PoC Project name:
Connection case of fiber sensing with APN-G PoC Report

Classification: IOWN Global Forum Recognized PoC

Stage: SSF PoC Report

Confidentiality: Public

Version: 1.0

DECEMBER 13, 2023

Connection case of fiber sensing with APN-G PoC Report

1. PoC Project Completion Status

This document is a report on the results of the implementation of a PoC listed in the PoC reference document "Open APN Architecture PoC Document", which is being discussed in the OAF TF of the IONW Global Forum.

The PoC described in this report is based on the section 2.5 "Connection case of fiber sensing with APN-G" in the reference document "Open APN Architecture PoC Reference"

For the fiber sensing architecture for implementing fiber sensing in APN defined by "IOWN Global Forum Fiber Sensing for Open APN", we use of APN-G as a switching function of a sensing fiber where APN-G is prepared in APN and shared with communication service. This PoC will verify if this APN-G can be used for fiber sensing.

This report shows the PoC of some possible connection between APN-G and fiber sensing. However, the specifications of APN as a whole, including APN-G, are still under discussion, and the implementation model of fiber sensing will be updated as it evolves, and multiple technical PoCs will likely be required.

2. Connection case of fiber sensing with APN-G PoC Project Participants

Specify PoC Team:

- PoC Project Name: Connection case of fiber sensing with APN-G PoC

- NTT, Daisuke Iida   Contact: daisuke.iida@ntt.com

- NTT, Chihiro Kito   Contact: chihiro.kito@ntt.com

- NEC, Yoshiaki Aono   Contact: jwa32@nec.com

- NEC, Takahiro Kaneko   Contact: ta.kaneko@nec.com

3. Confirmation of PoC Demonstration

- Venue: NTT Musashino R&D center, NEC Abiko Office

- PoC Demonstration Event Details:

Reference case in this PoC is shown in Figure 1. In this system, we confirmed the features described in PoC reference document "Open APN Architecture PoC Document".
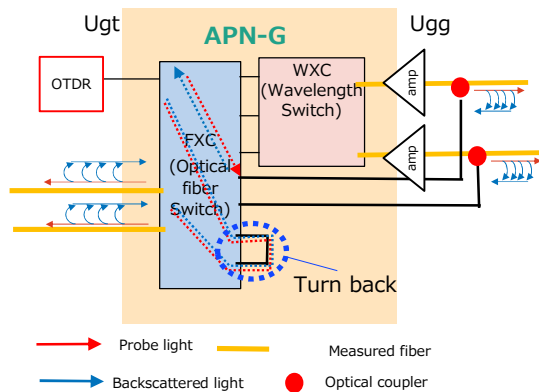
Figure 1 Reference case in this PoC

As PoC of the connection between the APN-G and fiber sensing, the APN-G is configured to include the wavelength switch (WXC) and the optical fiber switch (FXC), with the amplifier on the Ugg side, for compensating optical loss of fibers and APN-G.

The spectral width of a light source of Optical Time Domain Reflectometry (OTDR) is typically very wide, a few nm, which is very much larger than the wavelength dividing width in the WDM devices used as WXC for APN-G, making it impossible for OTDR light to pass through WDM devices. In the system with the circulator described in Figure 15 of the Appendix of the PoC reference document "Open APN Architecture PoC Document", the OTDR light has to pass through the WXC.

Therefore, the configuration with circulators described in Figure 15 of the Appendix in PoC reference document "Open APN Architecture PoC Document" was not used in this PoC.

With FXC's turn back feature, the fiber on both sides, Ugg, Ugt, can be measured by one interrogator.

A coupler system in Figure 16 of the Appendix in PoC reference document "Open APN Architecture PoC Document" was adopted alternatively, because the optical loss in circulator system with WXC assumed to be large.

Features to be measured.

- Span loss between the interrogator and the measured fiber (described in 6.3.1 in this report)

- OTDR waveform measured in 2^{10} =1024 times averaged with a pulse width of 100 ns

  (described in 6.3.2 in this report.)

