Functional Architecture for Multi-domain IOWN Networking

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Legal

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1. Introduction

Open All-Photonic Network (APN) defined in [1] by the IOWN Global Forum (IOWN GF) delivers a connectivity with deterministic Quality of Service (QoS) and high energy efficiency. To deliver such connections to wider industries and more customers with enhanced scalability, reliability, and flexibility, Multi-domain IOWN Networking aims to realize the interconnection of Open APNs operated by different organizations. Such interconnections among Open APNs of different organizations are not explicitly described in [1] while user-owned APN-Ts are described in the Annexes. Multi-domain IOWN Networking enables interconnected Open APNs by multiple Open APN service providers, not only carrier but also other organizations such as data center (DC) providers. By interconnecting multiple Open APN domains, optical wavelength path reach can be expanded to wider geographical areas, and more optical redundant paths also can be prepared. In addition, flexible control of computing across different domains allows more efficient resource utilization.

NOTE: The control of computing resource itself is not scope of this document and FFS.

Interconnecting Open APNs of different organizations involves several new technical challenges as follows:

- Framework for information exchange that achieves desired features, such as on-demand path provisioning and automated fault recovery, without forcing providers to expose all details about their infrastructures, such as topology and capacity
- Mechanism that enables APN providers to monitor the quality of optical signals without spoiling the advantage of optical peering
- Mechanism that enables APN providers to protect their networks from unadmitted signals without spoiling the advantage of optical peering

To address the above challenges, this document aims to define a functional architecture for Multi-domain IOWN Networking to realize the interconnection of Open APNs by different organizations.

The document covers the following aspects:

- Describe scenarios where Multi-domain IOWN Networking is utilized, key features, and functional requirements
- Define a functional architecture for Multi-domain IOWN Networking to meet the requirements
- Describe example sequences for operation in Multi-domain IOWN Networking

2. Requirements for Multi-domain IOWN Networking

This section describes the application scenarios, key features, and the list of requirements for Multi-domain IOWN Networking.

2.1. Application Scenarios

When considering general multi-domain scenarios, optical networks operated by various organizations, such as carrier, DC provider, cloud service provider, research and academic institution, and campus/building/wireless tower owner, are interconnected as shown in Figure 1, where Open APNs operated by different organizations are directly adjacent to one another. By establishing such interconnection among various APN providers, large networking space with high bandwidth, low latency, and high energy efficiency could be realized as social infrastructure for a cyber-physical society. In addition, resilience for disaster recovery could be realized by connecting different organizations, where one organization provides an optical path between two end-points with a certain route and another organization provides an optical path between the same end-points with a different route.

This section describes example scenarios where Multi-domain IOWN Networking is applied by using the existing IOWN GF Early Adoption Use Cases.

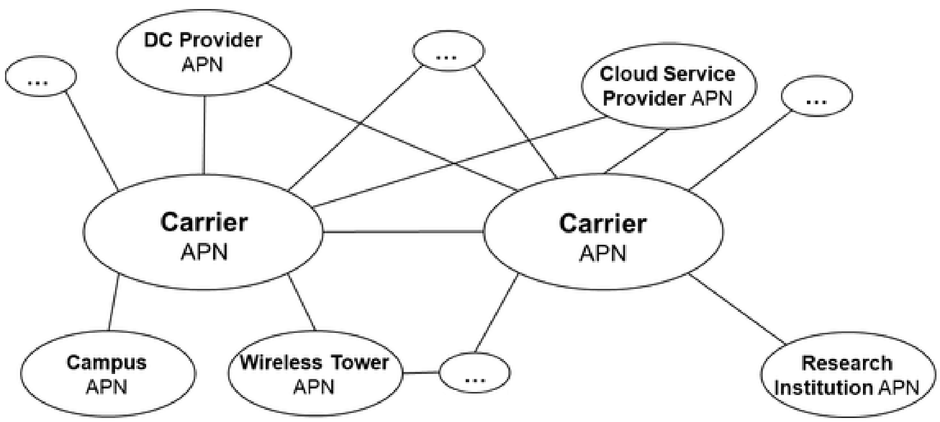

Figure 1: Interconnected Open APNs of Various Organizations

2.1.1. Scenario 1: Carrier - Carrier

In the reference case of Media Production Resource Sharing described in Section 4.1 of [2], when each Broadcast Station and Media Production Center are geographically separated, Multi-domain IOWN Networking could be applied, involving multiple carriers (e.g., Carrier X and Carrier Y). In such a geographically wide-area scenario, multi-domain network composition enables broadcast companies to connect wider areas using optical networks of multiple carriers. Figure 2 shows a structure of Multi-domain IOWN Networking applied in this scenario.

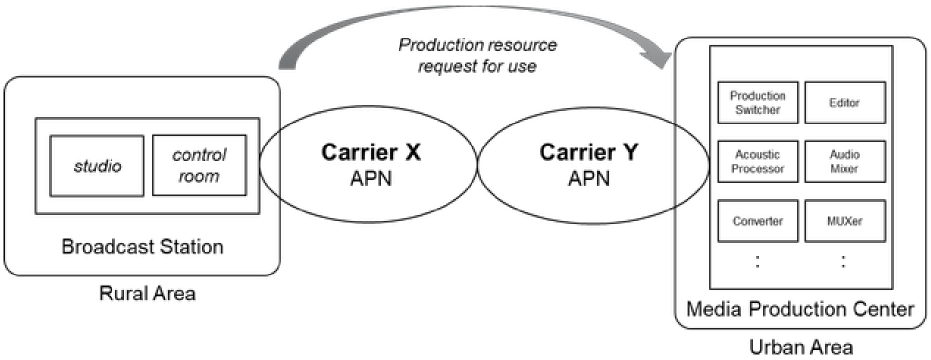

Figure 2: Structure of Carrier - Carrier Scenario

2.1.2. Scenario 2: DC Provider - Carrier - Campus

In the reference case of Remote GPU over Open APN described in Section 4.1 of [3], when Green Data Center that owns GPU computing and User Site that owns the training data storage are connected by DC provider's APN, WAN Carrier's APN, and Campus APN provided by the owner of campus where User Site is located, they can apply Multi-domain IOWN Networking. With the evolution of transmission systems that enables to downsize optical devices with open interfaces, not only telecom carriers but also other organizations such as DC provider and campus owner can operate their own APN in their managed area. Figure 3 shows a structure of this scenario.

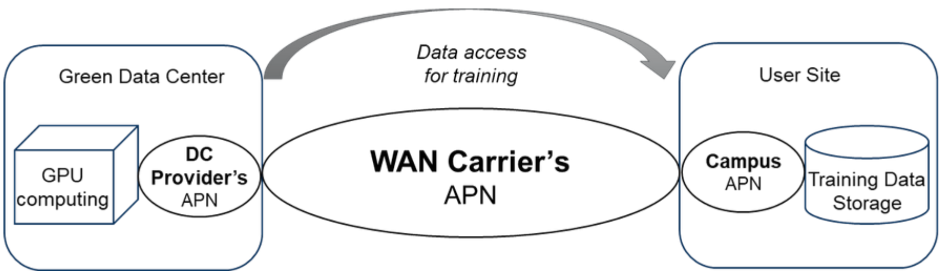

Figure 3: Structure of DC Provider - Carrier - Campus Scenario

2.1.3. Scenario 3: Multiple Carriers - DC Providers

In the reference case of Inter-regional Back-Ups and Migration to Improve Resiliency in Section 3.2 of [4], when DC provider A in Region A uses their own APN inside the region and Carrier X outside the region for WAN connection and DC provider B in Region B uses their APN inside and Carrier Y for WAN, Multi-domain IOWN Networking could be applied to connect two DCs located in a different region. Figure 4 presents a structure of Multi-domain IOWN Networking applied in this scenario.

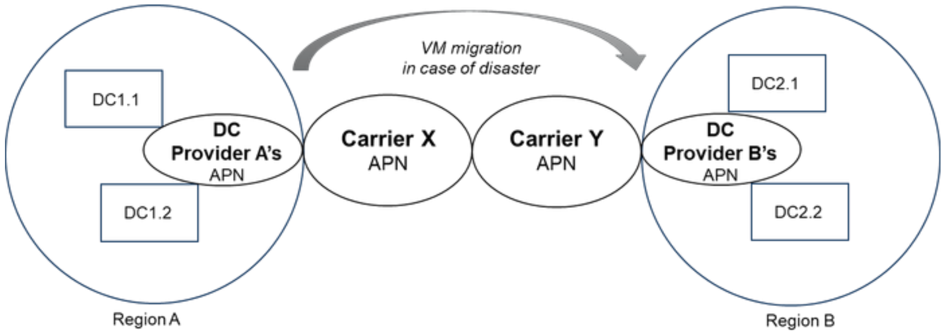

Figure 4: Structure of Multiple Carriers - DC Providers Scenario

2.2. Key Features

This section describes two key features of Multi-domain IOWN Networking, on-demand path provisioning and automated fault recovery. A scenario of two organizations such as scenario 1 in Section 2.1 is used as a basic case.

