Fibre to the Node / Fibre to the Home Network Architectures

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This technical paper was written in response to a range of presentations and discussions at the Budde Communications Strategic Roundtable on Fibre to the Home – Strategies for Fibreing Australia, held in Sydney on Thursday 18th October 2007. Following a presentation by Senator Stephen Conroy - Shadow Minister for Communications - on Fibre Policies for Australia, there was a general consensus that whilst Fibre to the Node (FTTN) was an inevitable first stage broadband fibre rollout due to the commercial realities of Labor's proposed $8 Billion budget, the vision and the end-game must be Fibre to the Home (FTTH) so that Australia does not slip further behind other OECD countries' FTTH infra-structure and the new broadband applications that this supports. Given this, a pre-requisite for any interim FTTN architecture and associated equipment design is that both the architecture and the equipment must easily migrate to a FTTH implementation – both for Greenfield and for Brownfield deployments. The purpose of this paper is to outline existing Broadband Access Networks and associated FTTN architectures that have evolved or are evolving to support them, and the associated street cabinet and equipment requirements for a seamless migration from FTTN to FTTH access networks using both Active Optical Network (AON) and Passive Optical Network (PON) technologies and platforms.

1. Existing Broadband Access Networks and FTTN Upgrades

1.1 DSL Networks

Digital Subscriber Line or "DSL" is today part of the vocabulary of the average broadband user since this is one of three popular alternatives for purchasing broadband Internet access. The other popular alternatives include "Cable" and more recently "Wireless".

DSL can be delivered over twisted-pair copper cable from an Access Multiplexer in the Central Office (CO) or telephone exchange all the way to the home, passing through a "Pillar" which is just a passive distribution frame in the street. The Pillar does not require power, consumes little space and rarely requires maintenance since there is nothing electronic that can fail. For these reasons, carriers and environmentalists alike prefer the passive "pillar" approach over alternative active cabinets and it is these same reasons which are driving carriers and environmentalists around the globe towards Passive Optical Networks (PONs) for major broadband infra-structure upgrades.

Of course, major broadband infra-structure upgrades won't happen overnight. So in the interim, to increase the peak capacity to the home using the existing twisted-pair copper infra-structure, the passive Pillar can be upgraded to an active cabinet and the DSL Access Multiplexer (DSLAM) previously located in the CO is relocated out to the street cabinet. Bundles of copper pairs that were previously dedicated to each customer are now "bonded" together electronically to provide a shared backhaul capacity in the range 8-10 Mbit/s per DSLAM. The shared, higher capacity backhaul combined with the increased bandwidth and reduced crosstalk of shorter twisted-pair cables from the cabinet to the home (the "Last Mile" in US carrier terms), means that the average and peak ADSL capacity to each home is increased. Statistical multiplexing within each DSLAM enables backhaul capacity not currently consumed by some customers to be allocated to other customers on an ATM cell-by-cell or IP packet-by-packet basis. This migration from the passive Pillar to remote DSLAMs in active street cabinets is effectively a Copper to the Node (CTTN) network as illustrated in Figure 1.

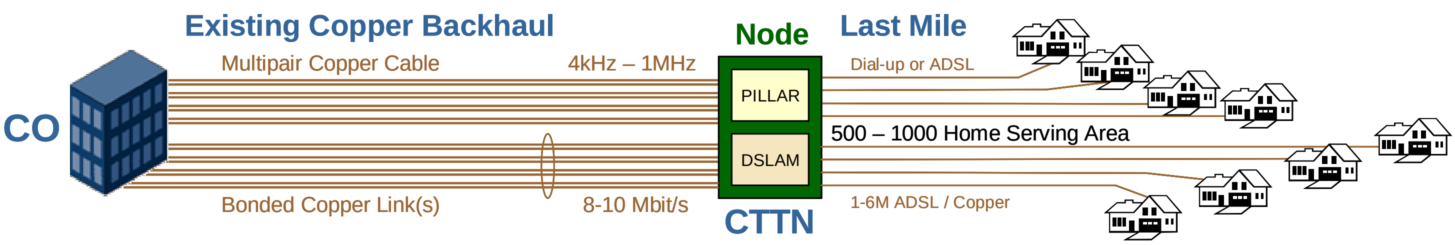

Figure 1 Twisted-Pair Copper-to-the-Node (CTTN) Access Network

Such a CTTN network may service 500 – 1000 homes depending on the size of the cabinet and one does not have to be a mathematician to realise that for a high broadband take-up area, the average capacity per home during peak Internet access periods is not much better than dial-up. Thus, the problem with the interim CTTN architecture is lack of scalability to match increasing customer demand for bandwidth consuming and fuel / resource saving activities, such as working from home; and new bandwidth consuming services such as E-Bay, Google Maps, You Tube, Joost, IP Telephony, High Definition TeleVision (HDTV), Video-on Demand VoD) and Near Video on Demand (NVoD).

Fibre to the Node / Fibre to the Home Network Architectures

The bottleneck that limits the capacity to each home of the CTTN network is the backhaul network, not the Last Mile network. By upgrading the Last Mile network with the latest DSL technologies such as ADSL2+ and VDSL, downstream speeds from the remote DSLAM to each and every home of 12-24 Mbit/s and 50-100 Mbit/s respectively are possible, depending on the actual transmission distance and the quality of the twisted pair cables connected to the home. This is referred to as a Brownfield xDSL upgrade. To enable these speeds to be attained requires a backhaul upgrade from copper to typically 1 Gbit/s over fibre to remove the bottleneck, ie, a Fibre to the Node upgrade as illustrated in Figure 2.

