

IOWN GF PoC Report

NTT's Open APN PoC

Submission of this PoC Report is subjected to policies, guidelines, and procedure defined by IOWN GF relevant to PoC activity. The information in this proof-of-concept report ("PoC Report") is not subject to the terms of the IOWN Global Forum Intellectual Property Rights Policy (the "IPR Policy"), and implementers of the information contained in this PoC Report are not entitled to a patent license under the IPR Policy. The information contained in this PoC Report is provided on an "as is" basis and without any representation or warranty of any kind from IOWN Global Forum regardless of whether this PoC Report is distributed by its authors or by IOWN Global Forum. To the maximum extent permitted by applicable law, IOWN Global Forum hereby disclaims all representations, warranties, and conditions of any kind with respect to the PoC Report, whether express or implied, statutory, or at common law, including, but not limited to, the implied warranties of merchantability and/or fitness for a particular purpose, and all warranties of noninfringement of third-party rights, and of accuracy

Introduction

This PoC project is a single-phase project. A PoC demonstration was conducted at the event described in Section 3. The performance measurements and evaluations were conducted using the demonstration system described in Section 4. Section 4 also describes the relationships to the PoC Reference [1]. Although it is intended to be a single-phase project, as there might be some successor PoC projects in future, some additional performance evaluations would be considered using the PoC system in this PoC

1. PoC Project Completion Status

- Overall PoC Project Completion Status: completed

2. NTT's Open APN PoC Project Participants

Specify PoC Team:

- PoC Project Name: NTT's Open APN PoC Project
- Member A: NTT Network Service Systems Laboratories Contact: tomonori.takeda@ntt.com
- Member B: NTT Network Innovation Laboratories Contact: hideki.nishizawa@ntt.com
- Member C: NTT Access Network Service Systems Laboratories Contact: shin.kaneko@ntt.com
- Member D: NTT COMWARE Corporation Contact: m.sadakari@nttcom.co.jp

3. Confirmation of PoC Demonstration

- PoC Demonstration Event Details
 - PoC was demonstrated in a metro area network (includes demonstration in NTT R&D Forum) (see Figure 1).
 - Date of PoC was 11/1/2022~11/18/2022, and 2/27/2023~4/10/2023.

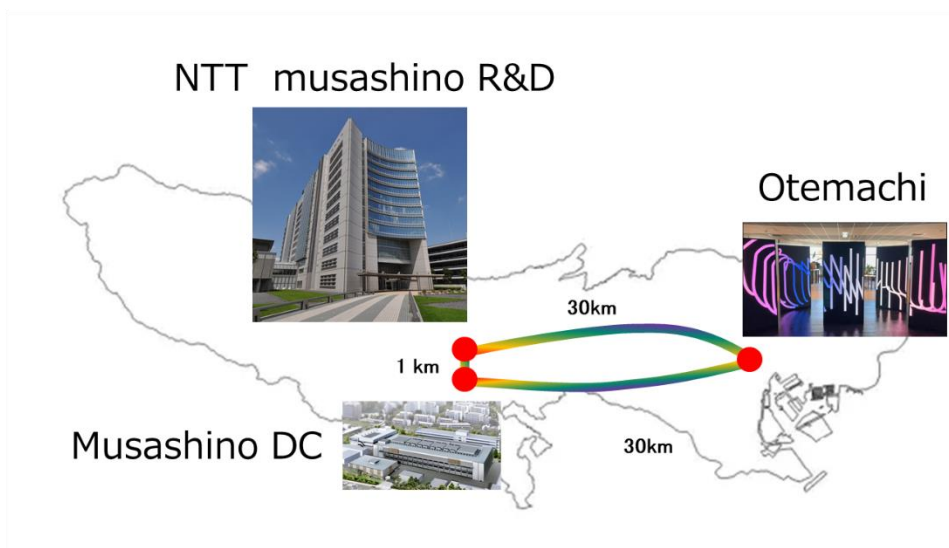


Figure 1 PoC in a metro network

4. PoC Goals Status Report

- PoC Project Goal #1: Confirm corresponding features of PoC Document: Met,
 - Feature1: Support for APN-G functions (section 3.1 of [1]),
 - Feature2: Open interface verification (section 3.2 of [1]),
 - Feature4: Automatic provisioning (section 3.4 of [1]),
 - Feature7: network attachment mechanism for user-owned transceivers (section 3.7 of [1]), and
 - Feature8: Monitoring with streaming telemetry (section 3.8of [1]).
- PoC Project Goal #2: measure benchmarks corresponding to features above: Met.
 - Benchmark 1: APN-G functions (section 4.1 of [1]),
 - Benchmark 2: Open interface verification (section 4.2 of [1]),
 - Benchmark 3: Fast monitoring with streaming telemetry (section 4.3 of [1]), and
 - Benchmark 4: Automatic provisioning (section 4.4. of [1]).

5. NTT's Open APN PoC Technical Report

5.1. Objective

We verified Customer end-to-end lambda connection use case (Figure 2) in the Open APN PoC Document Section 2.3 [1]. In order to verify this use case, we verified the following features. (Note: Annex2 shows the detailed model used in this POC, based Open APN PoC reference document [1].)

- Verify feature 1: Support for APN-G functions and benchmark 1: APN-G functions,
- verify feature 2: Open interface verification and benchmark 2: Open interface verification,
- verify feature 4: Automatic provisioning and benchmark 4: Automatic provisioning,
- verify feature 7: network attachment mechanism for user-owned transceivers, and
- verify feature 8: Monitoring with streaming telemetry and benchmark 3: Fast monitoring with streaming telemetry.

2.3. Customer end-to-end lambda connection

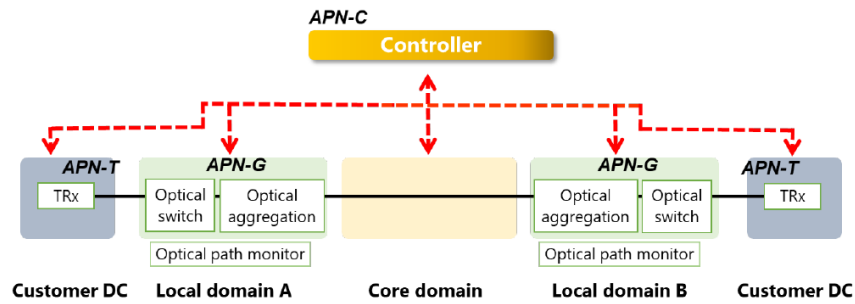


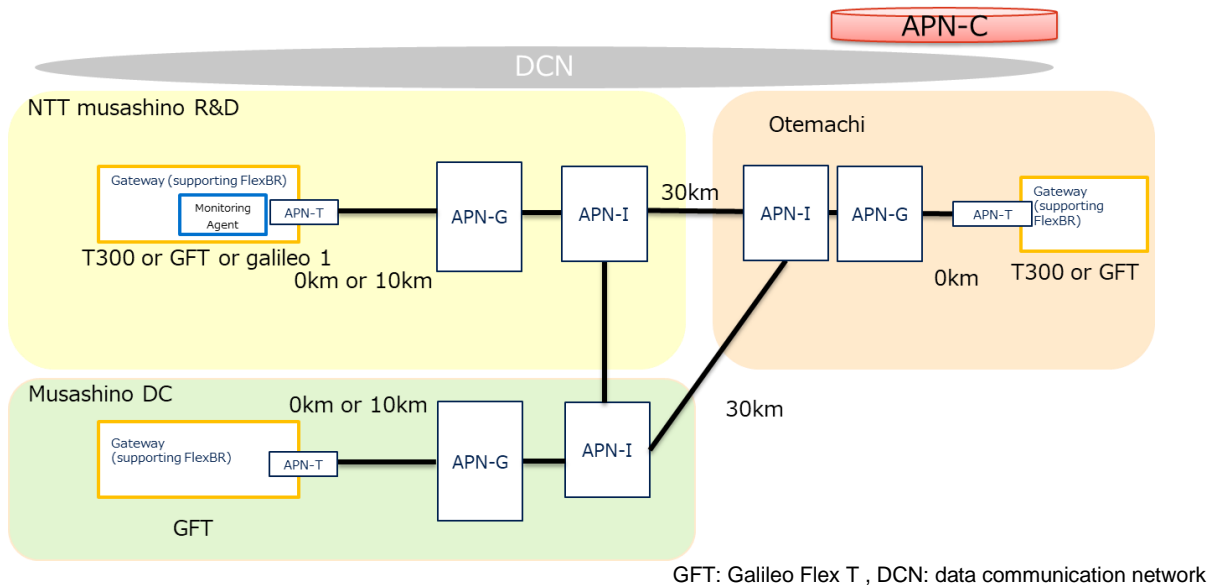
Figure 7. Architecture for customer end-to-end lambda connection

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.

Figure 2 Customer E2E lambda connection in Open APN PoC Document [1] Section 2.3. (Note that figures 6 and 7 are not in this report but in the PoC Document [1].)

5.2. Implemented System

POC was achieved with the system in Figure 3.



GFT: Galileo Flex T, DCN: data communication network

Figure 3 Implemented System

5.3. Measurement Method

Measurement method for each feature is as follows:

- Feature 1: Support for APN-G functions and Benchmark 1: APN-G functions:

- Feature 1: Support for APN-G functions
 - APN-G five functions, (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, were verified by spectrum monitoring.
- Benchmark 1: APN-G functions

We verified benchmark 1 (2) Measurement of acceptable distance and loss between APN-T and APN-G in the loop-back operation, benchmark 1 (3) Measurement of acceptable distance and loss between APN-T and APN-G in the non-loop-back operation, and benchmark 1 (4) Measurement of power consumption per port.

 - The benchmark (2) and (3) were verified by adding the loss between APN-T and APN-G and measuring the relationship of loss and pre-fec-ber. Note that acceptable distance could be estimated using fiber loss per km.
 - Benchmark (4) was measured by watt meter.
- Feature 2: Open interface verification and Benchmark 2: Open interface verification
 - Feature 2: Open interface verification
 - This verification is path setup sequence, which starts with path setup request via NBI, and ends with setting parameters of APN-T, G, and I via SBI. Open interfaces were verified by logs for optical path setup as follows:
 - between APN-C (SBI) and APN-T: by logs (in this PoC, Open ROADM 10.0.0 is used), and
 - additionally, between APN-C (NBI) and External System: by logs (in this PoC, TAPI 2.1.1 is used).
 - Benchmark 2: Open interface verification
 - Path setup time was measured by logs. Path setup time consists of the following steps. Note that time includes only controller processing time, not hardware configuration time (that is measured in Feature 4).
 - Step1: Path set up request via NBI and calculate required OSNR,
 - Step2: Compute candidate paths, and
 - Step3: Select the path and set to the APN-G, and APN-I.
- Feature 4: Automatic provisioning and Benchmark 4: Automatic provisioning
 - Feature 4: Automatic provisioning
 - Automatic provisioning was verified by confirming that the client signal of an APN-T reached the other APN-T.
 - As described in the PoC document, the following capabilities of APN-Ts were used.
 - W 100-200G 31.6 Gbaud of Open ROADM MSA Optical Specification Version 5.0, and

- W 200-400G 63.1 Gbaud of Open ROADMSA Optical Specification Version 5.0.
 - Benchmark 4: Automatic provisioning
 - Time of optical path provisioning was measured by logs in APN-C.
 - Feature 7: Network attachment mechanism for user-owned transceivers
 - The following steps on automatic registration of user-owned transceivers were verified by logs in APN-C.
 - Step1: Registration of user-owned transceivers to the APN-C including registration of parameters such as the modulation format, and
 - Step2: Optical path setup using the registered user-owned transceivers.
 - Additionally, registration time is measured by logs. Registration time consists of the following steps:
 - Step1: retrieve capability of APN-T, and
 - Step2: assign of ID.
 - Feature 8: Monitoring with streaming telemetry and Benchmark 3: Fast monitoring with streaming telemetry
 - Feature 8: Monitoring with streaming telemetry
 - Monitoring items including optical power values and BER were verified by APN-C's dashboard.
 - OSNR is omitted because it can be calculated using BER.
 - Benchmark 3: Fast monitoring with streaming telemetry
 - Periods of reporting were verified by APN-C's graphical user interface.

