# Gigabit Passive Optical Network - GPON

Ivica Cale
*T-HT d.d., Split, Croatia*
*ivica.cale1@t.ht.hr*

Aida Salihovic
*University Computing Centre, University of Zagreb, Croatia*
*aida.salihovic@srce.hr*

Matija Ivekovic
*RECRO-NET d.o.o., Zagreb, Croatia*
*mivekovic@recro-net.hr*

**Abstract**. *New services like Television (IPTV) and Video on demand (VoD) over internet together with High Speed Internet access (HSI) have demand for very high bandwidth to customers. XDSL have some form which can satisfy bandwidth demand (VDSL2) but have restriction regarding distance.*

*Probably only suitable solution for high bandwidth demand with a long reach is using optical cable to customers (FTTx). One of the ways is using some type of Passive Optical Network (PON). Gigabit PON (GPON) is the most often type used by European and US providers (in addition with APON and BPON) while providers in Asia predominantly use EPON/GePON.*

*This paper provides an overview of Gigabit PON and analyses network architecture, transmission mechanisms and power budget in GPON systems.*

**Keywords.** PON, GPON, HSI, IPTV, VoD

## 1. Introduction

Passive Optical Networks (PON) technologies are available since the mid 90s, but in the last few years standards have matured and commercial standards are being implemented. First of all PON was, ATM PON (APON) which evolved in Broadband PON (BPON). BPON is backward compatible with APON. Ethernet PON (EPON and newer GePON) is alternate solution for PON networks. It is IEEE standard not compatible with A/BPON. It is PON exclusively for Ethernet and IP traffic.

Gigabit Passive Optical Network (GPON) is defined by ITU-T recommendation series G.984.1 through G.984.4. GPON has enhanced capability comparing with APON and BPON and is backward compatible. G.984 standard series define general characteristics of GPON (G.984.1) as well as physical layer specification (G.984.2), transmission layer specification (G.984.3) and ONU (Optical Network Unit) management and control specification (G.984.4). GPON can transport not only Ethernet, but ATM and TDM (including PSTN, ISDN, E1 and E3) traffic by using GPON encapsulating method (GEM).

## 2. GPON fundamentals

Active transmission equipment in GPON network consists only of Optical Line Termination (OLT) and Optical Network Unit (ONU). Figure 2.1 shows logical network architecture with different FTTx options.

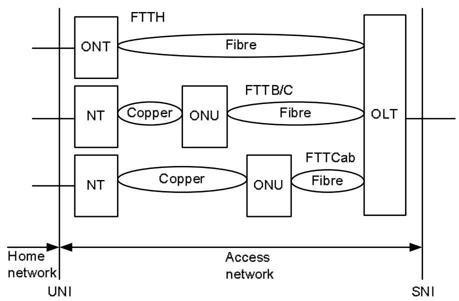


**Figure 2.1. FTTx network architecture**

Starting at the central office, only one single-mode optical fiber strand runs to a passive optical power splitter near users' locations



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(Figure 2.2). At this point the splitting device simply divides the optical power into N separate paths to the subscribers. The number of splitting paths can vary from 2 to 64. From the optical splitter, individual single-mode fiber strand run to each user (home, businesses, etc.). The optical fiber transmission span from the central office to the each user can be up to 20 km.

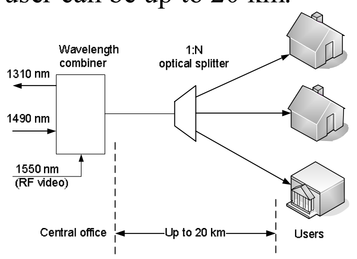


**Figure 2.2. Typical GPON architecture**

GPON standard defines a lot of different line transmission rates for downstream and upstream direction.

**Table 1. GPON Nominal bit rate**

| Transmission direction | Bit rate |
|---|---|
| Downstream | 1244.16 Mbit/s |
| | 2488.32 Mbit/s |
| Upstream | 155.52 Mbit/s |
| | 622.08 Mbit/s |
| | 1244.16 Mbit/s |
| | 2488.32 Mbit/s |

Although all combination are possible (except downstream 1.2 Gbit/s and upstream 2.4 Gbit/s), the most often vendors offers only 1.2 Gbit/s in upstream and 2.4 in downstream direction.

