PoC Reference for Wavelength Conversion for Open APN

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1. Introduction

1.1. Purpose: Why we encourage this PoC

All-Photonic Network (APN) aims to provide end-to-end optical paths across multiple domains. Currently, optical paths are typically provisioned on a per-domain basis. Domains are delineated according to distinct perspectives, even within a single organization—for example, by geographical region, by network segments (core/metro/access), or by the number of network equipment. Furthermore, each domain is generally managed independently. In such environments, detailed resource information, such as wavelength allocation or transmission conditions, is not necessarily shared across domains.

Extending provisioning from a single domain to multiple domains therefore requires cross-domain coordination of wavelength resource management and assignment. These tasks were previously performed independently per domain due to the wavelength-continuity constraint which requires a single common wavelength throughout domains. In addition, differences in fiber types (e.g., dispersion characteristics or usable spectrum) may limit the available wavelength bands in each domain, making end-to-end wavelength continuity difficult. Such coordination typically increases provisioning lead times. Moreover, depending on per-domain wavelength occupancy and fiber type, available wavelengths may be insufficient even when wavelength assignment is coordinated between domains, necessitating new fiber or equipment deployment and consuming limited fiber resources. Increased lead times and additional fiber deployment reduce on-demand capability and increase CAPEX/OPEX, which can raise service prices and weaken a carrier's competitiveness.

Furthermore, anticipated APN growth is expected to increase optical-path demand and the number of required wavelengths. One way to accommodate more wavelengths within limited fiber is band extension [1]. However, equipment for new bands (e.g., amplifiers and other devices) is typically more expensive and deploying it broadly across all APN-I/G/T would increase CAPEX and service pricing.

To address these challenges, Open APN Functional Architecture Release 3 specifies Wavelength Conversion (WC) as an APN-I function [1]. Note that technology options of WC can be found in Annex B.3.6 in [1]. WC enables wavelength translation along an optical path, relaxing the wavelength-continuity constraint and allowing provisioning without a single common wavelength end-to-end. Deploying WC at domain boundaries permits independent per-domain wavelength selection, reducing cross-domain coordination. Additionally, WC supports band-crossing conversions, allowing signals in existing bands to be transmitted in new bands, thus expanding the available wavelength resources and alleviating the need for new fiber while minimizing the amount of new-band equipment that must be deployed.

The purpose of this PoC is to evaluate the feasibility of WC and promote multi-domain connectivity and APN adoption [2]. (For the relationship between the Functional

Architecture(FA) for multi-domain (MD) and this document, as well as the multi-domain concept, see Section 1.3.)

1.2. Objective: What we shall accomplish

The objective of this PoC is to verify that the following capabilities can be realized using WC.

(1) **Relaxation of the wavelength-continuity constraint**:
Verify that WC enables path establishment even when end-to-end wavelength continuity cannot be guaranteed across multiple fiber segments, such as when the available wavelength bands differ or when the segments belong to multiple domains with different wavelength management policies or network segments (e.g., core, metro, or access).

(2) **Establish connectivity across different wavelengths while minimizing inter-domain coordination:**
Demonstrate that WC at domain boundaries enables independent wavelength selection in each domain and minimizes inter-domain coordination. In other words, demonstrate that a single wavelength path can be established using different wavelengths on either side of the WC.
(As described in Section 1-3, this PoC focuses on U-plane connectivity.)

(3) **Accommodation of new bands signals**:
For band-crossing conversion, demonstrate conversion from existing C/L bands to new bands (e.g., O/E/S/U) and joint accommodation of these signals along fiber segments.

Demonstrating any one - or any combination - of the above items provides valuable evidence; simultaneous demonstration of all items is not required.

1.3. Scope: Subjects covered within the PoC

This PoC evaluates wavelength conversion in configurations targeting multi-domain networks and heterogeneous fiber types. It assumes multi-domain U-plane connectivity within a single operator, where domains are partitioned by network segments and/or physical conditions. Therefore, the following points need to be considered.

(1) Multi-operator environments: This PoC primarily assumes a single-operator APN. Coordination across multiple operators is not explicitly addressed in this PoC, and is expected to be discussed and evaluated in a separate task force.

(2) C-plane and M-plane functions: This PoC focuses on U-plane connectivity. C/M-plane considerations may be beneficial for the IOWN community, but they are not mandatory for executing a PoC.

2. Reference cases

This section describes the reference cases used to verify the desired features and scenarios. By evaluating each feature and scenario based on these cases, the objectives of the PoC leveraging wavelength conversion (WC) technologies can be achieved. WC is defined as an optional function of an APN-I and a Border Gateway (BG) in references [1] and [2], respectively.
Note: Regarding BG, Reference [2] defines BG functions based on multi-organization scenarios, and its network assumptions differ from those of this document. However, the use of BG for connectivity may also be effective in single-organization scenarios. For example, this applies to cases where domains are divided across network segments within a single organization, as described in Section 1.1. Nevertheless, differences in required functions arising from the distinction between single- and multi-organization scenarios need to be considered separately.
WC within an APN-I is particularly effective in providing end-to-end optical paths spanning multiple segments, including fiber types with different available wavelength bands. On the other hand, WC within a BG is especially useful for relaxing wavelength continuity constraints and facilitating inter-domain connectivity with minimal coordination.
Considering typical use cases, this document defines the following two types of basic architectures and their corresponding minimum architectures, based on the unit of wavelength conversion and functional allocation:

A) Single-channel wavelength conversion at BG

B) Whole-band wavelength conversion at APN-I

The basic architecture is defined as a configuration that assumes actual operational deployment. The minimum architecture is defined as a configuration that includes the minimum set of functional blocks required for evaluation, enabling PoC participants to implement the PoC more easily. Therefore, for PoC implementation, the system configuration should be considered based on the minimum architecture.

