DWDM Aggregation and extension for TDM PON

A Technical Paper prepared for the Society of Cable Telecommunications Engineers
By

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Overview

Although there is little doubt that fiber is replacing copper as the last mail access network technology, the deployment cost of fiber to the home (FTTH) has been a major concern. Studies show that in urban and suburban areas the cost ratio of trench to equipment is roughly 1:1 while in rural area this ratio could be 4:1. Therefore, a large portion of the cost for FTTH is in the trench for trunk and distribution fibers.

In comparison with Telcos, MSOs have been considered less aggressive in deploying passive optical networks (PONs). However, when taking the cost ratio of trench to equipment into consideration, MSO may have advantages. The fiber portion of the HFC network is very close to the end-users, normally much less than one mile. When a MSO migrates to FTTH, using HFC fibers for PON optical distribution network (ODN) trunk fiber could save the cost on trenches that consists of 50 to 80 percent of the overall cost. As the result, brownfield FTTH for MSOs could have much lower costs than for Telcos. However, an optical node in HFC network typically has 2 to 4 fiber feeds from a headend, and supports more than 500 homes passed (HP). In order to support the same number of HP with time division multiplexed (TDM) PON, at least 16 trunk fibers are needed. When a shortage of fibers happens, dense wavelength division multiplexing (DWDM) technology is normally the choice. However, DWDM aggregation for TDM PON is an unsolved problem for the industry because the upstream wavelength of optical network terminals (ONTs) has a wide variety range of distribution that will not fit into a wavelength division multiplexing (WDM) or DWDM filter pass-band.

In the following sections, a new system architecture that solves the problems facing both MSOs and Telcos today, that uses DWDM technologies to aggregate TDM PONs, will be discussed.

TDM PON and FTTH CapEx Cost

EPON (Ethernet Passive Optical Network) and GPON (Gigabit Passive Optical Network) use TDMA (time division multiple access) for upstream multipoint-to-point MAC access, normally referred to as time division multiplexing (TDM) PON, in contrast with other type of PON such as DWDM PON. TDM PONs are the only PONs that have been standardized today. EPON and GPON have been deployed worldwide in the past decade. The next generation of TDM PON, including 10G EPON, XG-PON (10Gbit/s downstream and 2.5 Gbit/s upstream) and XG-PON2 (10Gbit/s downstream and 4x2.5 Gbit/s upstream) are in the early deployment stage. TDM PON is considered the main fiber access technology for FTTH. In general, a TDM PON supports 16 or 32 ONTs and up to 20 km reach due to the limitations of optical power budget.

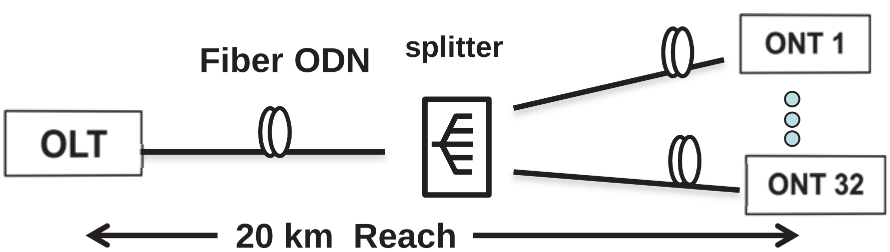

Figure [1] TDM PON Architecture

It is widely accepted that TDM PON will replace copper technologies as main access technology in the future; the major concern is that the deployment cost TDM PON is too high today. There are many studies published on the deployment cost of TDM PON based FTTH. The capital expenditure (CAPEX) cost of deployment of TDM PON could be divided into equipment cost and outside plant ODN cost. Although the actual cost of TDM PON deployment varies from country to country and region to region, many studies show that the ratios of equipment cost over outside plant cost are similar if PON deployments are categorized into urban, suburban and rural areas. Figure 2 shows the FTTH CAPEX cost by geographic regions based on the data from a study published by BH Telecom Sarajevo [1]. This study shows that the cost ratio of trench/equipment is roughly 1:1 for urban and suburban areas, and this ratio reaches to 4:1 in rural areas. Since major outside plant cost for FTTH is building/digging trenches, these graphics closely represent the CAPEX cost ratio of outside plan and equipment in the scenario that most of the fiber cables are buried in trenches.   Ariel cable infrastructures could have a lower CAPEX cost.

