Optical Access Network Evolution for Future Super-Broadband Services and 6G Mobile Networks

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Abstract *This paper first reviews the history and the current state of the optical access network. It then discusses how the optical access network will change given overall network evolution to realize super-broadband services as well as to support 6G mobile networks.*

Introduction

The optical access network has continually developed to support the continuous growth in broadband services over the last 20 years, and has become an indispensable foundation to our remote life, i.e. remote work as well as remote entertainment, to cope with the current global outbreak of infectious disease. The remote life inspires us to invent and develop applications to realize more natural and real communications such as live sport/music viewing with audience response, remote simultaneous interaction with music/games. This creates demand for super-broadband services with minimum latency. Optical access also plays an important role in constructing the Radio Access Network (RAN) needed to support mobile broadband services[1].

This paper first reviews the history and the current state of the optical access network. Then, it discusses how the optical access network will evolve given the trends in overall network services to realize the future super-broadband services as well as to support 6G mobile networks.

History and current state

Fixed broadband services are typically provided using Passive Optical Network (PON) systems as they provide point-to-multipoint connections as well as video distribution in a very cost-effective manner[2]. Fig. 1 summarizes the history of PON deployment in NTT. The first Internet connection service in 2001 provided the 10-Mbps service rate with the use of a proprietary PON system. After that, B-PON (ITU-T G.983 series) was introduced to provide the 100-Mbps service rate. 2004 saw the deployment of E-PON with 1-Gbps transmission speed (IEEE 802.3ah). This has been used for over 15 years to support the gradual increase of the service rate from 100 Mbps to 1 Gbps. A new broadband service with 10-Gbps service rate has commenced with the introduction of 10G-EPON (IEEE 802.3av).

Point-to-point optical access is typically used to connect remote antennas to the central office in RAN; 10-Gbps and 25-Gbps point-to-point optical access systems are supporting the deployment of 5G mobile fronthaul (MFH) to carry enhanced Common Public Radio Interface (eCPRI).

To accelerate service creation via broadband access, NTT introduced the ”Hikari Collaboration Model” as a new optical broadband strategy in 2014. In this strategy, NTT wholesales the fiber access to various

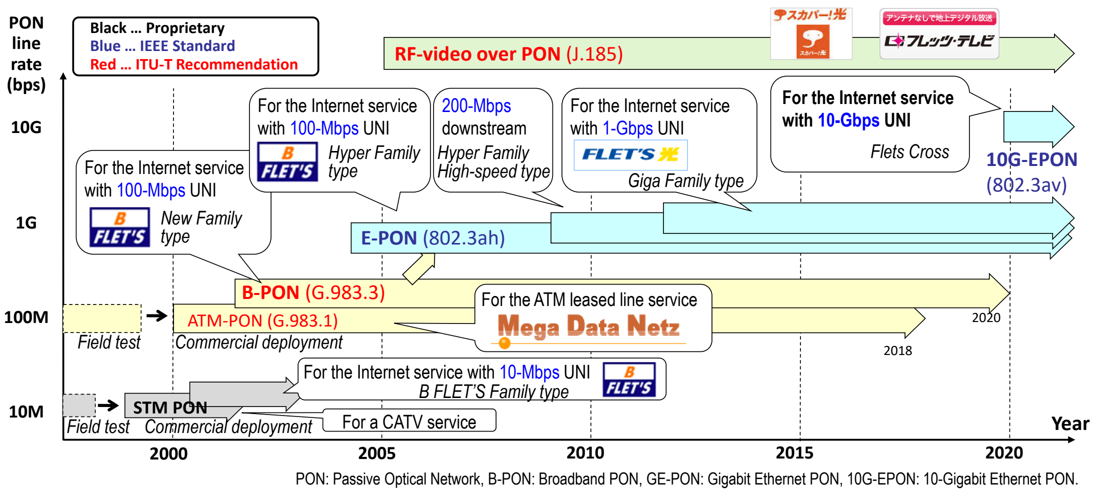

Fig. 1: History of PON deployment in NTT

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partner companies, such as Mobile Network Operators (MNOs), Mobile Virtual Network Operators (MVNOs), Internet Service Providers (ISPs), local cable-TV operators and video-rental companies. As of March 2020, 42% of optical broadband subscribers in Japan are serviced via the Hikari Collaboration Model[3].

