Navigating the XGSPON Journey From an MSO Perspective

A Technical Paper prepared for SCTE by

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1. Introduction

More than ever Multiple System Operators (MSOs) are faced with unprecedented network capacity demand. Internet traffic growth, online gaming, video streaming services with higher resolution and higher bit rates, and video conference calls from work-from-home customers are among the contributors to consumer demand. Beyond the need to support the actual required capacity, MSOs are often pressured by their telco competitors on speed offerings from their fiber-to-the-home networks.

While MSOs continue to extend the runway of their Hybrid Fiber Coax (HFC) infrastructure with new DOCSIS technologies such as DOCSIS 4.0 and Distributed Access Architecture (DAA), many cable operators have also started exploring or deploying Fiber-to-the-Home (FTTH) Passive Optical Network (PON) as a way to address customer capacity demand, as well as to compete with telco's high speed service offerings.

This paper will share some of the technical analysis process and decisions Rogers made in navigating our journey to deploy FTTH 10Gbps symmetrical passive optical network (XGSPON), and the technology, deployment and operational lessons learnt along our journey.

Note that this paper is not intended to be a technical deep dive of the gigabit-capable passive optical network (GPON) or ethernet passive optical network (EPON) standards or implementation best practice, as there are plenty of resources readily accessible from CableLabs, ITU, IEEE and other industry bodies. Instead, this paper will focus on sharing Rogers's PON journey from defining the PON architecture, the pros and cons of all the technical assessments and decisions we had to make, and the lessons learnt from a cable operator's perspective in implementing and operationalizing PON.

1.1. Why PON? Business Drivers behind expediting PON introduction

For decades cable operators have successfully leveraged the high bandwidth of Hybrid Fiber-Coax (HFC) network and DOCSIS technology to provide triple-play services: high-speed internet, video and voice, to residential customers successfully, often beating its telco competitors with significant edge in service penetration over their DSL offerings. However, with heavy investments from the telcos in passive optical network (PON) deployments starting in the early 2000s, telcos who have made the investment in PON deployment now have a very competitive service offering in their PON footprint.

Competitive Pressure from Telcos

The major business driver for cable companies to invest in PON is competitive pressure on internet speed. Telcos coming from a DSL access network in the past could not compete with cable providers' DOCSIS technology in the 1990's and early 2000's. However for telcos who have started deploying PON to replace their DSL network, they have now come to a point where they can provide very competitive service offering in their PON footprint. Current generation 10G PON, as we will discuss further in this paper, has a line speed of symmetrical 10Gbps to each subscriber's home. Some PON service providers, including Rogers, are already offering 8Gbps symmetrical services because of the low utilization and small serving group (usually 32 homes). These high-speed service offerings present a challenge to cable operators in trying to match their speed while cable operators are actively modernizing their networks to prepare for introduction of next generation DOCSIS 4.0 technology.

Since PON networks are expensive to implement, for the telcos that have paid the sunk cost to build the optical fiber to the home network already, their primary motive is to recuperate as much of the sunk cost as fast as possible via increased service penetration with aggressive marketing. Many telcos have begun to offer their ultra-high speed PON services (such as 8Gbps) at very competitive rate comparable to cable operators' "mass-market" offering (such as 1Gbps/50 Mbps service tier). This marketing strategy is putting pressure on cable operators trying to compete with DOCSIS service offerings.

Changing Consumer Usage Pattern

While HFC technologies continue to evolve, PON offers operators and customers many benefits, thanks to its ability to support multi-gig speeds and low latency experiences. While multi-gig is not critical today, emerging technologies may drive its importance in the future, such as:

- Many employees now work from their home offices full-time. While the typical conference call does not require more than 3-5 Mbps per call, some employees' jobs require them to send and receive large multi-gigabyte files to perform their job functions. Data scientists, for example, often need to download large data files daily. Video and graphic designers often need to download and upload large video files. The difference between a 30 Mbps upstream pipe and a 2 Gbps upstream pipe means the upload time is 67x faster. With the line between 'home' and 'office' becomes intertwined, the need to offer residential high speed symmetrical multi-gig internet service is becoming increasingly important.

- Many Rogers residential customers are also part-time or full-time video content generators on YouTube, Vimeo or other platforms. The need to frequently upload high resolution videos drives the need for a multi-gig symmetrical service.

- In 2023, the gaming industry is valued at over $160B and is among one of the highest revenue-generating industries globally. A good online gaming experience requires high bandwidth (especially with more and more gaming platforms shifting from a download model to cloud gaming model), but most importantly a low latency network. DOCSIS network averages ~30-45 ms in round trip latency today. With the emergence of low latency DOCSIS (LLD) cable operators aim to significantly reduce the latency to ~10 ms in an actual network. Today, PON offers low latency performance, and continues to be a popular solution with the gaming market. These business drivers show cable operators should at the very least consider deploying PON in strategical markets to remain competitive with telcos' offerings.

1.2. Primer: PON vs HFC Networks

While it is not the objective of this paper to compare DOCSIS technology to PON technology, this section should help provide the background for PON network and its fundamental technical differences from DOCSIS HFC networks.

In a traditional hybrid fiber coax (HFC) network, a CMTS (Cable Modem Terminal System) transmits an amplitude modulated (or often referred to "analog fiber") optical signal over fiber from the headend to an optical node in the field, which then converts the optical signal to radio frequency (RF) signal and transmits over coaxial cable to the customer homes, usually over cascade of active amplifiers and passive components such as multitaps and splitters.

The distributed access architecture (DAA) is a slight variation, where the CMTS .cCore will transmit 10GE signal over 'digital fiber' to the remote PHY nodes in the field, thus extending the 'digital fiber' further into the access network and increasing the bandwidth. However, the remote PHY node still transmits analog RF signal over coaxial cable as the last mile into the customer home.

Passive Optical Networks (PON) is an access network that is fully digital over an end-to-end fiber medium. The BNG (Broadband Network Gateway) in the headend transmits 10GE (or higher speed

Ethernet signals such as 40GE or 100GE) digital optical signals to an optical line termination (OLT), which may be located inside a site facility or in the field. The OLT transmits the PON optical signal to customer homes over fiber, via a local convergence point (LCP) which is an optical splitter / coupler, where the signal is split / combined to feed a combining group of typically 32 or 64 homes.

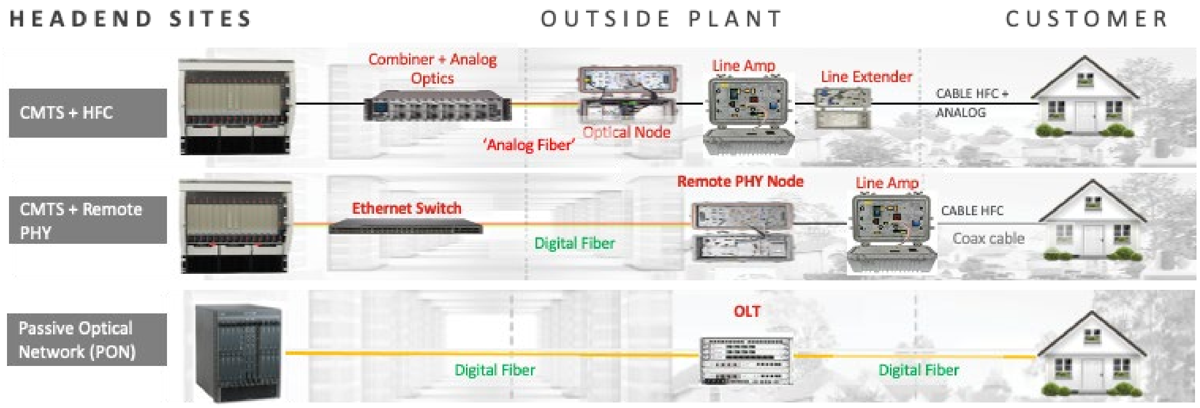

Figure 1 – Traditional CMTS, DAA, and PON

2. Architecture Comparison GPON vs. EPON Standards

2.1. Important Facts About PON Standards for MSOs

While there were various PON standards (such as ATM PON, BPON etc.) in the long history of PON technology development, there are only 2 relevant standards in 2023: GPON and EPON standards. The physical architecture design of either PON standard is largely the same : a broadband network gateway (BNG) in the primary hub (PHUB) to connect between the core IP network and the access network, an optical line terminal (OLT) to aggregate and terminate access connections, a local convergence point (LCP) to split and couple to 32 or 64 homes passed, and direct fiber from LCP to each individual customer home to terminate the optical signal on a customer premise equipment (CPE) called an optical network terminal (ONT) or optical network unit (ONU). This is common to both GPON and EPON, and their respective 10G or 25/50G standards.

