Open APN Architecture PoC Reference

Classification: APPROVED REFERENCE DOCUMENT

Confidentiality: PUBLIC

Version 1

November 2022

[Open APN PoC Reference]

Legal

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1. Purpose, Objectives, and Scope

Purpose: Why we promote this PoC

The Open All-Photonic Network (APN) is a network that connects endpoints directly with optical paths. It provides high-speed, ultra-reliable, low-latency connections. In today's networks, optical paths are disjointed and operated on a segment-by-segment basis, i.e., LANs, access networks, and inter-data-center networks. By contrast, the Open APN will enable one optical path to span multiple segments. This will allow end-to-end communication with deterministic performance. However, this approach will require more dynamic and granular control. Furthermore, the dynamic creation of optical paths (making the paths' performance demands impossible to predict until they are provisioned) will require a real-time performance measurement and monitoring mechanism; the mechanism will enable infrastructure to be set up with new optical paths having the projected achievable transmission speed. The Innovative Optical and Wireless Network (IOWN) Global Forum (GF) aims to establish an open architecture for photonic networking so that service providers can integrate photonic network functions into their entire computing and networking infrastructure with more granularity. The open architecture should also enable service providers to build an intelligent operations support system.

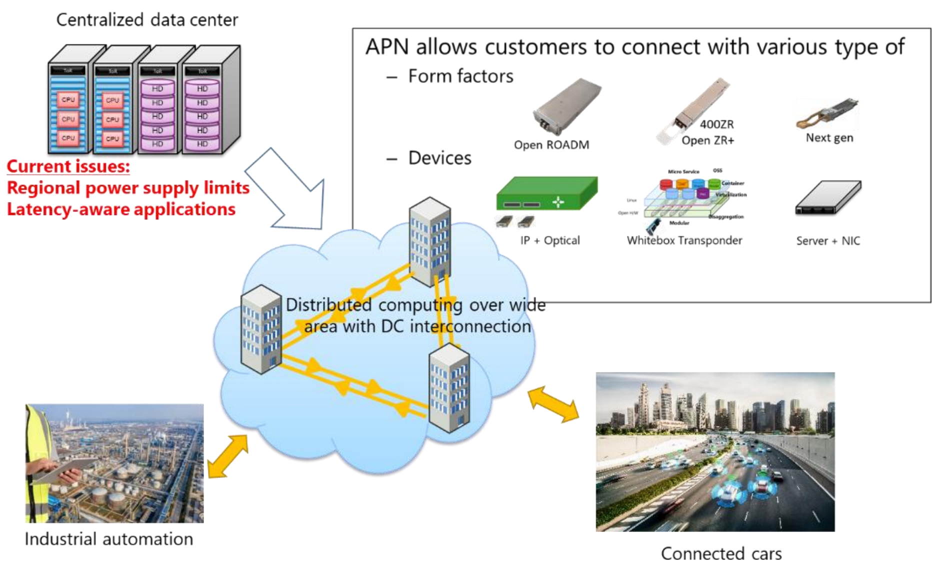


Figure 1. Data center interconnection use case for the Open APN, and various form factors and devices.

The left side of figure 1 shows an Open APN use case example of "data center (DC) interconnection". Huge, centralized data centers that focus on facility and operational efficiency are facing new challenges such as limited space, regional power supply limits, and support for latency-aware applications; moreover there is a shift toward distributed data centers that comprise smaller data centers connected by high-capacity optical links. Sales of DC interconnection devices are growing at a compound annual growth rate (CAGR) of over 10%, and the share of DC interconnection in all WDM networks is expected to exceed 40% by 2023. Computing, which performs calculations, and wide-area networks, which transfer data, have evolved independently. To achieve future applications such as connected cars and industrial automation, a new wide-area optical networking platform that is easily adaptable to distributed computing will be needed.

The right side of figure 1 shows various form factors and devices for this application. When the commercialization of digital coherent transmission systems started around 2010, it accelerated the downsizing, power reduction, and control interface commonality of transmission systems. After the definition of the management interface specification for the C Form-factor Pluggable (CFP), OpenConfig, which focuses on compiling a consistent set of vendor-neutral data models, began to define open configuration YANG models for optical transport. As the Open APN must accommodate multi-vendor/multi-generation form factors and devices; and must adapt to future technologies and innovations, the approach of openness and disaggregation for optical networks has been regarded as the most promising solution.

Although openness and disaggregation have been applied to data center networks since 2011, optical transport networks in telecommunication were left behind. One of the main reasons is the complexity of optical transport networks. In 2016, Open ROADM [Open ROADM] was launched for the purpose of defining interfaces and specifications to make reconfigurable optical add/drop multiplexer (ROADM) systems interoperable among vendors. The specifications include ROADM switches, transponders, and pluggable optics, and a YANG data model was defined to control each of these devices. In the same year, Telecom Infra Project Open Optical & Packet Transport (TIP OOPT) [TIP OOPT] was launched to define open technologies, architectures, and interfaces in optical and IP networking. Among this initiative's results to date are GNPy, an open-source library for building route-planning and optimization tools, and the Transponder Abstraction Interface (TAI), an API that provides a vendor-independent mechanism to control optical components. TIP OOPT also started the Mandatory Use Case Requirements for SDN for Transport (MUST) sub-group to accelerate and drive the adoption of SDN standards for IP/MPLS and optical transport technologies via OpenConfig YANG data models.

The operation of open, disaggregated optical transport networks and the future APN will require sufficient performance information about the networks to appropriately control and manage them. Such performance information will also contribute to fault diagnosis, configuration optimization, and intelligent operation. One of the main issues slowing the deployment of reference architectures is the unicity of their API definitions. Accordingly, the challenges for implementing the Open APN are as follows.

Lack of dynamic optical path design: In today's optical transport networks, optical paths are noncontiguous and separated by frame-based switches. That is, optical paths are created separately for access, metro, and core networks. As the Open APN aims to provide direct optical paths between any locations, including user premises, on demand, it will require a function to provision and manage wavelength resources throughout the network, i.e., from access to core. Furthermore, optical paths are designed offline and configured statically with homogeneous transmission parameters (e.g., the modulation format and baud rate) for optical paths of various distances along the longest path in the network. Such a design requires a high degree of skill and know-how and depends on the vendors and the generation of components. Many research results in this field have been reported since the commercialization of digital coherent technology. For example, Gaussian noise approximation has simplified the physical design of line systems [Carena, Curri], and its viability has been proven by various research organizations [Filer, Kaeval, Mano]. When applying the latest results, it is necessary to specify the architecture and protocols to implement the Open APN so as to allow for dynamic path creation, repeated setup, and deletion among various customer terminals.

