

PoC Reference for QKD over Open APN

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Contents

1. Introduction	4
1.1. Purpose: Why we encourage this PoC	4
1.2. Objectives: What we shall accomplish	5
1.3. Scope: Subjects covered within the PoC	5
2. Reference Cases	7
2.1. Case 1: Carrier backbone	8
2.2. Case 2: Metro data center interconnect (DCI)	9
2.3. Case 3: Mobile fronthaul	10
2.4. PoC reference model and common requirements	11
3. Desired Features	13
3.1. Feature 1: One-span PtP wavelength path provisioning	13
3.2. Feature 2: Add/Drop with well-shaped optical filtering	13
3.3. Feature 3: Transmission parameter design for feasible co-propagation of APN and QKD-related signals	13
4. Benchmarks	15
4.1. Environmental Conditions	15
4.2. Parameter Design	16
4.3. Common Test Procedure	17
4.4. Benchmark Metrics (What to Measure)	18
References	21
History	22

List of Figures

Figure 2-1: Conceptual architecture for QKD over Open APN	8
Figure 2-2: Add/Drop functional model	8
Figure 2-3: Basic architecture for carrier backbone use case	9
Figure 2-4: Basic architecture for metro DCI use case	10
Figure 2-5: Basic architecture for mobile fronthaul use case	11
Figure 2-6: PoC reference model commonly applicable to all three reference cases	12

List of Tables

Table 2-1: WDM transmission conditions for each of three reference cases	12
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1. Introduction

1.1. Purpose: Why we encourage this PoC

Today's optical networks primarily support optical signals aligned with the DWDM grid and are not regarded as modulation-format-agnostic and protocol-agnostic. In practice, they are limited to support digital-coherent signals designed for long-haul transmission over optical-amplifier-repeated links, and all traffic needs to be carried within OTN frames. The capability for transmitting other types of signals—such as those aligned with the CWDM grid, or optical signals with dedicated formats and/or non-OTN protocols required for emerging applications like quantum key distribution (QKD) and fiber sensing—has not been explicitly defined. This architectural limitation restricts the flexibility of carrier networks.

To overcome this limitation, Open APN Functional Architecture Release 3 [1] introduces the "One-span PtP wavelength path service," a specialized form of "PtP wavelength path" established over a one-span direct fiber between a pair of Open APN endpoints. This service enables the transmission of various optical signals described above even in the network segment where the fiber path service is not available, which could enhance the use case of the Open APN from the viewpoint of value-added services such as QKD and fiber sensing.

There is strong motivation from QKD service providers to integrate QKD network (QKDN) with IOWN infrastructure as described in Annex J of [1]. The QKDN includes a quantum layer, formed by point-to-point QKD links, and a key management layer that provides end-to-end key sharing across the network [2]. Current QKDNs have been designed primarily with a QKD-centric architecture, focusing on ensuring ideal conditions for the quantum channel which are susceptible to noise and decoherence – typically using dark fibers – and maximizing the key generation rates. Integrating these QKDNs into Open APN infrastructure will enable more cost-effective key delivery and accelerate wider commercial adoption of QKD services, which makes Open APN capable of supporting additional value-added use cases.

This PoC reference specifically evaluates the practicality of QKD link over Open APN using One-span PtP wavelength path (Level-1 integration in Figure J.2-1 in [1]). It also establishes common user requirements for all PoC implementers, thus demonstrating and promoting Open APN's capability to effectively support QKD as a promising value-added use case, which shows possibility of quantum-safe secure transport service market for network operators.

Furthermore, this PoC is intended to serve as a foundational study for future work items that will address advanced scenarios, such as use cases for fiber degradation (e.g. increased fiber attenuation, State of Polarization (SOP) fluctuation and multiple reflections from connectors) on the quantum channel in commercial deployment environments, and use cases for integration of control and management functionalities between Open APN and QKDN operated by different infrastructure operators.

1.2. Objectives: What we shall accomplish

To demonstrate the practicality of QKD link over Open APN, the following features should be clearly evaluated:

One-span PtP wavelength path provisioning for QKD

The QKD link consists of a quantum channel and one or more classical/clock channels. One-span PtP wavelength path shall be provisioned to carry these QKD-related signals without passing through optical amplifier. The objective is to verify that a QKD key-generation session can be successfully established over such a provisioned path between the endpoints of one-span PtP wavelength path.

Add/drop of QKD-related signals with well-shaped optical filtering

For cost-effective deployment, QKD-related signals shall be wavelength-multiplexed onto the fiber carrying APN DWDM main signals using add/drop devices. The objective is to verify that these add/drop components can provide well-shaped optical filtering – including sharp roll-off, sufficient isolation, and low insertion loss – so as to enable signal multiplexing while minimizing degradation of both the APN main signals and the QKD signals.

