitting level of 1:64 over a 1:128 lessens: GTC’s Payload and the period data transmission of the chain of frames. See Fig. 4.

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2. Now, the number of PON ports required to provide service to the projected population has to be calculated. An example of which is shown below:

$$Pop_{proj} = Pop_{actual} \cdot Co_{FTTH}$$

Fig. 4. Downstream data traffic relief.
\( Pop_{proj} = 21,517 \cdot 1.82; \) Sections 4.3 and 4.6 [7].  
\( Pop_{proj} = 39,160 \) subscribers

Thus,

\[
#PON = \frac{Pop_{proj}}{SR}
\]  \hspace{1cm} (6)

\( #PON \leq \frac{39,160}{64} \)
\( #PON = 611.87 \approx 612 \)

3. Once the number of PON ports is set, the QoS technical specifications must also be established [8, 9]:

- QoS: Bandwidth management, latency, jitter, and packet loss rate;
- QoS Model: DiffServ Model;
- DiffServ Components: Traffic classification, traffic policing and shaping, congestion management, congestion avoidance;
- ACL (Access Control List);
- Multi-level scheduling mechanism: HQoS (Hierarchical Quality of Service);
- Number of T-CONT: 16 per subscriber;
- Number of GEM ports: 3872 per PON port;
- Scalability: XG-PON1, XG-PON2, and NG-PON.

The specifications 1 to 5, detailed above, have to be software configured in the OLT, within the time range, with the most data traffic congestion occurs: 6 PM–9 PM, according to the case study [7].

GPON Technology allows a maximum physical distance of 20 km between OLT and ONT per PON port with the following ranges of link attenuation budgets [10]:

- Class A: 5 dB–20 dB (Splitting level 1:32).
- Class B: 10 dB–25 dB (Splitting level 1:64).
- Class B+: 13 dB–28 dB (Splitting level 1:64).
- Class C: 15 dB–30 dB (Splitting level 1:64).
- Class C+: 17 dB–32 dB (Splitting level 1:128).
- Class C++: 20 dB–35 dB (Splitting level 1:128).

For the case study [7], the following specifications are established [11]:

- Link Optical Budget: Class B+;
- Reach Method: RTD (Round Trip Delay) and EqD (Equalization Delay);
- The maximum distance between to ONTs in the same PON port: 40 km;
- Configuration of a quiet zone for RTD and EqD in the time zone: 6 PM–9 PM.
4. Results

Once the QoS technical specifications are set, the next step is to determine the brand, model, and the number of units needed to provide service. For the case study [7], the following specifications are set: Huawei, Model MA5800-X17, 3 OLTs, 41 slots Model H902GPHF with 16 PON ports [12].

Identification and Segmentation OLT Data Traffic

To easily identify a corresponding data traffic zone, the segmentation of PON ports must be executed. This process means that each port must provide service to only one area. However, it is expected, among several ISP’s FTTH designs, to provide service to many zones, regardless of proximity, to use the PON port’s full capacity.

This process can create complications, operation wise because it will make it difficult to accurately identify an affected port during service problems due to data congestion. On the other hand, the one-port-to-zone approach maximizes the efficiency of subscriber growth as it allows for proper planning for the next PON port. Calculations and results are shown below and in Fig. 5.

![Data traffic identification and segmentation.](image)

\[
\#\text{Subscribers}_{\text{PON}1} = 64 (X \text{ Zone})
\]

5. Then, \[
\#\text{Subscribers}_{\text{proj}}(X\text{Zone}) = \#\text{Subscribers}_{\text{PON}1} \cdot C_{\text{FTTH}}
\] (7)

\[
\#\text{Subscribers}_{\text{proj}}(X \text{ Zone}) = 64 \cdot 1.82 \\
\#\text{Subscribers}_{\text{proj}}(X \text{ Zone}) = 116.48 \approx 117
\]
Hence,
#SubscribersPON2 = 53(Xproj Zone); 11 subscribers left for CoBW.

