Future Standards of Optical Access Networks after Higher Speed PONs

Yuanqiu Luo, Frank Effenberger

Futurewei Technologies, Basking Ridge, New Jersey, USA 07920 yuanqiu.luo@futurewei.com

Abstract *This paper reviews the latest effort in both ITU-T and IEEE on the next generation optical access networks. It discusses progress in projects G.suppl.VHSP, G.9806, and 802.3dk. Related standardization endeavours in exploring new applications of optical access systems are also covered.*

1. Introduction

As the premiere solution of wireline broadband access, optical networks have been widely deployed by operators in the past two decades. By the end of 2022, the number of optical access network users was approaching 1 billion globally. We have envisioned the optical access network market size to exceed 10 billion US dollars [1].

International standards play a crucial role in promoting optical networking solutions to the global access market. During the last 30 years, both the International Telecommunication Union's Telecommunication Standardization Sector (ITU-T) and the Institute of Electrical and Electronics Engineers (IEEE) have developed multiple generations of optical access network standards. Successful examples are ITU-T G.983.x series on Gigabit passive optical network (G-PON) [2], G.987.x series on 10 Gigabit PON (XG-PON) [3], IEEE 802.3ah on Ethernet PON (EPON) [4], and ITU-T G.9807.1 on 10 Gigabit symmetric PON (XGS-PON) [5]. These standards allow interoperability between optical access systems and equipment. They provide vendors with a solid technical foundation on which to compete in the market. Standards are strategic tools and guidelines to facilitate the massive deployment of optical access networks. They are a major reason of the global optical access market growth.

The most recent standard in this area is 50 Gigabit PON (50G-PON). It is developed by the ITU-T Higher Speed PON (HS-PON) project. The baseline specifications were approved in 2021 as Recommendations G.9804.2 [6] and G.9804.3 [7]. 50G-PON supports up to 50 Gb/s line rate per wavelength channel. Telecom operators plan to start 50G-PON commercial deployment in late 2024.

In this paper we review the latest standardization effort on next generation optical access networks after 50G-PON. Progress in projects G.suppl.VHSP, G.9806, and 802.3dk are discussed. Related endeavours in exploring new applications of optical access networks are also covered.

2. Future PONs in ITU-T G.suppl.VHSP

In the September 2022 ITU-T SG15 plenary meeting, two amendments to the 50G-PON standards were consented. This indicates that the 50G-PON system specifications are mature to guide product development. After this, the ITU-T members initiated a supplement project on very high-speed PON (VHSP) systems that can operate at rates above 50 Gb/s per wavelength, the so-called G.suppl.VHSP [8]. Supporting member companies included AT&T, Huawei, Verizon, Adtran, Maxlinear, Nokia, Calix, British Telecom, and ZTE.

G.suppl.VHSP targets to collect system requirements, characteristics, and candidate technologies of PONs with a capacity beyond 50 Gbit/s per wavelength. It is a supplement project that paves the path to standardize the future PON systems after 50G-PON.

Since October 2022, about ten technical proposals have been contributed to the ITU-T standards meetings on G.suppl.VHSP. Various aspects, such as coexistence requirements, expected system capacity, trade-off between capacity and link power budgets, were under active discussion. Data rate options were reviewed with a focus on 100 Gb/s and 200 Gb/s per wavelength. Two contributions suggested power should be used as needed and in an efficient way during PON operation. They proposed to include power saving requirements in the supplement.

Several contributions reviewed technical challenges on 100 Gb/s or 200 Gb/s transmission in access networks. Fiber dispersion becomes severer when the data transmission rate goes beyond 50 Gb/s per wavelength. Using intensity modulation-direct detection (IM-DD), the receiver sensitivity would be degraded from -27 dBm at 50 Gb/s to -20 dBm and -16 dBm at 100 Gb/s and 200 Gb/s, respectively.

