DWDM Access for Remote PHY Networks Integrated Optical Communications Module (OCML)

A Technical Paper prepared for SCTE/ISBE by

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1. Introduction

MSO networks are evolving from traditional Hybrid Fiber Coax (HFC) to remote PHY (RPD) architectures. A typical 500 home node serving area may transition to one with up to 20 RPDs, each requiring a 10G input to provide sufficient bandwidth. An optical access trunk from the headend to the fiber node area will now have to support a high capacity 200G bi-directional link to support 20 RPDs with 10G. Provisions may also have to be made for a PON/10GPON overlay to feed PON networks as well as high capacity 10G/100G for business services from the same fiber trunk.

There are two optical trunk methodologies currently being investigated:

1. A bidirectional 10G DWDM optical trunk
2. A high capacity coherent optical link

A 10G DWDM multi-wavelength optical trunk to each original HFC node area is an efficient low cost solution that makes use of mature, readily available technology. High capacity coherent optical links may eventually be able to fulfill the requirement, but are not yet commercially available in a field hardened, cost effective package. It is likely that networks may have to be designed to allow for the coexistence of both 10G Non-Return to Zero (NRZ) and Coherent networks.

To that end, Cox has developed the OCML (Optical Communications Module Link Extender) concept for cost effectively transporting a mix of DWDM 10GbE, GPON and 10GEPON wavelengths over the same fiber to a typical HFC node serving area.

2. Optimum Optical Access

An optimum access solution for the last mile should be a scalable and technology agnostic solution which is cost, capacity and bandwidth efficient. Today, this calls for a solution which uses mature low cost DWDM 10G NRZ optics to feed multiple RPDs and at the same time allows for a migration to 25G NRZ and 100G coherent for higher capacity requirements. Figure 1 shows a network topology where the backbone and metro core is coherent while the optical access supports both 100G coherent and DWDM 10G NRZ. DWDM 25GHz NRZ for access (40Km) is currently being investigated by many manufacturers and will become available if there is a market need for it, since 25G non-DWDM is already available. However, it should be noted that it is unlikely that RPDs will need more than 10G in the next decade. So, it is important to choose an optical access solution that is technology agnostic and supports a variety of different technologies including 10G, 25G and coherent optics. This will make the last mile truly scalable and serve the needs of the industry for a long time. While it is unlikely that individual RPD's will require 100G anytime in the foreseeable future, it may be beneficial to be able to provide 100G coherent links for high capacity requirements such as enterprises and Multiple Dwelling Units (MDUs).

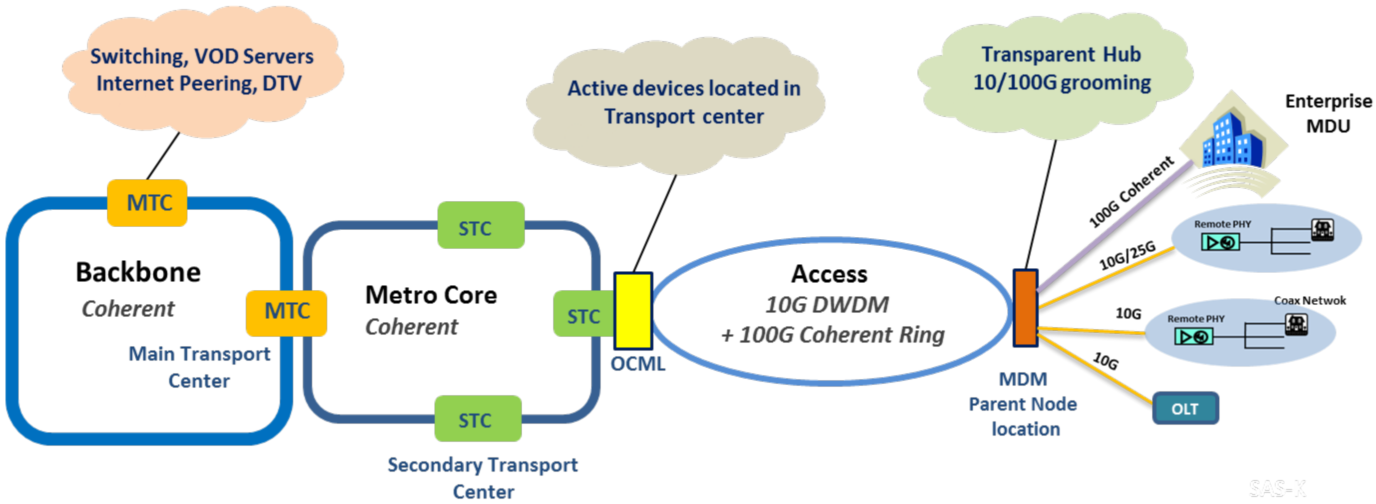

Figure 1 - Optical network: Backbone, Metro Core and Access

3. Access Network Fiber Infrastructure Evolution

The fiber infrastructure between the headend and the fiber node is the most constrained part of the network and the most expensive to upgrade. There is a need to evolve the Access Network fiber infrastructure between the headend and the fiber node to support digital optics thus transitioning away from the current analog (AM) optical connections. This transition is underway to accommodate the impending architectural shift to Remote PHY.

3.1. Optical Access Design Goal

The most important design goal in the transition from analog to digital optics is to preserve the existing fiber network. As all initial Remote PHY Devices will natively support 10G, the use of 10G DWDM optics allows for a direct connection between the RPD and the corresponding aggregation device. This eliminates the need for additional active devices in the field. The placement of active devices in the field are problematic, as these would increase the operational costs to maintain the network and reduce robustness.

3.2. Bandwidth Projections

Cable operators have seen exponential growth in broadband traffic in recent years, with both downstream and upstream traffic growing significantly due to the consumption of video which accounts for a large and growing percentage of bandwidth used in hybrid fiber-coaxial (HFC) networks.

In the access migration to support digital optics, it is projected that each fiber between the headend and the parent node (formerly HFC fiber node) may need to accommodate up to 20 RPDs. Sufficient wavelength capacity remains available with current filter structures to support 80 or more wavelengths. Each RPD can support approximately 64 HHP with a single service group initially shared among up to 4 RPDs. Given current projections it is believed that 10G interconnections between the RPD and aggregation point provides ample capacity for growth. As a 25G DWDM NRZ becomes available, the RPDs could be upgraded to 25G where required, and only the network ends would need to be changed.

