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ENSURING THE FUTURE OF YOUR FIBER ACCESS

HIGH-SPEED CONNECTIVITY IS GUARANTEED WITH DEEP FIBER ACCESS.

Operators can deploy a PON-based FTTH network with the confidence that their investment is protected. Next Generation PON technology ensures future bandwidth demand will be met.

THE NEED FOR SPEED

The demand for higher speed connectivity is relentless. It has been estimated that network connection speeds for high-end home users will increase 50% per year.* History has shown that this sort of dynamic fosters a self-feeding system whereby one action begets another. To illustrate, the supply and demand for automobiles depended on the availability of roads; the more roads, the more cars and the better the roads, the faster the cars. In communications, the faster the connection, the more and richer the services offered.

A 2008 study commissioned by the FTTH Council Europe showed that operators collected 30% higher average revenue per user (ARPU) because users where paying for more services, not because their services were higher priced. The study also showed that FTTH subscribers consumed up to five times more bandwidth than ADSL subscribers. This demonstrates that the supply will be consumed if available.[1]

The demand for video is clearly the primary driver for higher connection speeds. According to a recent report[2], HDTV penetration worldwide for 2010 was estimated to be just 6% of consumer households with nearly 50% penetration in the United States. It is predicted that worldwide penetration will reach 21% by 2014**.** The penetration will rise simply because the only TVs sold in some markets are HDTVs. HDTV sets are also getter bigger, moving from 32" to 152" with 3D lending and an almost corresponding increase in connectivity speed. "Super Hi-Vision" TV with 32x the information density of HDTV could enter the market in 2020 with a rate of 65 Mbps. As more and bigger HDTV sets are brought into households, the demand for HDTV content will push home connectivity demand beyond 100 Mbps.

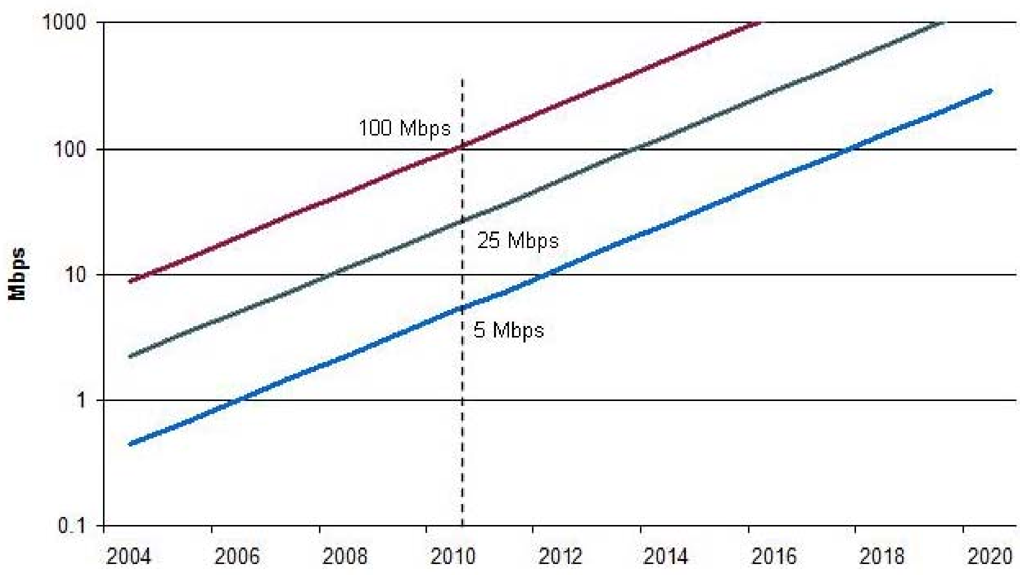

Figure 1 Nielsen's prediction for 3 service rates in 2010

Another impact on network capacity is the way in which we view TV. Traditional TV viewing has been through video broadcast through off-air or CATV networks designed explicitly for broadcast video with content from the legacy TV networks. This broadcast architecture resulted in an efficient content delivery system since one video channel could be distributed to many subscribers.

* Nielsen's Law

However, for telephony network operators whose access networks were designed for person to person connectivity, delivering efficient and cost effective video over the existing infrastructure requires IPTV with IP multicast technology. IP multicast enables one channel to be replicated for each viewer of that channel, thereby optimizing capacity of the access equipment.

But with the rapid increase of Over-the-Top (OTT) video, not only is the business of video service impacted, but the network as well. Since OTT is a unicast experience, it is not able to take advantage of IP multicast efficiencies as the content is not sourced or managed by the network provider (i.e. 'Over the Top'). Although there is no difference in the subscriber connection speed between an IPTV and an OTT video channel, the access network equipment capacity is dramatically affected as each viewer is provided their own exclusive video channel. OTT will have a significant impact on the network as it's estimated that the number of OTT video subscribers will surpass IPTV by 2013[3].