One possible solution is to take advantage of coherent technologies on receiver sensitivity improvement. Coherent detection also provides the opportunity to compensate fiber dispersion using digital signal processing (DSP). Previous research showed coherent technologies could support a data rate of 200 Gb/s per wavelength with a receiver sensitivity of -32 dBm. The drawback of employing coherent technologies in optical access is its high complexity. This would lead to high cost and large power consumption. There is a lot of effort on simplified coherent systems for optical access. Some trade off the coherent system capacity for a simpler optoelectronics. Some allow the use of less complicated modulation schemes to reduce the transmitter and receiver complexity.

Another solution is to continue the direction of IM-DD by adopting technologies on dispersion compensation and power budget enhancement. For example, employing DSP equalization at the receiver would reduce signal distortion. Using a low chirp transmitter could improve the signal performance. Additionally, zero-dispersion wavelengths can be selected to minimize the dispersion penalty.

Porpular technical topics in G.suppl.VHSP include signal modulation options, optical transmitter design, optical receiver design, and wavelength considerations. The G.suppl.VHSP project will continue in-depth discussion on candidate technologies to cover different possibilities of future PON systems. The future PON system selection decision will be made after the completion of G.suppl.VHSP. Most operators view the effort of VHSP standardization as an important task in the timeframe of 5 to 10 years.

3. Future PtP access in ITU-T G.9806 and IEEE 802.3dk

Another successful optical access network solution uses point-to-point (PtP) fiber. Different from the point-to-multipoint (PtMP) architecture in PON, the PtP solution transmits optical access signals bidirectionally (BiDi) via a single fiber. The PtP BiDi solution targets for access applications that require higher capacities and better quality of service than what PON can provide. The optical access PtP BiDi link is different from other PtP links specified in the SONET, Ethernet, and OTN standards. The PtP BiDi link is the access interconnection using a single fiber that operates bidirectionally, while other PtP links often assume the use of two fibers to connect the link, each carrying one direction in signal transmission.

After consenting 10, 25, and 50 Gb/s PtP BiDi link specifications, the ITU-T members are working on the 100 Gb/s PtP BiDi link. This is in the scope of ITU-T Recommendation G.9806 Amendment 3 (Amd3) [9]. The current draft of G.9806Amd3 defines two power budget classes. Class S_L ranges from 0 dB to 10 dB. It supports a reach of up to 10 km. Class S_U is between 5 dB to 15 dB. Its reach is up to 20 km. Both classes adopt pulse amplitude modulation 4-level (PAM4) as the modulation format. At the rate of 53.125 GBaud, the PAM4 modulation generates a PtP BiDi line rate of 106.25 Gb/s. The receiver sensitivity is selected as -12.8 dBm in both classes, making the transmitter in Class S_U 5 dB powerful than that in Class S_L. Specifications of the S_L and S_U 100 Gb/s PtP BiDi links were consented in the April 2023 meeting. Specifications of Class B- (10-23 dB) are for future study.

A parallel effort of optical access PtP BiDi standardization in IEEE is conducted in the 802.3dk Task Force (TF) [10]. The objectives are to define physical layer specifications of 100 and 200 Gb/s PtP BiDi links. The distance options include 10, 20, and 40 km. The 802.3dk TF has met four times since January 2023. Members have discussed over 10 technical presentations on wavelength plan, rate selection, as well as power budget design. Multiple proposals on 100 Gb/s PtP BiDi for 10 and 20 km have been analysed. The standardization plan is to come up with baseline proposals in the middle of 2023. An initial draft is expected to be ready in Q4 of 2023.

It is important to coordinate the two groups on PtP BiDi standardization. One possible topic for collaboration would be power budget design. At 10, 25, and 50 Gb/s, the ITU-T power budget classes are categorized as 0-15 dB and 10-23 dB, while the IEEE power budget classes are 0-6.2 dB, 0-15 dB, and 10-18 dB. At high speeds of 100 Gb/s and above, the avalanche photodiode (APD) receivers have an overload problem to cover a dynamic range of 15 dB. It leads to redesign the power budget classes and thus an opportunity of collaboration. An ideal outcome would be both standards share the same baseline assumptions. This would join the effort on supply chain and system development, thus building a larger market for massive production.