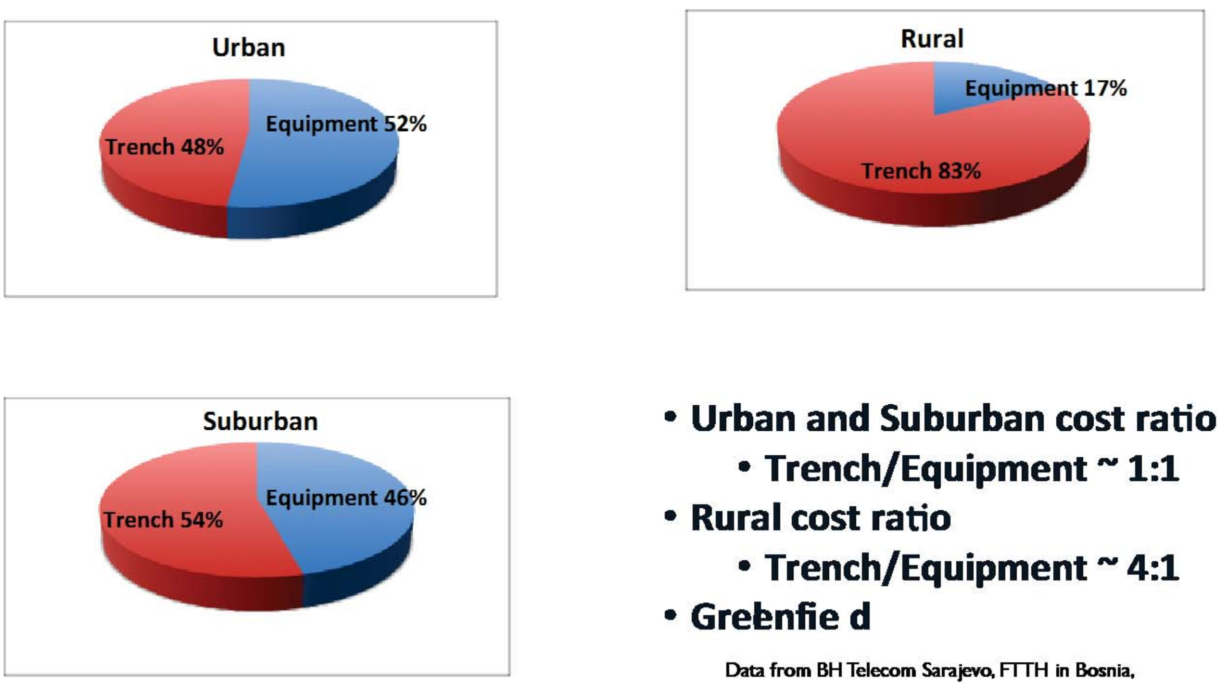

Figure 2. FTTH CAPEX cost by geographic regions

Advantage for MSO in FTTH and Challenges

The MSOs use HFC (Hybrid Fiber Coax) network to deliver video, voice and data services to the end-users. In a HFC network, as shown in Figure 3, cable modem termination system (CMTS) and edge quadrature amplitude modulation (QAM) equipment in the head-end send analog modulated optical signals over a P2P (point-to-point) optical fiber to an optical node, located in the field, which converts the optical signals to be transmitted to cable modems (CM) over P2MP (point-to-multiple point) coax cable plant. The P2P optical fiber portion of HFC network could stretch more than 60 km in distance but normally would be less 20 km. The HFC optical nodes are very close to the end-users, typically within few hundred to few thousand feet. In the early deployment of HFC networks two fibers are needed for an optical node, one for 1550nm downstream and another for 1310nm upstream. When WDM is used for upstream and downstream, which is typical today, one fiber could be free for other services. Further more, in most of the HFC deployment there are backup fibers reserved for each optical node. Therefore, we can safely assume that there are at least 2 or more P2P fibers connected to each optical node from the headend.