3.3. Passive Field Infrastructure

A design goal in the transition to digital optics in the access is to preserve (as much as feasible) a passive outside plant / field infrastructure. As all initial Remote PHY Devices will natively support 10G the use of 10G DWDM allows for a direct connection between the RPD and corresponding hub located aggregation device. Alternative solutions have been suggested that require active aggregation devices in the field but have the disadvantage of increased operational costs to maintain the network and reduced robustness. The OCML concept places all active components in the MTC/STC facilities, with a completely passive Mux/DeMux (MDM) device in the field.

3.4. Time to Market

As the industry begins to implement initial Remote PHY rollouts next year, the OCML provides for the use of available technology, insuring a transport solution is available in time to support the access solution. Finally, although Cox has decided to utilize 10G DWDM NRZ as the initial technology in the transition to digital optics in the access, the underlying infrastructure has been based on ITU standard compliant wavelength plans in anticipation of the requirement to deploy 100G (and beyond) wavelengths.

3.5. 10G DWDM

Figure 2 shows a multi-wavelength 10G DWDM network. Some of the main points are:
10G NRZ is a mature technology and all associated components such as DWDM passives and hardened, pluggable SFP optics are readily available. Some of the main features of an all 10G DWDM access solution are:

- 10G NRZ is low cost, mature and readily available
- Scalable to 25G and 100G coherent
- Large capacity, single fiber pair accommodates 400G (40x10G) – 800G (80X10G)
- Transparent All PASSIVE hub
- Pay-As-You-Grow. Parent node can grow from 2 RPDs to 20 RPDs

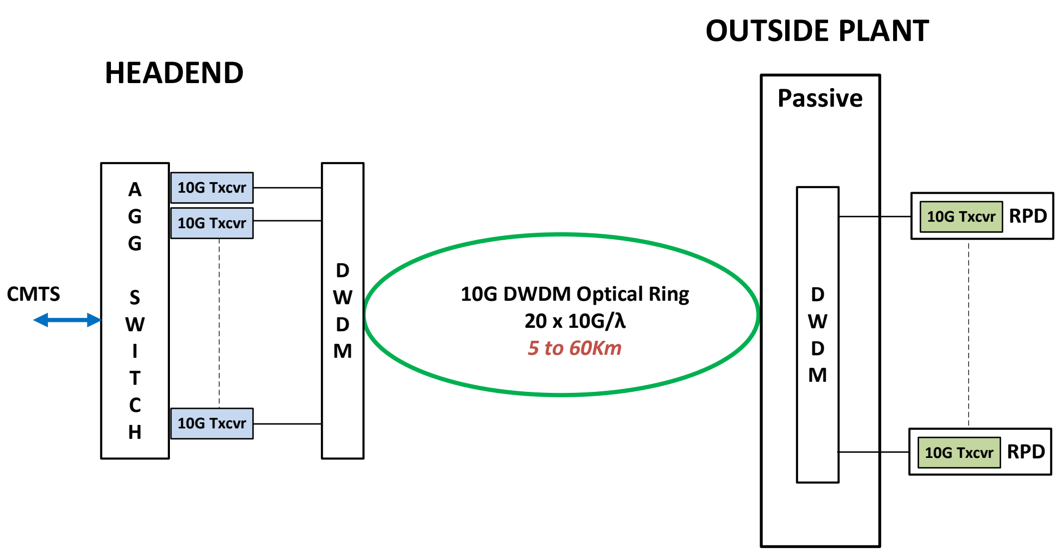

Figure 2 - 10G Multiwavelength DWDM Ring

4. Cox Network Transformation

A typical Cox HFC network is shown in Figure 3 where the primary node is connected via dual (redundant) primary and secondary fiber links which can be between 5 to 60 km, with the primary usually the shorter ring. As we migrate to a distributed RPD architecture, these fibers will migrate to a multi-wavelength 10G ring to feed multiple RPDs. Figure 4 shows how a typical HFC node 500 home serving area can be converted to a 20 X 10 DWDM 10G Optical trunk where each RPD can be fed by a 10G. This allows the outside plant to remain passive using a simple 40 channel thin film DWDM.