5.4. PoC Technical Finding

According to architecture in Annex 2, APN-T registration and path setup sequences were demonstrated using the implemented system. In this demonstration, measurement for each feature was done according to the measurement method.

Summary of the PoC is listed in Table 1.

Table 1 Summary of PoC

Category	Feature/Benchmark	Status	Remarks	
APN-G functions	Feature 1(1) Benchmark 1(1)	five functions of APN-G	OK	
	Benchmark (2)	Acceptable loss and distance between APN-T and APN-G in the non-loop-back operation.	OK	Acceptable distance can be estimated by using the fiber loss per km.
	Benchmark (3)	Acceptable loss and distance between APN-T and APN-G in the loop-back operation.	OK	Acceptable distance can be estimated by using the fiber loss per km.
	Benchmark (4)	Measurement of power consumption per port	OK	
Open interface	Feature 2	Open interfaces verification	OK	
	Benchmark 2	Path setup time	OK	
		Path deletion time	Not yet	
Path re-setup time		Not yet		
Automatic provisioning	Feature 4	Optical path provisioning verification	OK	
	Benchmark 4	Optical path provisioning time for physical design	OK	
		Optical path provisioning accuracy for physical design	Not yet	We confirmed enough accuracy for path-setup was achieved.
Network attachment mechanism for user-owned transceivers	Feature 7	User-owned APN-T registration process verification	OK	
		Path setup for user-owned APN-T verification	OK	
Monitoring with streaming telemetry	Feature 8	Monitoring items verification	OK	
	Benchmark 3	Monitoring interval verification	OK	

In the following subsection, procedure, results, and lessons learnt for each feature are described in detail.

- Feature1: Support for APN-G functions and Benchmark 1: APN-G five functions:
 - Procedure (Figure 4)
 - Path setup requests between APN-Ts for each feature were post to APN-C.
 - According to requests, APN controller created path information and set configuration for each APN-T, APN-G, and APN-I.
 - APN-G is composed as the following. In this PoC, SRG was constructed by FXC (Fiber Cross Connect) and AWG (Arrayed Waveguide Gratings), DEG was constructed by WSS and amplifier, and turn-back module was constructed using two WSSs connected back-to-back. For control-channel provisioning to remote transponder, O-band is used for the remote control-channel and O/C-band filters

are placed on the access side of the APN-G.

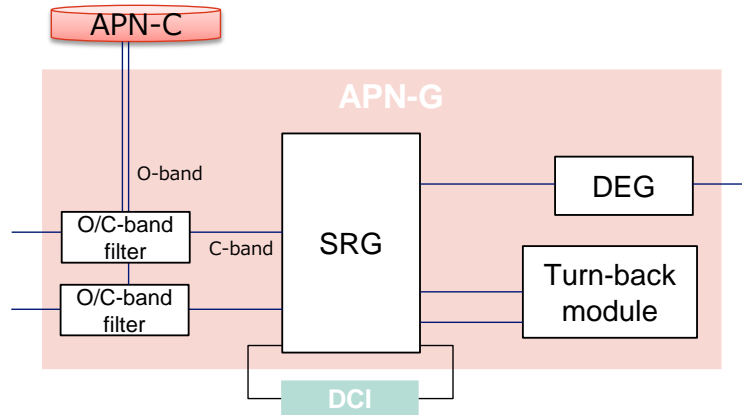


Figure 4 APN-G architecture

- Results

- Feature 1 (1)

To validate the feature 1 (1) “provision of control channels to communicate with connected APN-Ts”, we got the log and spectrum when setting the optical path. The figure 5 (a) shows the log of the controller to set the wavelength of the APN-T. The figure 5 (b) shows the spectrum of the control and main signals. The control signal was multiplexed with the main signal by using 1.3- μm wavelength.

- Feature 1 (2)

To validate the feature 1 (2) “admission control in U-plane”, we set the optical path between 2 APN-Ts in different sites. Figure 6 shows the experimental configuration and spectrum of input/output at APN-G. The wavelength specified by the APN-C, 1541.3 nm, was observed at APN-G. In the direction from Musashino DC to musashino R&D, multiple wavelengths were input from APN-I to APN-G, but only the specified wavelengths were dropped to the terminal as shown in (3) and (4).

-

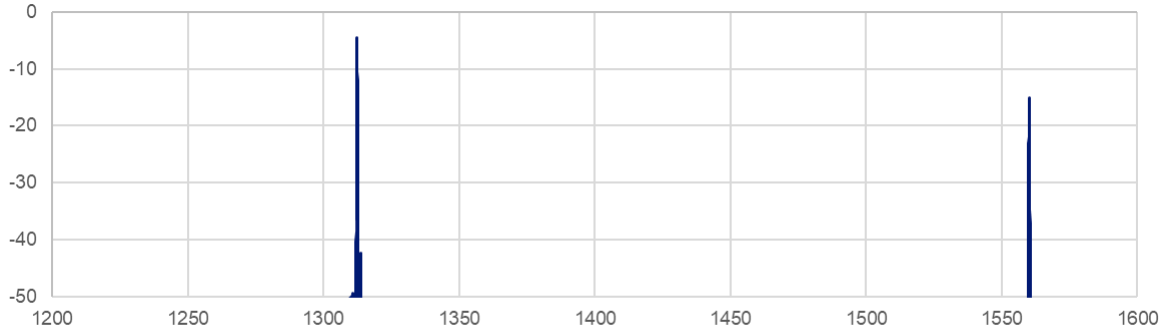

```

21:11:13.085,[DEBUG],[Queuing2],UdpConnectionSendManager$sendMessage start.
21:11:13.085,[DEBUG],[Queuing2],UdpConnectionSendManager$sendMessage udp -> device[DeviceInfo[device_number[13], communication control
21:11:13.085,[DEBUG],[Queuing2],UdpConnectionSendManager$sendMessage communication_control_mode[1]
21:11:13.085,[DEBUG],[Queuing2],UdpSender$send start. message[["id":"setFrequency","serialNumber":"S2009201295","wavelength":1558578]]
21:11:13.085,[DEBUG],[Queuing2],UdpSender$send UDP Send success.
21:11:13.085,[INFO],[Queuing2],[UDP_SEND] send message:["id":"setFrequency","serialNumber":"S2009201295","wavelength":1558578]
21:11:13.085,[DEBUG],[Queuing2],AccmControllerServiceBase$sendUdp end.
21:11:13.085,[DEBUG],[Queuing2],serchWaveLength arg devno(4) portno(325)

```

(a) Log of controller to set wavelength for APN-T

Figure 5 (a) Results for Feature1(1) -1



(b) Spectrum of control and main signals

Figure 5 (b) Results for Feature1(1) -2

1

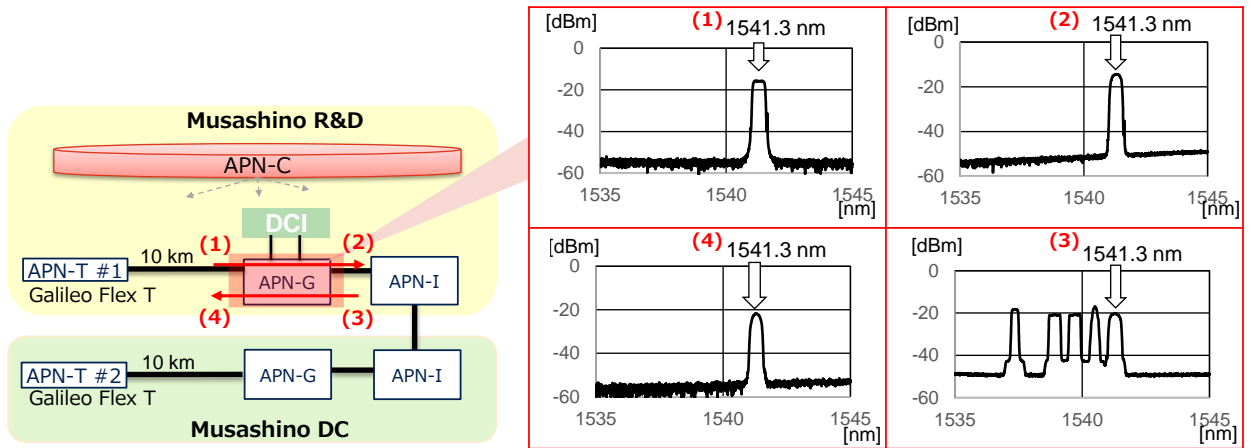


Figure 6 Results for Feature1(2)

- Feature 1 (3)

To validate the feature 1 (3) “Multiplexing/demultiplexing”, we set the optical path using the APN-G at Musashino R&D. Only in this experiment, the second direction of the APN-G was used to show the function of distributing wavelengths to multiple directions. Figure 7 shows the experimental configuration and spectrum of output at APN-G for 2 directions. We confirmed that a total of 16 CW lights (1554 ~ 1562 nm) were passed through the APN-G.

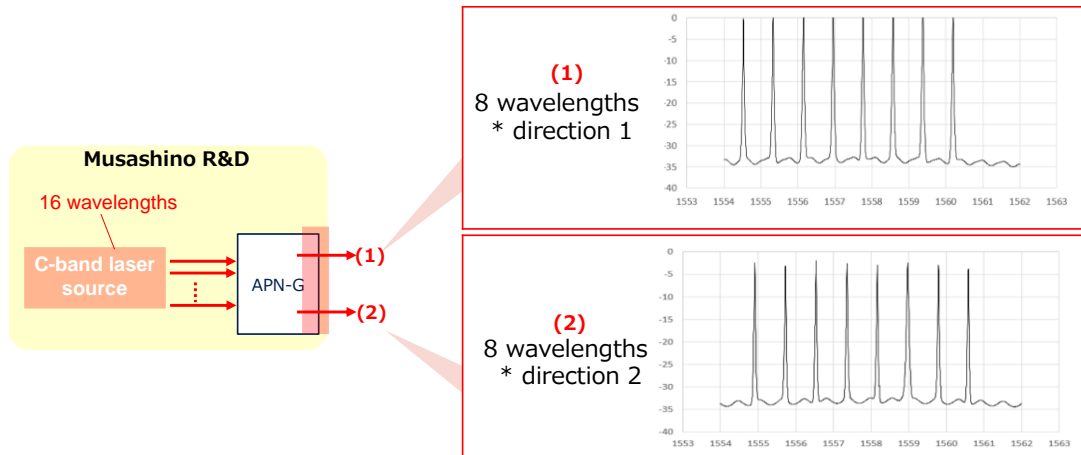


Figure 7 Results for Feature1(3)

- Feature 1 (4)

To validate the feature 1 (4) “turning back”, we set the optical path between 2 APN-Ts in the same APN-G. Figure 8 shows the experimental configuration and spectrum of input/output at APN-G. The wavelength specified by the APN-C, 1541.3 nm, has passed through the turn back module in the APN-G.