Issues of fast performance measurement and monitoring mechanism: First, many deployed optical transport network performance monitoring mechanisms are mostly triggered by the controller, the ask-and-response mechanism. Instead, the streaming telemetry applies a subscription mechanism and fast monitoring. Once the network controller subscribes, the attached hardware will automatically report its performance information during the subscription period with a faster cadence. Such monitoring period can be seconds. Second, the performance monitoring items in many deployed optical transport network are quite limited due to insufficient openness and disaggregation of the optical transport network and immature standards and data models. By enhancing the performance monitoring granularity, the network controller can get more comprehensive performance information of the attached equipment and configure them in a more efficient fashion. It is worthy to note that, to avoid decreasing the network operation efficiency with tremendous performance monitoring data, the monitoring items should be selected according to the requirement of the networks, instead of open up everything to the controller. For example, a network with low tolerance to connection failure will require to always monitor the receiving signal quality, while a network requiring real-time interaction will monitor the latency all the time.

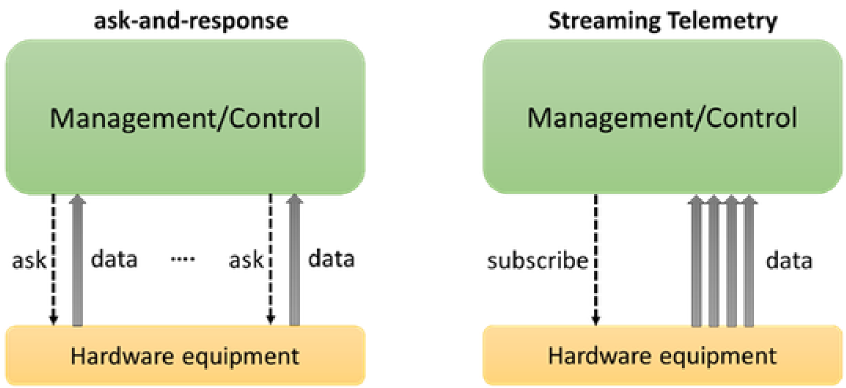


Figure 2. Left: Conventional performance monitoring mechanism; Right: Streaming telemetry performance monitoring mechanism.

Here are two examples of performance monitoring mechanism with streaming telemetry.

1. The transport signals may be saturated in optical power after optical amplifications, which usually bring signal distortions and even cross interferences to adjacent channels. To relieve such amplification saturations, the streaming telemetry can be applied to reply to the optical power values measured at the outputs of optical amplifiers. With the quick response nature of streaming telemetry, the network controller can take some actions in a short time based on the reported optical power value, such as decreasing the gain of the optical amplifier to mitigate power saturations.
2. The transport signal qualities are usually distorted after transmissions. To maintain the received signal qualities acceptable, the network controller can always monitor the signal-to-noise ratios (SNR) or the bit-error rates (BER) to configure the equipment. In such case, the streaming telemetry with its quick response nature can help. During the monitoring period, the controller can get the periodic report automatically from the attached equipment. Once the reported SNRs imply distorted signal qualities, the controller can take actions in a short time, such as enhance the launched optical power or even change the optical path. Moreover, the reported SNR values can be collected for long-term analysis of the performances of optical paths, which can be utilized for predictions of hardware life cycles.

Fiber link monitoring: To support customer end-to-end dynamic optical paths set-up, Open APN monitoring mechanism needs to cover not only carrier's core network but also customer's access fiber link. In this PoC, optical time domain reflectometry (OTDR) will be applied for customer access link monitoring; OTDR is a fiber sensing technology that has traditionally been designed as a separate system from the communication system.

Bandwidth granularity gap between user traffic and optical path

The Open APN requires end-to-end QoS evaluation. In some use cases, there is a bandwidth granularity gap between user traffic and optical paths. For example, the data rate of 5G mobile front haul is about 25Gbps, whereas the data rate of an optical path is 100 or 400Gbps. The All-Photonic Network Function Architecture document defines a Flexible Bridging Service (FlexBr) to close this gap.

Lack of network attachment mechanisms for user-owned transceivers: In today's optical transport networks, carriers prepare and manage all the equipment, including transceivers. In contrast, the Open APN allows user-owned transceivers, which requires network attachment mechanisms.

Objectives: What we shall accomplish

In this PoC work, we plan to evaluate following major items.

Verification of basic APN functions. Open APN Functional Architecture release 1 defines the Open APN Transceiver (APN-T), Open APN Gateway (APN-G), and Open APN Interchange (APN-I) as the basic components for the APN User plane, and the Open APN Controller (APN-C) as the basic component for the APN Control and Management plane. We will achieve end-to-end optical connection through the use of APN-T and APN-G, while the use of APN-I may be optional because the network scale for this PoC may be relatively small. We will verify the APN-G architecture in which communication and sensing are integrated (Type II as described in [IOWN GF FSOA]).

Open interface verification. In contrast to proprietary networks, the control and management of equipment in an open, disaggregated network should be conducted separately with standardized open interfaces. Accordingly, we will verify that open, disaggregated equipment can be attached to a controller with open interfaces.

Multi-environment support. Dynamic optical path design should consider a networking environment of multiple network operators, multiple administrative domains, and/or optical transport devices from multiple vendors; that is the environment is multi-technology and multi-vendor, and it crosses administrative or ownership boundaries. Also, dynamic optical path design should consider the minimization of photoelectric conversion for lower latency and lower power consumption.

Fast monitoring with streaming telemetry. To handle the complexity of open and disaggregated network, the controller must obtain sufficient performance information about the equipment in an efficient manner. Instead of conventional ask-and-response mechanism, streaming telemetry technology makes equipment automatically report the performance monitoring information to its controller. In this PoC work, we will evaluate streaming telemetry functions.

Automatic provisioning. Selection of a coherent module's optimal transmission mode according to the quality of the fiber link system, including the customer's access link, is a key factor in dynamically provisioning optical paths. This requires accounting for the generation of a coherent digital signal processing (DSP) LSI, the characteristics of forward error correction (FEC) and the installed optical components, and the quality of the optical fiber path in term of the total required transmission capacity. It also requires a skilled engineer for optimal design of each of these conditions, by accounting for the bit-error-rate versus the optical signal-to-noise ratio (OSNR) characteristics of the receiver.

Verification of flexible bridging functions. The Open APN Functional Architecture defines a Flexible Bridging Service as a bridging service that aggregates and forwards multiple data flows into a single optical path. This service is at the endpoint of the Open APN, where it aggregates multiple data flows from user devices or other network elements and sends them over an Open APN optical path.

