New FTTH-based Technologies and Applications

A White Paper by the
Deployment & Operations Committee

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Fibre to the Home Council Europe

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Introduction

The evolution of fibre to the home (FTTH) technology is a key issue for the telecom industry. Operators need to consider today which optical access platform will allow them to adapt most cost-effectively and intelligently as future bandwidth demand and applications evolve. And, as the massive deployment of FTTH networks continues worldwide, operators expect more from FTTH-based technologies. They expect next-generation technologies to enhance bandwidth and service support capabilities while supporting coexistence with their existing equipment and outside plant.

There are two main technical approaches to delivering FTTH. A point-to-point Ethernet network provides each user with a dedicated optical channel. However, the passive optical network (PON), which provides point-to-multipoint connectivity, has become increasingly popular because it enables operators to make more efficient use of their optical fibre infrastructure. Two flavours of PON exist: Ethernet PON (EPON) and Gigabit PON (GPON).

PON has been widely deployed around the world. In Europe, early adopters and smaller operators have installed point-to-point Ethernet networks, but GPON is rapidly becoming the preferred choice among major operators. GPON is already the dominant technology choice in North America. Asia saw significant EPON deployments in Japan and South Korea, and China – the world's largest FTTH market – recently embarked on a large-scale deployment using a mix of EPON and GPON.

This white paper will consider the optimum evolutionary path of FTTH-based technologies within the framework of next-generation PON, and the applications that will drive this evolution.

Drivers for Increased Bandwidth Demand

Today, commercial triple-play service packages offer typical bandwidths between 20 and 100 Mbps to residential customers. According to Nielsen's Law, which predicts that a high-end user's Internet connection increases by 50 percent every year, one can envisage that a subscriber enjoying a 58-Mbps service in 2013 would require 130 Mbps by the year 2016. In addition, the European Commission has set a target that by 2020 half of all households in Europe should have broadband subscriptions at speeds of at least 100 Mbps.

Although current technologies, such as GPON, will easily meet the short- to medium-term needs of residential consumers, over the longer term they will struggle to answer the requirements of highly demanding services like HDTV, 3D-TV, multiple image and angle video services, growth in unicast video (versus multicast), cloud computing, telepresence, multiplayer HD video gaming and more.

It is anticipated that the highest bandwidth demands will come from business users and mobile backhaul, which are already starting to take advantage of FTTH networks to deliver their data content. The higher bandwidth available via optical access networks represents an attractive, lower cost option compared to a leased line or dedicated point-to-point Ethernet connection.

By 2020 it is estimated that there will be 50 billion connected devices using the fixed and mobile broadband network. This will create the networked society, in which everything benefiting from a connection will have one. From 2012 to 2017 the total amount of data exchanged between mobile users is expected to increase by 66 percent annually, according to Cisco's Visual Networking Index. The tremendous growth in mobile data will place huge pressure on operators.

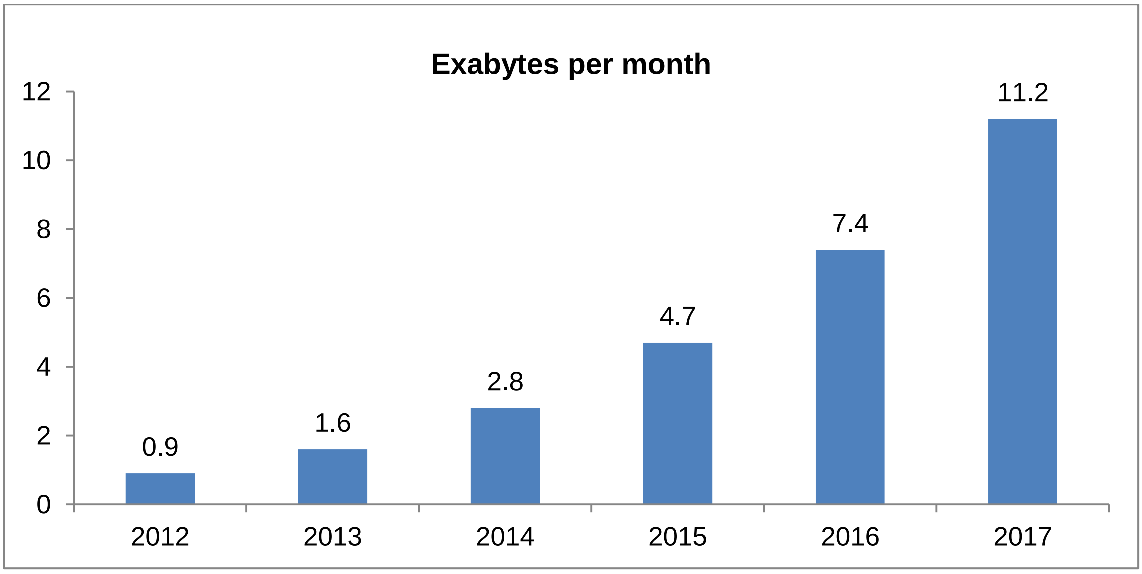

Figure 1: Mobile data traffic growth. Source Cisco VNI Mobile Forecast, 2013

Business services and mobile backhaul are expected to require sustained, symmetric data rates of 1 Gbps and beyond, while residential customers may be less demanding because require the peak bandwidths for shorter durations. Symmetric high-bandwidth pipes are not usually available over current-generation FTTH networks however, due to lack of bandwidth resources and the asymmetric design of existing PON technologies. Next-generation PON will address this issue while also providing the higher bandwidth and quality of service levels that these services require.