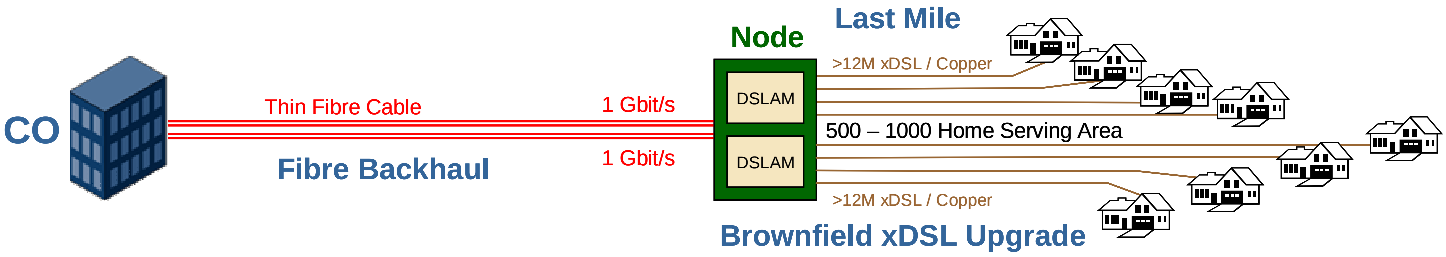

Figure 2 Access Network Upgrade from CTTN to FTTN and Dial-up or ADSL to ADSL2+ or VDSL

Using the latest ADSL2+ technologies, the DSLAM power requirements are typically 1.5 watts per home. To support a 1000 home serving area, a street cabinet requires access to a local 240VAC supply from a power authority and a total power of approx. 2kW taking into account switching/routing overheads, power conversion efficiencies, etc. The cabinet space required is approximately 2m^3 per 1000 homes – allowing for DSLAM equipment, distribution frame, power supply and backup batteries. These parameters will be important going forward as we seek painless FTTH migration solutions.

In contrast to PON-based FTTH networks, FTTN backhaul networks to remote DSLAMs only require a “thin fibre-cable” comprising typically 6 fibre strands. As will be outlined in more detail later, thin fibre-cables alone are generally not suitable for future FTTH upgrades using PON architectures.

1.2 Cable Networks

In the early 1990s, one of the first FTTN networks rolled out was Hybrid Fibre Coax (HFC). Such networks form the basis of the broadband access service which we refer to as “Cable”. They employ multiple 7 MHz analog video channels onto which are modulated 28 Mbit/s - 40 Mbit/s digital transport streams using QAM modulators at the HFC Hub node (CO etc).

Coaxial cable “video” distribution networks were upgraded with a fibre backhaul in conjunction with other improvements such as bi-directional amplifiers and smaller coaxial cable serving areas to support new broadband Internet access and telephony services. The fibre segments of these HFC networks may be 5-40km in length. They terminate at a small active node in the street which includes fibre-coax media converters (optical transceivers, electrical amplifiers and coaxial RF transceivers). These nodes are small since all the smarts associated with multiplexing and modulation occurs in the local head-end which may be a CO in the case of a carrier-provided HFC network. A typical HFC network is shown in Figure 3.

The effective digital capacity of HFC networks is 1 Gbit/s or more, but most of this is generally consumed with broadcast video and near video on demand. The shared capacity allocated to telephony and broadband Internet data will generally be less than 40 Mbit/s for each service. However, for a 500 – 1000 home serving area, this is not bad given the statistical multiplexing provided and that not all customers will be on-line and downloading or uploading simultaneously.

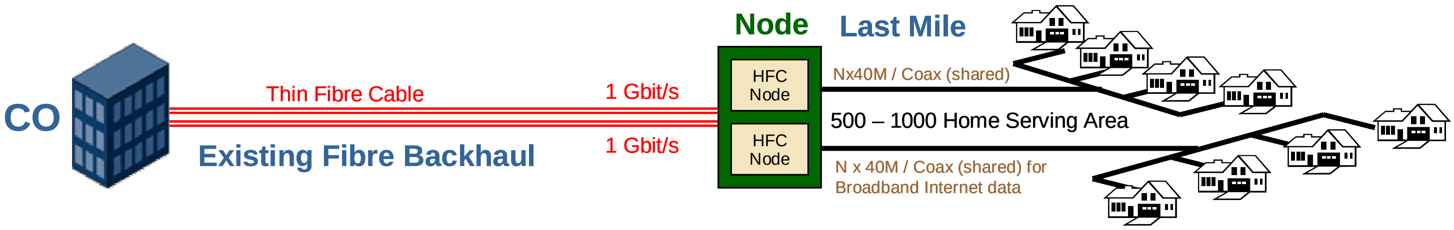

Figure 3 Hybrid Fibre Coax (HFC) Access Network

As discussed in section 2.3, HFC networks can migrate to FTTH networks simply by extending the “F” part of HFC deeper into the access network. However, the legacy of the HFC multi-channel analog structure and QAM modulated data protocols must be abandoned for HFC fibre networks to achieve the same throughput that PON technologies can provide.

1.3 Wireless Networks

Wireless networks are complementary to DSL and Cable networks since they support mobility – both within a home and beyond the home. Narrowband wireless networks have been available for many years, commencing first with the mobile equivalent of dial-up. General Packet Radio Service (GPRS) is a more efficient packet-switched service, which means that multiple users share the same transmission channel, only transmitting when they have data to send. Narrowband wireless networks utilize base stations as local access points serving large areas, although serving areas are reducing with time as more wireless data capable base stations are deployed or upgraded. Traditionally, the backhaul from wireless base stations to COs is via trunk radio links, having capacities from 2 Mbit/s to 34 Mbit/s. This is illustrated in Figure 4. In some countries, another narrowband packet radio backhaul option includes DSL to the nearest DSLAM. As such, narrowband wireless networks rarely offer any infrastructure that is suitable for future FTTH upgrades.