NOTE: Other features (e.g., infrastructure sharing) and different scenarios (e.g., more than three organizations) will be studied in the future document.

2.2.1. On-demand Path Provisioning

This section describes on-demand path provisioning of end-to-end connectivity service using Open APN across two domains (Organization X and Y). Figure 5 shows the steps of on-demand path provisioning. User in the figure is a consumer of end-to-end connectivity service using Open APN. In this figure, Multi-domain IOWN Networking is realized by the IOWN-GF Infrastructure management and control plane (M/C-plane) and IOWN-GF Infrastructure user plane (U-plane) in provisioning.

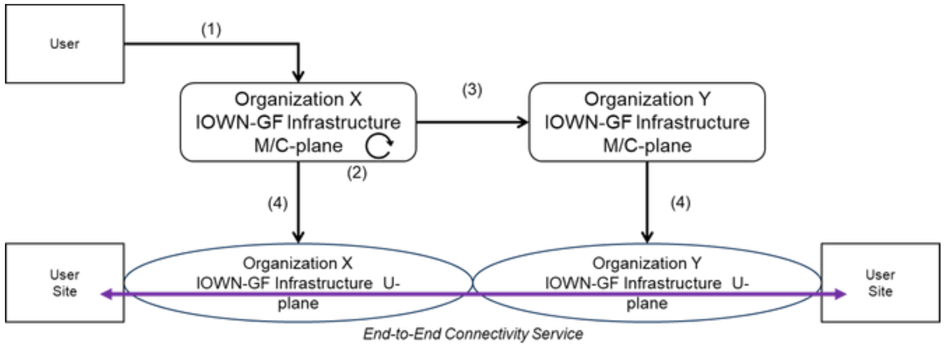

Figure 5: On-demand Path Provisioning

The detail of each step is as follows.

(1) A user who needs an end-to-end connectivity service using Open APN sends a request to an APN service provider (Organization X).

(2) IOWN-GF Infrastructure M/C-plane of Organization X designs an end-to-end connection using optical path. If the customer request cannot be met only with the resources of X, X coordinates with another APN service provider (Organization Y) to deliver the path. For coordination, M/C-plane of X designs an end-to-end connection with the network resource information of X and that of Y.

(3) M/C-plane of X sends a request for support to M/C-plane of Y according to the path design created in the previous step. In this case, X provides a part of end-to-end connection while Y provides the other part of it. Therefore, the request

sent from X to Y contains the information required for establishing an optical path that is expected to be delivered by Y. After checking the internal information, M/C-plane of Y replies to M/C-plane of X with the information for end-to-end connection including an interconnection point.

(4) According to the time requested by the user, M/C-plane of X initiates the path provisioning. M/C-plane of X configures equipment of X while configuring equipment of Y by the coordination of M/C-plane of X and Y. The notification is sent to the user after the end-to-end connectivity service is established.

2.2.2. Automated Fault Recovery

This section describes automated fault recovery of end-to-end connectivity service provisioned in the previous section. Figure 6 shows the steps of automated fault recovery.

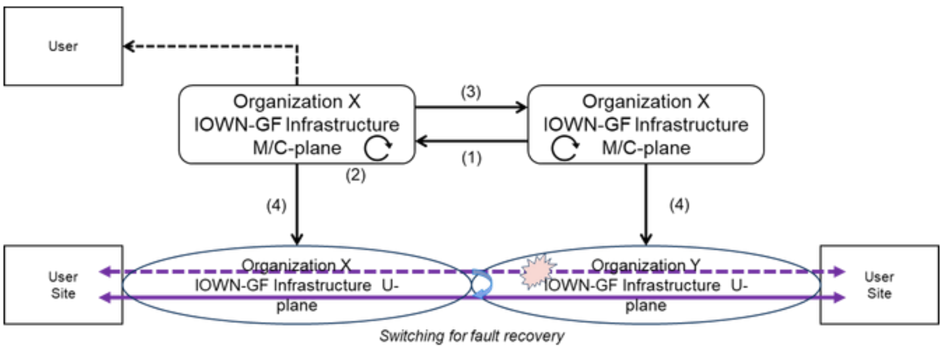

Figure 6: Automated Fault Recovery

The detail of each step is as follows.

(1) If a failure occurs on the optical path provisioned by Organization Y, IOWN-GF Infrastructure M/C-plane of Y detects a failure by analysing quality information collected from IOWN-GF Infrastructure U-plane and notifies to Organization X of trouble occurrence.

(2) M/C-plane of X checks the policy for fault recovery set in the end-to-end connection where the affected path of Y is included. In this case, a redundant path that is expected to be provided by the same organization Y is set in the fault recovery policy.

(3) M/C-plane of X sends a request for switching to M/C-plane of Y according to the policy. M/C-plane of Y replies to M/C-plane of X with the information for switching path including an interconnection point. If the redundant path is not available causing SLA violation, the notification is sent to the user.

(4) For fault recovery, M/C-plane of X initiates the path switching. M/C-plane of X configures equipment of X while configuring equipment of Y by the coordination of M/C-plane of X and Y.

2.3. Requirements

2.3.1. Functional Requirements

This section describes functional requirements of Multi-domain IOWN Networking. These functional requirements are divided into two aspects. One is the requirement for M/C-plane, which are described in Section 2.3.1.1. The other is the requirement for U-plane in Section 2.3.1.2.

2.3.1.1. Management and Control Plane

Functional requirements for management and control plane are collected according to three operation steps (Design, Setup, Monitoring). The requirements for the M/C-plane of IOWN GF infrastructure are listed in Table 1.

Table 1: Functional Requirements for Management and Control Plane

NO.	OPERATION STEP	REQUIREMENT
FUNC-REQ-MC-1	Design	The M/C-plane of IOWN GF infrastructure shall support the capability to receive a creation/update/delete request for a connectivity service using Open APN from a user (e.g., DCI Infrastructure Orchestrator).
FUNC-REQ-MC-2	Design	The M/C-plane of IOWN GF infrastructure shall support the capability to store and read network resource information (e.g., end-point, available wavelength) under its control.
FUNC-REQ-MC-3	Design	The M/C-plane of IOWN GF infrastructure shall support the capability to exchange network resource information (e.g., end-point, available wavelength) with authorized other domains that is abstracted enough to keep confidentiality.
FUNC-REQ-MC-4	Design	The M/C-plane of IOWN GF infrastructure shall support the capability of path design considering network resource availability to establish a connectivity service that is requested from a user including options to utilize Open APN in authorized other domains as part of the connectivity service.
FUNC-REQ-MC-5	Design	The M/C-plane of IOWN GF infrastructure shall support the capability to send a request for support to create/update/delete an optical path utilized as part of a connectivity service to authorized other providers with necessary information (e.g., end-point) in a confidential manner.
FUNC-REQ-MC-6	Design	The M/C-plane of IOWN GF infrastructure shall support the capability to receive a request for support from authorized other providers with necessary information to create/update/delete an optical path utilized as part of a connectivity service.
FUNC-REQ-MC-7	Design	The M/C-plane of IOWN GF infrastructure shall support the capability to determine whether the path requested from authorized other providers can be established and send a decision result to a requester with additional information (e.g., available wavelength, cost).
FUNC-REQ-MC-8	Setup	The M/C-plane of IOWN GF infrastructure shall support the capability of coordination with authorized other providers for an establishment of end-to-end connectivity.
FUNC-REQ-MC-9	Setup	The M/C-plane of IOWN GF infrastructure shall support the capability to configure equipment at the border with authorized other domains to create/update a connectivity service.
FUNC-REQ-MC-10	Setup	The M/C-plane of IOWN GF infrastructure shall support the capability to remove configurations of equipment at the border with authorized other domains to delete a connectivity service.
FUNC-REQ-MC-11	Setup	The M/C-plane of IOWN GF infrastructure shall support the capability to notify a user and authorized other providers that deliver their Open APN for support of a result of creation/update/delete request for a connectivity service.

FUNC-REQ-MC-12	Monitoring	The M/C-plane of IOWN GF infrastructure shall support the capability to collect alarms and/or performance data from equipment at the border with authorized other domains.
FUNC-REQ-MC-13	Monitoring	The M/C-plane of IOWN GF infrastructure shall support the capability to detect and analyze a failure/degradation of a connectivity service.
FUNC-REQ-MC-14	Monitoring	The M/C-plane of IOWN GF infrastructure should support the capability to maintain a connectivity service upon a failure/degradation by taking some action (e.g., rerouting) in coordination with authorized other providers.
FUNC-REQ-MC-15	Monitoring	The M/C-plane of IOWN GF infrastructure shall support the capability to notify authorized other providers that deliver their Open APN for support of failure/degradation occurrence in a connectivity service.
FUNC-REQ-MC-16	Monitoring	The M/C-plane of IOWN GF infrastructure should support the capability to notify a user of a change in the connectivity service (e.g., route change).

2.3.1.2. User Plane

In this section, the functional requirements for the user plane are collected with three aspects (Connection, O&M, Security). The requirements for the U-plane of IOWN GF infrastructure are listed in Table 2.

