Full Service Broadband with GPON

GPON plays a key role in delivering high bandwidth to residential end users and network nodes with high capacity requirements. GPON will be a key enabler to deliver a wide range of services to any type of end user.

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Contents

1 Executive Summary

Gigabit-capable Passive Optical Network (GPON) is currently one of the fastest access technologies to attract market interest. This white paper describes the current status and future possibilities with GPON.

Several market analysts have predicted a rapid growth of GPON deployments, leading in a few years to the predominance of GPON in fiber access technology. Other technologies, such as Broadband PON (BPON) and Ethernet PON (EPON) are likely to be in place for years to come but to a lesser extent.

GPON's popularity is due to several factors. It supports a wide range of applications/services, in particular high-bandwidth unicast and broadcast video/TV. It may be deployed in many network architectures: for example, in combination with Very-high speed Digital Subscriber Line 2 (VDSL2, with fiber to the curb, FTTC) or as residential access (fiber to the home, FTTH).

A GPON solution is an integral part of a Full Service Broadband Architecture, which is designed to meet the needs of fixed–mobile convergence and next generation networks across residential and enterprise service offerings.

The GPON evolution and standardization offers many new capabilities that will support broadband access networks and services for the future. The next step in the evolution will be increased bit-rate, from today's 2.5 Gbps to 10 Gbps in the downstream and 1.25 Gbps to 2.5 Gbps in the upstream direction. Migration will be enabled by wavelength planning allowing for co-existence of multiple GPON´s in the same optical distribution network.

Many operators and vendors in the industry view Wavelength Division Multiplexed PON (WDM-PON) as the ultimate long-term PON technology, where a PON topology supports a logical point-to-point network. WDM-PON offers an alternative to the GPON time-shared transmission scheme in which each ONT transmits and receives on a specific wavelength. Although currently cost-prohibited compared to GPON, intensive research in optical components may allow for significant cost-reductions in the next decade.

Finally, several operators are currently considering central office consolidation to reduce access network operational expenditure (OPEX) by closing small access sites and reducing travel to site. This is facilitated by the proposal of reach-extended GPONs.

2 Full Service Broadband with GPON

2.1 Introduction

Video components in the service bundle call for higher bandwidth, forcing most telecommunications operators to contemplate upgrading or completely renewing their copper –centric legacy access networks. Gigabit capable passive optical network (GPON, [1]) and Ethernet passive optical networks (EPON, [2]) are two standards that open the door to new opportunities both for vendors and operators.

Major vendors have added PON technology to their broadband access portfolios, and operators around the world have shown considerable interest in deploying this technology in combination with Very-high speed Digital Subscribe Line 2 (VDSL2 with fiber to the cabinet, FTTC) or as residential access (fiber to the home, FTTH).

The three major PON standards are BPON (Broadband PON, [3]), EPON and GPON. BPON and its successor GPON are International Telecommunication Union - Telecommunication Standardization Sector (ITU-T) recommendations sponsored by the Full Service Access Network (FSAN), a vendor and operators committee. EPON is a standard developed by the Institute of Electrical and Electronics Engineers (IEEE) Ethernet in the first mile (EFM) initiative.

Given that operators are driving GPON standardization via FSAN, the GPON standard directly reflects operator needs.

Although all three systems work on the same principle, there are several differences between them, see Table 1.

Table 1. PON flavours and their key features. DS: downstream, US: upstream.

Characteristics	**EPON**	**BPON**	**GPON**
Standard	IEEE 802.3ah[1]	ITU-T G.983	ITU-T G.984
Protocol	Ethernet	ATM	Ethernet, TDM
Rates	1000 Mbps[2], DS and US	622 Mbps DS, 155 Mbps US	2488 Mbps DS, 1244 Mbps US
Span (km)	10	20	20
Split-ratio[3]	16 or 32	32	32 or 64

[1] In 2005 it was included into the base IEEE 802.3 standard
[2] 1 Gbps is the data rate while the physical line rate is 1.25 Gbps due to 8b/10b line coding.
[3] Typical values for deployed networks.

An alternative to PON used by smaller operators, municipalities and open network providers is Ethernet FTTH, also known as point-to-point fiber. This technology carries all the fibers from each user to the central office (CO) providing a relatively simple point-to-point fiber transmission. The choice between point-to-point and (G)PON depends on multiple factors regarding deployment and business environment. Point-point fibre tends to imply active network equipment relatively near the customer, but is simple to deploy and transparent to services. Where operators try to consolidate equipment locations, it requires more fibre in aggregation. Managing many fibers at large nodes can be inconvenient.