Convergence of voice and data service on a single optical network has proven to be the right choice for regional and core networks; similar efficiencies could be achieved in the access network. Larger split ratios, increased range, wavelength availability and fibre reuse can enable operators to serve more customers with less investment. Next-generation PONs will enable the smooth evolution from existing optical access networks, which are mainly residential, to converged access networks comprising residential, business services and mobile backhaul.

PON Standards Development

The Institute of Electrical and Electronics Engineers (IEEE) developed the Ethernet in the First Mile (IEEE 802.3ah 2004) family of standards, which includes EPON. The 10-Gbps version, 10G-EPON, was ratified in 2009, as IEEE 802.3av. The standard supports two configurations: asymmetric, operating at 10 Gbps in the downstream (provider to customer) direction and 1 Gbps upstream (consumer to provider); and symmetric, operating at 10 Gbps in both directions.

Meanwhile, the special interest group Full Service Access Network (FSAN) has been leading GPON technology development, passing the work to the ITU Telecommunication Standardization Sector (ITU-T) when it the technical requirements are stable and ready for standardization.

In 2006, FSAN/ITU-T began to consider the system that would follow GPON. Initially, the focus of this work was to develop additional specifications for the GPON system that would enable a smoother migration to whatever system came later. This work resulted in the G.984.5 recommendation, which refined the spectrum plan for GPON and defined blocking filters in the GPON optical network units (ONTs) to prevent crosstalk from non-GPON wavelengths.

In 2007, the focus moved towards defining the new system itself. A wide range of technical options were raised as candidates, many of which were quite different in architecture and service profile from GPON. Finally, in 2010, ITU-T Recommendation G.987: 10-Gigabit-capable passive optical network (XG-PON) systems, was defined, based on a TDM-PON architecture.

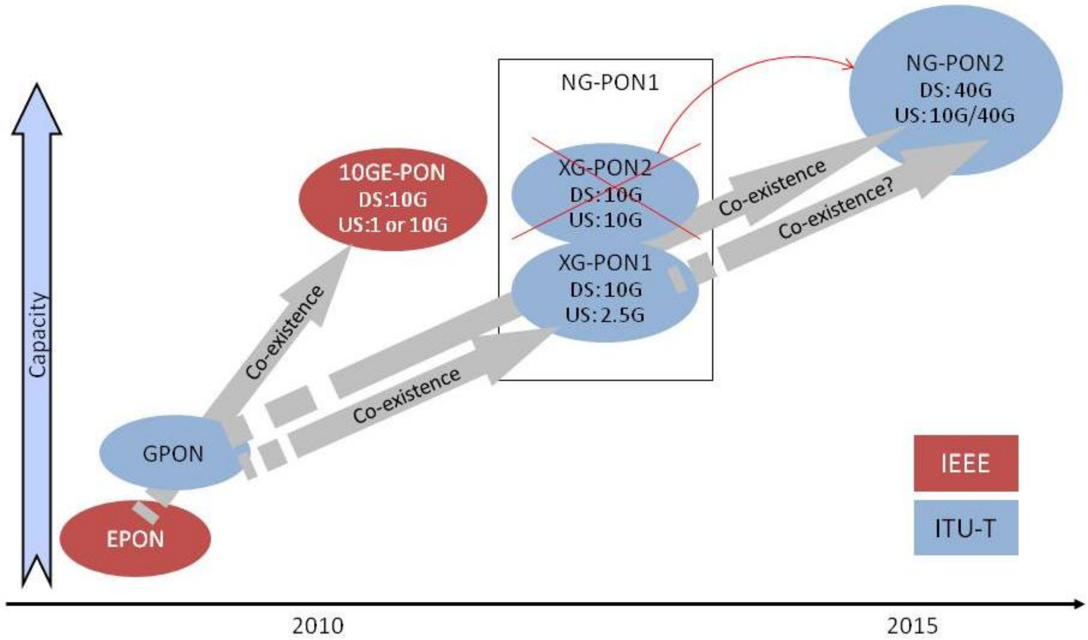

Figure 2: Optical access standards evolution

Since the optical distribution network represents approximately 70% of total investments in FTTH networks, it is crucial that future IEEE and ITU-T standards are backwards compatible, enabling operators to re-use their existing investments.