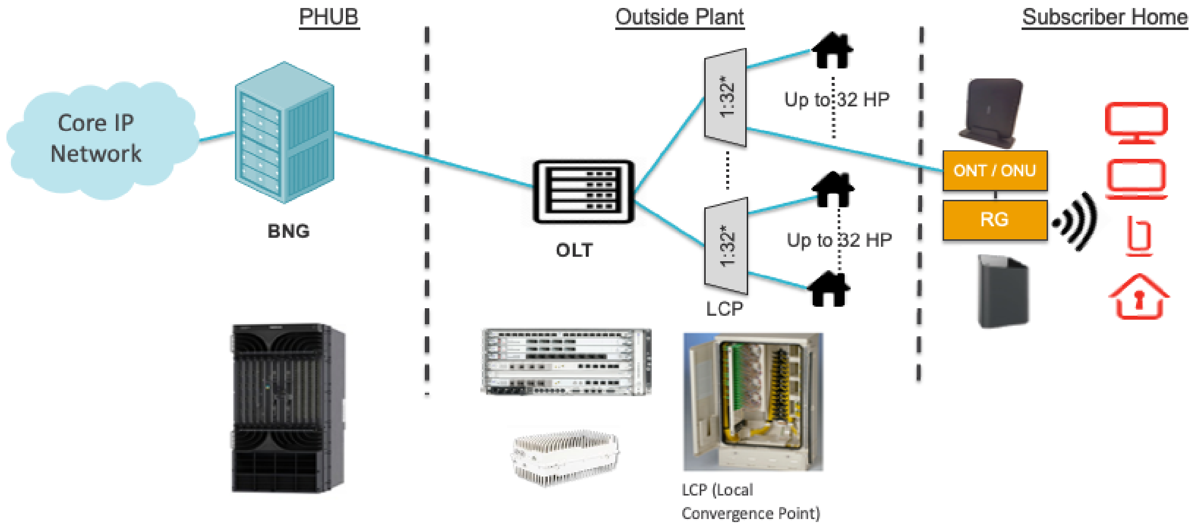

Figure 2 – PON Physical Network Architecture

While the physical network design is largely similar between GPON and EPON standards, the supporting provisioning, policy and other OSS and BSS platforms are very different. Any cable operator who plans on deploying PON must first understand the pros and cons of each standard and decide which of these 2 standards to adopt. Deciding on the PON standard is often the biggest decision cable operators have to make in their fiber-to-the-home PON strategy.

i) **Gigabit Passive Optical Network (GPON)** is an ITU standard G.984 that was originally standardized in 2003. The original GPON standard supports a line rate of 2.5 Gbps downstream, and 1.25 Gbps upstream.

   The ITU GPON standard has evolved over the years to support 10 Gbps (Initially asymmetrical 10/2.5 Gbps XGPON or XGPON1, and the more popular 10/10 Gbps Symmetrical XGSPON ITU G.987). The next generation of 25Gbps and 50Gbps (ITU G.9804) products are expected to be generally available in 2023.

   The GPON family supports co-existence of different speeds on the same PON, meaning when operator upgrades from 2.5G GPON to 10G XGSPON, both 2.5G and 10G ONTs (customers) can co-exist on the same optical distribution network (ODN), and allows upgrading of PON customers from 2.5G to 10G (and subsequently to higher speed such as 25G) on a per ONT basis.

ii) **Ethernet Passive Optical Network (EPON)** is an IEEE standard 802.3 that was originally standardized in 2004. The original EPON standard supports a line rate of 1 Gbps symmetrical.

   Over the years the EPON standard has also evolved to support 10 Gbps which includes the asymmetrical 10/1 Gbps EPON and the more popular symmetrical 10G EPON. Like the ITU GPON standard, the IEEE standard EPON is developing 25G/50G EPON products and they are expected to be generally available in 2023 as well. And similar to GPON, different speeds of EPON can co-exist on the same optical distribution network (ODN) without having to upgrade the entire PON with higher speed ONU.

While it is sometimes misinterpreted that telcos adopt GPON and cable operators adopt EPON, that is not the case at all. Most cable operators in Europe, and South and Central America have deployed GPON instead of EPON. The largest current EPON deployments globally are in Asian markets including China, Japan and Korea, where EPON is equally adopted by telcos and cable companies. In fact, even among the cable operators in North America, Comcast and Charter are the only operators for large scale EPON deployment.

2.1.1. DOCSIS Provisioning Over EPON (DPoE)

In the early 2010s CableLabs working group developed a DOCSIS specification over EPON (DPoE) standard that is an extension to the EPON standard. The objective of DPoE is to help cable operators easily manage the provisioning and performance management aspects of EPON network by abstracting and translating EPON configuration information into virtual CMTS and virtual cable modems, so that cable operators can continue to use cable provisioning and network management platforms they are familiar with to manage the EPON network, without having to introduce network platforms like policy and charging rules function (PCRF), subscriber profile repository (SPR) etc., which are foreign to a lot of cable operators.

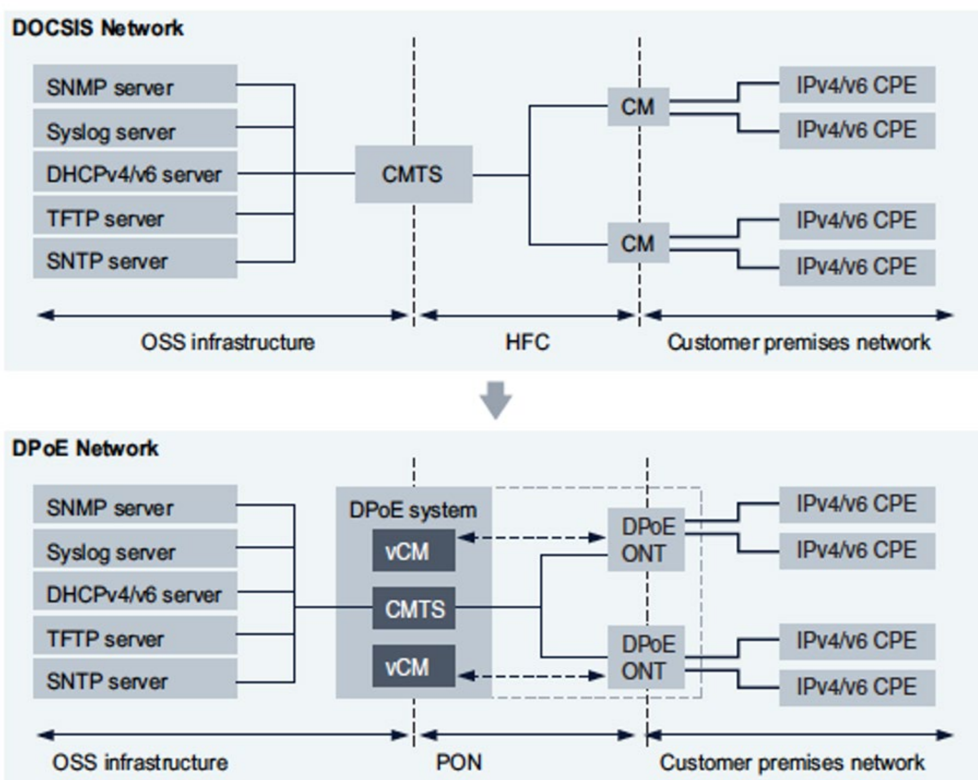

Figure 3 – Logical Comparison of DOCSIS and DPoE Network

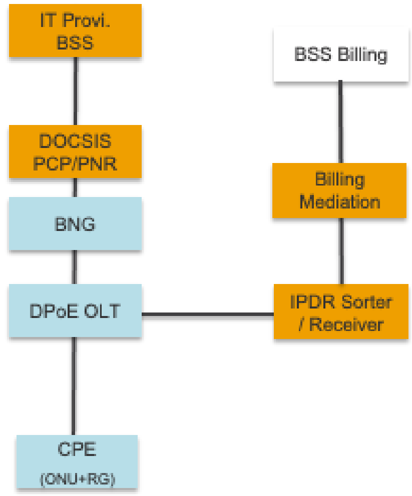

Figure 4 – Logical Network Diagram of DPoE EPON Network

The other significant advantage of DPoE is that it successfully standardizes the interoperability between different vendors' DPoE OLTs and ONUs. In the GPON standard, even though the OLT–ONT communication and management interface ONT management control interface (OMCI) is fully standardized, almost all major OLT vendors have inserted their own proprietary measures and information on top of the OMCI to enhance their ONT management, As a result, 3rd party ONTs are rarely 'plug and play' when paired with a different vendor's OLT. In fact, OLT–ONT interoperability is always challenging and unpredictable among GPON vendors, and many operators have chosen to avoid interoperating OLT and ONTs from different vendors. DPoE EPON completely eliminates this interoperability issue.