2.2 Market outlook

The momentum and early signs of success and market acceptance for GPON worldwide is increasingly evident. The market outlook for GPON is very bright and consistent in current industry analyses. A recent study from Heavy Reading [4] predicts that the number of fiber to the home (FTTH) subscribers worldwide 2008 will be 20 million and increase to 90 million by 2012. Another study from Infonetics Research [5] predicts that GPON will already overtake Ethernet PON (EPON) as the pre-dominant technology in 2008/2009. Figure 1 shows the predicted market growth.

The rapid market increase of GPON is due to:

- The trend toward higher bandwidth “media-rich” services such as unicast and broadcast video/TV is stimulating many telecom operators to look into possibilities for upgrade or total renewal of the copper-centric legacy access network.
- Major vendors have added GPON technology to their broadband access portfolios, and operators world-wide are interested in deploying the technology in combination with VDSL2/FTTC or as residential FTTH access on a large scale in the coming years.
- GPON is very well suited to supporting mobile backhaul since it is time division multiplexed (TDM) based, and hence supports synchronous bearer services and stratum-traceable timing distribution.
- Since GPON allows multiple users to share the same fiber, there is less need for duct space in the access network and fiber management in the central office, reducing capital and operational expenditure.
- Using passive optical network vs. a copper infrastructure can reduce the annual operational expenses by as much as 80%. A PON has no electronics in the outside plant and is thus virtually maintenance free.

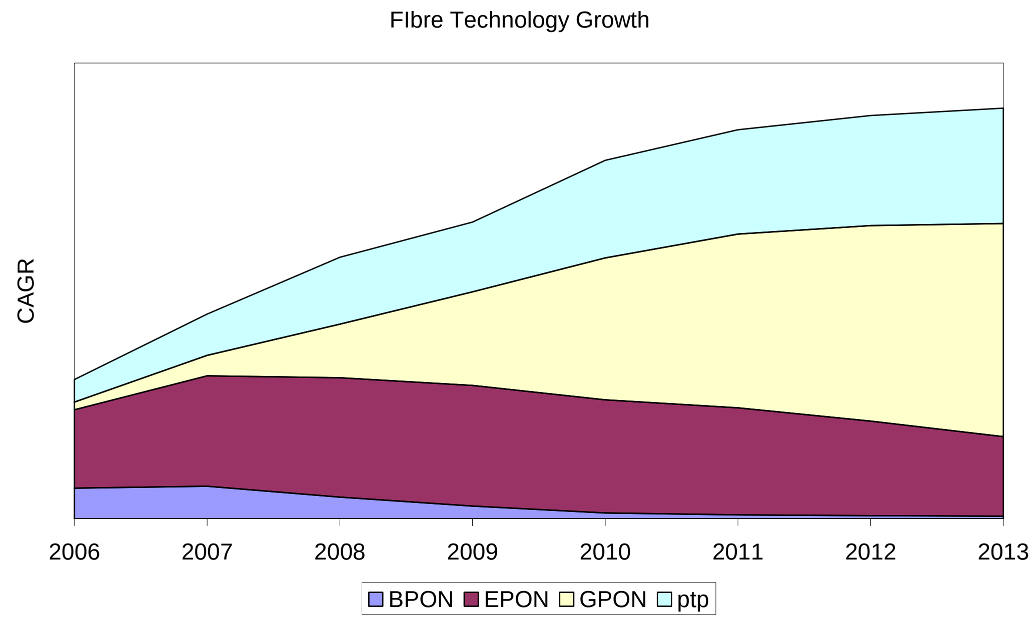

Figure 1. Predicted market growth of different fiber access technologies. CAGR: Compound annual growth rate (arbitrary unit).

2.3 GPON in the Full Service Broadband Architecture

A Full Service Broadband architecture [6] is designed to meet the needs of fixed–mobile convergence (FMC) and next generation networks (NGN) across residential and enterprise service offerings. At its core is a reliable, secure and cost-optimized transport network. Overlaid on this are a variety of access technologies, each evolving in support of Full Service Broadband, with access heterogeneity handled through multi-access edge capabilities. IMS (Internet Protocol Multimedia Subsystem) supports the development and deployment of end-to-end services. User mobility and convenience are enabled through consistent and open User-to-Network Interfaces (UNI), while open Network-to-Network Interfaces (NNI) ensure interoperability with partners such as other operators and enterprises.

Figure 2 shows the overall Full service broadband architecture. The GPON solution is part of the Wireline Access function, which functionally interfaces the Devices and CPEs (Customer Premises Equipment) and Multi Access Edge. On the topological view, GPON access interfaces the Metro network, which is covered in [7].