- Specifications of Optical switch function and Model number of the OTDR unit

  (described in 6.2 in this report)

- Specifications of the APN-G (described in 6.2 in this report)

When the probe light or the back scattered light passes through APN-G for selecting measured fiber, the following additional item is required to be reported:

- Specification of internal crosstalk of the APN-G between sensing light and communication light (described in 6.2 in this report)

The wave form measured with a real time mode is described as to be measured in the reference document "Open APN Architecture PoC Document". Since we could not obtain a single pulse waveform without averaging, only averaged waveforms are reported in this report.

4. PoC Goals Status Report

The main goal of this PoC was to obtain fiber loss distribution waveforms using commercially available OTDRs with any architecture that bypasses the amplifiers introduced in the APN-G. The sensing fiber was a commercial single-mode optical fiber over 10 km. It was evaluated by the OTDR waveform measured by averaging $2^{10}=1024$.

Additionally, a PoC was conducted when the sensing source is a DAS (Distributed Acoustic Sensor) rather than the OTDR. It provides more practical knowledge of the interference between the sensing signal and the communication signal.

- PoC Project Goal #1: To obtain fiber loss distribution waveforms with OTDR connecting to APN-G. Goal Status (Demonstrated)

- PoC Project Goal #2 (additional): To study the mutual interference between DAS sensing signal and communication signal when the distributed fiber optic sensor (DFOS) is connected to APN-G. Goal Status (Demonstrated)

5. PoC Feedback Received from non-member (Optional)

- None in particular

6. Connection case of fiber sensing with APN-G PoC Technical Report

6.1. Fiber loss distribution PoC

The main goal of this PoC was to obtain fiber loss distribution waveforms using commercially available OTDRs. Among the 3 architectures proposed in PoC reference document to bypass the amplifiers introduced by the APN-G, the architecture with external switch and coupler (without circulator) was used here.

6.1.1. Implemented System

Experiments were conducted on a total of four patterns of systems shown in Fig. 2, 3, 4, and 5, depending on which fiber was measured on the Ugg or Ugt side and whether the external optical switch other than APN-G (but which can be included in APN- G) was used. The external optical switch is a switch for selecting the APN-G connected to OTDR from multiple APN-Gs.
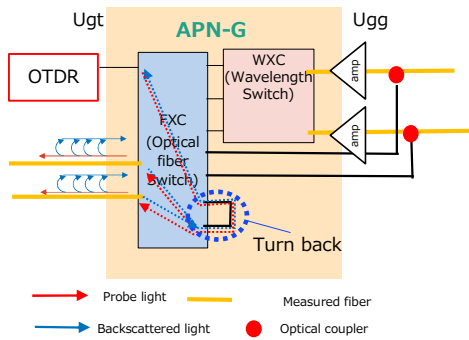
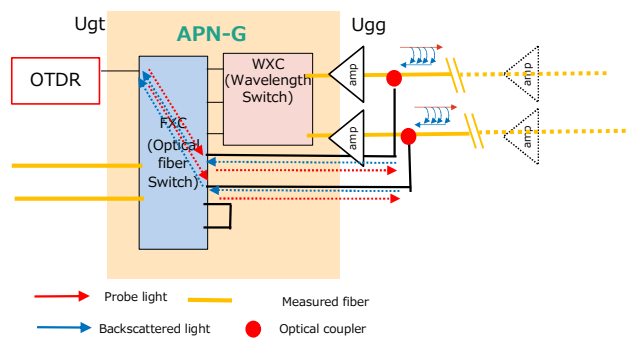Figure 2 Ugt side measurement with turn back
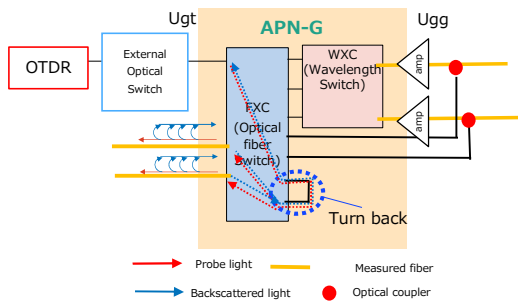