For cable operators considering the EPON standard, DPoE should be a natural decision due to all the above advantages to a cable operator. However, cable operators should carefully consider the advantages and disadvantages of EPON (or, DPoE EPON) vs. GPON before making architectural decision on either standard. This will be addressed in great detail in the second half of this section.

Subsequent to DPoE, CableLabs has also released a DOCSIS provisioning over GPON (DPoG) standard with the objective to allow cable operators to maintain their current provisioning and network management platforms while interfacing with a GPON access platform. However, DPoG was never widely adopted, and since in 2023 the eco-system is almost non-existent, the standard is no longer relevant.

2.1.2. RF Over Glass (RFoG)

In the early days of fiber to the home (FTTH) deployment, some MSOs chose to deploy RF over Glass (RFoG) as an alternative or precursor to PON deployment. While RFoG allows cable operators to deliver fiber to the home without major changes to their DOCSIS – HFC ecosystem, RFoG essentially uses an analog modulated (or 'analog') fiber to replace the last mile coax cable from the fiber node out into the customer home. The RF optical signal is terminated at a customer ONU, converted to RF over coax, and feeds respective cable modem or set top box equipment. This does not provide any real advantage over an HFC network, with the exception of the potential of slightly more RF spectrum.

RFoG lacks the bandwidth and speed of true PON technology, since it is still using quadrature amplitude modulation (QAM) modulation over fiber, and further, it creates optical beat interference (OBI) issues in the upstream that prohibits the deployment of orthogonal frequency-division multiple access (OFDMA) in the same serving group. Cable operators that plan to turn on OFDMA in the upstream for their DOCSIS customers will need to introduce some kind of OBI suppression mechanism on the CMTS, or migrate their RFoG customers to PON.

The main advantage of RFoG is it allows operators to offer RF services such as traditional video services and DOCSIS voice service. For operators that must continue to offer RF services in a FTTH setting, RFoG is the only option.

RFoG can also be overlayed with PON deployment over different wavelengths on the same access fiber for operators that need to provide high speed internet services over PON and traditional RF services over RFoG to the same household. The downside to that is it essentially doubles the network cost by having parallel CMTS and PON network equipment serving the same customer, all the way from headend access platform to customer CPE. It also doubles the number of network equipment that needs to be operated and maintained, thus inflating the operating cost and complexity.

In 2023 RFoG is no longer a viable technology, and many operators are removing RFoG from their network and replacing it with PON deployment.

2.1.3. Delivering Services Over PON

One challenge cable operators faced in the early days of PON was how to provide triple-play (internet, voice and video) services, since PON is a purely digital access platform, there is no backward compatibility for legacy RF services such as traditional QAM based video or DOCSIS voice.

PON can provide triple-play using internet protocol television (IPTV) and digital session initiation protocol based (SIP) voice services. However, if the operator does not support IPTV and SIP voice services yet, then the only remaining solution is to deploy parallel PON and RFoG access networks to serve the same customer home, and offer high speed internet over PON, and legacy video and voice services over RFoG. As aforementioned, this is not recommended as it doubles the network cost and operating cost.

As for business services, OLT is often superior to traditional DOCSIS network since many OLTs are capable layer 2 and layer 3 devices and offer operators an abundance of layer 2 and layer 3 business services to customers. PON also offers defined quality of service (QoS), and lower latency.

PON is also a capable access technology to complement or support wireless services. The high bandwidth and low latency of PON make it a viable option for LTE / 5G wireless service backhaul, and potentially mid-haul or front-haul using 25G/50G PON. PON also supports timing and frequency synchronization protocols such as Sync-E and IEEE 1588, allowing wireless operators to provide Precision Time Protocol (PTP) timing over the PON network to their wireless platform in absence of other medium such as GPS antenna. Note that the GPON family has much better wireless services support compared to the EPON family, this will be discussed in more detail in later sections.

2.1.4. Service Syndication

Note that although Comcast has adopted EPON standard for their PON deployment, their syndicated IPTV and voice services are access network agnostic and work equally well over GPON or EPON networks. The Comcast PON solution uses a 2 box solution, where the ONU (for EPON, or ONT for

GPON) terminates the PON signal, and the Comcast XB CPE will be enabled with EWAN (Ethernet-WAN) mode, which connects its WAN connection to the ONT/ONU, and functions as a home wifi gateway.

2.2. The Case for EPON

For many cable operators EPON may be the natural choice to deploy PON, because throughout the years CableLabs has been very supporting in defining DPoE EPON standard, and many North American cable companies have indeed deployed EPON as well.

In analyzing EPON vs. GPON standards, the main advantages of EPON from a .cCable operator's perspective are as follows:

2.2.1. Re-use DOCSIS Provisioning Platforms

Through DPoE's simulation of ONUs as virtual cable modems (vCM) and OLTs as virtual CMTS (vCMTS), cable operators can reuse the existing DOCSIS provisioning system (PVP/PNR, as an example) and its workflow to complete automated provisioning. Implementation of DPoE does effectively allow the current DOCSIS provisioning workflow to work with very little customization or changes over EPON.

For cable operators to adopt GPON standard for their PON deployment, they will need to introduce new provisioning platforms such as policy and charging rules function), (PCRF subscriber profile repository (SPR), and Policy and Charging Enforcement Function (PCEF), which is usually supported by the broadband network gateway (BNG). This requires new technology platform introduction, training and operationalization.

2.2.2. Re-use DOCSIS OSS Platforms for Network Performance Monitoring

Similarly, through DPoE standard cable operators can re-use current DOCSIS OSS systems to monitor network performance of OLTs and ONUs as vCMTS and vCMs, through the same OSS interfaces such as internet protocol data record (IPDR) and simple network management protocol (SNMP).

The GPON ecosystem does not support IPDR, hence cable operators will need to introduce new element management system (EMS) and integrate that with existing OSS platforms to monitor network alarms and performance KPIs. Subscriber usage metering is also not provided over IPDR, thus there needs to be additional integration between usage metering OSS platform and the Policy and Charging Enforcement Function (PCEF)/BNG.

2.2.3. ONU Interoperability

DPoE standard has successfully enforced interoperability among different ONU vendors so cable operators that adopt DPoE EPON will have the advantage to easy integration if they wish to introduce different ONU vendors.

OLT-ONT interoperability is very weak in the GPON vendor eco-system, regardless of 2.5G, 10G or 25/50G PON platforms. Extensive testing and integration are expected among most OLT/ONT vendors to achieve interoperability. Even when full interoperability is finally validated, there needs to be continuous interop testing with new firmware versions on the OLT and ONT side. Interoperability is even more difficult for GPON vendors that sell in both the ONT and OLT spaces due to the competitive environment. GPON operators that desire to keep dual GPON vendors often resort to geographical division instead of interoperation between different vendors' OLT and ONT equipment for ease of operation simplicity.

2.2.4. Familiar Vendor Ecosystem

Due to popularity of DPoE EPON among North American cable operators, many of the largest EPON vendors are also large DOCSIS CMTS vendors. In fact, many DOCSIS CMTS vendors also manufacture DPoE EPON module for their distributed access architecture (DAA) remote PHY nodes to support an upgrade roadmap from DAA to PON. This familiar vendor eco-system gives cable operators an advantage of sales volume and vendor relationship compared to introducing new GPON vendors who may not be familiar to cable companies.