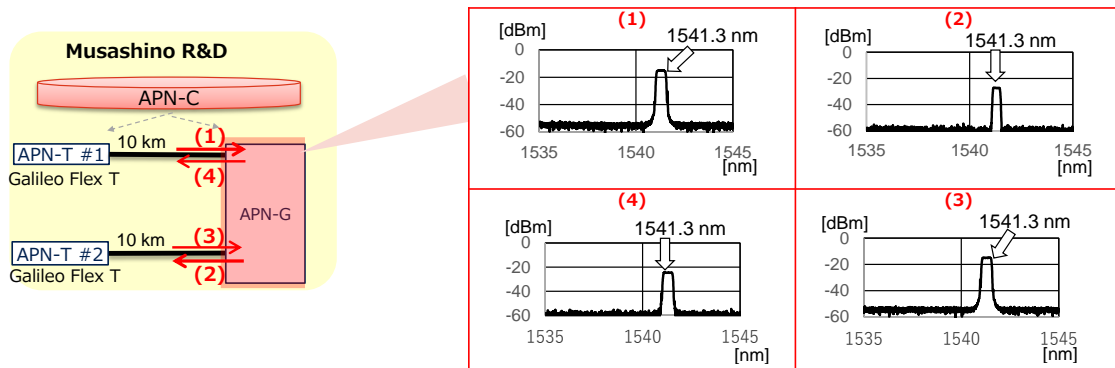


Figure 8 Results for Feature1(4)

- Feature 1 (5)

To validate the feature 1 (5) “adding dropping”, we set the optical path via data-centric-infrastructure (DCI) between 2 APN-Ts in different sites. Figure 9 shows the experimental configuration and spectrum of input/output at APN-G via DCI. The wavelength specified by the APN-C, 1541.3 nm, was dropped once from the APN-G as shown in (2), and then added to the APN-G as shown in (3)

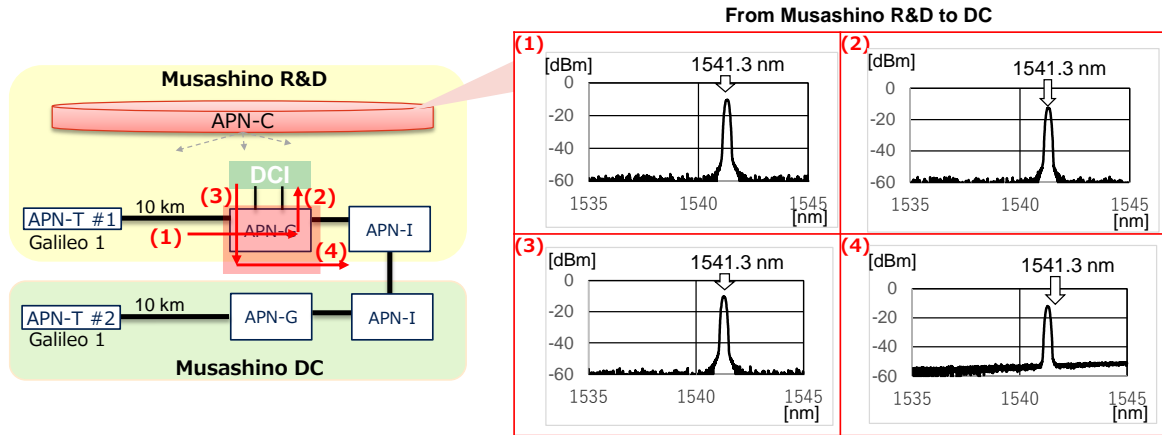


Figure 9 Results for Feature1(5)-1

Figure 10 shows results of the opposite direction. We can see that the wavelength specified by the APN-C, 1541.3 nm, was dropped once from the APN-G as shown in (2), and then added to the APN-G as shown in (3), similarly.

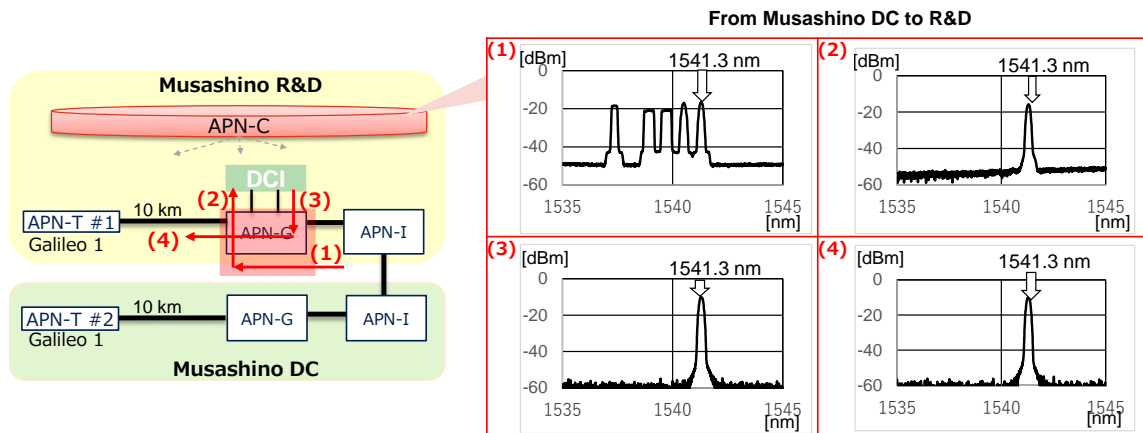


Figure 10 Results for Feature1 (5)-2

- Benchmark 1 (2)

As benchmark (2), the pre-fec-ber was evaluated for turn-back communication by changing the attenuation loss of the section between APN-T and APN-G. The same attenuation loss was added for 2 access sections. In the condition that the pre-fec-ber is below 10⁻³, 6.5-dB loss can be added. The post-fec-ber is also shown as the reference.

Parameters	Value
Transmission scheme	DP-QPSK
Symbol rate	32 Gbaud
FEC scheme	SD-FEC

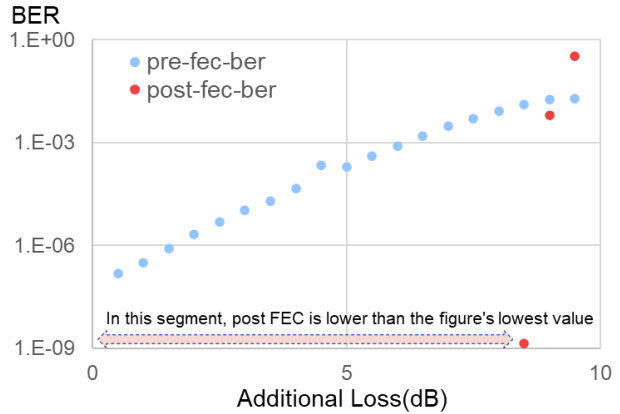
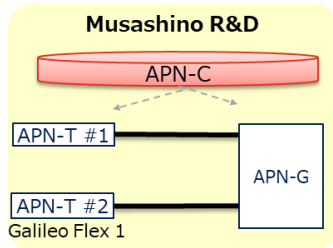


Figure 11 Results for benchmark 1 (2)

▪ Benchmark 1 (3)

As benchmark (3), the pre-fec-ber was evaluated for inter-site communication by changing the attenuation loss of the section between APN-T and APN-G. The same attenuation loss was added for 2 access sections. In the condition that the pre-fec-ber is below 10⁻³, 6.5-dB loss can be added. The post-fec-ber is also shown as the reference.

Parameters	Value
Transmission scheme	DP-QPSK
Symbol rate	32 Gbaud
FEC scheme	SD-FEC

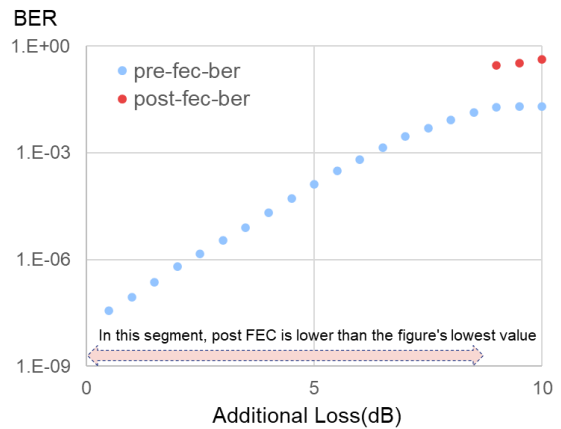
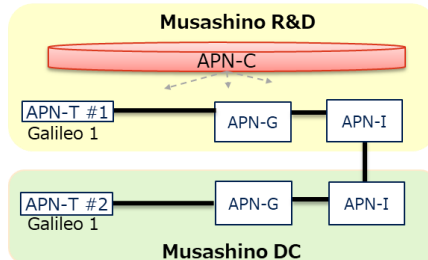


Figure 12 Results for benchmark 1 (3)

▪ Benchmark 1 (4)

Figure 13 shows the example of APN-G configuration and power consumption per port. After turning on the APN-G, the peak and standby power were measured.

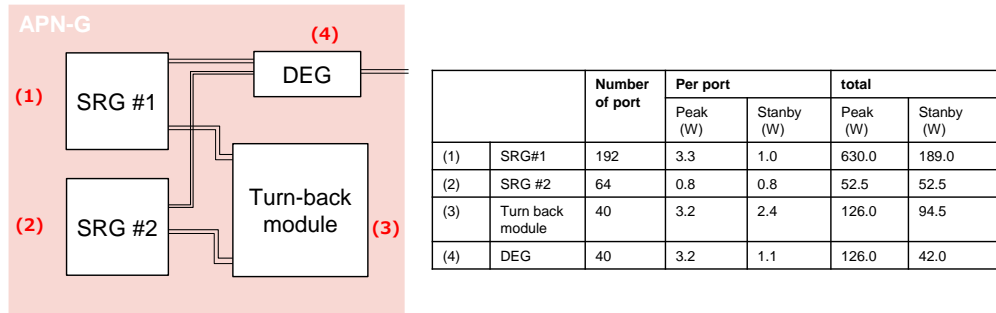


Figure 13 Results for benchmark 1 (4)

o Lessons Learnt & Recommendations

- In this PoC, the SRG was constructed by FXC and AWG. We confirmed APN-G is feasible and can accept 6.5-dB access fiber loss with this configuration. Note that some commercial-level APN-Gs use other types of SRG; evaluation results for these are described in PoC reports by individual vendors.