Figure 3 Ugg side measurement with couplers

Figure 4 Ugt side measurement with turnback
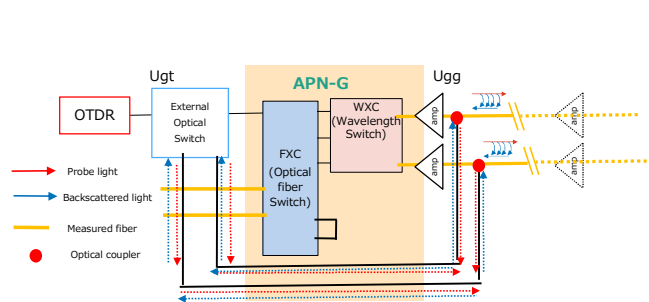
and external optical switch

Figure 5 Ugg side measurement with couplers

and external optical switch

6.1.2. Measurement Method

- Measured fiber :11 km single mode fiber

- Specifications of external optical switch: Anritsu MN9674N specified loss < 2.5 dB @1550 nm

- Model number of the OTDR unit: Yokogawa AQ7932

- Specifications of the APN-G and its crosstalk:

  APN-G was the photonic gateway (Ph-GW) proposed in "M.Yoshino, et al., W3F.5 in OFC2023".

  Crosstalk of FXC in the Ph-GW > 50 dB.

- Span loss (which was not described reference document "Open APN Architecture PoC Document":

We measured the span loss from the OTDR to a connecting point with fiber under test. Continuous light was launched into the port where the OTDR was connected. The input and output power at the connecting points were measured with an optical power meter (EXFO FPM-300), and the difference was defined as the span loss.

6.1.3. PoC Technical Finding

6.1.3.1. Span loss between the interrogator and the measured fiber

The following results were all measured with 1550 nm wavelength.

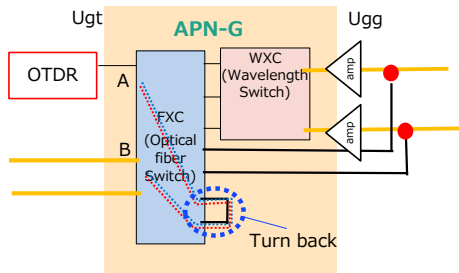- Figure 2 system:　　1.7 dB between A and B shown in Figure 6

Figure 6 Loss measurement span in the configuration described in Figure 2

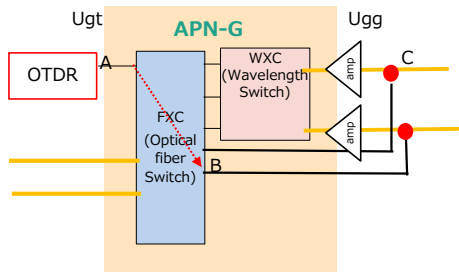- Figure 3 system:　　5.0 dB between A and C shown in Figure 7

Figure 7 Loss measurement span in the configuration described in Figure 3

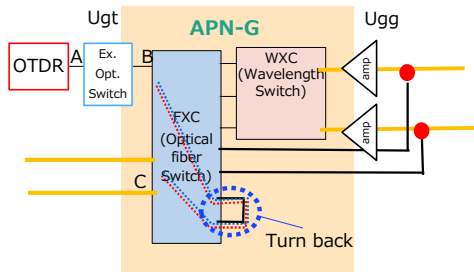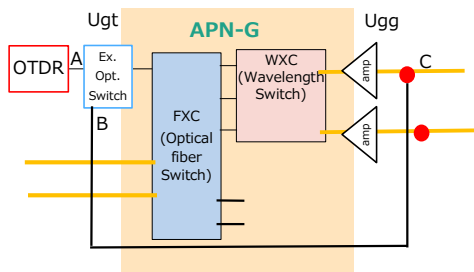- Figure 4 system:　　3.0 dB between A and C shown in Figure 8

Figure 8 Loss measurement span in the configuration described in Figure 4

- Figure 5 system:　　5.8 dB between A and C shown in Figure 9

Figure 9 Loss measurement span in the configuration described in Figure 5

The loss value itself depends on the connection system and optical devices used.

