Study on Open All-Photonic Network in IOWN Global Forum

Hideki Nishizawa, Jun-ichi Kani, Takafumi Hamano, Koichi Takasugi, Tomoaki Yoshida, and Seisho Yasukawa

Abstract

The IOWN Global Forum is developing the Open All-Photonic Network (Open APN) to provide direct optical paths between any location on demand to implement use cases of the Innovative Optical and Wireless Network (IOWN). This article describes the Open APN design goals and technical challenges as well as its functional architecture, with reference to the technical document "Open All-Photonic Network Functional Architecture" published in early 2022.

Keywords: IOWN, Open All-Photonic Network, functional architecture

1. Introduction

The IOWN Global Forum (IOWN GF) has released documents for two use cases, Cyber-Physical Systems (CPS) and AI-Integrated Communications (AIC). These use cases have already started to be implemented worldwide at some level. However, the evolution of sensing/capture technologies suggests that the critical requirements of these use cases will be much higher than those achievable with current technologies. IOWN GF is developing the Open All-Photonic Network (Open APN) [1] to establish an open architecture for photonic networking so that service providers can integrate photonic network functions with their entire computing and networking infrastructure with more granularity.

2. Design goals of Open APN

Open APN is being developed for achieving the following concepts:

- **End-to-end lambda connection**: Users will have transceivers that connect directly to remote sites via a service provider's network (wavelength tunnels in **Fig. 1**).
- **Dynamic optical-path provisioning/control**: To provide optical transport services that directly connect users flexibly, a method of provisioning and controlling optical paths is required.
- **Energy efficiency**: Open APN based on an end-to-end direct optical connection will enable networking with less energy consumption by minimizing electrical processing. The architecture and specifications of Open APN should be defined in such a way that lower power consumption can be properly achieved in accordance with the policy.
- **Multi-operator's environment**: The network will be an environment that accommodates multiple federated network operators. Each network operator can deploy end-to-end lambda connections seamlessly without being annoyed by complicated resource-sharing procedures and any conflicts when isolating defects.
- **Computing-networking convergence**: To implement CPS and AIC use cases, new optical networking that is easily adaptable to distributed computing is needed. It will connect computing resources in distant locations with high-capacity optical paths on demand with target quality of transport definable by computers.
- **Automated resource reallocation**: The network will need to efficiently scale bandwidth up and down per endpoint as user demand shifts over time.
- **Format-free optical communication**: Open APN should allow a variety of optical modulation

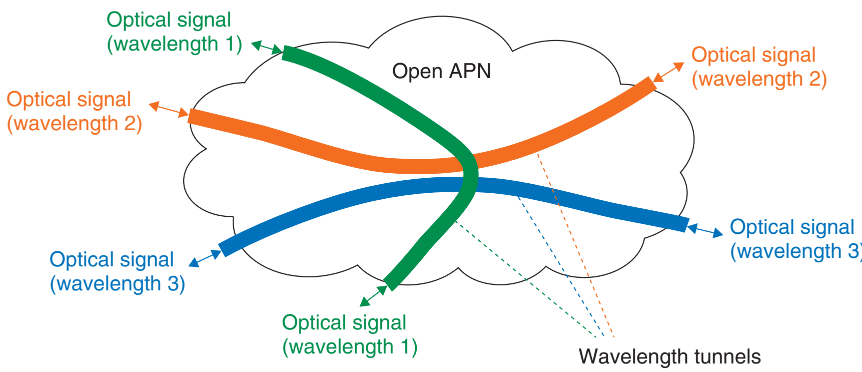


Fig. 1. Image of wavelength tunnels in the Open APN.

formats and upper-layer protocols. This will enable users to create new use cases with fiber infrastructures.

- **Intelligent monitoring**: To achieve more dynamic operations of Open APN, the network control-and-management systems must obtain sufficient information from Open APN devices. These systems should be low latency and highly secure for data collecting, storing, processing, analyzing, and sharing.