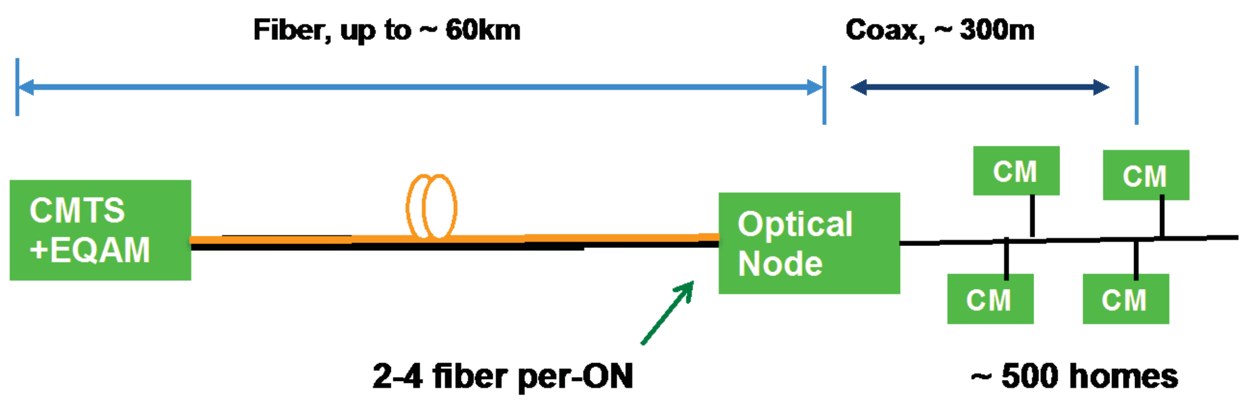

Figure 3. HFC network

If these extra P2P optical fibers could be used as trunk fiber for TDM PON, a large portion CAPEX cost of the trench build could be avoided. Considering trench cost consists of 50% to 80% of the CAPEX cost, the saving could be significant.

A TDM PON consists of a P2P trunk optical fiber from head-end to the field where an optical splitter or splitters split the optical signal from OLT into 16 or 32 portions to the P2MP branch fibers. One basic assumption for FTTH is fiber rich; one P2P trunk fiber of a PON only servers 32 users. However, a HFC optical node normally supports as many as 512 users. When migrating to TDM PON based FTTH, 16 TDM PONs are needed to support 512 end-users. Therefore, 16 trunk fibers are needed in this migration scenario; clearly there is a shortage of trunk fibers. Figure 4 shows that in order to cover the service area of an optical node with 512 HP, multiple trunk fibers (16) are needed.

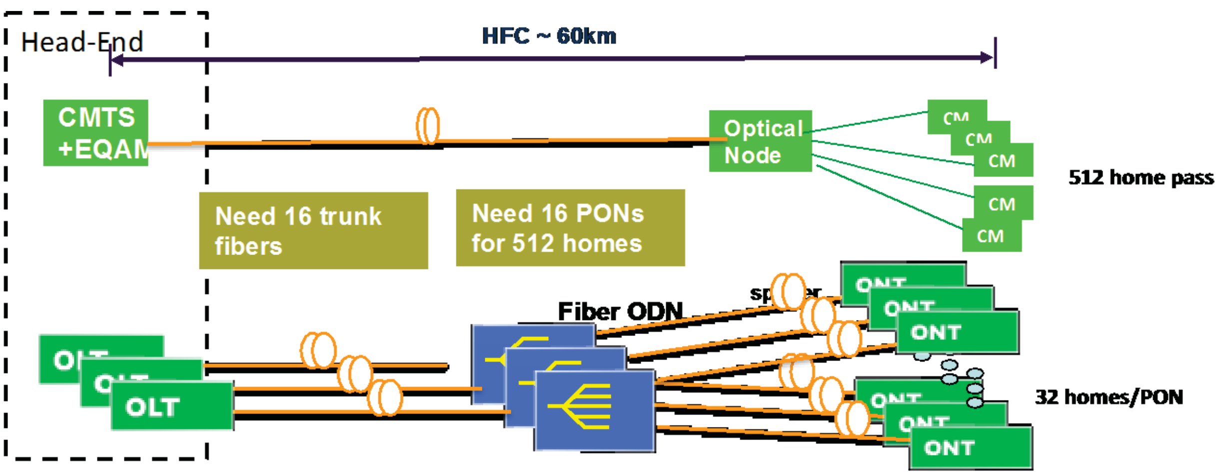

Figure 4. Multiple TDM PON overlay on optical fiber cable

Normally fiber shortage could be solved by WDM or DWDM technologies. The solution is referred to as WDM or DWDM aggregations. However, WDM or DWDM aggregations cannot be used directly on a TDM PON. A DWDM filter has a narrow passing band. Consider a 200GHz DWDM filter for example, in which the passing band is +/- 0.25 nm. On the other hand, the wavelength variation of a TDM PON ONT greatly exceeds the passing band of a DWDM filter. Take EPON for example, the upstream wavelength range for ONTs is from 1260 nm to 1360 nm. Obviously a DWDM filter centered on 1310 nm will filter out an ONT's upstream transmission. Without DWDM aggregations, migration to TDM PON using existing HFC trunk fiber will be limited in scope and scalability although there is a clear cost advantage.