6.1.3.2. OTDR waveform

Waveforms here was measured in 2^{10} =1024 times averaged with a pulse width of 100 ns.
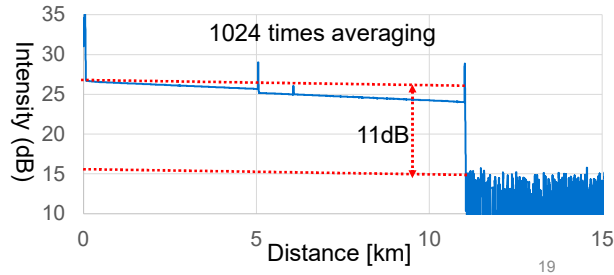
- Figure 2 system:

Figure 10 Waveforms measured in Figure 2 system

The measurable range of Rayleigh backscattered light power is the difference between the maximum backscattered light power excluding reflections at the input end of the fiber under test and the noise floor as shown in the figures, which is proportional to the length of the fiber that can be measured. In Figure 2 system, the measurable range was 11 dB, and it was declined by the FXC loss, but the loss distribution could be measured.

Since optical fibers have optical loss, this range provides a guide for measurable fiber lengths. For example, waveform in figure 10 has a range of 11dB, and when with a fiber loss of 0.3 dB/km, the measurable fiber length is about 36 km (=11dB/(0.3dB/km)).
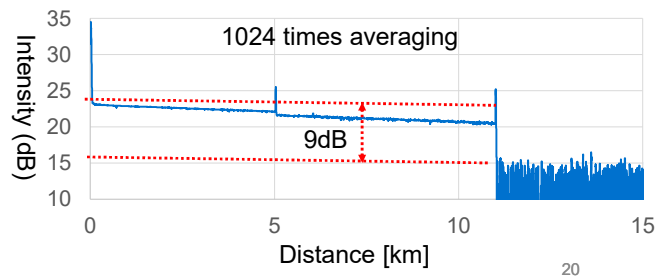
- Figure 3 system:

Figure 11 Waveforms measured in Figure 3 system

Figure 3 system, the measurable range was 9 dB, and it was declined by the FXC loss, but the loss distribution could be measured.
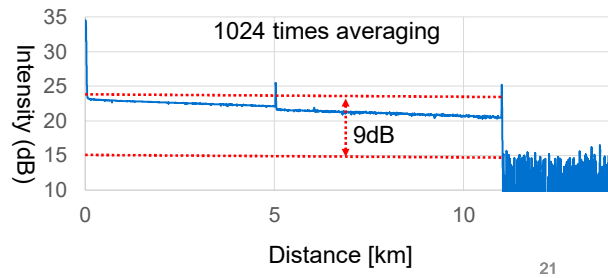
- Figure 4 system:

Figure 12 Waveforms measured in Figure 4 system

Figure 4 system, the measurable range was 9 dB, and it was declined by the FXC loss, but the loss distribution can be measured.
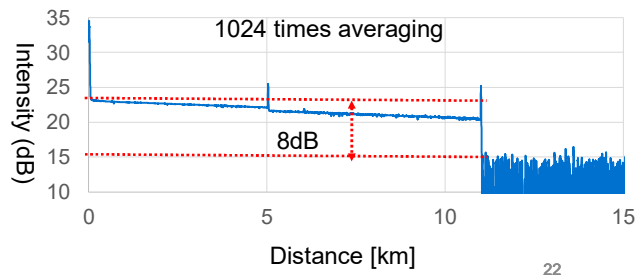
- Figure 5 system:

Figure 13 Waveforms measured in Figure 5 system

Figure 5 system, the measurable range was 8 dB, and it was declined by the FXC loss, but the loss distribution could be measured.

By using a coupler and an external switch together, it is possible to avoid the APN-G amplifier and measure the loss distribution waveform by OTDR.