2.1. Basic architecture for single-channel wavelength conversion at BG

Figure 1 illustrates a basic architecture for single-channel wavelength conversion, in which two APN-T nodes are interconnected through multiple APN-G and APN-I nodes, with a pair of Border Gateways (BGs) equipped with Wavelength Conversion (WC) functions positioned between the domains. In this architecture, wavelength conversion is performed by the BGs between APN-I nodes to enable single-channel wavelength conversion. In this case, WC converts a single-channel wavelength signal which is a demultiplexed WDM signal into another wavelength.

At minimum, two domains are required, as the function operates across inter-domain links. However, the number of domains is not limited to two.

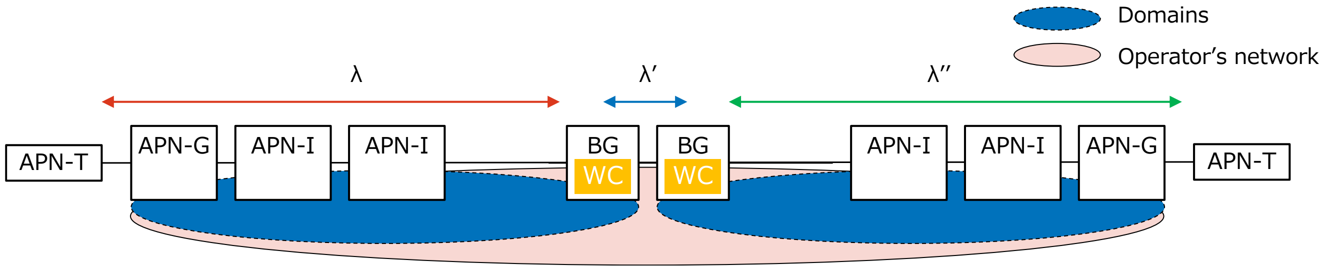


Figure 1: Basic architecture for single-channel wavelength conversion

In addition, direct single-channel wavelength connections between APN-I nodes are not assumed in normal operation, as such connections are not feasible due to differences in Tx/Rx optical power ranges. Therefore, when adopting this architecture, the BGs are required to include an optical amplification function. This requirement is specified as a mandatory function in Section 3.

2.2. Minimum architecture for single-channel wavelength conversion at BG

Figure 2 illustrates the minimum architecture for evaluating single-channel wavelength conversion. This configuration represents a simplified version of the basic architecture, in which unnecessary nodes are removed while still enabling proper functional verification.

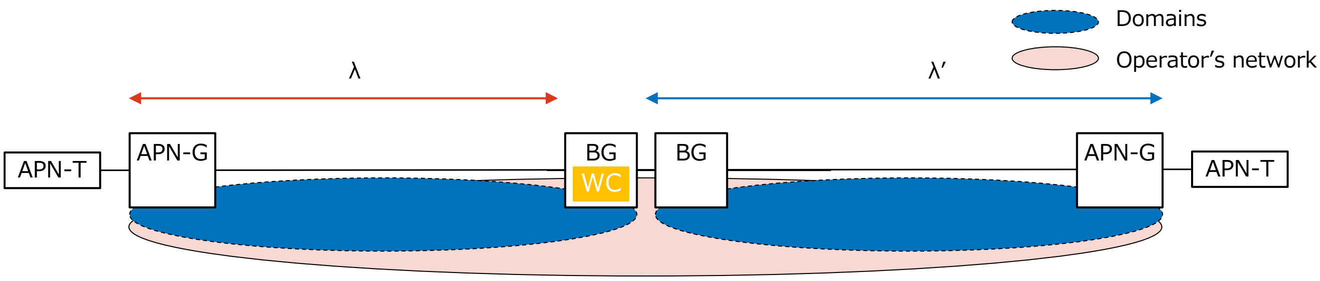


Figure 2: Minimum architecture for single-channel wavelength conversion

The differences from the basic architecture are as follows:

- **Allocation of WC**
  Either one of the wavelength conversion functions may be omitted. Since each WC performs the same function and operates independently, evaluating the function at a single WC on either side of the BG is sufficient.
  From a practical deployment perspective, demonstrating functionality using a single wavelength converter is also important, as it reduces the number of required devices and improves cost efficiency.

- **Elimination of intermediate APN-Is**
  Intermediate APN-Is can be omitted. Since APN-Is simply transmit WDM signals between nodes and do not affect the evaluation of WC functions, these nodes can be excluded from the configuration.

2.3. Basic architecture for whole-band wavelength conversion at APN-I

Figure 3 illustrates the basic architecture for whole-band or multi-wavelength conversion within APN-I nodes, and this configuration primarily focuses on wavelength conversion between the C-band and L-band.