Another problem for migrating from HFC to FTTH is the reach of TDM PON. Although the HFC trunk fibers are typically less than 20 km, there are situations that HFC trunk fibers could stretch more than 60 km in distance. This brings the needs for DWDM aggregations for TDM PON. For different reasons, for example CO (central office) consolidations, Telco operators also require extending the reach of TDM PON beyond 20 km. As the result, various TDM PON extension architectures have been proposed. Generally speaking, there are two types of TDM PON extension architectures, one is all optical and another is based on OEO (optical-electrical-optical) conversions.

In summary, there is a clear need for DWDM aggregation as well as extension of TDM PONs from both cable and Telco operators. However, DWDM aggregation for TDM PON is still an unsolved problem for the industry.

Remote OLT architecture

Before getting into the details of DWDM aggregation of TDM PON, we first discuss the solutions on the market today. One obvious solution is to install more fibers; one fiber per PON. This may be the solution for greenfield but certainly it is not suitable for brownfield. Another solution used today is called remote OLT as shown in figure 5.

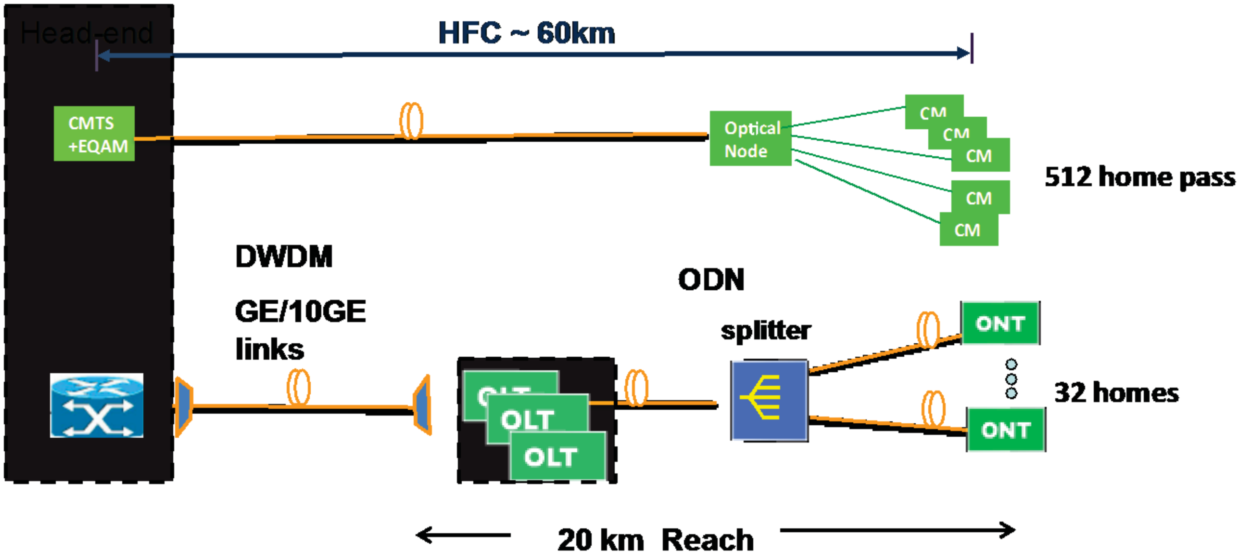

Figure 5. Remote OLT for uplink TDM PON DWDM aggregation

Remote OLT is a work around for shortage of trunk fibers due to the lack DWDM aggregation technology for TDM PON. By placing OLTs at field locations, DWDM can be used for uplink aggregation, for example with Gigabit Ethernet, using existing trunk fibers. The remote OLT solution seems to solve the trunk fiber shortage problem but it introduces other problems.

There are many operational issues associated with the remote OLT architecture; for example, troubleshooting, service provisioning, environment control and etc. First, troubleshooting millions of users from the field, rain or snow, is not an easy task. Second, the OLT is designed for indoor environment with temperature control. When placing OLT shelves at remote locations power supplies could be a problem, and cooling will make it worse by adding more power consumption. Third, we cannot always assume that all services can be aggregated via GE uplink. Service provisioning of remote units with voice, data and video applications could be a challenge. Therefore, the remote OLT architecture could be a strategy for small scales of PON deployment but may not be feasible to scale to millions of users.

DWDM aggregation for TDM PON Architecture

The problem for TDM PON DWDM aggregation can be solved with upstream wavelength conversion, ie., converging the upstream wavelength of ONTs in the range of 1260nm to 1360nm to an ITU grid DWDM wavelength. Wavelength conversion needs an OEO operation and this task can be conveniently combined into PON reach extenders. There are all-optical-based and OEO-based PON reach extenders. Figure 6 shows a hybrid architecture that solves the above mentioned two problems facing MSOs and Telco operators, ie., using DWDM for TDM PON aggregation and extending the reach of TDM PONs beyond the 20 km standard reach.