Table 2: Functional Requirements for User Plane

NO.	TYPE	REQUIREMENT
FUNC-REQ-U-1	Connection	The U-plane of IOWN GF infrastructure should support the capability to connect different Open APNs operated by different organizations by optical wavelength without electrical conversion.
FUNC-REQ-U-2	Connection	The U-plane of IOWN GF infrastructure should support the capability to connect different Open APNs operated by different organizations using upper layer than optical such as OTN, Ethernet, and IP.
FUNC-REQ-U-3	Connection	The U-plane of IOWN GF infrastructure shall support the capability to drop abnormal incoming optical signals, OTN and Ethernet frames, and IP packets from Open APNs of different organizations that do not meet the negotiated conditions (e.g., higher optical input level).
FUNC-REQ-U-4	O&M	The U-plane of IOWN GF infrastructure shall support the capability to configure itself based on the configuration and policy information received from the M/C-plane of IOWN GF infrastructure to establish a requested connection.
FUNC-REQ-U-5	O&M	The U-plane of IOWN GF infrastructure shall support the capability to collect performance data about interfaces connected with different Open APNs (e.g., level of light received/transmitted, amount of traffic received/transmitted, number of errors) and send this information to the M/C-plane of IOWN GF infrastructure periodically.
FUNC-REQ-U-6	O&M	The U-plane of IOWN GF infrastructure shall support the capability to detect events (e.g., interface down) related to interfaces connected with different Open APNs and reports them immediately to the M/C-plane of IOWN GF infrastructure.
FUNC-REQ-U-7	O&M	The U-plane of IOWN GF infrastructure shall support the capability to send optical monitoring signals such as OTDR to the connected different Open APNs for troubleshooting disconnection/quality degradation.

FUNC-REQ-U-8	Security	The U-plane of IOWN GF infrastructure shall support the capability to restrict access privileges only to the owners of Open APN when it is connected to different Open APNs.

NOTE: At least one of FUNC-REQ-U-1 and FUNC-REQ-U-2 need to be supported for interconnecting different Open APN domains.

2.3.2. Non-functional Requirements

For Further Study.

3. Functional Architecture for Multi-domain IOWN Networking

Section 2 describes the requirements for the M/C-plane and U-plane of IOWN GF infrastructure to connect one Open APN domain with another domain of different APN provider. This section describes the high-level architecture and defines functions for each newly required element to fulfill these requirements.

3.1. High-level Architecture

3.1.1. Overall Architecture for Multi-domain IOWN Networking

The high-level architecture for Multi-domain IOWN Networking supports to provide an end-to-end connectivity service across multiple domains of different APN providers using Open APN defined in Section 2 of [1]. This architecture consists of M/C-plane, and U-plane, as shown in Figure 7. M/C-plane contains Multi-domain Orchestrator, Border Gateway Controller (BG-C), and APN Controller (APN-C) to establish an end-to-end connection using Open APN including interconnection of multiple APN domains provided by different organizations. U-plane contains APN-T, APN-G, APN-I, and Border Gateway (BG) to transmit user data in optical signals including interconnection links between BGs. In this architecture, different APN domains are directly adjacent to one another with the interconnection points of BG and Multi-domain Orchestrator that are owned and managed by APN provider of each domain.

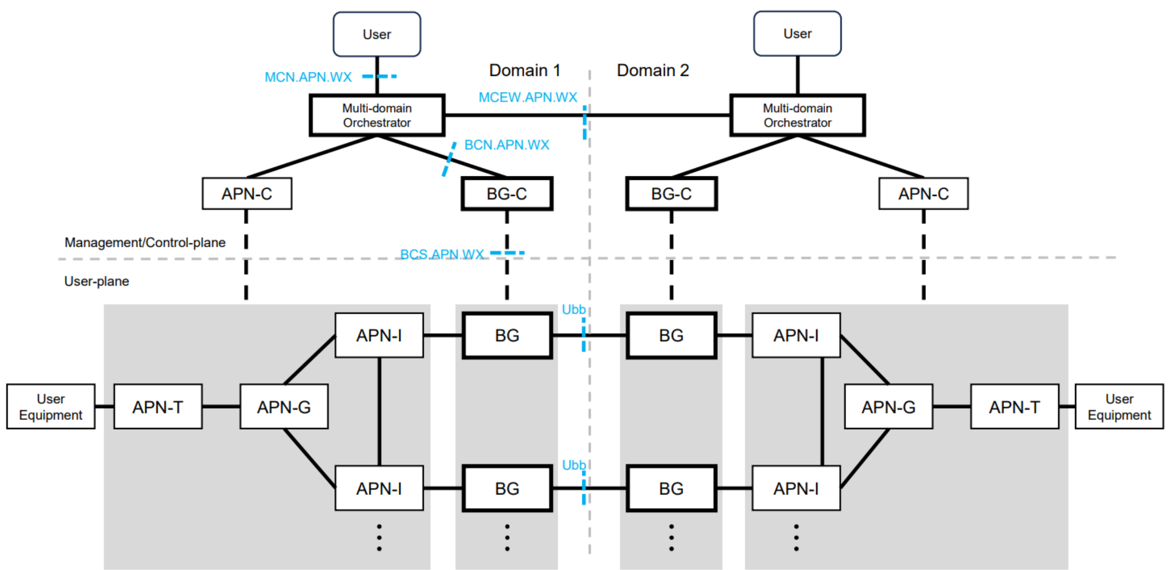

Figure 7: High-level Architecture for Multi-domain IOWN Networking

When a user requests an end-to-end connectivity service using Open APN for deterministic QoS and high energy efficiency and the requested service cannot be established only by one APN domain, the M/C-plane negotiates the information necessary for connecting different APN domains (e.g., connection interface, wavelength) and transfers the detailed information for configuring the U-plane nodes. Each node (APN-T, APN-G, APN-I, and BG) that comprises the U-plane configures itself according to the configuration information to establish an end-to-end connection across multiple APN domains. Table 3 summarizes the responsibilities of each newly introduced element in this architecture. More detailed definitions of each element are provided in the following sections.

Table 3: Elements in High-level Architecture for Multi-domain IOWN Networking

ELEMENT	PLANE	DESCRIPTION
Multi-domain Orchestrator	M/C-plane	Multi-domain Orchestrator is an orchestrator for setup of optical paths in multiple or single Open APN domains. Multi-domain Orchestrator negotiates and requests the setup of paths with orchestrators of other Open APN domains. Multi-domain Orchestrator also requests the setup of the paths and configurations of BG to the controllers (APN-C and BG-C) within its own Open APN domain.
Border Gateway Controller (BG-C)	M/C-plane	Border Gateway Controller (BG-C) is a controller for BG and provides functions related to control and management of BG, such as equipment registration, resource management, configuration management, and quality management.
Border Gateway (BG)	U-plane	Border Gateway (BG) is a gateway in U-plane that is the interconnection point for different Open APN domains. BG exchanges optical signals with BG in another domain directly.

Interface reference points that are newly introduced in Figure 7 are defined as follows:

- Ubb: User plane interface between BG and BG.
- MCN.APN.WX: Management and control plane interface to expose management and control plane functions of the Multi-domain Orchestrator to User.
- MCEW.APN.WX: Management and control plane interface to expose management and control plane functions of the Multi-domain Orchestrator of own domain to the Multi-domain Orchestrator of another domain.
- BCN.APN.WX: Management and control plane interface to expose management and control plane functions of BG-C to the Multi-domain Orchestrator of own domain.
- BCS.APN.WX: Management and control plane interface for configuring and managing BG.

NOTE: The interface and API details of these reference points will be studied in the future document.

3.1.2. Functional Split: Orchestrator and Controller

This section describes the function split between Orchestrator (Multi-domain Orchestrator) and Controller (APN-C and BG-C). As illustrated in Figure 7, Multi-domain Orchestrator manages multiple controllers and the functional split with the controllers needs to be considered mainly in terms of scalability. More specifically, if Multi-domain Orchestrator, which manages large-scale networks, carries out device-level management (device management, configuration management, quality management etc.) of APN-T, APN-G, and APN-I, the amount of information that needs to be stored and processed by Multi-domain Orchestrator would significantly increase, resulting in performance degradation such as severe processing delay. Therefore, such device-level management needs to be delegated to controllers, and Multi-domain Orchestrator only performs domain-level management.

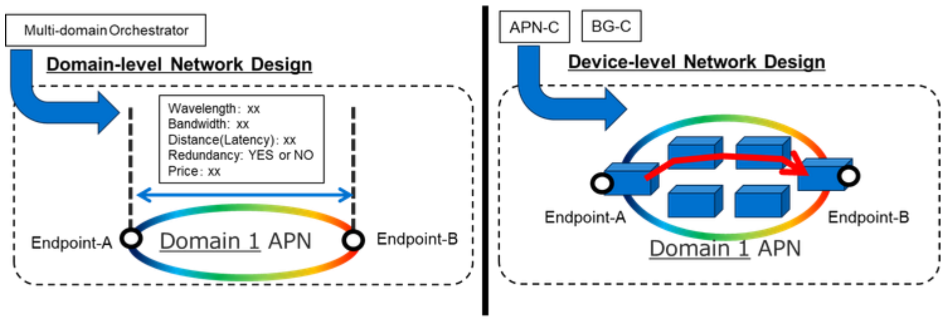

Figure 8: Functional Split: Orchestrator and Controller (Example of Network Design)

As shown in Figure 8, domain-level management corresponds to management including resource management, optical path management, and quality management between end-points that form the boundary of APN domain and eliminates detailed information on intermediate nodes. This abstraction of information and delegation of functions improves the scalability of the Multi-domain Orchestrator.