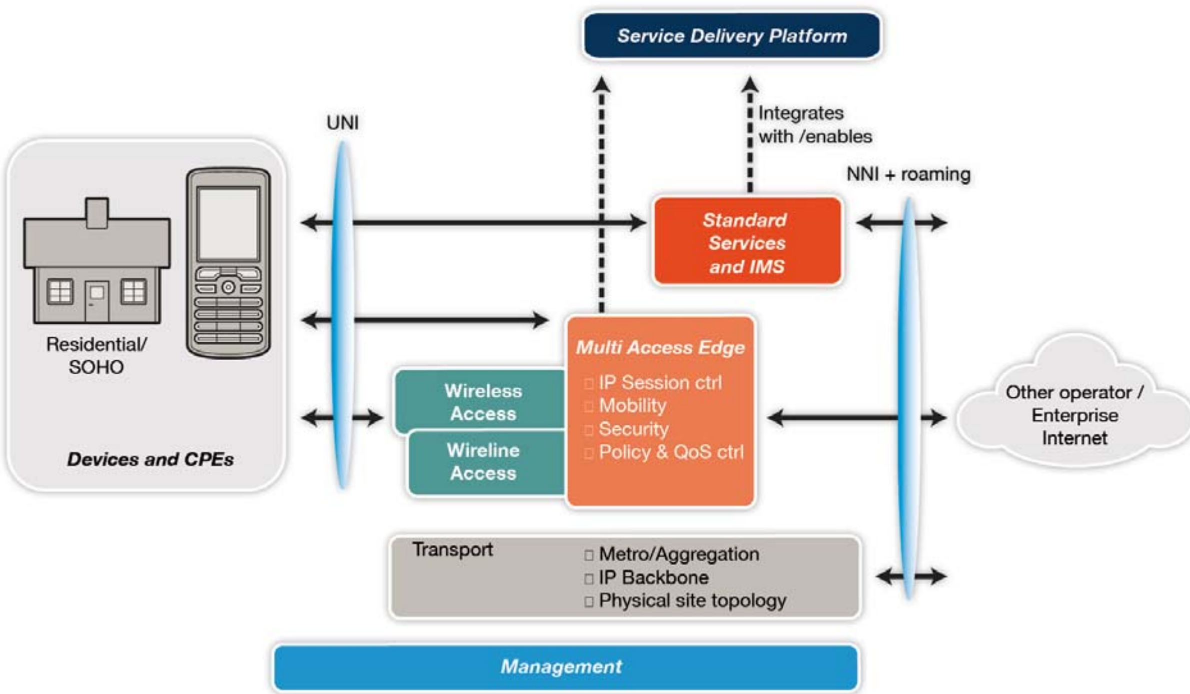

Figure 2. Full Service Broadband Architecture [6].

3 GPON Use Cases

The GPON system consists of an Optical Line Terminal (OLT) at the CO and a number of optical network terminals (ONTs) at the customer premises. Alternatively, optical network units (ONUs) can be used for reaching the premises with another technology, for example VDSL2. Both of these devices are active and require power. Instead of using powered electronics in the optical distribution network (ODN), passive splitters divide the bandwidth to serve multiple users. Hence there are no active components between the CO and the customer premises. This reduces both capital expenditures (CAPEX) and operational expenditures (OPEX), as passive components do not require power to operate. They are also generally less expensive to initially deploy and maintain in the outside plant. As multiple users share part of the distribution network, less sub-rack space is needed in the CO for active interfaces and optical distribution frames.

Figure 3 shows the different GPON use cases. When the ODN reaches all the way to the end-user as in FTTH, the CPE termed Optical Network Termination (ONT) is used. Using alternative drop technologies to the end-user, such as copper or radio, the Optical Network Unit (ONU) is used. With the ONU, different architectures can be used depending on the distance from the ONU to the end-user: Fiber to the building (FTTB) for the shortest and fiber to the node (FTTN) for the longest, with FTTC for intermediate distances and corresponding placement of the ONU equipment.