Transmission parameter design for feasible co-propagation of APN main signals and QKD-related signals

When QKD-related signals co-propagate with APN DWDM main signals in the same fiber, spontaneous Raman scattering (SpRS) induced by the DWDM signals can degrade QKD performance, particularly the key generation rate. The objective is to verify that appropriate wavelength allocation with guard-band settings and WDM launch power coordination can achieve stable co-propagation with acceptable performance for both APN main signals and QKD-related signals.

1.3. Scope: Subjects covered within the PoC

This PoC reference document aims at evaluating the practicality of QKD link over Open APN by verifying key features such as provisioning of One-span PtP wavelength path, add/drop of QKD-related signals with well-shaped optical filtering, and design of transmission parameters for feasible co-operation of APN and QKD-related signals.

Items listed below are out of the scope of this PoC reference document.

- Development and evaluation of advanced non-trusted relay techniques at the quantum layer to extend transmission distances, such as measurement-device-independent QKD and quantum repeaters. This PoC will use only commercially available technologies for trusted key relay-based QKDN, focusing on the QKD link over one-span PtP wavelength path.

- Development and evaluation of network-wide end-to-end key sharing by integrating the QKD module and key manager (KM) into IOWN-defined logical network equipment (e.g., FDN/DCI gateways and logical nodes), which is described as the level-2 integration in [1]. This PoC will focus on the Level-1 integration.
- Development and evaluation of the QKD link over PtP fiber path service at the Open APN.FX layer, where APN.FX enables cost-effective deployment of QKDN through one-to-many QKD transmission among multiple parties, as described in Section J.3 of [1]. This PoC will focus on the QKD link over one-span PtP wavelength path at the Open APN.WX layer.
- Development and evaluation of scenarios involving multiple infrastructure operators, especially those related to inter-domain control and management integration. This PoC will assume both Open APN and QKDN are operated by a single infrastructure operator. However, the results and insights from this PoC are expected to provide a solid foundation for such future studies on advance multi-operator integration and coordination.
- Development and evaluation of scenarios involving fiber degradation effects such as increased fiber attenuation, State of Polarization (SOP) fluctuations and multiple reflections from connector end faces on the quantum channel in commercial deployment environments. The results and insights from this PoC are expected to provide a solid foundation for such future scenarios for QKD signal transmission over field-deployed fibers.
- Development and evaluation of QKD transmission over alternative fiber technologies such as hollow core fiber (HCF). Although HCF is not assumed in the current PoC reference due to its limited deployment, it is recognized as a promising technology for certain high-end use cases (e.g., short-reach data center interconnects) due to its potential advantages such as reduced latency and nonlinear effects. Evaluation of QKD over HCF is therefore considered a potential subject for future versions of this document.

2. Reference Cases

Conceptual architecture shown in Fig. 2-1 comprises a user plane and a control/management (C/M) plane. On the user plane, a QKD link is provisioned with a specified wavelength using the one-span PtP wavelength path service defined in Section 2.2.4 of APN release 3. As shown in Fig. 2-2, the add/drop functional block provides MUX/DEMUX functionality to multiplex and demultiplex PtP wavelength paths for APN main signals and One-span PtP wavelength paths for QKD-related signals. It should be noted that the mux/demux functionality is not assumed to be embedded within a specific system component such as APN-G/-I or QKD equipment but can be realized as an external function. This approach allows the definition of required functionalities and characteristics (e.g., supported wavelength bands, filtering performance) to be independent of the functionality or the implementation maturity of WDM systems or QKD equipment. This functionality would fall within the scope of APN-S defined in [1] and may be realized by specific APN-S implementations, such as WDM filters (e.g., thin-film filters or AWGs). It may also incorporate bidirectional single-fiber / unidirectional dual-fiber conversion functionality as well as APN-S function.

In principle, control and management of this QKD link are handled by the QKDN management function, which negotiates wavelength assignment and WDM launch power with the APN controller (APN-C) via the infrastructure orchestrator [3]. Although detailed mechanism and algorithm for the negotiation are out of scope of this PoC reference document, the outcomes of this PoC will give useful insights for the requirements of such C/M-plane interactions.

QKD performance in this conceptual architecture can vary significantly depending on the infrastructure use case and its WDM transmission conditions, primarily because Raman-noise characteristics induced by the co-propagating APN main signals differ across the WDM transmission conditions. Therefore, three typical use cases are introduced in this section each of which has different WDM transmission condition. When defining benchmark scenarios for QKD link over Open APN (Section 4), it is desirable to set experimental conditions that reflect these differences so that the evaluation captures realistic performance impacts.

PoC implementers are expected to conduct the PoC based on at least one of the reference cases below and may choose the case(s) that best align with their targeted deployment scenario and business objectives.