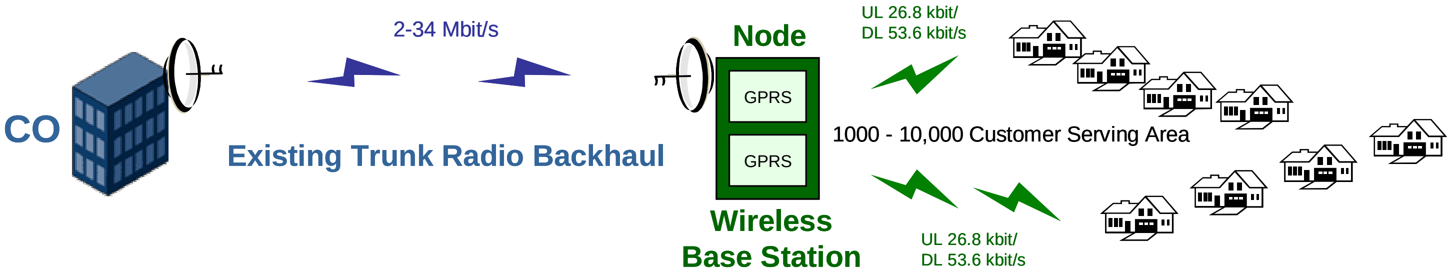

Figure 4 Narrowband Wireless Access Network

The evolution of broadband wireless networks based on new technologies is however, driving the need for FTTN upgrades to wireless base stations and more base stations are moving deeper into the access network to support higher data rates per user. As an example, High-Speed Downlink Packet Access (HSDPA) is a 3G (third generation) mobile communications protocol which allows mobile infra-structure networks to have higher peak data transfer speeds and higher average capacity. Current HSDPA deployments support down-link speeds of 1.8, 3.6, 7.2 and 14.4 Mbit/s. An example of a broadband HSDPA wireless network with a new fibre backhaul is shown in Figure 5. Again, as is the case for many FTTN backhaul networks, thin fibre cables are often deployed to meet the future demand for current generation networks – not next generation networks. The backhaul fibre capacity employed for broadband wireless networks is generally in the range 100 Mbit/s to 1 Gbit/s.

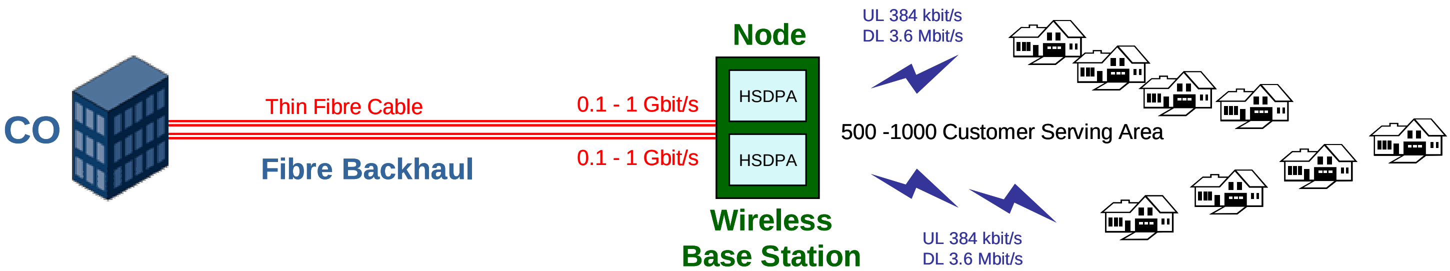

Figure 5 FTTN Upgrade – Broadband Wireless Access Network

Due to the relatively large size and power requirements of wireless base stations, those that are fibre-fed are ideal candidates as local hubs for future FTTH network upgrades based on AON technologies and platforms. Additionally, since broadband wireless access is complementary to broadband wireline access, the wireless base station nodes are pivotal to a whole range of future broadband upgrade options. To maximise the exploitation of this likely permanent infra-structure for future PON based FTTH architectures, it is important that as FTTN upgrades are carried out, that additional fibres in the cable and/or duct space be provided for pulling or blowing through at least 10x more backhaul fibre than is required initially (assuming a broadband wireless base station node with a 1000 home serving area). It is possible that the cost of a 72 fibre cable for example is not much more than the cost of installing additional ducts for future backhaul fibre upgrades, although additional ducts may be more suitable for “Open Access” infra-structure upgrades.

2. Active Optical Network Upgrades for FTTH

2.1 Overview

Active Optical Networks (AONs) are an equally viable architecture for FTTH as Passive Optical Networks (PONs). The differences are that AONs don't meet the carrier and environmental preferences for passive "Pillar" type implementations which require no power, almost no maintenance and small, less conspicuous access nodes in the street; and AONs are less amenable to an "Open-Access" regime as being adopted in Europe and as proposed for Australia's broadband fibre rollout. Nevertheless, once a FTTN network has been implemented as a backhaul upgrade to a DSL, Cable or broadband Wireless network, it is then a given that there is already some form of active node (cabinet etc) in the street which can become a local powered hub for a FTTH network. Of course, the devil is in the details and the viability of extending a FTTN network to a FTTH network using existing active nodes in the street depends on the power and space required for the AON equipment compared to the space and power required and provided for the existing remote DSLAMs, HFC fibre-coax media converters or Wireless base station equipment. The following sections present various AON options for implementing "Brownfield" FTTH upgrades for each type of existing broadband delivery service (DSL, Cable & Wireless).

2.2 DSL to FTTH Network Upgrades

An AON architecture for upgrading a remote DSL cabinet to a FTTH hub is illustrated schematically in Figure 6. This AON architecture is already a well developed FTTH upgrade solution with many DSLAM suppliers having developed FTTH interface cards as alternative plug-in replacements for existing 24-port DSL cards. There are a number of options for implementing a FTTH interface card that fits inside an existing DSLAM, but the most popular two options are as follows:

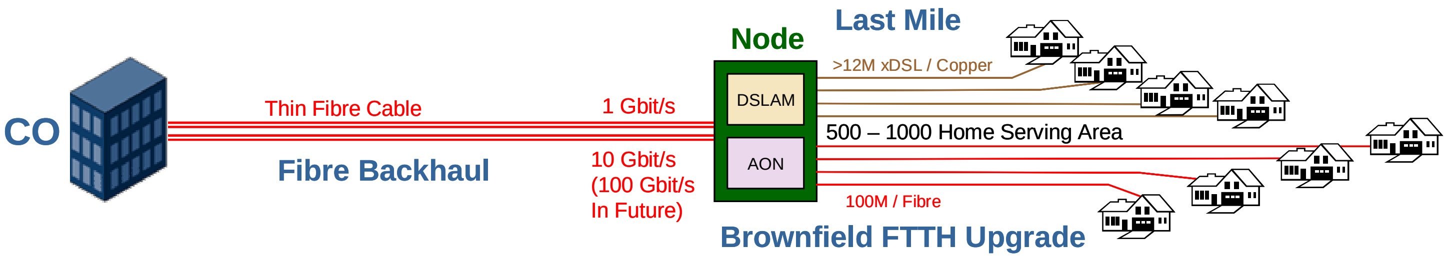

Figure 6 AON Upgrade of Existing FTTN xDSL Network

i) Ethernet in the First Mile (Point-to-Point Ethernet) [1]