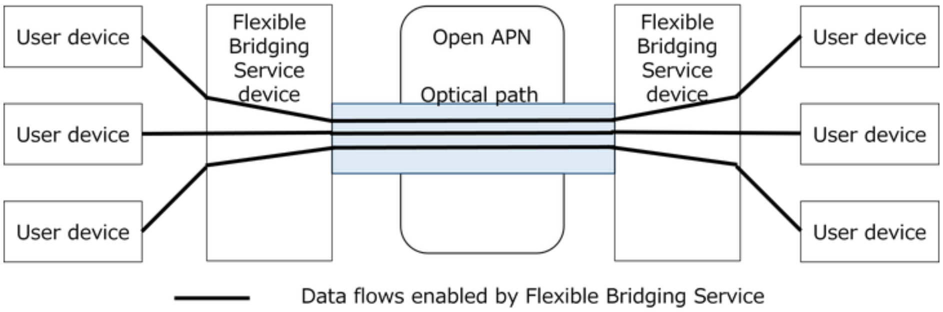
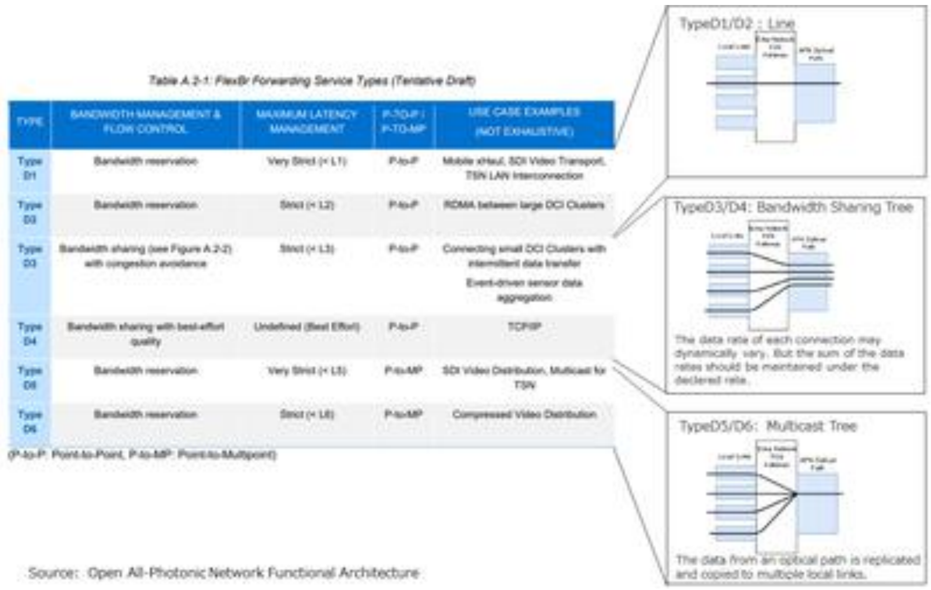


Figure 3. Flexible Bridging Service

To maintains the benefits of optical transport, this service requires the following extreme QoS functions for the use cases which are defines by IOWN Global Forum. The architecture document defines the following service types.



TYPE	BANDWIDTH MANAGEMENT & FLOW CONTROL	MAXIMUM LATENCY MANAGEMENT	P-TO-P / P-TO-MP	USE CASE EXAMPLES (NOT EXHAUSTIVE)
Type D1	Bandwidth reservation	Very Strict (< L1)	P-to-P	Mobile xHaul, SDI Video Transport, TSN LAN Interconnection
Type D2	Bandwidth reservation	Strict (< L2)	P-to-P	RDMA between large DCI Clusters
Type D3	Bandwidth sharing (see Figure A.2-2) with congestion avoidance	Strict (< L3)	P-to-P	Connecting small DCI Clusters with intermittent data transfer Event-driven sensor data aggregation
Type D4	Bandwidth sharing with best-effort quality	Undefined (Best Effort)	P-to-P	TCP/IP
Type D5	Bandwidth reservation	Very Strict (< L5)	P-to-MP	SDI Video Distribution, Multicast for TSN
Type D6	Bandwidth reservation	Strict (< L6)	P-to-MP	Compressed Video Distribution

(P-to-P: Point-to-Point, P-to-MP: Point-to-Multipoint)

Figure 4. Flexible Bridging Service Service Type

This PoC intends to show the benefits of using the Flexible Bridging Service (FlexBr) to aggregate traffic over the APN while maintaining the advantages of optical transport, such as reserved bandwidth and bounded delay variation; and to make FlexBr applicable to any of use cases which are defines by IOWN Global Forum. Multicasting is also defined. We will archive end-to-end optical connections by using the FlexBr. This will require QoS functions such as delay to maintain the benefits of optical paths as mentioned above.

Verification of network attachment mechanism for user-owned transceivers. The Open APN can create an optical path using user-owned transceivers. This requires functions such as authentication and parameter registration of user-owned transceivers.

Scope: What we do and what we don't do.

In this PoC work, we plan to evaluate dynamic (automatic) optical path design methods, as well as its open interfaces, multi-environment support, and automatic provisioning functions, as described above. If necessary, the work may also include abstraction, analysis, and strategization of monitoring data and further feedback for network optimization, and integration of open, disaggregated networks with proprietary networks. However, the items listed below may be out of the scope of this PoC work.

- Development of open and disaggregated equipment. (This PoC will apply currently available technology.)
- Development of open interface and data model. (This PoC will apply currently available interfaces and data models.)
- Selection, analysis, and strategization of performance monitoring data and further feedback for network optimization.

For verification of fiber sensing in the Open APN, in this PoC, we will also evaluate configurations for Type II implementations as described in the reference document [IOWN GF FSOA]. The items listed below may be out of the scope of this PoC work.

- Demonstration Type I and Type III configurations.
- Demonstration that the APN can transfer a large amount of measured data to DCI or other site.

- Clarification of the required interface for an interrogator to transfer a large amount of measured data to DCI or other site with the APN.

For verification of the Flexible Bridging Service, we will evaluate Type D1, D2, D3, D4, D5, and D6 service data planes and the service's QoS performance by using actual devices as references for any use case. The Flexible Bridging controller is out of the scope of this PoC.

2. Reference Cases

2.1. Open APN controller reference model

Figure 5 (a) shows a reference implementation model of the Open APN Controller (APN-C). A single APN-C controls an Open APN Transceiver (APN-T) and an Open APN Gateway (APN-G). For simplicity, the figure omits the Open APN Interchange (APN-I).

The APN-C could have alternative implementation models, for reasons such as technical maturity, equipment availability, and so forth. Figure 5 (b) shows one example, in which the APN-C is a collection of multiple controllers in a hierarchical structure, with one (controller B) controlling the APN-G and the other (controller A) controlling APN-T and controller B. Controller B can be called an “APN-G controller”, as it controls the APN-G through a proprietary interface. This model is referred to as a partially open and disaggregated optical network [Lopez].

