

GPON is more than just a faster PON

Although GPON's most famous feature is its downstream rate of 2,488 Mbits/sec, it is GPON's architecture and upstream quality-of-service (QoS) functions that offer real transport capability for high-quality voice, high-bandwidth IPTV, and data along with support for legacy business services. Yet, as with any emerging technology, questions naturally arise in the minds of carriers who are evaluating the technology. For example, although GPON is considerably faster than other TDM PONs, is it fast enough? Does it have the right QoS mechanisms to ensure that upstream high-speed services don't starve high-QoS applications? A close look at GPON's attributes answers these questions.

Downstream: The need for speed

The primary driver for GPON is the expected consumer bandwidth demand for IP-based standard-definition TV (SDTV) and particularly high-definition TV (HDTV) services. Reports indicate that nearly 60% of all homes in the United States will have HDTV sets by 2010.¹ It then becomes obvious that HDTV content will begin to dominate TV programming shortly thereafter. While an SDTV channel with MPEG2 encoding requires ~3 Mbits/sec of capacity, HDTV needs ~18 Mbits/sec—and thus will very quickly consume PON downstream capacity. The question is, how fast must a PON be to support a mix of IPTV content and still provide basic IP services such as voice and high-speed Internet?

This question is not simple to answer. It depends on factors such as demographics; take rate; whether traffic transmission is broadcast, multicast, or unicast; and network planning. Without attempting any IPTV traffic modeling, a simple capacity usage model can be created to establish how many subscribers can be supported or are available for basic high-speed Internet and voice services if a given number of IPTV channels are on the PON for a given a mix of SDTV and HDTV content. The model simply sets the mix of IPTV channels on the PON and calculates the corresponding number of subscribers that can be serviced with the remaining bandwidth. For illustrative purposes, GPON at 2,488 Mbits/sec will be compared to the popular EPON of 1.25 Gbits/sec.

The assumptions for this simple model are:

- HDTV channel = 18 Mbits/sec
- SDTV channel = 3 Mbits/sec
- GPON downstream rate = 2,488 Mbits/sec × 92% efficiency = 2289 Mbits/sec
- EPON downstream rate = 1250 Mbits/sec × 72% efficiency = 900 Mbits/sec (For an explanation of how these efficiency percentages were derived, see Table 1 in "GPON vs. EPON: A Cost Comparison," *Lightwave*, September 2005, page 27.)
- High-speed Internet = 100 Mbits/sec per subscriber with 20:1 oversubscription
- Voice over IP (VoIP) will not be considered since the most bandwidth used per channel is only 100 kbits/sec and has a negligible effect on the outcome.

The results of the model as seen in Figure 1 illustrate how drastically the number of subscribers supported drops when HDTV content increases—particularly with EPON. For example, with 45 SDTV and 5 HDTV channels on the PON, EPON can service up to 135 subscribers with high-speed Internet while GPON can support up to 413. However, as the video content goes to 100% HDTV with 50 video channels on the PON, EPON's downstream capacity is exhausted while GPON can still guarantee high-speed Internet service to 278 subscribers.