**ONT Technical Parameters**

6. The QoS technical specifications for data traffic relief for the case study [7] are shown below [13]:

- Standard: ITU-T G.984.2 Class B+;
- Maximum reach: 20 km;
- Reception sensibility: $-27 \text{ dBm}$;
- The flexible mapping between GEM and T-CONT ports;
- BW map: SR-DBA (Status Reporting - Dynamic Bandwidth Allocation) y NSR-DBA (Non-Status Reporting – Dynamic Bandwidth Allocation);
- Broadcast packet rate limitation;
- Queue data traffic relieves SP (Strict Priority) and WRR (Weighted Random Robin).

In the QoS technical specifications, shown above, the reception sensibility and reach were determined with the ONT’s default parameters: $-27 \text{ dBm}$ and 20 km for maximum distance, respectively. However, for purposes of design efficiency, it is not recommended to use these values because they are geared towards maximum limits. Using alternative values is an excellent way to avoid future deficiencies in the service, especially during peak data traffic, because of collisions and loss of data frames.

7. The recommended value for the link attenuation budget is 25 dB, and the recommended length is shown in the next section [14].

8. Results

Once the QoS technical specifications are set, the next step is to determine the brand and model needed to provide service. For the case study [7], the following specifications are Huawei, Model HG8045H [13].

**B. ODN Sizing and Technical Specifications**

**ODN Technical Parameters**

This section shows the ODN’s link attenuation budget and the calculations to determine maximum distances: the feeder network, distribution, and drop networks; for a 1:64 splitting level.

1. At first hand, we have established the following:

\[ DpN(DropNetwork)length = 0.25 \text{ km}; \] For maintenance purposes [14].
2. For the Feeder Network (FN), the maximum length of a fiber cable reel is 5 km, and in the case study [7], the Central Office (CO) is located at \( \frac{3}{4} \) of a distance from the service area. Therefore, the Feeder Network’s (FN1) length is set at 4 km. For the extension of the Feeder Network (FN2), a maximum distance of 1 km has been determined.

Then,

\[
FN = FN_1 + FN_2
\]

\[
FN = 4.00\ km + 1\ km = 5.00\ km
\]

**Table 1.** Link attenuation budget for a splitting level 1:64 [13]

| Name              | Type               | Loss (dB) | Quantity | Total loss (dB) |
|-------------------|--------------------|-----------|----------|-----------------|
| Connection point  | Pigtail/Patchcord  | 0.50      | 4.00     | 2.00            |
|                   | Melt splicing      | 0.10      | 6.00     | 0.60            |
|                   | Quick connector    | 0.60      | 1.00     | 0.60            |
| Optical splitter  | 1:2                | 3.25      |          | 2.00            |
|                   | 1:4                | 6.50      |          | 19.50           |
|                   | 1:8                | 9.75      |          |                 |
|                   | 1:16               | 13.00     |          |                 |
|                   | 1:32               | 16.25     |          |                 |
|                   | 1:64               | 19.50     |          |                 |
| Optical cable     | 1310 nm (dB/Km)    | 0.35      | FN + DN + DpN |
| (G652.D)          | 1490 nm (dB/Km)    | 0.30      |          |
|                   | 1550 nm (dB/Km)    | 0.25      |          |
| **TOTAL**         |                    | **22.70** |          |

The ODN link attenuation budget, shown in Table 1, is broken down by element. The total attenuation loss, not including cables’ length, is 22.70 dB. The recommended total attenuation loss is at 25 dB, which leaves 2.30 dB left to calculate the physical cables’ lengths.

3. Given the values above, the following calculations must be used:

Loss for length of cable by km (1310 nm) = 0.35 dB.

\[
\text{dB left to recommended link attenuation budget} = 2.30\ dB.
\]
Therefore,

\[ \text{Km Cable ODN} = \frac{\text{dB left}}{\text{Loss km}} 1310 \text{ nm} \tag{9} \]

\[ \text{Km Cable ODN} = 2.30 \frac{\text{dB}}{0.35 \text{ dB}} \]
\[ \text{Km Cable ODN} = 6.57 \]

Where,
\[ DpN = 0.25 \text{ km} \]