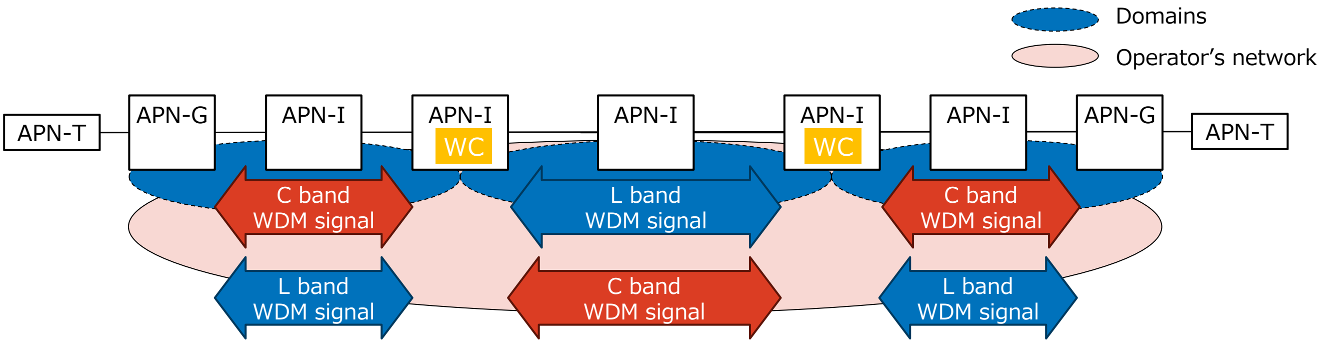


Figure 3: Basic architecture for whole-band wavelength conversion

Two WCs are placed at the boundaries between domains, enabling bidirectional whole-band wavelength conversion between the C-band and L-band. At minimum, three domains are required because two conversions (C⇔L⇔C or L⇔C⇔L) are needed to align the wavelength bands between the APN-Ts.

2.4. Minimum architecture for whole-band wavelength conversion at APN-I

Figure 4 illustrates the minimum architecture for evaluating whole-band or multi-wavelength conversion. This configuration represents a simplified version of the basic architecture, in which unnecessary nodes are removed while still enabling proper functional verification.

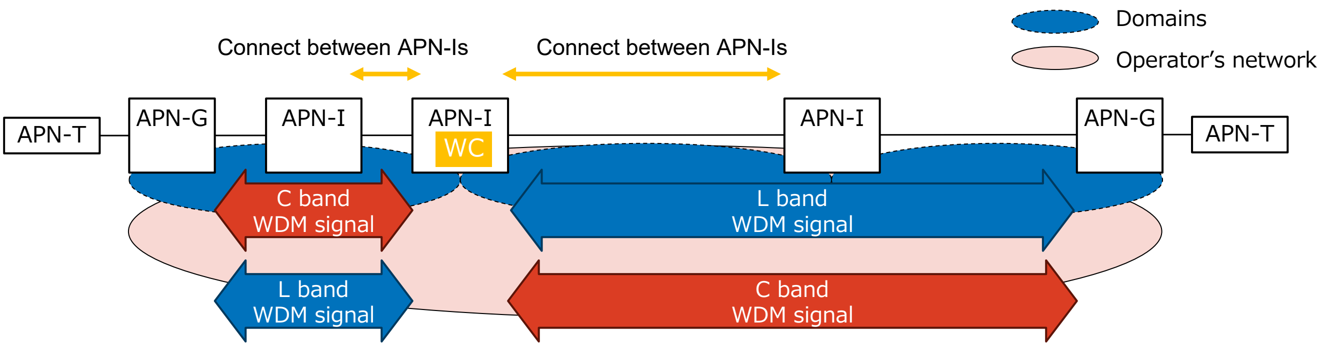


Figure 4: Minimum architecture for whole-band wavelength conversion

The differences from the basic architecture are as follows:

- **Allocation of WC**
  Either one of the wavelength conversion functions may be omitted. Since each WC performs the same function and operates independently, evaluating the function at a single WC on either side of the APN-I is sufficient.

From a practical deployment perspective, demonstrating functionality using a single wavelength converter is also important, as it reduces the number of required devices and improves cost efficiency.

- **Elimination of intermediate APN-Is**
  Intermediate APN-Is can be omitted. Since APN-Is simply transmit WDM signals between nodes and do not affect the evaluation of WC functions, these nodes can be excluded from the configuration.

2.5. Basic architecture for S-band wavelength conversion at APN-I

Figure 5 illustrates the basic architecture for whole-band wavelength conversion specific to S-band introduction and this configuration primarily focuses on wavelength conversion between the C-band and S-band.
Two WCs are placed at the boundaries between domains, enabling bidirectional whole-band wavelength conversion between the C-band and S-band. At minimum, three domains are required because two conversions (C+L⇔C+L+S⇔C+L) are needed to align the wavelength bands between the APN-Ts.

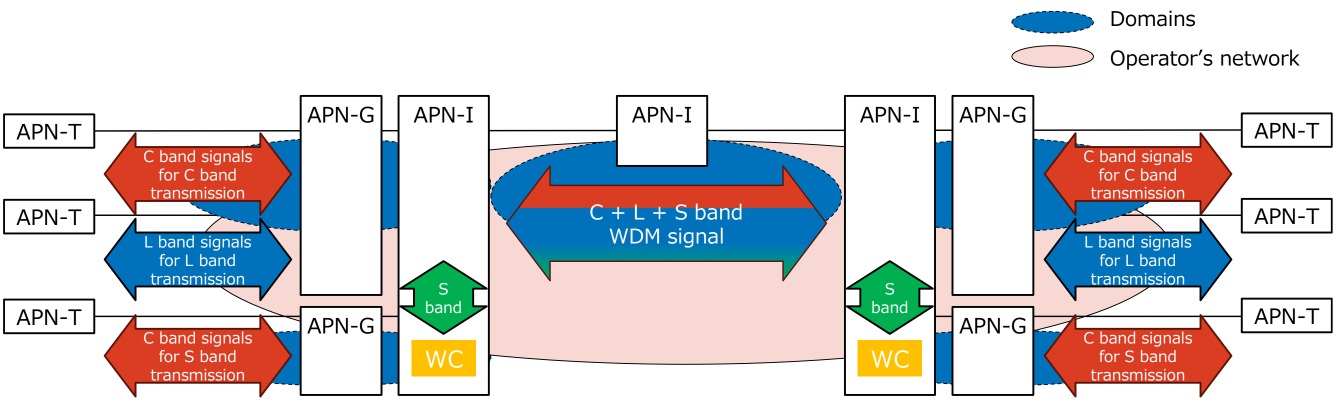


Figure 5: Basic architecture for S band wavelength conversion

3. Desired features

The following features are defined for wavelength conversion. Feature 1 is mandatory, while Features 2 through 4 are optional. The optional features may be evaluated selectively, depending on implementation status and evaluation objectives.