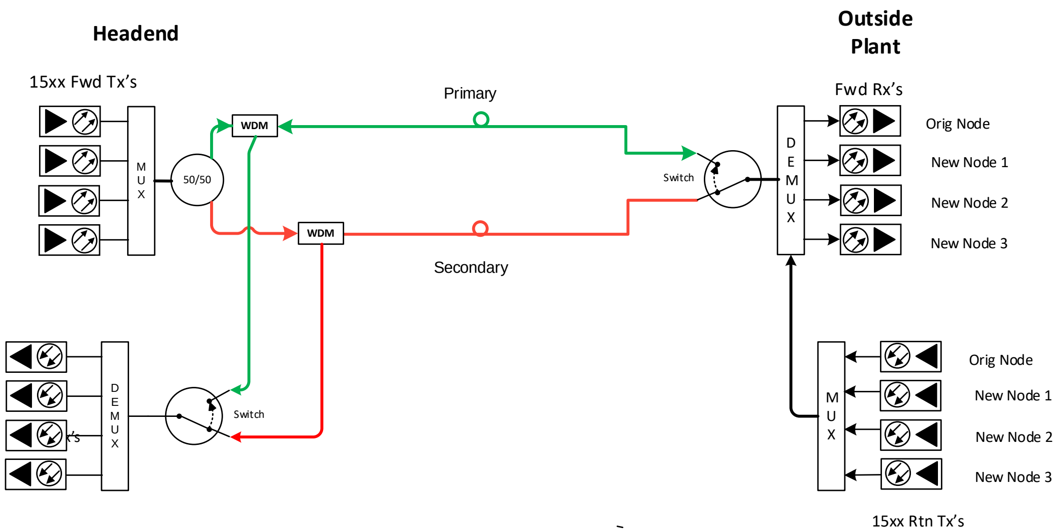

Figure 3 - Current Cox HFC Analog Optical Network

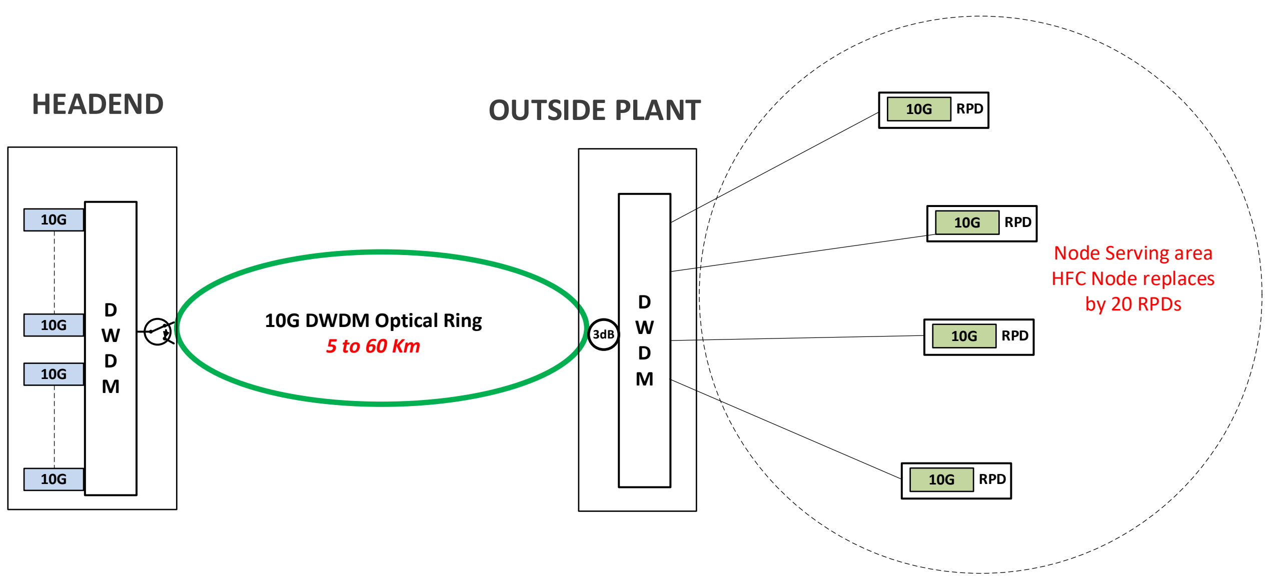

Figure 4 - HFC Node converted to 10G RPD

5. Optical Communication Link Extender (OCML)

Figure 5 below shows a simple 10G DWDM with a GPON/10GEPON overlay, while Table 1 shows the associated loss budget. This shows that the fiber distance associated with such a network is less than 10Km. At Cox, our network supports dual rings of 5 to 60Km and would require field amplifiers as shown in Figure 6.

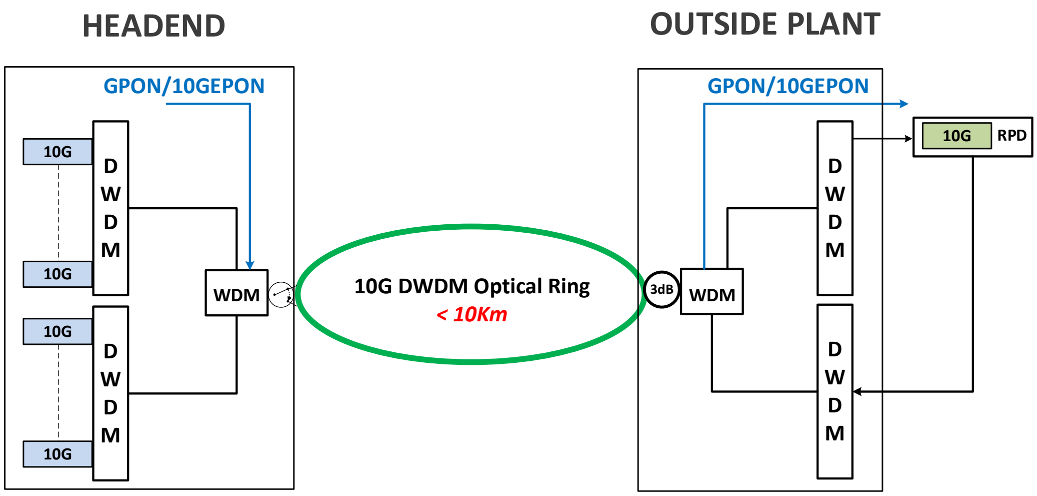

Figure 5 - Multi-wavelength 10G optical trunk without EDFAs

Table 1 - Link loss for 5 km RPD Ring

PARAMETER	LOSS BUDGET		
Headend			
10GbE Txcvr Pwr/WL		0.0	dBm
Fiber Length Headend to MDM	5	1.1	dB
Fiber Length MDM to RPD	2	0.44	dB
Headend DWDM Mux		4	dB
GPON/XGPON WDM		2	dB
Switch		1.5	dB
Outside Plant			
50% Optical Splitter		3.5	dB
WDM		2	dB
DWDM		4	dB
Connectors (2 @0.3dB)		0.6	dB
Safety Margin		3	dB
	Total loss	22.14	dB
	FieldRx I/P	-22.1	dBm

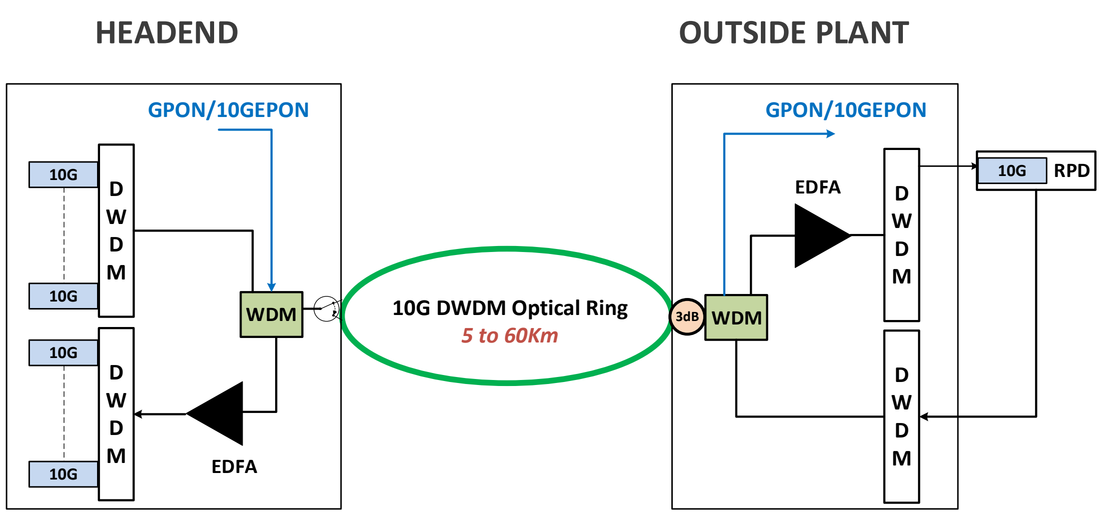

Figure 6 - Multi-wavelength 10G optical trunk with field EDFAs

5.1. The Optical Communications Module Link Extender (OCML)

We have created the Optical Communications Module Link Extender (OCML) concept which allows all the active components of a 10G DWDM access network to be placed in the headend while keeping the outside plant all passive with a Mux/Demux (MDM). The OCML and the remote outside plant MDM unit were required to support next-generation fiber deep DWDM access networks.

