Distributed PON Architectures for North American MSO's Next-Generation Access

Keiichi TSUJIMOTO*, Yohei HAMADA, Howard ABRAMSON, and Kazuya MATSUMOTO

A traditional PON (passive optical network) consists of an OLT (optical line terminal) installed in a cable television headend and ONUs (optical network units) at subscriber premises (Fiber-to-the-Premise, FTTP) or a distribution point serving multiple subscribers (Fiber-to-the-Distribution-Point, FTTdp). This paper describes a new class of products Sumitomo Electric Industries, Ltd. is introducing to assist North American MSOs (multiple system operators) to address fundamental requirements for their access networks such as distance, subscribers served per port, trunk fiber conservation, uniform operations support systems, and the cost of space, power, and cooling of equipment.

Keywords: 10G-EPON, FTTH, DPoE

1. Introduction

PON (passive optical network) is an efficient, economical, large capacity method for providing network access to subscribers. A conventional PON architecture, which connects an OLT (optical line terminal) installed in a cable television headend, or a hub, and an ONU (optical network unit) on the subscriber side, has the following challenges when MSOs*[1] (multi system cable operators) provide services.

(1) Distance between OLT and ONU
(2) Number of subscribers served by individual OLT PON ports
(3) Number of available trunk fibers
(4) Economic burden for space, power supply, and cooling
(5) Uniform management of each device in the network

This paper presents a next-generation architecture as a solution to these challenges, as well as a migration path to this new architecture using Sumitomo Electric Industries, Ltd.'s FSU7100 10G-EPON (Ethernet passive optical network) OLT and related products.

2. Outlook of MSO Network

2-1 MSO access network design

Traditional cable MSO network has its roots in the original one-way CATV (cable access television) analog video designs first introduced in the late 1940s and 1950s. These tree-and-branch networks were originally designed to improve broadcast television services and have evolved into HFC (hybrid fiber coaxial), two-way digital networks using analog optics and RF (radio frequency) optical transceivers to interconnect data, video, and telephony headends and subscriber-side access equipment. Figure 1 summarizes the design of a present-day MSO access network. For brevity's sake, the figure does not elaborate details of the MSO headend, primary and secondary hub architecture, and OSP (outside plant) power supplies (used to power fiber nodes and amplifiers).

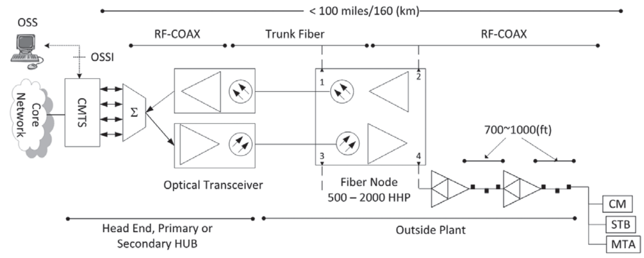

Fig. 1. MSO Access Network

The DOCSIS (data over cable service interface specification) was developed and common infrastructure has been used in deploying PON within an MSO network. A DOCSIS CMTS (cable modem termination system) provides similar functionality to an OLT. A CM (cable modem) provides similar functionality to an ONU. As MSOs move towards all-IP (Internet Protocol) service delivery and per-subscriber capacity expectations increase, PON and DOCSIS are becoming competitive alternatives to serving cable subscribers.

The CMTS has evolved from the original introduction of DOCSIS version 1.0 in the mid-1990s to the present day DOCSIS 3.1 and Remote PHY specifications. First- and second-generation CMTS were fully integrated systems (I-CMTS). Third-generation CMTS introduced with DOCSIS 3.0 included a modularization that separated the downstream physical layer from the I-CMTS. Fourth-generation CCAP (converged cable access platforms) were defined as very high port density systems that include CMTS, Edge QAM*[3] (IP Video), and optional EPON capabilities. Fifth-generation MSO access systems are being defined to further modularize and distribute the CCAP between the headend, hub, and OSP.

2-2 Challenges in MSO access network

(1) Distance

Although the MSO access network has evolved to provide bi-directional multimedia services, the fundamental characteristics of the HFC network remain rooted in the original CATV plant and subscriber geographic topology.