3.1. Feature 1: Wavelength conversion (Mandatory)

The most fundamental function required in this PoC is, naturally, the wavelength conversion function. Depending on the use case, wavelength conversion is required at the following levels:

Feature 1-1: Single-channel wavelength conversion

Single-channel wavelength conversion is required when optical paths must be converted individually, such as for relaxing wavelength-continuity constraints or coordinating wavelengths across different organizations.

Feature 1-2: Whole-band wavelength conversion

Whole-band conversion is necessary in scenarios where unused optical spectrum must be utilized by combining different fiber types or when extending the usable spectrum, for example, toward the S-band.

3.2. Feature 2: Abnormal Signal Cutoff (Optional)

The abnormal signal cutoff function is not a feature specific to WC. However, from the perspective of WC use cases, it should be evaluated in combination with WC. When connecting multiple domains managed by different administrators, if an unintended signal is inserted—either due to configuration errors or malicious activity—the system must be capable of detecting and cutting off the abnormal signal to prevent it from affecting other signals.

3.3. Feature 3: Signal Performance Monitoring (Optional)

Similarly, the signal performance monitoring function is not specific to WC, but it plays an important role in WC-related use cases. When connecting multiple domains managed by different administrators, monitoring the quality of signals entering from each domain enables assurance of optical path quality and helps isolate the causes of degradation when performance issues occur.

3.4. Feature 4: Loss compensation/adjust (Optional)

The optical amplification function is also not specific to WC, but rather a general function in optical systems. It is required to compensate for optical power reductions that occur during wavelength conversion. In addition, it is necessary for adjusting power levels in architectures where the input and output optical power levels differ before and after wavelength conversion, such as the architectures defined in Sections 2-1 and 2-2.

4. Key benchmarks

This section defines the key benchmarks for each feature. The evaluator shall assess the benchmarks mapped to the features to be verified and report the results in the PoC report. The PoC report shall describe both the measurement results and the measurement methods. Evaluation may be performed using all benchmarks or a selected subset, depending on the evaluation objectives. Comparative evaluation across multiple wavelength conversion methods is also useful, but optional.

4.1. Benchmarks for Feature 1

The following benchmarks should be evaluated for Feature 1.

Benchmark 1-1 : Wavelength conversion capability
This should be evaluated using the optical signal spectrum. The expected result is optical spectrum data before and after wavelength conversion obtained with optical power splitters and spectrum analyzer. It is recommended to confirm the conversion accuracy, i.e., the difference in center wavelength (or frequency) between the configured value and measured one. It is also recommended to describe reasons if distortions in the optical spectrum are observed.
Furthermore, it is desirable to evaluate the behavior under colorless reception, especially in single-channel wavelength conversion, when wavelengths other than the target wavelength are present at the input. For example, this can be evaluated by simultaneously inserting the target wavelength and an adjacent-channel wavelength.

In addition to verifying optical wavelength conversion, it is also necessary to confirm that the client signal is properly carried end to end. The expected approach is to inject a client signal into the APN-T using a traffic generator (or equivalent tool) and verify error-free transmission.

Benchmark 1-2 : Power consumption
To evaluate power efficiency, measure the power consumption during wavelength conversion. The measurement can be performed using test equipment (i.e., a power meter). Differences in power consumption due to the modulation format, baud rate, conversion range, etc., of the signal being converted should be reported.

Benchmark 1-3 : Latency
Benchmark 1-4 : Jitter
Benchmarks 1-3 through 1-4 are evaluated by comparing measurements taken on the wavelength paths with and without wavelength conversion. The impact of the wavelength-conversion function is assessed based on the differences between the two sets of results. The expected results are measurement data obtained using test equipment (i.e., a traffic analyzer).
For jitter evaluation, if the inter-packet gap (IPG) or inter-frame gap (IFG) is known, one possible approach is to evaluate the variance of each packet's or frame's arrival interval relative to the expected arrival interval. If the IPG or IFG is not known, the variance of each packet's or frame's latency relative to the average latency may instead be used for evaluation.

Benchmark 1-5 : Transmission performance
This benchmark shall be evaluated by measuring the signal quality of the optical path. In particu-

lar, signal quality should be compared between the case where wavelength conversion is applied and the case where it is not applied. Possible performance metrics include bit error rate (BER), Q-factor (e.g., derived from pre-FEC BER measurable at the APN-T), and optical signal-to-noise ratio (OSNR). In addition, where applicable, it is recommended to evaluate the impact of multiple wavelength conversions (i.e., cascading conversions).

4.2. Benchmarks for Feature 2

The following benchmarks should be evaluated for feature 2.

Benchmark 2-1 : Signal cut off capability

Benchmark 2-2 : Types of detectable abnormal signals

This feature shall be evaluated by verifying detection of an abnormal input signal and the cutoff of the corresponding output. The results should include (1) the types of abnormal signals that can be detected, (2) evidence of the abnormal input signal, and (3) confirmation that the associated output signal has been cut off, given as a paired result. Here, “cutoff” refers to a condition in which no optical signal is output. The types of abnormal signals considered include unintended inputs—such as frequency deviations of the wavelength signal, unmodulated signals—as well as excessively strong or weak optical power.
For example, when evaluating frequency deviation as an unintended input, the evaluation should verify this using the signal spectrum. Specifically, the spectrum analyzer should confirm both that a wavelength signal with a frequency other than the expected one has been input and that the corresponding wavelength signal has been cut off—that is, no signal is output.