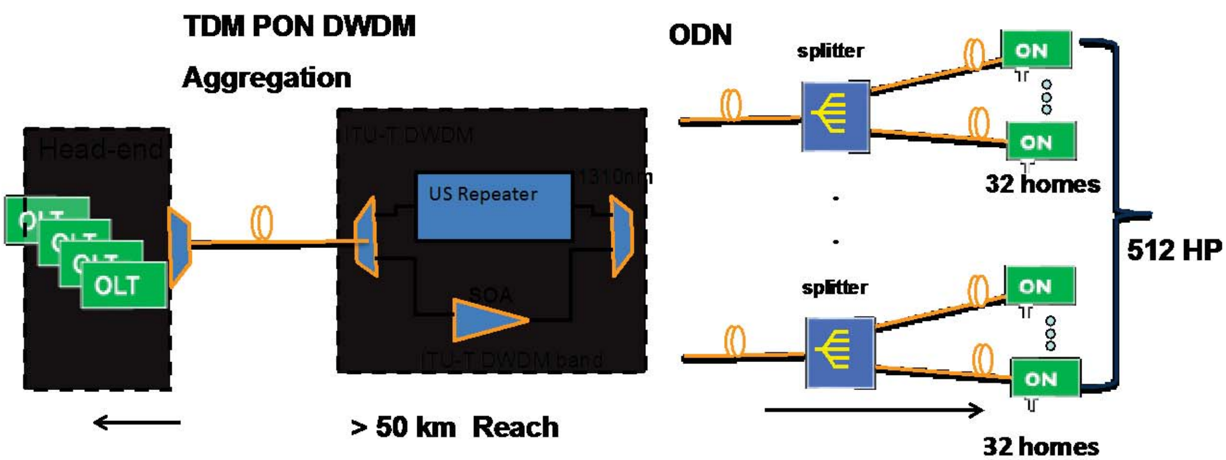

Figure 6. Hybrid DWDM Aggregation and Extension for TDM PON

Hybrid DWDM Aggregation and Extension for TDM PON architecture consists of downstream and upstream modules. In the downstream direction, an optical amplifier, such as EDFA (erbium doped fiber amplifier) or SOA (semiconductor optical amplifier) is used in this architecture. Although an OEO module could be used for downstream, there are advantages in using optical amplifiers. An optical amplifier is simple and has low latency. What is more important for DWDM aggregation is that an EDFA or a SOA can amplify multiple wavelengths, so that one EDFA or SOA could be used to extend the reach of multiple TDM PON downstreams, for example 16 or 32 wavelengths in C band or other bands.

In the upstream direction an OEO repeater is used for extending the reach of TDM PON upstream as well as converging the TDM PON upstream wavelengths from the range of 1260 nm to 1360 nm to a wavelength that fits into the ITU-T grid DWDM wavelength in C band or other bands. The upstream repeater is transparent to MAC and above layers. Figure 7 shows an implementation example of hybrid DWDM aggregation and extension for EPON and 10G EPON.