## 3. GPON features

### 3.1. Operating wavelength

The operating wavelength range is 1480-1500 nm for the downstream direction and 1260-1360 for upstream direction. In addition, the wavelength range 1550-1560 nm can be used for downstream RF video distribution.

### 3.2. Forward error correction

Forward Error Correction (FEC) is a mathematical signal-processing technique that encodes data so that errors can be detected and corrected. With FEC, redundant information is transmitted along with the original information. The amount of redundant information is small so FEC doesn't introduce a lot of overhead. FEC results in an increased link budget by approximately 3-4 dB. Therefore, higher bit rate and longer distance from the OLT to the ONU can be supported, as well as higher number of splits per a single PON tree.

### 3.3. Transmission containers

Transmission containers (T-CONT) are used for the management of upstream bandwidth allocation in the GPON. T-CONTs are primarily used to improve the upstream bandwidth use on the GPON. ONU sends traffic using one or more T-CONTs. T-CONTs enable Quality of Service (QoS) implementation in upstream direction.

There are five T-CONT types which can be allocated to user. T-CONT 1 guarantees fixed bandwidth allocation for time-sensitive applications (VoIP). T-CONT 2 guarantees fixed bandwidth allocation for not time-sensitive applications. T-CONT 3 is mix of minimum guaranteed bandwidth plus additional non-guaranteed. T-CONT 4 is best effort, dynamically allocated without any guaranteed bandwidth. T-CONT 5 is mix of all service categories.

### 3.4. Dynamic bandwidth allocation

Dynamic bandwidth allocation (DBA) is a methodology that allows quick adoption of user's bandwidth allocation based on current traffic requirements. DBA is controlled by OLT, which allocates bandwidth volume to ONUs. This technique works only in upstream direction, in downstream direction traffic is broadcasted.

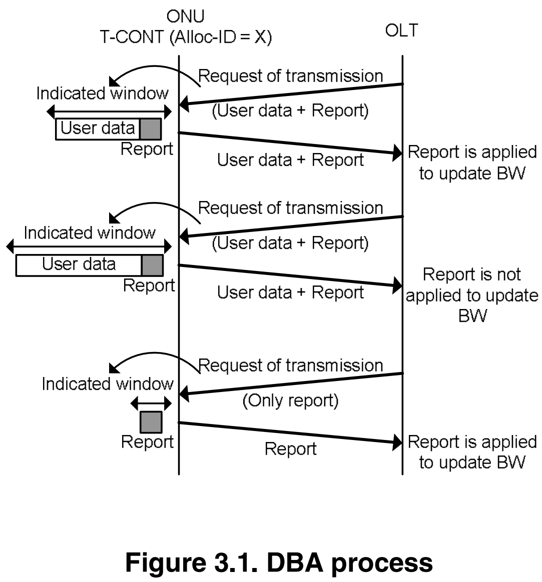


**Figure 3.1. DBA process**

To determine how much traffic to assign to an ONU, the OLT needs to know the traffic status of the T-CONT associated with the ONU. In status reporting method, as part of its traffic status a T-CONT indicates how many packets are waiting in its buffer. Once the OLT receive this information, it can reapportion the grants to various ONUs accordingly. When an ONU has no information waiting to be transported, upon receiving a grant it sends an idle cell upstream to indicate that its buffer is empty. This informs the OLT that the grants for that T-CONT can be assigned to other T-CONTs. If an ONU has a long queue waiting in its buffer, the OLT can assign multiple T-CONTs to that ONU.

### 3.5. Security

The basic functionality of GPON is that downstream data are broadcasted to all ONUs and every ONU have allocated time when data belongs to him (TDM like). Because of that, some malicious user can reprogram his own ONU and capture all downstream data belonging to all ONUs connected to that OLT. In upstream direction GPON uses point-to-point connection so all traffic is secured from eavesdropping. Because of that, every confidential upstream information, like security key, could be sent in clear text.