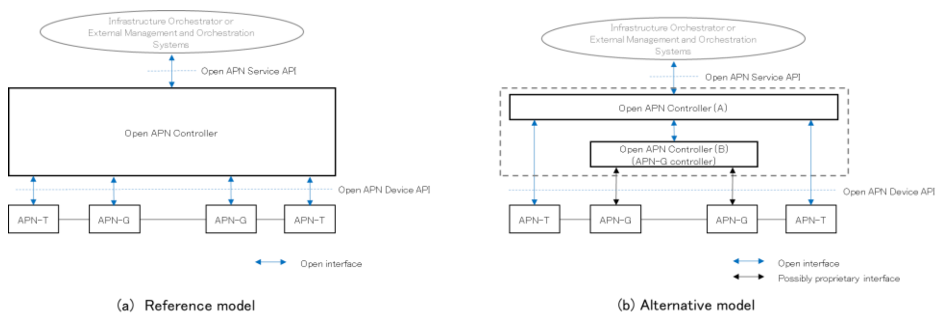


Figure 5. Open APN Controller reference model.

In this PoC, we do not restrict the APN-C’s implementation models.

2.2. Open and disaggregated network and streaming telemetry monitoring

The reference architecture in Figure 6 shows a open and disaggregation network to evaluate the streaming telemetry function. In this work, the Open APN Controller may be implemented with either model mentioned in Section 2.1.

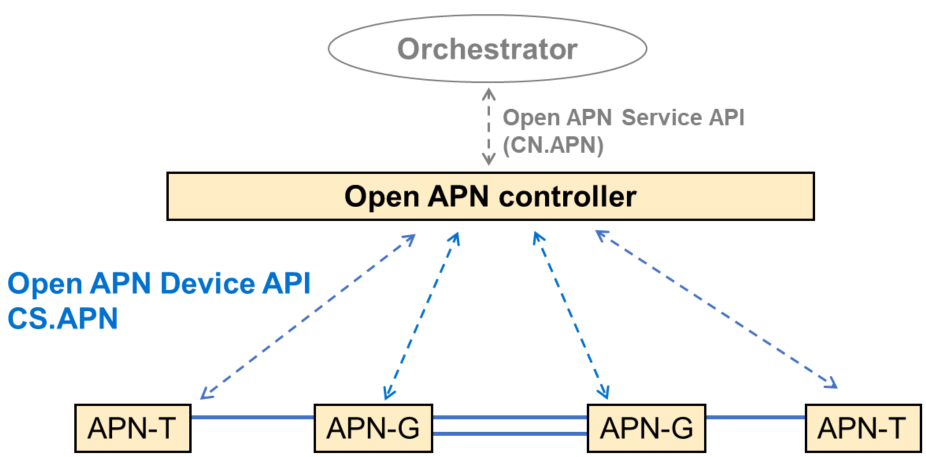


Figure 6. Open and disaggregated network for streaming telemetry monitoring

Optical layer:

This work applies an architecture of optical transport network. As shown in Fig. 6, both sides of this system are Open APN Transceiver (APN-T), and the equipment items in-between are Open APN Gateway (APN-G). In this system design, the APN-T will be implemented with muxponder, and the APN-G will be implemented with open line system (OLS). The muxponders and OLS equipment items should be provided by different vendors.

The **APN-T**, implemented with muxponder, should support open interface and controlled by Open APN Controller with those open interfaces. They should also support streaming telemetry performance monitoring functions and be able to automatically report to the controller. In the implementation, the muxponders on both sides are considered to be the same model. It is optional/desirable that the APN-T supports a control and management channel to communicate with APN-G (See Sections 3.1 and 4.1).

The **APN-G**, implemented with open line systems (OLS), are considered to be the same model in this work. The APN-G should be able to automatically report the performance monitoring data to the Open APN controller. Also, the APN-G should support two degrees of optical path routing function, as illustrated in the figure above.

Controller Layer:

The **Open APN controller (APN-C)** should support the open interfaces and control the APN-T and APN-G with those open interfaces. A transport SDN controller (T-SDN controller) will be applied as this open APN controller. There should be a collector function in the Open APN Controller to collect the performance monitoring data reported by the equipment items in the optical layer.

Orchestration Layer:

As many conventional optical transport networks, there is supposed to be an orchestrator implemented above the Open APN Controller. However, this may not be included in the work of this PoC.

2.3. Customer end-to-end lambda connection

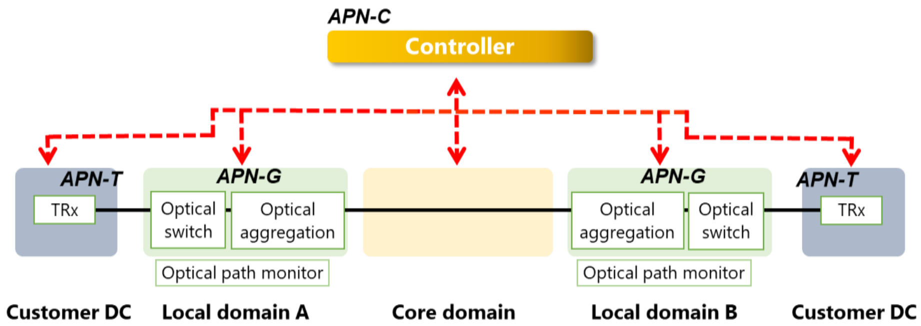


Figure 7. Architecture for customer end-to-end lambda connection

Conventionally, long-distance optical transport devices have been located inside the carrier network, and customer terminals are connected to these devices via carrier access lines. The controller in Figure 7 includes both the APN-C and the APN-G controller shown in Figure 6.

2.4. Expanded functionality with fiber sensing

Figure 8 shows examples of fiber sensing use case. The figure above illustrates the use of fiber sensing technology for access link monitoring during deployment. The optical path monitor and APN-G work together to achieve this installation process. The figure below shows an example of failure restoration. The APN-G and APN-T are connected by a short access fiber link and a long backup link. If a failure occurs on the access fiber link, this is detected using optical path monitoring, and the access fiber link is switched to a backup line.

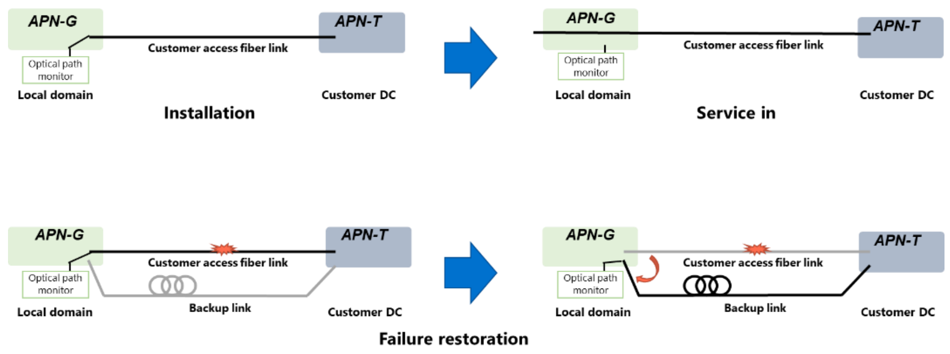


Figure 8. Examples of fiber sensing use case

2.5. Connection case of fiber sensing with APN-G

Type II -1 fiber sensing architecture described in [IOWN GF FSOA] are shown in Figure 9. Type II -2 is omitted because only the operation of the fiber is different from Type II-1 and the connection configuration is the same.