For example, while requirements for the distance between a CMTS and a subscriber CM has remained 100 miles (160 km) since the introduction of two-way cable plants and the DOCSIS in the mid-1990s, actual distance provided is less than 15 miles (24 km). As the DOCSIS 3.1 standard highlights, MSOs' requirements to cover areas with different population density have not changed much.[(1)]

(2) MSO Subscriber split ratios

Evolution of the MSO's outside plant continues to try to keep up with subscribers' growing demand for an increased access capacity. With finite bandwidth available over the copper used in coaxial cables, the capacity has been increased by decreasing the number of HHP (house holds passed) per network segment. This can be achieved by drawing fibers deep into the MSOs' network, pushing FNs (fiber nodes) closer to premises, and branching FNs, thereby doubling the bandwidth between a FN and a premise. The number of HHP has been reduced in the new versions of the DOCSIS.

Extending the fiber portion of the HFC deep into the network with active fiber-to-copper FNs results in fewer subscribers to be served, roughly equivalent to the split ratios defined in the present-day PON. The ability to leverage node splitting to add subscriber capacity is directly related to the availability of trunk fiber between the headend/hub(s) and FNs.

Table 1. Change of HHP per FN in DOCSIS

Generation of CMTS/CCAP	DOCSIS Version	Number of HHP per fiber node
1st- and 2nd- generation I-CMTS	DOCSIS 1.0	< 1000-2000 HHP
	DOCSIS 2.0	< 1000 HHP
3rd-generation I/M-CMTS	DOCSIS 3.0	< 500-750 HHP
4th-generation I/M-CCAP	DOCSIS 3.1	< 128–256 HHP
5th-generation distributed CMTS	MHAv2 / R-PHY	< 64 HHP

MHAv2: Modular Headend Architecture version 2

(3) Trunk fibers

The connection between the headend/hub distribution facility and FNs currently uses amplitude-modulated RF signals over trunk fiber. Currently fiber nodes use a single wavelength or WDM (wavelength division multiplexing) optical transceivers. In order to divide a fiber node, additional trunk fiber or optical wavelength is required. A headend/hub that provides services to tens of thousands of subscribers needs to terminate many optical fibers or wavelengths. When a hub is installed in a common facility, in particular, a limit of the number of fibers in practical use is a problem. Consideration must also be given to the number of available wavelength and optical budget to the subscriber network. For the introduction of PON into an MSO network, trunk fibers need to be shared between the legacy DOCSIS, RF video, and PON services.

(4) Space, power, and cost of hubs

While operators are working to increase the overall capacity of their access networks, the economic impact of equipment space, power supply, and cooling is leading many MSOs to close distribution hubs and smaller headend to consolidate personnel and associated expenses. In addition to demand for much denser and lower-power-consumption access equipment, the conflicting requirements of adding capacity and consolidating facilities force a redistribution of access technology from centralized headend/hubs to the outside plant. Equipment must not only deliver more capacity at lower cost and power, it must also be reliable and manageable by fewer operation personnel.

(5) Networking and network management

The DOCSIS standard includes a common OSSI[(2)] (operations support system interface) specification for securing interoperability and accelerating development of compatible operations support systems and/or associated business support systems.

The utility of uniform provisioning, network & management interfaces, and common equipment user interfaces is reinforced by the introduction of the DOCSIS provisioning of EPON (DPoE) standards, in 2010.[(3)] One of the core objectives of the DPoE specifications is to adapt DOCSIS-based back office provisioning and operation models to EPON and to reuse as much of the existing DOCSIS OSSI specification as possible.

3. PON Architecture for MSO

3-1 Choices for MSO PON architecture

In this paper, MSO PON architecture is classified into the following four models.

(1) I-PON (integrated PON) model
(2) I-PON + R (I-PON + repeater) model
(3) R-PON (remote PON) model
(4) M-PON (modular PON) model

Table 2 summarizes the partitioning and location of functionality for OLT designs described in this paper using the DPoE protocol reference model.

Table 2. Basic Models of PON Architecture

Function	DPoE System function			
	Operation and Management	Layer 2/3 packet transfer	MAC and the upper protocol layers	Physical layer
DPoE Specification	OSSI	IP-NE/MEF	MULPI/OAM	PHY
(1) I-PON	← headend/hub →			
(2) I-PON+R	← headend/hub →			← Outside plant →
(3) R-PON	← Outside plant →			
(4) M-PON	← headend/hub →		← Outside plant →	

(1) I-PON (integrated PON) model

The I-PON follows the traditional conventions of an OLT chassis connected to a passive ODN (optical distribution network). For MSOs, referring to the evolution of the CMTS, the single-box OLT chassis is very much like an I-CMTS with PON ports (Fig. 2).