Ethernet in the First Mile (EFM) is IEEE customer-centric terminology which is the same as the "Last Mile" in US carrier terms. This AON option includes multi-port Fast Ethernet cards with 100 Mbit/s bi-directional (bi-di) 1310nm / 1550nm WDM transceivers and dedicated single fibre cabling to each home. For business applications, 1 Gbit/s (Gigabit) Ethernet can be delivered in the same way. The DSLAM is also upgraded with a high speed Ethernet packet switch card and a higher speed backhaul interface. Given that the typical power consumption of a 100Mbit/s – 1Gbit/s optical transceiver is only 1 watt and that the typical power consumption of an ADSL 2+ port is 1.5 watts, then it is clear that power requirements are not a roadblock to this FTTN to FTTH upgrade solution. However, DSLAM shelf and cabinet space may become a roadblock to a 100% seamless overlay if the number of optical transceiver ports per card is less than 24. New parallel optical transceiver technology may be needed to avoid any future FTTH upgrade limitations when deploying this AON overlay option. Alternatively, for new FTTN deployments, the remote DSLAM cabinet size can be specified so that a future FTTH upgrade of this type is supported using existing Ethernet optical transceiver technologies and products.

ii) Collapsed PON (Point-to-Multipoint) [3]

This is the most space and power efficient AON upgrade option. It is implemented by incorporating one or more standard PON Optical Line Terminal (OLT) ports on a card that plugs into the existing DSLAM. The PON is collapsed since the OLT and the 1:32 passive optical splitter are often co-located in the same street cabinet. Several major DSLAM suppliers have already developed and deployed this AON option in North America.

As an example of the space and power efficiency of this FTTH upgrade option, a typical new DSLAM platform will support up to 16 cards, each of which can be a 24 port ADSL 2+ or VDSL card, or a 4-port GPON OLT card. Thus a single DSLAM shelf has the power and space to support up to 384 xDSL ports or 2048 Optical Network Terminals (ONTs) assuming a 1:32 passive split ratio. The collapsed PON upgrade option is therefore over 5x more space & power efficient.

Comparison of Point-to-Point Ethernet and Collapsed PON options

The Point-to-Point Ethernet solution requires one optical transceiver per customer fitted to the DSLAM line card, whereas the collapsed PON solutions require only one high speed optical transceiver for every 32 customers. It is for this reason that the collapsed PON has space and power efficiency advantages compared to the Point-to-Point Ethernet approach.

However, there are also statistical multiplexing benefits of the collapsed PON approach. A deficiency of the Point-to-Point Ethernet option is that to keep the cost down, 100 Mbit/s Fast Ethernet optical transceivers are currently used on the DSLAM line card and at the customer's premises. This means that the total instantaneous capacity requirements of the residential customer cannot exceed 100 Mbit/s, whereas alternative collapsed Ethernet PON (EPON) and Gigabit PON (GPON) overlay solutions support 1 Gbit/s and 2.5 Gbit/s peak downstream capacities respectively which are shared across 32 customers. When some customers are not using the available PON capacity, other users have access to it instead, thus increasing the instantaneous capacity available to each user.

AON Backhaul Upgrade

When we increase the total capacity delivered from the street cabinet to the customer's premises using AON FTTH technologies, the backhaul capacity from the CO to the cabinet must increase accordingly. Examples of higher speed backhaul interfaces available today for each of the above AON options include 10 Gbit/s SDH (STM-64) or 10 Gigabit Ethernet. If more capacity or a seamless overlay to existing DSLAM backhaul is required, then Coarse WDM and Dense WDM FTTN solutions are available [4], requiring no upgrade to the existing backhaul fibre cabling.

In the future, as FTTH take-up increases, each remote DSLAM shelf may become filled with 4-port GPON cards for example, with no DSL cards remaining. This equates to 64 x 2.5 Gbit/s = 160 Gbit/s peak downstream capacity from the one DSLAM shelf. To support this FTTH capacity, the FTTN backhaul network will again require upgrading. With 100 Gigabit Ethernet now under development, this is likely to become a viable backhaul option for future AON upgrades, again requiring no upgrade to the existing backhaul "thin" fibre cabling.

2.3 Cable to FTTH Network Upgrades

In many respects, the design of a HFC network is similar to the design of a Passive Optical Network, albeit with active elements such as fibre-coax media converters and RF amplifiers. It is difficult to match the small size and power of HFC nodes with AON-type nodes as used for DSL to FTTH upgrades. Such upgrades would require the installation of a larger street cabinet or enclosure to house the new AON equipment, or would require a much lower number of active ports. For example, upgrading HFC nodes to support a 100 Mbit/s Ethernet based FTTH network - replacing the existing Coax to the premises network - is challenging but it has been done [2] – albeit without volume related success. Some products of this type have subsequently disappeared. Only a few active ports per node can be supported since the space and power required for the AON equipment cannot be greater than the space and power required for the fibre to coax media converter installed in an existing remote enclosure. The reason for the small number of active Ethernet ports is that all the complexities associated with modulating and transporting multiple 40 Mbit/s data streams over hundreds of 7 MHz RF channels is contained within the CO, enabling the remote HFC node equipment to be simple, small and low power.

Given the above power/space issues, an alternative HFC AON upgrade option as shown in Figure 7 is having greater success. This is implemented by simply extending the 1550nm fibre backhaul segment all the way to the customer premises using optical splitters and taps. Such products may then use PON TDMA type protocols for the upstream traffic. In effect, such FTTH implementations are just HFC networks with the "C" segment relegated to inside the home. Small, low power AON nodes are implemented as active (amplified) splitters to enable much larger split ratios than 1:32 so that existing "thin" fibre backhaul cables can be used. The benefit of this architecture is that existing coax equipment is used in the home. A disadvantage is that the backhaul and FTTH capacity is not increased compared to existing HFC networks.