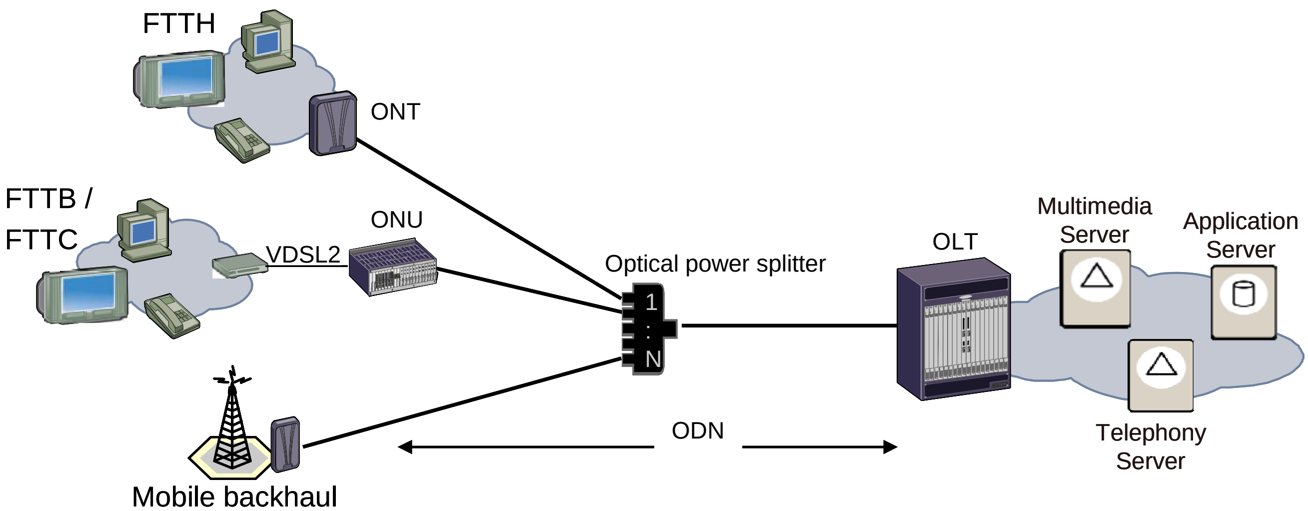

Figure 3. GPON use cases.

The current GPON standard allows for different link-budgets and consequently different reach and capacity over the ODN. Table 2 list typical technical merits for GPON.

Table 2. Overview of GPON technical merits for commonly used systems [1].

Type	**Value**	**Comment**
Link-budget	28 dB	Class B+ optics
Fiber distance	20 km	Typical value, depending on split ratio, connector losses and system margin
Split ratio	1:32	Also 1:16 and 1:64 are common
Capacity per PON	2488 Mbps / 1244 Mbps	Downstream (DS) and upstream (US)
Wavelengths	1490 / 1310 nm	DS / US for 1-fiber GPON.

For the ODN, the splitter can be deployed in a centralized (one physical location of for example a 1:32 splitter) or distributed (for example two location of first a 1:4 splitter and then four 1:8 splitters) way. The distributed split allows in theory for optimal placement of the splitter parts to optimize the fiber cable distances. In practice this may be difficult to achieve, and the centralized split allows for easier maintenance and upgrades. Of course, the centralized split approach can be realized with several physical splitter stages at a site, for example one stage of 1:4 followed by one stage of 1:8 splitters to achieve a total of 1:32.

3.1 Residential services

Many operators view GPON as ideally suited for a residential FTTH application. The sharing of the passive infrastructure and the OLT part is a good match to the small to medium capacity demands of the typical residential user. For shorter loop lengths (<20 km) a split ratio of 1:64 can be used. The higher the split ratio, the lower the dedicated capacity will be.
Typically a GPON system supports delivery of IP-based data and telephony services, broadcast IPTV, and on demand content delivery. A typical residential ONT, for example the single-family unit (SFU) type, includes a number of gigabit Ethernet ports; some of the more advanced types also include support for Network Address Translation (NAT), firewalls, Dynamic Host Configuration Protocol (DHCP) and Domain Name Server (DNS) servers etc. The ONTs can be of either indoor or outdoor type depending on the deployment scenario, and may serve single dwellings or multi-dwelling units.

3.2 Business services

As GPON is very flexible in the allocated bandwidth per user, residential users may share a PON with higher capacity business users. To accommodate the specific communication needs of businesses, several Single Business Unit (SBU) types exist. The SBUs support different numbers of POTS ports, DS1/E1 ports and Private Branch Exchange (PBX) extensions, and Ethernet at 100 Mbps or 1 Gbps.

3.3 VDSL back-haul (fiber to the curb)

DSL technology was originally intended to provide a data connection over the conventional copper loop from a CO to subscriber premises. A series of inventions has driven several generations of DSL, offering progressively faster speeds and higher frequencies over shorter and shorter copper loops.

VDSL2 technology can support up to 100 Mbps over short loops, while speeds of 50-75 Mbps can be achieved up to 1 km (depending on grade of copper, cable lengths and interference). By using vectoring even higher speeds are feasible, typically 100Mbps per copper pair over a couple of hundreds of meters.

In most cases the number of end users who can be reached directly by VDSL2 from the CO is quite limited because the loop lengths from the exchange to the subscriber are typically too long. VDSL2 is an excellent option, however, where the copper runs are short – for instance, for services over existing copper from a building basement or street side cabinet. A VDSL2 DSL Access Multiplexer (DSLAM) aggregates many copper subscribers lines onto a 1 Gbps backhaul link to a metro Ethernet switch and here a GPON backhauling link is a very suitable choice.