Some of the key requirements in designing the OCML were to create an integrated module which could support:

- 5 to 60 Km dual and variable fiber rings -
- 10G DWDM - transport up to 20 X 10G bi-directional wavelengths
- GPON/10EGPON transport over 20Km

The OCML was designed with a view that it could support future requirements for:

- 100GEPON
- 100G Coherent

An added benefit of keeping all the subsystems of the OCML integrated in a box is the estimated cost reduction over individual components.

The Optical Communications Module – Link Extender (OCML) enables DWDM aggregation for optical trunks up to 60 km without any active field devices such as optical amplifiers or optical switches, reducing equipment costs and operating expenses while greatly simplifying installation. The OCML schematics are given in Figure 7 below.

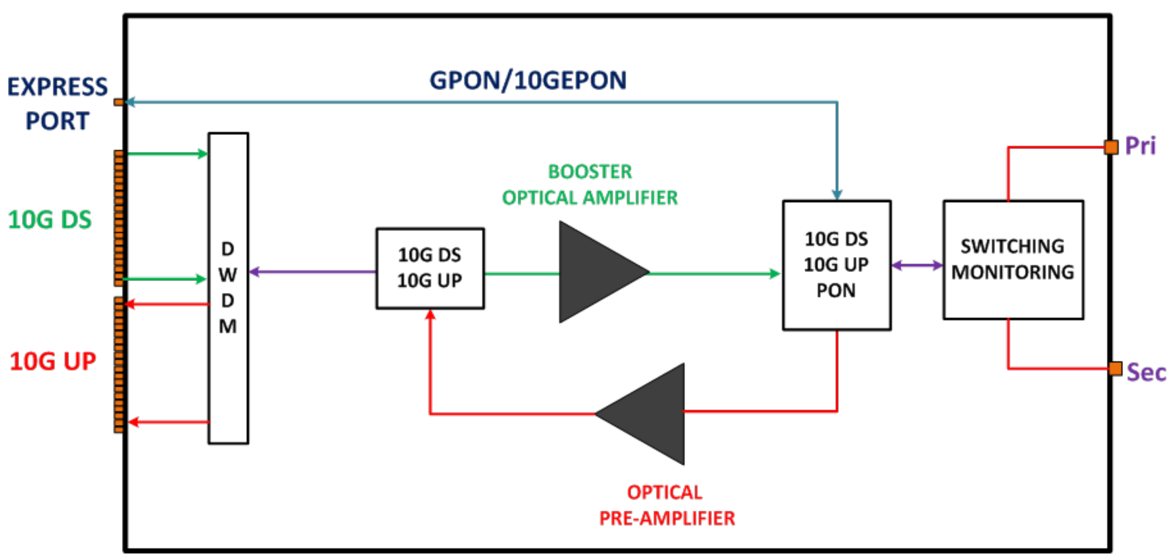

Figure 7 - OCML Block Diagram

The OCML wavelengths to be transported are depicted in Figure 8 below. Future requirements may also include 100GEPON and a 100G/200G/400G coherent to be transported over the same fiber network via the OCML.

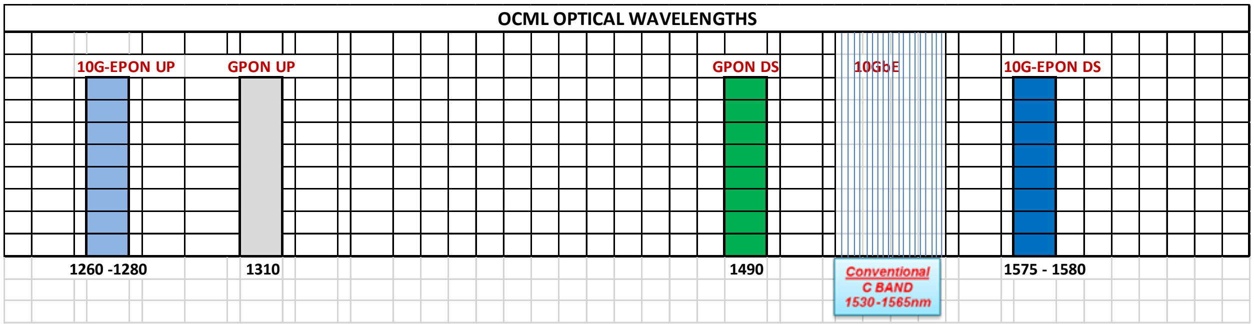

Figure 8 - OCML Optical Wavelengths

5.2. Outside Plant Mux/Demux (MDM) unit

To keep with an all passive outside plant, a Mux/DeMux device is used in the field as shown in Figure 9 below. The MDM is essentially an integrated passive module which reduces cost and keeps with the philosophy of keeping the outside plant simple and passive as much as is possible.