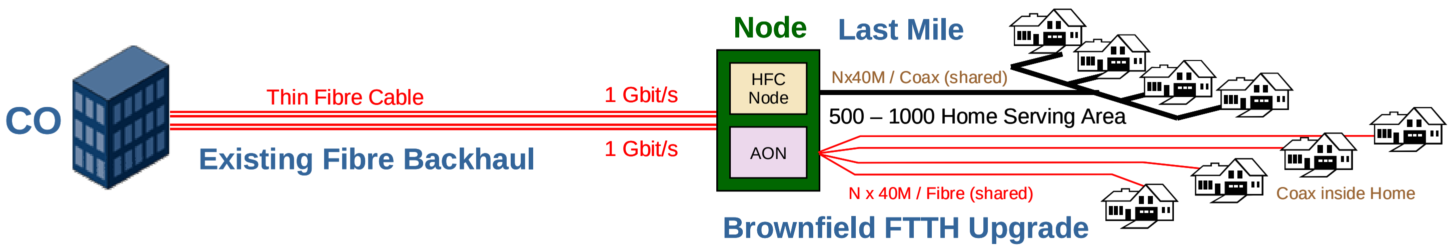

Figure 7 AON Upgrade of Existing FTTN HFC Network

2.4 Wireless to FTTH Network Upgrades

Due to the large size and power requirements of fibre-fed, broadband wireless base stations, these are excellent candidates as active hubs for FTTH network upgrades. This is illustrated in Figure 8.

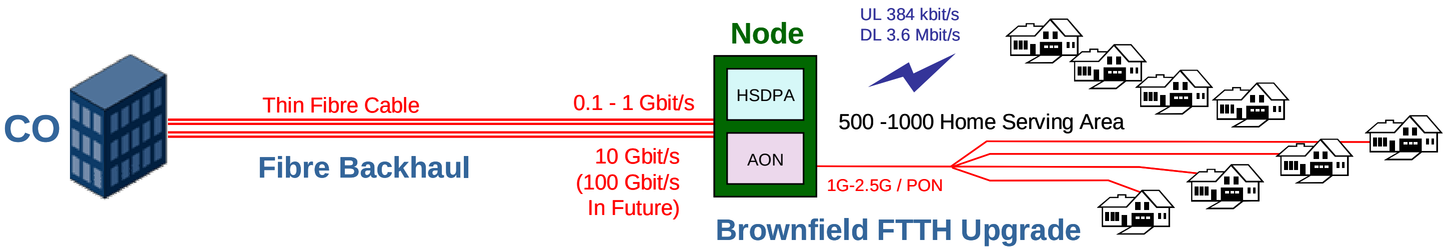

Figure 8 AON Upgrade of Existing FTTN Wireless Network

The most likely difference compared to DSL to FTTH network upgrades is the possibility that the broadband wireless serving area may be much greater than 1000 homes. The effect of this is that instead of being the hub for a small number of collapsed PONs for example, the base station may be the hub for a larger number of traditional PONs, with 1:32 splitters deployed closer to the customer's premises, rather than co-located with the OLT equipment in the base station. Unless the wireless base station is also the DSLAM hub for an existing DSL network, then there is no need to install DSLAMs fitted with multi-port PON cards. Instead, a wider selection of PON OLT equipment options is possible.

Another implication of the wireless to FTTH AON architecture is that the point-to-point Ethernet FTTH upgrade option is less viable given the potentially longer point-to-point fibre distances from the base station to the customer's premises.

3. Passive Optical Network Upgrades for FTTH

3.1 Overview

Passive Optical Networks (PONs) are the basis of traditional FTTH networks, stemming from the CO all the way to the customer's premises with no active network elements in between. As a result, PONs meet the carrier and environmental preferences for passive "Pillar" type implementations which may house a number of 1:32 splitters but require no power, and almost no maintenance. The PON equivalent of the "Pillar" is an inconspicuous access node in the street (above ground or below ground). Each PON can for example, be a symmetric 1.0/1.0 Gbit/s Ethernet PON (EPON) [6] or an asymmetric 2.50/1.25 Gbit/s Gigabit PON (GPON) [7]. PONs are generally specified to be no larger than 20km in size.

3.2 DSL to PON Network Upgrades

The architecture for upgrading a FTTN / DSL network to a PON based FTTH network is illustrated in Figure 9. The key differences between this PON architecture and previously discussed AON architectures is that there are typically 10x more fibres required in the backhaul network between the CO and the remote node and there is no active equipment at the node as part of the PON based FTTH network. The remote node will be fitted with existing DSLAMs where required and multiple 1:32 passive splitters serving 16-32 PONs for an associated 500-1000 home serving area with 100% saturated fibre to the home cabling.

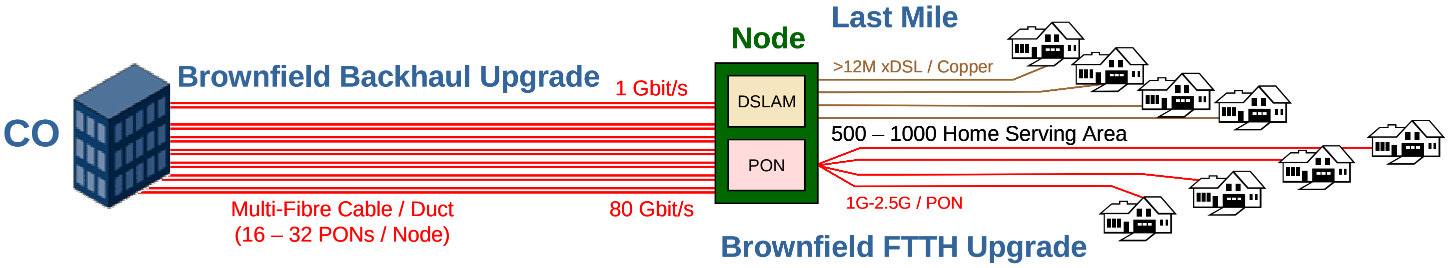

Figure 9 DSL to PON Fibre Backhaul Upgrade

Fibre to the Node / Fibre to the Home Network Architectures

As shown in Figure 9, Brownfield FTTH network upgrades to an existing FTTN based DSL access network require both the Cabinet to the Home last mile segment to be upgraded with multiple point-to-multipoint fibre links; and the Cabinet to the CO Backhaul segment to be upgraded with multiple point-to-point fibre links (one per PON). For such network upgrades, the multiple PON splitters are ideally located inside the remote cabinet, replacing previously installed, power-consuming and space-consuming DSLAM equipment.

Since FTTN networks for DSL and other broadband access technologies are generally backhauled with just a few fibres, it is important that when these FTTN networks are first installed, additional fibres per cable and/or duct space be provided for pulling or blowing through additional fibres to enable future Brownfield upgrades to PON based FTTH architectures.