4. Other standards on future optical access

Most of the standardized PON systems are based upon time division multiplexing (TDM). The 5G wireless fronthaul transport requires very high bandwidths at a significant number of endpoints. This application motivates the standardization of wavelength division multiplexed PON (WDM-PON). The G.9802.2 project specifies a WDM-

PON system with up to 20 wavelength channels in the C-band [11]. A cyclic arrayed waveguide grating (AWG) is used to multiplex all the transceiver signals onto the common feeder fiber. The AWG is designed so that wavelength channels are arranged in two free spectral ranges, with one range used for downstream and the other for upstream. Each wavelength channel is operated at 10 or 25 Gb/s to transmit wireless fronthaul signals, such as common public radio interface (CPRI) or evolved CPRI (eCPRI). The main specifications in G.9802.2. were consent in April 2023. This is the first WDM-PON standard after many years' research in the area.

Besides specifying characteristics and interfaces of optical access network systems, ITU-T is exploring new applications of PONs. The G.sup.PONlatency project investigates the deterministic capability of PONs [12]. Determinism provides predictable and guaranteed data transmission with bounded latency, jitter, and packet loss. It promotes PON applications in data acquisition, deterministic control, process automation, and industrial IoT (IIoT). Methods on upstream latency reduction and access scheduling are analysed. PON use cases in manufacturing industry are under active study. The goal is to meet deterministic latency and jitter requirements at the level of millisecond or lower.

The G.sup.eOLT project studies the architecture and requirements of OLT supporting IT functions [13]. This supplement investigates PON applications in content delivery network (CDN) and edge computing. Both integrated OLT equipment and distributed OLT systems are considered. In particular, computing capabilities of ONUs and OLTs are expected to be coordinated in the PON domain. Instead of transmitting all data over multiple network segments to servers or control centres, this work could help to fulfil tasks close to data sources.

The G.fin project [14] focuses on the design of fiber-based in-home networks, also called fiber to the room (FTTR). PON is studied in this project as an option of fiber networks. In this case, PON can be employed for FTTR applications. Instead of serving a house by using an ONU, a PON system can be installed to cover a house. The FTTR effort promotes fiber penetration in the residential area from curbs and/or houses all the way to rooms.

Outside of ITU-T, the European Telecommunication Standards Institute (ETSI) has been working on standard projects of optical access network applications in various industries. Emerging PON use cases in mining, tele-educating, and smart city are under study in the fifth generation fixed network (F5G) industry specification group. GR-F5G-007 [15] defines a generic network architecture using PON to support industrial applications, which is called industrial PON. It brings multi-access services to a unified platform. Industrial PON system descriptions, key functions, and interfaces have been defined. Technical points of industrial PON, such as end-to-end management, service security, and industrial environment adaptation methods are under active investigation by operators, vendors, and academic groups.

In addition to industrial PON, the F5G industry specification group deep dive PON for telemetry. GS-F5G-011 [16] defines telemetry framework for access networks using PON. The overall telemetry system and the interfaces with data models for configuration and collection have been specified. This framework supports telemetry functions including subscription configuration, data collection, information processing, data storage, analysis, and report.

F5G studies FTTR as a promising application of optical access networks in the residential area. GR-F5G-002 [17] specifies a use case of employing cascaded PONs to provide home networking services. The first tier of PON links houses to the central office. The second tier of PON is installed at each house. Within a house, each room is served using one ONU plus one WiFi access point (AP). This implementation is extremely attractive to new houses. Its benefits include lower power consumption, higher bandwidth provisioning, and longer home network lifetime.