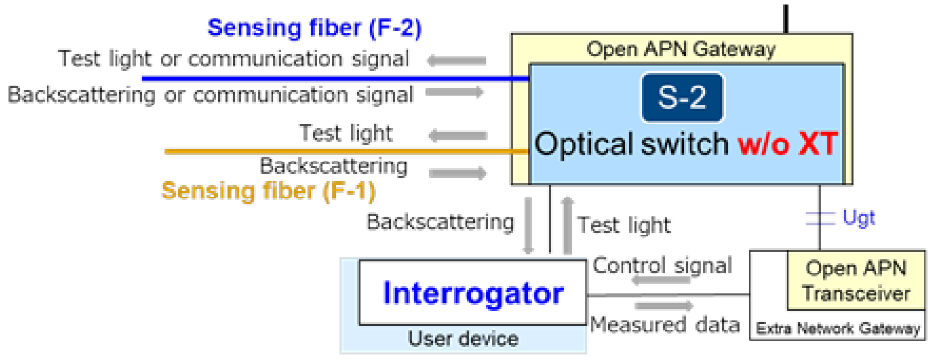


Figure 9. Fiber sensing architecture Type II-1

In Type II, fiber sensing interrogator is connected to the APN-G and APN-G is used as a measurement fiber selection node.

2.6. Flexible Bridging Services

To verify the Flexible Bridging Service, we will evaluate the following reference cases.

(1) Type D1/D2 service for DC interconnection

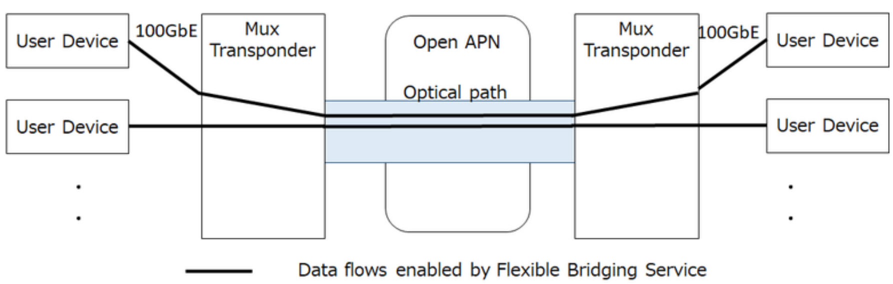


Figure 10. Type D1/D2 service for Datacenter interconnect

(2) Type D3/D4 service for DC interconnection

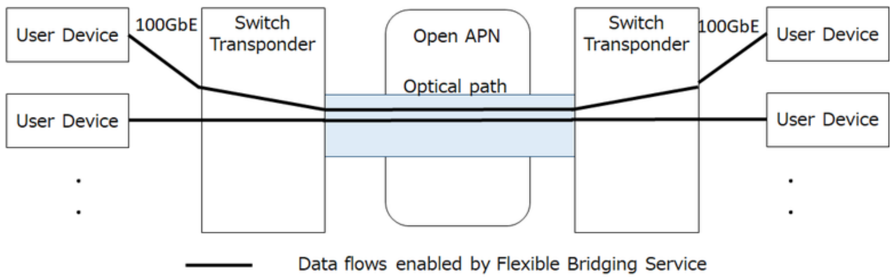


Figure 11. Type D3/D4 service for Datacenter interconnect

(3) Type D1/D2 service for Mobile xHaul

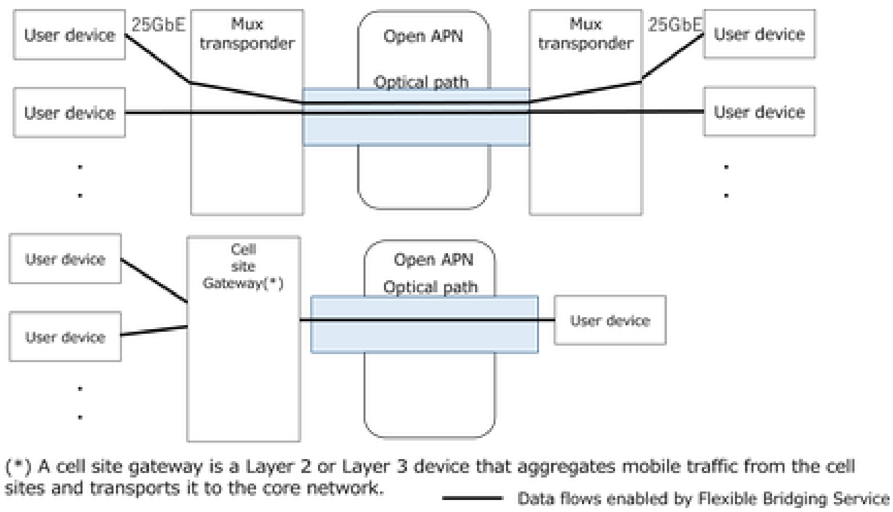


Figure 12. Type D1/D2 service for Mobile xHaul

(4) Type D5/D6 service for video distribution

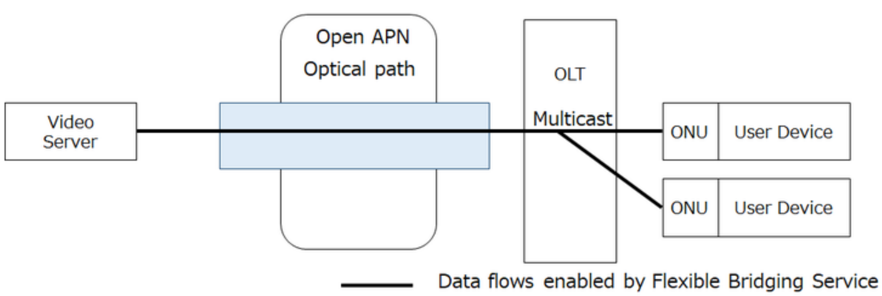


Figure 13. Type D5/D6 service for video distribution

3. Desired Features

3.1. Feature 1: Support for APN-G functions

Support for the following APN-G functions should be verified: (1) provision of control channels to communicate with connected APN-Ts, (2) admission control in the U-plane, (3) multiplexing/demultiplexing, (4) turning back and (5) adding/dropping.