2.3. The Case for GPON

While GPON standards (2.5G GPON, XGSPON, or upcoming 25G/50G PON) are traditionally unpopular among cable operators, there are good reasons for cable operators to seriously consider GPON before finalizing the standard and architecture.

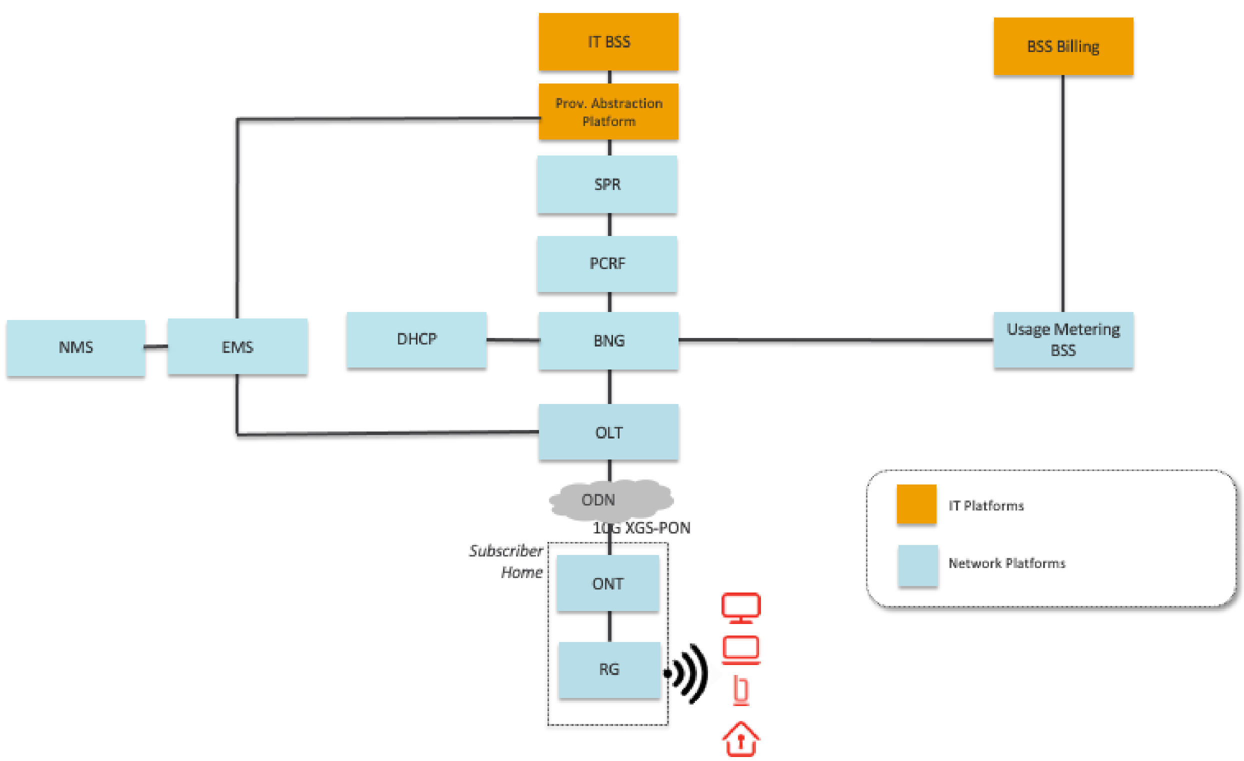

Figure 5 – Logical Network Diagram of XGSPON Network

2.3.1. Global Market Dominance

In 2023, GPON standards (2.5GPON, XGSPON combined) dominate over 92% of global market share compared to EPON standards (1GEPON, 10GEPON combined) with less than 8% market share.[1] This is expected to increase to 99% dominance for GPON standards in 2026 as the Asian market moves further away from EPON to GPON.

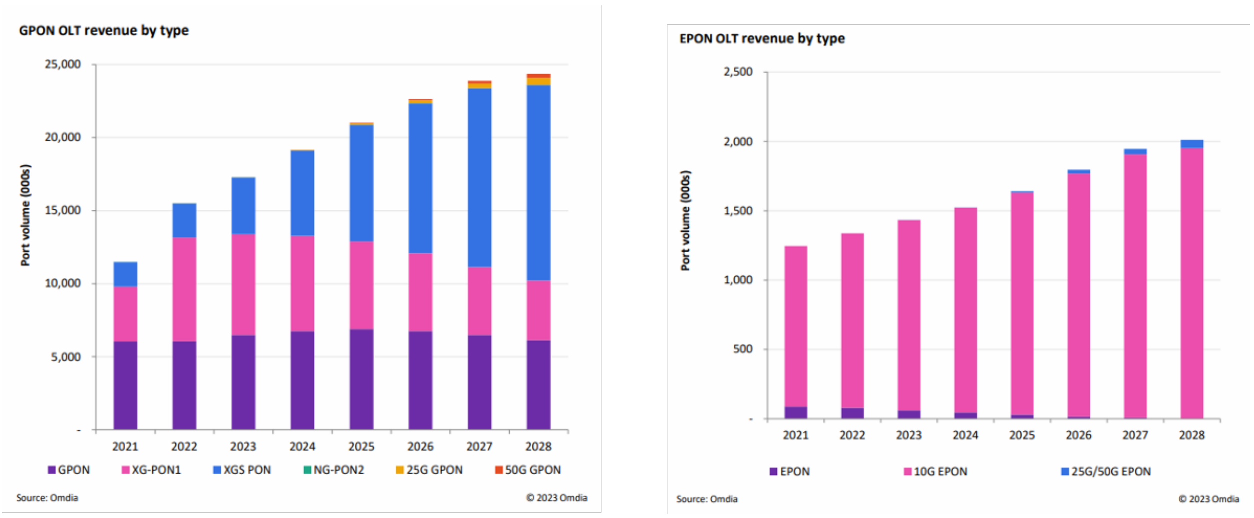

Figure 6 – GPON vs EPON Industry Landscape Comparison[1]

Contrary to popular beliefs where telcos deploy GPON and cable operators deploy EPON, actually a majority of EPON deployments were in the Asian-pacific market where China, Korea and Japan started deploying EPON in the late 2000s. Outside of the Asian-Pacific market GPON standards have over 95% market share. However, over the past 7 years with a lot of Asian-Pacific operators switching from EPON to XGSPON for their new deployments, this further widens the gap between GPON and EPON standards in global markets.

With a lopsided market split, operators need to be concerned about long term development and vendor support of the EPON platforms. GPON platforms have a much healthier vendor ecosystem, and operators can expect to have better equipment pricing due to volume, and better supply chain structure. GPON standards can also expect more research and development resources invested in it, thus supporting more new features to fill customers' and service providers' needs. This is evident from the difference in vendor ecosystems actively engaged in providing upcoming 25G/50G PON equipment from both the GPON and EPON standards.

Likewise for network platforms to supplement the GPON architecture, such as PCRF and SPR, are also commonly deployed by many GPON providers across the globe. They have a large vendor ecosystem with continuous development and support, competitive pricing and supply chain structure. Compared with DOCSIS's provisioning (PCP/PNR) provisioning platform, PCRF-SPR offers a vastly better vendor ecosystem for future support and roadmap.

[1] Source : Report by independent industry researcher Omida in *"PON OLT Vendor Landscape Report – 2023"*

2.3.2. Business Services Synergy

While EPON and GPON may be on par for residential service offering, the GPON platform provides improved business service support and synergy; not as much from a standard definition perspective, but from a market demand and equipment offering perspective. As an example, it is very common for GPON vendors' OLT chassis to support PON access cards for residential or small / medium business customers, and also point to point ethernet cards for large or enterprise business customers, thus installing 1 OLT node service, a provider will be able to provide a residential or small./medium sized business with PON 'best effort' offerings, and large business and enterprise businesses with guaranteed service level agreement ethernet services over point-to-point ethernet, plus wireless (more on that in next section) services. An EPON vendor OLT chassis typically focus on residential services, but the same OLT often lack business-oriented support and features such as point-to-point ethernet card support, layer 3 and MPLS services etc. When Rogers considered deploying DPoE EPON, it became very apparent that in order to offer most of our current enterprise and business services, we would have to overlay the EPON PON network with a separate equipment network to satisfy our business services needs. This doubles the access equipment cost, fiber wavelength usage, and maintenance and operation cost and complexity. Being able to provide all these services from a single PON network is an advantage for the GPON standard.