4.3. Benchmarks for Feature 3

The following benchmarks should be evaluated for Feature 3.

Benchmark 3-1 : Performance monitoring capability

Benchmark 3-2 : Types of measurable performance metrics

This feature is evaluated based on the types of performance information that can be obtained and the performance information actually obtained. The evaluation should confirm that signal quality can be obtained through the performance monitor. Possible performance information to be collected includes optical signal indicators—such as input and output optical power levels (maximum, minimum, and average)—as well as client-signal indicators such as packet loss and frame loss. Since the indicators that can be collected vary depending on the WC method used, they must be configured appropriately. The expected result is a time-series data set of measurement data demonstrating that the specified performance metrics were collected at defined intervals over a certain period of time.
For the measurement interval, typical values used in common equipment are expected (e.g., 15 minutes, 8 hours, or 1 day). Other intervals may also be used, as appropriate.

4.4. Benchmarks for Feature 4

The following benchmarks should be evaluated for Feature 4.

Benchmark 4-1 : Optical power level adjustment capability

Benchmark 4-2 : Range of adjustable optical power

This function shall be evaluated by confirming that the WC can adjust output optical signal power levels. The evaluation shall verify the acceptable input optical power range and the adjustable output optical power range.
The expected result is a set of measured values showing both the input optical power and the corresponding amplified output optical power.
In particular, it is recommended to evaluate (1) the supported optical input/output power ranges and (2) the impact of receiving multiple channels, as specified in standards such as the Open ROADM MSA W-IF specification.

For example:

- For (1), refer to the Open ROADM W-IF interface optical transmit/receive specifications.
- For (2), refer to the "Signal-to-ASE (Res = 0.1 nm) power ratio for transmitter in out-of-band channels."

5. Other Considerations

This section outlines items that are not examined or evaluated in this PoC but should be considered for practical implementation, as well as perspectives and discussion points that may be useful for further study.

5.1. C-plane and M-plane Requirements

In this PoC reference, the primary scope is defined as U-plane connectivity. However, for practical implementation, specification and validation of the C-plane and M-plane will also be required. For example, the following items should be considered:

- Management interfaces for wavelength conversion (WC)
- Path management models for enabling WC
- Alarms and notifications handling
- Information that needs to be exchanged between domains for end-to-end path provisioning
- OAM (Operations, Administration, and Maintenance) capability for real-time monitoring

5.2. Further Improvement of Spectrum Management

While this PoC focuses on demonstrating WC functionality, it is also important to evaluate scenarios that assess the benefits of WC. For example, spectrum defragmentation can be further enhanced by WC. In scenarios where available spectral slots are non-aligned across domain boundaries—often resulting in 'stranded capacity'—WC enables these fragmented resources to be utilized for end-to-end paths. Furthermore, WC allows each domain to independently optimize its internal grid allocation (e.g., migrating paths to clear contiguous blocks for high-bandwidth signals) without requiring rigid wavelength continuity from adjacent domains. Considering such scenarios would be highly valuable as representative use cases for this technology.

5.3. Comparison of Wavelength Conversion Technologies

As shown in [1], several wavelength conversion technologies are available. Since the purpose of this PoC is to evaluate functional feasibility, this document does not define any selection criteria among these technologies. However, comparing and summarizing the characteristics, advantages, and disadvantages of each technology can provide useful reference information for operators considering the adoption of wavelength conversion. Therefore, when a PoC is conducted using multiple approaches, it is recommended to document and compare these aspects for each technology.

Annex

A. Reference implementation model

This section describes reference implementation models (RIMs) as practical guidelines not only to facilitate conducting PoCs but also to accelerate deployment of wavelength conversion in the field. In particular, such RIMs aim to clearly show how to utilize commercially-available ROADM systems in the PoC and how to deploy or "add on" wavelength conversion to ROADMs.

Although the main scope of this PoC document is U-plane (i.e., data transmission), as mentioned in Section 1, this section also covers C-/M-plane perspectives for further discussion and/or validation of operability for practical use.