• Feature 2 and Benchmark 2: Open interface verification

o Procedure (Figure 14)

- Path setup request between OR_DEVICE1 and OR_DEVICE2 with 400G/ODUc4 is post to APN controller.
- The APN controller creates path information and set configuration for each APN-T, APN-G, and APN-I.
- The operation ends when APN-C received the response from APNT/G/I . Note that APN-T sends response before finishing optical signal setup.

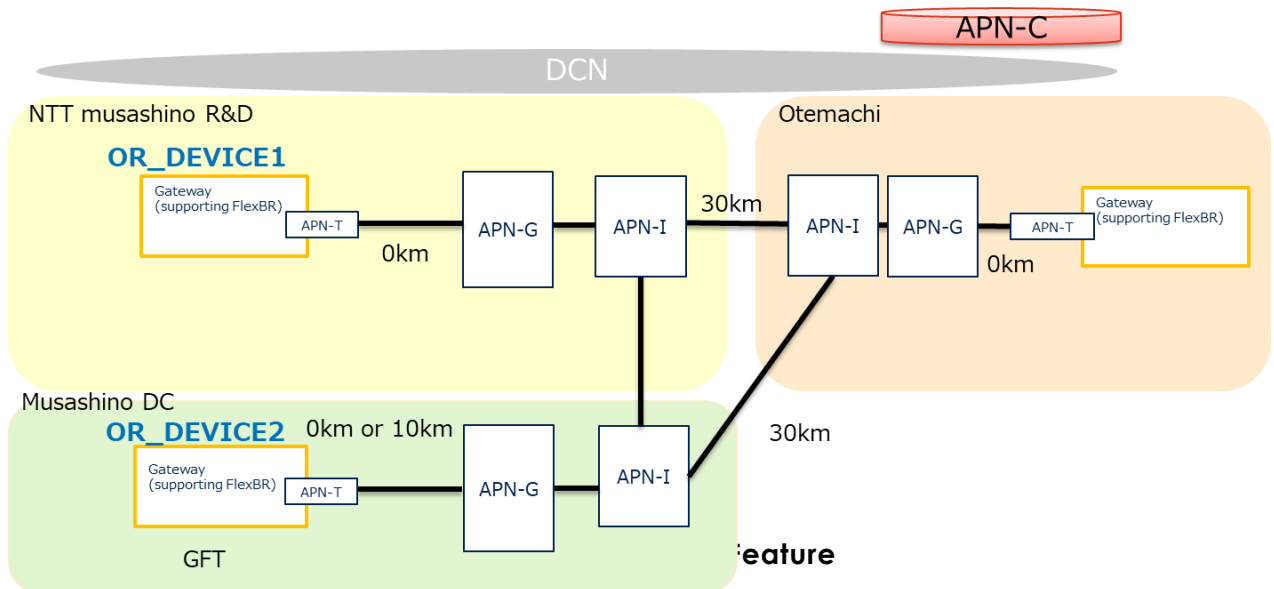


Figure 14 Environment on Feature

- Results

- Logs on Path setup request on TAPI-based NBI are shown in Figure 15.
- Logs on setting to APN-T are shown in Figure 16 and Figure 17. These logs show the appropriate transmission mode and wavelength is set to APN-T using Open ROADM SBI.
- Measurement results for path setup time are shown in Table 2. In the following part, each item of path setup time is described with logs' timestamp.
 1. Receive path setup request and obtain the required OSNR based on required bandwidth and APN-T capability (7.569sec) in Figure 18,
 2. Calculate candidate paths that meet required OSNR (693msec) in Figure 19, and
 3. The appropriate path is selected from the OSNR and usage of wavelength and set to the APN-T. (9.408 sec) in Figure 20.

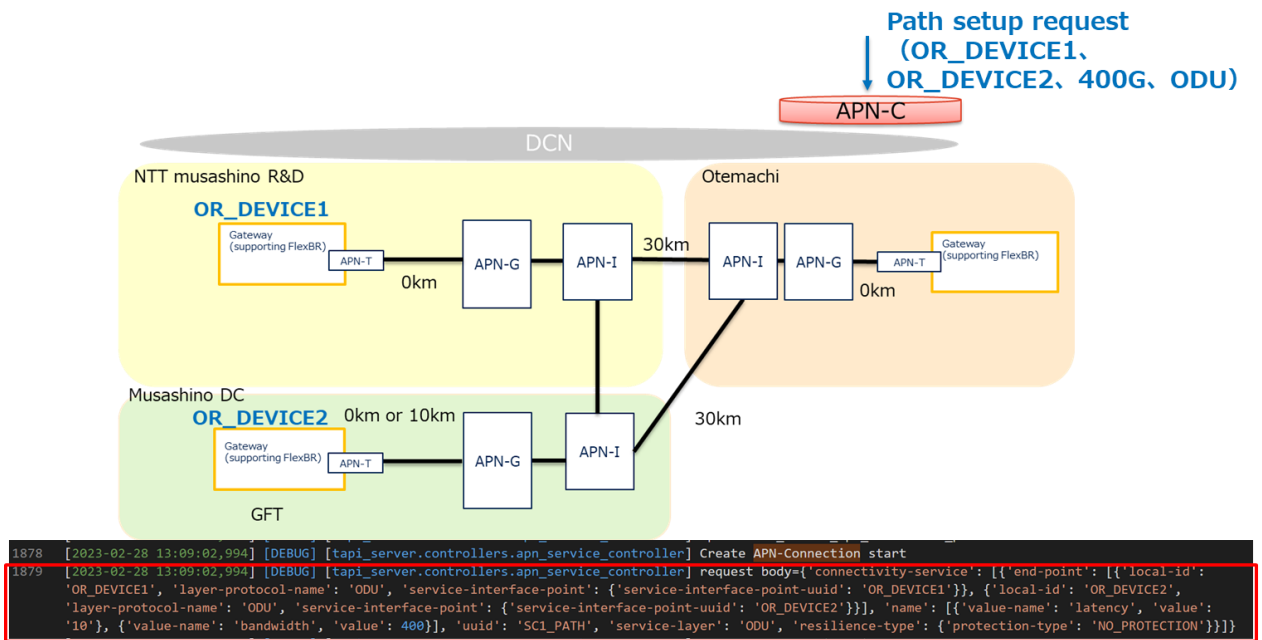


Figure 15 Path setup request by TAPI

```
Optical path handler for TEST_PATH_ZY has been created
TEST_PATH_LAB: Optical path is successfully ESTABLISHED.
TEST_PATH_ZY: Optical path is successfully ESTABLISHED.
Create connection 2:13 on fxc_tk11
Create connection 11:33 on fxc_musashino
Optical path handler for E2E_PATH_1 has been created
Change frequency(wavelength) to 195600156258405 of E2E_PATH_1
</frequency nc:operation="merge">195.6</frequency>
```

Send the configuration (OPEN_ROADM) to OpenROADM_DEV1:

```
<nc:config xmlns:nc="urn:ietf:params:xml:ns:netconf:base:1.0">
  <org-openroadm-device xmlns="http://org/openroadm/device">
    <interface>
      <name>otsi-piul</name>
      <supporting-circuit-pack-name>piul</supporting-circuit-pack-name>
      <otsi xmlns="http://org/openroadm/optical-channel-tributary-signal-interfaces">
        <frequency nc:operation="merge">195.6</frequency>
      </otsi>
    </interface>
  </org-openroadm-device>
</nc:config>
```

```
</frequency nc:operation="merge">195.6</frequency>
```

Send the configuration (OPEN_ROADM) to OpenROADM_DEV2:

```
<nc:config xmlns:nc="urn:ietf:params:xml:ns:netconf:base:1.0">
  <org-openroadm-device xmlns="http://org/openroadm/device">
    <interface>
      <name>otsi-piul</name>
      <supporting-circuit-pack-name>piul</supporting-circuit-pack-name>
      <otsi xmlns="http://org/openroadm/optical-channel-tributary-signal-interfaces">
        <frequency nc:operation="merge">195.6</frequency>
      </otsi>
    </interface>
  </org-openroadm-device>
</nc:config>
```

Figure 16 set wavelength of APN-Ts using Open ROADM API

```
Change modulation-format from nan to dp-16-qam of E2E_PATH_1
<modulation-format nc:operation="merge">dp-qam16</modulation-format>
```

Send the configuration (OPEN_ROADM) to OpenROADM_DEV1:

```
<nc:config xmlns:nc="urn:ietf:params:xml:ns:netconf:base:1.0">
  <org-openroadm-device xmlns="http://org/openroadm/device">
    <interface>
      <name>otsi-piul</name>
      <supporting-circuit-pack-name>piul</supporting-circuit-pack-name>
      <otsi xmlns="http://org/openroadm/optical-channel-tributary-signal-interfaces">
        <modulation-format nc:operation="merge">dp-qam16</modulation-format>
      </otsi>
    </interface>
  </org-openroadm-device>
</nc:config>
```

Figure 17 Set transmission mode of APN-T using Open ROADM API

Table 2 Path setup time

items	sec
(1) Receive path setup request and calculate required OSNR	07.569
(2) Create candidate paths	00.693
(3) Select the path and set to the APN-T, APN-G, and APN-I	09.408