NOTE: The detailed method of abstracting device-level network resource information as domain-level information is FFS.

3.1.3. Functional Split: APN-C and BG-C

In this section, the functional split between the APN-C defined in Section 3 of [1] and the BG-C introduced in this document is described. APN-C is defined as '*a controller with the functions of Open APN Control and Management plane*' [1] and is a logical entity that controls the Open APN Wavelength Exchange (Open APN.WX) and the Open APN Fiber Exchange (Open APN.FX) On the other hand, BG-C is a controller for the BG, which is described in detail in Section 3.4.

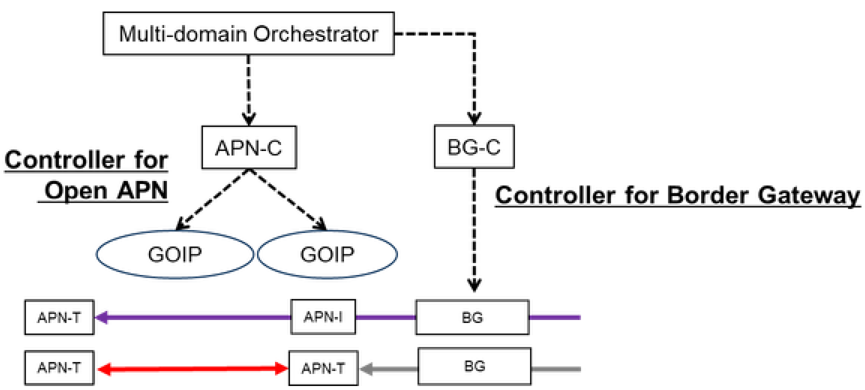

Figure 9: Functional Split: APN-C and BG-C

As depicted in Figure 9, this functional split means that APN-C is responsible for controlling end-points (APN-T, APN-I etc.) of wavelength paths and fiber paths within the domain under its control, and BG-C is responsible for controlling and managing BG, which is the interconnection point between different APN domains. BG-C is also a logical entity, and the implementation details are not specified or restricted in this document. Figure 9 is an example where APN-C and BG-C are implemented in a different server/VM/container. Additionally, another potential example is to integrate the BG-C functions for BG into the APN-C implementation. This integration can result in reduced operation cost and simplified network control and management.

NOTE: Recommendations for controller implementation will be described in future documents.

3.1.4. Example Sequence: Path Provisioning in Multi-domain IOWN Networking

Figure 10 shows the diagram of path provisioning, where a user who needs an end-to-end connectivity service using Open APN requests it and the path is setup across multiple domains. When receiving a path creation/update/delete request from a user (e.g., via customer portal, API) (1), Multi-domain Orchestrator negotiates path design with other domains (2). According to the negotiation result, Multi-domain Orchestrator requests BG-C and APN-C to create the path. BG-C controls BG to communicate with BGs in other domains (3). APN-C controls Open APN devices such as APN-T, APN-G, and APN-I which are notated APN-X in Figure 10 (4).

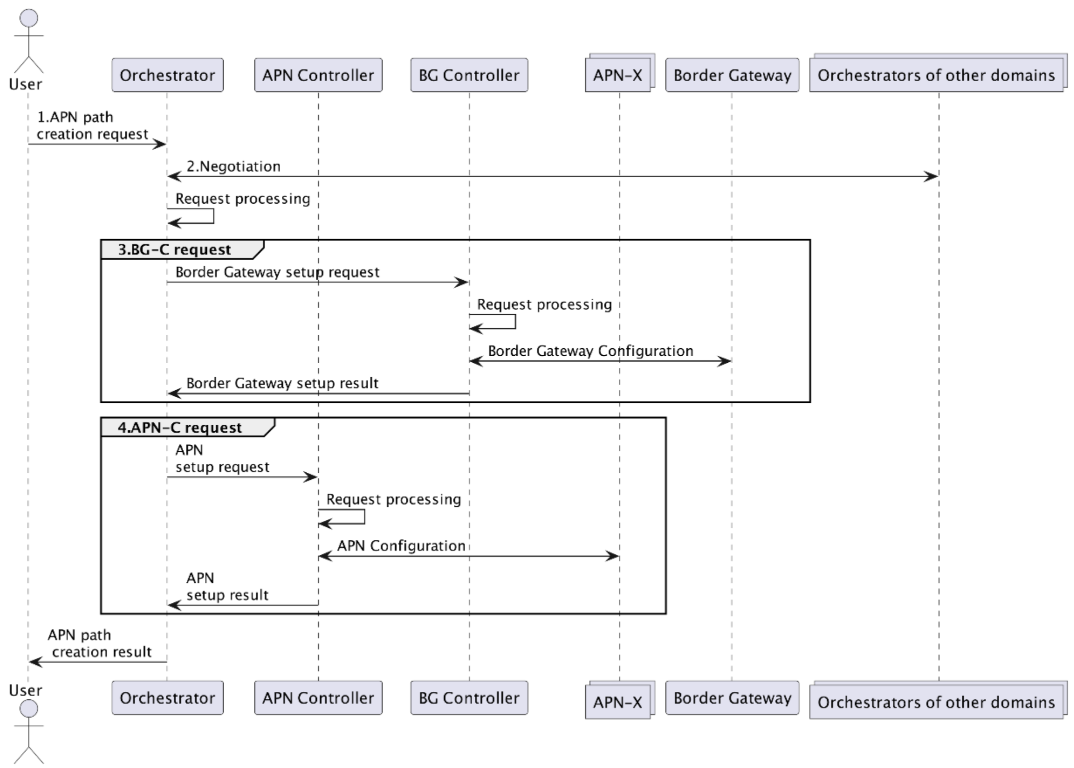

Figure 10: Example Sequence Diagram of Path Provisioning

3.2. Multi-domain Orchestrator

3.2.1. General Concept of Multi-domain Orchestrator

This section explains the general concept of Multi-domain Orchestrator, which is an element that performs overall coordination of multi-domain Open APN connections. Figure 11 shows the internal functional blocks of the Multi-domain Orchestrator.

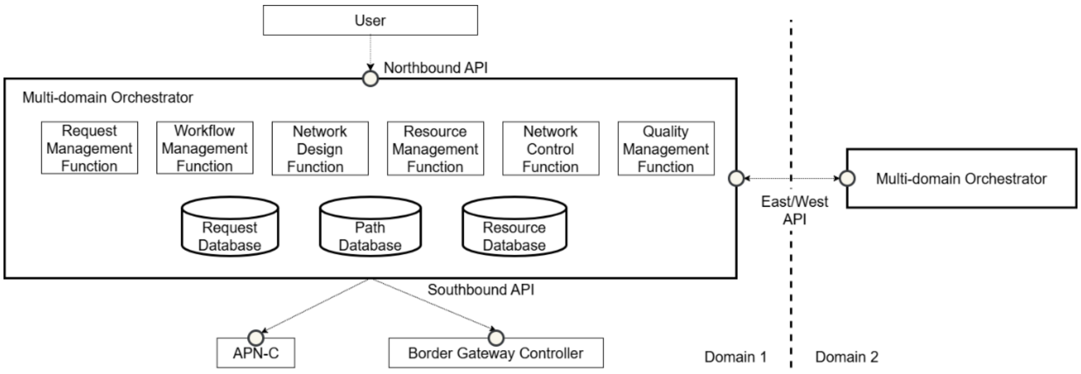

Figure 11: Multi-domain Orchestrator Functional Block

As shown in Figure 11, the Multi-domain Orchestrator is equipped with multiple functional blocks, databases, and APIs (Northbound, East/Westbound, and Southbound APIs). The Multi-domain Orchestrator receives requests from users to establish Open APN paths through Northbound API (MCN.APN.WX), and (if necessary) requests another Multi-domain Orchestrator of a different domain to establish another domain's APN path through East/West API (MCEW.APN.WX) and then establishes the APN path within its own domain via Southbound API (CN.APN.WX [1] and BCN.APN.WX). Furthermore, Table 4 briefly explains the roles of each functional block and database of the Multi-domain Orchestrator, and specifies the relevant requirements specified in Section 2.3. In particular, since the Multi-domain Orchestrator is an element for the M/C-plane, the applicable requirements are summarized in Section 2.3.1.1.

NOTE: The functions of Multi-domain Orchestrator may be included in the Infrastructure Orchestrator described in the documents of [1] and [5]. The definition of the Infrastructure Orchestrator and/or the relationship with it will be described in future documents in align with relevant documents.