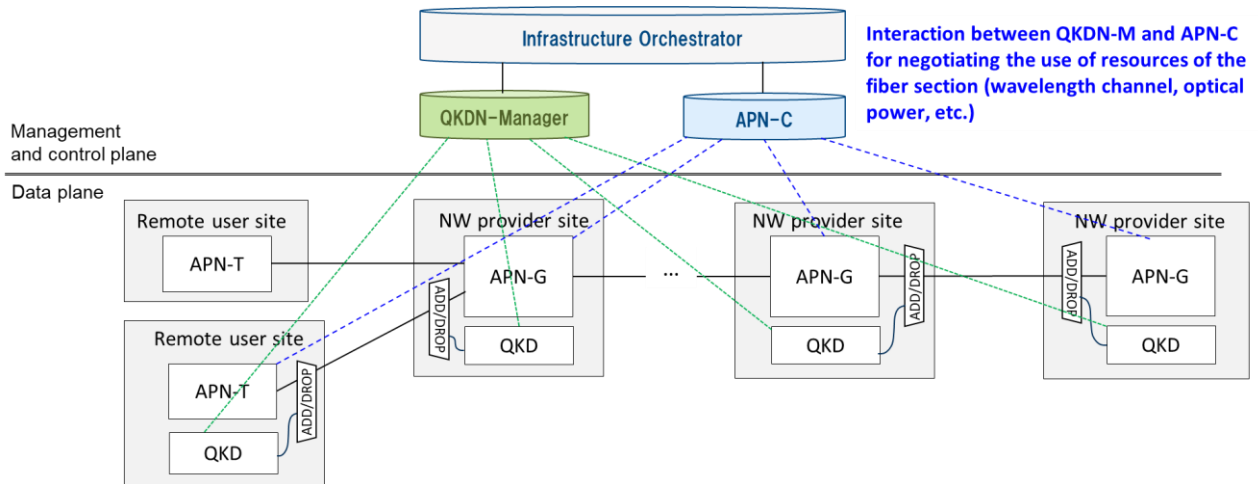


Figure 2-1: Conceptual architecture for QKD over Open APN

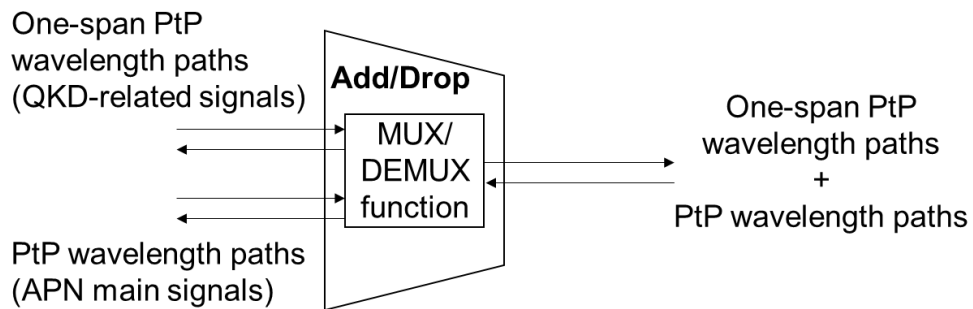


Figure 2-2: Add/Drop functional model

2.1. Case 1: Carrier backbone

The basic architecture for carrier backbone case is shown in Figure 2-3. Carrier backbone networks interconnect metro and national domains using long-reach, multi-span WDM systems that carry critical government, enterprise, and internet traffic. Inline optical amplifiers, typically EDFAs spaced every repeated span, enable transparent reaches on the order of > 500 km (and up to ~1000 km in some designs) between electrical regeneration points [1][4]. In this environment, quality of transmission (QoT), typically characterized by OSNR or GSNR, is the dominant design constraint. In such systems, the WDM launch power is typically optimized to maximize GSNR margin under the trade-off between amplified spontaneous emission (ASE) noise and nonlinear interference (NLI). This optimization leads to operation at a high launch power regime (e.g., on the order of 0~+2 dBm/ch), as commonly reported in long-haul optical systems [5].

Carrier backbone links are generally operated as unidirectional dual-fiber transmission (i.e., a fiber pair for bidirectional service) and traverse multiple APN-G/Is. Frequent wavelength and direction reconfiguration can cause power transients along the path. These combinational

conditions of high total launch power, many amplified spans, and multiple APN-G/Is make QKD coexistence most challenging in this scenario.

The red lines in Figure 2-3 illustrate the quantum channel over one-span PtP wavelength path. In addition to the quantum channel, practical QKD systems require associated classical signals for post-processing, which may be transmitted in both forward and backward directions. In dual-fiber transmission systems, the backward classical signals can be carried over the reverse fiber (e.g., from Central Office 2 to 1 and from Central Office 3 to 2). The figures therefore include both forward and backward classical channels to reflect a more realistic deployment scenario.

