# PoC Project name:

# Combine APN with “Optical Duplexer” PoC

Classification: IOWN Global Forum Recognized PoC
Stage: SSF PoC Report
Confidentiality: Public
Version: 1.2
[February 5, 2025]

# Combine APN with “Optical Duplexer” PoC Report

## 1. Introduction

For the next-generation requirements, IOWN Global Forum aims to establish a reference architecture for mobile Fronthaul (FH) / Midhaul (MH) / Backhaul (BH), and demonstrate the benefits and viability of Open APN [Open APN FA] [PoC Reference of Mobile Fronthaul over APN].

Aiming to extend the range of the all-photonic network to the mobile edge, operator may face the lack of fiber resources, and the synchronization error due to the asymmetric delay of unequal optical transport paths. Therefore, Single-fiber bidirectional access architecture has been proposed.

We built the trial network by combining APN with “Optical Duplexer” in our Lab and evaluate the feasibility of this architecture.

## 2. PoC Project Completion Status

- Overall PoC Project Completion Status: COMPLETED

  This document reports on the results of the single-fiber bidirectional access architecture using the “Optical Duplexer” PoC listed in the PoC reference document “PoC Reference of Mobile Fronthaul over APN v2.0” [PoC Reference of Mobile Fronthaul over APN] with the Benchmark-First process.

## 3. PoC Project Participants

Specify PoC Team:

- PoC Project Name: Combine APN with “Optical Duplexer”
- PoC Stage Completion Status: Significant Step Forward (SSF)

| Member Company | Name | Email |
|---|---|---|
| Chunghwa Telecom (CHT) | Jian-Kai Huang **(contact person)** | jkhuangk@cht.com.tw |
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# 4. Confirmation of PoC Demonstration

PoC Demonstration Event Details:

- This PoC had been conducted in Chunghwa Telecom Laboratories, Taoyuan, Taiwan.
- The PoC was conducted during the period from 7th November 2023 to 17th April 2024
- PoC result submission date – 23rd April 2024

# 5. PoC Goals Status Report

With the Benchmark-First process, we focus on evaluating the synchronization and latency requirements of mobile networks.

- PoC Project Goal #1: Goal Status Achieved the original PoC objectives.
- Comply with IOWN-GF PoC Reference of Mobile Fronthaul over APN v2.0
    - Evaluation of feasibility of Mobile Fronthaul over APN with single-fiber bidirectional access architecture
        - Saving the fiber resources between the RU and DU sites.
        - Using optical duplexer or other passive optical component is acceptable.
        - No additional power supply is needed.
        - Reducing/eliminating synchronization error introduced by asymmetric delay of unequal optical transport paths.

# 6. PoC Technical Report

The PoC is based on the Step 2 definition as outlined in the document "IOWN-GF-RD-MFH_over_APN_PoC_Reference_2.0" [IMN PoC Reference v2.0]. This PoC involves creating scenarios that reflect actual conditions, such as specifying the number of RUs per RU site and the number of RU sites per DU site.

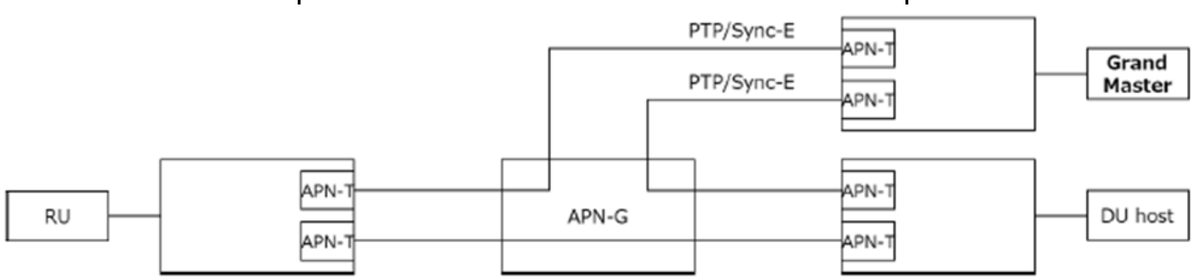



*Figure 1. Time synchronization scenario in Step2*

Furthermore, we implement the single-fiber bidirectional access architecture with this scenario based on “IOWN-GF PoC Reference of Mobile Fronthaul over APN v2.0” Appendix III, to evaluate of feasibility of this architecture.