(1) Provision of control channels to communicate with connected APN-Ts:

- Verify that the wavelength of an APN-T at a user premise can be configured remotely from the APN-G controller.

(2) Admission control in U-plane:

- Verify that the optical signal from an APN-T at a user premise can be passed and blocked by changing the APN-G configuration from the APN-G controller.

(3) Multiplexing/demultiplexing:

- Verify that at least 16 wavelengths on the C band can be multiplexed and forwarded to an uplink port (Ugg [2], Ugi [3]).
    - [1] Table 3.3.1 in Open APN Functional Architecture release 1 specifies that the minimal viable version of the Open APN shall provide at least 16 wavelengths on the C band.
    - [2] Ugg: Optical interface between two APN-Gs
    - [3] Ugi: Optical interface between APN-G and APN-I

(4) Turning back:

- Verify that the optical signal from an APN-T at a user premise can be forwarded to an APN-T at another user premise under the same APN-G by changing the APN-G configuration from the APN-G controller.

(5) Adding/dropping:

- Verify that the optical signal from an APN-T collocated with the APN-G can be forwarded to another APN-T at a user premise by changing the APN-G configuration from the APN-G controller. Also, verify that the optical signal from an APN-T at a user premise can be forwarded to another APN-T collocated with the APN-G.

It is desirable for a 10-km optical fiber to be inserted between the APN-G and APN-T at the user premise in tests (1) to (5).

Note that tests (1) and (2) may be optional.

3.2. Feature 2: Open interface verification

This feature will verify that open and disaggregated equipment from various vendors can be attached to an Open APN Controller (APN-C) via open interfaces, and that an APN-C can control that equipment, as well.

- Open interfaces will be applied to the following places:
    - between open APN-C and APN-T;
    - between open APN-C and APN-G.
- The options of open interfaces include OpenConfig and ONF specifications. [OpenConfig]
- The major control functions include the following three functions.
    - optical path setup.
    - optical path deletion.

- optical path re-configuration.

3.3. Feature 3: Multi-environment support

The APN-T and APN-G should be from different vendors. The interoperability of multi-vendor equipment in this PoC work mainly concerns the interoperability of the APN-T and APN-G.

The evaluation items will include the following:

- Traffic: traffic evaluations will be conducted with all the defined data rates on the optical paths. (unit: Gbps)
- Stability: a traffic evaluation will be conducted for a long time. (unit: hours)

3.4. Feature 4: Automatic provisioning

It should be verified that optical path provisioning includes physical design with the link parameters such as fiber types and signal power profile can be done in about 10 minutes by using the standard mode described in the Open APN Architecture release 1 documentation.

- W 100-200G 31.6 Gbaud of Open ROADM MSA Optical Specification Version 5.0
- W 200-400G 63.1 Gbaud of Open ROADM MSA Optical Specification Version 5.0

It should also be verified that optical paths can be established with sufficient accuracy over a short reach in a metro region by using standard physical design methods.

3.5. Feature 5: Fiber sensing with APN-G

Any architectures may be used as long as the amplifiers are bypassed. The following features are desired for any configurations:

- The Interrogator is the Optical Time Domain Reflectometer (OTDR) for general loss measurement. The wavelength of OTDR is 1550 nm.
- Circulators or couplers should be common commercial products.
- The optical switch function is a commercial switch assumed to be used at 1550 nm.
- The sensing fiber shall be over 10 km of commercial single-mode optical fiber.

In any configuration, in addition to the desired features above, the following are the items that should be confirmed and reported:

- Span loss between the interrogator and the measured fiber
- Waveform measured with real time mode measurement with a pulse width of 100 ns by OTDR
- OTDR waveform measured in 2^{10} =1024 times averaged with a pulse width of 100 ns
- Specifications of Optical switch function and Model number of the OTDR unit
- Specifications of the APN-G

When the probe light or the back scattered light passes through APN-G for selecting measured fiber such as Figure 9, the following additional item is required to be reported:

- Specification of port to port crosstalk of the APN-G

3.6. Feature 6: Flexible Bridging Service

This feature will verify the forwarding service that aggregates and forwards multiple data flows into a single optical path with extreme QoS performance.

3.7. Feature 7: Network attachment mechanism for user-owned transceivers

This feature will verify automatic registration of user-owned transceivers that terminate the optical path, as follows.

- Registration of user-owned transceivers to the APN-C.
- Optical path setup using the registered user-owned transceivers.

The registration of user-owned transceivers includes registration of parameters such as the modulation format.

3.8. Feature 8: Monitoring with streaming telemetry

Once the open APN controller subscribes, the open APN controller will collect the performance monitoring data automatically and periodically reported by the APN-T and APN-G controller.

- performance monitoring items: (include but not limited to) optical power values, SNR, BER.

4. Key Benchmarks

We will expect implementers to use the following benchmarking methods.

4.1. Benchmark 1: APN-G functions

(1) Demonstration of the five functions described in section 3.1

(2) Measurement of acceptable distance and loss between APN-T and APN-G in the loop-back operation

(3) Measurement of acceptable distance and loss between APN-T and APN-G in the non-loop-back operation

(4) Measurement of power consumption per port

4.2. Benchmark 2: Open interface verification

- Time of optical path setup, deletion, re-configuration. (unit: μs)

4.3. Benchmark 3: Fast monitoring with streaming telemetry

- Performance monitoring interval: the period of reporting. (unit: second)
- Power consumption: the overhead power consumed while streaming telemetry operation. (unit: Watt)

4.4. Benchmark 4: Automatic provisioning

- Optical path provisioning time for physical design : within 10 minutes.

4.5. Benchmark 5: QoS performance of Flexible Bridging Service

(1) Throughput: packet loss between user devices (unit: bit per second (bps)).

(2) Delay: packet delay between user devices (unit: μs).

(3) Delay variation: packet delay variation between user devices (unit: μs).

5. Other Considerations

The timeline of this PoC work is listed below. (WIP schedule)

1. By August 2022: Preparation of the PoC work.
2. By December 2022: Execution of the PoC work (Features 2 to 6, and 8).
3. By February 2023: Execution of the PoC work (Features 1 & 7).
4. By March 2023: Finalization of the PoC work and conclusion with a report.
5. By June 2023: Insertion of the results in the deliverable report.