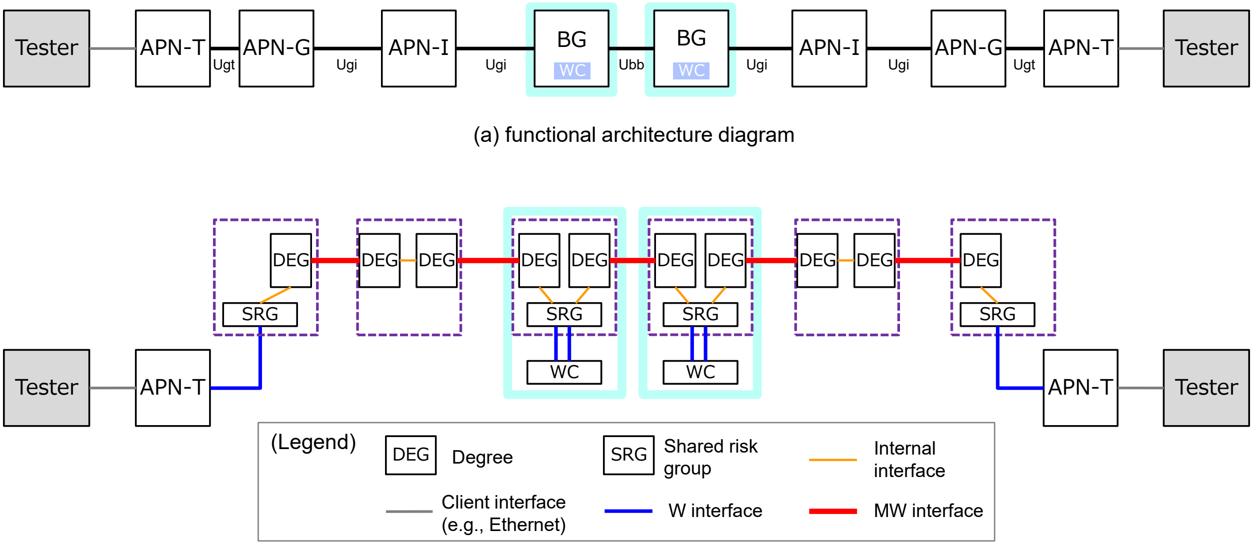
A.1. RIMs for U-plane validation

For validating physical-layer feasibility of a network solution utilizing wavelength conversion, viable implementation examples are provided as references. Note that it is not mandatory to exactly match a PoC setup with one of the following RIMs. However, a PoC report is required to include the PoC setup and conditions in as much detail as possible, considering Reference Cases described in Section 2.

A.1.1. RIMs for single-channel wavelength conversion-enabled solutions

This section presents viable configurations where single-channel wavelength conversion is applied. Note that such configurations correspond to PoC reference cases described in Section 2.1 or 2.2.

Figure A-1 shows a configuration example where single-channel wavelength conversion is applied, and the relationship between functional diagram and physical implementation is also depicted. Note that "degrees" and "shared risk groups (SRGs)" are defined in the OpenROADM MSA, and interfaces of "W" and "MW" are also specified [3]. Also note that degrees generally include wavelength-selective switches (WSS) and amplifiers while SRGs can include WSS, multicast switches (MCS), or couplers. This model clearly indicates commercially-available ROADM systems compliant with OpenROADM MSA (purple dotted rectangles in the figure) can be used in the PoC. In this model, single-channel wavelength converter is connected to SRG within ROADM via W interface.

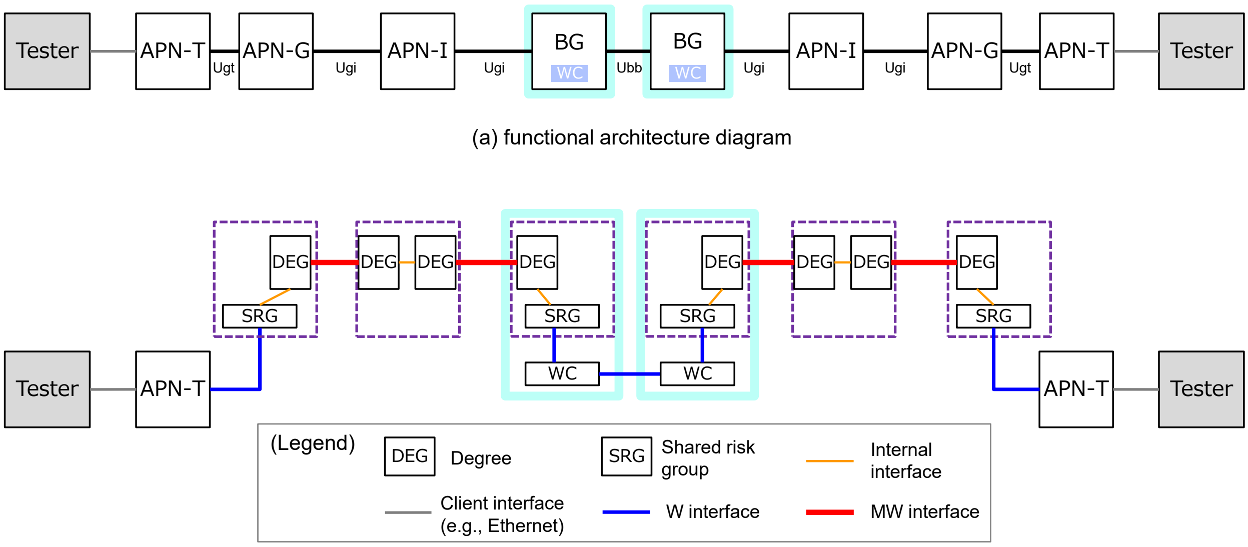


(a) functional architecture diagram

(b) configuration example

*Figure **Error! Use the Home tab to apply Annex to the text that you want to appear here.** - 1 : Configuration example 1: Multi-wavelength BG interconnection using single-channel wavelength conversion*

Another model with single-channel wavelength conversion is shown in Figure A-2. The difference from Figure A-1 is in the BG interconnection configuration. Note that Figure A-2 shows a single-channel wavelength interconnection case.



(a) functional architecture diagram

(b) configuration example

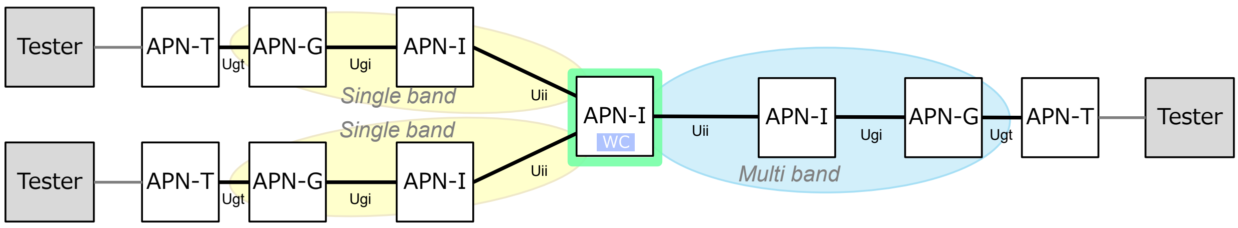
*Figure **Error! Use the Home tab to apply Annex to the text that you want to appear here.** - 2 : Configuration example 2: Single-channel wavelength BG interconnection using single-channel wavelength conversion*

The PoC report should describe applied interface of input/output to/from wavelength converter. If W interface (specified in OpenROADM MSA) is used, operational-mode information (e.g., modulation format, line rate, and FEC) should be included in PoC report.