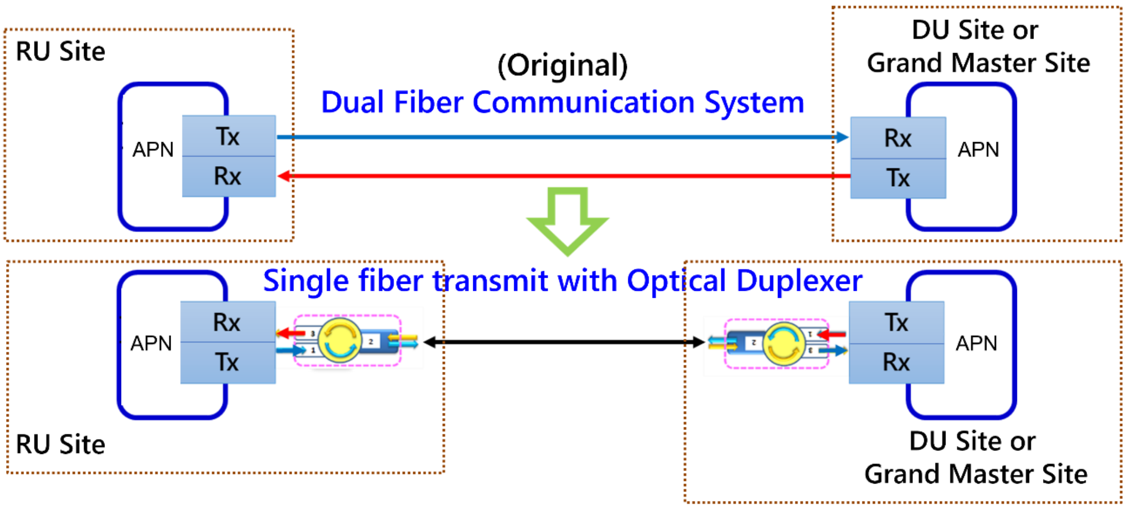



*Figure 2. Single-fiber bidirectional access architecture*

## 6.1. Implemented System

The network configuration encompasses four distinct architectures.

In the first and second architectures, the RU site and DU site are connected via APN-T on both ends. The intermediate connections between APN-Ts are made using either pairs of optical fibers or a single optical fiber with two Optical Duplexers at both ends. The Optical Duplexer facilitates the conversion of dual-fiber transmission into single-fiber transmission, enabling bidirectional transmission by merging both the transmit and receive signals into a single optical cable.

In the third and fourth architectures, both the RU site and DU site are equipped with APN-T, APN-G and APN-I, and the connection between them is established through APN-I. The intermediate connections are made using pairs of optical fibers, or alternatively, pairs of Optical Duplexers is employed to convert the dual-fiber transmission into single-fiber transmission, allowing for two-way communication over a single optical cable.

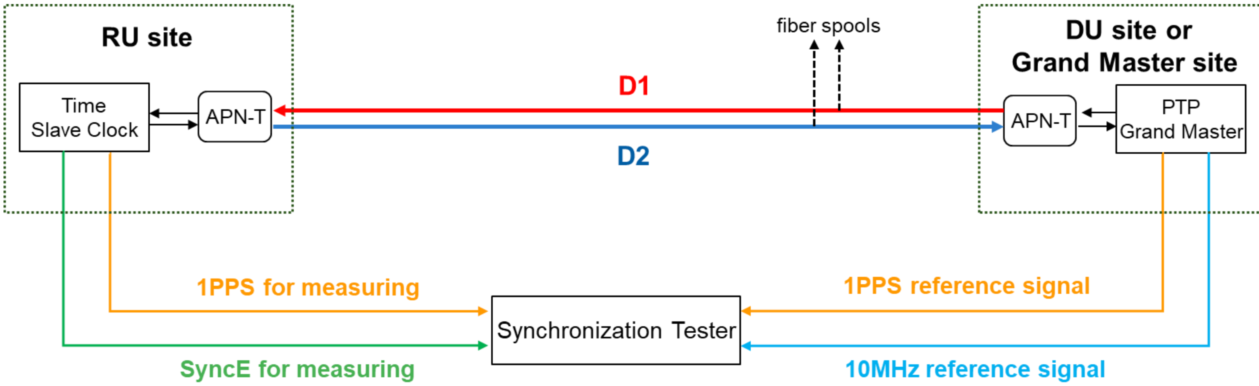



*Figure 3. Architecture 1 details network topology and the corresponding position of the optical fiber spools*