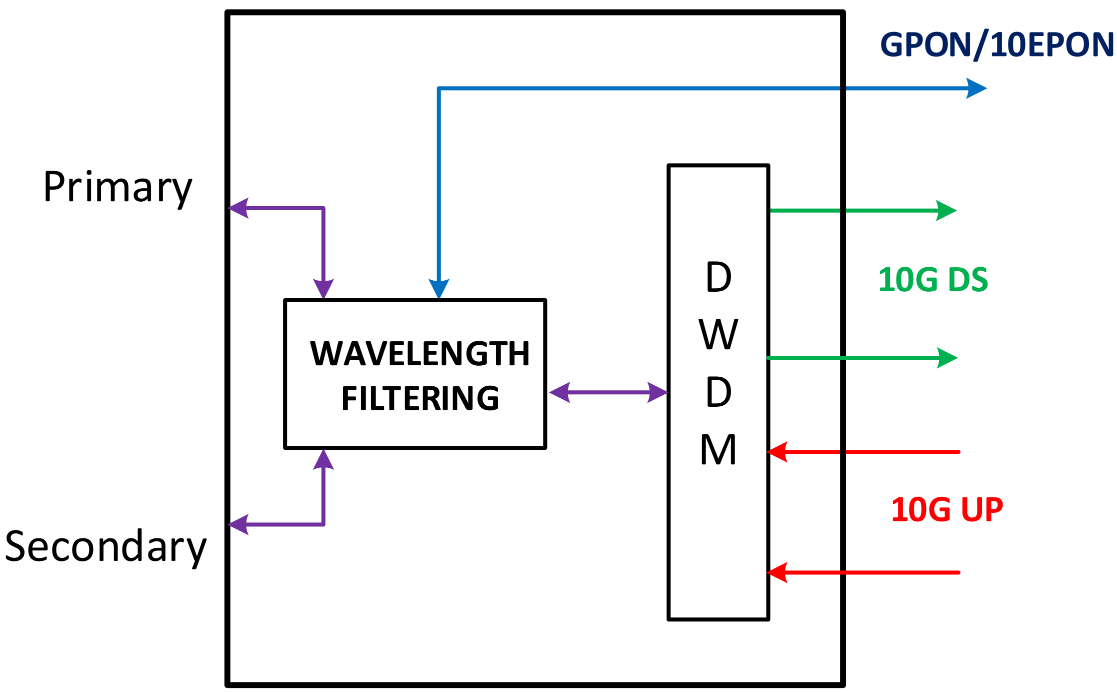

Figure 9 - Outside Plant MuxDemux (MDM)

Figure 10 below shows the numerous applications which can conceivably be fed via a multi-wavelength DWDM ring which also supports other wavelengths outside the C band such as GPON and 10GEPON. Such an architecture can also support a 100G coherent which can be used for high capacity requirements. This is a truly powerful and scalable network architecture which allows various technologies to be transported. In the future, 10G NRZ could be upgraded to a 25G NRZ which is basically a market driven application. If there is a market requirement, 25G NRZ will become available in cost and quantity.

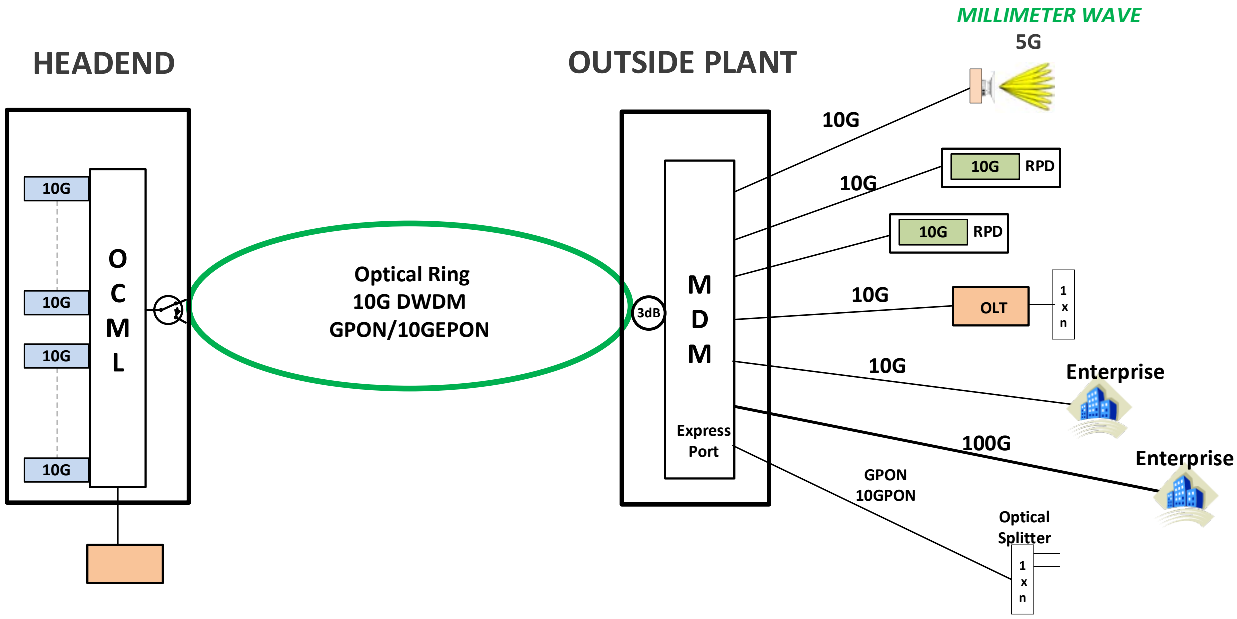

Figure 10 - OCML and MDM Applications

6. Technical Design Considerations of the OCML

DWDM transmission in fiber is always prone to fiber nonlinearities. The potential debilitating impact of Stimulated Raman Scattering (SRS) was considered in the design of the OCML. SRS is a nonlinear process where higher frequency optical channels are depleted and lower frequency optical channels amplified. Figure 11 below shows an illustration and the effect of spontaneous Raman scattering and its impact. If two wavelengths are propagating in fiber and depending on their wavelength separation, polarization states and optical launch power, SRS crosstalk can occur which depletes shorter (pump) wavelength and amplifies the higher (stokes) wavelength. It is sensitive to the power level of the lower wavelength signal, the separation between the two wavelengths and the fiber length. The effect is on the lower RF frequencies carried at the longer wavelength optical carrier. The primary way it manifests itself in FTTH systems is interference from the 1490nm downstream data signal cross talking and causing interference into the 1550nm 10G signals**.**

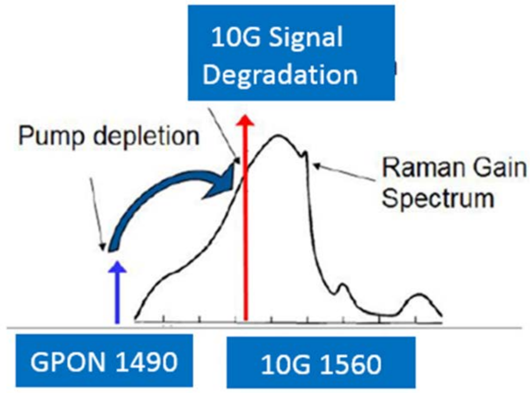

Figure 11 - Stimulated Raman Scattering (SRS) Illustration

SRS induced crosstalk is given by the following equation:

$$XT_{SRS,i} = P^2 \sum_{k \neq i} \frac{g^2_{i,k}}{A_{eff}} \left(\left(1 - e^{-\alpha L}\right)^2 + 4e^{-\alpha L} \sin^2\left(\frac{\Omega d_{i,k} L}{2}\right) \right) / \left(\alpha^2 + \Omega^2 d^2_{i,k}\right)$$