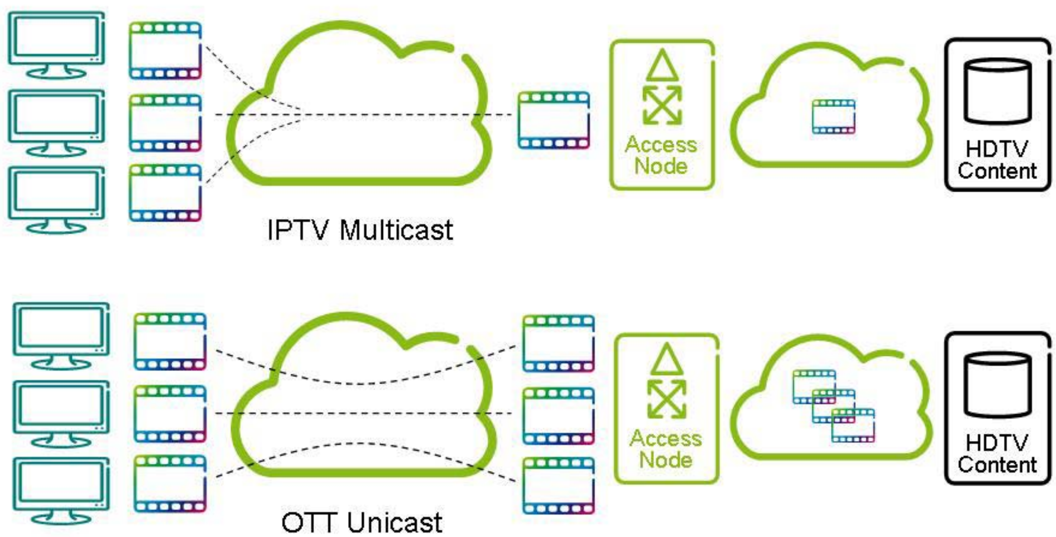

Figure 2 The effect of OTT video on the network

So far, only the downstream or service provider to consumer connection has been considered. With social networking, high-speed gaming, video and picture sharing, database back-up and video interactivity, the upstream connection speed is also critical for a high quality of experience.

While HDTV content is driving the downstream subscriber connection rate, social and media rich interactivity is driving the upstream rate and the way in which we view video via OTT content is pushing the capacity requirements of the access equipment. These factors will have a bearing on next generation access technology choices.

MEETING THE NEED

The major obstacle of meeting the connection speed demand is doing so economically over the legacy copper plant. To optimize the existing speed-distance of the existing copper, fiber is taken as close as financially feasible to the end-user in Fiber to the Node (FTTN) and Curb (FTTC) configurations with service rates ranging from 20 to 100 Mbps using ADLS2+ and VDSL2. While various bonding and noise reduction DSL technologies may double or even triple the rate over the same distance, doing so en masse in an economically efficient manner is uncertain given the various conditions of the outside plant (OSP).

A cost-effective means for urban high-speed connectivity is via Fiber to the Building (FTTB). Many network operators have selected FTTB with Fast Ethernet (FE) to the apartment over CAT-5 cable for new buildings as 100 Mbps can be delivered over distances of 100 meters at low cost. For older buildings with existing telephone wire, FTTB+DSL is used.

The ultimate future proof, high-speed access is a Fiber to the Home (FTTH) architecture. The world's largest fixed access network operators have selected Passive Optical Network (PON) based FTTH/B as it provides the best cost advantages for mass deployment with an inherent broadcast architecture for video. A single port from an operator's Optical Line Terminal (OLT) can be shared with up to 128 Optical Network Terminations (ONTs), thereby significantly reducing overall subscriber cost, power and fiber management compared to dedicated point-to-point technologies.

The value of a PON was recognized as far back as the late 1980s and deployment was realized with Telephony PON (TPON) in the late 1990s. In 1995, the Full Service Access Network (FSAN) organization was formed as an initiative by network operators who endeavored to build high-speed access networks. With standardization of FSAN work being done through the ITU, standards based PON began in 1998 with ATM PON (APON) which eventually became Broadband PON (BPON ITU-T G.983). Deployment began in 2004, providing an aggregate 622 Mbps downstream (DS) and 155 Mbps upstream (US) (622/155).

Around the same time, Ethernet PON (EPON) was established as a result of work from the Ethernet in the First Mile (EFM) group with standardization by the IEEE (IEEE 802.3ah). This became the first Gbps PON with a 1/1 Gbps rate. EPON, in its various flavors, is currently deployed to more subscribers than any other PON with deployments primarily in Asia.

As EPON was beginning mass deployment in Asia, Gigabit PON (GPON ITU-T G.984) was ratified. With its 2.5/1.25 Gbps rate, GPON is now the fastest mass deployed PON today. Due to its speed, efficiency and ability to support more subscribers per PON, it has the lowest total cost of ownership (TCO) of any fiber access technology[4].