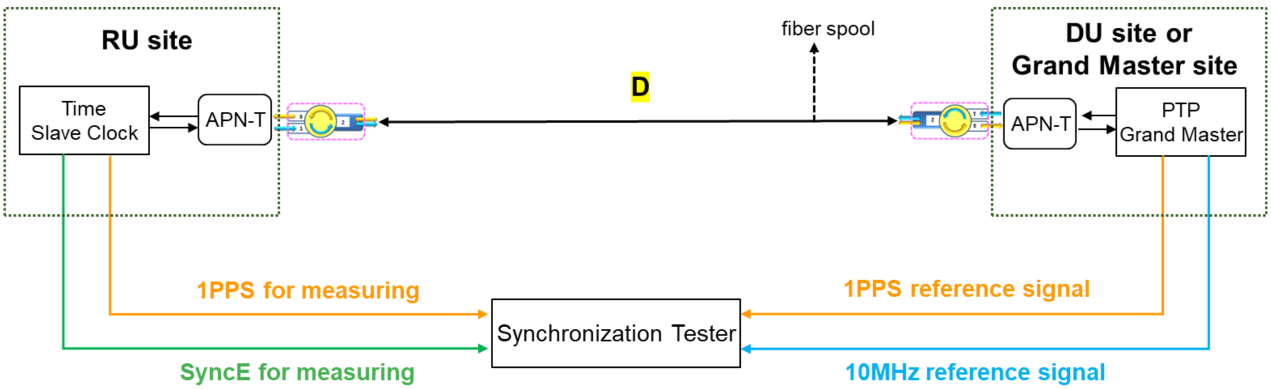



*Figure 4. Architecture 2 details network topology and the corresponding position of the optical fiber spool*

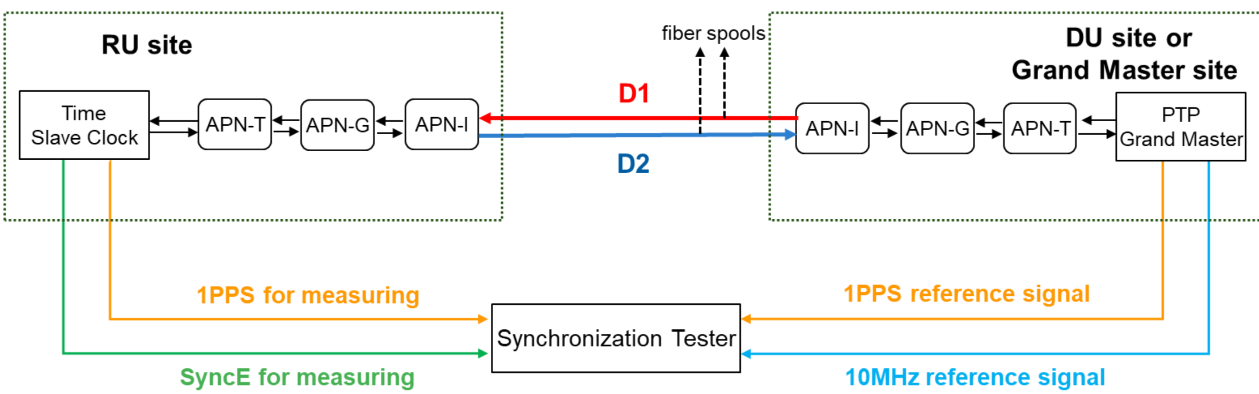



*Figure 5. Architecture 3 details network topology and the corresponding position of the optical fiber spools*

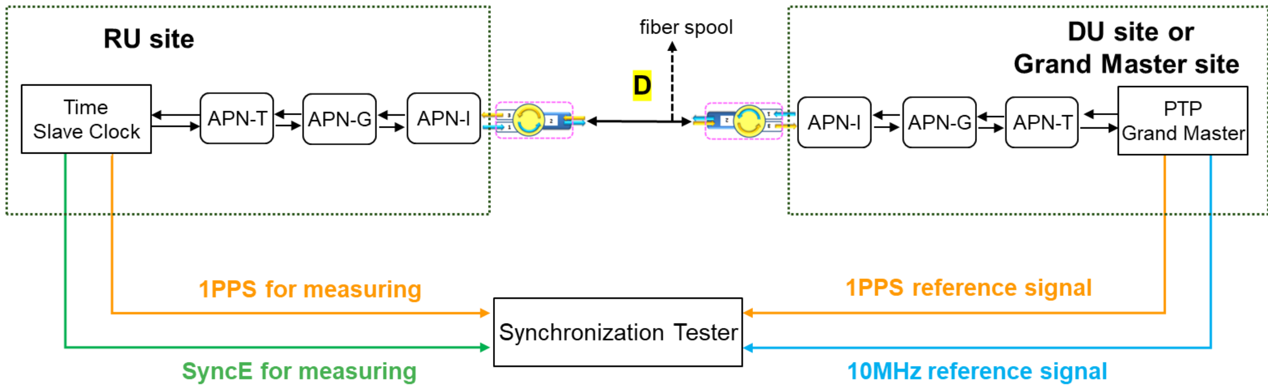



*Figure 6. Architecture 4 details network topology and the corresponding position of the optical fiber spool*