References

[Open ROADM]	Open ROADM, http://openroadm.org/.
[TIP OOPT]	Telecom Infra Project Open Optical & Packet Transport, https://telecominfraproject.com/oopt/.
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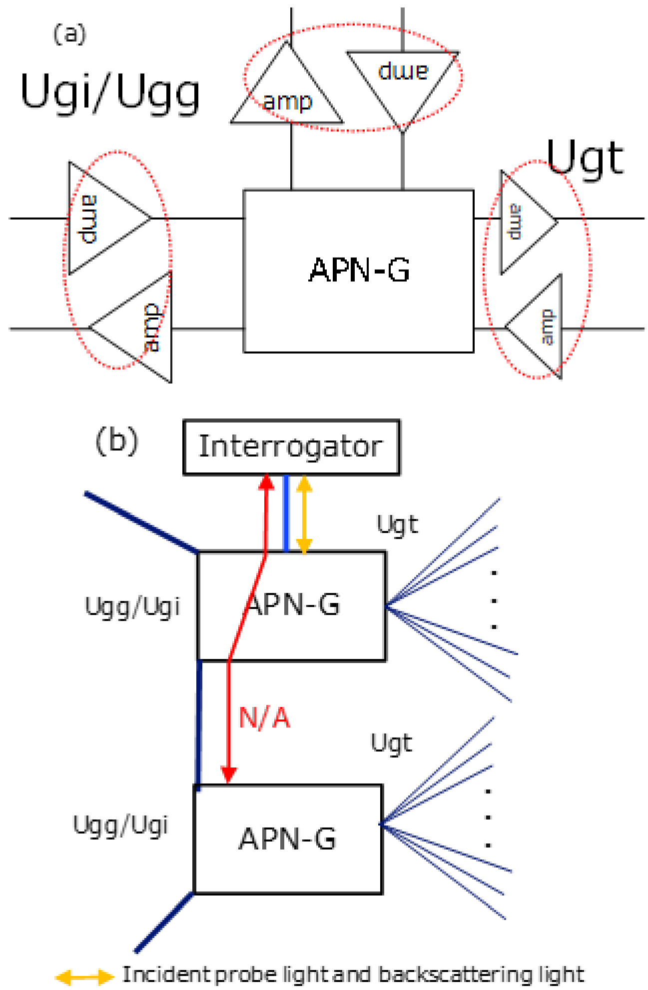
[Kaeval]	K. Kaeval, T. Fehenberger, J. Zou, S. L. Jansen, K. Grobe, H. Griesser, J-P Elbers, M. Tikas, and G. Jervan, “QoT assessment of the optical spectrum as a service in disaggregated network scenarios,” JOCN Vol. 13, No. 10, (2021).
[Mano]	T. Mano, et al., "Accuracy of nonlinear interference estimation on launch power optimization in short-reach systems with field trial," 2022 European Conference on Optical Communication (ECOC), 2022.
[IOWN GF FSOA]	IOWN Global Forum, “Fiber sensing for Open APN” release-1,” 2022.
[Lopez]	V. Lopez, W. Ishida, A. Mayoral, T. Tanaka, O.G. de Dios, and J.P. Fernandez-Palacios, “Enabling fully programmable transponder white boxes [Invited],” JOCN vol.12, no.2, (2020).
[OpenConfig]	https://www.openconfig.net/projects/telemetry/

Note: The above documents are available on https://iowngf.org/ .

Appendix

Architecture examples for fiber sensing

Figure 14 (a) shows an APN-G configuration with amplification. Given the current situation of commercially available switching node, APN-G is expected to use amplification. Amplifiers would be inserted in Ugg/Ugi side fibers. When the switching loss to the Ugt side is large, there also would be an amplifier for Ugt side. The amplifier in the APN-G configuration restricts the direction of light propagation to one direction. On the other hand, the fiber sensing techniques we discuss are reflectometry-based techniques that measure backscattered light and in backscattered light measurements, probe light and scattered light travel in opposite directions in the same fiber. Therefore, the interrogator should be connected to the APN-G in such a configuration that the probe and backscattered light can propagate simultaneously in the one measured fiber and the fiber sensing can be performed normally. Also, since it is difficult for the probe light from the interrogator to pass through multiple APN-Gs as shown in Figure 14 (b), a switch function might be required to select each APN-Gs as shown in Figure 14 (c). Figure 15 and 16 shows examples of the configuration to overcome the issues with the switching and circulator. Note that configurations adopted in PoC activities are not limited to the configurations shown in Fig. 15 and 16.



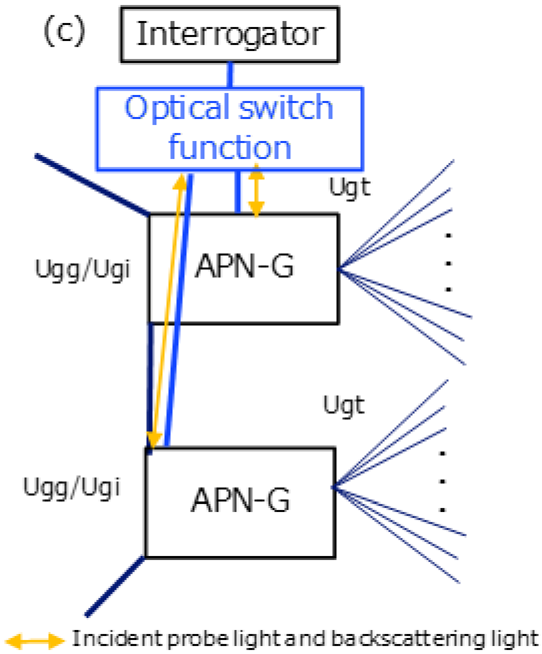
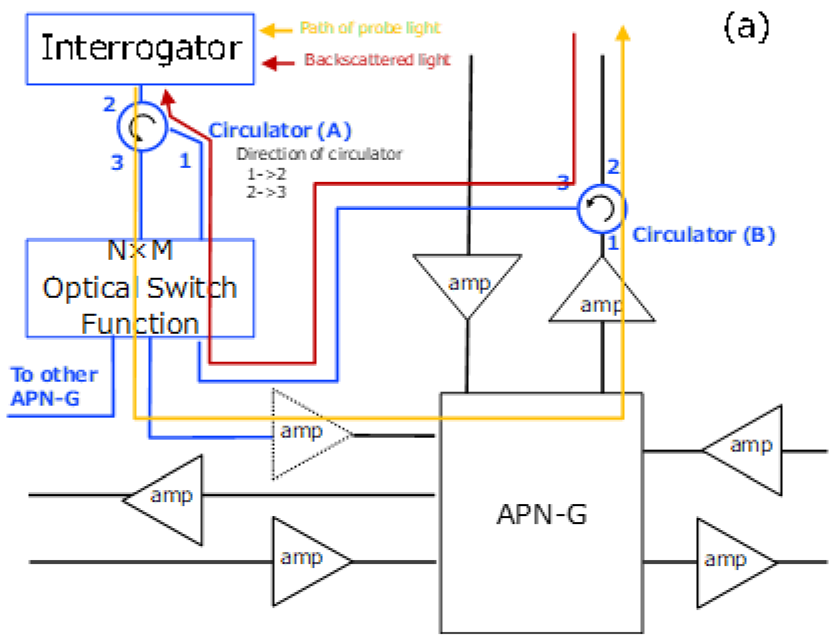