Table 4: Multi-domain Orchestrator Function and Database

FUNCTION/DATABASE	DESCRIPTION	RELATED REQUIREMENT
Request Management Function	A function that processes the request for Open APN path establishment received from user	FUNC-REQ-MC-1 FUNC-REQ-MC-11 FUNC-REQ-MC-16
Workflow Management Function	A function that manages each workflow (e.g., path calculation, path creation) and issues instructions to each function and database	FUNC-REQ-MC-4 FUNC-REQ-MC-14
Network Design Function	A function that performs domain-level network design based on the user request and network resources	FUNC-REQ-MC-4 FUNC-REQ-MC-5 FUNC-REQ-MC-6 FUNC-REQ-MC-7
Resource Management Function	A function that manages the network resources (e.g., available wavelength) of own domain's Open APN	FUNC-REQ-MC-2
Network Control Function	A function that controls (creates/updates/deletes) the Open APN path of own domain and other domains	FUNC-REQ-MC-8 FUNC-REQ-MC-9 FUNC-REQ-MC-10 FUNC-REQ-MC-11

Quality Management Function	The function that continuously monitors the quality of the established Open APN path and detects SLA-violation event	FUNC-REQ-MC-12 FUNC-REQ-MC-13 FUNC-REQ-MC-14 FUNC-REQ-MC-15 FUNC-REQ-MC-16
Request Database	A database that stores the request information, status, and historical data of path establishment requests from user and processed by the Request Management Function	FUNC-REQ-MC-1 FUNC-REQ-MC-11 FUNC-REQ-MC-16
Path Database	A database that stores information and status of Open APN paths that are designed by the Network Design Function and established by the Network Control Function	FUNC-REQ-MC-8 FUNC-REQ-MC-9 FUNC-REQ-MC-10 FUNC-REQ-MC-11 FUNC-REQ-MC-12 FUNC-REQ-MC-13 FUNC-REQ-MC-14 FUNC-REQ-MC-15
Resource Database	A database that stores the network resource information for own domain's Open APN obtained by the Resource Management Function.	FUNC-REQ-MC-2

3.2.2. Inter-domain Negotiation via Multi-domain Orchestrator

As described in 3.1, the role of the Multi-domain Orchestrator is to connect different Open APN domains that are adjacent through one or more BGs. This section explains the inter-domain negotiation that Multi-domain Orchestrator performs with different domains to fulfill this role.

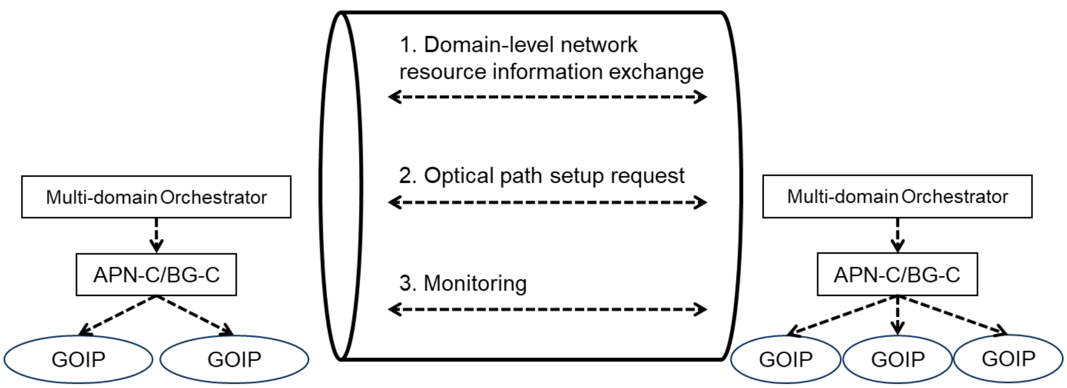

Figure 12: Inter-domain Multi-domain Orchestrator Negotiation

As shown in Figure 12, the negotiation performed by Multi-domain Orchestrator includes 1) domain-level network resource information exchange, 2) optical path setup request, and 3) monitoring.

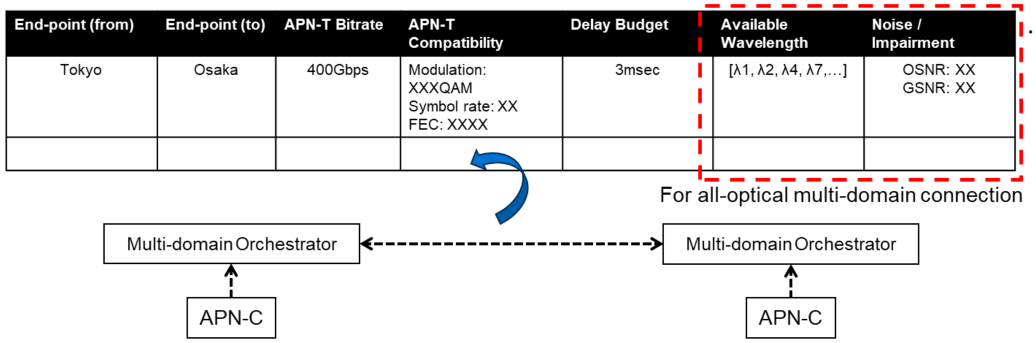

Figure 13: Domain-level Network Resource Information Exchange

First, in 1) domain-level network resource information exchange, Multi-domain Orchestrator provides information on available Open APN resources that can be provided in its own domain to other domains. As explained in Section 3.1.2, Multi-domain Orchestrator performs abstracted domain-level design and control, therefore this network resource information is also exchanged with the abstracted domain-level granularity. The information required for wavelength path design and setup is defined in Section 3.3.4.1 of [1]. As depicted in Figure 13, this information is aggregated into the abstracted information for each combination of end-points where BG is deployed, and the information is exchanged between the Multi-domain Orchestrators. Additionally, it is also possible to exchange business-related information of each network resource. For on-demand optical path service using such information, it is necessary to exchange service catalog information (e.g., pricing per wavelength channel, subscription period).

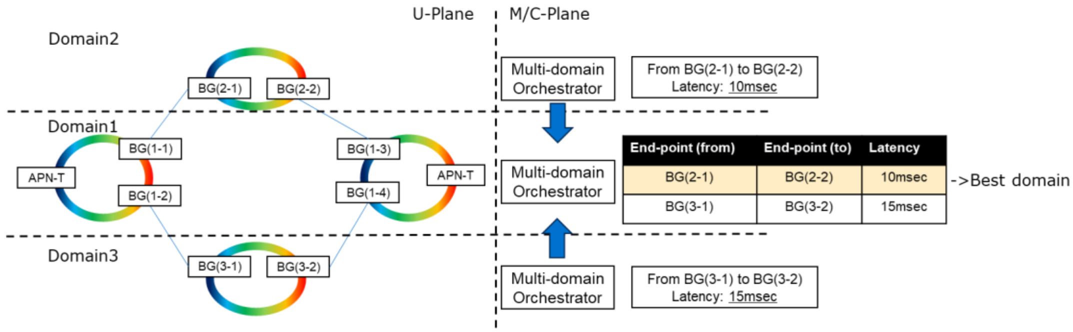

Figure 14: Example of Domain Selection

Figure 14 illustrates an example of domain selection that is necessary before path setup. In this example, Domain1 requests other domains (Domain 2 and Domain 3) to provide an optical path for core network. If the user request prefers a lower latency in the connection, Domain 2, which has less delay than Domain 3, is selected in this case. Furthermore, it is necessary to specify its own BGs that connect to other domains. In this example, Domain2 notifies optical path resource information between BG (2-1) and BG (2-2), which are the BGs of Domain2, and BG (1-1) and BG (1-3) need to become the BGs of Domain1 for establishing respective connection with Domain2. Thus, a method is required for linking the identifiers of the sender/receiver end-points specified by the resource information of other domains with its own BGs. The detailed method for that is not defined or restricted in this document, but for example, an outbound communication protocol between Multi-domain Orchestrators could be used in M/C-plane, or an information exchange protocol such as Optical Supervisory Channel (OSC) could be used in U-plane, or the mapping database between BGs could be created and maintained offline between human administrators of each domain.

NOTE: The domain selection method needs to take into account non-functional requirements such as scalability (the number of domains) and processing speed at M/C-plane, and a specific decision algorithm will be described in future documents.

In the second step of negotiation, 2) optical path setup request, a setup request is issued to another domain for an optical path. As mentioned in Section 3.1.2, the setup request only includes abstracted information between the end-points of the optical path to be established in the other domain and does not include detailed information such as entire explicit-route information. To request for a redundant path, it is necessary to send a setup request such as “path that is completely diverse from the already existing path.”

Finally, in 3) monitoring, quality and event information on the established optical path is collected from other domains. Quality information on the optical path is sent periodically (e.g., every 10 minutes) from the Multi-domain Orchestrator of the other domain that requested it, or the Multi-domain Orchestrator of the requesting domain itself may request it. Event information, such as failure occurrence in the optical path due to fiber cut etc., is sent in an event-driven way. Therefore, it is sent immediately from the Multi-domain Orchestrator of other domains when some events occur in other domains.