However, the loss of those power branching devices declined the measurable range.

6.2. Integration PoC

The additional goal of this PoC is to study the mutual interference between DAS sensing signal and communication signal when the DFOS is integrated to APN-G. Here, both Type II-2 and Type III architecture described in "Fiber Sensing for Open APN version 1.0" are tested.
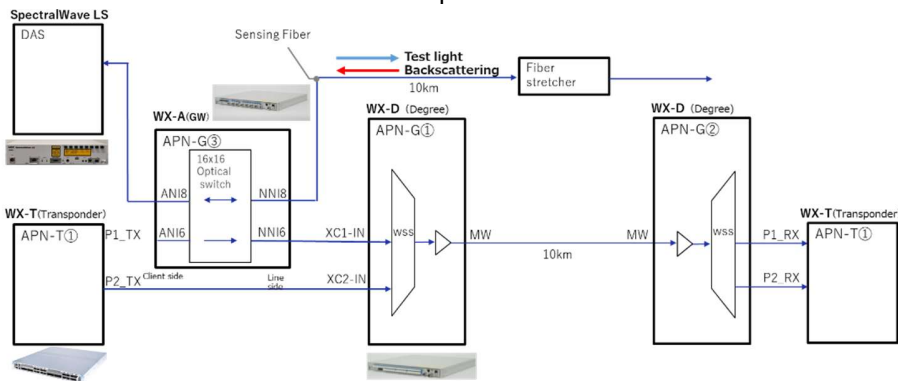
6.2.1. Implemented System
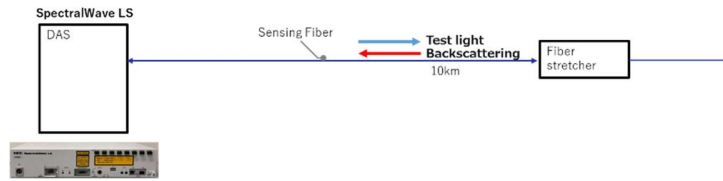
(1) Configuration ① : Reference configuration
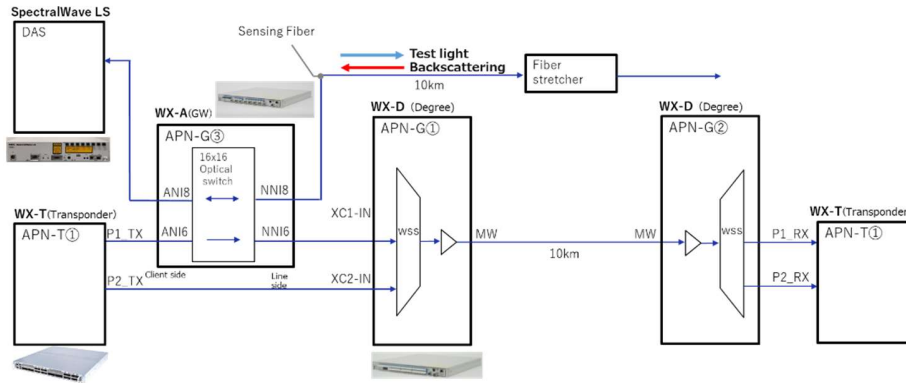
(2) Configuration ② : Type II-2, connecting the sensing light and the communication light to the path via WX-A

(3) Configuration ③ : Type II-2, connecting the sensing light to the path via WX-A, and connecting the communication light via WX-D
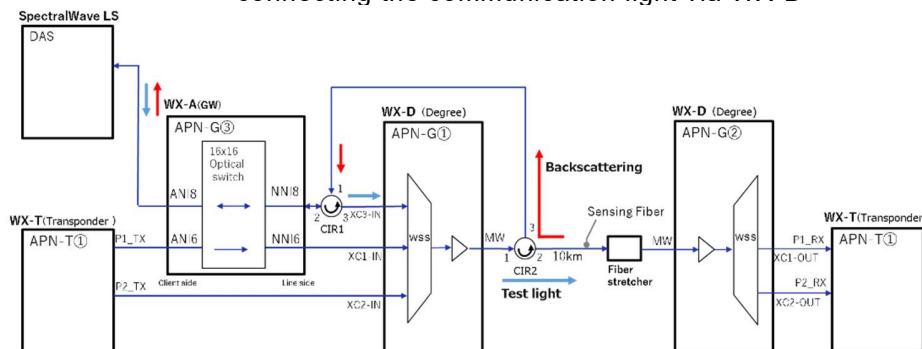
(4) Configuration ④ : Type III, connecting the sensing light and the communication light to the path via WX-A, and use circulator to bypass WX-D for the sensing signal