Thus, the GPON recommendation G.984.3 describes the use of an information security mechanism to ensure that users are allowed to access only the data intended for them. The encryption algorithm to be used is the Advanced Encryption Standard (AES). It accepts 128, 192, and 256 byte keys which makes encryption extremely difficult to compromise. A key can be changed periodically without disturbing the information flow to enhance security.

### 3.6. Protection

The protection architecture of GPON is considered to enhance the reliability of the access networks. However, protection is considered as an optional mechanism because its implementation depends on the realization of economical systems.

There are two types of protection switching, Automatic switching and Forced switching. The first one is triggered by fault detection, such as loss of signal, loss of frame, signal degrade and so on. The second one is activated by administrative events, such as fiber rerouting, fiber replacement, etc.

## 4. GPON transmission

GPON uses GEM (GPON Encapsulation Method) as a method which encapsulates data over GPON. Although any type of data can be encapsulated, actual types depend on service situation. GEM provides connection-oriented communication. This method is based on slightly modified version of the ITU-T recommendation G.7041 Generic framing procedure (specification for sending IP packets over SDH networks)

### 4.1. Downstream GPON Frame format

Downstream traffic is broadcasted from the OLT to all ONUs in TDM manner. Every ONU must take into account only frames intended for him what is assured by encryption. The downstream frame consists of the physical control block downstream (PCBd), the ATM partition and the GEM partition. The downstream frame provides the common time reference for the PON and provides the common control signaling for the upstream.

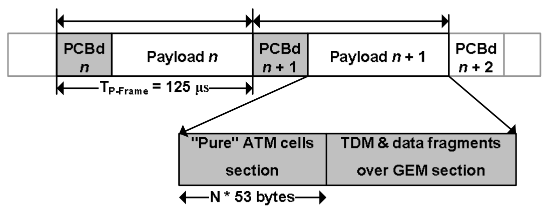


**Figure 4.1. Downstream GPON frame**

A diagram of the downstream frame structure is shown in Figure 4.1. The frame is 125 μm for both downstream data rates. The PCBd length range is the same for both speeds and depends on the number of allocation structures per frame. If there is no data for sending, downstream frame is still transmitted and used for time synchronization.

### 4.2. Upstream GPON Frame format

Upstream traffic uses TDMA, under control on the OLT located at the CO, which assigns variable time length slots to each ONU for synchronized transmission of its data bursts.

The upstream frame consists of multiple transmission bursts. Each upstream burst contains at a minimum the Physical Layer Overhead (PLOu). Besides the payload, it may also contain the PLOAMu (Physical Layer Operations, Administration and Management upstream), PLSu (Power Leveling Sequence upstream) and DBRu (Dynamic Bandwidth Report upstream) sections.

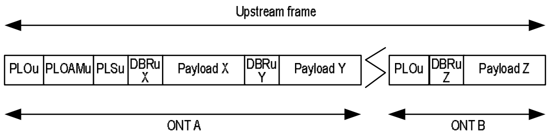


**Figure 4.2. Upstream GPON frame**

A diagram of the upstream frame structure is shown in Figure 4.2. The frame length is the same as in the downstream for all rates. Each frame contains a number of transmissions from one or more ONUs. The BWmap dictates the arrangement of these transmissions. During each allocation period according to the OLT control, the ONU can send from one to four types of PON overheads and user data.

## 4.3. T-CONT

T-CONTs are a PON-layer mechanism for upstream QoS whereby services of the same CoS type as determine by Layer 2 and Layer 3 methods use the same T-CONT type.

In the upstream direction, the bandwidth to be used by individual ONU not only depends on the traffic scenario at concerned ONU, but also on the traffic pattern at other ONUs in the network. As the medium is shared, any self-initiated transfer by any ONU in upstream direction would result in collision and retransmission causing degraded performance. Therefore, this shared media is made to behave as multiple point-to-point connections between an ONU and an OLT by use of TDMA. The OLT, being the central point, is told about the bandwidth demand at each ONU. Based on the traffic pattern at all the ONUs it grants access to the ONU at fixed slot with respect to downstream frame. For the upstream traffic, the frame can be considered to be divided into different container types. There are five types defined in GPON. Type-1 T-CONT service is based on unsolicited periodic permits granting fixed payload allocation or catering to fixed bandwidth requirements. This is a static T-CONT type and is not serviced by DBA. Type-2 T-CONT is intended for variable bit rate with bounded delay and jitter requirements like video and voice over IP. Type-3 T-CONT is intended for guaranteed delay. Type-4 T-CONT is for the best effort traffic. Type-5 T-CONT is combined for two or more of the other four types defined above and in this case the individual bandwidth reporting and assignment is done at the ONU.