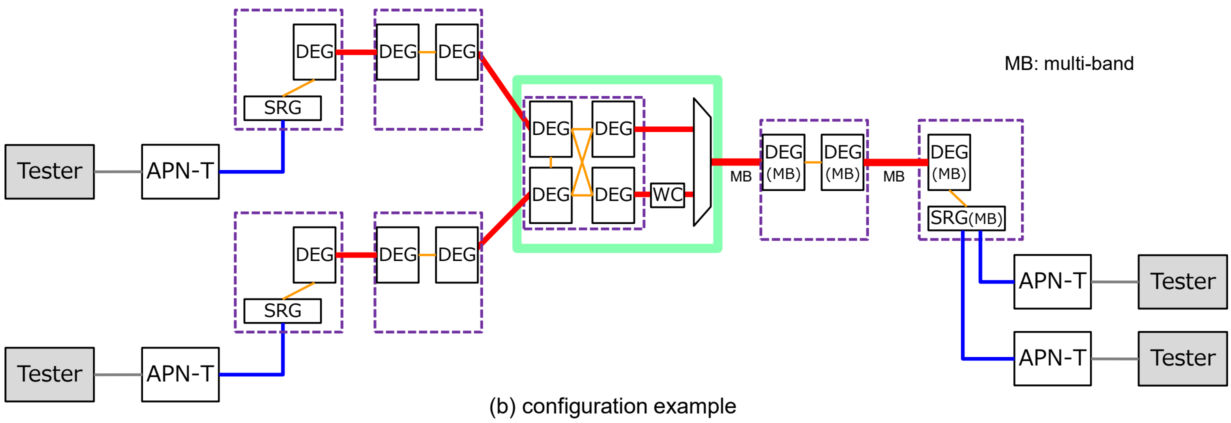
A.1.2. RIMs for single-channel wavelength conversion-enabled solutions

This section presents viable configurations where whole-band wavelength conversion is applied. Note that such configurations correspond to PoC reference cases described in Section 2.3 or 2.4.

Figure A-3 shows a configuration example where whole-band wavelength conversion is applied, and the relationship between functional diagram and physical implementation is also depicted. In this model, commercially-available ROADM systems compliant with OpenROADM MSA can be used, and whole-band wavelength converter is connected to degree within ROADM via MW interface.



(a) functional architecture diagram

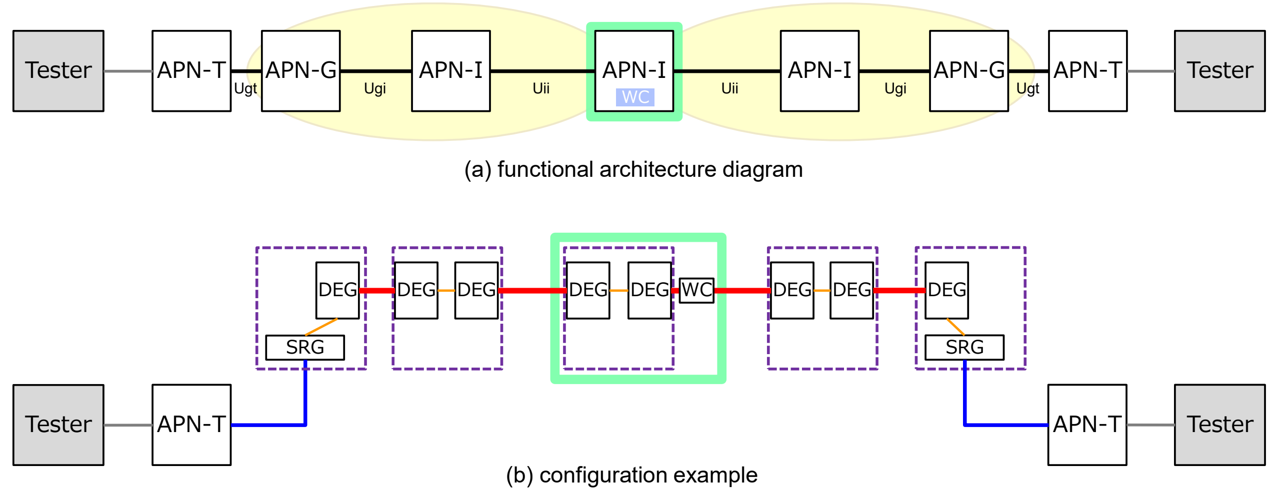


(b) configuration example

*Figure **Error! Use the Home tab to apply Annex to the text that you want to appear here.** - 3 : Configuration example 3: Whole-band wavelength conversion within APN-I, enabling wavelength-band adaptation*

Note that this model would serve as one of viable use cases of whole-band wavelength conversion described in Open APN FA (see Figure 6.1.5-3 (b) in [1]).