Given the demand for speed, BPON and EPON are quickly running out of capacity for video. With DS/US rates of 622/155 and 1000/1000 Mbps respectively and a PON split ratio of 32, each BPON subscriber can be offered a sustained rate of 20 Mbps while EPON can provide 30 Mbps. Each PON technology's bandwidth enables a range service rates. With GPON at 2.5/1.25 Gbps, a sustained rate of 80 Mbps is provided with enough PON capacity to deliver the needed FTTH service rates well into the next decade. This is illustrated below as the three PON technologies are mapped against Nielsen's predication for three service offerings of 5, 25 and 100 Mbps in 2010.

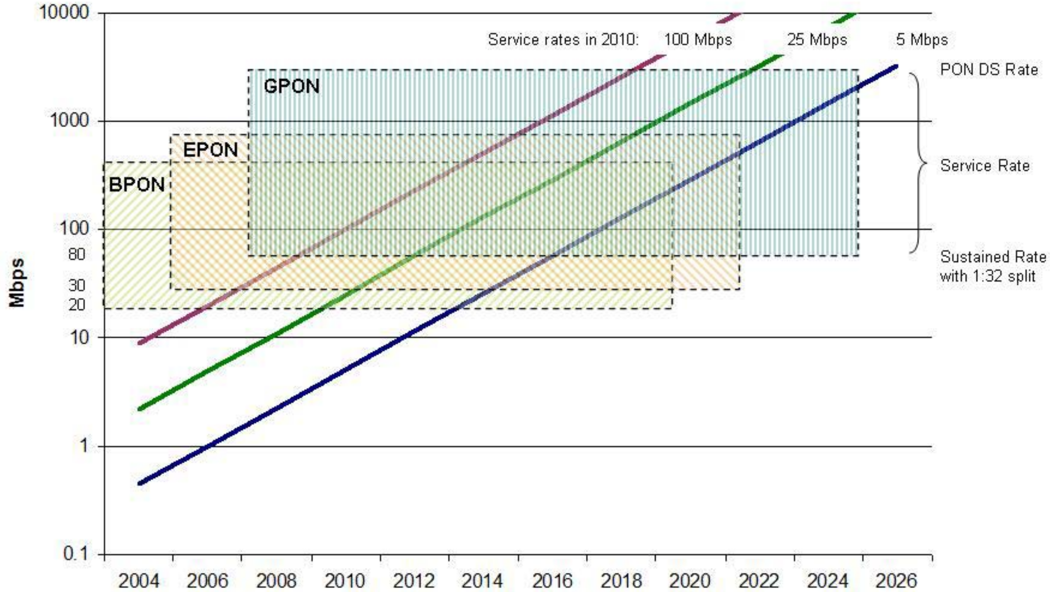

Figure 3 PON technologies applied to Nielsen's prediction for 3 service rates in 2010

As a result, network operators that have deployed BPON have now switched to GPON. With GPON deployment in most of the world, including Asia, GPON has now surpassed EPON in its deployment rate[5].

Even though GPON can economically satisfy the subscriber speed requirements for FTTH for the next 10 to 15 years, the dominant multi-dwelling unit FTTB application in Asia, and the predictable and relentless demand for end-user bandwidth, has led FSAN and the IEEE to initiate next generation PON technology research.

READY FOR THE NEAR FUTURE

In 2006, the IEEE embarked on a 10 Gbps EPON (10G EPON) initiative due to a sense of urgency created by 1 Gbps EPON's lack of capacity for triple-play services for FTTB applications in Asia. There also was the threat of GPON providing 2.5 times more DS capacity and perhaps seizing the market opportunity. The 10G EPON initiative became the IEEE 802.3av standard in late 2009 and provides coexistence with currently deployed EPON systems on the same optical distribution network (ODN). This is achieved by employing a combination of WDM and TDM techniques that allow network operators to transition from a 1 Gbps to a 10 Gbps PON. However, due to lack of cost-effective technology, the initial 10G EPON deployment was an asymmetrical 10/1 Gbps rate providing a sustained 310/30 Mbps service rate for up to 32 ONTs. There is a symmetrical 10/10 Gbps EPON variant, but it is currently cost prohibitive.

FSAN also embarked on a next generation PON initiative involving two paths:

1. NG PON1 for new technologies to operate on existing ODNs
2. NG PON2 for new technologies to operate on existing ODNs as optional

As a NG PON1 solution, XG-PON1 (X for the Roman numeral 10) was endorsed and became the ITU-T G.987 suite of standards in January 2010 building upon the existing GPON ITU-T G.984 suite. It also employs a combination of WDM and TDM techniques to ensure coexistence with legacy GPON systems on the same ODN. Like 10G EPON, it provides 10 Gbps DS but unlike 10G EPON, it delivers ~2.5x the capacity in the US at 2.5 Gbps (10/2.5 Gbps). With XG-PON1, a sustained 310/80 Mbps service rate can be delivered for up to 32 ONTs.