In the I-PON model, when distance and trunk fibers are not a major factor, the I-PON model is consistent with all the features, functions, and expectations of MSOs.

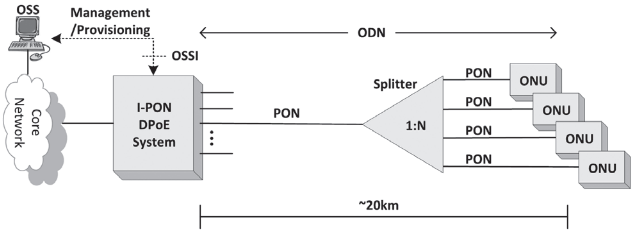

Fig. 2. I-PON Model

(2) I-PON+R (I-PON and repeater) Model

To address some of the limitations in distance, the number of subscribers served by individual OLT ports, and trunk fiber conservation, I-PON+R model has been offered by some PON suppliers.

In this architecture, a PON repeater is inserted in the ODN between OLT and ONUs (Fig. 3). Sumitomo Electric was one of the pioneers in defining the concept of applying a repeater to the 1G-EPON system in 2006[(4)] and evolved it to the 10G-EPON system.[(5)]

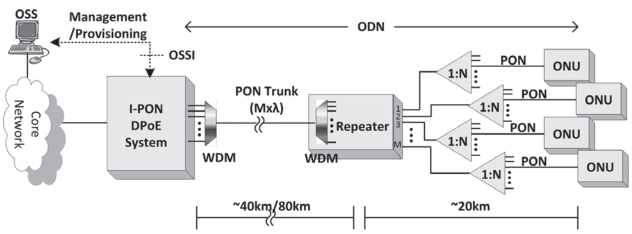

Fig. 3. I-PON+R Model

By connecting the I-PON OLT and the PON repeater with a WDM optical link, it is possible to secure a distance of 60 km or more (based on the choice of optics) and save the trunk fiber at the same time. The limit of this approach is the total number of ONUs that can be served by an OLT due to the use of a single OLT port and it does not help to decrease space and power consumption in headends/hubs. If the number of subscribers increases, additional wavelengths or trunk fibers are required.

(3) R-PON (remote PON) model

Figure 4 shows an integrated R-PON model with all the functional specifications of DPoE. While the R-PON

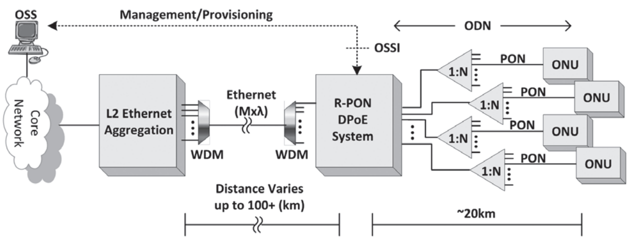

Fig. 4. R-PON Model

DPoE system satisfies trunk fiber conservation and distance requirements MSO must deploy a larger number of R-PON OLT devices to support equivalent scale with a single integrated I-PON system. MSO must manage these independent devices one by one. In general, an R-PON OLT device is implemented by reducing the number of slots from a large enclosure of the I-PON system. Common components with I-PON OLT, such as switch cards and line cards, rise the R-PON OLT device price.

(4) M-PON (modular PON) model

The M-PON model incorporates the latest configuration of the fourth and fifth generation CMTS described in Section 2-1. In the M-PON system, the functions implemented in the I-PON line card are distributed to the M-PON core and a plurality of independent remote MAC / PHY nodes (Fig. 5).

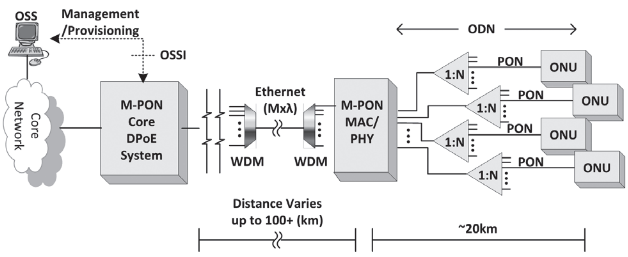

Fig. 5. M-PON Model

In the M-PON model, the function of I-PON model OLT is divided into two. The M-PON core handles the operation/management function and the layer 2/layer 3 network function,*5 and the PON physical layer function and MAC layer function are provided by the remote MAC/PHY device. Since the remote MAC/PHY device can be regarded as a remote line card in a typical I-PON model OLT, in the M-PON model, management of all system functions is enabled with the integrated provisioning and management interfaces provided by the M-PON core. This model incorporates the best of all previously summarized solutions and can operate with both I-PON ports as well as distributed R-PON ports.