3.4 Mobile Back-haul

With the next generation of radio networks such as high-speed packet access (HSPA) and long-term evolution (LTE) the capacity to/from the base station will increase significantly compared with today’s requirement of a couple of E1/T1s. In some cases the backhaul capacity for a three sector site will be in the order of 100-400 Mbps. This clearly requires more backhauling capacity. Since cell-size is decreasing and fiber is driven deeper into the network an attractive option is then to use GPON as a backhauling technology to/from base stations.

4 The evolution of GPON

After some initial deployment of BPON, the industry belatedly realized that a BPON ODN could not be incrementally upgraded to any next-generation technologies. The logistics of upgrading an entire PON simultaneously were daunting, and the cost of installing a parallel upgrade PON was prohibitive. Consequently, it was a requirement from the early days of GPON development that next-generation upgrade be incrementally possible on the same ODN.

There were, and are, many candidates for next-generation PON systems, so the ITU community developed G.984.5, which reserved wavelengths for use by next-generation applications, but did not otherwise constrain them.

In detail G.984.5 includes:

- Wavelength ranges to be reserved for future use. G.984.5 specifies three optional enhancement bands with option 1 in the E band (water-peak band), option 2 in the C and L bands, and the radio frequency (RF) band as option 3 for future services in case video overlay is not deployed, see Figure 4.

- Wavelength blocking characteristics for filters protecting the GPON downstream signal in the ONT/ONU from interference from the new bands.

- GPON upstream wavelength reduction options, to free spectrum in the O band for future services. The DFB-option is likely to be most widely deployed.

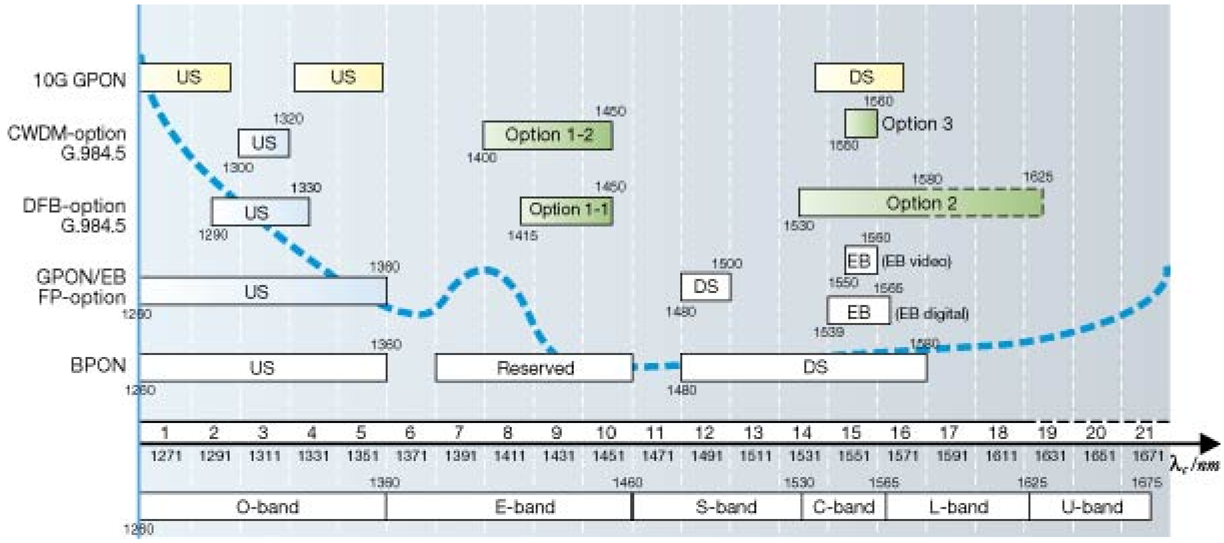

Figure 4. Wavelength allocation for GPON (including G.984.5 option B) and NG-PON on the CWDM grid (G.694.2).DS: Downstream, US: Upstream, EB: Enhancement band, DFB: Distributed Feedback laser, FP: Fabry-Perot laser.