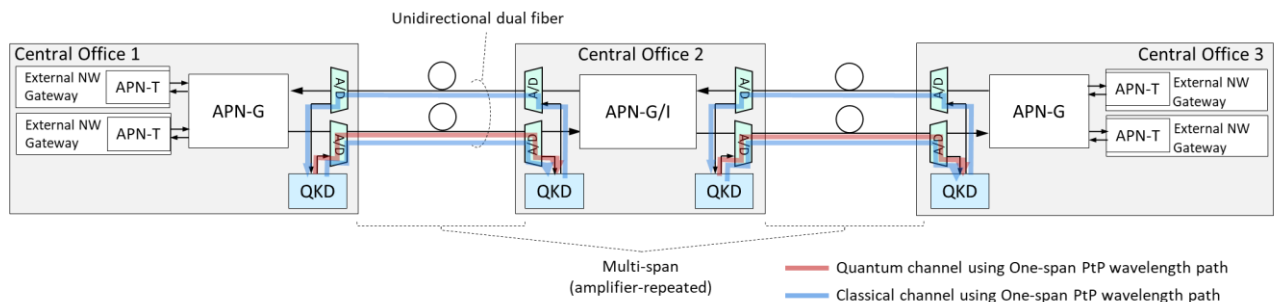


Figure 2-3: Basic architecture for carrier backbone use case

2.2. Case 2: Metro data center interconnect (DCI)

The basic architecture for metro DCI case is shown in Figure 2-4. Metro DCI links typically use a single, unamplified fiber span of up to about 100 km within a metro area [1]. For financial industry infrastructure, intra-regional application deployment is assumed to be 50-100 km [6]. In contrast to carrier backbone networks, inline optical amplifiers and intermediate ROADMs are rarely used, and the end-to-end path is usually a straightforward point-to-point connection between two data-center sites.

Metro DCI carries high-capacity, latency-aware traffic. Because of the shorter transmission reach and simpler topology, the QoT margins are generally more relaxed than in carrier backbone networks [7]. As a result, the total WDM launch power may not need to be fully optimized for GSNR, and operation at relatively lower launch powers may be acceptable depending on system design and operational policy, which makes QKD/APN coexistence relatively easier.

The red lines in the figure highlight the quantum channel using the one-span PtP wavelength path. In practical QKD implementations, however, classical signals required for post-processing are transmitted in both forward and backward directions. These classical channels may utilize the reverse fiber in a dual-fiber configuration. Accordingly, Figure 2-4 explicitly illustrate both forward and backward classical channels in addition to the quantum channel.

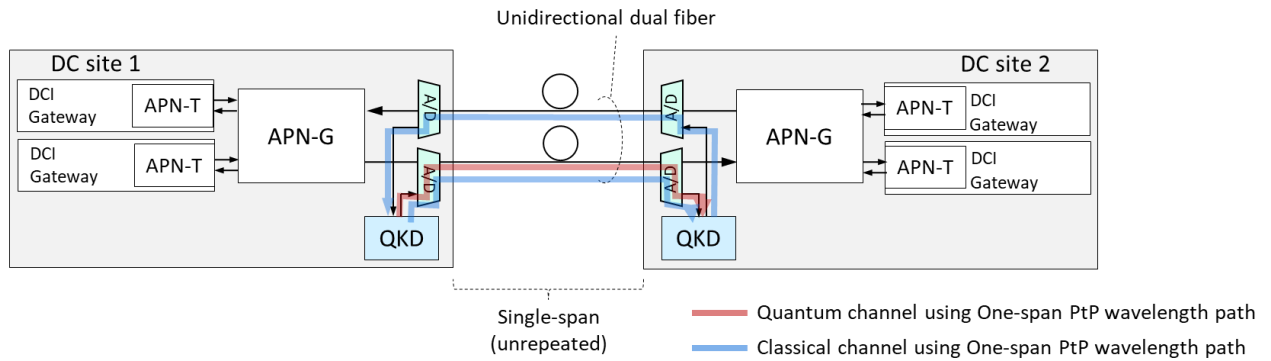


Figure 2-4: Basic architecture for metro DCI use case

2.3. Case 3: Mobile fronthaul

The basic architecture for mobile fronthaul case is shown in Figure 2-5. Mobile fronthaul links connect radio units (RUs) to distributed units (DUs) over short distances up to ~30 km under strict latency constraints [8]. To reduce fiber count between the RU and DU sites, end-to-end passive DWDM architectures are commonly considered as a simple deployment scenario, where RUs connect directly to APN-T[8], [9], [10]. The configuration where APN-G provides multiplexing and demultiplexing function to aggregate multiple APN-Ts is also considered [1], [11]. In such configurations, where a limited number of wavelengths is aggregated (e.g., eight wavelengths in the MFH use case in [10]), the system typically operates under low launch power regimes, although the values depend on the implementation. Single-fiber bidirectional transmission is also widely used to save fiber resources. Although APN-G or low-cost optical nodes may be introduced to improve scalability and flexibility of fronthaul segments, they are not considered in this PoC reference for simplicity.

In this environment, QKD-related signals are expected to coexist not only with co-propagating APN main signals but also with counter-propagating signals due to bidirectional transmission. While the short reach and relatively low launch power operation may reduce fiber-induced Raman noise, counter-propagating APN main signal may affect QKD performance more severely than co-propagating one.

In this configuration, quantum channel signals together with the associated forward and backward classical channel signals are primarily assumed to be transmitted over a bidirectional single fiber. However, depending on the QKD equipment and system implementation, a separate fiber may be required to support classical channel signal transmission. In such cases, the use of an additional fiber for classical channels is also considered acceptable for PoC evaluations.