3-2 Comparing the models

Table 3 compares the four models. Currently, the M-PON model is the most appropriate model in promoting

Table 3. Comparing the Models

	I-PON model	I-PON+R model	R-PON model	M-PON Model
Distance between a headend/hub and the subscribers	△	○	◎	◎
Number of branches	△	△	○	○
Number of trunk fibers	△	○	○	○
Required space in a headend/hub	△	△	○	△
Cost of outside plant	◎	○	×	△
Uniform management of devices	◎	○	△	○

◎ :The best, ○ :Good, △ :Fair, × :Poor

the decentralization of network functions from the deployed I-PON model.

4. Putting It All Together

FSU7100[6] is a carrier grade OLT system based on the I-PON model. It supports the DPoE specification and satisfies MSO's requirements for residential and business services. The system is constructed of dual switch cards (FSW7112) that support 8-port 1G/10G uplinks, and up to 16 PON modules using 10-port 1G EPON (FCM7121) or 8-port 10G EPON (FCM7133) line cards.

4-1 M-PON architecture with FSU7100

To realize the M-PON architecture using FSU7100, Sumitomo Electric developed a 10G Ethernet line card (FCM7151: equipped with 8 10G-Ethernet ports) and a remote MAC/PHY device FSR7143. FSR7143 has 4 10G-EPON ports and 4 10G-Ethernet ports and is housed in an outdoor enclosure. The combination of the FSR7143, FCM7151, and FSU7100, supports all MSO requirements for subscriber service, operations & management, and layer 2/3 networking.

Figure 6 shows an example in which FCM7151 and FSR7143 are connected to the FSU7100. The FSR7143 is treated as a remote line card installed in the 17th and following line card slot. As such, all features, functions, and management of FSR7143 are identical to those of integrated PON cards physically inserted into the FSU7100. The ability to simultaneously support integrated and remote PON ports in the same chassis allows the MSO a graceful migration to a more distributed architecture.

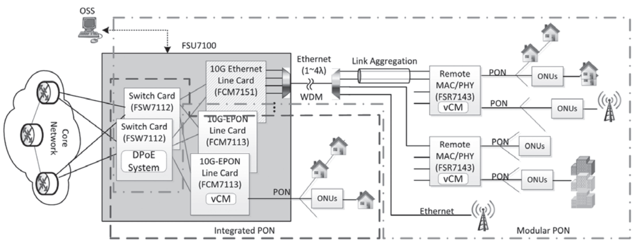

Fig. 6. M-PON Model with FSU7100

Use of WDM optics with the M-PON model helps the MSO to solve the difficult challenge of distance to all subscribers and limitation to existing trunk fibers. The remote MAC/PHY also supports PON to trunk fiber aggregation to the FSU Ethernet ports. When using the common technique of over-subscription, aggregation of multiple PON ports into a single trunk port conserves the limited number of trunk fibers. LAG (Link Aggregation) can be used on the trunk ports when redundancy is required.

Sumitomo Electric also plans to develop an option to use the 10G Ethernet port for business services and an optional function to increase the number of subscribers connected by cascading multiple remote MAC/PHY devices.

4-2 Distributed M-PON and S-PON

(1) Concept of distributed M-PON

The distributed M-PON model separates the remote MAC/PHY from the FSU7100 over a Layer2/Layer3 network (Fig. 7).

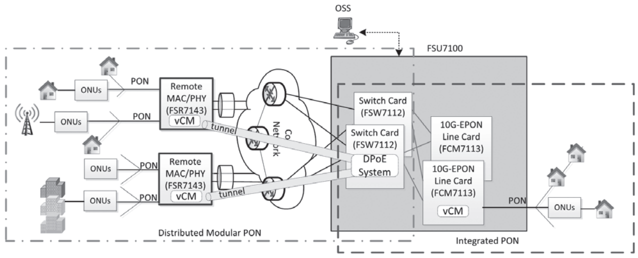

Fig. 7. Concept of Distributed M-PON Model

All the features, functions, interoperability, and manageability of I-PON and M-PON become available over a distributed Ethernet or IP network to overcome the challenges related to the distance, port number, and subscriber densities that today's I-PON designs face. This distributed M-PON design becomes a software-defined solution where the control and orchestration are provided by the familiar look, feel, and capability of the existing FSU7100. As such, transitioning from a distributed M-PON solution to future S-PON architectures becomes a matter of software re-programming of the FSR7143.