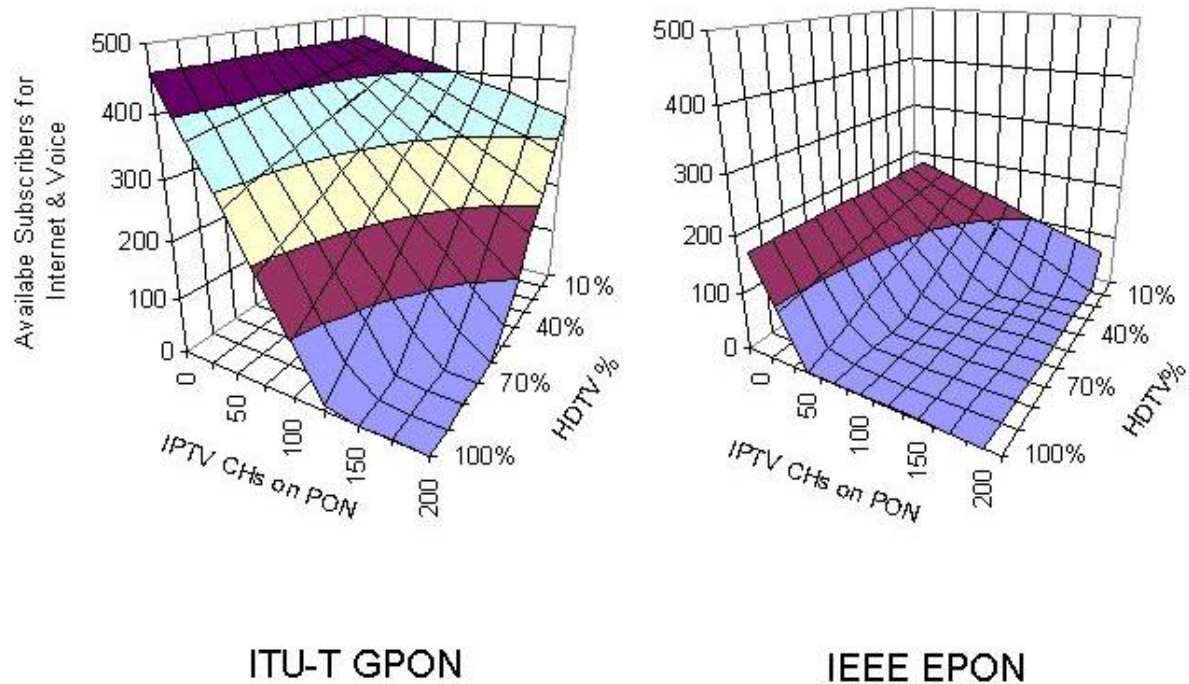


Figure 1 The more HDTV streams there are, the fewer subscribers can enjoy high-speed Internet access. GPON provides greater overall bandwidth than EPON; therefore, it can support a greater number of subscribers with combined HDTV/Internet service offerings.

Using this example in a multiple-dwelling-unit (MDU) application, with a split ratio of 1:32, GPON can support basic high-speed Internet service and voice to 32 optical network units (ONUs) supporting eight subscribers each (i.e., $278 \div 32$). Statistically, the number of subscribers can be even more and will depend on the technical and business practices of the service provider.

However, it is anticipated that there will be many more TV channels to the home due to multiple picture-in-picture viewing for sporting events, digital video recording (DVR), and all this TV content going to more than one TV set per home. Even in a single-family-unit (SFU) network with a split ratio of 1:32, EPON will be stretched to guarantee basic high-speed Internet service in an HDTV-rich PON. Fundamentally, it is GPON's efficient 2,488-Mbit/sec downstream transport that is the enabler for IPTV delivery with sufficient capacity for HDTV, even for an MDU PON.

Upstream: Guaranteeing QoS

Many see IPTV as not just a technology change but an entirely new service type—a video experience offering two-way entertainment, gaming, commerce, and communications. These two-way, high-speed services require QoS mechanisms that will challenge the upstream TDMA capability of a PON. Also, legacy business services such as TDM require robust, low-latency, low-jitter performance with the same transport protection that service providers offer with their current architectures. The ITU G.984 GPON standard not only supports redundancy but provides an intrinsic PON-layer QoS mechanism

that goes beyond Layer 2 Ethernet and Layer 3 IP class-of-service (CoS) methods to ensure delivery of high-quality voice, video, and TDM data over a TDMA-based shared media.

Without question, Ethernet is the delivery mechanism for a converged access network delivering IP services. As a result, Ethernet has evolved to include service-delivery technology that supports the various CoS requirements for video, voice, and data. IEEE 802.1p was developed to establish service priority levels and 802.1q was devised to support VLAN tagging for establishing specified transmission links within an Ethernet network for those services.

However, Layer 2 and Layer 3 CoS mechanisms will only be as good as the QoS of the transport. If the transport is subject to latency and jitter, so the services will be no matter how they are prioritized. For TDMA PON, the upstream QoS capabilities become the issue when all of the ONUs on the PON compete for upstream capacity and priority in a TDMA fashion. Although the GPON upstream data rate throughput of 1.25 Gbits/sec is 20% higher than EPON, it is GPON's upstream QoS mechanisms that truly differentiate it.