### 6.1.1 DU site (or Grand Master site) and RU site Configuration

| Item | RU site | DU site (or Grand Master site) |
|---|---|---|
| PTP Grand Master | n/a | Microchip TP4100 |
| Time Slave Clock | Cisco NCS 540 | n/a |
| APN-T | Fujitsu T310 with Fujitsu CFP2 coherent module | |
| APN-G | Fujitsu L110 | |
| APN-I | Fujitsu L100 | |
| Synchronization Tester | Calnex Paragon x | |

| Optical Characteristics | Specifications for Optical Duplexer |
|---|---|
| Insertion Loss | ≤ 1.0dB |
| Isolation | ≥ 35 dB |
| Polarization Dependence | ≤ 0.2dB |
| Directivity | ≥ 50 dB |
| Return Loss | ≥ 45 dB |
| Polarization Mode Dispersion | ≤ 0.1ps |
| Maximum Power Handling | ≥ 500mW |

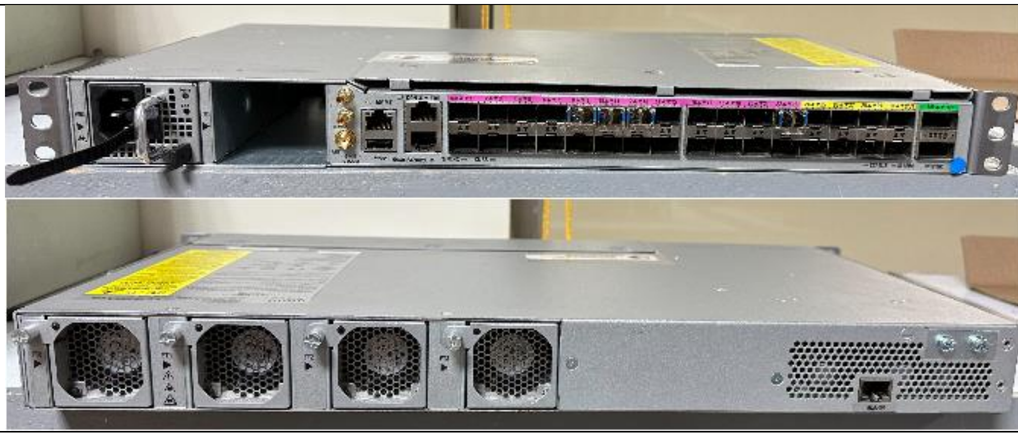
*Table 1. PoC features and configuration details*

| Item | PoC reference | Conditions for this PoC |
|---|---|---|
| Layer split option | option 7.2 | option 7.2 |
| Category for use case | eMBB | eMBB |
| Bandwidth per RU | 10G/25G/50G | 10G |
| Distance between RU and DU | L1+L2 equal 7km, 30km | L1+L2 equal 5km, 30km |
| Number of RU site | TBD (more than 2) | 1 |
| Number of RU per RU site | TBD (more than 2) | 1 |
| Number of RU site per DU site | TBD (more than 2) | 1 |
| Traffic volume from UE | applying a model that varies over time (TBD for more detail) | fixed |
| Time synchronization scenario | Scenario 4 in IMN document 5.2.6.2, which is correspond to LLS-C3 | Scenario 3 in IMN document 5.2.6.2 |

The following is the detailed setting diagram of the APN device:

*Table 2. Photographs showing PoC rack-mounted equipment in the laboratory*

| |
|---|
| PTP Grand Master |
|   |
| Time Slave clock |



Synchronization Tester


APN-T & APN-G & APN-I

Fiber spools

## 6.2. Measurement Method

The synchronization signals being tested include PTP, ITU-T G.8275.1, and SyncE. Both PTP and SyncE are transmitted over Ethernet, and we send these signals to downstream devices via a Grandmaster (GM) and measure the time error (TE). This measurement encompasses all noise components, including constant time error (cTE) and dynamic time error (dTE) noise. The All-Photonic Network (APN) receives the PTP and SyncE signals from the GM and transparently transmits them to the telecom time slave clock (T-TSC).

Additionally, we utilize pairs of optical duplexers to enable bidirectional transmission over a single optical cable, effectively reducing the optical fiber infrastructure by half compared to the original architecture. This solution significantly improves the time error caused by the different lengths of downlink and uplink optical cables and eliminates synchronization issues arising from asymmetric delays in optical transmission.