Both the IEEE and ITU-T standards allow the coexistence of different generations of PON technology. However, the proposed NG-PON2 standard already offers a clear path to higher capacities, and therefore is expected to better address the needs of operators in the future.

Next-generation PON Evolution

XG-PON1

The XG-PON1 approach, defined by ITU-T G.987 for near term deployment, operates with existing optical distribution networks and equipment. It provides 10 Gbps of shared downstream bandwidth, combined with 2.5 Gbps of upstream bandwidth.

XG-PON1 inherits the framing and management from GPON. Full-service operation is provided via higher data rate and larger split while keeping a flattened network structure – adding more features and capacity without adding complexity to the optical distribution network.

Driven by the 10G optical transceiver market and the available bands for achieving legacy compatibility, FSAN selected the XG-PON1 downstream wavelength of 1575nm and upstream wavelength around 1270nm. For GPON and XG-PON systems to coexist on the same network requires the addition of a wavelength coupler located at the central office, which has already been defined as WDM1r in ITU-T G.984.5.

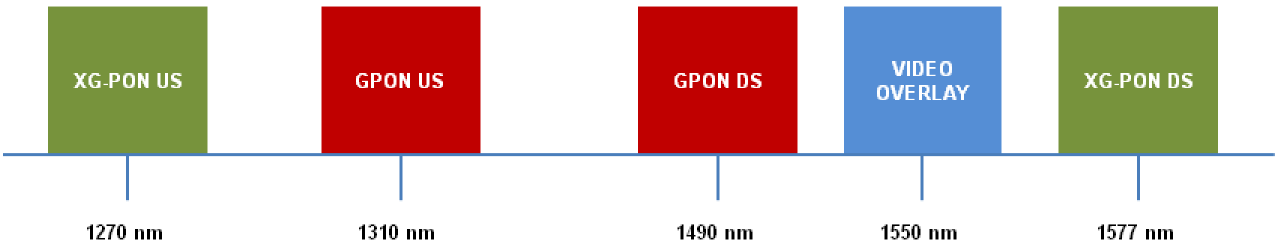

Figure 3: ITU-T G.987 wavelength plan

GPON class B+ defines a 28dB power budget. Due to the addition of the WDM1r combiner, some slight additional loss was added to the XG-PON1 power budget, resulting in an equivalent 29 dB budget. Additionally, XG-PON1 specifies 31, 33, and 35 dB options for the power budget.

A potential barrier to the deployment of GPON and XG-PON1 on the same outside plant is the existence (or non-existence) of wavelength blocking filters at the optical networking terminals (ONTs) in the customer premises. Most modern GPON ONTs have an integrated filter to eliminate interference from XG-PON1 wavelengths. However, older installed ONTs won't have such a filter. Service providers with older ONTs deployed will have to install filters at the ONT locations to enable GPON and XG-PON1 co-existence.

For configuration, operation and maintenance, GPON and XG-PON use the same, generic Optical network unit Management and Control Interface (OMCI), specified in ITU-T G.988.

Main features of XG-PON1	
Optical fibre	Single fibre transmission, compliant with ITU-T G.652
Wavelength plan	Upstream 1260nm to 1280nm / downstream 1575nm to 1580nm
Bandwidth	Downstream: Up to10Gbps / Upstream: Up to 2.4Gbps Support for dynamic bandwidth allocation (DBA) Full QoS and traffic management
Nominal line rate	Upstream: 2.48832 Gbps / downstream: 9.95328 Gbps
Media access control layer	Upstream: TDMA / Downstream: TDM Forward error correction with scrambled NRZ line encoding
Optical power budget	Between 29 dB and 35 dB
Split ratio	1:32, 1:64, scalable up to 1:256
Fibre distance	Differential distance of 20 km or 40 km. Logical Distance of up to 60 km.
Synchronization	Enhanced timing and time-of-day synchronization for mobile backhaul applications
Enhanced security	Strong mutual authentication; Authentication to protect the integrity of the PON management messages and the PON encryption keys.
Power saving features	Reduce the load during power failures (so batteries last longer), by turning off inactive user network interfaces (UNI) Deactivating the transmitter for routine transmissions ("dozing") Sleep mode, in which the ONT deactivates both its transmitter and receiver when the user has no activity ("sleeping")

Figure 4: Main features of XG-PON1 ITU-T G.987

NG-PON2

The next-generation technology, NG-PON2, is expected to increase PON capacity to at least 40 Gbps downstream and at least 10 Gbps upstream by 2015. Since the implementation is further ahead in time, it opens up the possibility of using more innovative approaches. Some of the proposals under consideration by FSAN include:

- 40Gbps TDM PON
- Time- and wavelength-division multiplexed (TWDM) PON
- WDM-PON
- Coherent ultra-dense WDM-PON (PON UDWDM)
- Orthogonal Frequency Division Multiplexing (OFDM) PON

FSAN has already selected TWDM-PON as the primary approach for NG-PON2, which is now in the process of being standardized by ITU-T. Operators consider TWDM-PON to be less risky, less disruptive and less expensive than other approaches because it reuses existing components and technologies. TWDM-PON can be viewed as multiple XG-PON1 systems operating on different pairs of wavelengths, so that they can be "stacked" onto the same physical fibre plant.