(2) Future S-PON[7]

Finally, as illustrated in Fig. 8, the same FSR7143 and later versions will be capable of S-PON support by adding external software interfaces for future SDN protocols.

Sumitomo Electric's vision and actions for assisting MSOs to deploy PON is encompassed by the progression from today's I-PON and M-PON, to tomorrow's distributed M-PON, and a path towards future S-PON.

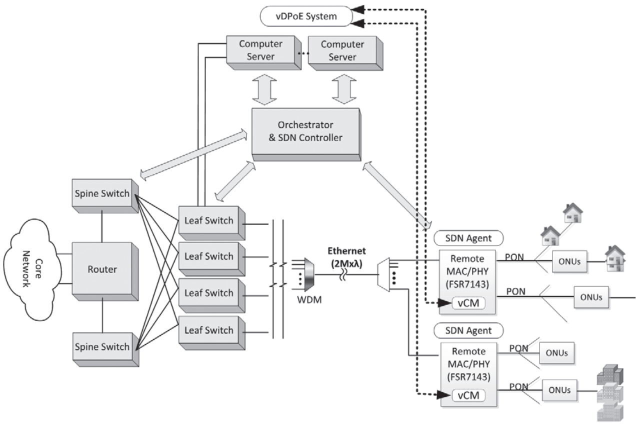

Fig. 8. Concept of S-PON Model

4. Conclusion

This paper has presented fundamental challenges to MSOs including FTTx (fiber-to-the-x) as part of their access network. Background on PON technology & network design and the evolution of the MSO DOCSIS network was presented to better appreciate appropriate solutions. Four basic options for re-organizing and re-partitioning OLT functionality were described and compared.

This paper has demonstrated that an integrated PON (I-PON) solution accommodating modular PON components (M-PON) is capable of operating in future distributed M-PON and S-PON environments. This provides the best path forward for MSOs choosing to include FTTx in their access networks. Introduction of the FSR7143 and FCM7151 provides the capability beginning with operator-qualified and field-proven FSU7100 OLT designs.

Technical Terms

∗1 MSO (multi-system cable operators): Operators who have multiple cable television systems.

∗2 DOCSIS (data over cable service interface specifications): Technical specification established for the purpose of providing Internet access by using coaxial cable for television signal transfer.

∗3 Edge QAM: A gateway device for converting a video stream into a QAM (quadrature amplitude modulation) signal.

∗4 All-IP service: An architecture that packetizes various types of information such as voice, video, and mobile data, and provides services by IP (Internet Protocol).

∗5 Layer 2/3 network function: Ability to perform packet transfer etc. using information of layer 2 (MAC) or layer 3 (IP)

∗6 SDN (software defined network): General techniques for building virtual networks with software.

∗7 NFV (network function virtualization): A method of implementing the functions of network devices as software on the virtualization infrastructure of a general-purpose server.

References

(1) CableLabs DOCSIS 3.1, Physical Layer Specification, CM-SP-PHYv3.1-I11-170510 (May 10, 2017)

(2) CableLabs DOCSIS 3.1 Cable Modem Operations Support System Interface Specification, CM-SP-CM-OSSIv3.1-I10-170906 (September 6, 2017)

(3) https://www.cablelabs.com/specifications-library/dpoe/

(4) D. Umeda, et al., "Bidirectional 3R-repeater for GE-PON Systems," ECOC 2006, Mo4.5.6 (2006)

(5) D. Umeda, et al., "10G-EPON Dense Wavelength Division Multiplexing Repeater Expands Transmission Distance up to 60 km," SEI Technical Review (April 2017)

(6) Y. Kai, et al., "10G-EPON System Featuring High-Speed and High-Capacity Layer 3 Switching," SEI Technical Review (October 2016)

(7) T. Anschutz, et. al., "CORD: The Central Office Re-architected as a Datacenter," A White Paper, Proof-of-concept demonstration at Open Networking Summit, onosproject.org (June, 2015)

Contributors The lead author is indicated by an asterisk (∗).

K. TSUJIMOTO*
• Senior Assistant General Manager, Broad Networks Division

Y. HAMADA
• Assistant Manager, Information Network R&D Center

H. ABRAMSON
• Former VP
Sumitomo Electric Lightwave Corp.

K. MATSUMOTO
• General Manager, Broad Networks Division