## 6.3. Results

### 6.3.1. Mandatory Requirements

The mandatory requirements specified in the PoC reference are as follows:
(1) Interface

*Table 3. Interface of mandatory requirements*

| Item | PoC Reference | The conditions and results in this PoC |
|---|---|---|

| | | |
|---|---|---|
| Optical interface between APN-T and APN-G | 1. In the case Flexible Bridging Service is used for aggregating several RUs,<br>➢ W 100-200G 31.6 Gbaud of Open ROADM MSA Optical Specification Version 5.0 | Compliant |
| | 2. In the case RUs connect to APN directly,<br>➢ NRZ 10G (N, W) of ITU-T G.698.2 | Compliant<br><br>Although not connect with the real RU- We confirmed that the uplink throughput/downlink throughput meet maximum throughput of the 10G interface |
| The MAC layer connection between the RU and DU | MAC layer interface between RU and DU<br>➢ Ethernet（for transporting eCPRI and PTP/SyncE）<br>➢ CPRI IEEE- 1914.3 (for transporting CPRI over a packet-based infrastructure) | Compliant |

(2) Latency

*Table 4. Latency of mandatory requirements*

| PoC Reference | The conditions and results in this PoC |
|---|---|
| Metrics definitions and requirements:<br>➢ Packet delay（one-way）： 0-160μs<br>➢ Packet Delay Variation： 0-10μs<br><br>Examination Method and Success Criteria: To be studied. At this moment, we don't intend to normalize the measuring method. We expect PoC implementers to report the measuring method they have adopted. PoC implementers may use RU emulators instead of real RUs. | The result of back-to-back and with 5km fiber satisfied.<br><br>But result with 30km fiber exceeds the requirement.<br>Details are described in 6.3.3. |

(3) O-RAN specification

*Table 5. O-RAN specification of mandatory requirements*

| Item | PoC Reference | The conditions and results in this PoC |
|---|---|---|
| S-plane | Metrics definitions and requirements:<br>➢ Maximum frequency error：±50 ppb<br>➢ Maximum absolute time error at RU air interface：1500 nsec | Compliant as described in 6.1<br><br>Although not measured with the real RU - We confirmed that the S-Plane signal was processed correctly.<br><br>Details are described in 6.3.2 |
| C/U-plane | The uplink throughput/downlink throughput must reach the target data rate of the performance level described in O-RAN Fronthaul WG's Interoperability Test Specification (Target data rate varies depending on RU/DU). PoC implementers must use RU/DU as a real server. | Partially compliant as described in 6.1<br><br>Although not measured with the real DU/RU<br>・U-Plane: We confirmed that the uplink throughput/downlink throughput was the same whether we inserted an APN device between the RU and DU or not.<br>Details are described in 6.3.3 |

Although the switching function was not measured in this PoC, it is necessary to consider the impact of transceiver performance on tight synchronization when used in the primary or secondary switching paths due to the digital signal processors (DSPs) in optical pluggables according to the Mobile Optical Pluggables Alliance (MOPA) Technical paper on Optical pluggable performance for tight synchronization [MOPA_Tight-Sync_Paper-v1.0.pdf (mopa-alliance.org)], we will consider look into the influence of synchronization quality which is caused by the optical pluggables in our future PoC. Furthermore, we expect that APN can lower the impact of the content and time of service when switching by providing less than 50ms switching protection.

### 6.3.2. Time Error Measurement

We categorized the four architectures illustrated in Figures 3 to 6 into two groups: the first group includes Figures 3 and 4, and the second group comprises Figures 5 and 6. In the architecture and testing of these two groups, we measured the time error using optical fibers of varying lengths and enhanced the asymmetry of optical transmission through the use of pairs of optical duplexers. The test results are detailed in Tables 6, 7, and 8.

*Table 6 The First Group of measurement data*

| First Group (Architecture 1) | 0.002 km (Dark Fibers) | 5 km (Dark Fibers) | 30 km (Dark Fibers) |
|---|---|---|---|
| Length deviation | 0 [km] | 0.05 [km] | 0.043 [km] |
| 1PPS TE | 139～154 [ns] | -167～-180 [ns] | -315～-301 [ns] |
| 1PPS MTIE | 15 [ns] | 13 [ns] | 14 [ns] |
| 1PPS cTE | 146.660 [ns] | -173.593 [ns] | -307.678 [ns] |
| SyncE TIE | -1～1 [ns] | -1～1 [ns] | -1～0 [ns] |
| PTP Sync PDV | 0～33 [ns] | 0～26 [ns] | 0～37 [ns] |

| First Group (Architecture 2) | 5 km (optical duplexer) | 30 km (optical duplexer) |
|---|---|---|
| Length deviation | 0 [km] (single fiber) | 0 [km] (single fiber) |
| 1PPS TE | 52～63 [ns] | 185～199 [ns] |
| 1PPS MTIE | 11 [ns] | 14 [ns] |
| 1PPS cTE | 56.33 [ns] | 191.513 [ns] |
| SyncE TIE | -1～1 [ns] | -1～1 [ns] |
| PTP Sync PDV | 0～22 [ns] | 0～30 [ns] |