The client traffic, queues, T-CONT mapping and reporting is shown in Figure 4.3.

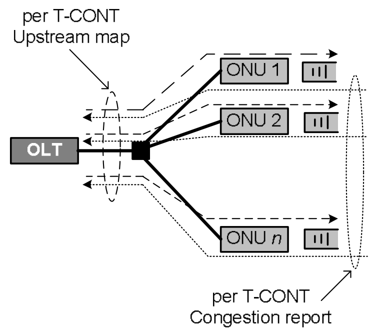


**Figure 4.3. T-CONT mapping and reporting**

## 4.4. GEM Segment

GPON supports two methods of encapsulation: the ATM and GPON encapsulation method (GEM). With GEM, all traffic is mapped across the GPON network using a variant of SONET/SDH generic framing procedure (GFP). GEM supports a native transport of voice, video, and data without an added ATM or IP encapsulation layer. GPON supports downstream rates as high as 2.5 Gbits/sec and upstream rates from 155 Mbits/sec to 2.5 Gbits/sec.

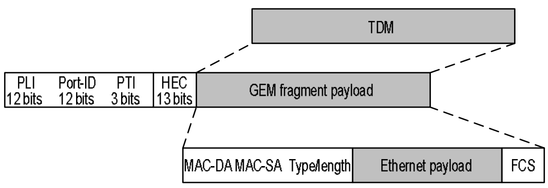


**Figure 4.4. GPON encapsulation method**

## 5. Optical Splitter

The typical PON connects a single fiber from an Optical Line Terminal (OLT) to multiple Optical Network Units (ONUs). The point-to-multipoint connectivity between OLT and multiple ONUs is obtained using one or more passive branching devices in the fiber path.

At the hart of a PON is a passive optical splitter. This device has a single input and multiple outputs. Typically the number of outputs is $2^n$ (e.g. 2, 4, 8, etc) and the optical power is split evenly between outputs. As a rule of thumb the optical power at each output is reduced relative to the input by a factor of $n$ x 3.5 dB ($10 \log 2^n = n \cdot 10 \log 2$; 0.5 dB are added to include losses in splitter).

An optical splitter is a bi-directional device. Because of this the splitter is sometimes referred to as a splitter/coupler. The optical signal is attenuated by the same amount ~ ($n$ x 3.5 dB) for both directions.

There are two techniques for manufacturing splitters: Fused Biconical Taper (FBT) and Planar Lightwave Circuit (PLC). A 1x2 FBT splitter is made by precisely fusing two fibers together. Higher split ratios are achieved by cascading multiple 1x2 splitters. A PLC splitter consists of a microscopic optical circuit that is typically etched in silicon.

### 5.1. Splitting loss

One of the key parameters for every FTTH network designer is the achievable span between the central office and the subscribers, in other words, the maximum optical budget allowed in the system. The optical budget is comprised of attenuation from splices, connectors, the transmission fiber and the optical splitters. The optical splitter is by far the most demanding component in terms of losses (a typical 1x32 optical splitter insertion loss could range between 17 dB and 18 dB).

## 6. Architecture of optical access network (link budget)

Typical PON is composed of OLT and ONUs and optical distribution network (ODN) which constitutes the optical transmission media for the connection OLT to ONUs. The ODN's characteristics such as losses are very important in designing optical access network. Normally it consists of the following passive optical elements: single mode optical fibers, optical fiber connectors, passive branching components, passive optical attenuators and splices. Optical path losses are associated with above elements.

The link budget is given in Table 2. This budget covers all optical components between OLT and ONU.