Figure 14. (a) Typical APN-G configuration (b) Unavailable of transmitting probe light to multiple APN Gateways and (c) Optical switch function for selecting APN-G



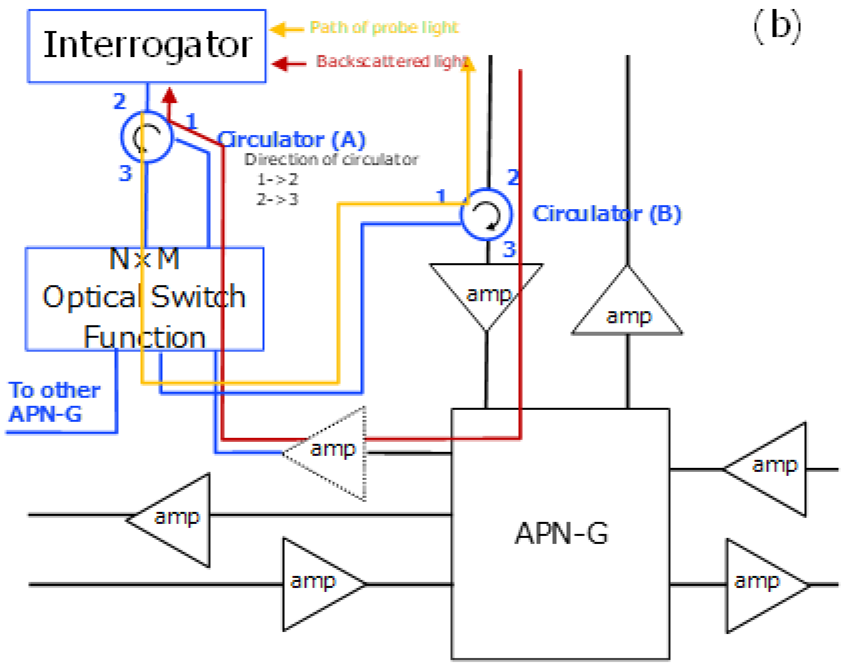


Figure 15. Examples of connecting configuration using a switch and a circulator

In Figure 15 (a), a probe light is inserted to APN-G through the circulator (A) and injected to the fiber through the APN-G and the circulator (B). Scattering light is separated with the circulator (B), transmitted to the circulator (A) and received by the interrogator. Because of two circulators, the probe light can be inserted into the measurement fiber and the backscattered light can be extracted from the measurement fiber with a low loss. The loss of APN-G can be compensated by the amplifier. The APN-G can be utilized for selecting sensing fiber. In Figure 15 (b), paths of the probe light and scattering light are exchanged. The effect of being able to bypass the amplifier is the same.

The probe light insert port and the backscattered light output port and the connection port of the measurement fiber of APN-G may be either the Ugi/Ugg side or the Ugt side.

It is also possible to simply connect only the coupler without using the circulator shown in Figure 16 which is also an example.

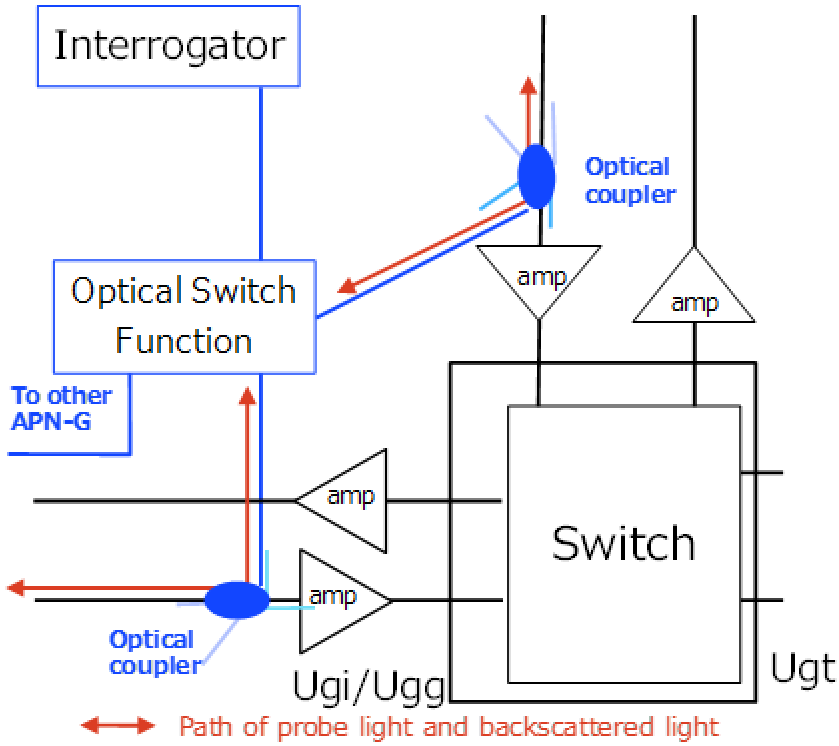
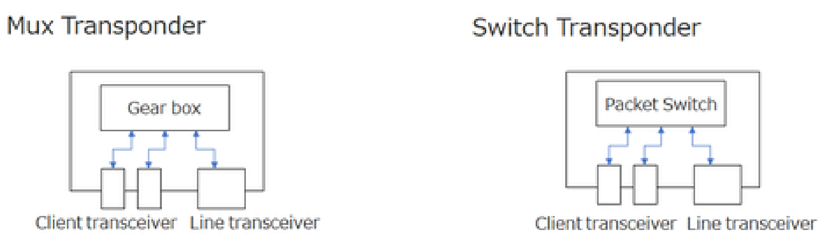


Figure 16. Example of simply connection using only the coupler without the circulator

Architecture examples for Flexible Bridging service transponder

We plan to use mux and switch transponders to implement a Flexible Bridging Service that supports bandwidth reservation and strict latency requirements. The mux transponder supports aggregation by using a dedicated logical link and low-latency forwarding; it can be used for Types D1, D2, and D3. The switch transponder supports bandwidth sharing; it can be used for Types D3 and D4.



	Mux transponder	Switch Transponder
Bandwidth	Reservation	Sharing
Congestion	No	Occurred
Latency	Low latency	Difficult to manage. Additional QoS functions are required
Packet delay variation	low	Occurred
Applied Service Type	D1, D2 and D3	D3 and D4

Figure 17. Examples of Flexible Bridging Service transponder

History

Revision	Release Date	Summary of Changes
1	November 2022	Initial Release