Hence,

\[ \text{KmODN} = FN + DN + DpN \tag{10} \]

\[ DN = \text{Km ODN} - FN - DpN \]
\[ DN = 6.57 \text{ km} - 5.00 \text{ km} - 0.25 \text{ km} \]
\[ DN = 1.32 \text{ km} \]

**Feeder Network Technical Capacity (FN)**

To calculate the capacity of the fiber power cables, the total number of PON ports for the OLTs is needed. In this case study [7], it is determined using the criterion:

\[ \#\text{Fibers}_{\text{proj}} (FN) = \#\text{PON}_{\text{ports}}; \text{ from (4)} \]
\[ \#\text{Fibers}_{\text{proj}} (FN) = 612 \]

To calculate the number of feeder cables needed, segmentation by zones of the area of service is required. In the case study [7], based on the location of the CO, the area was segmented in 5 zones: Miravalle, Jacaranda, Cumbaya Central, San Juan de Cumbaya, and La Primavera.

4. Thus,

\[ \#\text{FiberCapacity}_{\text{proj}} (FN) = \frac{\#\text{Fibers}_{\text{proj}} (FN)}{\text{Zones}} \tag{11} \]

\[ \#\text{FiberCapacity}_{\text{proj}} (FN) = \frac{612}{5} \]
\[ \#\text{FiberCapacity}_{\text{proj}} (FN) = 122.40 \text{ fibers (This value is not standardized).} \]

Then,

\[ \#\text{FiberCapacity}_{\text{proj}} (FN) = 144 \text{ fibers} \]

The FN will need five cables with a capacity of 144 fibers for each line. Note, although in the calculations above contemplate the feeder cable only requiring 123 fibers, it is highly recommended to have redundant threads. For the zone “Sector Central,” the results
of the surveys showed less interest in having an FTTH-GPON service [7], so for this sector, the feeder cable will only need 96 threads.

The segmentation and identification of data traffic of the FN is shown below in Fig. 6.

**Distribution Network Technical Capacity (DN)**

5. To calculate the capacity of the cables of the DN, for the case study [7] Sect. 4.3, it is necessary to use the number of projected subscribers and the optimal splitting level. Additionally, in the subsection “Identification and segmentation of OLT data traffic” of this article, it has been stated that one PON port will be used for present data traffic and another PON port for future data traffic, for one specific zone. Therefore, each PON port
will provide service to eight NAPs, and each one of these will provide service to eight subscribers.

However, because of CoFTTH (subscriber’s growth), the SSC and each NAP will have space to install one more 1:8 splitter (next PON port), as shown in Fig. 7.

Consequently, the cable’s capacity for the DN is 24 fibers: 8 fibers to provide service to present subscribers, 8 for future subscribers, and 8 for redundancy purposes. The redundancy component is recommended by Ecuador’s National Corporation of Telecommunications (CNT EP, by its Spanish acronym) [14].

\[ \text{FiberCapacity}_{\text{proj}}(\text{DN}) = 24 \text{ fibers} \]

6. Results

The ODN architecture will have two splitting levels of 1:8 (1:64 in total). The first splitting level is located at the Splitting and Splicing Closure (SSC) and the second at the Network Access Point (NAP). This process is shown in Fig. 8.
5 Conclusions and Future Works

This article helps demonstrate that the determination of the technical specifications of the core equipment of the FTTH-GPON network has to comply with adequate sizing for the handling and growth of data traffic, with calculations with real and reliable data from accredited sources. No technical parameters were calculated empirically.

Determining the make and model of an OLT requires meeting all technical specifications for current and future data traffic management rather than selecting by the number of PON ports and slots, which is a common error in most designs.

The identification and segmentation of data traffic in the OLT and ODN is of vital importance to solve, in a timely and efficient manner, problems such as congestion, collision, or packet loss.

As future work, we want aim at: 1) conduct a research related to the pandemic caused by the SARS-COV2 virus, which has generated the growth of FTTH-GPON subscribers and Internet bandwidth in Quito, Ecuador; 2) study how this subscriber growth affects the sizing of the GPON core equipment.

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