This indicates that SRS induced crosstalk is higher for larger channel separation and smaller for higher modulation frequency. One may consider the potential debilitating impact of SRS when coexisting 10GbE with the 1490 nm GPON downstream wavelength since it is only 60nm away for the C band wavelengths of the 10G signals and hence it falls within the Raman Gain profile and can potentially cause crosstalk. This is calculated from the above equation to be about 35 dB and is acceptable**.**

6.1. Link Loss Budgets

The OCML is a somewhat complex system supporting many variable parameters resulting in careful management of the OCML gains. 10G Link performance is dependent on four main factors:

- Transceiver Rx Power
- Type of receiver technology: PIN or APD
- Dispersion which is dependent on the fiber
- EDFA OSNR: 58dB – NF – Pin
    - NF is the noise figure
    - Pin is the input optical power

In the OCML, the downstream has a high OSNR > 40 due to the relatively high optical input levels of the DS EDFA. On the upstream, DCM are incorporated to reduce fiber dispersion to compensate for the lower OSNR, this creates a robust OCML which can work over a variable 5 to 60Km fiber distance. DCMs will also create negative dispersion over shorter fiber lengths so 10G transceivers should be specified to work over a wide range of negative to positive dispersion. Figure 12 shows measurements which were done with an APD transceiver, 60Km fiber and DCM (30Km) for different OSNR values. BER > $10E^{-12}$ can be achieved with a low OSNR of 23dB. In the downstream transceivers need to operate over a lower optical receive power so 80Km APD based receiver diodes are used. In the upstream, both lower cost PIN diode or APD based transceivers can be utilized. All these factors require a careful management of EDFA gains and transceiver input power levels.

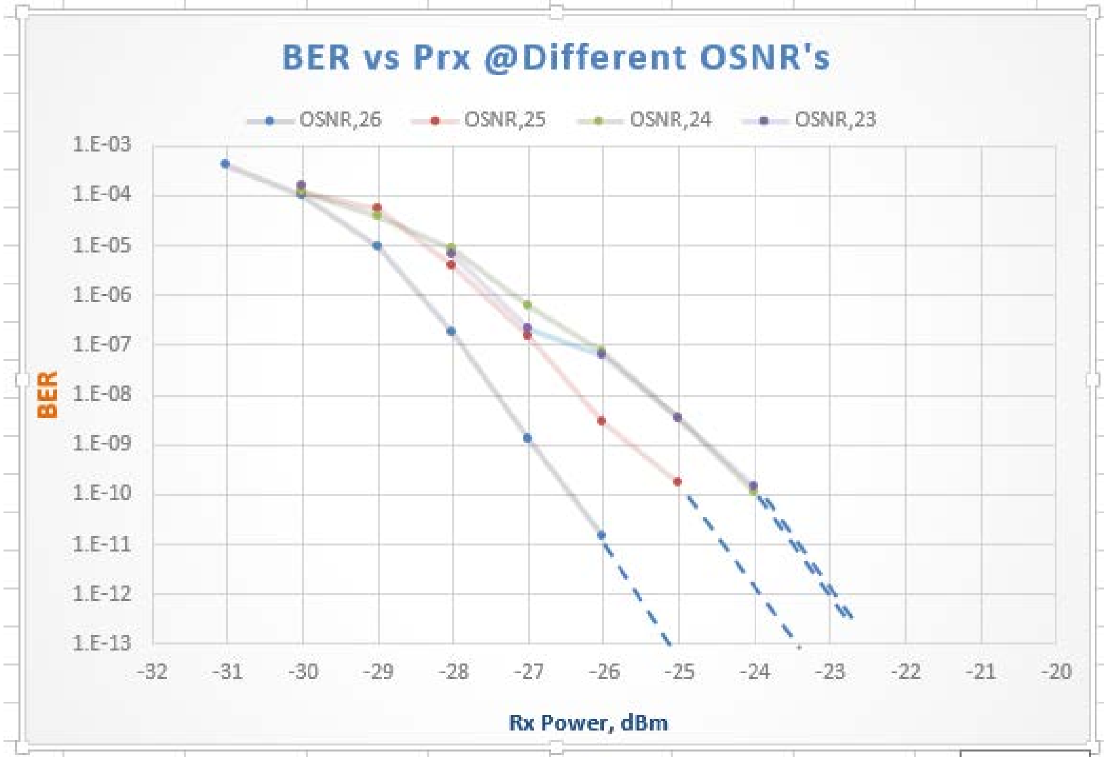

Figure 12 - BER v/s OSNR, 60Km fiber, 30Km DCM

Figure 13 below shows the dispersion penalty which is considered by adding a dispersion penalty in the loss budget and/or a dispersion compensating module (DCM) which results in a better upstream link performance since the OSNR could be as low as 23 or 24 dB over longer links. Adding a DCM in the OCML plus a 3-dB margin (for fiber repair, aging of lasers, etc.) makes for a very robust OCML system.