EPON uses Ethernet as the service/transport vehicle for IP. However, to preserve the basic architecture of Ethernet in a PON architecture, the logical link ID (LLID) concept was added as part of the emulation of point-to-point and broadcast Ethernet. Thus, each ONU will be assigned at least one LLID.² Each EPON ONU is responsible for prioritizing its upstream traffic based on Layer 2 or Layer 3 CoS mechanisms and then bursting this traffic in its designated time slot with an LLID in the upstream TDMA link (see Figure 2).

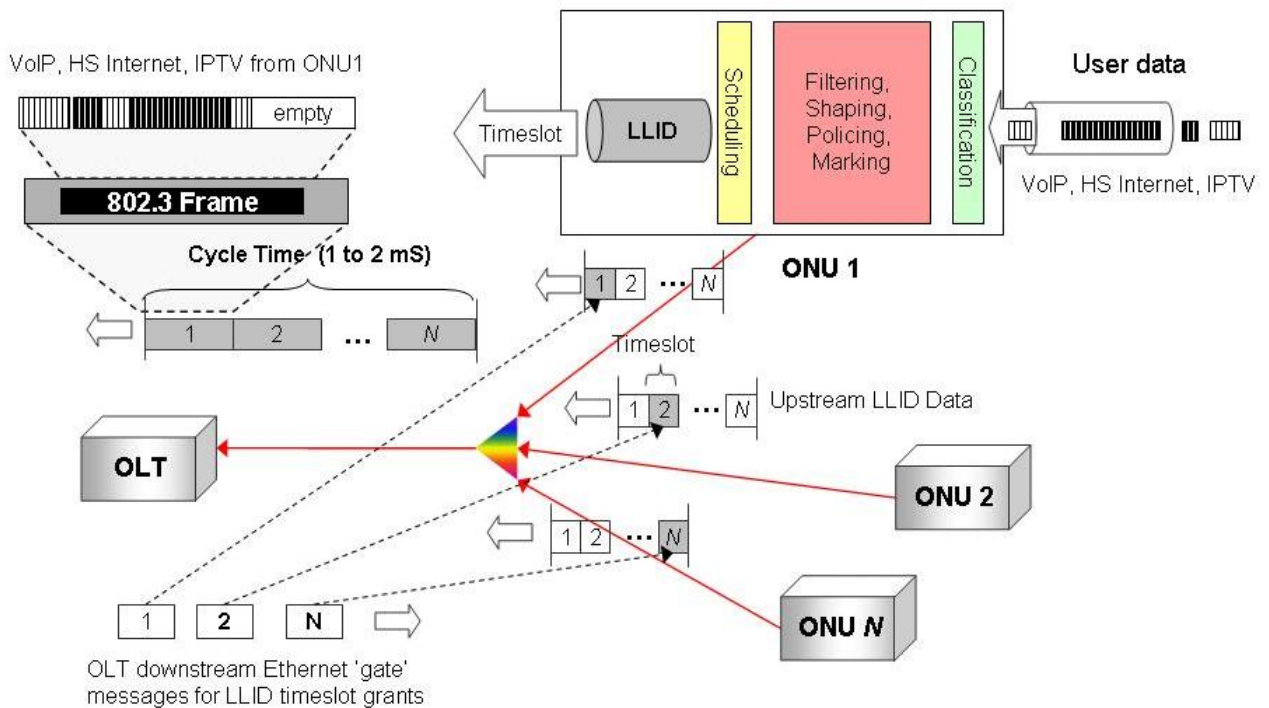


Figure 2 EPON provides a mechanism for delivering quality of service based on class-of-service mechanisms. But these mechanisms can consume valuable bandwidth capacity.

Each ONU accesses the PON uplink within its burst time slot, taking its turn in a cycle with the other ONUs. This timing is determined by the optical line terminal (OLT). The number of ONUs on the PON will determine the cycle time, which should typically be 1 to 2 msec. This cycle time will be the dominant contributor to service delivery delays on the PON as well as to bandwidth utilization efficiency. Setting the cycle time too large will increase the delay; setting it too small will result in bandwidth waste due to guard intervals and a high ratio of unused fragmented bandwidth allocations.