Table 1 shows the total traffic volume for fixed broadband subscribers in Japan as estimated from the traffic of the nine major ISPs[4]. It can be seen that the traffic growth per year has increased from ~115 % to ~155 % after the global epidemic of COVID-19 in early 2020. Also, it is reported that Terabit-class traffic can occur due to a single event such as an update of a popular on-line game (happened on March 2021) and an on-line live concert of a popular J-pop idol group (happened in Nov and Dec 2020)[4]. However, the current network is not truly scalable to realize more natural remote experiences such as live sport/music viewing with audience response, remote simultaneous play of music/games.

Tab. 1: Total traffic amount of fixed broadband subscribers in Japan

Month Year	Downstream traffic (Growth per year)	Upstream traffic (Growth per year)
May 2019	12.086 Tbps (117.5 %)	1.500 Tbps (114.6 %)
Nov 2019	12.650 Tbps (115.2 %)	1.571 Tbps (112.1 %)
May 2020	19.025 Tbps (**157.4 %**)	2.321 Tbps (**154.7 %**)
Nov 2020	19.821 Tbps (**156.7 %**)	2.373 Tbps (**151.1 %**)

Expectations and technologies

Given the current state reviewed in above, it is important to consider the evolution of whole network, including optical access, from the following viewpoints.

1. *Cope with service evolution*: The network should be evolved to support both very low latency and super-broadband connections for realizing more natural remote experiences. Also, future machine type communication beyond the ability of humans will demand response times much shorter than human limits, e.g. <10 ms.
2. *Continue to support service creation*: For this, the network should allow the development of collaborative services with various partner companies.
3. *Support and enhance 6G-mobile services*: It is expected that the enhanced Mobile Broadband (eMBB) and Ultra-Reliable and Low Latency Communications (URLLC) will be simultaneously realized in 6G. As this is basically as same as what is discussed above for fixed broadband, we can expect a deeper convergence between the fixed and mobile network in the 6G era, both in core and access. Moreover, the number of mobile antennas will continue to increase as small cells will become more seamless in the 6G era.

The concept of the Innovative Optical and Wireless Network (IOWN) with disruptive technologies has been proposed as such a future network. IOWN Global Forum was launched by SONY, Intel, and NTT in 2019 to discuss technologies to accelerate the realization of such a network[5]. IOWN comprises the Data-Centric Infrastructure (DCI) subsystem and the Open All-Photonic Network (APN)[6]. The DCI subsystem is intended to provide applications with a distributed and heterogeneous computing and networking environment that spans end-to-end, i.e. across cloud and edges, and customer, while the Open APN is intended to provide high-speed, ultra-reliable, and low-latency paths realized by optical data transport.

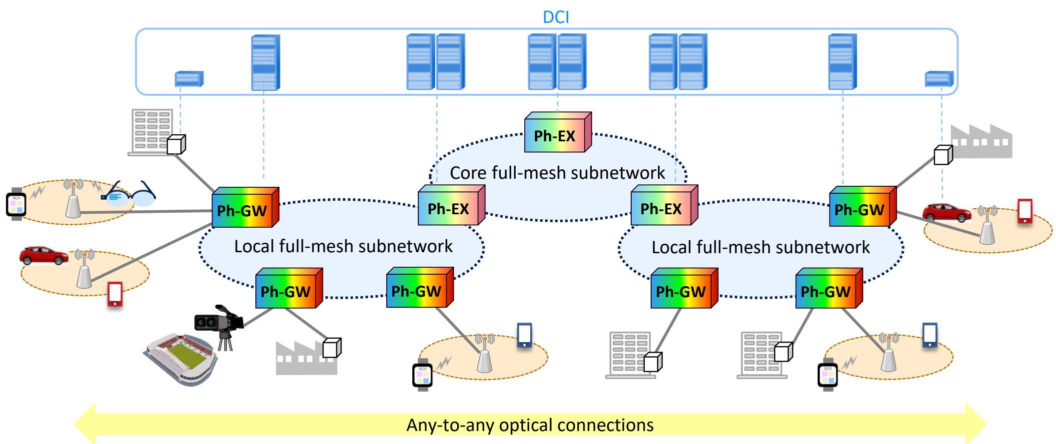

Fig. 2: Physical network image of APN[7]

Fig. 2 shows a physical-layer image of APN[7]; note that this figure focuses on the physical transport while the control functions of APN are not illustrated for simplicity. APN comprises Photonic Gateways (Ph-GWs) to form local full-mesh subnetworks as well as Photonic Exchanges (Ph-EXs) to form the core full-mesh subnetwork. Opto-electronic conversion is done only when necessary, so APN provides direct optical connections between any two customers, between any two computing resources comprising the DCI, and between a customer and a computing resource in the DCI. APN will also provide direct optical connections to external cloud and edge data centers.