Since midhaul and backhaul segments (e.g., between DUs and CUs) will have similar WDM link characteristics to metro/backbone networks, the Case 3 focuses on the fronthaul links as the representative “mobile xHaul” use case.

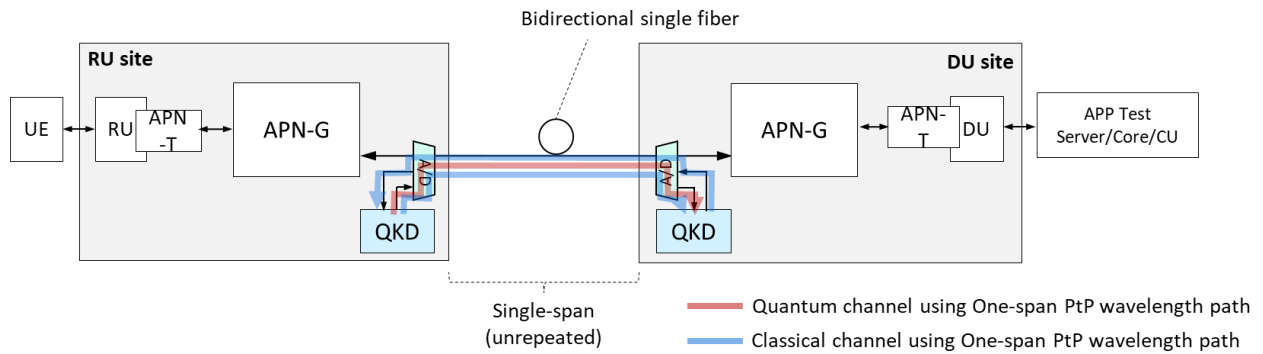


Figure 2-5: Basic architecture for mobile fronthaul use case

2.4. PoC reference model and common requirements

The PoC reference model commonly applicable to all three reference cases is shown in Figure 2-6. The add/drop function is inserted immediately after the outgoing interface of the APN-G and before the incoming interface of its peer APN-G.

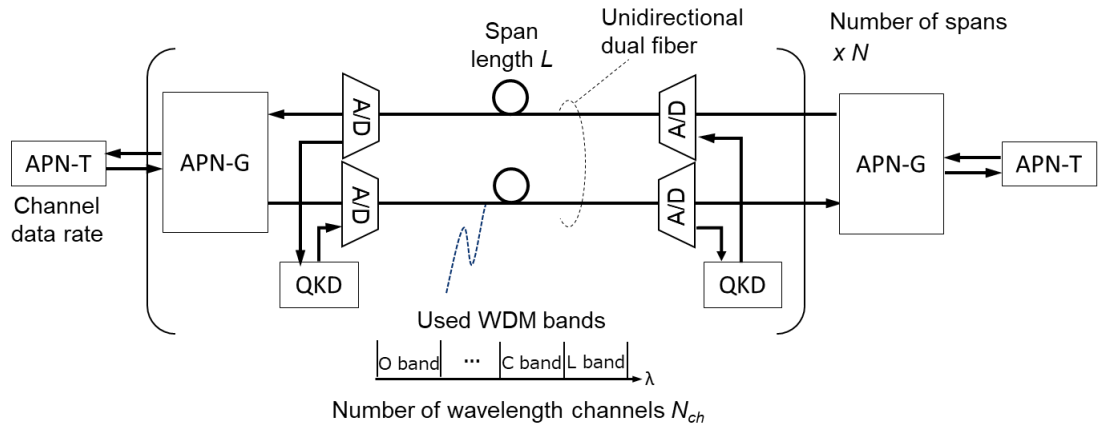
In practical QKD implementations, the associated classical channel signals for key distillation are bidirectionally transmitted and are therefore considered in the same way as the quantum channel signal in this model. For Case 1 and Case 2, these classical channels may utilize the reverse fiber in a dual-fiber configuration. For Case 3, although transmission is primarily assumed over a bidirectional single fiber, a separate fiber may be required for classical channel signals depending on the implementation. Such a two-fiber configuration is also within the scope of this PoC reference model.

To realistically capture performance impacts on both the APN main signal and QKD-related signal for each use case, common requirements are defined based on the WDM transmission conditions specified in Table 2-1 including span length, number of spans, used WDM bands, number of wavelength channels, channel data rate and transmission mode of the APN main signal – which are derived from the operational characteristics described in Sections 2.1 through 2.3. These requirements are extracted from commercially available and deployable WDM system and designed to highlight the differences in SpRS characteristics from APN main signals and their impact on QKD performance.

PoC Implementers shall configure the PoC setup according to the WDM transmission conditions in Table 2-1 for the target reference case and evaluate the benchmark metrics – including QoT of APN main signal and QKD performance – as specified in Section 4.4.