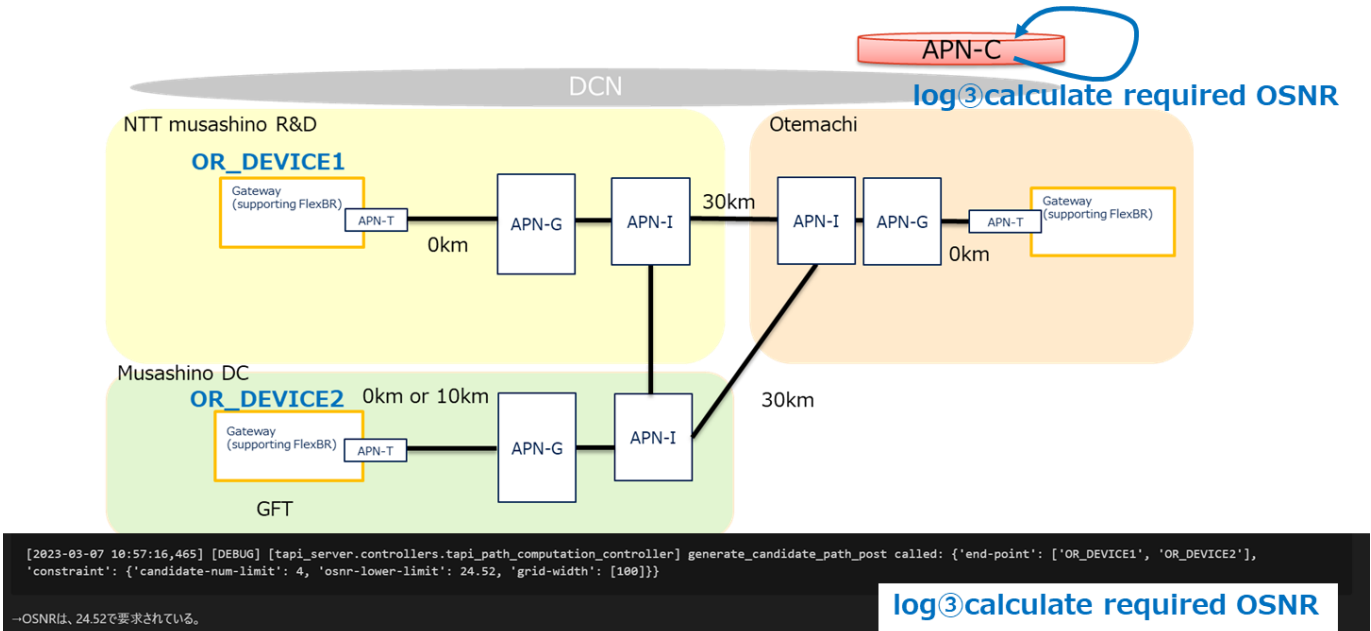


Figure 18 logs on item (1)

```

candidate_id: path-aec98c4b-084d-491c-81e4-f355484c698d
osnr: 25.709999084472656
Candidate path list:

candidate_id      osnr  wavelength  frequency  distance  delay
-----
path-aec98c4b-084d-491c-81e4-f355484c698d  25.71  1541.35    194500    1.2  0.00400277
100
path-c0e0c64f-761c-4c18-bcc9-7e42b1074711  24.56  1541.35    194500    60.2  0.200806
100
-> Select a candidate path to establish

[2023-03-03 10:57:20,199] [INFO] [gnpy.tools.cli_examples] Computing path requests /home/apn-11/apn-controller/RT/opt-gnpy/gnpy/example-data/meshTopologyExampleV2.xls into JSON format
[2023-03-03 10:57:20,470] [DEBUG] [tapi_server.apn_design_tool] add candidate route: {'uid': '', 'sip': 'OR_DEVICE1', 'sip2': 'OR_DEVICE2', 'hopList': [{'node': '6f8913b2-c15d-4d8e-af66-9f08492cd0b0', 'neplList': [{'uid': '0e66289b-81f5-46ea-89b7-dc652e476880', 'frequency': [194500.0]}, {'uid': 'c62173cd-3d2f-489c-b91f-64891ba35191', 'frequency': [194500.0]}]}, {'node': 'node-phgw-1', 'neplList': [{'uid': 'nep-phgw-1-access-01', 'frequency': [194500.0]}, {'uid': 'nep-phgw-1-core-01', 'frequency': [194500.0]}]}, {'node': 'node-phex-1', 'neplList': [{'uid': 'nep-phex-1-01', 'frequency': [194500.0]}, {'uid': 'nep-phex-1-03', 'frequency': [194500.0]}]}, {'node': 'node-phex-3', 'neplList': [{'uid': 'nep-phex-3-02', 'frequency': [194500.0]}, {'uid': 'nep-phex-3-01', 'frequency': [194500.0]}]}, {'node': 'node-phgw-3', 'neplList': [{'uid': 'nep-phgw-3-core-01', 'frequency': [194500.0]}, {'uid': 'nep-phgw-3-access-01', 'frequency': [194500.0]}]}, {'node': '08f45dd-2b58-4688-af37-593dbac6f43f', 'neplList': [{'uid': 'ee27fd80-9625-43a0-9cc2-cbc4048af92b', 'frequency': [194500.0]}, {'uid': '1c7f7581-f3c3-452d-a805-76ad0e22badd', 'frequency': [194500.0]}]}]}
[2023-03-03 10:57:20,470] [DEBUG] [tapi_server.apn_design_tool] add candidate. estimated quality: {'candidate-id': '', 'estimated-quality': {'SNR-bandwidth': 18.49, 'SNR-0.1nm': 25.71, 'OSNR-bandwidth': 18.49, 'OSNR-0.1nm': 25.71, 'CD': 20.04, 'PMD': 0.04}, 'path-frequency': 194500.0, 'path-frequency-width': 100.0, 'path-distance': 1.2, 'path-delay': 0.00400277825}

[2023-03-03 10:57:20,836] [DEBUG] [tapi_server.apn_design_tool] add candidate route: {'uid': '', 'sip': 'OR_DEVICE1', 'sip2': 'OR_DEVICE2', 'hopList': [{'node': '6f8913b2-c15d-4d8e-af66-9f08492cd0b0', 'neplList': [{'uid': '0e66289b-81f5-46ea-89b7-dc652e476880', 'frequency': [194500.0]}, {'uid': 'c62173cd-3d2f-489c-b91f-64891ba35191', 'frequency': [194500.0]}]}, {'node': 'node-phgw-1', 'neplList': [{'uid': 'nep-phgw-1-access-01', 'frequency': [194500.0]}, {'uid': 'nep-phgw-1-core-01', 'frequency': [194500.0]}]}, {'node': 'node-phex-1', 'neplList': [{'uid': 'nep-phex-1-01', 'frequency': [194500.0]}, {'uid': 'nep-phex-1-02', 'frequency': [194500.0]}]}, {'node': 'node-phex-2', 'neplList': [{'uid': 'nep-phex-2-01', 'frequency': [194500.0]}, {'uid': 'nep-phex-2-02', 'frequency': [194500.0]}]}, {'node': 'node-phex-3', 'neplList': [{'uid': 'nep-phex-3-03', 'frequency': [194500.0]}, {'uid': 'nep-phex-3-01', 'frequency': [194500.0]}]}, {'node': 'node-phgw-3', 'neplList': [{'uid': 'nep-phgw-3-core-01', 'frequency': [194500.0]}, {'uid': 'nep-phgw-3-access-01', 'frequency': [194500.0]}]}, {'node': '08f45dd-2b58-4688-af37-593dbac6f43f', 'neplList': [{'uid': 'ee27fd80-9625-43a0-9cc2-cbc4048af92b', 'frequency': [194500.0]}, {'uid': '1c7f7581-f3c3-452d-a805-76ad0e22badd', 'frequency': [194500.0]}]}]}
[2023-03-03 10:57:20,836] [DEBUG] [tapi_server.apn_design_tool] add candidate. estimated quality: {'candidate-id': '', 'estimated-quality': {'SNR-bandwidth': 17.28, 'SNR-0.1nm': 24.51, 'OSNR-bandwidth': 17.34, 'OSNR-0.1nm': 24.56, 'CD': 1005.34, 'PMD': 0.31}, 'path-frequency': 194500.0, 'path-frequency-width': 100.0, 'path-distance': 60.2, 'path-delay': 0.2008058530928755}
    
```

Figure 19 logs on item (2)


```

candidate_id      osnr    wavelength    frequency    distance    delay
grid
-----
path-aec98c4b-084d-491c-81e4-f355484c698d  25.71    1541.35      194500      1.2  0.00400277
100
path-c0e0c64f-761c-4c18-bcc9-7e42b1074711  24.56    1541.35      194500      60.2  0.200806
100
-> Select a candidate path to establish

127.0.0.1 [07/Mar/2023:01:57:16 +0000] "POST /operations/generate-candidate-path/ HTTP/1.1" 200 178 "-"
"Python-urllib/3.11"
Received message at conn-context: path-aec98c4b-084d-491c-81e4-f355484c698d,TEST_PATH_AB:TEST_PATH_ZY,
['10.166.101.66', '8081']

Request candidate path:
Requesting candidate path path-aec98c4b-084d-491c-81e4-f355484c698d to APN-Controller...

```

Figure 20 logs on item (3)

- Lessons Learnt & Recommendations
 - We confirmed that path can be setup by using Open interface.
 - In this PoC, path constraints were not taken into accounts. For further study, we are planning extension to be able to take into accounts path constraints to apply Open APN to real cases such as data-center-interconnect.

Feature 4 and Benchmark 4: Automatic provisioning

- Procedure (Figure 21)

We evaluated the entire provisioning process including the path request, path calculation, and device setup as follows:

- OSNR estimation for Alien Access Links (AALs) and carrier-segment.
- End-to-end OSNR estimation assuming Gaussian Noise (GN) model.
- Select the best transmission mode and establish optical path by controlling customer transceivers.

We verified the correctness of our provisioned path by checking the operational status, input-power, and bit-error-rate recorded at DSPs inside APN-Ts.

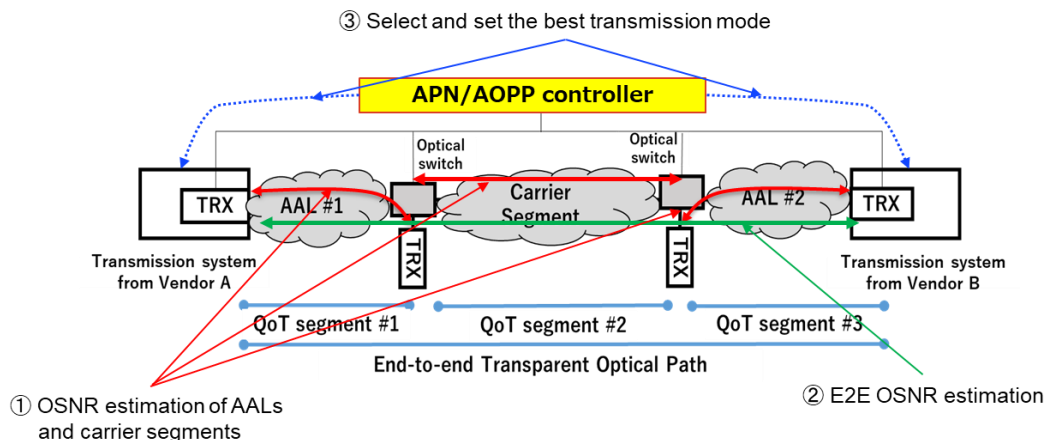


Figure 21 Environment on Feature4

- Results

- Scenario 1: Galileo 1 and T300 are used (Figure 22).
 - End to end QoT is estimated as **27.9 dB** in total (Simple patch code is used for AALs).
 - Since controller takes their interoperability into account, 100G/dp-qpsk is automatically configured and establishes optical path by 79 secs.

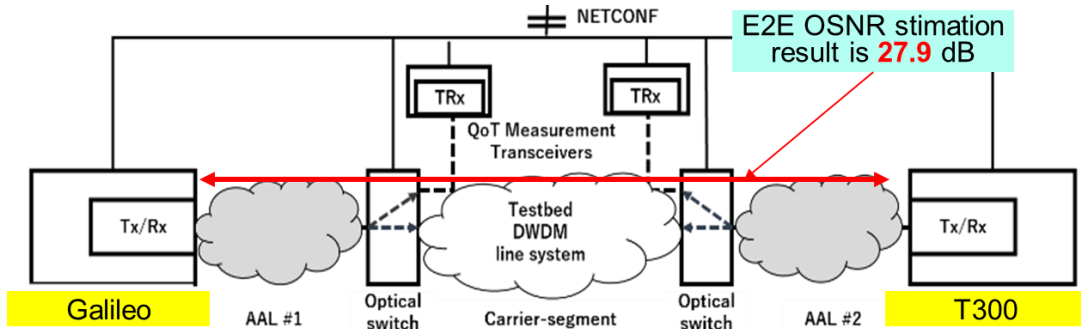


Figure 22 Results for scenario 1

- Scenario 2: Only T300 are used (Figure 23).
 - End to end QoT is estimated as **27.9 dB** in total (Simple patch code is used for AALs).
 - 200G/dp-16-qam is automatically configured and establishes optical path by 4 min 13 secs.