This may be a lesser issue in suburban areas where residential areas and business areas rarely overlap, but in a city it becomes expensive from a network build cost and maintenance cost perspective to overlay 2 separate fiber networks to serve the residential and enterprise customers in the same geographic area.

2.3.3. Wireless Network & Services Synergy

While this may not be the requirement for every cable provider, the GPON standard is a better strategic choice for wireless x-haul and providing timing and sync for 5G Wireless networks. The ITU standards include the stringent frequency, phase and latency requirements to support wireless x-haul and wireless synchronization. GPON network can be used to provide timing and synchronization via ONTs to wireless nodes that have no access to GPS antenna. The GPON (XGSPON and 25/50G PON) network can also be used for backhaul and mid-haul of the wireless network. This is lacking on the EPON network, especially on vendor support. EPON ONUs that support timing and sync standards (IEEE1588v2 or Sync. E standard) are non-existent because of lack of demand from EPON operators.

Wireless services may not be on top of many cable operators' priority list, but note that this also eliminates the PON network owner from a potential revenue stream to provide x-haul and network synchronization to other wireless providers.

3. Expediting Time To Market

Implementation of FTTH PON network is not only costly but is also time consuming especially in brownfield deployments. This section explores options where cable operators may be able to expedite time to market with PON offerings with a few 'out of the box' options.

3.1. Microwave Backhaul

Although connecting an OLT to the IP distribution network over fiber is preferred, having alternative solutions, such as microwave backhaul, that provide sufficient capacity and accelerate deployment timelines are often very helpful. Wireless transport often provides lower cost solutions when connecting difficult to reach areas such as islands, mountainous communities or even urban communities impacted by construction moratoriums. Microwave backhaul for PON services is particularly useful for quadruple play service operators such as Rogers with extensive wireless infrastructure and in-house wireless backhaul expertise; OLT equipment serving the nearby community is installed in the existing wireless shelter and connected to a high-capacity microwave link mounted on the collocated cellular tower or rooftop sites. The microwave link is part of the mobile backhaul network that provides IP connectivity to the BNG at the core location.

Modern multi-band microwave equipment combines the best characteristics of different frequency bands to extend high capacities over longer distances. Combination of high-capacity channels in millimeter E-band with high availability channels in the traditional11-32 GHz frequency bands allows for microwave link capacities up to 20 Gbps over 10 km reach.

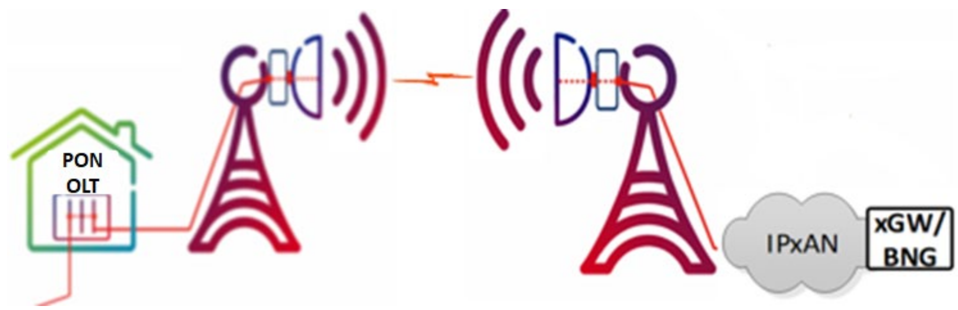

Figure 7 – Digital Microwave Backhaul for PON

3.2. RFoG to PON Migration

RFoG homes that cable operators have built over the past 2 decades may be the low hanging fruit to convert to PON, because the optical distribution network (ODN) to the customer homes already exists. Furthermore, RFoG does not offer any technical advantage over HFC DOCSIS offerings but creates its own limitations such as it inhibits turning on OFDMA for upstream.

Transitioning from RFoG to PON can be challenging for MSOs. The goal is to build a PON network parallel to the RFoG network while reusing as much of the existing RFoG network as possible to minimize costs. In general, the steps are as follows:

1. Build the parallel PON network.
2. Stop selling RFoG to new customers.
3. Migrate existing RFoG customers to PON.
4. Decommission RFoG plant.

While building the PON network, the link to the remote OLT should utilize existing RFoG links that can be freed up whenever possible. Options for reutilizing links include leveraging existing protection links and converting dual fiber RFoG feeds to single fiber feeds and repurposing the freed fiber for PON.

Migrating existing customers from RFoG to PON will be the largest challenge for MSOs. Ideally, as soon as the PON network is built, the customers will all be converted and the RFoG network can be decommissioned. This is unlikely to happen as customers may be slow to migrate, and steps will need to be taken to allow for coexistence of RFoG and PON customers until the last RFoG customer switches.

If a second fiber is available from the splitter location to the customer premise, using this fiber to feed PON to the customer is the most simplistic approach. It does, however, require additional splitters to connect the OLT to the customer premise.

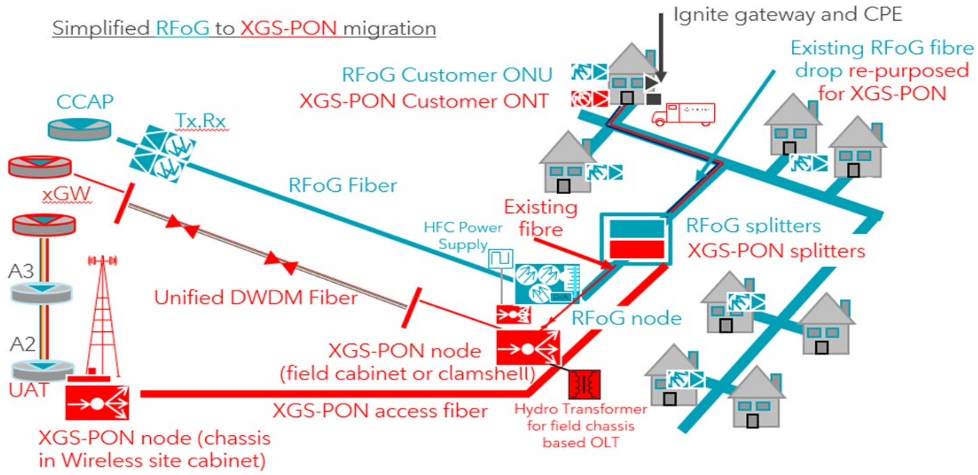

Figure 8 – RFoG to XGSPON Migration

If there is only a single fiber between the splitter and each home, combiners can be used to carry the PON wavelengths on the same fiber as the RFoG wavelengths. One example is shown below.

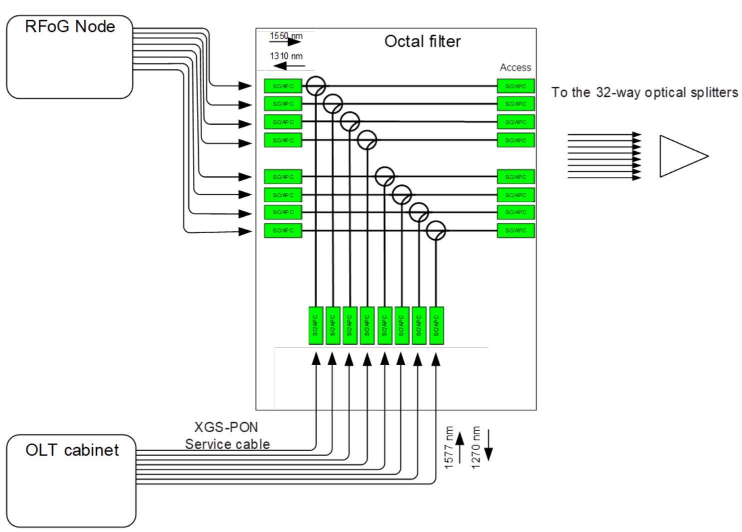

Figure 9 – Using Combiner for RFoG to XGSPON Migration

A disadvantage to this method is the additional insertion loss incurred on the RFoG path, making it necessary to re-align the upstream path. A second potential issue is that the SCTE specifies that RFoG ONUs must receive 1540 nm to 1565 nm but does not limit the upper band of the ONU downstream receiver. Some manufacturers allow a wider band that allows the XGSPON downstream wavelength (1577 nm) to pass through to the ONU, impairing the RFoG signal. To mitigate, an optical filter may be added in-line to RFoG customers to filter out the XGSPON wavelength.