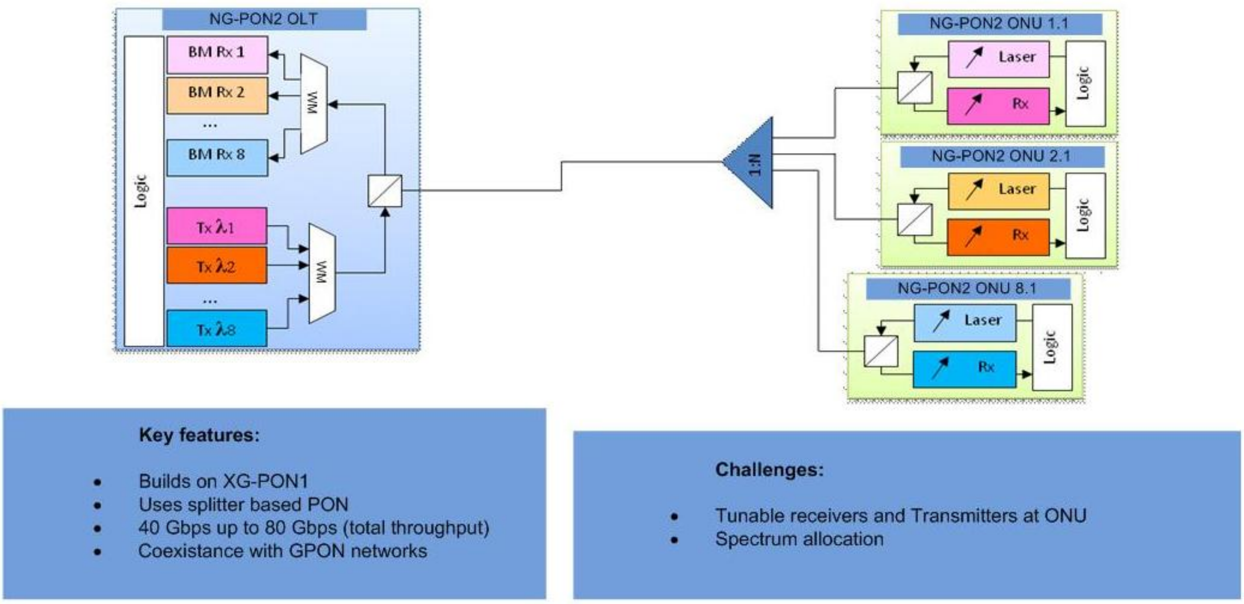

Figure 5: TWDM-PON architecture

NG-PON-2 was also designed to "pay as you grow", allowing operators to place the different technologies – GPON, XG-PON and NG-PON2 – on the same optical distribution network. Coexistence is ensured by a passive element, called the coexistence element (CE), which combines/splits the various wavelengths associated with each technology generation.