The XG-PON2 is also part of the NG PON1 solution, which offers 10/10 Gbps transmission. However, as with the 10G/10G EPON variant, it also is viewed as cost prohibitive.

The pedigree of the various NG PON technologies is outlined below:

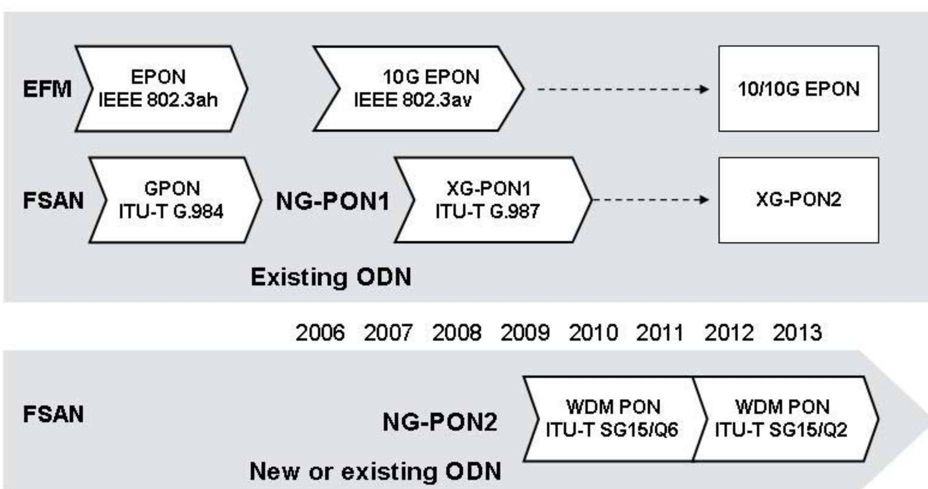

Figure 4 NG PON standards activity

Coexistence of legacy PON with video overlay and new 10G PON on the same ODN is achieved through a careful wavelength plan and WDM separation by means of the wideband WDM1r filter specified in ITU-T G.984.5. To enable cost-effective optical transceivers, the same 10G PON wavelengths are used for both 10G EPON and XG-PON1.