Benefits of migrating RFoG plant to XGS-PON:

- Provides 10 Gbps symmetrical capacity that will readily scale in the future.
- Provides unified fiber DWDM wavelength capacity for XGS-PON, DWDM based R4B EON, and any future adjacent R-PHY nodes.
- Harvests valuable DOCSIS ports for conventional node segmentation work.
- Avoids future costs and potential customer impact because RFoG technology is near end-of-life and end-of-support and it will soon become difficult and expensive to procure parts.
- Harvests RFoG equipment from early RFoG to XGS-PON migrations that may be used to segment RFoG plant as required before those areas are also migrated.
- Avoids future product impact because RFoG cannot be upgraded to DOCSIS 4.0, is limited to a spectrum of 1.0 GHz DS and 42 MHz US and cannot accommodate OFDMA.

3.3. 3.3 Distributed Split Design & Design Automation

Rogers has standardized on a distributed split architecture using air blown fiber (ABF) and a 2nd generation micro duct infrastructure for both greenfield and brownfield underground deployments for its speed of implementation, lower cost per unit and availability of multiple vendors to de-risk supply. The splitters are housed in fiber distribution hubs (FDH) and are available in multiple split ratios (1:2, 1:4, 1:8, 1:16, 1:32).

Micro duct is available in different configurations and sizes, and MSOs will need to select sizes and configurations that make sense for them based on their topology. Rogers has standardized on 7/3.5 mm (OD/ID) hard wall micro duct for distribution and a 14/10 mm micro duct for larger count transport cables. To access the micro duct from the sheath, a window cut is performed, and the duct is cut and spliced along with the toning wire. The unused end of the tube must be capped. After the micro duct lateral has been run, the air blown fibre (ABF) can be jetted to the side of the house.

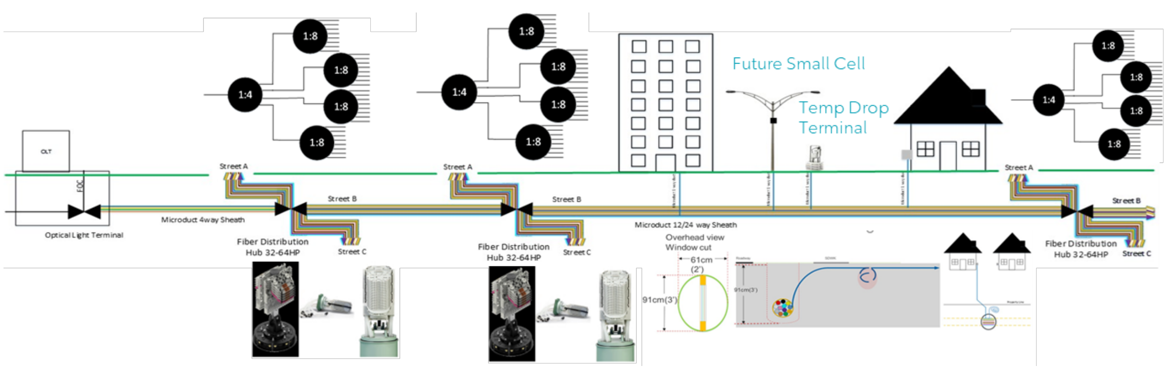

Figure 10 – Underground Microduct Infrastructure for brownfield and greenfield

Benefits include:

- capital cost reduction per home pass due to less street furniture
- less splicing and avoids additional ducts due to tether aggregation
- standardizes design and product components across greenfield and brownfield deployments

- improved equipment installation efficiency compared with BAU methods
- Fusion splitter; improved reliability, no tube distribution centres
- uses duct all the way to the home
- leverages existing pedestals for temporary drops. Maximizes splitter feed efficiencies

Blowing distance is heavily dependent on the size of the ABF and the size of the duct. The table below shows standard diameters and blowing distance for various fibre counts and duct size.

Table 1 – Air Jetting Distance Chart

AIR JETTING DISTANCE CHART			
CABLE TYPE and TYPICAL OD	CABLE DIAMETER (millimeters)	TUBE OD/ID (millimeters)	AIR JETTING DISTANCE (meters)
2 Fibre Unit	~1.1	5/3.5 and 7/3.5	1000
4 Fibre Unit	~1.1	5/3.5 and 7/3.6	1000
12 Fibre Unit	~1.6	5/3.5 and 7/3.7	600+
24 Fibre Unit	~2.05	5/3.5 and 7/3.8	600
48f-144f micro cable	≤ 8	14/10	1500
288f + micro cable	≤ 9.6	16/12	1400

Assumptions:
up to 15 changes of direction
15-27% penalty, factored to account for bore and plough depth variation
Recommendation is no more than 15 bends per km
Recommend use of MD lubricant for micro cables

Standardizing on splitters and micro duct sizes allows for the utilization of automated design tools. Automation can be accomplished by inputting a series of rules, criteria, and constraints that normally are factored into the design of a PON area. The automated design tool can then optimize the layout of the network, selecting the most cost-effective design and placement of equipment including splitter locations and ducts. Using AI/ML, automation tools can simulate many designs in a fraction of the time it would take to manually design a single layout. The tools also have the ability to transfer the design directly into MSOs' design/inventory platforms and can generate design reports and bill of materials (BOMs.)

Summary

Generated Date	2022-05-25
Generated Time	11:29:06 AM
Job	AUTO DESIGN GAMEBRIDGE FTTX_LL 25 May 2022 11:25:28 (Open)
Processing Time (s)	250.564
Boundary Address Count	717
Addresses Excluded from Auto Design	0
Addresses Not Connected	0
Warnings	0
Creation Failures	0

Note: 717HP area design completed in 4 mins

Input Parameters

Boundary	Future Development Boundary: AUTO DESIGN GAMEBRIDGE
Architecture Type	Distributed Split (FDH + blown fibre)
Max drop cable length	1000.000
Network to Trace	Support generated from Roads
OLT/LCP Location	<Error: No such entity {ISP_BUILDING,583009903}>
OLT Name	XXXXXXXXOLT
Use Unbalanced Couplers For Rural Areas	No
NAP/FDH Type	FDH
Crossing at Junction Multiplier	1.000
Crossing Mid-Road Multiplier	2.000
Generate trenches around end of cul-de-sacs	No
FDH Spare Fibers	2

Generated network statistics

Item Class	Typecode	Count	Length
AddressConnectionPoint	fCSE_acp	717	
Boundary	FDA	37	
Cable	BFC-12F 1x12	13	4960.761
Cable	BFC-24F 2x12	8	2807.806
Cable	BFC-2F 1x2	724	178618.783
Cable	BFC-4F 1x4	12	4349.915
Cable	BFC-72F 6x12	10	3460.928
DuctConnector	CONNECTOR	1249	
FiberAddressTerminationDevice	fCSE_2port	717	
FiberCoupler	16 WAY COUPLER	4	
FiberCoupler	2 WAY COUPLER	2	
FiberCoupler	32 WAY COUPLER	34	
FiberCoupler	4 WAY COUPLER	7	
FiberCoupler	8 WAY COUPLER	1	
FiberSpliceCase	FDH	31	
FiberSpliceCase	FOSC 100 B2	1	
FiberSpliceCase	SPLICE CASE	19	
IspBuilding	GPON_SITE	1	
SupportTube	12_MD_7_3.5	238	16942.250
SupportTube	24+1_MD_7_3.5	270	12444.170
SupportTube	MICRODUCT	4342	547416.070
SupportTube	SINGLEDUCT_7_3.5	717	33004.820
SupportUndergroundLinearHousing	MULTIDUCT	52	1869.310
SupportUndergroundLinearHousing	TRENCH-12MULTIDUCT7/3.5	228	15246.720
SupportUndergroundLinearHousing	TRENCH-24+1MULTIDUCT	247	10401.100
SupportUndergroundLinearHousing	TRENCH-SINGLEDUCT7/3.5	717	33004.820
SupportUndergroundNodeHousing	LAT_BREAKOUT_POINT	477	
SupportUndergroundNodeHousing	VAULT_B	31	
SupportUndergroundNodeHousing	VAULT_D	18	