Although GPON is considered to offer enough capacity for some years to come, the Next Generation GPON systems (NG-PON) are evolving to future-proof the investment of currently deployed GPONs and fiber infrastructures. The basic requirements of NG-PON are thus to offer higher capacities than GPON while maximally re-using the GPON protocol, components and infrastructure

The GPON evolution as depicted in Figure 5 defines two evolution stages:

- The first step, NG-PON1, is compatible with GPON deployments in accordance with the wavelength plan of G.984.5. Using GPON reach extenders also for NG-PON1 is also expected, but has not yet been explored in detail. NG-PON1 systems are anticipated to be ready around 2010. Candidates are:
  - A GPON supporting 10 Gbps downstream, and 2.5 Gbps upstream. This candidate is called XG-PON1[4],
  - A symmetric GPON supporting 10 Gbps both downstream and upstream, this candidate is called XG-PON2,
  - A WDM option to overlay[5] multiple GPONs and/or point-to-point overlays with different wavelengths (i.e. WDM) on the same fiber infrastructure as defined in G.984.5 enhancement bands.
  - There are also plans to use optical components providing larger link-budgets than that of class B+ (see Table 2).

[4] "X" refers to the roman number 10. XG-PON is sometimes called 10G GPON.
[5] Overlaid GPONs were previously termed "stacked GPONs".

- The second step, Next Generation PON 2 (NG-PON2), recognizes that higher capacities and more wavelengths will be required in the future and that new developments will obviate the need for backward compatibility. Hence, NG-PON2 is not constrained by the current GPON ODN. Also, new modulation formats, such as orthogonal frequency division multiplexing (OFDM) and code division multiplexing (CDM) are discussed for NG-PON2. Standards are anticipated to be available around 2015.

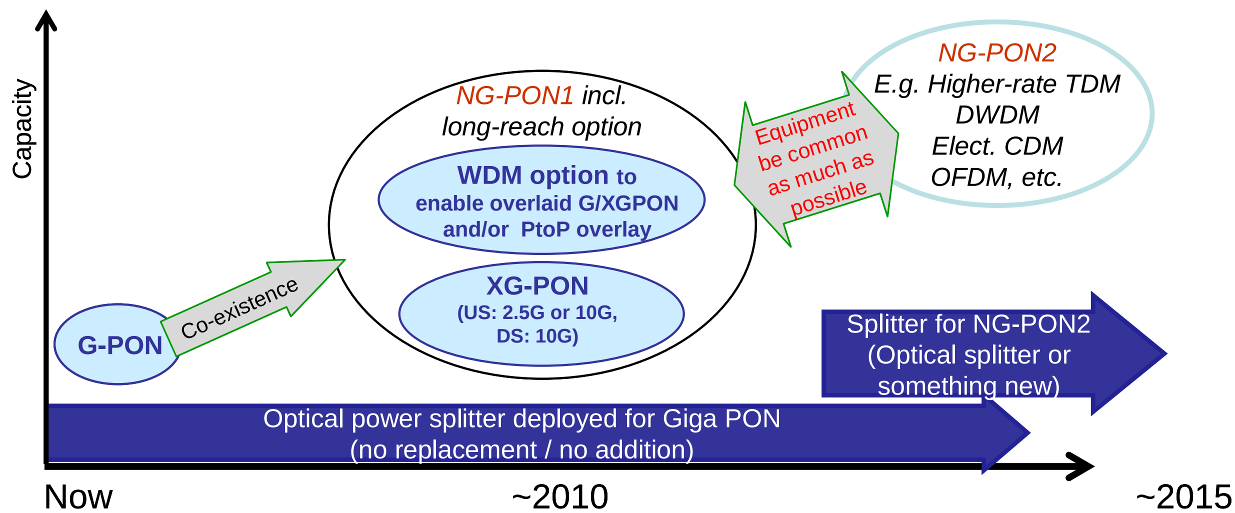

Figure 5. Coexistence and migration as discussed in FSAN.

4.1 10G GPON

To satisfy ever increased appetite for more bandwidth, the current 2.5 GPON system will be upgraded to support 10Gbps in the downstream direction. In a residential scenario with HDTV distribution the 10GPON will be able to support thousands of streams simultaneously, with a very fast switch over times between the channels due to the broadcast nature of the PON, whilst also supporting the full range of unicast personalized services. It is anticipated that 10G GPON will find its first applications in FTTB and FTTC scenarios.

The most likely next generation 10G GPON candidate will have a serial 2.5 Gbps wavelength in the upstream; in FSAN terms this corresponds to XG-PON1. The 10G GPON physical layer and optical components must be cost-effective while offering the same link-budget as GPON. Especially for the ONTs, due to their large numbers, it is critical to use low cost components.

As required by FSAN, the 10G GPON system must be able to co-exist with an already deployed GPON on the same ODN. An example of this is shown in Figure 6. The co-existence is achieved by placing the 10G GPON system on different wavelengths compared to the GPON system. At the OLT side, the two systems are combined with an optical “co-exister” filter (also called “WDM1” in G.984.5). At the ONTs wavelength blocking filters (WFB) are used to block un-wanted wavelengths.