**Table 2. Loss budget for the GPON system**

| Items | Unit | Path loss |
|---|---|---|
| Minimum optical loss 1490 nm | dB | 13 |
| Minimum optical loss 1310 nm | dB | 13 |
| Maximum optical loss 1490 nm | dB | 28 |
| Maximum optical loss 1310 nm | dB | 28 |

### 6.1. Power Budget

The transmitter's power and receiver's sensitivity are two parameters that define the possible reach of the access network. In Table 3. typical parameters of commercially available burst mode transceivers capable of supporting 1.25 Gbps are shown. To calculate the worst case scenario power budget the minimum receiver sensitivity is subtracted from the minimum transmitter power. For these devices the available power budget is around 22 dB and 23 dB typically. Based on these values the total loss in the network is known and the maximum reach of the network can be calculated from (1), where P is power budget, FCA is Fiber Cable Attenuation in dB/m, L is a distance and SL is a splitter loss.

$$P = FCA \cdot L + SL + Penalties \qquad (1)$$

Penalties stand for additional costs such as losses at splices and connectors. The typical attenuation of a single mode fiber is about 0.4 dB/m for a wavelength of 1310 nm and 0.3 dB/m for 1550 nm (ITU-T Rec. G.652.C and G.652.D).

As an example, assuming that the power budget is equal to 23 dB, a single mode fiber operating at the wavelength of 1550 nm is used, SL is 14 dB and there are two mechanical splices and two connectors, the maximum reach of the network can be calculated from (1):

$$\frac{23[dB] - SL - 2 \cdot 0.5[dB] - 2 \cdot 0.5[dB]}{FCA\left[\frac{dB}{km}\right]} \approx 20km$$

The minimum power budgets for typical configurations of PONs are shown in Table 3.

**Table 3. The minimum Power Budget for different PON configuration**

| ONUs | L | λ | FCA | SL | Penalties | Required Power Budget |
|---|---|---|---|---|---|---|
| 16 | 10km | 1310nm | 0.4dB/m | 14.5dB | 2.5dB | 21dB |
| 16 | 20km | 1550nm | 0.3dB/m | 14.5dB | 2.5dB | 23dB |
| 32 | 10km | 1310nm | 0.4dB/m | 17dB | 2.5dB | 23.5dB |
| 32 | 20km | 1550nm | 0.3dB/m | 17dB | 2.5dB | 25.5dB |

## 7. Summary of GPON characteristics

- Performance

GPON supports several line rates for the upstream and downstream directions. It also supports legacy ATM and packet-based transport. It even has an efficient Ethernet transport capability, i.e. some of the Ethernet overhead is extracted during the encapsulation process. Additionally, GPON supports packet fragmentation, enabling efficient utilization of transport media. GPON provides adequate bandwidth and QoS for the residential customers and small businesses and some of the large enterprise services can also be supported.

- Services

GPON is planed to support efficiently legacy, current and future services. This is enabled by the GEM encapsulation method, which can be enhanced to support future technologies. In respect to scalability, GPON overcomes EPON with several line rate options and, especially, with the larger offered bandwidth. Security can be implemented with different encryption techniques, among which AES is the most advanced one. For the traffic provisioning, GPON uses 12-bit port IDs as are used for the Ethernet VLAN and ATM virtual channel identification.

- Video services (IPTV, CATV)

IPTV provides video service based on IP multicast. At the source end, different program sources are configured with different multicast addresses, and reach the ONU device through a series of broadcast servers.

In CATV mode, analog signals of traditional TV programs are transmitted over the cables. Through electrical-to-optical conversion, video stream is converted into downstream optical waves on the OLT, and then superposed with downstream optical waves of the GPON in WDM mode (RF video - 1550nm). The superposed waves are transmitted in downstream through an optical fiber. After these waves reach the ONUs/ONUs, video signals are separated to provide video services.

- Cost-efficiency

In respect of cost, GPON cannot compete with EPON, due to the tighter physical requirements of the transport components. GPON is the most complex of all the PONs bringing challenges to the maintenance. The remote maintenance follows the same standard as is used in SDH/SONET networks, already familiar to operators world-wide.

- Convergence

GPON has the best support of all the PONs for heterogeneous networking. The most important advantage of GPON is the GFP based adaptation layer, which is capable of supporting any service whether it is packet or circuit oriented.

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