Note: For Case 1 (Carrier backbone), fully preparing for experimental setup for multi-span transmission and per-span QKD pairs may not be easy. In such cases, an alternative approach would be acceptable: measuring GSNR vs. input power characteristics using the single-span setup of Case 2 (Metro DCI), then estimating multi-span performance from the derived Gaussian Noise (GN) model parameters (see Section 4.4.1 for details).

PoC reference model for case 1 & 2



PoC reference model for case 3

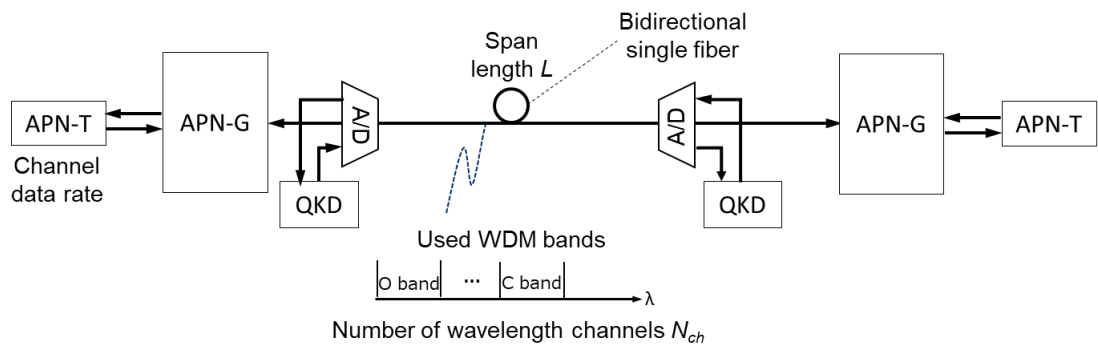


Figure 2-6: PoC reference model commonly applicable to all three reference cases

Table 2-1: WDM transmission conditions for each of three reference cases

	Carrier backbone	Metro DCI	Mobile fronthaul
Span length L	≥ 50 km	≥ 50 km	30 km
No. of spans N	≥ 5	1	1
Used WDM bands	C + L	C + L	O or C
No. of wavelength channels N_{ch}	Not specified; e.g., 128 @ 75 GHz grid	Not specified; e.g., 128 @ 75 GHz grid	$\geq 8^*$ (Uplink+Downlink)
Channel data rate	≥ 400 Gbps	≥ 400 Gbps	25 Gbps*
Transmission mode	Unidirectional dual fiber	Unidirectional dual fiber	Bidirectional single fiber
Remarks	* PoC conditions for All-photronics front case: see [10]		

3. Desired Features

This section defines the features that PoC implementers should test to meet the objectives described in Section 1.2 and explains how each feature is verified.

3.1. Feature 1: One-span PtP wavelength path provisioning

This PoC system shall provision a set of wavelengths required by the operation of QKD, including one quantum channel and classical/clock channels.

The feature to be verified is that a QKD key-generation session can be successfully established by confirming pass-through integrity of the quantum, classical, and clock channels between the endpoints of one-span PtP wavelength path.

3.2. Feature 2: Add/Drop with well-shaped optical filtering

To enable one-span PtP wavelength path provisioning, the add/drop function shall be inserted immediately after the outgoing interface of an APN node and before the incoming interface of its peer APN node, so that QKD-related signals can be inserted and extracted. The add/drop function providing mux/demux capability is defined independently from specific system implementations (e.g., WDM system or QKD equipment) and is assumed to be realized as an external optical filtering function. This allows flexible support of various wavelength configurations required by different QKD implementations. This add/drop function may affect the transmission quality of both APN main signals and QKD quantum signals to some extent depending on its device characteristics, and its impact should be minimized.

In practice, the add/drop components are often implemented using WDM filters. The filter shape should be appropriately designed to reduce the filtering effect on APN main signals, suppress channel crosstalk into the QKD receiver, and keep the insertion loss low.

The following features should be verified:

- QKD-related signals can be wavelength-multiplexed/demultiplexed with APN main signals over the same fiber using add/drop function
- Add/drop components provide well-shaped optical filtering, including sharp roll-off, sufficient isolation and low insertion loss.

3.3. Feature 3: Transmission parameter design for feasible co-propagation of APN and QKD-related signals

APN main signals and QKD-related signals are co-propagated over the same fiber using the features described in Sections 3.1 and 3.2. In this co-propagation environment, the transmission quality of both signals should meet the requirements for their performance degradation. To

achieve this, major transmission parameters should be carefully designed by balancing the APN capacity limit and the performance of QKD.

The following features should be verified:

- Wavelength allocation design for APN main and QKD-related signals with appropriate guard-band setting is carried out considering spontaneous Raman scattering noise from the APN main signals.
- The APN main-signal launch power is appropriately coordinated by applying constraints on the total launch power to attain feasible QKD performance while maintaining the quality of transmission (QoT) of APN main signals.

4. Benchmarks

This section defines the benchmark metrics (what to measure) which include environmental conditions, parameter designs, test procedures, and benchmark metrics. Benchmarks are designed to verify the features described in Section 3 and to reflect the representative WDM transmission conditions described in Section 2.