5. Conclusions

Optical access network standards have been advanced to 50G-PON in the past few years. This paper reviews the future trend of standards in three directions. Project G.suppl.VHSP is the effort to pursue the very high-speed PON solution at a rate of beyond 50 Gb/s per wavelength. Projects G.9806 and 802.3dk focus on 100 and 200 Gb/s PtP BiDi optical access solutions. Other projects explore new applications of optical access technologies. In the following years, these endeavours will jointly guarantee optical access networks as the premiere solution of wireline broadband access.

References

[1] P. Wadhwani and S. Gawande, "GPON Market Size and Share", *Global Market Insights*, Jan 2023, https://www.gminsights.com/industry-analysis/gigabit-passive-optical-network-equipment-market, accessed on 1 May 2023.

[2] ITU-T Recommendation G.984.1, "Gigabit-capable passive optical networks (GPON): General characteristics", March 2008, https://www.itu.int/rec/T-REC-G.984.1-200803-I/en, accessed on 1 May 2023.

[3] ITU-T Recommendation G.987.1, "10-Gigabit-capable passive optical networks (XG-PON): General requirements", March 2016, https://www.itu.int/rec/T-REC-G.987.1-201603-I/en, accessed on 1 May 2023.

[4] IEEE 802.3ah-2004, "IEEE Standard for Information technology-- Local and metropolitan area networks-- Part 3: CSMA/CD Access Method and Physical Layer Specifications Amendment: Media Access Control Parameters, Physical Layers, and Management Parameters for Subscriber Access Networks," September 2004, https://standards.ieee.org/ieee/802.3ah/3179/, accessed on 1 May 2023.

[5] ITU-T Recommendation G.9807.1, "10-Gigabit-capable symmetric passive optical network (XGS-PON)", February 2023, https://www.itu.int/rec/T-REC-G.9807.1-202302-P/en, accessed on 1 May 2023.

[6] ITU-T Recommendation G.9804.2, "Higher speed passive optical networks - Common transmission convergence layer specification", September 2021.

[7] ITU-T Recommendation G.9804.3, "50-Gigabit-capable passive optical networks (50G-PON): Physical media dependent (PMD) layer specification", September 2021.

[8] ITU-T Supplement work item, G.suppl.VHSP, "PON transmission technologies above 50 Gb/s per wavelength", https://www.itu.int/ITU-T/workprog/wp_item.aspx?isn=18554, accessed on 1 May 2023.

[9] ITU-T Recommendation G.9806 Amd3, "Higher speed bidirectional, single fibre, point-to-point optical access system (HS-PtP) - Amendment 3", consented in April 2023.

[10] IEEE P802.3dk Greater than 50 Gb/s Bidirectional Optical Access PHYs Task Force, https://www.ieee802.org/3/dk/, accessed on 1 May 2023.

[11] ITU-T Recommendation G.9802.2, "Wavelength Division Multiplexed Passive Optical Network: Physical media dependent (PMD) and Transmission Convergence (TC)", consented in April 2023.

[12] ITU-T Supplement work item, G.sup.PONlatency, "Latency control and deterministic capability over a PON system", https://www.itu.int/ITU-T/workprog/wp_item.aspx?isn=18281, accessed on 1 May 2023.

[13] ITU-T Supplement work item, G.sup.eOLT, "Enhanced optical line termination with IT functions", https://www.itu.int/ITU-T/workprog/wp_item.aspx?isn=18282, accessed on 1 May 2023.

[14] ITU-T Recommendation work item, G.fin-SA, "High speed fibre-based in-premises transceivers - system architecture", https://www.itu.int/ITU-T/workprog/wp_item.aspx?isn=18226, accessed on 1 May 2023.

[15] ETSI Group Report F5G 007 V1.1.1, "F5G Industrial PON", January 2023.

[16] ETSI Group Specification F5G 011 V1.1.1, "Telemetry Framework and Requirements for Access Networks", November 2022.

[17] ETSI Group Report F5G 002 V1.1.1, "F5G Use Cases Release #1", February 2021.