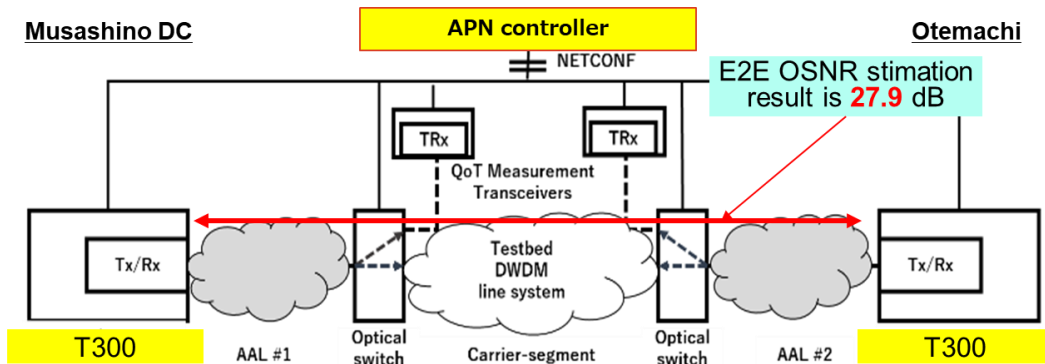


Figure 23 Results for scenario 2

- Scenario 3: Only T300 are used and configuration of AAL #1 is changed (Figure 24)
 - End to end QoT is estimated as **20.7 dB** in total (Simple patch code is used for AALs).
 - 100G/dp-qpsk is automatically configured by considering low value of OSNR.

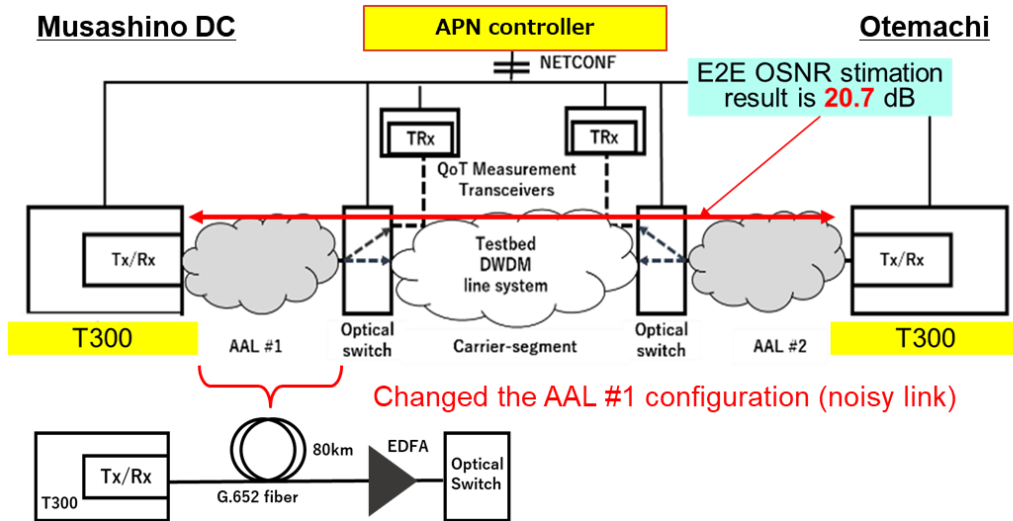


Figure 24 Results for scenario 3

o Lessons Learnt

- We confirmed that time of automatic provisioning was within 10mins for all three cases.
- The time for DSP re-start is the main item of provisioning time.
- We confirmed that client signal reached the other client by setting transmission mode appropriately.
- For further study, we are planning to update the implementation and architecture of APN-T to improve the provisioning time.

Feature7: Network attachment mechanism for user-owned transceivers

o Procedure (Figure 25)

- APN-T registration request for OR_DEVICE1 and OR_DEVICE2 is posted through NBI.

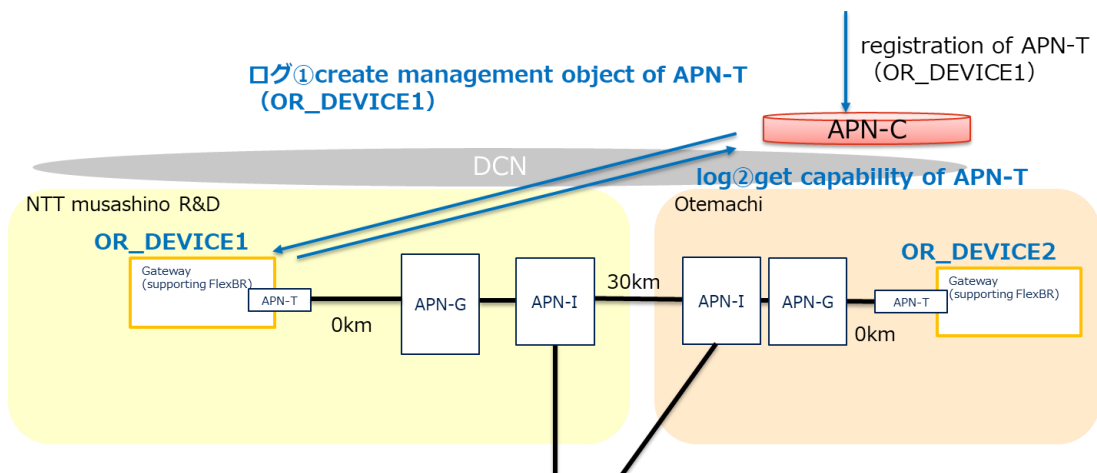


Figure 25 Environment on Feature 7

- The APN controller collects APN-T's capability through SBI.
 - The APN controller issues the ID of APN-T.
- Results
- APN-C could obtain the model number using SBI. The transmission mode and available wavelength of APN-T was retrieved using the model number. The time for the process is 12.175sec (OR_DEVICE1) and 14.175sec (OR_DEVICE2) (see Figure 26).
 - APN-C assigned the ID for APN-Ts (OR_DEVICE1 and OR_DEVICE2) after retrieving capability of APN-T (13msec and 17msec) (see Figure 27).

```

Transponder OR_DEVICE1 (communication method/model:NETCONF/OPEN_ROADM) is created.
log① create management object of APN-T (OR_DEVICE1)

OR_DEVICE1
Received message at get-device-info: OR_DEVICE1,10.166.101.216,830,NETCONF,OPEN_ROADM
Getting model name of OR_DEVICE1 ...
Getting model name of OR_DEVICE1 ...
Getting model name of OR_DEVICE1 ...
Getting model name of OR_DEVICE1 ...
Getting model name of OR_DEVICE1 ...
Getting model name of OR_DEVICE1 ...
Getting model name of OR_DEVICE1 ...
Getting model name of OR_DEVICE1 ...
Getting model name of OR_DEVICE1 ...
The model name of OR_DEVICE1 is LDC040-DO.
It's capability is {'model_number': 'LDC040-DO', 'available_lambda': {'min': 191150, 'max': 196100}, 'mode': [('dp-qpsk', 200, 'ofec'), ('dp-16-qam', 400, 'ofec')]}
10.42.0.91 [07/Mar/2023:01:54:15 +0000] "POST /operations/get-device-info/ HTTP/1.1" 200 304 "-" python-requests/2.28.2
log② obtain capability of APN-T

```

Line Rate	Modulation	FEC	Client Mapping	Baud Rate [GHz]	Organization
100G	DP-QPSK	SC FEC	OTU4-LR	28.0	OpenROADM, CableLabs, ITU-T, IEEE
100G	DP-QPSK	oFEC	FlexO-LR	31.6	OpenROADM
100G	DP-QPSK	oFEC	ZR	30.0	OpenZR+
200G	DP-16QAM	oFEC	FlexO-LR	31.6	OpenROADM, CableLabs
200G	DP-QPSK	oFEC	FlexO-LR	63.1	OpenROADM, CableLabs, ITU-T
200G	DP-QPSK	oFEC	ZR	60.1	OpenZR+
300G	DP-8QAM	oFEC	FlexO-LR	63.1	OpenROADM
300G	DP-8QAM	oFEC	ZR	60.1	OpenZR+
400G	DP-16QAM	oFEC	FlexO-LR	63.1	OpenROADM, ITU-T
400G	DP-16QAM	oFEC	ZR	60.1	OpenZR+
400G	DP-16QAM	CFEC	ZR	59.8	OIF

Figure 26 logs on Feature 7 (retrieve capability)

```

1834 [2023-02-28 13:08:14,357] [DEBUG] [tapi_server.controllers.apn_service_controller] operations_regist_terminal_post Start
1835 [2023-02-28 13:08:14,357] [INFO ] [tapi_server.controllers.apn_service_controller] request_body = {'node_attribute': {}, 'sip_attribute': {}, 'ugt_id': 'ugt_2', 'management_ip': '10.166.101.217', 'management_port': 830, 'management_protocol': 'NETCONF', 'management_device_model': 'OPEN_ROADM', 'auth_id': '', 'user': 'root', 'password': 'x1'}
1836 [2023-02-28 13:08:14,358] [INFO ] [tapi_server.controllers.apn_service_controller] select contract_manage DB result=[('ugt_2', 'OR_DEVICE2', 'nep-phgw-3-access-01')]

```

Figure 27 logs on Feature 7 (issue ID)

- Lessons Learnt
- According to architecture in Annex 2, we confirmed that APN-C could get the capability of the user-owned APN-Ts and create the optical path with appropriate optical parameters between these APN-Ts.
 - Open interfaces (both NBI and SBI) need to be extended to register and retrieve the capabilities of user-owned APN-T through API.

Feature8: Monitoring with streaming telemetry

- Procedure (Figure 28)
 - The monitoring architecture is shown in Figure 28. Monitoring Agent is deployed in OR_DEVICE1 and Monitoring Server is on APN-C.
 - Set the monitoring parameter of telemetry via APN-C API.
 - Start the monitoring of APN-T.

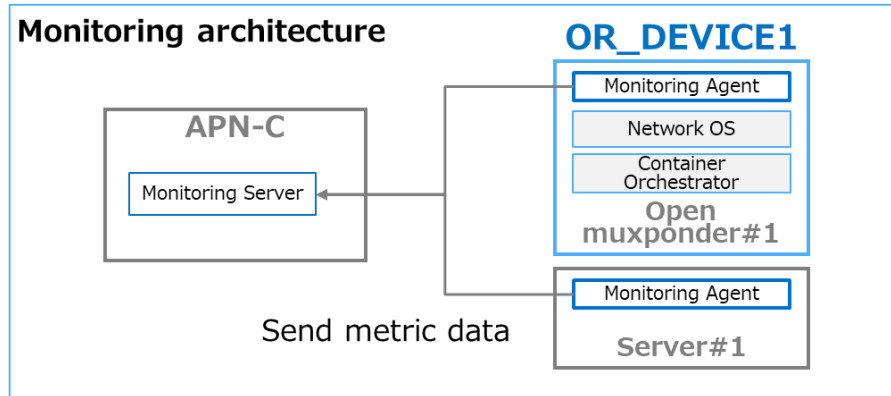


Figure 28 Monitoring architecture

- Results
 - We set the following items include BER and power-consumption on the APN-C's GUI (see Figure 29).