*Table 7 The Second Group of measurement data*

| Second Group (Architecture 3) | 0.002 km (Dark Fibers) | 5 km (Dark Fibers) | 30 km (Dark Fibers) |
|---|---|---|---|
| Length deviation | 0 [km] | 0.08 [km] | 0.082 [km] |
| 1PPS TE | -151～-142 [ns] | -276～-285 [ns] | -501～-486 [ns] |
| 1PPS MTIE | 9 [ns] | 9 [ns] | 15 [ns] |
| 1PPS cTE | -146.256 [ns] | -280.700 [ns] | -497.190 [ns] |
| SyncE TIE | -1～1 [ns] | -1～1 [ns] | -1～1 [ns] |
| PTP Sync PDV | 0～31 [ns] | 0～22 [ns] | 0～24 [ns] |
| Second Group (Architecture 4) | 30 km (optical duplexer) | | |
| Length deviation | 0 [km] (single fiber) | | |
| 1PPS TE | -125～-117 [ns] | | |
| 1PPS MTIE | 8 [ns] | | |
| 1PPS cTE | -120.116 [ns] | | |
| SyncE TIE | -2～0 [ns] | | |
| PTP Sync PDV | 0～24 [ns] | | |

#### 6.3.3. Latency Measurement (one-way)

Following the previous section about time error measurement results, we measured the latency of single-fiber bidirectional access architecture illustrated in Figures 6 by using APN-T, APN-G, APN-I and Optical Duplexer with different distance of fiber spools, frame size and FEC settings to further verify its feasibility.

The latency is mainly caused by the APN device and the fiber spools distance. The combined measurement results are as follows.

- 10GbE Client
    - Back-to-back (with 0.0002km dark fiber)

| Frame size [bytes] | 100G / dp-qpsk / sdfec | | | 100G / dp-qpsk / scfec | | |
|---|---|---|---|---|---|---|
| | Throughput [Gbps] | Latency [μs] | Delay Variation [μs] | Throughput [Gbps] | Latency [μs] | Delay Variation [μs] |
| 64 | 10 | 70.170 | 0.01 | 10 | 50.100 | 0.01 |
| 128 | 10 | 70.170 | 0.01 | 10 | 50.110 | 0.01 |
| 256 | 10 | 70.180 | 0.01 | 10 | 50.105 | 0.01 |
| 512 | 10 | 70.175 | 0.01 | 10 | 50.115 | 0.01 |
| 1024 | 10 | 70.180 | 0.01 | 10 | 50.110 | 0.01 |
| 1280 | 10 | 70.180 | 0.01 | 10 | 50.110 | 0.01 |
| 1518 | 10 | 70.175 | 0.01 | 10 | 50.115 | 0.01 |

- With 5km dark fiber

| Frame size [bytes] | 100G / dp-qpsk / sdfec | | | 100G / dp-qpsk / scfec | | |
|---|---|---|---|---|---|---|
| | Throughput [Gbps] | Latency [μs] | Delay Variation [μs] | Throughput [Gbps] | Latency [μs] | Delay Variation [μs] |
| 64 | 10 | 94.990 | 0.01 | 10 | 74.920 | 0.01 |
| 128 | 10 | 94.985 | 0.01 | 10 | 74.930 | 0.01 |
| 256 | 10 | 94.985 | 0.01 | 10 | 74.925 | 0.01 |
| 512 | 10 | 94.995 | 0.01 | 10 | 74.935 | 0.01 |
| 1024 | 10 | 94.990 | 0.01 | 10 | 74.920 | 0.01 |
| 1280 | 10 | 94.995 | 0.01 | 10 | 74.920 | 0.01 |
| 1518 | 10 | 94.995 | 0.01 | 10 | 74.935 | 0.01 |

- With 30km dark fiber

| Frame size [bytes] | 100G / dp-qpsk / sdfec | | | 100G / dp-qpsk / scfec | | |
|---|---|---|---|---|---|---|
| | Throughput [Gbps] | Latency [µs] | Delay Variation [µs] | Throughput [Gbps] | Latency [µs] | Delay Variation [µs] |
| 64 | 10 | 219.090 | 0.01 | 10 | 199.020 | 0.01 |
| 128 | 10 | 219.085 | 0.01 | 10 | 199.015 | 0.01 |
| 256 | 10 | 219.095 | 0.01 | 10 | 199.025 | 0.01 |
| 512 | 10 | 219.090 | 0.01 | 10 | 199.020 | 0.01 |
| 1024 | 10 | 219.090 | 0.01 | 10 | 199.020 | 0.01 |
| 1280 | 10 | 219.095 | 0.01 | 10 | 199.025 | 0.01 |
| 1518 | 10 | 219.095 | 0.01 | 10 | 199.025 | 0.01 |