Although fixed time slots are shown in Figure 2, dynamic bandwidth allocation (DBA) is used to grant bandwidth to ONUs based on their demand and service-level agreement (SLA). The OLT will grant ONUs an increase in their slot time for more bandwidth while granting a reduced slot time to others. In EPON, the LLID is the granted entity for upstream bandwidth. The granting is done by in-band packet-based messages directed to an LLID that are limited in size. To allocate multiple time slots with fine granularity, the DBA will require frequent messages downstream, which consumes downstream bandwidth. As a result, it is very challenging to support small granting cycles.

As can be seen in this single-LLID-per-ONU approach, a bandwidth grant is given per ONU for all its services, with the ONU responsible for scheduling its services based on CoS mechanisms without any knowledge of capacity on the PON. As a result, fairness becomes an issue in a highly utilized EPON, as high-priority user data on one ONU may receive less bandwidth than low-priority user data on another ONU.³ To overcome this issue, a more CoS-centric EPON was developed by assigning an LLID to each CoS on each ONU. Thus, DBA will assign time slots based on the service type per ONU. The price paid for this multiple LLID EPON implementation is the considerable loss of revenue bandwidth in both the downstream and upstream due to the increase of in-band messaging.⁴

The fundamental difference between EPON and GPON is that GPON is a transport technology for Ethernet as well as TDM and ATM. Also, GPON uses an out-of-band bandwidth allocation map with the concept of traffic containers (T-CONTs) as the upstream-granted entity. The downstream and upstream frame timing is the standard telecom 8 kHz, and services are encapsulated into frames in their native format by a process called GPON encapsulation mode (GEM). As in SONET/SDH, GPON supports protection switching in less than 50 msec.

The key aspect of GPON's low-latency capability is that all upstream TDMA bursts from all ONUs can occur within an 8-kHz frame (125 μ sec) as illustrated in Figure 3. Each downstream frame includes an efficient bandwidth allocation map that is broadcast to all ONUs and can support a fine granularity of bandwidth allocation. This out-of-band mechanism enables the GPON DBA to support very small grant cycles without compromising bandwidth utilization.