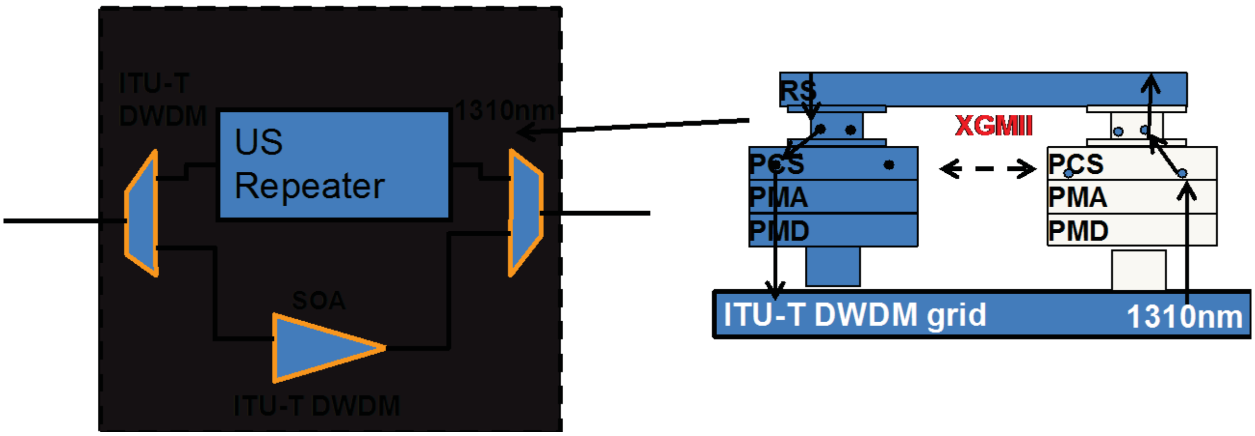

Figure 7. Hybrid DWDM aggregation and extension for EPON/10G EPON

Figure 8 gives details of the Hybrid WDM Aggregation and Extension for TDM PON architecture that supports multiple OLTs, for example 16 OLTs or 32 OLTs. Each OLT support multiple ONTs, for example 16 ONTs, 32 ONTs or 64 ONTs.

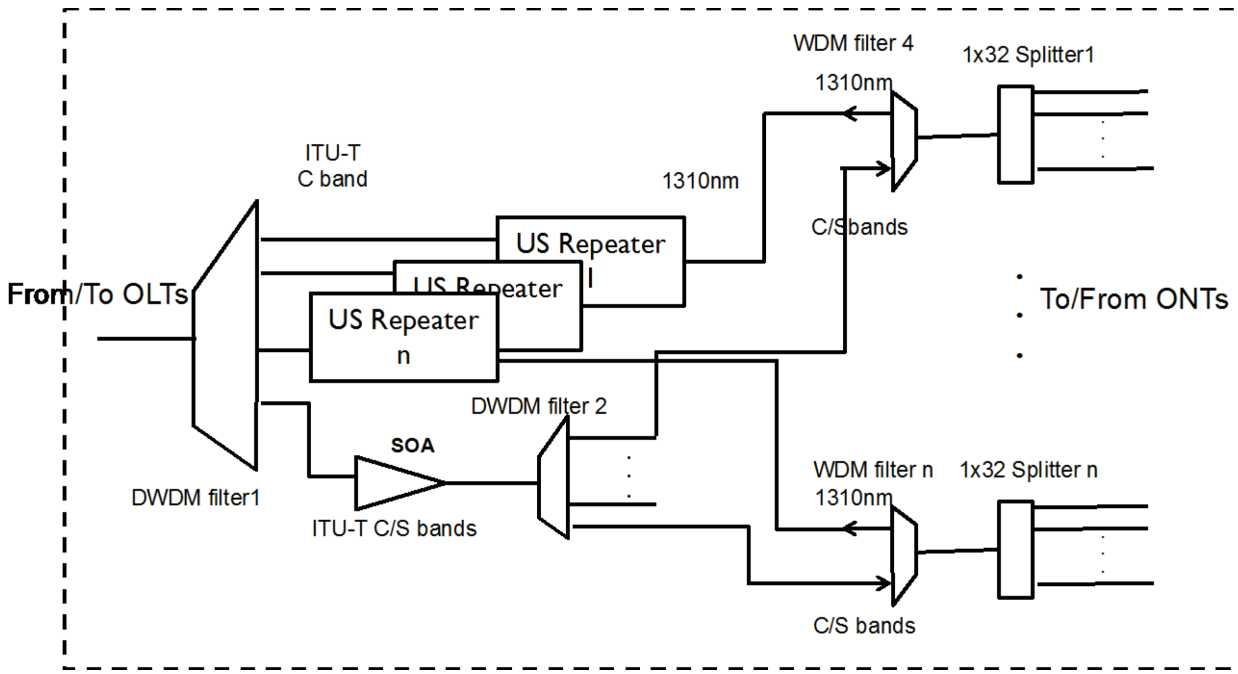

Figure 8. A Hybrid DWDM Aggregation and Extension for TDM PON architecture

In the downstream direction, DWDM aggregation of TDM PON is not a problem. The PON OLT normally use cooled DFB lasers; it is feasible to have a group of OLTs set to different ITU-T grid DWDM wavelengths. In Figure 8 we assume the optical singles from OLTs consists of multiple wavelengths in C band or other band DWDM grid. The downstream DWDM signals passing DWDM band-pass filter 1, see Figure 8, with entire wavelengths in C band feed into a SOA. The amplified optical signals contain all the wavelengths from OLTs and further feed into DWDM filter 2 that separate the incoming wavelengths into individual wavelengths. As shown in Figure 8, one of the downstream wavelengths from DWDM filter 2 that comes from one of the OLT in the head-end feeds into feed to PON 1. Similarly, another output from DWDM filter 2 eventually feeds into PON n, where n is the number TDM PONs supported in this architecture. The downstream architecture shown here is not much different from an all-optical PON extension except multiple wavelengths are amplified to feed into multiple TDM PONs.