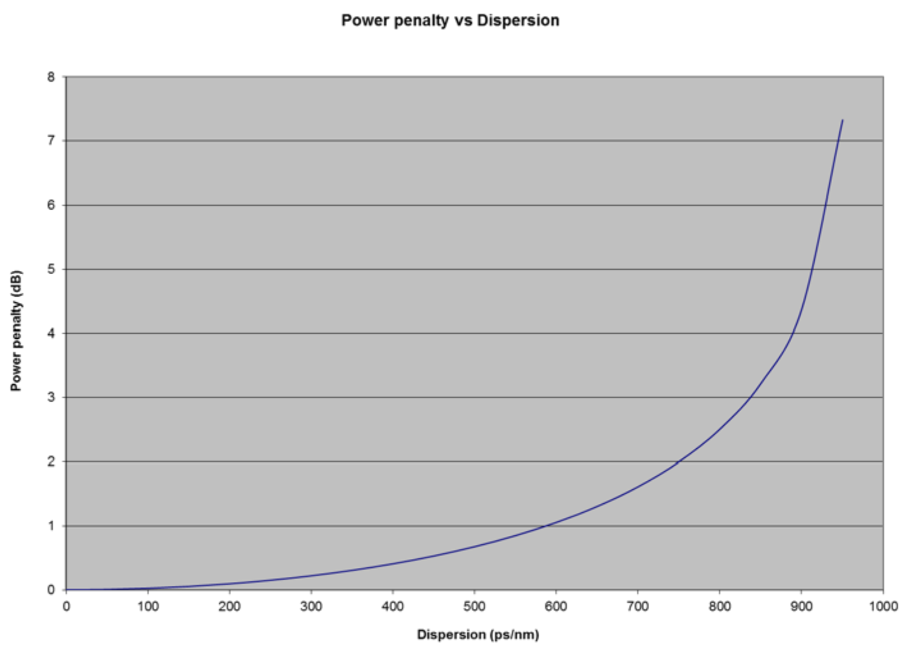

Figure 13 - Dispersion Penalty in Optical Fibers

7. OCML Proof of Concept (POC) Test Results

We have developed a Proof of Concept (POC) for the OCML and while early in the test cycle, it has shown very good optical performance. Figure 14 shows the overall block diagram of the OCML, Figures 15 show the DS OSNR (>40) and figure 16 the UP OSNR > -26 over 60Km of fiber. Figure 17 shows downstream crosstalk as > 35dB. Figure 18 shows upstream crosstalk as >40 dB