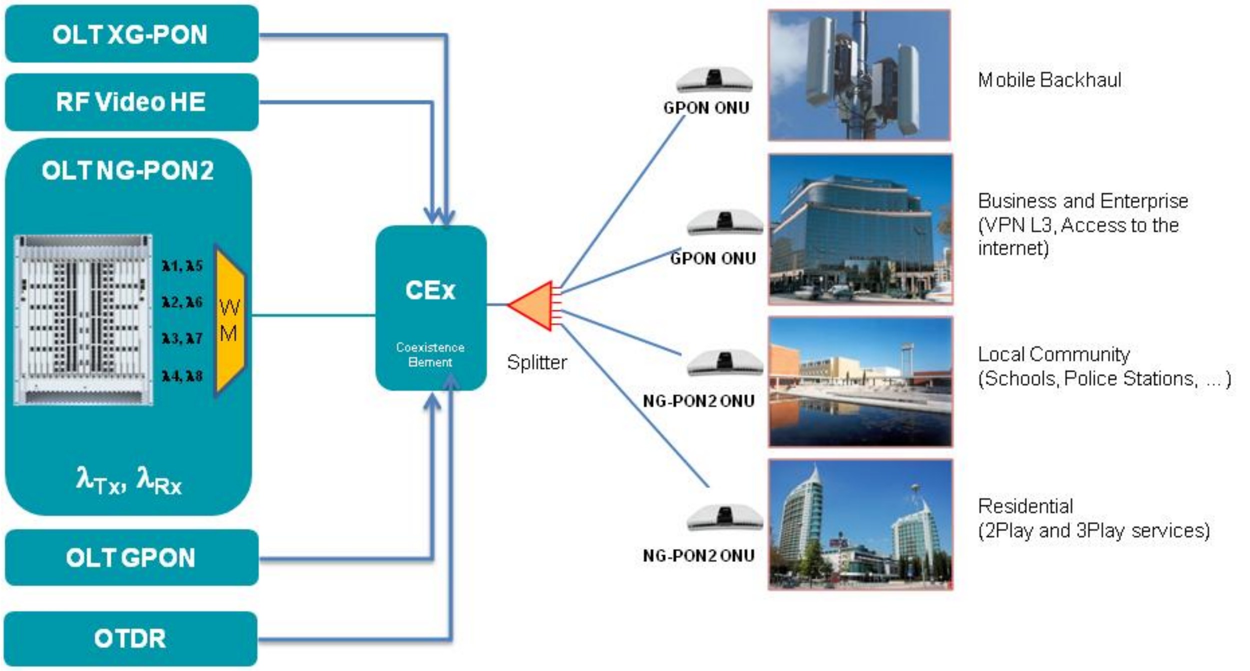

Figure 6: Coexistence element (draft ITU-T G.989)

The main challenges of implementing NG-PON2 are the spectrum allocation (bearing in mind that compatibility with sensitive RF services is a must) and the need for "colourless" ONTs, which must be able to send and receive signals on any of the specified wavelengths. The ONT transmitter must be tunable while the receiver requires a tunable filter.

Colourless ONTs based on tunable transmitters and receivers are likely to be more expensive than GPON ONTs. Optical component vendors are developing new technologies to help bring down costs. The use of photonic integrated circuits (PICs) in the ONT is highly attractive because a low-cost manufacturing process would enable mass deployment.

Furthermore, since tuning technologies mainly rely on temperature control, a key challenge is to maintain low power consumption in the ONT in compliance with the stringent EU Code of Conduct on Energy Consumption of Broadband Equipment. Ingenious power saving mechanisms will help to reduce the power consumption.

Four variants of TWDM-PON are currently being developed by ITU-T Study Group 15:

- **Basic:** 40 Gbps downstream and 10 Gbps upstream capacity, using four wavelengths
- **Extended:** 80 Gbps downstream and 20 Gbps upstream capacity, using eight wavelengths
- **Business:** Symmetrical services, 40/40 Gbps and 80/80 Gbps
- **Mobile fronthaul:** point-to-point WDM overlay

It is also expected that NG-PON2 devices will support mobile backhaul timing specifications (such as IEEE 1588v2 Boundary Clock and Transparent Clock) to support the precise frequency and phase time requirements in mobile networks.

GPON to NG-PON2 Transition

Some operators are targeting a direct migration from GPON directly to NG-PON2, and may therefore skip XG-PON1.

The key to a successful upgrade is to make sure that no changes are required to the optical distribution network. This requires the operator to place a coexistence element (CE) in the central office, and to make sure the current GPON ONTs/ONUs are equipped with the WDM filters as described in ITU-T G.984.5.

Figure 8 shows the typical arrangement of a current GPON network.