Where AON based FTTH upgrades are first implemented due to the lack of spare backhaul fibre, it is evident that the collapsed PON option offers yet another advantage over the point-to-point Ethernet option, being that when more duct space is installed, the AON can be upgraded to a full (non-collapsed) PON simply by substituting the AON equipment in the remote cabinet with additional backhaul fibres (one per PON splitter) and relocating the AON equipment back to the CO. In this PON upgrade scenario, there is no need to modify the last-mile fibre segment of the previously installed AON since the 1:32 splitters co-located in the remote cabinet for the collapsed PON become the same 1:32 splitters for the full (non-collapsed) PON. In contrast, the point-to-point Ethernet AON option requires 1:32 splitters to be installed and spliced or connected to 32 fibres and 32 homes, thus increasing the down-time associated with the PON based FTTH upgrade.

3.3 Cable to PON Network Upgrades

As mentioned in Section 2, PON-like upgrades to existing HFC networks are more frequently deployed simply by extending via passive splitters and taps, the fibre segment of the HFC network all the way to the customer's premises (as illustrated in Figure 10). This is still effectively an HFC network, except that the "C" segment is confined to the customer's premises – which may be a home or an apartment block.

Such HFC-PONs [5] employ the same N x 7MHz channel structure, 40 Mbit/s QAM modulation and customer equipment (RF/fibre modems, set-top-boxes etc) as traditional HFC networks and thus differ substantially from EPON and GPON networks which employ a single high speed baseband digital channel rather than multiple different 40 Mbit/s channels. From a statistical multiplexing perspective, the EPON and GPON approach is much more efficient. Anyone familiar with queuing theory will know that a single high capacity server is much more efficient than multiple lower capacity servers.

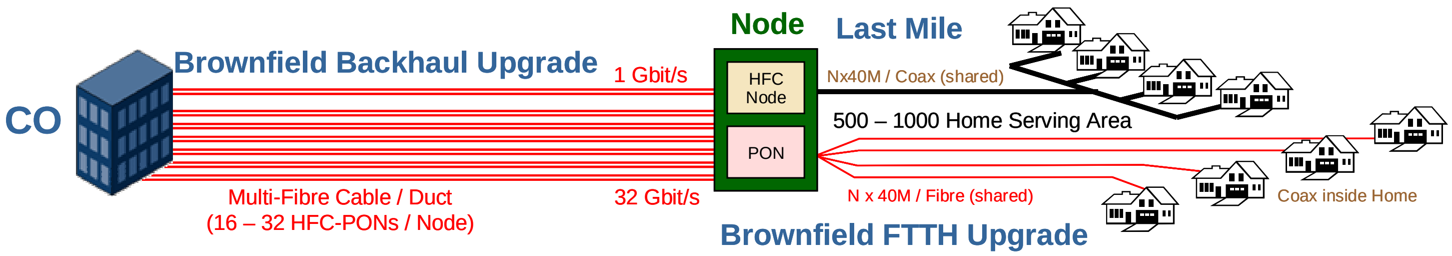

Figure 10 Cable to PON Fibre Backhaul Upgrade

Since each HFC-PON has a capacity of the order of 1 Gbit/s, the number of HFC-PONs required for a 1000 home serving area is approximately 32 (to be comparable to EPON capacities). Hence 32 backhaul fibres are also required between the CO and the remote Node. As for DSL to PON network upgrades, it is important that larger ducts be provided in the fibre backhaul segment of the initial HFC network to support the additional backhaul fibres required for a HFC-PON upgrade.

3.4 Wireless to PON Network Upgrades

Figure 11 illustrates a full PON upgrade to the previous AON based FTTH network shown in Figure 8.

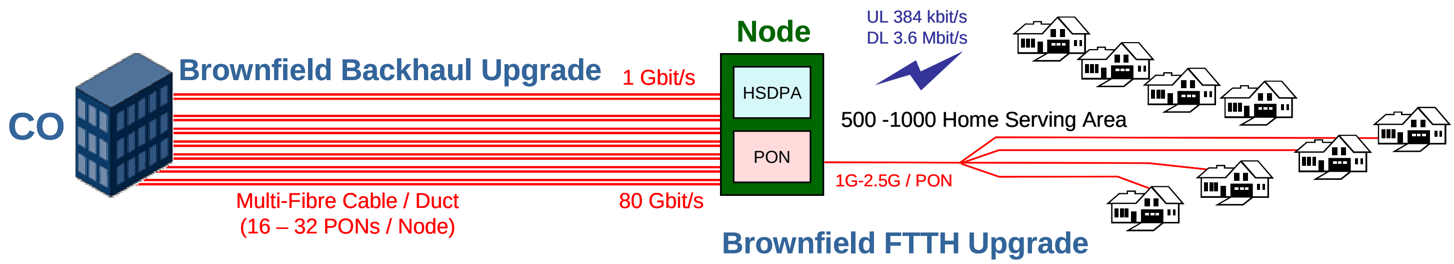

Figure 11 Wireless to PON Fibre Backhaul Upgrade

This upgrade requires a multi-fibre backhaul upgrade with the AON equipment relocated back to the CO. Since the 1:32 splitters may already be located remote from the wireless base-station, the base-station node becomes nothing more than a fibre distribution point interfacing the backhaul segment to the last mile segment of the FTTH network. If the base-station is only serving 500 – 1000 homes, then the backhaul segment may only require 16-32 fibres for the same number of PONs required. If the base-station is serving many more than 1000 homes, then the backhaul fibre count will need to be commensurately larger. Once again, additional fibres in the cable or additional duct space should be provided between the CO and the broadband wireless base-stations to support future PON upgrades as described here.

3.5 Greenfield PON Networks

For Greenfield applications, such as new estates, it is feasible and cost effective to install a PON based FTTH network from day one. In this case, the remote nodes which contain the 1:32 splitters can be quite small and optimised for the pure PON application, since they are not encumbered by the power and space requirements of previous active equipment. The passive splitter nodes can be located above ground or below ground. Such a Greenfield PON based FTTH network as illustrated in Figure 12 is the fibre equivalent of the older generation twisted-pair copper networks with a passive pillar in the street. They meet the carrier and environmental requirements for fully passive access networks with remote nodes requiring little space and no power, and as outlined in the next section, they better support “Open Access” regimes by enabling end-end WDM overlays.