The major difference of "Hybrid DWDM Aggregation and Extension for TDM PON" architecture from a typical PON reach extender is on the upstream. Here, wavelength conversions are employed. Although all-optical wavelength conversion is possible in principle, considering the wide distribution of ONT upstream wavelength ranges and due to economic reasons, we choose OEO for upstream. Shown in figure 8, in the upstream direction the optical single from an ONT, ranges from 1260nm to 1360nm, is separated by WDM band pass filter 4, and then feeds into an upstream OEO repeater. At an upstream OEO repeater the upstream optical single in 1310nm range is converged into electrical signal and processed accordingly, and then converged back to optical signal but to a C band or other band ITU grid DWDM wavelength.

DWDM filter 1, on the left side in figure 8, combines multiple upstream wavelengths from multiple TDM PONs, in C band or other band DWDM grid, and sends to upstream via a trunk fiber to the OLTs in the head-end. At the head-end another DWDM filter separates the upstream optical signal into individual wavelengths to feed into individual OLTs.

There are a number of advantages for the hybrid TDM PON DWDM aggregation architecture, it solves two problems in one compact architecture, using DWDM technologies to aggregate TDM PON, such as EPON and GPON, in order to save trunk fiber resources and extending the reaches and increasing the splitting ratio of TDM PON. It is an architecture that puts wavelength conversion, DWDM aggregation and reach-extension together. In this architecture, OLTs are located at headend; therefore, all service provisioning is directly conducted from the headend. Besides, a TDM PON DWDM aggregation and extension device is at the physical layer that make troubleshooting and maintaining much easier than on the remote OLT architecture. It should have much low power consumption than that of remote OLT, since it is basically a repeater, and it could fit into an enclosure similar to a HFC optical node.

Standardization and wavelength plans

The standardization of GPON and EPON reach extenders are either completed or in progress. GPON reach extension as defined in G.984.6 [2] had completed in 2008. 10G EPON reach extension standardization is in progress at IEEE 802.3bk. The OEO based upstream repeater is an option for both GPON and EPON reach extenders. Most of the works on GPON extender at ITU-T and 10G EPON reach extender at IEEE could be used for the upstream repeater module in "Hybrid DWDM aggregation and extension for TDM PON" architecture. What is needed for further standardization is DWDM wavelength plans for upstream wavelength conversions and downstream.

The current wavelength plans for EPON, 10G EPON, GPON and XG-PON are shown in figure 9.

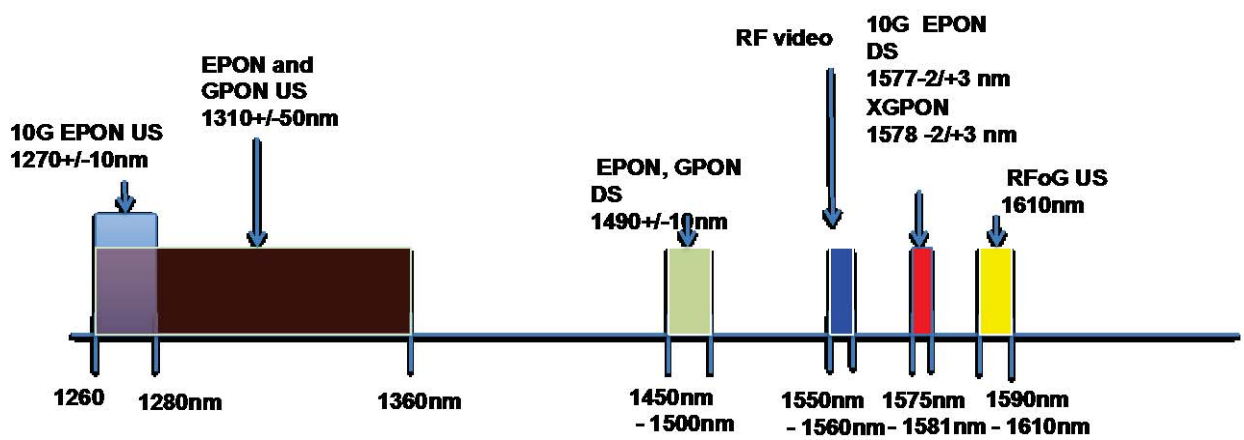

Figure 9. Wavelength plans of TDM PONs

There are two considerations when choosing downstream DWDM wavelength plan for TDM PON DWDM aggregation, one is the use of optical amplifier and the other is the compatibility with current ONTs.