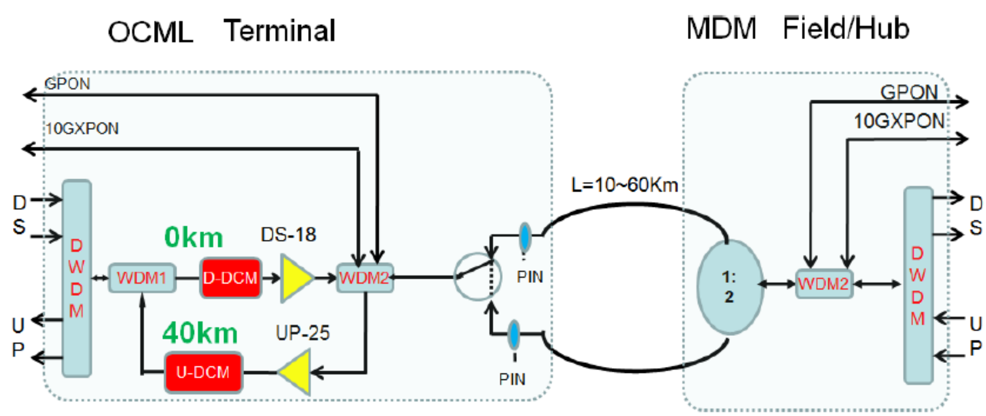

Figure 14 - Block Diagram of Network Set up

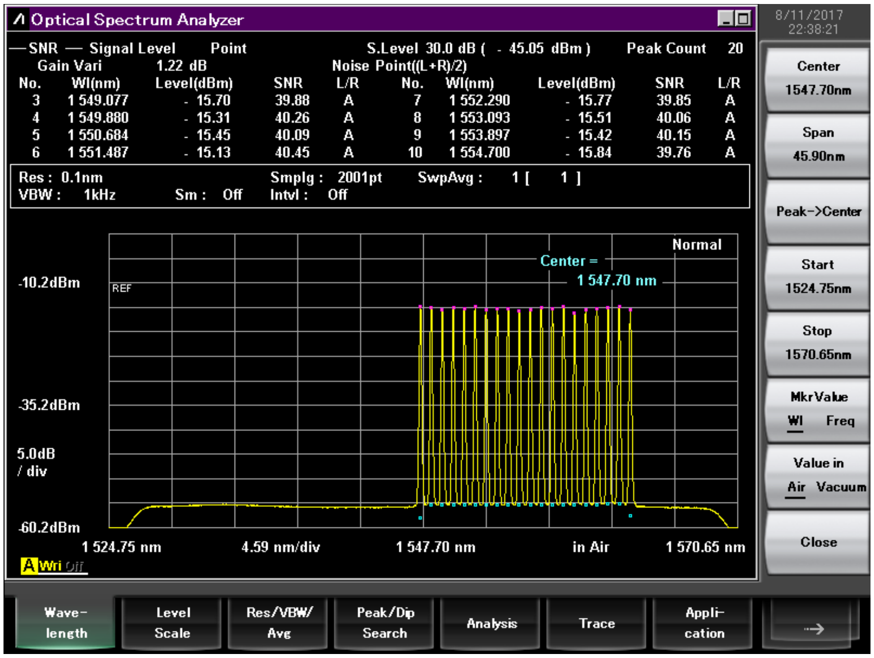

Figure 15 - OCML Downstream OSNR

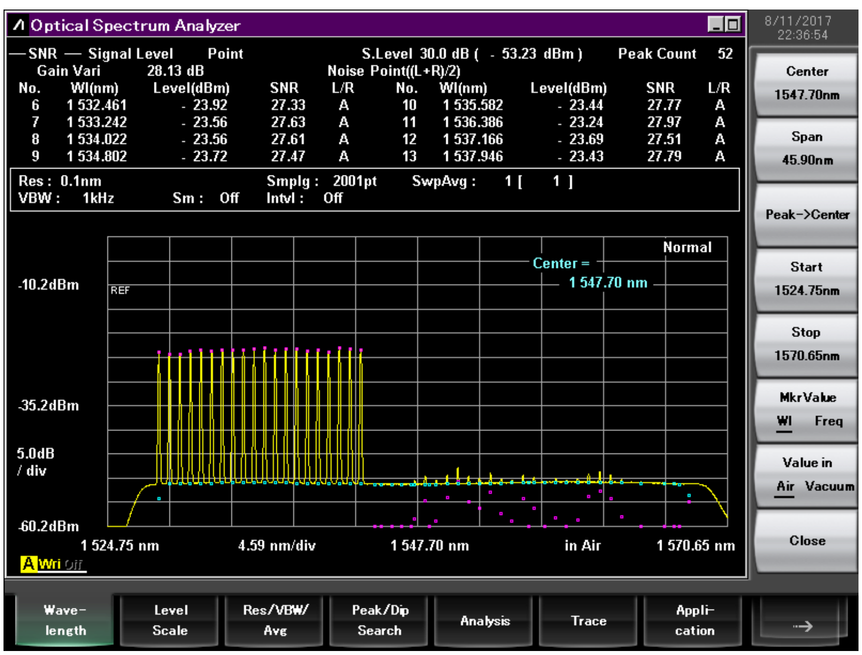

Figure 16 - OCML Upstream OSNR

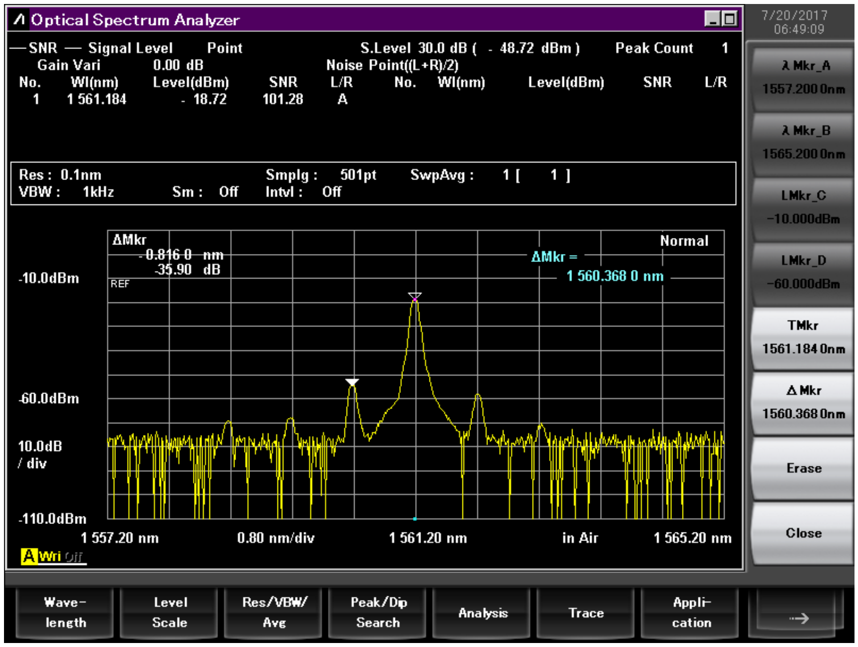

Figure 17 - OCML Downstream Crosstalk

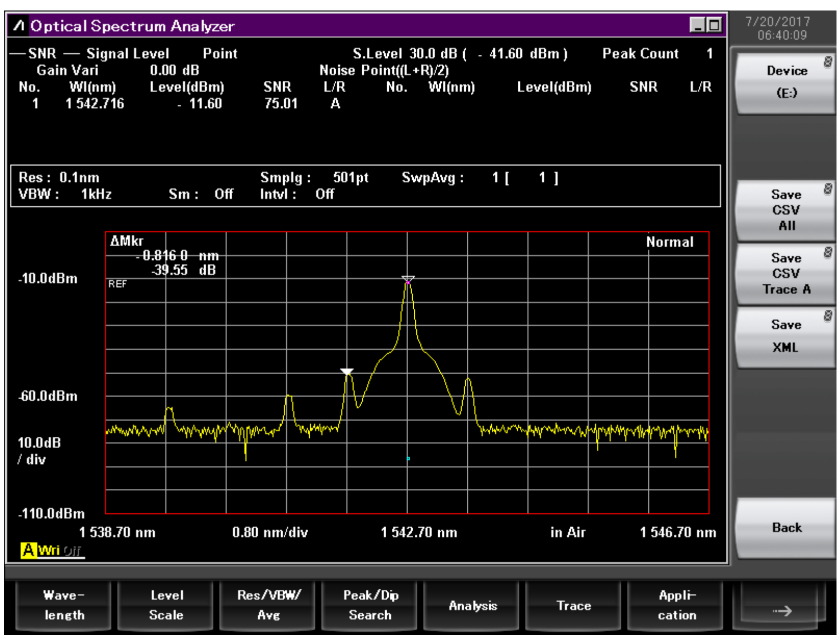

Figure 18 - OCML Upstream Crosstalk

Early testing shows very good results with error free performance over 60Km observed at a low 20dB OSNR and optical receive power of -17 dBm (with PIN 10G transceivers) and -23 dBm with APD 10G transceivers. These were measured with a 40Km DCM which provided at least 2 dB noise penalty margins.

8. Conclusion

Optical feeds to R-PHY networks can be 10G NRZ DWDM or potentially 100G Coherent. This paper shows that 10G DWDM provides enough capacity for R-PHY networks for the foreseeable future. It is a low cost, mature and scalable technology, plus the network can be all passive from the optical headend to the R-PHY node. A 10G DWDM solution provides 400G of duplex bandwidth over a single fiber (46 wavelengths down and 46 wavelengths up) and is a "Pay-As-You-Grow" network, allowing 10G increments to be added at minimal cost.

The Optical Communications Module Link Extender (OCML) is an innovative low cost solution developed by Cox and will primarily be used for 10G feeds to R-PHY. The OCML is also designed to transport an overlay of GPON and 10GEPON. Future requirements may call for 100GEPON or a coherent optical signal to be transported with the 10G traffic. The combination of the OCML and an all passive outside plant module (MDM) are important building blocks in the evolution from traditional HFC to a Remote PHY architecture. The OCML allows both 100G coherent and 10G DWDM to be transported over the same fiber, making it a very powerful and scalable solution. Optical access networks should be able to coexist with 10G DWDM and coherent technologies to maximize the benefits of both. At the end of the day, it is about building a network that is cost, capacity and bandwidth efficient.

Abbreviations

OCML	Optical Communications Module Link Extender
MDM	Mux DeMux
MTC	Master Terminal Center
STC	Secondary Terminal Center
10G	10Gbps
Bps	bits per second
FEC	Forward error correction
HFC	Hybrid fiber-coax
SCTE	Society of Cable Telecommunications Engineers
OIF	The Optical Internetworking Forum
DCM	Dispersion Compensation Module
NRZ	Non-Return-to-Zero
DWDM	Dense Wavelength Division Multiplexing
RPD	Remote PHY Device
FTTH	Fiber to the Home
PON	Passive Optical Network
GPON	Gigabit-capable Passive Optical Network
PIN	PIN diode has a wide, undoped intrinsic semiconductor region between a p-type semiconductor and an n-type semiconductor region.
APD	Avalanche photo diode
OSNR	Optical to Signal Noise Ratio

Bibliography & References

1. 40Gbit/s & 100Gbit/s Implementation tradeoffs. Paul Morkel et al. Adva, Internet2 Meeting, April 2009
2. FTTx Networks. Technology Implementation & Operation, Weyl Wang et al, 2017
3. Nonlinear Optical Crosstalk in WDM CATV systems, Dogan Atlas, Antec Corporation
4. Optical Fiber Telecommunications. Ivan P. Maminow. Tingye Li, Alan E. Willner
5. CNR determination at 1550nm. Harj Ghuman, Lightwave 2009