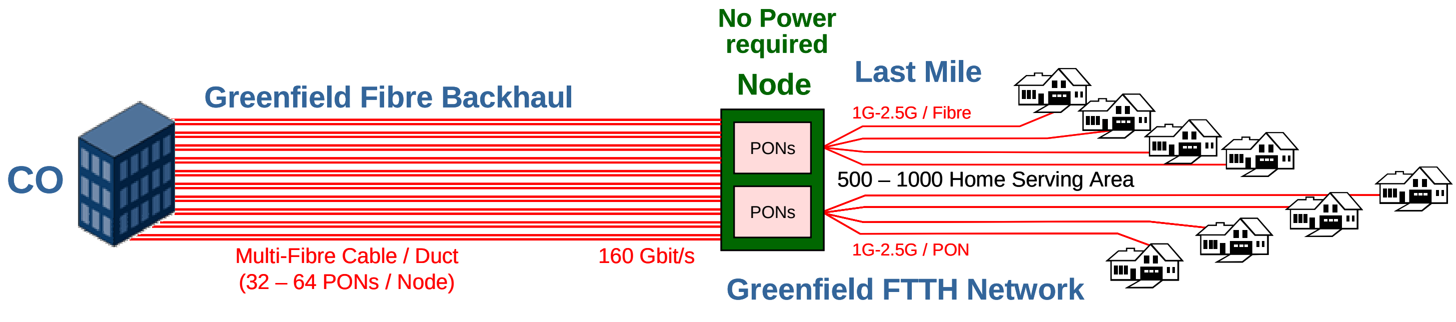

Figure 12 Greenfield PON based FTTH Network

4. Next Generation PONs (NG-PONs)

One of the benefits of the pure PON architectures – from the CO to the customer’s premises – is that once installed, they offer enormous capacity for future upgrades using Wavelength Division Multiplexing. Initial EPON and GPON deployments only use the wavelength bands 1290 - 1330nm (upstream Ch1) and 1480 - 1500nm (downstream Ch1).

Ideally, the legacy 1550nm – 1560nm downstream analog RF (HFC) band will be abandoned, since this is a barrier to future exploitation of the most useful C-Band DWDM wavelengths available. We should assume that in Australia we are late enough in PON deployments and have sense enough not to waste this precious DWDM wavelength band with an HFC legacy that was introduced 20 years too-late to Australia compared to the rest of the world.

Assuming that good sense prevails, this leaves the following wavelength bands for NG-PONs (with 10nm guard bands):

1260 - 1280 nm (for NG-PON upstream CWDM capacity – eg, NG-PON Ch2)
1340 - 1360 nm (for NG-PON upstream CWDM capacity – eg, NG-PON Ch3)
1360 - 1430 nm (when low water-peak PON fibre is installed);
1430 - 1470 nm (for NG-PON upstream CWDM capacity – eg, NG-PON Ch4 & Ch5)
1510 - 1530 nm (for NG-PON downstream CWDM capacity – eg, NG-PON Ch5)
1530 - 1570 nm (for C-Band DWDM capacity for NG-PON Ch6 - Ch25 using 20 upstream & 20 downstream wavelengths)
1570 - 1620 nm (for NG-PON downstream CWDM capacity – eg, NG-PON Ch2, Ch3 & Ch4)
1625 nm (for live OTDR testing)

Additionally, every one of these NG-PON channels can be upgraded to 10Gbit/s and later 100 Gbit/s, but the first upgrade is expected to be 10GEPON using NG-PON Ch2 (1260 - 1280nm upstream / 1574 - 1580nm downstream) [8].

For “Open-Access” networks as being deployed in Europe and as proposed for Australia, the benefit of the PON based FTTH rollout is that each NG-PON Channel (1 – 25) can be allocated to a different Service Provider with simple insertion and removal of different services via passive WDM filters, with negligible interference to other services already operating.

5. Conclusion

Australia is currently behind many OECD countries in its rollout of both Fibre to the Node (FTTN) and Fibre to the Home (FTTH) access networks. Such networks are needed to support Video Entertainment applications such as High Definition TeleVision (HDTV), Video-on Demand (VoD) and Near Video on Demand (NVoD); plus low latency for IP Telephony applications and an increasing range of broadband Internet applications such as: E-Bay, Google Maps, You-Tube & Joost.

In contrast to the late 90s, the network capacity is now demand driven not technology driven. But new technology is required to meet this demand. Opportunities are available for Australia to leap-frog the traditional FTTN rollout and instead rollout the latest FTTH technologies to meet both current and future demands for network capacity.

Two FTTH technologies have been outlined in this paper:

- One is based on an evolution over time from all copper and all wireless networks to mixed FTTN backhaul networks plus copper and wireless Last Mile networks; and then subsequently to FTTH Last Mile networks via Active Optical Network (AON) upgrades; and then finally to completely passive FTTH networks via end-end Passive Optical Network (PON) upgrades. FTTN - Broadband Wireless would also be maintained as a less dense parallel network to support mobility for cell-phones, laptops and PDAs.

- The other is to bypass all the above steps (except FTTN - Broadband Wireless networks) – something that is only economically feasible for a FTTx technology lagging country such as Australia – and jump directly to FTTH Wireline networks from the Central Office (CO) to the customer's premises based on the latest generation EPON and GPON technologies and Next Generation 10GEPON and xWDM PON technologies.

The advantages of PON based FTTH networks, which are considered the "target network" or "end-game", are as follows:

- For carriers – PONs eliminates expensive power consuming cabinets in the street which require connections to local AC power, expensive replication of battery backup facilities (without the added benefits of backup generators), regular maintenance and longer down-times than CO-based equipment when failures occur;
- For environmentalists and the social conscious – PONs eliminates large conspicuous cabinets in the street and enable a larger proportion of the work force to employ remote office access applications to work from home thus saving previous material resources such as fuel and family resources such as commute time to/from the office;
- For service providers – PONs better facilitate the provision of "Open Access" networks using simple service separating technologies such as Wavelength Division Multiplexing (WDM);
- For service providers, carriers and end-customers, PONs enable the largest possible capacity and data throughput from the CO to the customer's premises, supporting both residential broadband applications and business applications for the lifetime of the installed fibre infrastructure.