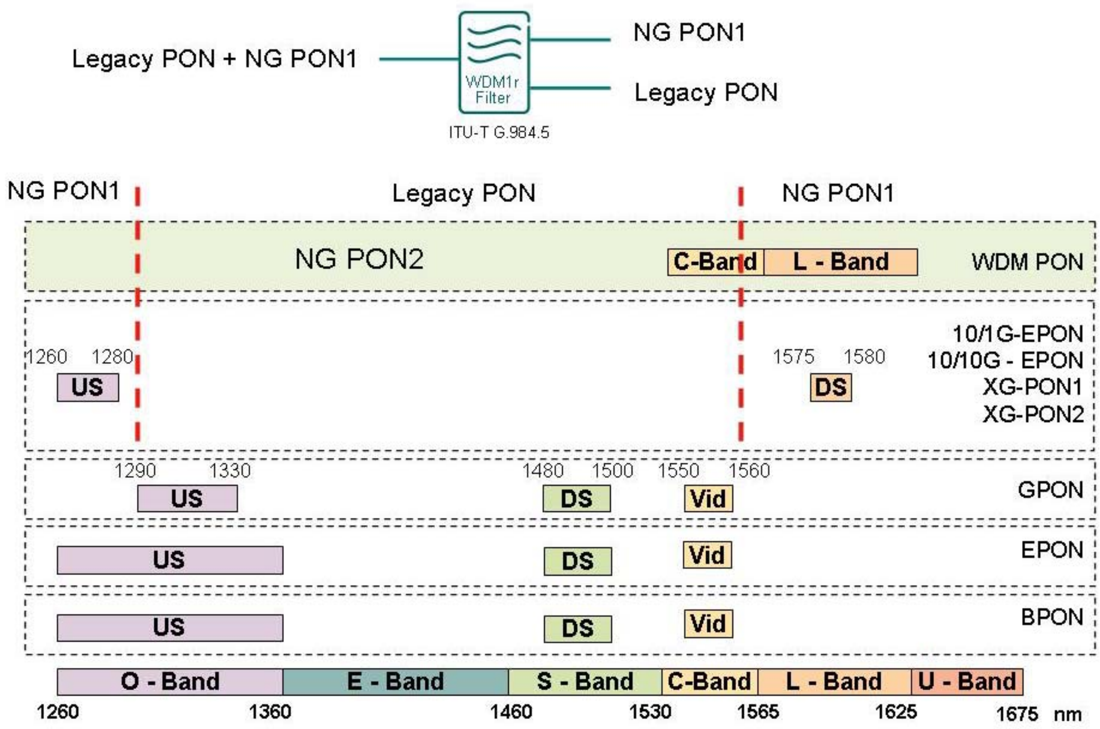

Figure 5 Wavelength plan for PON and NG PON coexistence

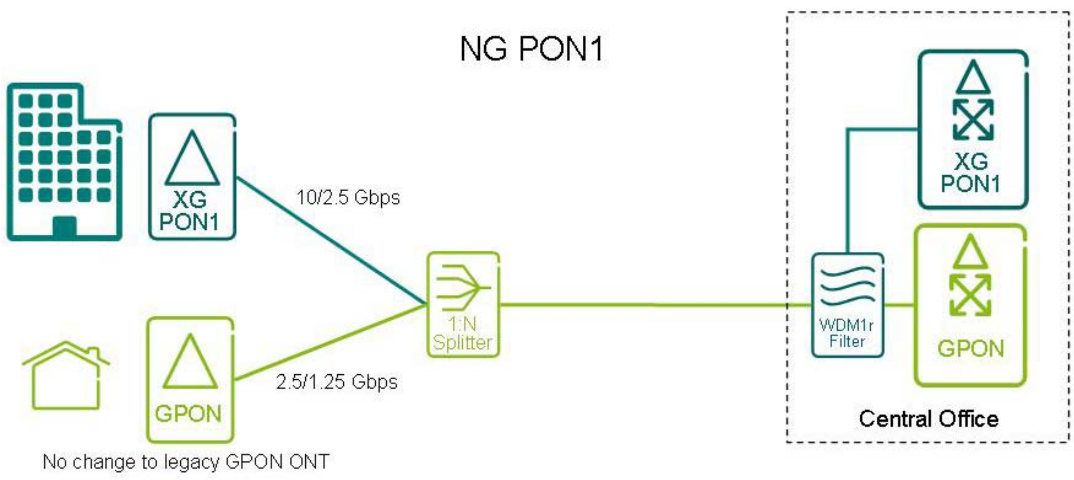

Figure 6 Seamless upgrade of GPON ODN with XG-PON1

SET FOR THE LONG TERM

Currently, FSAN is studying NG PON2 proposals which include technologies such as:

- WDM stacked 10G TDM PON
- 40G TDM PON
- Orthogonal FDM PON
- WDM PON

WDM-PON is seen as the most promising of the NG PON2 technologies as it provides the benefits of symmetrical, dedicated point-to-point virtual connections over a cost-effective PON. This approach uses an optical wavelength splitter instead of an optical power splitter in the PON to provide the physical point-to-multipoint connection. Unlike a power splitter which splits the incoming optical power among the ports producing a corresponding optical loss, the WDM filters each wavelength accordingly to provide a constant loss regardless of the number of splits on the PON. Furthermore, as a result of a wavelength plan as is shown in figure 5, an existing B/E/GPON ODN can be enhanced to carry WDM-PON traffic by using the WDM1r filter as shown below.