Fig. 3 takes a closer look at APN in the access network. The access fiber topology can be a star (i.e. PON) for economical services, point-to-point for higher-bandwidth guaranteed services, or a loop for cost-optimized higher-reliability services. Ph-GW is set at the access node, and handles the optical signals incoming from / outgoing to the access fibers. Ph-GW mainly comprises wavelength multi/demultiplexers and an optical switch, and switches each optical signal to the electrical function block, or to the local full-mesh network. Namely, only the optical signals that are processed in the access node are dropped and terminated while each of the other signals is carried to its destination without electrical termination.

The electrical function block in the access node is built on the concept of disaggregation and virtualization[8], and provides both computing and networking functions. Namely, this includes an edge part of DCI to offer local data center functions while Ph-GW allows direct optical connections to external local data centers as well. The electrical function block comprises optical interface cards/modules to terminate various types of optical signals such as PON and high-speed Ethernet that may carry eCPRI, electrical switching fabric, and servers. Service functions run on the servers include the virtualized Broadband Network Gateway (vBNG) for broadband access services, virtualized Distribution Unit (vDU) and virtualized Centralized Unit (vCU) for MFH signal termination, and more advanced service functions to handle future applications. Control functions include remote wavelength assignment to the transponders at the user location, and control of optical switches. Thus, the fixed access and MFH/MBH can be supported by the same platform. This architecture also accelerates the creation of various services by the provision of appropriate Application Programming Interfaces (APIs) for service and control functions.

As described, Ph-GW will support both of very low latency connections to local data centers, e.g. for edge computing services, as well as very high capacity connections to cloud data centers e.g. for advanced cloud services, in a protocol-transparent manner, and will also accommodate existing PON ONUs. Thus, it can effectively evolve the access network towards the 6G era while leveraging new features provided by DCI.

Conclusions

This paper summarized the history and the current state of the optical access network and discussed future service evolution to enhance our remote life. Then, it introduced IOWN and APN as future disruptive network elements to support such services, and described the corresponding optical access network evolution. The APN and future access architecture will accelerate service creation as well as enhancing the 6G mobile network.

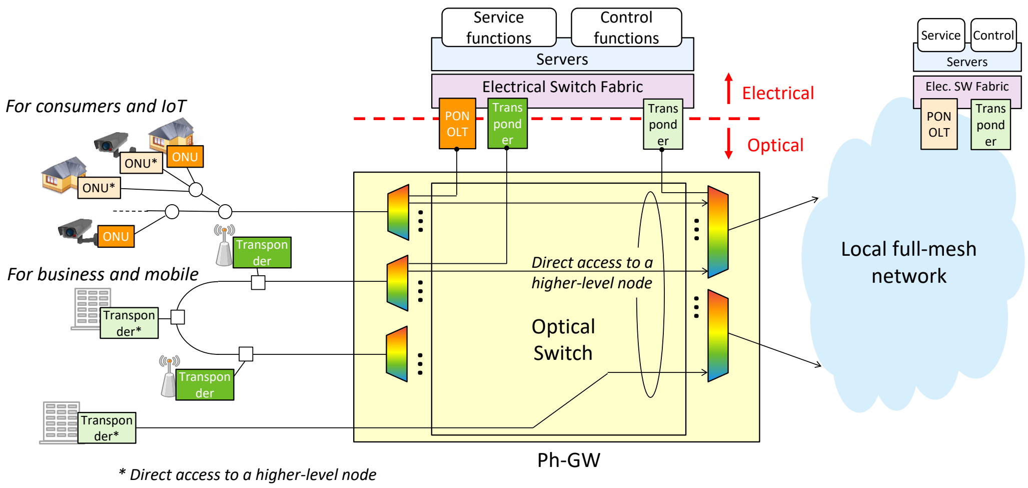

Fig. 3: Access network structure as a part of APN

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