Notwithstanding the above target or end-game, which as a minimum should be applied to Greenfield access network installations, this paper has presented the pragmatic case where the higher cost of PON rollouts cannot be justified from day one for all or even most Brownfield network upgrades. To this end, the paper has presented evolutionary FTTN and FTTH upgrades for three broadband service options: DSL, Cable & Wireless. In each case, interim FTTN / copper and wireless options are presented with street node/cabinet size and power requirements considered, so that subsequent AON based FTTH upgrades fit within the node/cabinet size and power available. For example, it was demonstrated that collapsed PON based AONs with typically 4 x OLT ports per Line Card are in fact 5x more space and power efficient than existing 24-port DSL Line Cards and are certainly more efficient than multi-port 100Mbit/s Ethernet Line Cards for FTTH.

Summarising, this paper has demonstrated that if FTTN is the selected evolutionary broadband rollout plan for Australia, then it should be a pre-requisite of any FTTN architecture that street cabinets and base stations be specified in terms of power and space to support subsequent AON upgrades to FTTH, and it has been demonstrated that such a requirement can with reasonable care, be readily implemented in most cases. To accommodate the target PON upgrades, it is also a pre-requisite FTTN architecture requirement that the backhaul fibre cable or duct have at least 10x more fibres installed than required initially (eg, 32 fibres per 1000 home serving area assuming a 1:32 passive split), or if this is not a financial option initially, then at least install additional cable ducts for later fibre expansion. With such FTTN network design rules in place, both AON and PON based Brownfield FTTH upgrades can be implemented readily and rapidly when justified by increased customer demand. On the other hand, Greenfield FTTH networks should be rolled out as PONs from day one.

6. References

[1] **Ethernet based AONs:**
Ericsson EFN-324; Cisco ONS-15454 Multi-Service Provisioning Platform;
IEEE 802.3ah-2004 - Ethernet in the First Mile (Single fibre 1310/1550nm option - 100BASE-BX10);

[2] **Ethernet / HFC AONs:**
"Harmonic Demos Ethernet Switching Modules for Deep-Fiber Platform" (PWRBlazer)
(http://lw.pennnet.com/articles/article_display.cfm?article_id=86249 - 2001)

[3] **Collapsed PON based AONs:**
Tellabs 1134 Multi Service Access Platform; NEC AM3160 Multi Service Access Node;

[4] **CWDM FTTN Backhaul – Ethernet & Collapsed PON based AONs:**
R. Halgren, J. Hash, RBN Inc., "Comparison of CWDM and PON Transport Architectures in Enabling Appropriate Network Planning", National Fibre-Optic Engineers Conference, September 7-12, 2003, Orlando, Florida, USA

[5] **HFC PONs:**
Motorola "Cable PON"; Commscope "Brightpath"; Pacific Broadband Networks Light Link® Series 2;

[6] **EPONs:**
Hitachi nuPON1000; Huawei S6500; Wave-7 Optics Trident7; Pacific Broadband Networks Light Link® Direct;

[7] **GPONs:**
Ericsson EDA-1500; NEC AM3160; Wave-7 Trident7; Alcatel-Lucent 7342 Intelligent Services Access Manager;

[8] **NG-PONs:**
IEEE P802.3av 10GEPON Task Force (2007)

7. About RBN and the Author

Ross Halgren has followed a career in Photonic networks since undertaking Sydney University Electrical Engineering faculty's first undergraduate thesis project on Optical Fibre Communications in 1976, using 20 metres of multimode fibre donated by Dr Don Nicol from AWA Research Laboratory. Ross's first industry research experience was then working for Dr Don Nicol and Dr Jim Harvey in the AWA Communications Lab, eventually going on to managing the AWA Laboratories. His main area of Photonics research at AWA was in triple-play Fibre Optic Local Area Networks and by virtue of AWA's Defence systems focus, this technology was quickly picked up and targeted at multimedia Air Traffic Control and Emergency Services Communications Systems, followed by Shipborne and Airborne Command & Control Communications Systems – with many such optical local area networks still in service today in Australia and overseas.

Since 1998, after undertaking an International Benchmarking Mission on Photonics for DIST and the Sydney University Warren Centre, Ross focused on broadening the commercialisation focus of the Australian Photonics CRC from WDM components to WDM telecommunications systems, resulting in his joint founding of Redfern Broadband Networks Pty Ltd (RBN) with Dr Richard Lauder. Subsequent seed funding by Australian Photonics Pty Ltd (using proceeds from the sale of INDX to JDS Uniphase) led to a prototype bi-directional, single fibre working Metro Ethernet DWDM product which was demonstrated in 2000 at US trade shows. This led to subsequent multi-million dollar rounds of investment by US Optical Investors and Australian technology investment funds. Today, the lion's share of RBN is owned by the Australian technology investors – Jolimont Capital and Allen & Buckeridge. This initial investment resulted in a 64 wavelength Metro DWDM Reconfigurable Optical Add/Drop Multiplexer (ROADM) which unfortunately was mothballed in Oct' 2001 when the optical market collapsed. To address the post-2001 slimmed-down optical market requirements, RBN's technology was refocused as an 8 wavelength CWDM ROADM (called the GigaEdge 8200) for FTTN Access networks. The RBN 8200 won the AusIndustry National Innovation award for best Australian product in 2002. The 8200 is installed in many carrier FTTN and Inter-Office networks, enterprise networks, utility networks and military networks around the globe.

In 2003, RBN received an AusIndustry Start Grant to develop a new GigaEdge 2330 product which would increase the wavelength utilisation of the installed base of 8200 networks and other xWDM networks, by multiplexing up to 16 x ANY triple-play services into each wavelength. The RBN 2330 was developed using 100% programmable optical transport technologies and due to this innovation, the first hardware, firmware & software variant subsequently won in June 2004, the prestigious Supercomm SuperQuest Award for the best new optical networking product (presented in Atlanta USA).

By virtue of RBN's focus since 1999 on single fibre working xWDM Metro networks and FTTN access networks, the 2330 was recently demonstrated with short notice to a large Asian carrier, as a CWDM GPON Overlay network for business applications – supporting triple-play video, voice & data services to the business customer's premises using different upstream and downstream CWDM wavelengths to those employed by the GPON upstream and downstream traffic.