Scores

Score profile	Type	Count	Length	Score	Score formula
Default	12_MD_7_3.5	238	16942.250	847.112	0.05/m
Default	24+1_MD_7_3.5	270	12444.170	871.092	0.07/m
Rural	Crossing at Junction	24	317.420	360.000	15 each
Rural	Crossing Mid-Road	4	56.000	100.000	25 each
Rural	Drop	174	8033.380	1496.400	8.6 each
Rural	LAT_BREAKOUT_POINT	178		249.200	1.4 each
Rural	Standard Trench	203	16132.300	6452.920	0.4/m
Rural	VAULT_B	31		616.900	19.9 each
Urban	Crossing at Junction	19	250.240	285.000	15 each
Urban	Crossing Mid-Road	11	132.110	275.000	25 each
Urban	Drop	543	24971.440	1031.700	1.9 each
Urban	LAT_BREAKOUT_POINT	299		627.900	2.1 each
Urban	Standard Trench	264	10594.920	10594.920	1/m
Urban	VAULT_D	18		527.400	29.3 each
Total				**24335.544**	

Creation Failures

No creation failures

Addresses Not Connected

All addresses in boundary connected

Addresses Excluded from Auto Design

No addresses in boundary excluded from Auto Design

Warnings

No warnings

Figure 11 –Example of Design Automation Tool

4. Lessons Learnt In Introduction of XGSPON

4.1. Implementing XGSPON

This section shares some lessons learnt in Rogers' journey of implementing XGSPON. They are not definitive guidelines in implementing XGSPON network; however, they may be helpful to other cable operators in similar circumstances and conditions.

4.1.1. Enclosure and POP site

PON networks have a fixed optical link budget between the OLT and the customer homes, depending on the split ratio. In the case of 1:32 split ratio, most OLTs have to be within ~ 18km of customer homes. While this may be adequate for telcos to place their OLTs in their central office (CO) locations because they have been forced to move their COs close to their customer homes due to DSL technology limitations, most cable operators cannot serve the majority of their customers within 18km of hub sites.

Thus, the majority of cable operators will have to install their OLTs in environmentally controlled enclosures or point of presence (POP) sites in the field if they are available. This is due to the fact most chassis-based OLTs (or even micro-plug based Virtual OLTs) are not temperature hardened, and for most operators this means the OLT must be installed in a temperature-controlled POP site, or in an active environmentally controlled enclosure. Environmentally controlled enclosures complicate network planning and increases the deployment cost, because of the cost and size of the enclosure. Cable operators must also provide alarms and telemetry from the power supplies and batteries that may be inside the enclosure.

Cable operators are therefore recommended to locate the OLTs in close-by shelters, POP sites, multiple dwelling unit (MDU) telecom closets if the circumstances allow. However, that is not always the case, and installation of active enclosures may be inevitable as part of PON deployment.

Alternatively, many PON vendors offer clamshell OLTs which can be pole or strand mounted or can easily mount in passive enclosures or outside of buildings, because the clamshell already protects the OLT against environmental elements and human intrusions. However, pole mounted OLTs are harder to access especially in winter months in areas where there is snow. They will require a bucket truck or ladder for access. Clamshell OLTs have their advantages and disadvantages, which will be discussed in more details in the next section, but clamshell OLT is another viable option for field deployment.

4.1.2. Clamshell OLT

Many PON vendors offer clamshell OLTs which can be very appealing to cable operators whose access network is accustomed to deploying amplifiers, HFC nodes or remote PHY nodes using clamshells. Most clamshell OLTs can also leverage direct current (DC) square-wave cable power plant as well, which is an advantage to cable companies.

Clamshell OLTs eliminate the need to build enclosures in the field and provide an "all in one" solution that provides protection and security against outside elements and human intrusion. They can also be pole mounted (and in some cases, even strand mounted) offering more implementation options.

On the other hand, when evaluating clamshell OLTs, Rogers finds the per-home cost of the clamshell OLTs only make sense for relatively small subdivisions (<250 homes passed). As the size of the OLT grows, the per home cost of the clamshell OLT could begin to rise quickly, to a point it may cost 2x the

OLT equipment per-port-cost of a chassis based OLT for larger nodes (>500 homes passed), even including the associated active enclosure and power supply costs.

Cost aside, note that clamshell OLTs most often also lack the full features offered in the chassis based alternatives, such as business service support, wireless x-haul support etc. Operators should also expect that clamshell OLTs will be slow in supporting new features such as 25/50G PON compared to chassis-based solution due to lower market demand.

Operationally, clamshell OLTs are typically non-modular, meaning if there is any port or card failure the entire OLT module needs to be replaced, impacting more customers as compared to a modular chassis-based OLT.

Cable operators are recommended to assess the cost-benefits of both environmental enclosure solutions vs. clamshell OLTs based on their own circumstances and requirements. The advantages of clamshell based OLTs may not outweigh the disadvantages, and they may be best used as a corner case solution.

The clamshell OLT and chassis-based OLT cabinets have different costs and implementation considerations. Depending on the situation, the clamshell OLT or chassis-based OLT cabinet will be the most cost optimal. Choose a clamshell OLT or a chassis-based OLT cabinet for the most cost optimal long-term solution.

For example: In MDUs, space limitations and existing power supply electrical connections suggest clamshell OLTs will be most cost optimal; however, chassis-based OLT cabinets on the boulevard feeding multiple MDU buildings would be cost optimal.

4.1.3. Network Latency

Due to a reduced number of customers in a service group, the fiber medium and a reduction in number of network elements between the customer CPE and the broadband network gateway (BNG), PON offers excellent latency performance. Operators can expect 2-4 ms of round-trip latency with PON between the CPE and the core IP network, and ~10 ms in the worst case scenario.

Very low latency is a strength for PON; however, an operator should pay attention to the distance between the OLT and the BNG in the network design. relative to latency performance. Since the OLT to BNG link is simply a standardized Gigabit Ethernet (10GE typically) the PON connection will work over long distance over 100km as long as the signal level is within the link budget of the optics, but the distance will have an impact on the service latency. In one of Rogers's early PON trials customers were experiencing latency of over 40ms, which is very high for PON. It was later discovered the long haul transport network. routed the OLT–BNG link over a route of 100+km through another province. Fixing that issue improved the latency from 40 ms to under 5 ms.

4.2. Operationalizing XGSPON

This section discusses the lessons Rogers learnt in operationalizing XGSPON. Since PON as an access technology is quite different than what MSO operations teams are used to, the intent for this section is to share some lessons learnt in our journey of operationalizing PON that it may be helpful to other cable operators.

4.2.1. Network Performance Monitoring

Whether cable operator chooses to deploy GPON or EPON, building the OSS platform to capture network alarms and health telemetries must be part of the new technology introduction "day 1" requirements.

In terms of network health key performance indicators (KPI), because a PON signal is 100% digital from PHUB to customer CPE, the network KPIs are simpler compared to the network KPIs for an RF signal in a typical HFC plant. Nevertheless, PON network telemetries are not the same as DOCSIS telemetries, and an operator must work with the PON vendor to clearly understand the KPIs that are essential to maintaining the network.

In terms of service KPIs, since services do not change whether they are offered over HFC or PON network, the service KPIs are mostly consistent and agnostic of the access network. Operators can expect to use the same OSS system and same service KPI dashboards to monitor the services.

With the introduction of PON, an MSO must: 1. Define and test new KPIs for network performance, capacity, and triage; and 2. Develop new dashboards for Critical/Major/Minor alarm reporting

4.2.2. Power Supplies

Traditional HFC networks have transponders used for power plant monitoring. Typically, in a DOCSIS HFC network an external cable modem (CM) is used to backhaul the power supply monitoring signal out-of-band on the DOCSIS payload channel back to the PHUB, where it can then connect to the operator's management network and reach the power supply monitoring polling platform. The PON network does not have an identical solution for power plant monitoring, but a similar architecture that replaces the CM with ONT can be applied.