With the architecture of Figure 6, GPON ONTs can be replaced one-by-one by 10G GPON ONTs if/when suitable or new 10G GPON ONTs are to be added to an existing ODN.

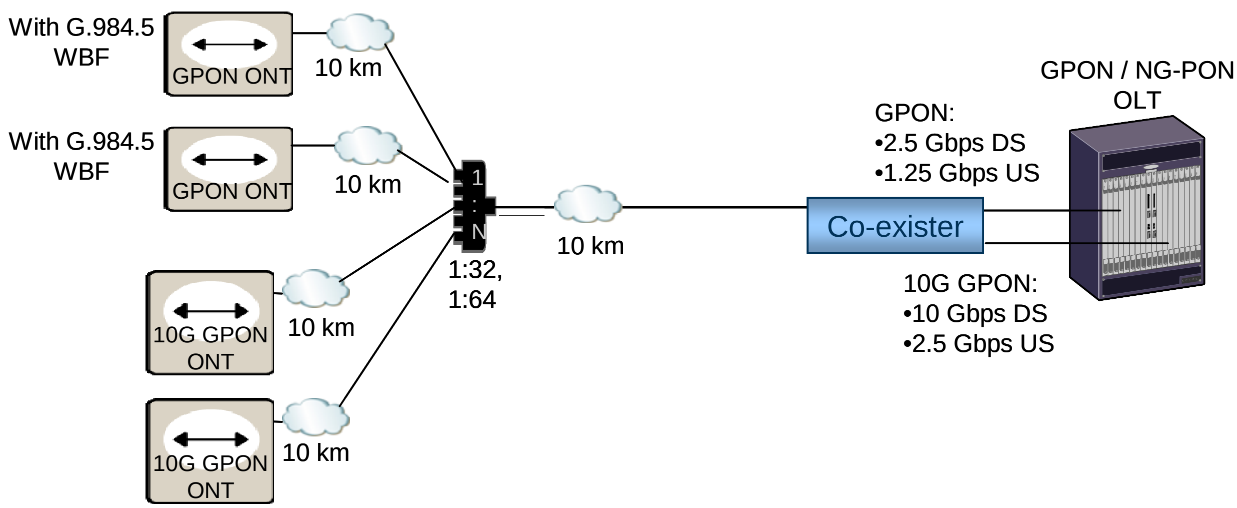

Figure 6. Co-existence of GPON and 10G GPON.

4.2 DWDM based access (WDM-PON)

Following the previous description of NG-PON2, many operators and vendors in the industry view DWDM based access in general and in particular WDM-PON as the most interesting long-term PON technology.

DWDM based access is a general transport technology where different services and networks can co-exist on the same fiber by using different wavelengths. In particular, WDM-PON offers an alternative to the GPON time-shared transmission scheme by having each ONT transmitting and receiving at a specific wavelength. Thus, the main difference between WDM-PON and the use of wavelengths on GPON (for overlaying several GPONs and/or 10G GPONs) is that WDM-PON may not use the GPON protocol but can use for example point-to-point Gigabit Ethernet. Of course, hybrid solutions with each WDM-PON wavelength carrying a GPON signal are also possible.

A typical WDM-PON architecture would replace the passive power splitter of Figure 2 with a wavelength selective filter. This filter is often implemented with an arrayed waveguide grating (AWG).

The benefits of WDM-PON include

- (Physical layer) un-contended bandwidth similar to point-to-point fiber, i.e. no bandwidth scheduling is needed as in GPON
- Effective use of fiber - up to 64 subscribers/fiber (similar to GPON)
- Longer reach is possible, using the low-loss AWG in contrast to the high-loss power splitter needed for GPON. Using the 28 dB link-budget of Table 1 and assuming a 64-way split, a WDM-PON at 1550 nm could reach >80 km compared to around 16 km for a GPON.
- Physical separation of subscriber signals

The main obstacle to WDM-PON is the cost, since the transmitters need to emit at a specified wavelength. This is especially critical for the subscriber units (ONTs) since this cost directly affects each subscriber line. At the CO side, the cost of the multi-wavelength signal can be lowered by optical integration. The subscriber side however needs solutions with a low number of unique hardware types to keep inventory and installation costs down. This ONT wavelength adaptive feature is termed “colorless”.

Several colorless architectures have been proposed and researched over the past decade. The tunable laser approach would be the most natural: the ONT wavelength would then simply be configured when taken into service, offering a high degree of flexibility and performance (reach, bitrate etc). The problem with tunables is cost-driving issues such as the potential need for wavelength locker or reference. Other more or less exotic WDM-PON techniques have also been proposed but are often found to be limited by technology (reach, capacity etc) or cost.