### 6.3.4. Return Loss and Pre-FEC Measurement

In this section, we measured the return loss of single-fiber bidirectional access architecture illustrated in Figures 4 & 6 by using APN-T, APN-G, APN-I and Optical Duplexer with different distance of fiber spools to further verify its feasibility.

| Architecture 2 | Back-to-back | 5 km (Dark Fiber) | 30 km (Dark Fiber) |
|---|---|---|---|
| Optical Power of Signal | -1.11 [dBm] | -2.45 [dBm] | -7.9 [dBm] |
| Optical Power of Noise | -54.16 [dBm] | -36.92 [dBm] | -33.4 [dBm] |
| Return Loss | 53.05 [dB] | 34.47 [dB] | 25.5 [dB] |
| Pre-FEC | 2.377 E-04 | 3.740 E-04 | 4.517 E-04 |

| Architecture 4 | Back-to-back | 5 km (Dark Fiber) | 30 km (Dark Fiber) |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Optical Power of Signal | 0.39 [dBm] | -1.12 [dBm] | -6.27 [dBm] |
| Optical Power of Noise | -48.81 [dBm] | -34.77 [dBm] | -33.47 [dBm] |
| Return Loss | 49.2 [dB] | 33.65 [dB] | 27.2 [dB] |
| Pre-FEC | 4.690 E-04 | 5.136 E-04 | 5.403 E-04 |

## 6.4. PoC Technical Finding

The results obtained in this PoC are as shown in Table 10:

*Table 10 The finding from the PoC*

| | | |
|---|---|---|
| Objective Id: | MFH/Basic Scenario Step1-specific scenario/1/Objective1 | |
| Description: | The integration of optical duplexers in existing communication systems can transform dual-fiber transmission into single-fiber transmission. This conversion effectively addresses synchronization issues that arise from asymmetric delays in optical transmission. | |
| Pre-conditions | Not applicable | |
| Procedure: | 1 | Use an OTDR to measure the length data of the fiber spools. |
| | 2 | In the APN configuration between the RU and DU, insert and use fiber spools of varying lengths for TE measurement. |
| | 3 | Compare the measured data to the theoretical latency to confirm they match. |

| | |
|---|---|
| Finding Details: | We demonstrated the synchronization measurement result for PTP with the single-fiber bidirectional access architecture.<br>**The main finding about OPEX include:**<br>● To save half of the fiber resources.<br>● No additional power supply is needed.<br>**The main finding about synchronization transmission include:**<br>● Reducing/eliminating synchronization error introduced by asymmetric delay of unequal optical transport paths.<br>● 1PPS TE has better performance with using optical duplexer.<br>**The main finding about latency include:**<br>● Different FEC settings will induce different latency value<br>● Need to consider the APN and the fiber distance to meet the latency requirement. |
| Lessons Learnt & Recommendations | We gained valuable insights from several aspects, as follows:<br>1. If the downlink and uplink transmission path lengths in a network are unequal, it can lead to delays and unnecessary time errors, which negatively impact the network's communication quality. To address this issue, we use pairs of optical duplexers to achieve bidirectional transmission over a single optical cable. This solution not only reduces the optical fiber infrastructure by half but also effectively minimizes the time errors caused by the differing lengths of the downlink and uplink optical cables.<br>2. Based on the latency measurement results show in 6.3.3, we evaluate different distance of fiber spools with different frame and different FEC settings, under back-to-back and with 5km fiber environment, the one-way latency satisfied the 160μs requirement. While with 30km fiber environment, the latency is about 219 and 199μs, which exceed the requirement.<br>3. The performance of APN-T with various FEC settings can impact the latency of transparent transmission. We can achieve better performance by selecting a lower-latency FEC for transparent packet transmission.<br>4. Assumed the latency induced by fiber is about 5μs /km, when the fiber distance within 20km, latency is about 150μs with SCFEC, which satisfied the latency requirement.<br>5. To meet the 160μs 30km latency requirement, there will be 150μs fixed latency induced by the 30km fiber distance, which means that the APN should induced less than 10μs latency. |

# 7. PoC's Contribution to IOWN GF

Use the table below to list any contributions to the IOWN GF (may indicate a particular Task Force Group) resulting from this PoC Project.

| Contribution | WG/TF | Study Item (SI)/Work Item (WI) | Comments |
|---|---|---|---|
| Combine APN with "Optical Duplexer" | IMN TF | n/a | This PoC demonstrates single-fiber bidirectional access architecture using optical duplexer of mobile transport network. |

# 8. PoC Suggested Action Items

## 8.1 Gaps identified in relevant standardization

- Not applicable.