3. Evolution of optical transport technologies

Since the commercialization of digital coherent transmission systems started around 2010, the downsizing, power saving, and control-interface commonality of transmission systems have accelerated. In 2016, with the launch of Open ROADM [2], which defines interfaces and specifications to make reconfigurable optical add/drop multiplexer (ROADM) systems interoperable among vendors, and the Telecom Infra Project Open Optical & Packet Transport (TIP OOPT) [3], which defines open technologies, architectures, and interfaces in optical and Internet protocol networking, the openness of optical transmission technologies has accelerated. The application of digital technology provides advantages such as (1) being simpler and more flexible for the transmission line and its design, (2) enabling the independent evolution of hardware and software, (3) enabling the real-time measurement of transmission quality without affecting transmission quality, and (4) enabling the rapid estimation of transmission-line characteristics that determine transmission distance and capacity by using a Gaussian noise model. Over the next ten years, the convergence of computing and networking is expected to accelerate with the advent of co-packaged optics.

In fourth-generation (4G)/5G mobile networks, the bitrate of the mobile front haul (MFH) link per antenna has been enhanced to 10 or 25 Gbit/s, and there is also much discussion about standardization for applying wavelength division multiplexing (WDM) technologies to the MFH link [4, 5].

For enhancing fixed broadband access, Next-Generation Passive Optical Network Stage 2 (NG-PON2), which combines traditional time division multiplexing with dense WDM (DWDM) technology with 4 to 8 wavelengths, has been standardized and commercialized [6, 7]. Super-PON is under standardization to develop a long-distance (over 50-km) PON system through combining a 2.5G- to 10G-class PON system with DWDM technology (16 wavelengths or more) [8]. It is expected that common WDM networking will efficiently accommodate traffic in a metro-access area.

4. Technical challenges to implement Open APN

To implement Open APN, it is necessary to accelerate the further development of the technological trends described in the previous section and address the technical challenges in **Table 1**. The Open APN function architecture is defined with these solutions in mind, and the high-level reference architecture, control-and-management-plane architecture, and user-plane architecture are described separately.

5. Functional architecture of Open APN

5.1 High-level reference architecture

Figure 2 shows a high-level reference architecture

Table 1. Technical challenges to implement Open APN.

Items	Challenges
Direct optical paths between any locations	• Provisioning and management of the wavelength resources throughout the network, i.e., user, access, metro, and core networks
Dynamic online optical-path design	• Automatic selection of the optimum transmission mode of a coherent module based on the quality of the fiber-link system • Standardization of control signals to interconnect modules of different types and vendors • Fast route planning of an optical path that satisfies the reliability requirements • Support of the networking environment of multiple network operators and administrative domains, and/or devices from multiple vendors
Network attachment mechanisms for user-owned transceivers	• Admission control functions (authentication and filtering) and resolution of optical-path wavelength and endpoint addresses for a user-owned transceiver
Node architecture to support direct optical paths and dynamic path setup	• Direct optical connections between transceivers under the same ROADM • Remote deployment of transceivers and the support of their control and management channel in the conventional ROADM node • Advanced control of optical amplifier chains to support wavelength reconfiguration that will occur more frequently
Real-time performance monitoring	• Faster response within seconds or even milliseconds • Granular monitoring parameters for multiple domains of multiple operators • High compatibility with the current mechanism without affecting the transmission quality of the service traffic
Secure transport mechanisms for the optical paths originating from user premises	• Secure transport, such as Authentication, Authorization, and Accounting (AAA) without additional latency in connections between terminals installed in the customer's environment