NOTE: The detailed information including interface for monitoring and required time for failure detection will be described in future documents.

3.2.3. Example Sequence: Path Creation Request Handling in Multi-domain Orchestrator

Figure 15 shows how the APN path creation request is processed within the Multi-domain Orchestrator. After the initial processing of the user’s APN path creation request is completed at the Request Management Function, there are two major phases: 1) Network design and 2) Path creation.

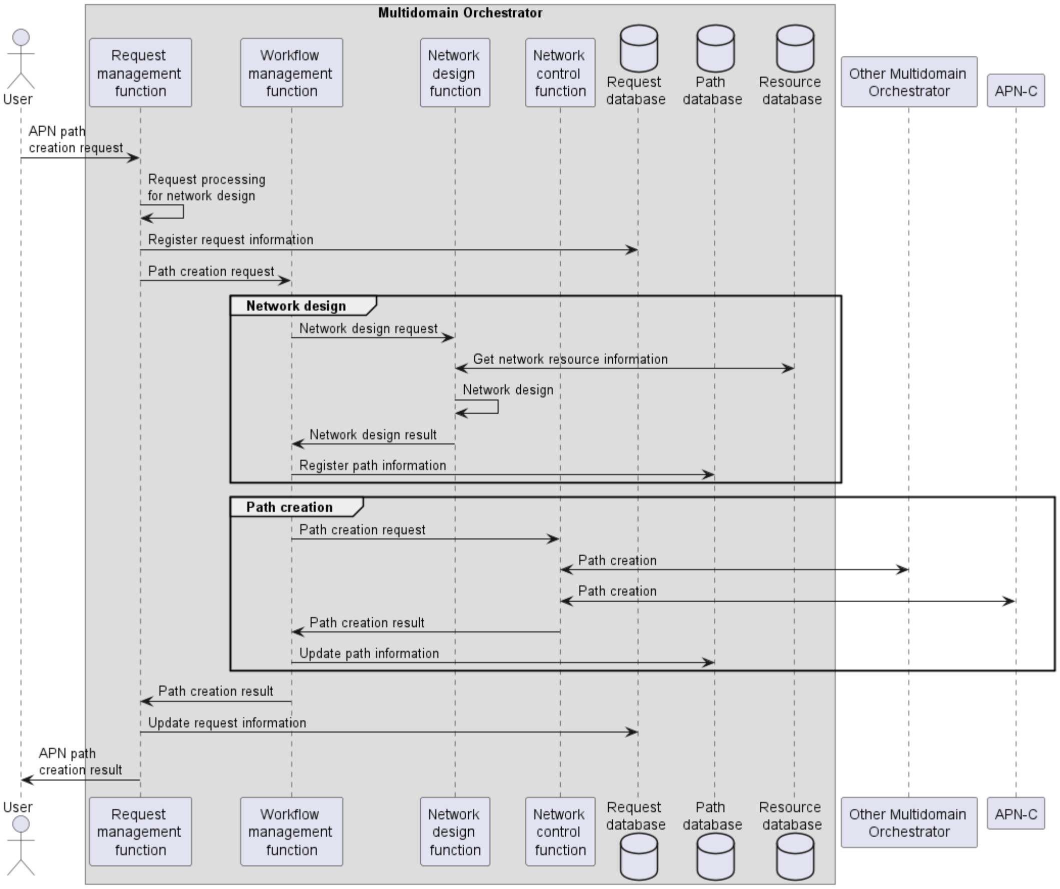

Figure 15: Example Sequence Diagram for Path Creation Request Handling

In the 1) Network design phase, the Open APN path that satisfies the user request is designed for each domain. For the network design, the Multi-domain Orchestrator is required to collect the resource information (e.g., available wavelength) for APN of each domain. First, the APN resource information of its own domain is received periodically from the controllers (APN-C and BG-C) responsible for its own domain. Second, as described in Section 3.2.2, the APN resource information of other domains is received (e.g., periodically or on-demand) from the Multi-domain Orchestrator of other domains. As APN resource information is potentially confidential, it is necessary to share only the minimum amount of information required for network design, by performing some kind of abstraction or anonymization process. Based on the obtained resource information, the Multi-domain Orchestrator decides which section (e.g., end-point A to end-point B) of the path is to be handled by each domain (domain selection). The decision of domain selection is performed in the Network design phase. For example, if multiple domains can provide the same quality of APN path in the same section, a design policy that prioritizes economic rationality, such as selecting the cheaper domain, could be considered.

Next, in the 2) Path creation phase, the Network Control Function mainly requests the creation of APN paths for each domain based on the results of the network design. As described above, the information from other domains is abstracted or anonymized, making it difficult to create a precise network design. Therefore, in this phase, it is necessary to negotiate the detailed connection conditions (e.g., wavelength) among different Multi-domain Orchestrators. It is possible that the APN path cannot be deployed under the negotiated conditions in the Path creation phase. In such a case, the process should be restarted from the Network design phase and other network designs (e.g., utilizing other domains, higher latency conditions) should be examined. In the worst case, if there is no available network design that satisfies the user's request, the Multi-domain Orchestrator would propose an alternative to the user or notify that the request is infeasible.

3.3. Border Gateway Controller

3.3.1. General Concept of Border Gateway Controller

This section explains the general concept of Border Gateway Controller, which is an element that controls resource, configuration, and quality management of Border Gateway. Figure 16 shows the internal functional blocks of BG-C.

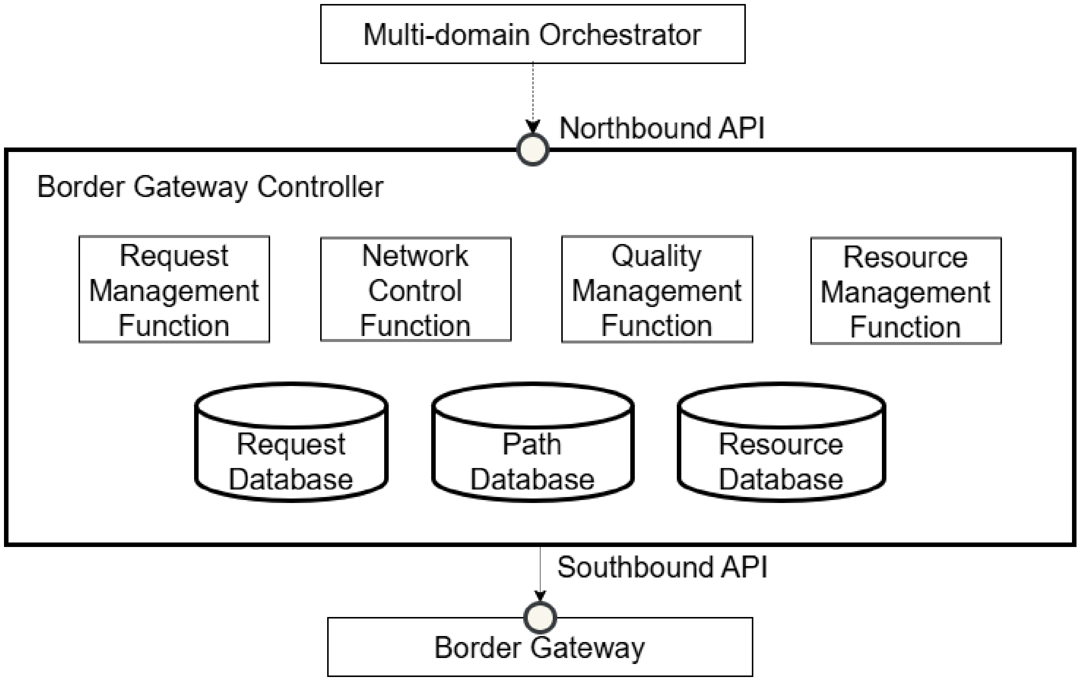

Figure 16: Border Gateway Controller Functional Block

As shown in Figure 16, BG-C is equipped with multiple functional blocks, databases, and APIs (Northbound and Southbound API). BG-C receives requests from the Multi-domain Orchestrator to configure BG for establishing an APN path across multiple domains via Northbound API (BCN.APN.WX) and controls BG within its own domain via Southbound API (BCS.APN.WX) for resource, configuration, and quality management. There are no restrictions on the relationship between BG-C and BG. Specifically, it is possible for one BG-C to control multiple BGs, or for one BG to be connected to multiple BG-Cs for the purpose of redundancy.

NOTE: If multiple BG-Cs control the same BG simultaneously, there is a concern of conflicting request. Therefore, even if such a situation is allowed for redundancy, BG-C needs to adopt an Active/Standby configuration to prevent such conflict.

Table 5 briefly explains the roles of each functional block and database of BG-C, and lists the relevant requirements specified in Section 2.3. In particular, since BG-C is an element of M/C-plane, the applicable requirements are summarized in Section 2.3.1.1.