Figure 14 Configuration diagrams for integration PoC

Four test configurations were tested in this part of the PoC experiment, which are shown in Fig. 14.

- Configuration ① is the reference case for the sensing signal (DAS) alone.

- Configurations ② is Type II-2, in which the sensing light and communication light described in "2.5. Connection case of fiber sensing with APN-G" of the "Open APN Architecture PoC Reference" do not propagate through the same fiber at the same time. Here the communication light is connected to the WX-A gateway (a 16 x 16 optical switch) where the sensing light is also connected,

- Configuration ③ is also Type II-2. However, the communication light is not connected to WX-A, but connected to WX-D (a degree node, which consists of a WSS and an optical amplifier).

- Configuration ④ is Type III, in which communication light and sensing light propagate simultaneously in the same fiber. Two DWDM communication channels were used. One is connected to WX-A then WX-D, and the other is directly connected to WX-D.

6.2.2. Measurement Method

- Measured fiber: 10 km single mode fiber

- DAS: NEC SpectralWave LS DAS (wavelength: 1550 nm, center frequency: 193.40 THz)

- Communication signal: 100G DP-QPSK transponder, center frequency ranges from 191.50 THz to 195.30 THz.

- WX-A type APN-G: ???

- WX-D type APN-G: ???

We measured the mutual influence on sensing light and communication light. The parameters include:

- Sensitivity measurement of sensing using a fiber stretcher
- Bit Error Rate measurement of communication light

6.2.3. PoC Technical Finding

6.2.3.1. Type II-2 architecture results

The table below shows the sensing sensitivity measurement results for Configurations ① to ③.

The results show that there was no difference in detection sensitivity, no matter whether the sensing light passes through WX-A or whether the communication light is connected to WX-A.

Configuration diagram	Sensitivity difference from reference [$n \varepsilon / \sqrt{Hz}$]	Connection of sensing light with WX-A	Connection of communication light(P1) with WX-A
①	(Reference)	With	—
②	less than 0.03	With	With
③	less than 0.03	With	Without

The table below shows the results of measuring the BER of communication light with and without connecting the sensing light to WX-A. It can be seen that there was no difference in BER of communication light with or without sensing light.

Configuration diagram	Pre FEC-BER	Connection of sensing light with WX-A	Connection of communication light(P1) with WX-A
②	1.1E-11	Without	With
②	1.0E-11	With	With

6.2.3.2.   Type III architecture results

In this experiment, the center frequencies of the two communication channels (P1 and P2) are varied to emulate different channel spacing settings between the communication light and the sensing light. Here the sensing light is fixed at 193.40 THz.

Center spacing(GHz)　※	Center frequency (THz） P1	Center frequency (THz） P2
50	193.35	193.45
100	193.30	193.50
450	192.95	193.85
1000	192.40	194.40
1900	191.50	195.30

The table below shows the sensing sensitivity measurement results for configuration diagrams ④. These results show that there was no effect on the detection sensitivity related to the wavelength spacing or whether the communication light is present or absent.

Configuration diagram	wavelength spacing [GHz]	Sensitivity difference from reference [n ε / √ Hz]	Connection of sensing light with WX-A	Connection of communication light(P1) with WX-A
④	50	less than 0.03	With	With
④	100	less than 0.03	With	With
④	450	less than 0.03	With	With
④	1000	less than 0.03	With	With
④	1900	(Reference)	With	With

The table below shows the results of measuring the BER of communication light with and without connecting the sensing light to WX-A. The results show that there was no effect on the BER related to the wavelength interval or whether the sensing light is present or absent.