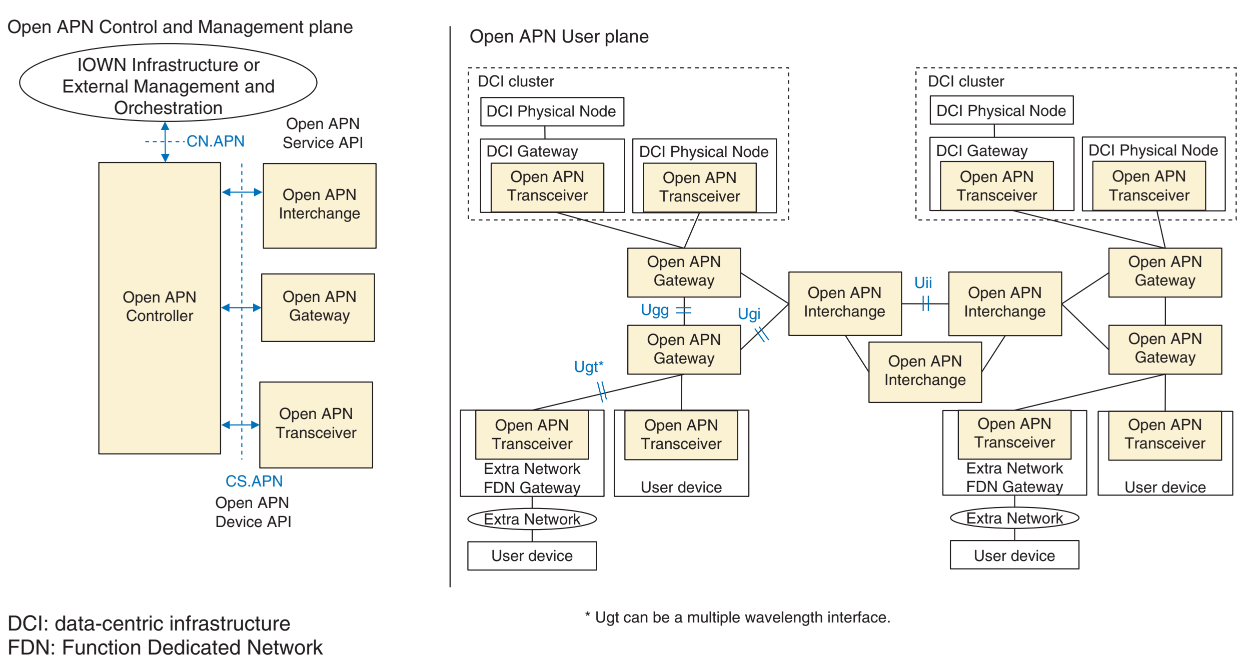


Fig. 2. Open APN high-level reference architecture.

of Open APN. The Open APN User plane consists of the Open APN Transceiver (APN-T), Open APN Gateway (APN-G), and Open APN Interchange (APN-I). The Open APN Control and Management plane consists of the Open APN Controller (APN-C) that communicates with the APN-T, APN-G, and

APN-I.

The APN-T is an endpoint for an optical path and transmits and receives optical signals. The APN-G is a gateway for an optical path and has the following five functions: (1) provision of control channels to communicate with the connected APN-Ts, (2) admission control in the user plane, (3) multiplexing/demultiplexing, (4) turn back, and (5) add/drop. The APN-I is an interchange for wavelength switching and has the following two functions; (1) wavelength cross-connect and (2) adaptation between the interfaces.

Compared with the current standard ROADM, the APN-G's functions (1), (2), and (4) and APN-I's function (2) can be regarded as the functions characteristic to Open APN.

5.2 Control-and-management-plane reference architecture

To implement the control-and-management plane of Open APN, as shown in Fig. 2, an Open APN Service application programming interface (API) is defined between the APN-C and external management-and-orchestration systems, and an Open APN Device API is defined between the APN-C and Open APN devices (APN-T, APN-G, and APN-I).

After authentication and activation of the APN-T, the APN-C creates, deletes, or resets an optical path between the APN-Ts on demand triggered by path-setup requests. The APN-C calculates the wavelength path route, wavelength to use, transmission/reception parameters for optical transmission devices, and configuration of optical transmission devices accordingly to satisfy user requirements regarding bandwidth, latency, and jitter.

The APN-C also monitors quality of transmission (QoT) information through the Open APN Device API in real time and determines whether user requirements about QoT are satisfied for each wavelength path. An example configuration of telemetry for the APN-C and Open APN devices and an example controller configuration for coordinating with the mobile system are shown in the document "Open All-Photonic Network Functional Architecture" [1].

5.3 User-plane reference architecture

The concept of Group of Optically Interconnectable Port (GOIP) has been introduced to implement scalable and interoperable Open APNs under physical constraints such as a limited number of wavelengths and transmission distance.

GOIP is defined as a group of optical ports for which a direct optical connection (Open APN optical path) can be established. The port means a connection interface between an APN-T and access link. The connection can be point-to-point and point-to-multipoint. **Figure 3** shows a configuration image of GOIP.

Because the total distance of the connection depends on bitrate and/or modulation methods, these methods of the optical transmission/reception between ports in GOIP are presented for each GOIP individually. In GOIP, there is at least one route that can establish a direct optical connection between ports. However, a direct optical connection may not be established when the shortest route is not available due to reasons such as shortage of wavelength resources, fiber cut, or equipment failure. GOIP design methods given these considerations are for further study.