## 8.2 PoC Suggested Action Items

- It is expected to adopt the single-fiber bidirectional access architecture in mobile fronthaul scenario to maintain the synchronization signal (PTP signal) quality.
- As for link speed above 100Gb/s with advanced modulation formats (PAM-4 or Coherent), the impact of which transceivers performance on tight synchronization is used should be considered.
- It is expected to further study on using optical connectors or splitters under conditions similar to actual field conditions.

## 8.3 Next Step

- With the Benchmark-First PoC results, we will start to think about how to adopt this architecture into develop a RIM of IMN TF.

# 9. Conclusion

The PoC report presents performance evaluations under several conditions on APN infrastructure and optical duplexer. The measured distance of fiber spools is 0.002km/5km/30km, and the measured frame size is 64/128/256/512/1024/1280/1518 bytes. The measurement results are based on the system configuration shown in section 6.1 and the methods described in section 6.2. The results are expected to provide feedback for further IOWN GF technology development such as Reference Implementation Model, use cases or PoC references.

# 10. Abbreviations and acronyms

For the purposes of this PoC, the following abbreviations and acronyms apply:

1PPS: 1 Pulse Per Second

APN-G: All Photonic Network-Gateway

APN-I: All Photonic Network-Interchange

APN-T: All Photonic Network-Transceiver

cTE: constant Time Error

CPRI: Common Public Radio Interface

dTE: dynamic Time Error

DU: Distributed Unit

eCPRI: enhanced Common Public Radio Interface

eMBB: enhanced Mobile Broadband

GM: Grandmaster

IEEE: Institute of Electrical and Electronics Engineers

IMN: IOWN GF for Mobile Networks

ITU-T: International Telecommunication Union Telecommunication Standardization Sector

LLS: Low Layer Split

MFH: Mobile Fronthaul

MTIE: Maximum Time Interval Error

O-RAN: Open Radio Access Network

OTDR: Optical Time Domain Reflectometer

PDV: Packet Delay Variation

PoC: Proof of Concept

PTP: Precision Time Protocol

ROADM: Reconfigurable Optical Add-Drop Multiplexer

RU: Radio Unit

SyncE: Synchronous Ethernet

TE: Time Error

T-TSC: Telecom Time Slave Clock

UE: User Equipment

uRLLC: ultra-Reliable and Low Latency Communications

FEC: forward error correction

# 11. Document History

| Version | Date | Author | Description of Change |
|---|---|---|---|
| 0.1 | July 09, 2024 | Jian-Kai Huang, CHT<br>Yu-Chuan Luo, CHT | • Initial draft |
| 0.2 | July 25, 2024 | Jian-Kai Huang, CHT<br>Yu-Chuan Luo, CHT | • Reflecting comments from IMN TF informal review |
| 1.0 | Sep 24, 2024 | Jian-Kai Huang, CHT<br>Yu-Chuan Luo, CHT | • Add Specifications for Optical Duplexer<br>• Add Return Loss Measurement results<br>• Reflecting comments from TWG formal review |
| 1.1 | Nov 18, 2024 | Jian-Kai Huang, CHT<br>Yu-Chuan Luo, CHT | • Add reference to MOPA Technical paper on Optical pluggable performance for tight synchronization published in March 2024.<br>• Add Pre-FEC Measurement results<br>• Reflecting comments from TWG formal review |
| 1.2 | Dec 17, 2024 | Jian-Kai Huang, CHT<br>Yu-Chuan Luo, CHT | • Reflecting comments from IMN TF formal review |

# 12. Reference

[Open APN FA] IOWN Global Forum, “Open All-Photonic Network Functional Architecture” Ver 2.0 (2023.10)

[PoC Reference of Mobile Fronthaul over APN] IOWN Global Forum, “PoC Reference of Mobile Fronthaul over APN” Ver 2.0 (2024.07)

[IMN PoC Reference v1.0] IOWN Global Forum, Mobile Fronthaul over APN PoC Reference” Ver 1.0 (2022.08)

[Recognized Mobile Front Haul over APN PoC Step1 Report] IOWN Global Forum, “Mobile Front Haul over APN PoC Step1 Report,” Ver 1.0 (2024.01)

[MOPA_Tight-Sync_Paper-v1.0.pdf (mopa-alliance.org)] Mobile Optical Pluggables Alliance (MOPA) Technical paper on Optical pluggable performance for tight synchronization Version 1.0 (2024.03.25)