4.1. Environmental Conditions

Conditions for the PoC which are determined and set as a physical environment are described in this subsection.

4.1.1. WDM Transmission Conditions

Implementers shall set the following parameters for the WDM transmission of APN main signal:

- Fiber span length L [km]
- Total span loss and loss distribution measured by OTDR [dB]
- Number of spans N_{span}
- WDM band (e.g., C, L, C+L)
- Number of WDM channels N_{ch} and channel grid

Total span loss and its distribution would be determined by fiber propagation loss, local connector loss, splicing loss, and add/drop insertion loss.

In the case that preparing actual multi-span ROADM environment is not feasible, implementers may emulate such environment by designing the total WDM launch power per fiber P_{tot} , N_{ch} , and band occupancy to reproduce a target Raman-noise level at the QKD receiver.

4.1.2. QKD Transmission Conditions

Implementers shall choose either DV-QKD (Discrete Variable QKD) or CV-QKD (Continuous Variable QKD) as typical variations of QKD protocol with the following related parameters:

- QKD protocol type (DV-QKD or CV-QKD)
- Fiber span length L [km]
- Total span loss and loss distribution measured by OTDR [dB]
- Wavelengths used for quantum, classical, and clock channels
- Propagation direction of quantum signals relative to the APN main signal (co-propagation / counter-propagation)
- Launch power of the QKD-related channels

Total span loss and its loss distribution would be determined by fiber propagation loss, local connector loss, splicing loss, and add/drop insertion loss.

The wavelength of the quantum channel may vary depending on the QKD protocol and its implementation. For example, in DV-QKD systems, the quantum channel may be placed in the O-band to mitigate SpRS noise when co-propagating with C-band WDM signals, whereas in CV-QKD systems, the quantum channel may be placed within the C-band. Therefore, implementers shall clearly specify the wavelength allocation of the quantum, classical, and clock channels as part of the QKD transmission conditions.

Although other new types of QKD protocols may want to be evaluated under this WDM/Co-propagation environment, application of such new QKD protocols is out of scope of this document.

4.1.3. Measurement and Metrology Considerations

In QKD systems, the quantum channel operates at extremely low optical power (typically around -80 dBm), and therefore measurement accuracy becomes a critical factor in evaluating system performance. PoC implementers shall carefully consider the following metrology aspects to ensure reliable results:

- Optical power measurement accuracy:
The measurement of quantum-channel power shall be performed using calibrated instruments with sufficient sensitivity and accuracy in the low-power regime.
- Wavelength and spectral analysis:
The spectral characteristics of both APN main signals and QKD-related signals shall be analyzed using appropriate instruments (e.g., OSA) with sufficient resolution bandwidth and dynamic range to detect out-of-band leakage and crosstalk components.
- Filtering and isolation verification:
The effectiveness of optical filtering (e.g., add/drop devices) shall be validated not only by nominal specifications but also by measured spectral profiles, including out-of-band suppression.
- Noise floor characterization:
The noise floor of the measurement system shall be characterized to distinguish actual quantum signal degradation from measurement error.

4.2. Parameter Design

There are parameters to define the details of the PoC system which may be set each time in order to measure and evaluate the results under various conditions. The parameter designs in this subsection provide the critical parameters for realizing Feature 3 in Section 3.3, i.e.,

practical co-propagation of QKD-related and APN main signals with acceptable degradation on both sides. In particular, there is a trade-off between APN capacity limit and QKD performance, depending on the WDM launch power and wavelength allocation with guard-band settings. Therefore, launch power and wavelength allocation with appropriate guard-band settings are tuned to balance APN capacity limit and QKD performance.

4.2.1. WDM Launch Power Design

Implementers shall define a nominal WDM launch power P_{to} per fiber, which may differ for each reference case (high for Case 1, moderate for Case 2, low-to-medium for Case 3), and evaluate at least one reference case. Concrete power values will depend on the implementation of the system.

4.2.2. Wavelength Allocation and Guard-band Design

Guard-band and wavelength placement also form a trade-off between spectrum utilization of WDM transmission system and QKD performance/stability.

Implementers should define a wavelength allocation with appropriate guard band for QKD-related signals and APN main signals. Choice of quantum-channel wavelength (e.g., O-band or C-band) significantly affects the co-propagation characteristics with APN main signals, including SpRS noise impact and filtering requirements. Implementers therefore should consider protocol-specific characteristics and system design constraints when defining wavelength allocation and guard-band settings. The impact of co-propagation on the performances of both QKD-related signals and APN main signals should be evaluated under multiple allocation settings (e.g., conservative vs aggressive).

4.3. Common Test Procedure

The benchmark metrics to be described in Section 4.4 should be measured and evaluated based on the common test procedure. The procedure below is structured to validate the desired features in Section 3 in a consistent manner. Step 0 establishes APN-only or QKD-only baselines, Step 1 confirms provisioning of the one-span PtP wavelength path (Feature 1) including add/drop function (Feature 2), and Step 2 evaluates the feasibility of co-propagation under the designed parameters (Feature 3).