In the Open APN architecture, wavelength tunnels should be managed appropriately in accordance with the specified bit rate and transmission distance, so a physical-layer reference architecture is defined and the physical reference of wavelength tunnels is described (**Table 2**).

6. Future outlooks

In IOWN GF, Open APN will evolve with a spiral approach that repeats the development of its specifications and demonstration. The Open APN functional architecture described in this article will be used as a base for proof-of-concept demonstration. The insights gained through the demonstration will be reflected in the future development of Open APN specifications and improvement in the Open APN functional architecture.

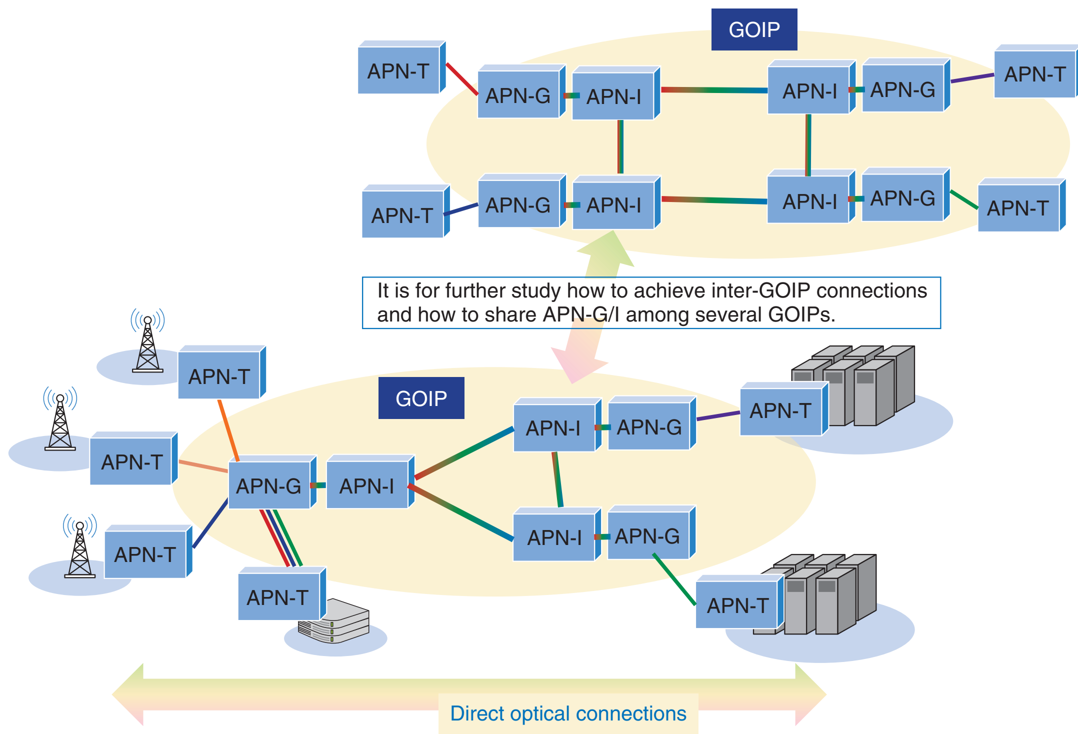


Fig. 3. Schematic diagram of GOIP.

Table 2. Physical reference of wavelength tunnels.

Category	Reference information
Requirements on the GOIP connection from the network	Required bandwidth
	Locations of the connected APN-T
Specifications of the connected APN-T connected by the wavelength tunnels	Information relative to the compatibility of APN-T for connection through wavelength tunnels (e.g., modulation format, symbol rate, used FEC, etc.)
	A bitrate of the APN-T connection
	Specification for the error-free transmission of APNT-T including tolerance to noise and impairments (e.g., OSNR tolerance or GSNR tolerance, tolerance to chromatic dispersion)
The physical reference of the wavelength tunnels	Physical information of the wavelength tunnels (e.g., used fibers, wavelengths, used bandwidth)

FEC: forward error correction
GSNR: generalized signal-to-noise ratio
OSNR: optical signal-to-noise ratio