Table 5: Border Gateway Controller Function and Database

FUNCTION/DATABASE	DESCRIPTION	RELATED REQUIREMENT

Request Management Function	A function that processes the request for Open APN path establishment received from Multi-domain Orchestrator	FUNC-REQ-MC-1 FUNC-REQ-MC-11 FUNC-REQ-MC-15
Network Control Function	A function that controls (creates/updates/deletes) the configuration of BG	FUNC-REQ-MC-8 FUNC-REQ-MC-9 FUNC-REQ-MC-10 FUNC-REQ-MC-11
Quality Management Function	A function that collects performance data (e.g., received optical power) from BG and sends the necessary information to Multi-domain Orchestrator	FUNC-REQ-MC-12 FUNC-REQ-MC-13 FUNC-REQ-MC-14 FUNC-REQ-MC-15
Resource Management Function	A function that manages the network resources (e.g., available wavelength) of own domain's BG	FUNC-REQ-MC-2
Request Database	A database that stores the request information, status, and historical data of Open APN path establishment requests from Multi-domain Orchestrator and processed by the Request Management Function	FUNC-REQ-MC-1 FUNC-REQ-MC-11 FUNC-REQ-MC-15
Path Database	A database that stores information and status of Open APN paths configured in BG by the Network Control Function	FUNC-REQ-MC-8 FUNC-REQ-MC-9 FUNC-REQ-MC-10 FUNC-REQ-MC-11 FUNC-REQ-MC-12 FUNC-REQ-MC-13 FUNC-REQ-MC-14 FUNC-REQ-MC-15
Resource Database	A database that stores the network resource information for own domain's BG obtained by the Resource Management Function	FUNC-REQ-MC-2

3.3.2. Example Sequence: BG Setup Request Handling in BG-C

Figure 17 shows how the BG setup request from the Multi-domain Orchestrator is processed within BG-C.

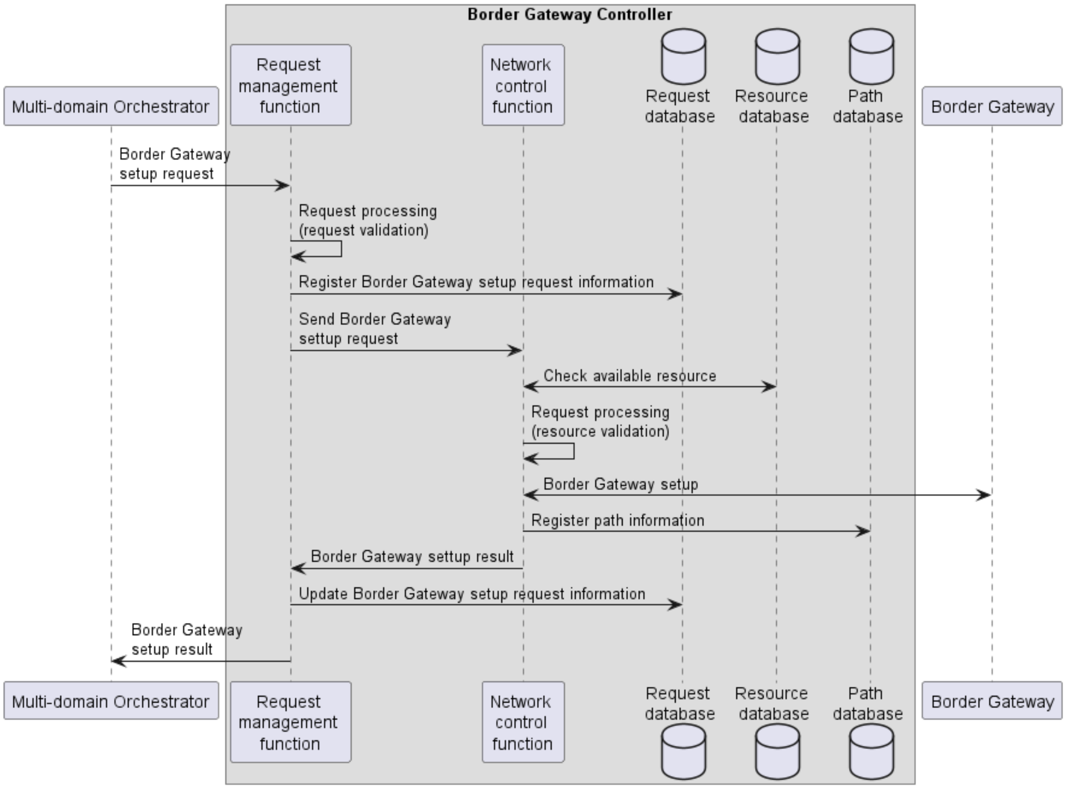

Figure 17: Example Sequence Diagram for BG Setup Request Handling

Firstly, the Request Management Function validates the setup request received from the Multi-domain Orchestrator, and if there are no request error (e.g., missing required parameters), it sends the setup request to the Network Control Function. Secondly, to resolve the forwarded setup request, the Network Control Function checks the available network resources in the Resource Database, identifies the optimal BG that can meet the request, and executes setup request to the optimal BG for configuration.

3.4. Border Gateway

This section describes the detailed functional architecture of the Border Gateway, which is responsible for the U-plane in Multi-domain IOWN Networking. The User-plane architecture of Open APN is defined in Section 3.3 of [1], and Open APN.WX is mainly defined. Under the Open APN.WX user plane architecture, the concept of Group of Optically Interconnectable Ports (GOIP) is introduced, and the definition of GOIP is as follows: *"GOIP is defined as a group of optical ports for which a direct optical connection through a wavelength path can be established (i.e., reachability is supported) between any two ports"* [1]. Given this definition, each APN provider's domain can comprise multiple GOIPs, and each GOIP in the domain is basically managed by the APN provider of its domain.

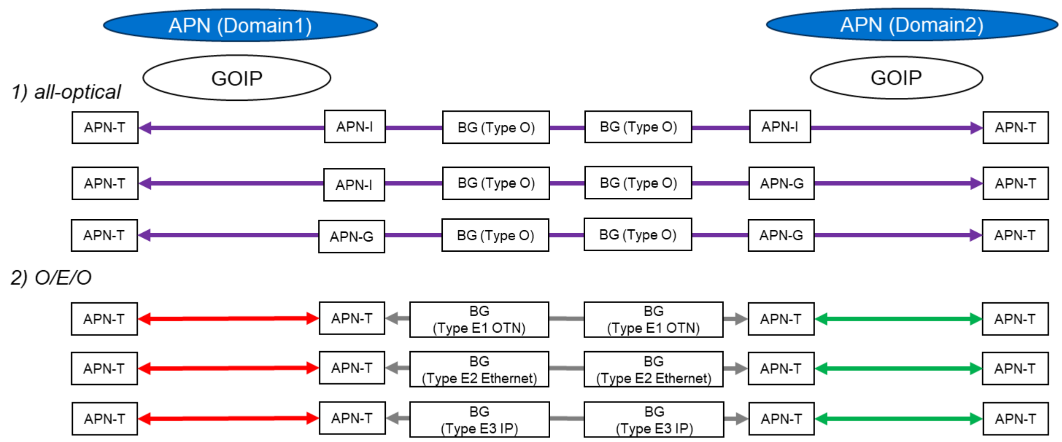

Figure 18: Functional Architecture for Border Gateway

Based on the requirements for the U-plane in Section 2.3.1.2 and the definition of Open APN in [1], Figure 18 depicts a functional architecture for BG. In this architecture, BG connects the GOIPs of different domains operated by different APN providers. Although each provider's domain can comprise multiple GOIPs, Figure 18 illustrates one GOIP per domain for simplicity. Given the wide variety of scenarios described in Section 2.1 and the requirements for the U-plane in Section 2.3.1.2, as depicted in Figure 18, BG can be considered to support at least one of the following connections:

1. All-optical connection
   - BG supports all-optical connections between different APN domains.
     - BG allows connections between any Open APN functions (APN-G, APN-I, etc.) across domains.
   - Related requirements: FUNC-REQ-U-1
2. O/E/O connection
   - BG supports L1-L3 connections with O/E/O between different APN domains.
     - BG needs to be connected to the APN-T for electrical conversion.
   - Related requirements: FUNC-REQ-U-2

In the 1) all-optical connection (BG Type-O), as depicted in Figure 18, the APN devices used in Open APN.WX, APN-I and APN-G, are connected between different APN domains via BG. Consequently, the BG needs to perform appropriate switching of the wavelength path input from APN-I and APN-G. Such connections between various types of APN functions (APN-I and APN-G) allows flexible utilization and wide adaptation of Open APN regardless organization type (e.g., carrier, DC provider, academic institution) or network scale.

NOTE: In Figure 18, two domains are depicted, but there is no restriction on the number of domains from an architectural perspective.

NOTE: BG is defined as "logical node that connects different APN domains operated by different providers", but there are no restrictions on its implementation. See Annexes A.

NOTE: The next version of Open All-Photonic Network Functional Architecture document considers new types of APN function such as APN-S. This document will add these new functions after its release.

Furthermore, BG may also be equipped with functions required at the domain boundary points. Table 6 shows the list of functions required for BG (Type O).