Configuration diagram	wavelength spacing [GHz]	Pre FEC BER	Connection of sensing light with WX-A	Connection of communication light(P1) with WX-A
④	50	1.7E-10 1.6E-10	With Without	With With
④	100	5.2E-10 5.0E-10	With Without	With With
④	450	1.8E-10 1.7E-10	With Without	With With
④	1000	2.1E-10 2.3E-10	With Without	With With
④	1900	2.7E-10 3.0E-10	With Without	With With

7. PoC's Contribution to IOWN GF

This PoC confirms that FXC in APN-G can be used to select fibers for fiber sensing. However, the loss depending on the device passing through affects the measurable range.

This result shows the feasibility that the implementation case of fiber sensing accommodated relying on APN switches, which is being considered in the OAF TF of the IOWN GF.

Contribution	WG/TF	Study Item (SI)/Work Item (WI)	Comments
It was confirmed that APN-G's FXC can be used to select fibers for fiber sensing.	OAF	- Extend technical PoCs to verify a specific sensing architecture/technology over open APN ->Fiber sensing network architecture (type I, II, III) technical demonstration	The implementation of fiber sensing accommodated in APNs using APN switches, which is being considered in the OAF TF of the IOWN GF, is possible
...			

8. PoC Suggested Action Items

8.1 Gaps identified in relevant standardization

Gap 1 affected to OAF TF and OAA TF

When APN-G's FXC is used simultaneously for communication signals and fiber sensing, it is necessary to examine the crosstalk of the FXC and investigate the influence of communication light on fiber sensing. This study is necessary for not only for OTDR but also for other fiber sensing technologies.

Gap2 affected to OAA and OAW TF

In contrast to gap1, we also need to examine the influence of fiber sensing on communication based on FXC's crosstalk. Also, in this report, when the FXC is used for fiber sensing, a power-branching optical

coupler is used to insert a pulse into the fiber to avoid an amplifier, which causes loss of communication light. It is also necessary to verify the influence of the optical loss caused by this coupler on the communication light.

Gap3 affected to OAA and OAW TF

APN-G configuration such as optical devices and specifications for optical signals transmitted on APNs can be a variety of things, and the specifications will change rapidly in future discussion. Fiber sensing also needs to adapt to the results of the latest OAA and OAW discussions.

8.2 PoC Suggested Action Items

- Action Item 1: Verification of the influence of crosstalk from communication to fiber sensing due to simultaneous use of communication and fiber sensing in the FXC part of the APN-G (for Gap 1 in 8.1)

    - Investigation of the crosstalk value itself

    - Influence on measurable fiber length

    - Influence on the accuracy of physical quantities to be detected (vibration, strain, temperature)

    - Differences in the influence of different fiber sensing techniques

- Action Item 2: Verifying the impact of fiber sensing on communications (for Gap 2 in 8.1)

    - Impact of loss of communication light due to use of couplers

    - Impact of fiber sensing crosstalk on communications at FXC

    - If fiber sensing is conducted with a communication fiber, the far end of the fiber may be already connected to transmission equipment. For fiber sensing under such a situation, investigation of the influence of test light pulses on transmission equipment at the far end of the measurement fiber and how to handle them are for further study.

- Action Item 3: Consideration of APN-G usage method for fiber sensing based on APN specification study (for Gap 3 in 8.1)

    - In parallel with the discussion of APN in OAA and OAW, confirm as needed whether the fiber sensing can be done with various system configurations discussed there.

8.3 Any Additional comments the PoC Team wishes to make?

- None in particular

8.4 Next Step?

- It would be the next step to discuss the effects on crosstalk from communication to fiber sensing described in Action Item 1 of 8.2.

9. Document History

Version	Date	By	Description of Change
1.0	July 26, 2023	NTT, NEC	Initial draft