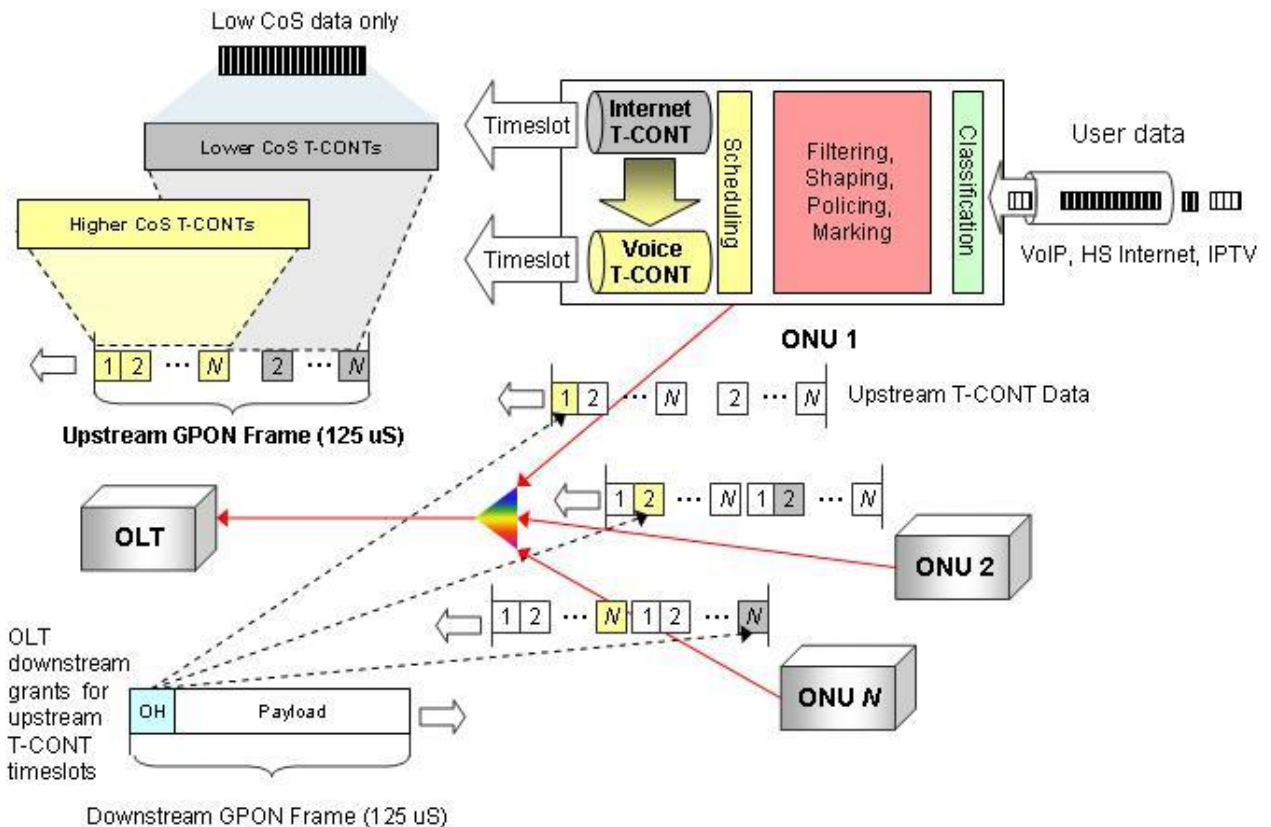


Figure 3 GPON's QoS/CoS capabilities are more bandwidth-efficient than EPON's. They also support fragmented payloads.

T-CONTs are a PON-layer mechanism for upstream QoS whereby services of the same CoS type as determined by Layer 2 or Layer 3 methods use the same T-CONT type. Thus, voice services will be assigned to a voice T-CONT by the ONU and best-effort data will be assigned to best-effort T-CONTs. DBA ensures that T-CONTs with a higher CoS, such as voice, get priority access on the PON and preempt lower-CoS T-CONTs, such as Internet data. This is similar in concept to the multiple LLID implementation in EPON, where each CoS is mapped into its perspective T-CONT, but without the excessive loss of bandwidth. T-CONT size and timing are then allocated on the PON by the OLT based on the CoS demands and resources on the PON.

GEM also supports fragmented payloads, which are not allowed in EPON. Thus, a low-CoS T-CONT can stop its upstream burst in the middle of a payload, allow a higher-CoS T-CONT its access, and then resume its transmission when told to by the DBA mechanism. Thus, in a highly utilized PON, large bursts of low-priority, best-effort data will have minimal affect on high-priority, delay-sensitive traffic like voice and TDM.

Driving safely to convergence

Ultimately, for a unified, low-cost network, all services will converge to IP delivered via Ethernet. The question is, how do you get there while supporting current legacy services? The answer in the optical

access network is GPON. Only GPON enables service providers to migrate their legacy TDM and ATM technology to 100% Ethernet. Conversely, with EPON as the optical access technology, the decision is immediate—all services must be Ethernet. Even with TDM circuit emulation service (CES), GPON still offers significantly better transmission performance over EPON due to CoS T-CONT assignments.⁵

As with BPON, the comprehensive nature of the ITU-T G.984 GPON standard provides the means for industry-wide interoperability of optical components, chips, and equipment. The global success of DSL can be attributed to interoperability because it enabled low-cost, high-volume commodity customer-premises equipment, which in turn has allowed service providers to deliver low-cost services. The same should prove true for GPON.

GPON is more than just a faster PON technology. Not only does it have the speed to support IPTV with HDTV even in an MDU application, it has the QoS needed to ensure CoS delivery for all Ethernet-based services, supports legacy TDM and ATM, provides redundancy, offers a low-risk migration path to convergence, and benefits from a standards body that enables industry-wide interoperability. Low-cost GPON technology is now available, equipment is being tested and deployed, and large carriers are planning installations for this year. GPON is no longer a promise of things to come—it is happening now.

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