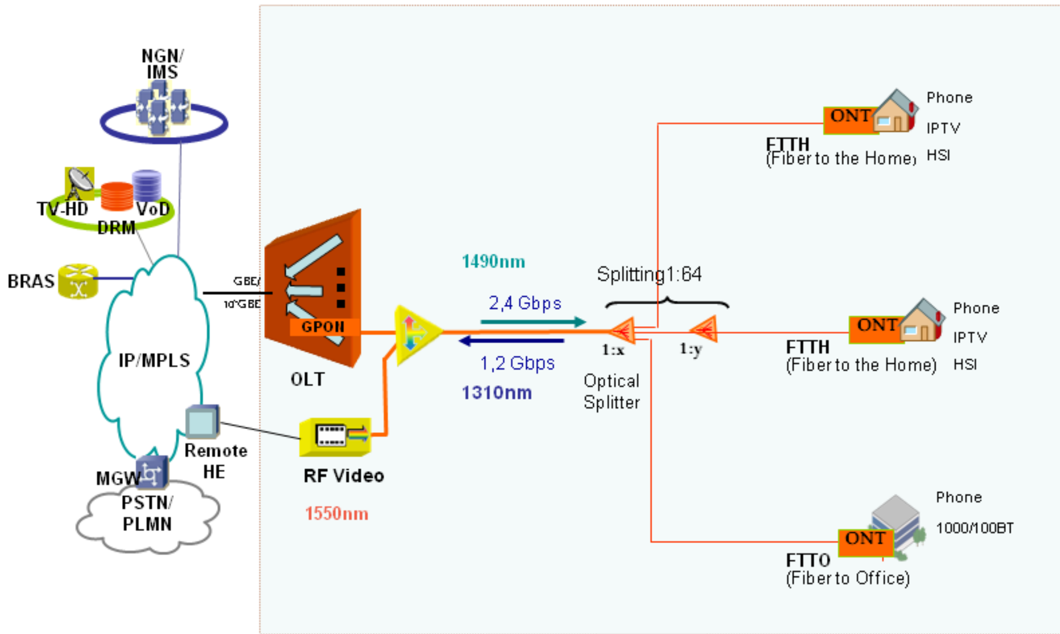

Figure 7: Current GPON deployment

The evolution to a NG-PON2 network can be performed by inserting a NG-PON2 blade at the optical line terminal (OLT) and routing the fibres to the coexistence element (CE).

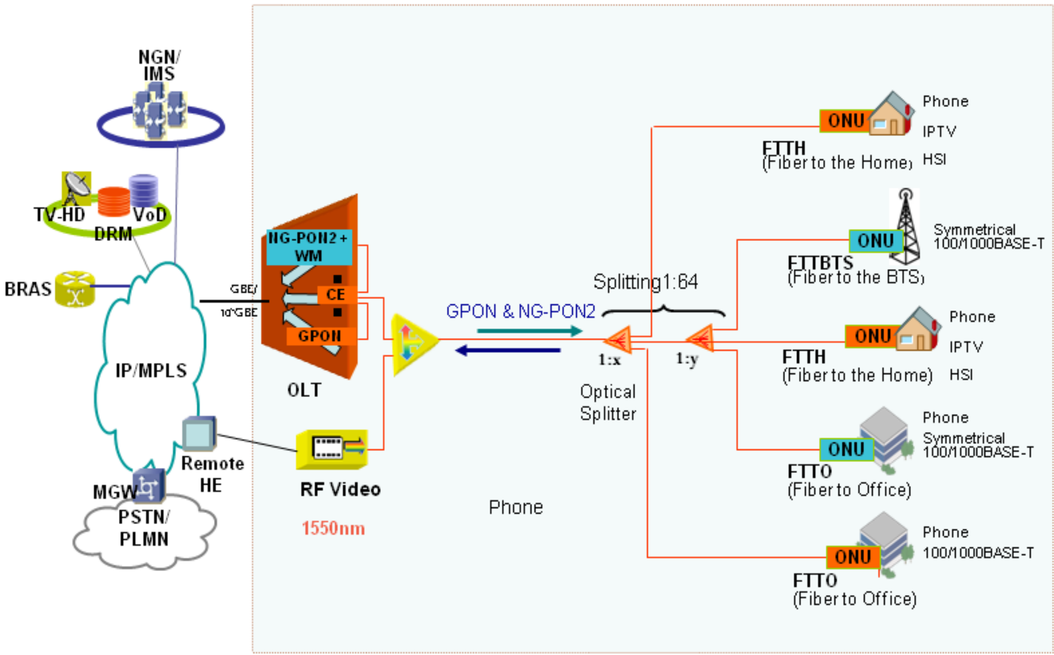

Figure 8: Coexistence of GPON and NG-PON2

Beyond NG-PON2

Bandwidth is expected to continue to grow exponentially and the capacity of optical access systems must keep pace. The theoretical capacity limit of optical fibre is extremely high; the limitations mainly arise from the combination of lasers, amplifiers and other equipment used to send and receive the optical signal. Commercial long-haul optical transmission systems with up to 8 Tbps of total capacity are available today. However, the economics of long-haul networks do not translate into the more cost-sensitive access network.

Looking beyond NG-PON2, the bandwidth delivered to end users is dependent on:

- The overall capacity of the optical access equipment.
- The split ratio – how many users share bandwidth in the feeder portion of the PON.
- The reach of the optical system may also be a factor due to the signal to noise ratio.

Although there are uncertainties in technological developments, the roadmap for the long-term evolution of PON networks indicates that the technology can be expected to address 100 Gbps data rates over distances in excess of 100 km by 2025:

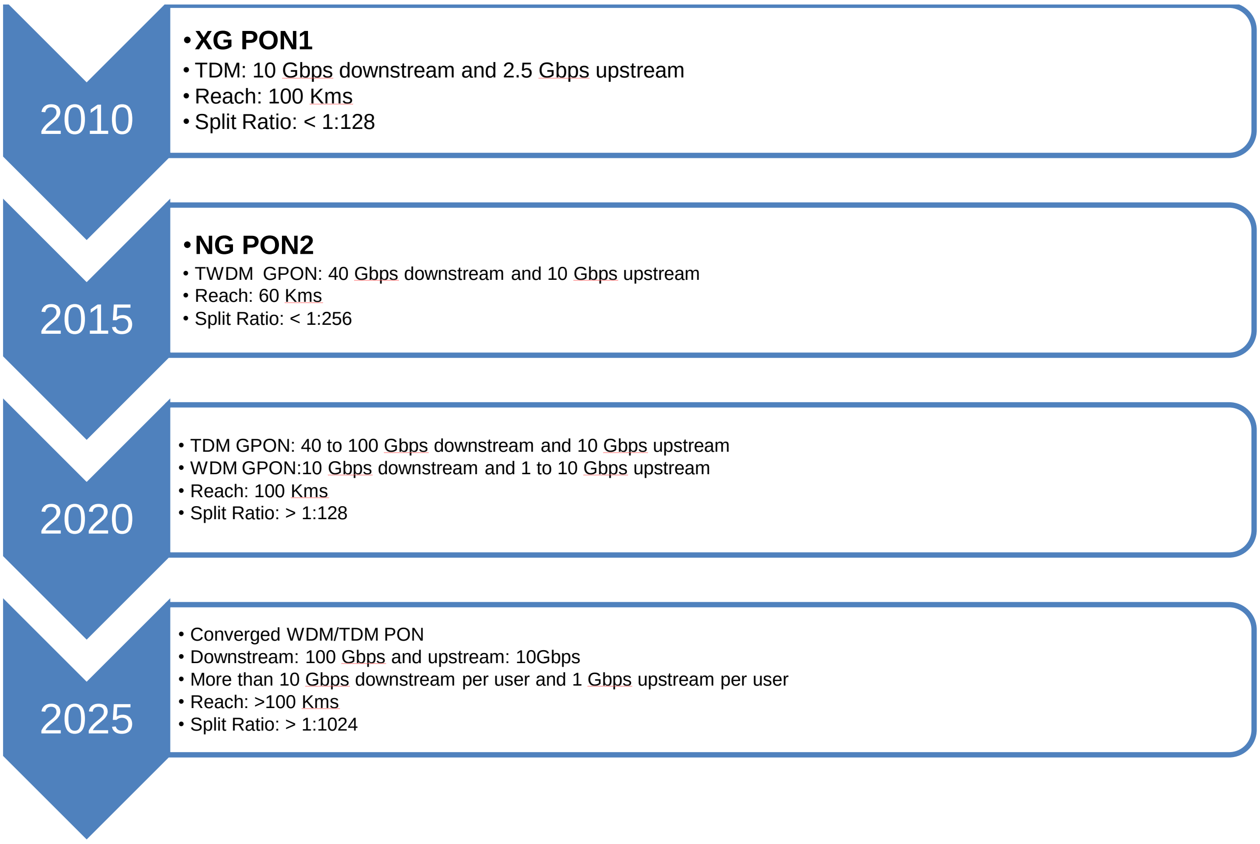

Figure 9: Beyond NG-PON2 - as envisioned by Analysys Mason, 2009

NG-PON2 Applications

Small Cell Backhaul

Mobile operators are deploying small cells at an increasing rate. These low-powered radio access nodes allow mobile operators to increase their capacity in high usage areas and increase their coverage, while also addressing social concerns about high levels of radiation and form factor.

For small cell sites to be successfully deployed, mobile operators need a cost-effective method to connect the site to their core network. Taking advantage of existing FTTH infrastructure makes a lot of sense. Indeed a new business model is emerging, where operators offer “Small Cells as a Service (SCaaS)” for mobile virtual network operators lacking fixed infrastructure.

Small cells have demanding quality of service (QoS) and performance requirements. They require high capacity backhaul, low latency and high availability. They also require synchronisation and frequency alignment with macro and other small cells to enable seamless mobility.

With this in mind, we believe that NG-PON2 technology is well positioned to address the requirements of small cell backhaul.

C-RAN Architectures

With developments in mobile broadband networks driven primarily by 4G and 5G, next-generation radio cells will be expected to support data rates of up to 10 Gbps. Mobile operators will have to significantly increase the capacity of their radio networks, while at the same time they must reduce their capital and operating costs because end user revenues will not keep pace.

This will unavoidably lead to the deployment of an increasing number of base stations with high spectral efficiency and high power demands. Power and space are a scarce resource at cell sites, and efficiencies can be achieved by moving some parts of the radio network function, which are currently co-located with the antenna at the cell site, to locations deeper in the network. This move to a “Cloud Radio Access Network”, or C-RAN, introduces a new transmission requirement into the overall mobile network infrastructure – mobile fronthaul.

The C-RAN architecture provides a cost-effective way for service providers to support emerging broadband wireless topologies. Simple remote radio base stations could be located in environmentally challenging locations and centrally controlled from the head office. This would reduce capital and operating costs. The installation costs would be lower, and fewer cell site visits would be required because upgrades and troubleshooting can be performed at the central location. In addition, by removing equipment from the cell site, security is improved (there is no cabinet to break into), and the need for heating and cooling of the enclosure at the cell site is eliminated.