With the different power plants in the field, a single solution must be developed to resolve this issue. Working with multiple vendors, Rogers is implementing a solution with a single application that will be capable of monitoring multiple vendors' power plant that will improve network performance and efficiency within the network.

An operator should pay attention to IT platform details such as white-listing the power supply monitoring ONT, and allowing traffic to traverse between public data networks and private management networks. If practicable, leverage existing HFC power supplies to power the new clamshell OLTs.

During the customer migration period while there are both RFoG nodes and clamshell OLTs being powered, ensure the power supply maximum current draw is not exceeded. But if necessary, battery standby time does not have to meet the 4-hour standby specification, and is waived for the migration period.

Another consideration with OLT power supplies is whether the MSO can avoid local power metering and continue to categorize them as unmetered scattered loads by their local utility provider.

4.2.3. Operations Teams

Traditionally, MSO field technicians are mostly familiar with coax cable and RF signal, being that the majority of their experiences are with the HFC network. Transitioning coax cable technicians to make the switch from coax to fiber can be very challenging.

Working with fiber cable in the field requires a new set of tools that cable operators must equip their frontline workers. Technicians may not be familiar with the new tools and require proper training. In addition, it requires technicians to be meticulous with a different frame of mind when dealing with fiber compared to coax cables. To help technicians overcome these challenges, proper training must be available, starting from basics such as emphasis on proper fiber cleaning.

In Rogers's experience, coax technicians were not accustomed to cleaning fiber and connectors. Dirty connectors were a major reason for service calls during early deployment of PON networks. Once our maintenance technicians were properly trained on fiber network maintenance we observed a significant reduction in service calls on PON network.

4.2.4. SFU and MDU Customer Premise Installations

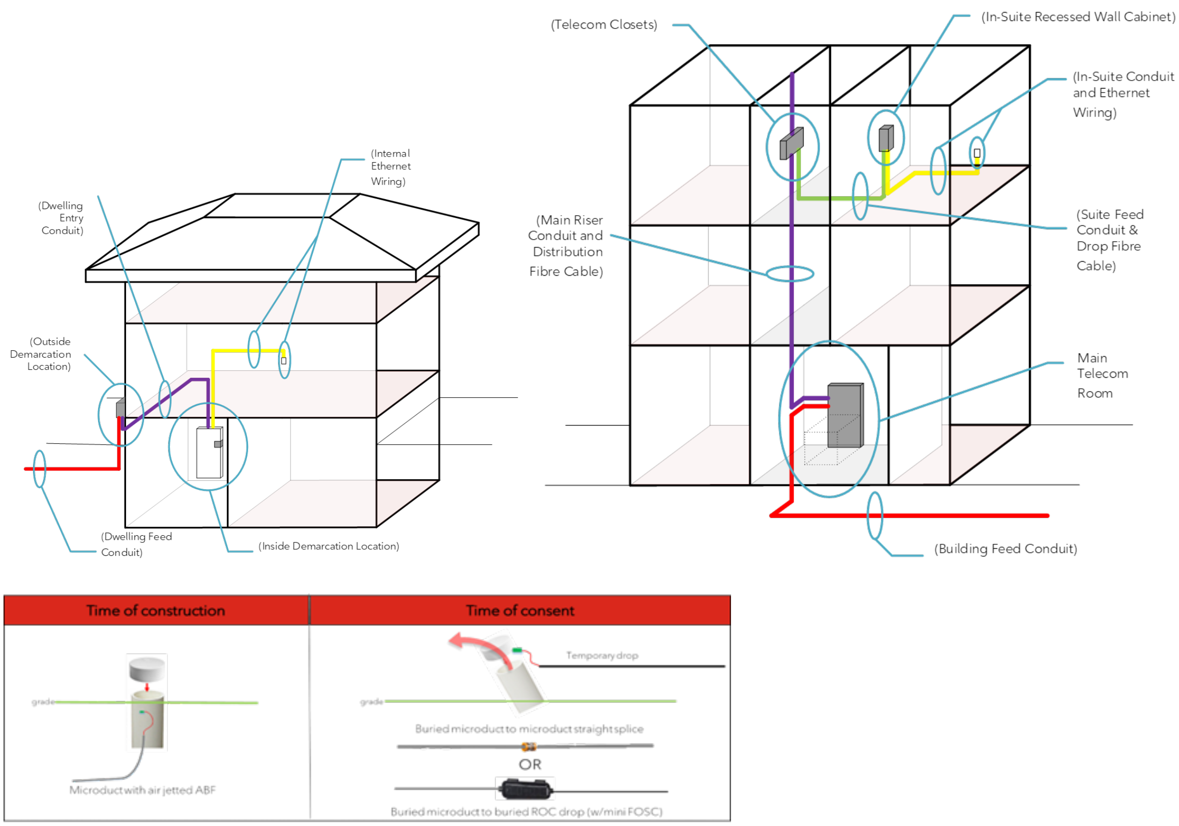

Figure 12 – Customer Premise Installation

For non-drop consents, Rogers established a low-cost container at the property line for single family units to use a temporary connection point when service is requested at a later date. Proper task procedure is required for lateral non-consent returns.

5. Conclusion

As cable operators and telcos continue to evolve their access networks to provide faster, lower latency, and more resilient and available services, PON offers a viable and high performance option.

While PON, and its associated network architecture and supporting network platforms may not be intrinsically native to traditional cable operators, it also is not an overly complex technology to master and operate.

To summarize, these are the takeaways of this paper:

- Cable operators are recommended to evaluate the pros and cons of GPON vs. DPoE EPON per their own requirements and constraints subjectively and select the standard that best fits their circumstances.
  - GPON standards have a significant advantage in global market deployment and will continue to dominate future PON deployments worldwide
  - DPoE provides cable operators with a fast track towards provisioning, BSS and OSS integration, and offer much higher interoperability among OLTs and ONTs from different vendors
- Cable operators can strategically expedite time to market with PON deployment with 'low-hanging fruit' use cases such as RFoG to PON conversion and using microwave as the OLT backhaul.
- Some lessons learnt in Rogers own journey of PON introduction were also shared in this paper, including the decision on appliance vs. clamshell OLTs, decisions on environmentally controlled enclosure vs. POP site installation, and some SFU/MDU installation guidelines.

This paper has shared some technical evaluation and decisions Rogers has made in introducing PON technology, and also lessons learnt in implementing and operationalizing PON from the perspective of a MSO. The hope is this paper and the experiences shared can be helpful as other cable operators navigate their path towards introducing PON.

Abbreviations

ABF	Air blown fiber
BNG	Broadband Network Gateway
BOM	Bill of material
BSS	Business Support System
CM	Cable Modem
CMTS	Cable Modem Terminal System
CO	central office
DAA	Distributed Access Architecture
DC	direct current
DOCSIS	Data Over Cable Service Interface Specification

DPoE	DOCSIS Provisioning Over EPON
EMS	element management system
EPON	Ethernet Passive Optical Network
FDH	fiber distribution hubs
FTTH	Fiber to the home
GPON	Gigabit Passive Optical Network
HFC	Hybrid Fiber Coax
IEEE	Institute of Electrical and Electronics Engineers
ITU	International Telecommunication Union
KPI	key performance indicator
LCP	Local Convergence Point
MDU	Multiple Dwelling Unit
MSO	Management Services Organization
OMCI	ONT management control interface
ODN	optical distribution network
OLT	Optical Line Termination
ONT	Optical Network Terminal
ONU	Optical Network Unit
OSS	Operations Support System
PCRF	Policy and Charging Rules Function
PHUB	primary hub
PON	Passive Optical Network
POP	Point of Presence
PHY	physical layer
QoS	Quality of service
RF	radio frequency
RFoG	radio frequency over glass
SCTE	Society of Cable Television Engineers
SFU	Single family unit
SIP	session initiation protocol
SPR	Subscriber Policy Repository
XGSPON	10Gbps symmetrical passive optical network