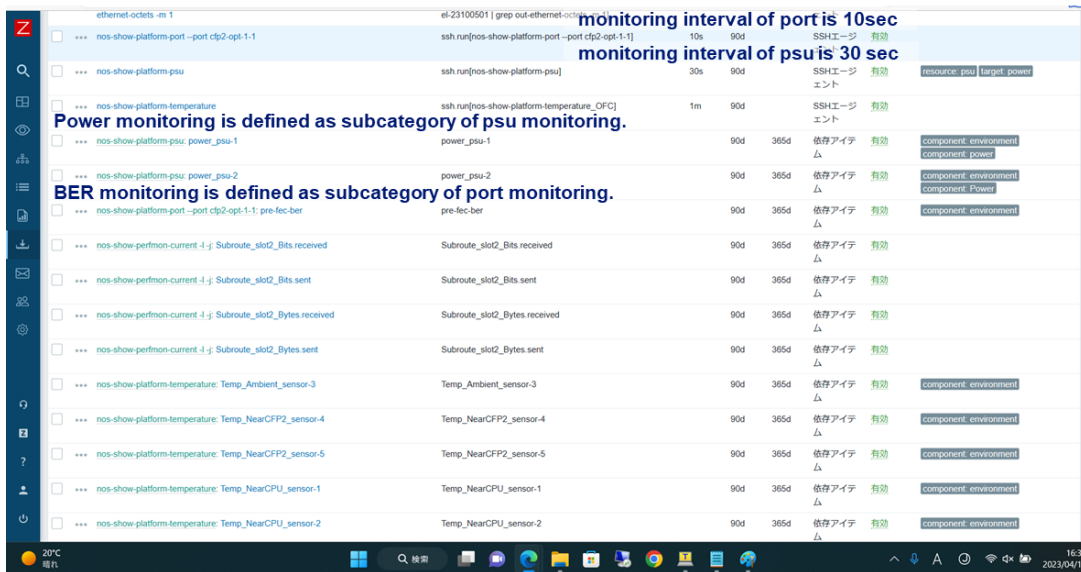


Figure 29 Results for Feature 8 (setting of monitoring items)

- Monitoring results were shown in the dashboard of APN-C (see Figure 30).

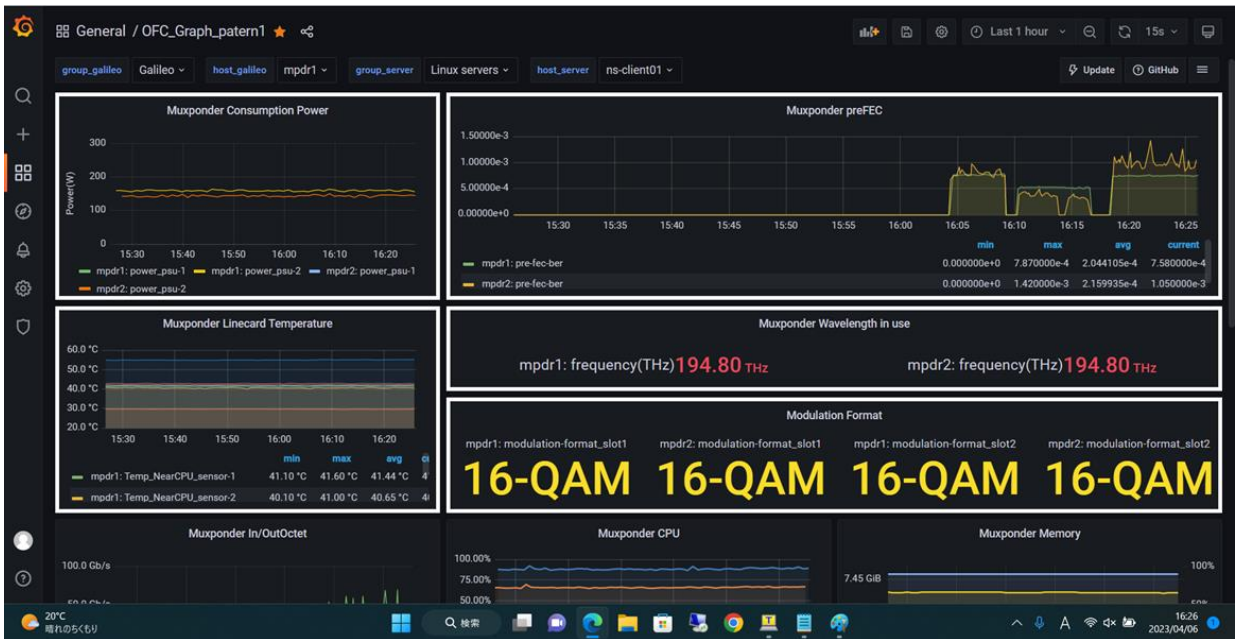
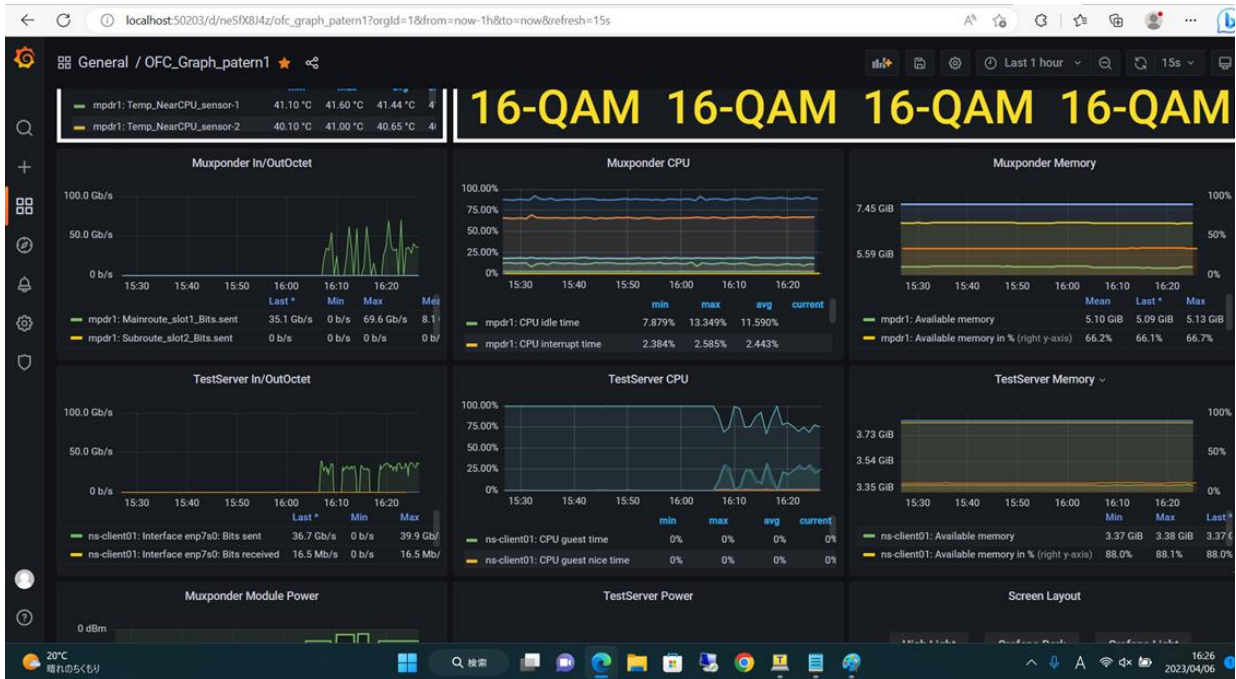


Figure 30 Results for Feature 8 (Monitoring dashboard)

- Lessons Learnt
 - We confirmed that the BER and power consumption were monitored using APN-C.
 - We confirmed that the monitoring period of there were under 1 min.
 - For further study, we are planning to implement asynchronous monitoring as well as synchronous monitoring to achieve high-definition and real-time monitoring.

6. PoC's Contribution to IOWN GF

Contribution	WG/TF	Study Item (SI)/Work Item (WI)	Comments
A	OAA	n/a	This PoC verified the goals stated in Section 4 in [1].
A	OAA	APN-C details	As an additional item, detailed APN-C functional architecture and examples of APN-C sequences based on this PoC help to clarify how APN-C can be realized. This is already incorporated into Open APN Functional Architecture Release 2.

7. PoC Suggested Action Items

9.1 Gaps identified in relevant standardization

Gap Identified	Forum/SDO	Affected WG/EG	WI/Document Ref	Gap details and Status
A	Open ROADM	OAA	Rel2	In regarding to feature 1 (1) and (4), remote control and turn-back path model are not defined in Open ROADM. We have already proposed the needs of remote control and turn-back path to Open ROADM.
B	ONF	OAA	Rel2	The PoC demonstrated that additional model and API for registration of user-owned APN-T are needed.
...				

9.2 PoC Suggested Action Items

- The results of PoC should be reflected to Open APN Rel2 architecture.

9.3 Next Step?

- We will brush up the implementation architecture to improve response time of path setup.
- We will verify open interface (SBI) between APN-C and APN-I/G as well as APN-C and APN-T to adapt SBI to new technologies mounted on these.

- This PoC demonstrated basic path management. For further study, we will consider advanced path management, path control and path computation, taking into accounts real use cases (such as path redundancy, etc).

8. Document History

Version	Date	By	Description of Change
1.0	June 05, 2023	T. Takeda, and S. Okada, et.al.	Initial draft
2.0	Nov 16, 2023	T. Takeda, and S. Okada, et.al.	Resolved comments

Annex 1 Container-based APN-T control

In this PoC, another approach to control APN-T, container-based APN-T control, was also demonstrated.

The architecture is same as Figure 28, that is, functions to control APN-T is deployed as lightweight k8s container. APN-C set transmission mode and wavelength to container in APN-T using http (Web GUI). Data model of it is Open Config.

Web GUI is shown in Figure 31 and logs of Open Config is in Figure 32.