References

[1] IOWN GF, "Open All-Photonic Network Functional Architecture," https://iowngf.org/technology/
[2] Open ROADM, http://openroadm.org/
[3] TIP OOPT, https://telecominfraproject.com/oopt/
[4] Mobile Optical Pluggable, https://www.ericsson.com/en/mobile-transport/mopa
[5] ITU-T Work Program, Recommendation ITU-T G.9802.1: Wavelength division multiplexed passive optical networks (WDM PON): General requirements, https://www.itu.int/itu-t/workprog/wp_item.aspx?isn=16803
[6] Recommendation ITU-T G.989: 40-Gigabit-capable passive optical networks (NG-PON2): Definitions, abbreviations and acronyms, https://www.itu.int/rec/T-REC-G.989/
[7] C. Wilson (ed.), "Verizon, Calix Roll Out Commercial NG-PON 2," Light Reading, 2018. https://www.lightreading.com/gigabit/fttx/verizon-calix-roll-out-commercial-ng-pon-2/d/d-id/740093
[8] IEEE P802.3cs Increased-reach Ethernet optical subscriber access (Super-PON) Task Force, https://www.ieee802.org/3/cs/

Hideki Nishizawa

Senior Research Engineer, Supervisor, Frontier Communication Laboratory, NTT Network Innovation Laboratories.

He received an M.S. in physics from Chiba University in 1996 and joined NTT the same year, where he has been engaged in research on ubiquitous networking, photonic switching systems, and photonic transmission systems. He is a member of Institute of Electronics, Information and Communication Engineers (IEICE).

Jun-ichi Kani

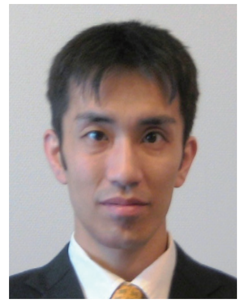
Senior Distinguished Researcher, Group Leader, Optical Access Systems Project, NTT Access Network Service Systems Laboratories.

He received a B.E., M.E., and Ph.D. in applied physics from Waseda University, Tokyo, in 1994, 1996, and 2005. He joined NTT Optical Network Systems Laboratories in 1996, where he researched optical multiplexing and transmission technologies. He has been with NTT Access Network Service Systems Laboratories since 2003, where he is engaged in research and development (R&D) of optical communications systems for metropolitan and access network applications and currently heads the Access Systems Technology Group. He has been participating in the International Telecommunication Union - Telecommunication Standardization Sector (ITU-T) and the Full Service Access Network (FSAN) initiative since 2003.

Takafumi Hamano

Senior Research Engineer, Supervisor, Network Architecture Project, NTT Network Service Systems Laboratories.

He received a B.E. and M.E. in engineering from Kyoto University in 1994 and 1996. He joined NTT in 1996 and moved to NTT Network Service Systems Laboratories in 2002. His research interests include next-generation transport network architecture and systems. He is a member of IEICE.



Koichi Takasugi

Executive Research Engineer, Director of Frontier Communication Laboratory, NTT Network Innovation Laboratories.

He received a B.E. in computer science from Tokyo Institute of Technology, M.E. from Japan Advanced Institute of Science and Technology, and Ph.D. in engineering from Waseda University in 1995, 1998, and 2004. He was involved in the design and standardization of the Next-Generation Network (NGN) architecture. He has implemented and installed super high-density Wi-Fi systems in several football stadiums. He was also active in the artificial-intelligence field, such as diagnosing diabetes through machine learning. He is currently leading research on the network architecture and protocols in optical and wireless transport networks.

Tomoaki Yoshida

Project Manager, Optical Access Systems Project, NTT Access Network Service Systems Laboratories.

He received a B.E., M.E., and Ph.D. in communication engineering from Osaka University in 1996, 1998, and 2007. In 1998, he joined NTT Multimedia Systems Development Center. In 1999, he moved to NTT Access Network Service Systems Laboratories and has been engaged in research on next-generation optical access networks and systems. From 2013 to 2015, he was involved in the research of WDM/time division multiplexing-PON and worked on the standardization of optical access systems such as NG-PON2. He is a member of the Institute of Electrical and Electronics Engineers (IEEE) and IEICE.

Seisho Yasukawa

Project Manager, Network Architecture Project, NTT Network Service Systems Laboratories.

He received a B.E. and M.E. in applied physics from the University of Tokyo in 1993 and 1995. Since joining NTT in 1995, he has conducted R&D of asynchronous transfer-mode-based multimedia switching and NGN architecture. He has also been involved in standardization efforts for point-to-multipoint multiprotocol label switching. His current research includes the IOWN architecture.