Table 6: Border Gateway (Type O) Function

FUNCTION	DESCRIPTION	MOTIVATION	MANDATORY/OPTIONAL
Abnormal Signal Cutoff	This function blocks abnormal optical signals that violate the pre-negotiated conditions (e.g., wavelength path, wavelength power) by Multi-domain Orchestrator. This function can be implemented either per-fiber or per-channel.	In all-optical connections, if abnormal optical signals with unexpected conditions are input from other domains, they may have a negative impact on other wavelength paths in their own domain. Therefore, such a protection function is required. Related requirements: FUNC-REQ-U-3	Mandatory
Signal Performance Monitoring	This function measures the characteristics of either the incoming optical signals from a neighbor BG or both the incoming and outgoing optical signals to and from a neighbor BG. This function can be implemented either per-fiber or per-channel.	In all-optical connections, optical signals from a neighbor domain need to be received with an appropriate level. The level is estimated based on noise and impairment in each domain and is negotiated by Multi-domain Orchestrator. Therefore, a verification function of the optical signal level is required. Related requirements: FUNC-REQ-U-5, 6, 7	Mandatory
Wavelength Conversion	This function converts the optical wavelength band/channel received from neighbor BGs and transmits it within its own domain.	For all-optical connection between different domains, a common wavelength channel available in both domains needs to be negotiated and used. However, the wavelength band/channel usage status and policies in each domain are basically different, which means that an available common wavelength band/channel may not exist. For such a case, a function of wavelength conversion is required.	Optional
Optical Switch	This function selects one fiber among multiple fibers according to a user's request. It can be used for failure protection with the function of Signal Performance Monitoring.	For all-optical connection between multiple different domains, flexible switching among domains can provide a more suitable connection to users. For that purpose, this switching function is required.	Optional
Optical Amplifier	This function amplifies optical signals directly in their optical state.	For all-optical connection between different domains, optical signal power may be reduced by line loss and insertion loss at BG (Type O). Therefore, a function that compensates for the reduction is required.	Optional

For the 2) O/E/O connection type, this is required as an option in cases where all-optical connection is difficult to provide due to various factors, and the optical signal is terminated at the APN-T, and interconnection between different domains is performed at each layer of Layer 1 (OTN: BG Type E1), Layer 2 (Ethernet, BG Type E2), and Layer 3 (IP, BG Type E3).

Furthermore, due to O/E/O conversion, the necessary functions are limited, but BG Type E1-3 may also be equipped with functions required at the domain boundary points as shown in Table 7.

Table 7: Border Gateway (Type E1-3) Functions

FUNCTION	DESCRIPTION	MOTIVATION	MANDATORY/OPTIONAL

Abnormal Packet/frame Filtering	This function blocks unadmitted frames/packets that violate the pre-negotiated conditions (e.g., IP address, MAC address, etc.) by Multi-domain Orchestrator.	In O/E/O connections, it is necessary to drop frames/packets that are not allowed in the pre-negotiated conditions. For that purpose, a protection function is required. Related requirements: FUNC-REQ-U-3	Mandatory

4. Conclusion

Multi-domain IOWN Networking realizes an optical network that is composed of multiple Open APN domains operated by different organizations such as carriers, DC providers, and cloud service providers. It supports to enhance the scalability, reliability, and flexibility of Open APN.
In this document, a high-level functional architecture for Multi-domain IOWN Networking is described, including the functional components of Border Gateway, Border Gateway Controller, and Multi-domain Orchestrator.
IOWN GF will work to develop the further specifications required for implementation and collaborate not only with other relevant task forces but also other Standards Developing Organizations and related communities for further technical work.

Annexes

A. Border Gateway Implementation Example

This annex describes an implementation example of Border Gateway and Figure 19 shows the implementation example of the BG. As described in Section 3.4, BG needs to support 1) all-optical connection and/or 2) O/E/O connection. Example A-1 presents the BG implementation that supports only all-optical connection. The interface of APN-I interconnection provides the BG-specific functions for Type O listed in Table 6 such as Abnormal Signal Cutoff and Wavelength Conversion. Note that such functions can be implemented within APN-I instead of at interface. Example A-2 and Example A-3 BG implementation supports only OTN connection by APN-T, in which the interface of APN-T interconnection provides the BG-specific functions described in Table 7. Just as Example A-1, such functions can be implemented within APN-T (not explicitly shown in Figure 19). Note that if high power budget is required for interconnection, back-to-back connected APN-T can be useful as the BG. Example A-4 shows the BG implementation includes both optical devices (APN-I, APN-G, and APN-T) and L2-3 upper layer devices (e.g., routers, switches). The interface of APN-I interconnection provides the BG-specific functions for Type O, while that of APN-T and L2/L3 devices provides the BG-specific functions for Type E1-3.

NOTE: The addition of functions to APN-I and APN-G may be considered and defined in the future version of Open All-Photonic Network Functional Architecture document.

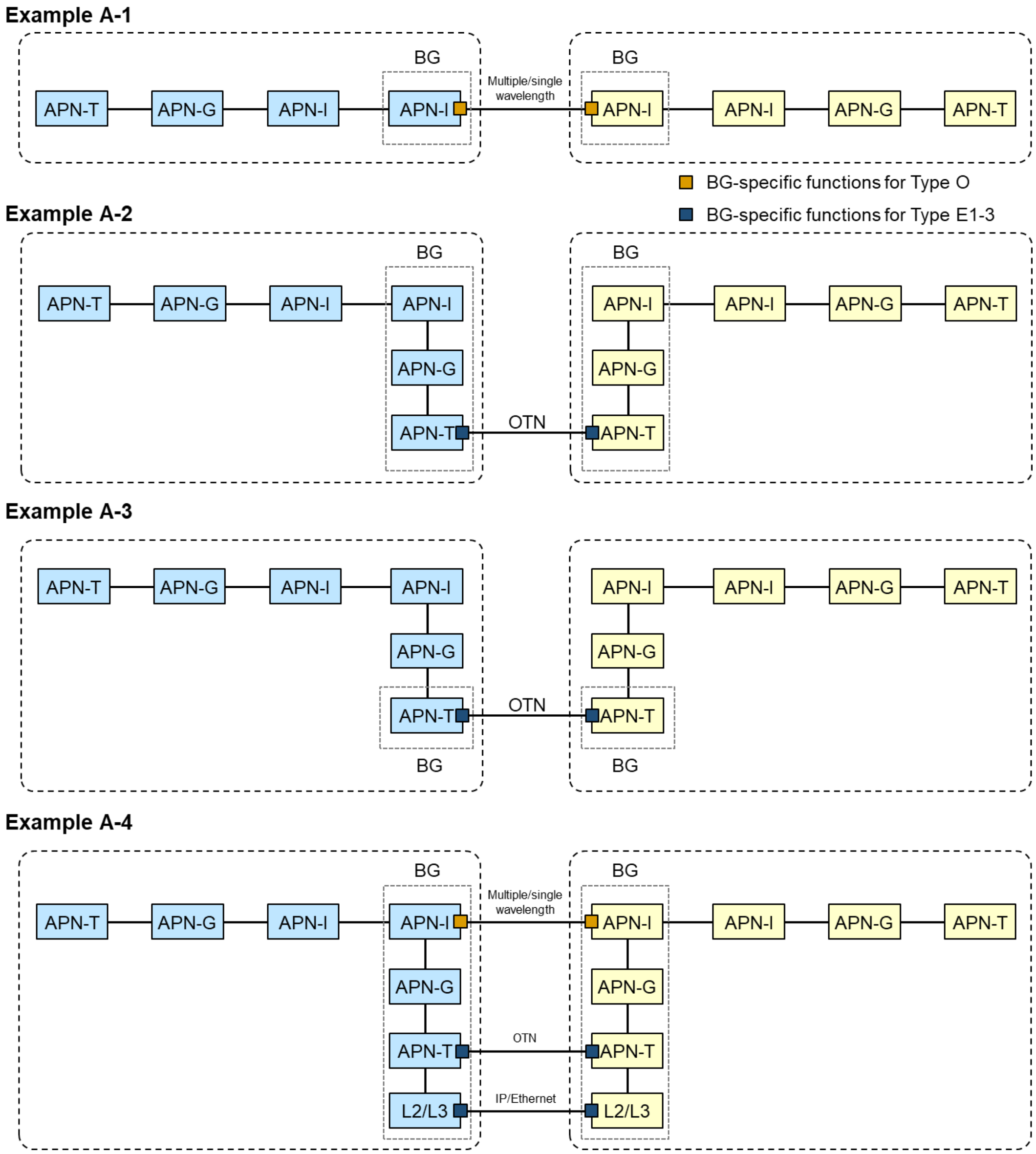

Figure 19: Implementation Example of Border Gateway

References

REFERENCE	DESCRIPTION
[1]	Open All-Photonic Network Functional Architecture Version 2.0
[2]	Remote Media Production for Broadcast Industry Use Case
[3]	Green Computing with Remote GPU Service for Generative AI / LLM Use Case- Light Speed Data Transfer for AI Training
[4]	Services Infrastructure for Financial Industry Use Case
[5]	Data-Centric Infrastructure Functional Architecture Version 2.0

History

Revision	Release Date	Summary of Changes
1	March 2025	Initial Release