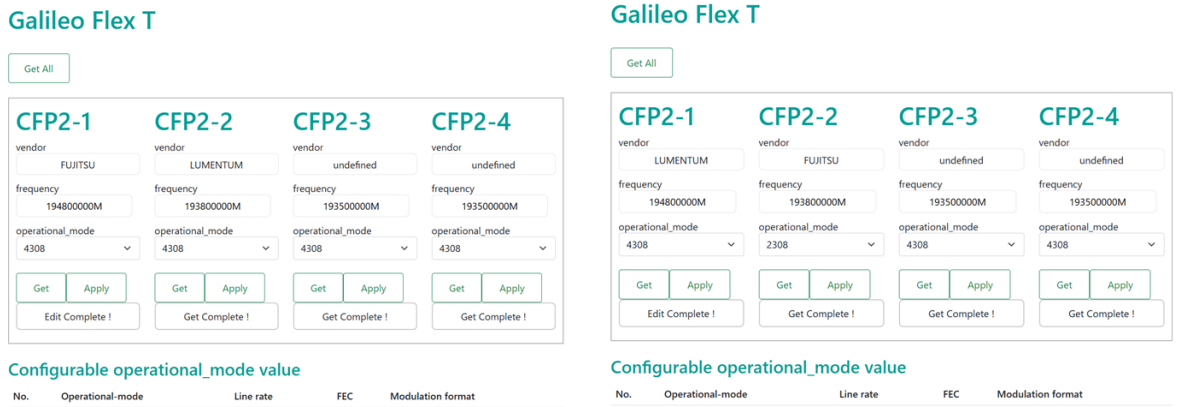


Figure 31 Web SO GUI


```

2023-04-06T16:13:27.701028218+09:00 =====Kantan Web Log=====
2023-04-06T16:13:27.701208058+09:00 port_name : cfp2-opt-1-1
2023-04-06T16:13:27.701265657+09:00 frequency : 194000000
2023-04-06T16:13:27.701283417+09:00 operational_mode : 4308
2023-04-06T16:13:27.701296857+09:00 =====send xml=====
2023-04-06T16:13:27.701308977+09:00
2023-04-06T16:13:27.701321457+09:00 <config xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
2023-04-06T16:13:27.701334017+09:00 <components xmlns="http://openconfig.net/yang/platform">
2023-04-06T16:13:27.701346857+09:00 <component>
2023-04-06T16:13:27.701359097+09:00 <name>cfp2-opt-1-1</name>
2023-04-06T16:13:27.701371737+09:00 <optical-channel xmlns="http://openconfig.net/yang/terminal-device">
2023-04-06T16:13:27.701384177+09:00 <config>
2023-04-06T16:13:27.701396777+09:00 <frequency>194000000</frequency><operational-mode>4308</operational-mode>
2023-04-06T16:13:27.701409257+09:00 </config>
2023-04-06T16:13:27.701421657+09:00 </optical-channel>
2023-04-06T16:13:27.701434057+09:00 </component>
2023-04-06T16:13:27.701446257+09:00 </components>
2023-04-06T16:13:27.701458417+09:00 </config>
2023-04-06T16:13:27.701470617+09:00
2023-04-06T16:13:27.701482777+09:00 =====response xml=====
2023-04-06T16:13:27.701494897+09:00 <?xml version="1.0" ?>
2023-04-06T16:13:27.701507457+09:00 <rpc-reply xmlns="urn:ietf:params:xml:ns:netconf:base:1.0"
message-id="urn:uuid:5f1af95a-80ff-431c-8a63-6d5b14546fd3">
2023-04-06T16:13:27.701519937+09:00 <ok/>
2023-04-06T16:13:27.701532697+09:00 </rpc-reply>

2023-04-06T16:17:25.684096714+09:00 =====Kantan Web Log=====
2023-04-06T16:17:25.684169834+09:00 port_name : cfp2-opt-1-1
2023-04-06T16:17:25.684186674+09:00 frequency : 194000000
2023-04-06T16:17:25.684200474+09:00 operational_mode : 4308
2023-04-06T16:17:25.684213233+09:00 =====send xml=====
2023-04-06T16:17:25.684225033+09:00
2023-04-06T16:17:25.684237793+09:00 <config xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
2023-04-06T16:17:25.684250313+09:00 <components xmlns="http://openconfig.net/yang/platform">
2023-04-06T16:17:25.684263233+09:00 <component>
2023-04-06T16:17:25.684275593+09:00 <name>cfp2-opt-1-1</name>
2023-04-06T16:17:25.684287953+09:00 <optical-channel xmlns="http://openconfig.net/yang/terminal-device">
2023-04-06T16:17:25.684300313+09:00 <config>
2023-04-06T16:17:25.684313193+09:00 <frequency>194000000</frequency><operational-mode>4308</operational-mode>
2023-04-06T16:17:25.684325673+09:00 </config>
2023-04-06T16:17:25.684337993+09:00 </optical-channel>
2023-04-06T16:17:25.684350233+09:00 </component>
2023-04-06T16:17:25.684362393+09:00 </components>
2023-04-06T16:17:25.684374713+09:00 </config>
2023-04-06T16:17:25.684387033+09:00
2023-04-06T16:17:25.684399273+09:00 =====response xml=====

```

Figure 32 Open Config logs

Annex 2 Open APN Architecture Proposed

We built detailed architecture and control sequence based on Open APN Architecture PoC Reference [1].

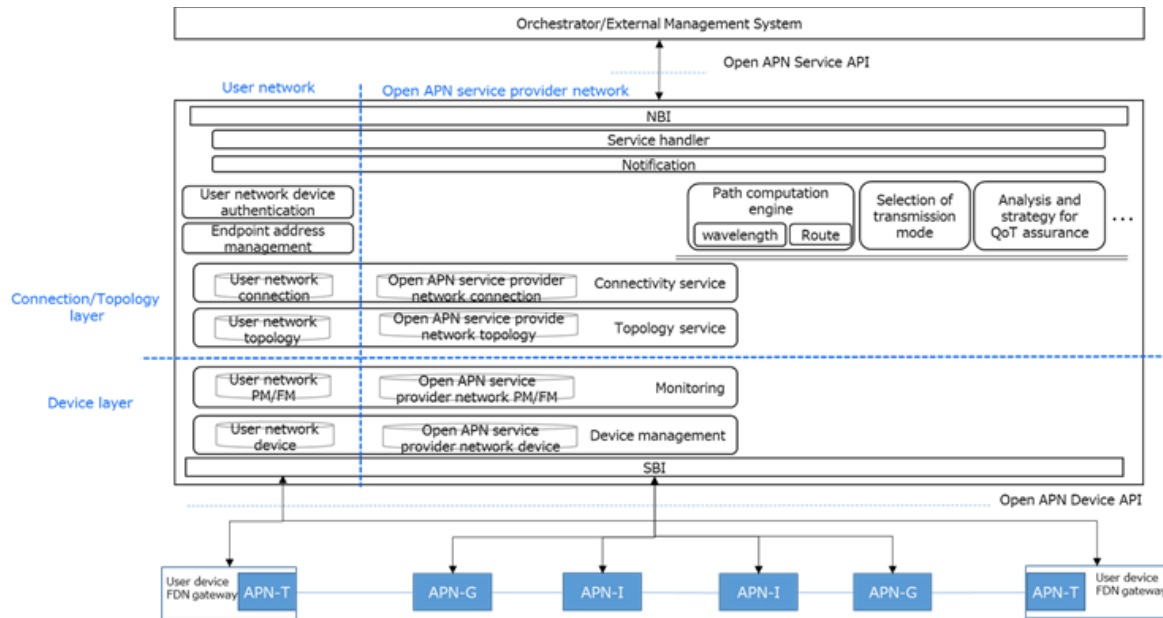


Figure 33 Open APN Architecture

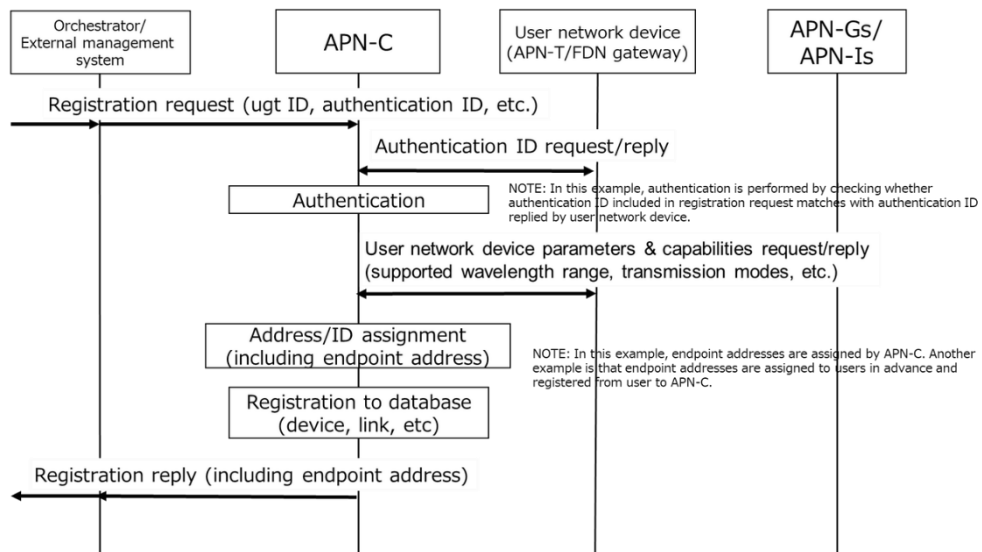


Figure 34 Detailed Sequences for Optical Wavelength

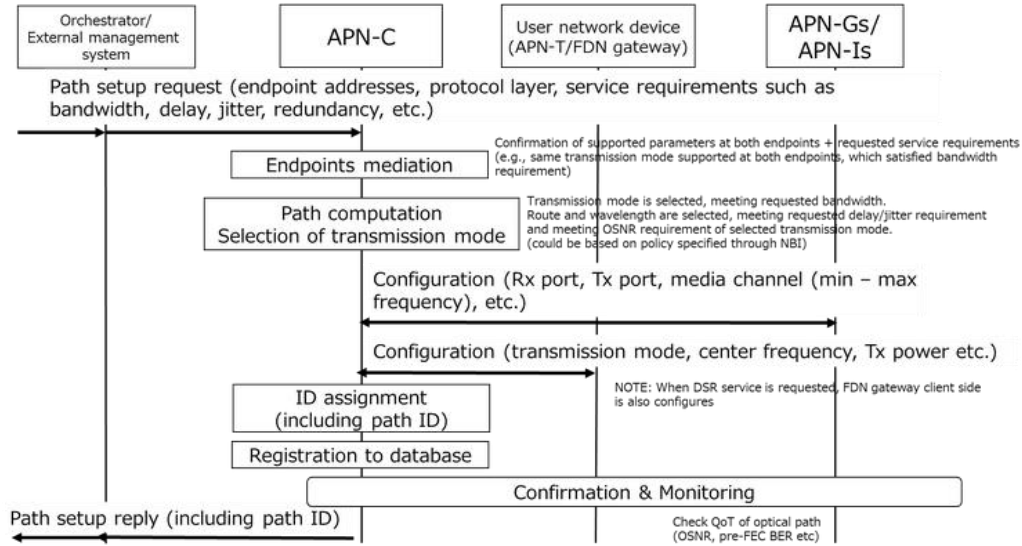


Figure 35 Detailed Sequences for Wavelength Path Setup

Reference

[1] IOWN Global Forum, "Open APN Architecture PoC Reference" (2022.11)

Acronyms

- DCN: data communication network
- GFT: Galileo Flex T
- FXC: Fiber Cross Connect
- AWG: Arrayed Waveguide Gratings