Currently, the baseband unit (BBU) is typically located in a cabinet at the cell site (or on the pole) and connected to the radio head at the top of the tower using the Common Public Radio Interface (CPRI) protocol (Figure 10). If the BBU is moved to a central location, high-bandwidth links will be required to connect the remote radio heads to that common central location.

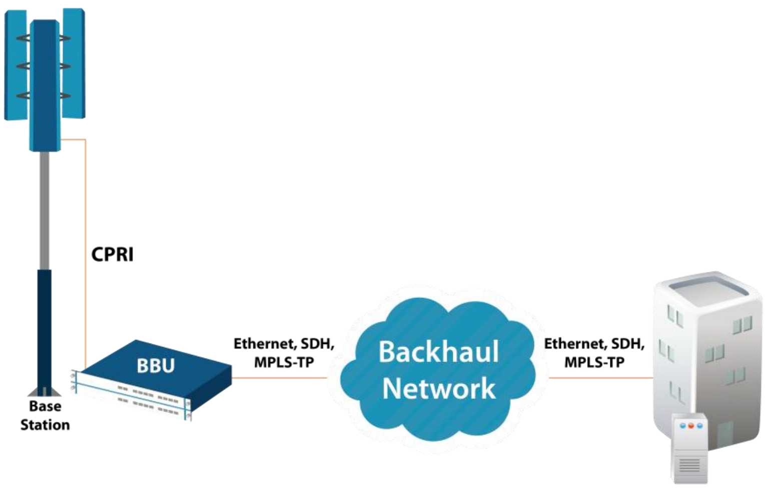

Figure 10: Current CPRI backhaul topology

The simplest option for mobile fronthaul to remote radio heads would be a dedicated optical fibre connection. Equipment based on protocols such as SDH and IP would be expensive to deploy and operate, however; hence, lower-cost alternatives have been suggested.

A more cost-effective option is to connect the BBU to the remote radio head over an NG-PON2 network, by assigning one of the available wavelengths defined for NG-PON2 to the cell site. The CPRI protocol has been defined with six speeds, including one that closely matches the 10Gbps data rate of NG-PON2 optics.

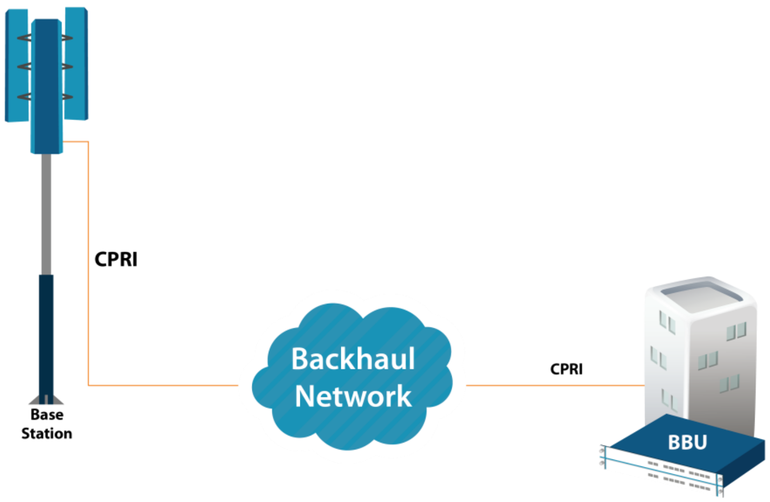

Figure 11: Dedicated wavelength for CPRI

Conclusions and Recommendations

Passive optical networks, especially GPON, will provide cost-efficient bandwidth to residential consumers in the short and medium term.

However, future high-bandwidth applications for residential users in combination with new bandwidth requirements from mobile backhaul and business services will exceed the capacity available from the current generation of PON equipment.

New technology has to be introduced without disruption to existing services and revenues. The upgrade must also be attractive from the business point of view, in order to combine the need for the bandwidth growth with the need for revenues.

Network operators and governments have made huge investments deploying optical fibre in the access network. They are extremely unlikely to accept new technologies that do not reuse their existing infrastructure.

In terms of bit rates, XG-PON technology is the natural successor to GPON, but the need for higher bandwidth will lead some operators to upgrade their networks directly to NG-PON2.

Time and wavelength division multiplexed PON (TWDM-PON) has been chosen as the primary technical solution for NG-PON2 because it reuses the investment in the outside plant.

Recommendations:

- Operators need to ensure that the evolution process has minimal impact on end user services and on current operation, administration and maintenance systems.
- The agreement of next-generation standards needs to speed up, especially NG-PON2.
- Fibre unbundling or wavelength unbundling must be enabled to support the regulatory requirements for competition.
- Emphasis needs to be put on R&D to enhance the cost and performance of optical components, especially the tunable transmitters and tunable receivers at the ONT.

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