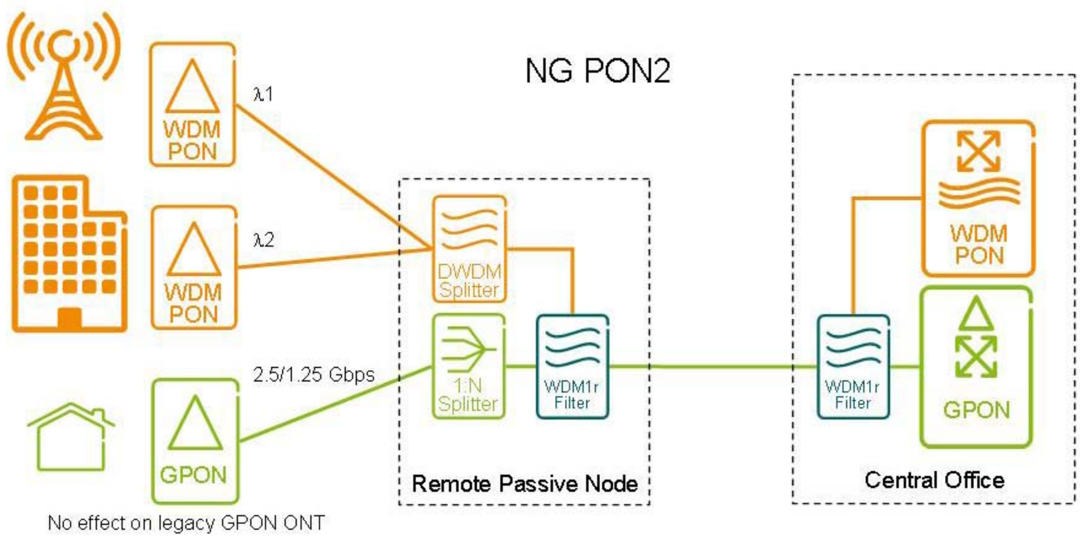

Figure 7 Upgrade of GPON ODN with WDM PON

Since a WDM-PON connection is established as point-to-point optical channel requiring corresponding transceivers at dedicated wavelengths (1:1) at the ONT and OLT, it is intrinsically not as cost effective as a TDM-PON where one transceiver at the OLT is shared amongst the ONTs (1:n). As a result, WDM-PON lacks an inherent broadcast mechanism. However, this may not be an issue as the video trend is moving from a broadcast and multicast nature to a unicast OTT experience as previously discussed. Nevertheless, WDM-PON's 1:1 optical configuration is protocol independent allowing for an optical channel to carry any protocol from GE to 10 GE, SONET/SDH to Fibre Channel to name a few. With 32 optical channels carrying GE, an aggregated PON line rate of 40 Gbps is achieved. Furthermore, with its dedicated, point-to-point, 1:1 configuration, no PON Media Access Control (MAC) is required as is with a 1:n TDM PON. Thus, no special PON MAC layer standardization or silicon is needed, which provides a cost advantage. Essentially, operators are delivering simple Ethernet based connectivity using WDM as the transport. The technology investment is in the WDM-PON optical devices.

For the WDM-PON to be viable for a network operator to deploy and operate, it must employ a 'colorless' WDM-PON technology. This enables any ONT to be connected anywhere on the PON and automatically tune to the appropriate optical channel. Presently, there are three colorless WDM-PON technologies under consideration:

1. Remotely Seeded
2. Wavelength Reuse
3. Tunable Lasers

Remotely seeded WDM-PON technology is based upon the principle of a broadband light source (BLS) located in the OLT being sent DS on the PON and seeding the ONT's low-cost Fabry-Perot (FP) lasers to lock onto the wavelength passing through that particular WDM filter port to form the US wavelength. Thus the OLT (remote) supplies the ONTs with the wavelength (seed) to tune to a particular WDM's port wavelength. Current technology enables 32 channels of one GE each for an aggregate PON line rate of 40 Gbps. This method will be the first colorless WDM-PON to be standardized as a result of the work by ITU-T SG15/Q6. It is also the technology employed in commercially available colorless WDM-PON systems today.

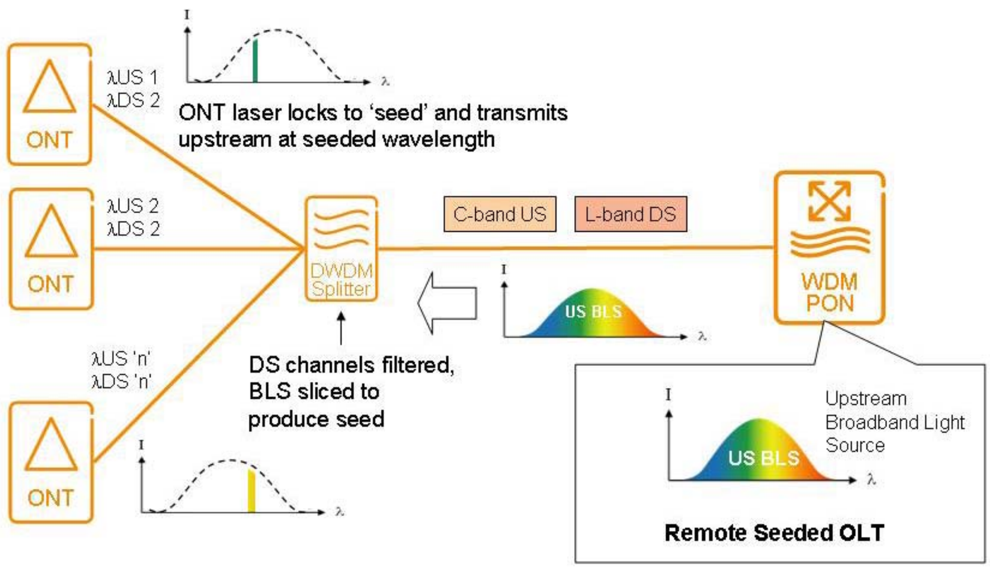

Figure 8 Remote seeded colorless WDM PON technology

Wavelength reuse is a technique where each DS wavelength has a part of its energy reused by the US modulated data. Thus, one wavelength forms a DS/US optical channel to effectively double the capacity over remotely seeded technology resulting in the best spectral efficiency. Another benefit of this approach is that it does not require a BLS enabling conventional optics to be used and thus reducing costs. The key to wavelength reuse technology is good US and DS channel separation achieved via optical directivity isolation and modulation techniques. This technology was demonstrated in 2010 where it achieved 96 channels of GE over 50km.