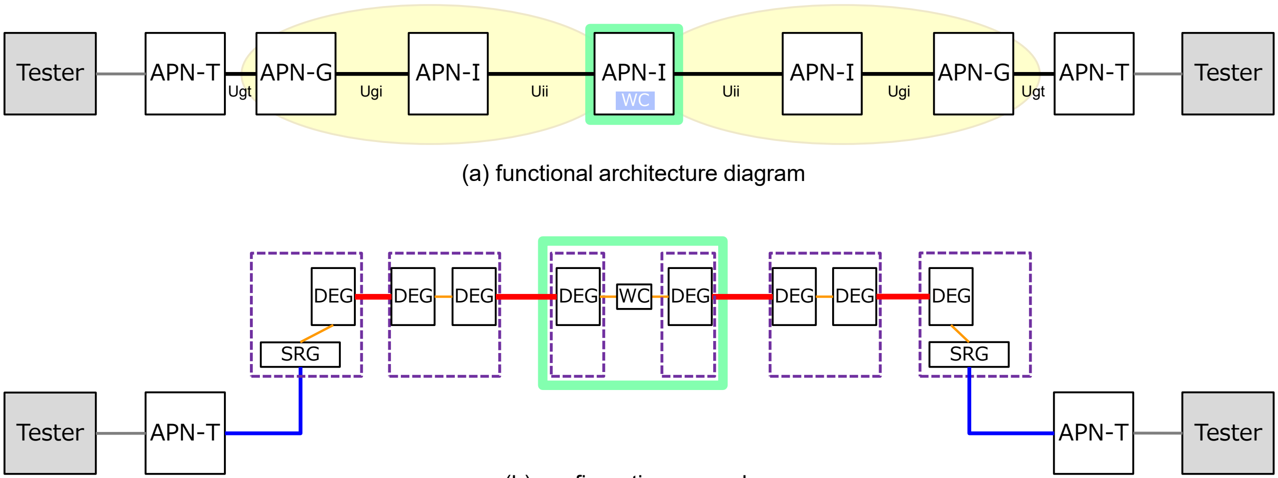
Other models with whole-band wavelength conversion are shown in Figures A-4 and A-5. These models match another use case described in Open APN FA (please see Figure 6.1.5-3 (a) in [1]). The difference between two figures lies in how (or where) a wavelength converter is applied.



(a) functional architecture diagram

(b) configuration example

*Figure **Error! Use the Home tab to apply Annex to the text that you want to appear here.** - 4 : Configuration example 4: Whole-band wavelength conversion within APN-I, enabling wavelength-band adaptation*



(a) functional architecture diagram

(b) configuration example

*Figure **Error! Use the Home tab to apply Annex to the text that you want to appear here.** - 5 : Configuration example 5: Whole-band wavelength conversion within APN-I, enabling wavelength-band adaptation*

It is recommended that PoC report include interface conditions for conducting PoC and challenges to be addressed if any.

A.2. Reference for C-/M-plane configuration

This section provides reference information that will be helpful as implementers proceed with other considerations. For a practical operation, an optical path is established between arbitrary pair of APN-Ts unless there is a wavelength resource shortage. In addition, OAM mechanisms (such as real-time performance monitoring) are provided for the established optical path. Moreover, in case of defects or failures, alarms must be properly handled and root cause analysis must be executed promptly.

Figure A-6 shows a reference model for network control and management. In particular, C-/M-plane perspectives are added to Figure A-1 (b), just as a viable example. Based on requests received via a service API, a controller creates/controls optical paths by communicating with ROADM systems and wavelength converters via a device API. Furthermore, a controller also monitors performance and failure conditions of optical paths by communicating with ROADM systems and wavelength converters via a device API. It is possible to use APIs based on OpenROADM MSA definitions. For example, the OpenROADM MSA has defined an API using NETCONF interface with a YANG-based data model abstracts the control and management of multi-vendor ROADM devices. Such definitions play the role of practical guidance of a possible C-/M-plane implementation although some modifications or extensions may be required for wavelength converters.

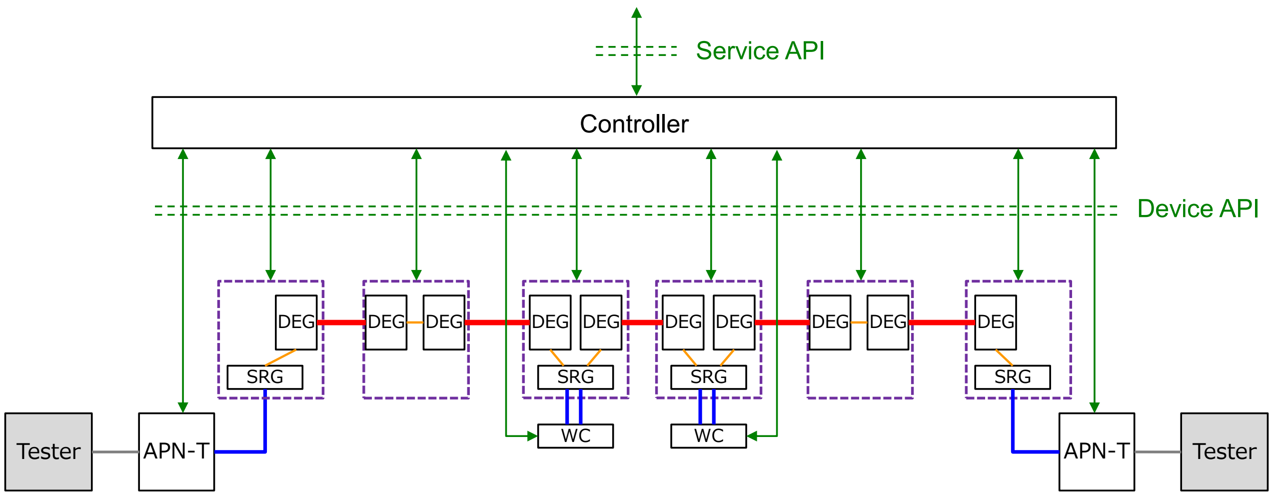


*Figure **Error! Use the Home tab to apply Annex to the text that you want to appear here.** - 6 : Reference case for control and management*

References

[1] Open All-Photonic Network Functional Architecture version 3

[2] Functional Architecture for Multi-domain IOWN Networking version 1

[3] OpenROADM MSA

History

Revision	Release Date	Summary of Changes
1	July 2026	Initial Release