Step 0: Baseline measurements (without co-propagation)

- APN only: transmit APN main signals without QKD-related wavelengths reserved/inserted, and measure APN QoT metrics.
- QKD only: transmit QKD-related signals on the provisioned one-span PtP wavelength path with no APN main signals, and measure QKD metrics.

Step 1: Provisioning and configuration

- Provision the one-span PtP wavelength path for QKD-related wavelengths
- Apply the wavelength allocation with appropriate guard band
- ASE noise loading with targeted launch power may be configured if necessary

Step 2: Co-propagation runs

- Activate APN main signals with configured launch power.
- Start QKD operation and run for a specified duration time T
- Record synchronized time series of APN QoT and QKD performance

4.4. Benchmark Metrics (What to Measure)

Metrics for both APN main signals and QKD are measured simultaneously to evaluate practicality for their coexistence.

4.4.1. QoT of APN Main Signal

APN QoT confirms that the designed co-propagation conditions including insertion of add/drop function remain acceptable for APN operation (Features 2 and 3).

PoC implementers shall measure the following:

- GSNR (Generalized signal-to-noise ratio) or equivalent QoT indicator
- Pre-FEC/post-FEC BER
- Ethernet Frame Error Rate (optional)

The raw values as well as relative differences from APN-only baseline (Step 0) for the same WDM transmission condition shall be measured. Furthermore, it is recommended to analyze the co-propagation penalty on WDM capacity limit using the measured GSNR. This limit depends on the number of reserved wavelengths for QKD-related signals (quantum + classical/clock) determined by wavelength allocation and guard-band design as described in 4.2.2.

As described in section B.3.3 of [1], the QoT of APN main signal can be estimated based on GSNR, which is defined as

$$GSNR = \frac{P_{ch}}{P_{ASE} + P_{NLI}}$$

where P_{ch} is the launch power per channel, P_{ASE} and P_{NLI} are the power levels of the disturbances in the channel bandwidth for ASE noise and NLI (Non-Linear Interference) respectively.

It is also possible to estimate the GSNR of APN main signal in multi-span transmission as below.

1. Single-span experiment: Measure the GSNR while sweeping the total WDM launch power P_{tot}
2. GN model fitting: Extract the single-span nonlinear coefficient η_1 from the measured GSNR

3. Multi-span extrapolation: Estimate the multi-span nonlinear coefficient $\eta_N \triangleq N_s \cdot \eta_1$

4. Multi-span GSNR estimation:

$$GSNR_N = \frac{P_{ch}}{N \cdot P_{ASE} + \eta_N \cdot P_{ch}^3}$$

4.4.2. QKD Performance

QKD performance captures the impact of Raman noise and crosstalk under co-propagation, and therefore serve as the primary indicators for verifying stable key generation and parameter feasibility (Feature 3).

- for DV-QKD: SKR, QBER, background noise count rate (or equivalent)
- for CV-QKD: SKR, excess noise (or equivalent), SNR-related metrics

Measure the raw values as well as relative differences from QKD-only baseline (Step 0) for the same QKD transmission condition with stability statistics over certain period T (e.g., average, minimum and standard deviation). All QKD performance metrics shall be measured with consideration of the metrology constraints described in Section 4.1.3.

4.4.3. Performance Correlations

PoC Implementers are recommended to analyze correlations from at least the following two perspectives:

- **Correlations between QoT of APN main signal and QKD performance**
 A trade-off with respect to WDM launch power is expected to emerge in correlations between QoT of APN main signal and QKD performance. This analysis will provide guidelines for transmission parameter design to enable feasible co-propagation of APN and QKD-related signals.
- **Correlations between QKD performance and the number of DWDM channels / span length**
 This correlation will help quantify how the QKD performance fluctuates as the network scales or as data channels are added.

4.4.4. Co-propagation Efficiency

In addition to individual performance metrics of APN main signals and QKD, it is desirable to evaluate the overall efficiency of their coexistence under co-propagation conditions. This “co-propagation efficiency” can be interpreted as a metric that can help to compare how effectively the PoC system enables co-propagation while minimizing performance penalties for both APN (e.g. WDM capacity limit or QoT) and QKD system (e.g., SKR). Several definitions of co-propagation efficiency have been proposed in the literature [12][13]. PoC implementers are therefore recommended to evaluate co-propagation efficiency using an appropriate metric of their choice,

clearly stating the definition used. Such evaluation is expected to provide useful insight into the practical design guidelines for the co-propagation of QKD and WDM systems.

For reference, the WDM capacity limit, calculated by the measured GSNR described in 4.4.1, is estimated by

$$C = 2 \sum_{i=1}^{N_{ch}} R_{s,i} \log_2(1 + GSNR_i)$$

where factor 2 accounts for the dual-polarization, $R_{s,i}$ is the symbol rate, and $GSNR_i$ is GSNR for the i th WDM channel, respectively [14].

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History

Revision	Release Date	Summary of Changes
1	September 2026	Initial Release