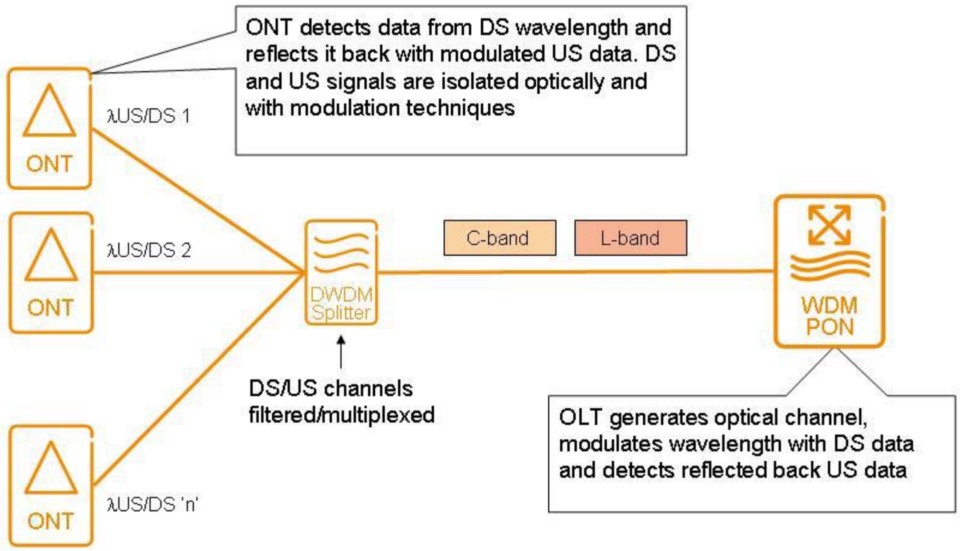

Figure 9 Wavelength reuse colorless WDM PON technology

Tunable laser technology is currently deployed in Dense WDM (DWDM) transport equipment for the metro and long-haul fiber markets. The same principle of operation is being applied to WDM-PON. The challenge is making the technology affordable for the cost sensitive access market. A tunable laser based WDM-PON was demonstrated in 2009 where it achieved 32 channels of GE over 85km.

A summary of the various colorless WDM-PON technologies shows the immense capacity that can be available in the access network. Already remote seeded technology is enabling up to 40 Gbps and with wavelength reuse and tunable laser technology, the capacity on a single PON can exceed 100 Gbps.

	Remote Seeded	**Wavelength Reuse**	**Tunable Laser**
ONTs per PON	32	48 in C-Band 96 for C+L Band	48 in C-Band 96 for C+L Band
Distance	40km	50km	85km
Channel rate	1Gbps	2.5Gbps	10Gbps
PON rate	Up to 40Gbps	Up to 240Gbps	Up to 1000Gbps
Issues	OLT integration	Achieving > 1Gbps	Costs
Standards	ITU-T S15/Q6 (target 12/2011)		
Availability	Now. Deployed.	2012	>2016

Table 1 Colorless WDM PON comparison

While WDM-PON is viewed as a long-term fiber access solution, it is already seeing high value in enterprise and Long Term Evolution (LTE) mobile backhaul applications where the return on investment is attractive. With its capacity-distance characteristics, network operators can deliver GE services to the enterprise without any active equipment between the Central Office (CO) and the end-user. This characteristic results in significant capital and operational cost savings as traditional aggregation and transport nodes can be eliminated in network design and COs consolidated as shown below. For LTE mobile backhaul, WDM-PON's low-latency and the transport redundancy built into some equipment provides a compelling solution with a low TCO.