4.3 Extending the reach of GPON

Many operators are currently considering CO consolidation to reduce the access network OPEX. Thus there are proposals for reach-extended GPONs. These technologies may allow much longer distances and potentially also higher splits.

There are basically two ways of doing reach-extended GPONs.

The first is to increase the optical power budget by introducing optical amplifiers in the OLT or somewhere along fiber link (called mid-span extension). This allows for distances up to 60 km, which is the logical reach limit of GPON [1]. Work is currently under way in FSAN/ITU-T with G.984.re to standardize this use of optical amplifiers or alternatively opto-electrical for GPON reach-extension.

To circumvent the 60 km limitation, another approach called remote protocol termination (RPT) can be used. The basic idea of RPT is to extend the backplane of an OLT with a 10 Gigabit Ethernet optical link to the GPON capable part. This way, reach-extension of up to 100 km can be achieved. The benefits of the RPT are considerable:

- Long-reach not logically limited to the GPON protocol, i.e. a decoupling of reach from delay
- Conventional optical transport technologies such as WDM and optical amplifiers can be used to reduce the fiber count in uplink network
- The uplink and RPT is flexible in terms of future services and protocols
- Uplink protection is straightforward: well-known Ethernet protection mechanisms can be used such as link aggregation (LAG) or rapid spanning tree (RSTP)
- Simple management of the RPT: Since it is an extension of the OLT backplane, the RPT is basically managed as a GPON card in the OLT

5 Recommendations and Conclusions

As fiber-deep access networks are gaining momentum world-wide, GPON stands out as the fastest growing technology. This is partly due to its superior support for a wide range of architectures and applications. The architectures include FTTH, both for residential and business services, as well as making use of various existing drop technologies, notably VDSL2 for FTTC and also mobile broadband. As shown in this paper, the broad range of GPON solutions meets the challenges the operators are facing today.

The point-to-multipoint characteristic of GPON, where 32 or more users share a feeder fiber, allows for fiber-lean CO and trunk networks. Especially when trunk ducts and CO spaces can not allow for large number of fibers and cables, this may be a decisive requirement.

Looking into the future, the GPON systems can be enhanced in several ways:

To assure longevity of currently deployed GPON systems, next generation GPONs are evolving in standardization, 10G GPON systems are currently being developed (four times the capacity of current GPON). Key to 10G GPON is the use of cost-effective components, while offering a smooth migration from GPON using 10G GPON overlay on the same fiber infrastructure.

WDM-PON may be the long-term preferred solution for fiber access. Key enablers for WDM-PON are evolution of cost-effective optical integration and a well-planned migration from the GPONs of today.

Finally, with reach extended GPON, operators may reduce the number of CO locations used. This may amount to large OPEX savings. Several reach extension technologies are allowed in the standards, allowing for up to 60 km distances.

For longer distances, the remote protocol terminator concept offers a solution in which 100 km or more can be bridged from the CO to the end-user.

6 Glossary

AWG	Arrayed Waveguide Grating
BPON	Broadband PON
CAPEX	Capital EXPenditure
CO	Central Office
CAGR	Compound Annual Growth Rate
CPE	Customer-Premises equipment
DHCP	Dynamic Host Configuration Protocol
DNS	Domain Name System
DS	Down-Stream
DS1	Digital Signal 1
DSL	Digital Subscriber Line
DSLAM	DSL Access Multiplexer
E1	E-carrier level 1
EPON	Ethernet PON
FMC	Fixed Mobil Convergence
FSAN	Full Service Access Network
FTTB	Fiber To The Building
FTTC	Fiber To The Curb,
FTTH	Fiber To The Home
FTTN	Fiber To the Node
GPON	Gigabit-capable PON
HDTV	High Definition Television
HSPA	High-Speed Packet Access
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
IPTV	IP Television
ITU-T	International Telecommunication Union - Telecommunication Standardization Sector
LTE	Long-Term Evolution
NAT	Network Address Translation
NGA	Next Generation Architecture
NG-PON	Next Generation PON
NNI	Network-Network Interface
ODN	Optical Distribution Network
OLT	Optical Line Termination
ONT	Optical Network Termination
ONU	Optical Network Unit
OPEX	Operational EXPenditure
PBX	Private Branch Exchange
PON	Passive Optical network
POTS	Plain Old Telephony System
RF	Radio Frequency
SBU	Single Business Unit

SFU	Single Family Unit
TDM	Time Division Multiplexing
UNI	User-Network Interface
US	Up-Stream
VDSL	Very-high speed DSL
WBF	Wavelength Blocking Filter
WDM	Wavelength Division Multiplexing
XG-PON	10 Gbps GPON

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