There are two choices for downstream optical amplifiers, one is EDFA and the other is SOA. In order to use EDFA the downstream wavelengths have to be in the C band window. A SOA does not have this limitation. In principle the center wavelength of a SOA can be placed at any wavelength band of interest with more than 50nm gain range.

The compatibility consideration requires that the hybrid DWDM aggregation for TDM PON architecture is backwards compatible with GPON and EPON ONTs on the market today. Both GPON and EPON use 1490nm for downstream transmission. The diplex filter at ONT optical front-end separate 1490nm downstream from 1310nm upstream and 1550nm video overlay. Take GPON for example, the pass band of 1490nm downstream filter is from 1450 nm to 1500nm that has 50nm range for TDM PON DWDM aggregation. Therefore, to our interest it is sufficient to aggregate much more than16 TDM PONs on a single fiber without changing the ONT triplex filter design. The detailed wavelength plans need to be standardized.

As far as 10 Gigabit PONs are concerned, both 10G EPON and XG-PON have a narrower downstream transmission range when compared with that of EPON and GPON. Therefore, diplex filter for downstream should also have narrower pass-band. That means narrower DWDM grid such as 50 GHz DWDM filters are needed to provide enough aggregation channels. But on the other hand 10 Giga PON may not need as much aggregations since a single 10 Giga PON already provides much higher bandwidth.

The choice of upstream wavelength plan for hybrid DWDM aggregation is much simpler since OEO repeaters are used and there is freedom for wavelength conversion.
Refer to Figure 6 in the upstream direction, the optical single ranges from 1260nm to 1360nm from a TDM PON, for example PON1, is fed into a corresponding upstream repeater. At the upstream repeater the upstream optical signal in 1310nm range is converged into electrical single and processed accordingly, and then converged back to

optical signal in C band or other band ITU-T grid DWDM wavelength. Each repeater in Figure 6 converges the upstream wavelength of corresponding TDM PON to a C band or other band ITU-T grid DWDM channel. Unlike the downstream, there is no backward compatibility limitation for choosing upstream wavelength since OLT for this architecture is a new design. Although there is no changes in MAC and above layers, the OLT lasers have to be designed in order to fit into ITU-T DWDM grid, at the same time the optical filters in the OLT are also need to be resigned.

If downstream uses a OEO repeater instead of SOA then there will less registrations in choosing DWDM wavelength plans.

Standardization of both upstream and downstream wavelength plans are required to preserve interoperability, and it could be done at IEEE, ITU-T or SCTE.

Conclusions

With the combination of wavelength conversion, DWDM aggregation and reach-extension in a compact architecture, the “hybrid DWDM aggregation and extension for TDM PON” architecture solves problems facing MSOs and telecommunications operators. For example, MSOs can use DWDM technologies to aggregate TDM PON to save trunk fiber resources, extend the reaches and increase the splitting ratio of TDM PON.

Using “hybrid DWDM aggregation and extension for TDM PON” solution, MSOs are able to take advantage of the existing HFC fibers to directly aggregate multiple TDM PONs on a single HFC fiber for brownfield FTTH deployment and thus achieve significant saving on trunk fibers in the outside plant ODN.

Standardization of upstream and downstream wavelength plans is desired.

Bibliography

[1] Zijad Haviü, “Economic Model Computing for FTTH Access Network” p 218- 222, Pervasive Computing and Applications (ICPCA), 2010 5th International Conference.

[2] ITU-T G.984.6 Gigabit-capable passive optical networks (GPON): Reach extension

Abbreviations and Acronyms

CAPEX	Capital expenditure
CM	Cable Modem
CMTS	Cable Modem Termination System
CO	Central Office
DWDM	Dense wavelength division multiplexing
EDFA	Erbium doped fiber amplifier
EPON	Ethernet Passive Optical Network
FTTH	Fiber to the home
GPON	Gigabit Passive Optical Network
HFC	Hybrid fiber coax
HP	Homes pass
MSO	Multiple system/service operator
ODN	Optical distribution network
OEO	Optical-electrical-optical
OLT	Optical line termination/terminal
ONT	Optical network termination/terminal
P2P	Point to point
P2MP	Point to multiple points
PON	Passive optical network
QAM	Quadrature amplitude modulation
SOA	Semiconductor optical amplifier
TDM	Time division multiplexing
TDMA	Time division multiple access
TDM PON	Time division multiple-access PON
WDM	Wavelength division multiplexing
WDM PON	Wavelength division multiple-access PON