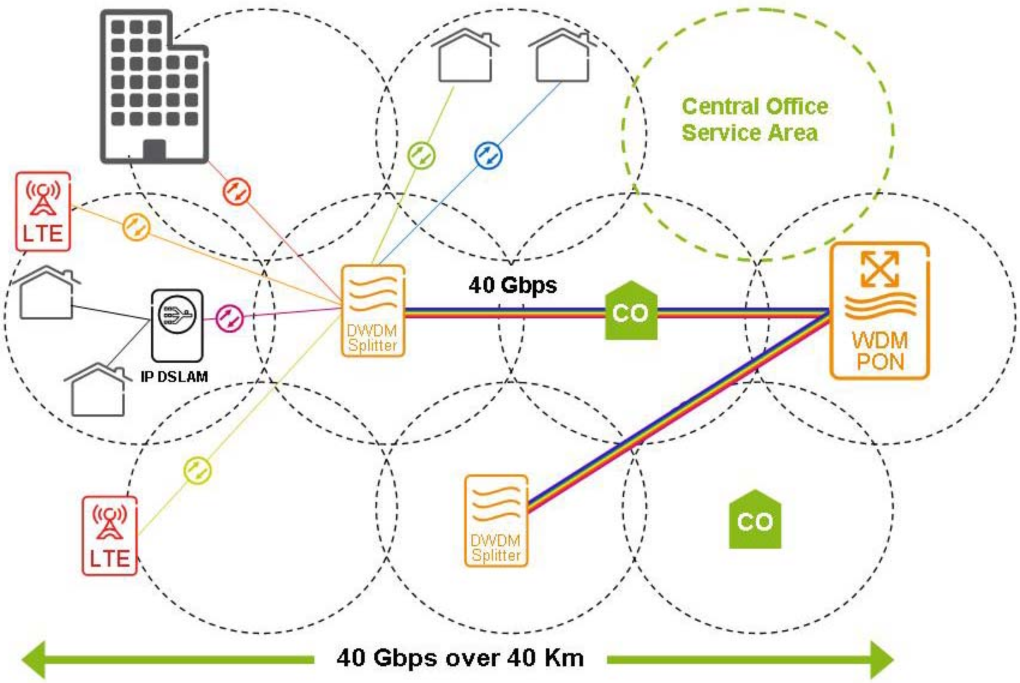

Figure 10 WDM PON providing node and CO consolidation

FUTURE ENSURED

A fixed broadband network operator's greatest asset is its OSP. For a deep fiber based network, the investment is more than 50 years. The industry has ensured that the investment in PON is well protected with the availability of cost-effective next generation technology. Even now, network operators can deliver FE rate service over BPON and EPON and with GPON, GE service connectivity is attained satisfying the FTTH subscriber speed demand well into the next decade. With NG-PON technologies such as 10G EPON, XG-PON1 and WDM-PON currently addressing FTTB and transport applications, these technologies provide a means to supply the access bandwidth demand for the next 30 years.

Will connectivity rates have a limit? Does Nielsen's prediction become asymptotic? It's difficult to say with certainty what the connection rate demand will be in the future. However, one thing can be certain - PON technology will meet the demand. As shown below with the overlay of PON technologies on Nielsen's prediction, deploying PON is an investment for the coming generations.

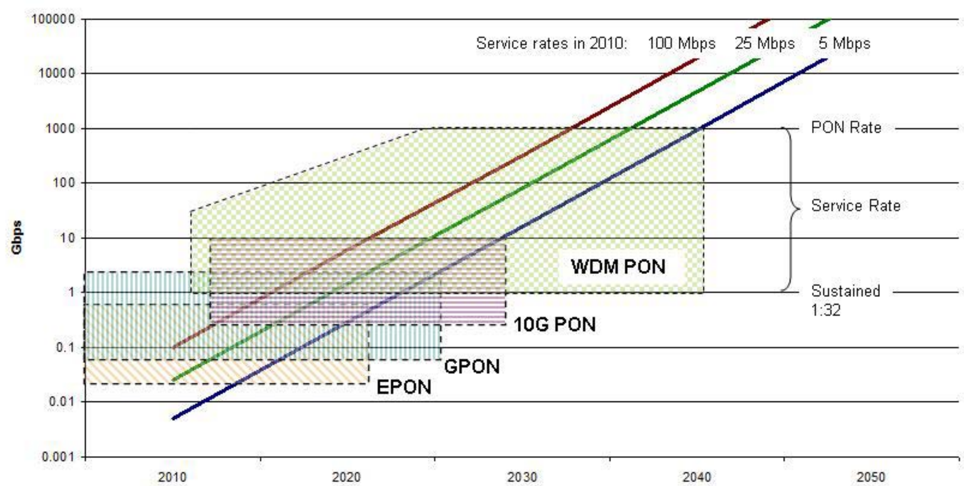

Figure 11 PON technologies applied to Nielsen's prediction for 3 service rates in 2010

GLOSSARY

ADSL	Asymmetric DSL
APON	ATM PON
ARPU	Average Revenue per User
BPON	Broadband PON
CATV	Community Access Television
CO	Central Office
DS	Downstream
DSL	Digital Subscriber Line
DWDM	Dense WDM
EFM	Ethernet in the First Mile
EPON	Ethernet PON
FE	Fast Ethernet
FP	Fabry-Perot
FSAN	Full Service Access Network
FTTB	Fiber to the Building
FTTC	Fiber to the Curb
FTTH	Fiber to the Home
GDP	Gross Domestic Product
GE	Gigabit Ethernet
GPON	Gigabit PON
HDTV	High Definition Television
HSIA	High Speed Internet Access
IEEE	Institute of Electrical and Electronic Engineers
IPTV	Internet Protocol Television
ITU	International Telecommunication Union
LAN	Local Area Network
LTE	Long Term Evolution
MAC	Media Access Control
NG PON	Next Generation PON
TCO	Total Cost of Ownership
TDM	Time Division Multiplex PON
TPON	Telephony PON
ODN	Optical Distribution Network
OLT	Optical Line Terminal
ONT	Optical Network Termination
OSP	Outside Plant
OTT	Over The Top
PON	Passive Optical Network
US	Upstream
VDSL2	Very high bit rate DSL
WDM	Wavelength Division Multiplex
XG-PON1	10/2.5G TDM PON
XG-PON2	10/10G TDM PON

REFERENCES

[1] FTTH Business Guide 2nd Edition 16/01/2011 Fibre to the Home Council Europe
[2] http://www.hdtvmagazine.com/columns/2010/04/hdtv-almanac-hdtv-just-6-worldwide.php
[3] http://broadcastengineering.com/news/ott-video-overtake-iptv-2013-20110328/#
[4] GPON vs. EPON: A cost comparison Lightwave 08/2005
[5] Infonetics PON and FTTH Equipment Report 08/2010