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Fiber Sensing Crosstalk Study for Open APN PoC Reference

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[FS for Open APN PoC Reference]

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1. Purpose, Objectives, and Scope

1.1. Purpose

Fiber sensing, in particular, distributed fiber optic sensing (DFOS), has been proposed to be a new feature for IOWN GF's Open All Photonics Network (APN). DFOS will bring new capabilities to the fiber optic network and improve its operation reliability. It will also enable new applications and services for the Open APN network, such as utility health monitoring, traffic monitoring and management, and natural disaster monitoring.

As a new type of signal added to the conventional fiber optic communication network, there are new technical challenges to study and solve. Even though the DFOS signals, including the probe light and the backscattering light, also operate at the same or similar spectrum as the WDM optical communication signals, the optical characteristics of the DFOS signals are quite different from the regular WDM optical communication signals. For example, the DFOS probe signals has short pulses with long repetition rate, its optimum peak power is usually higher than the communication signals, the laser linewidth for certain sensing systems needs to be narrower than for communication channels, and it requires bidirectional operation over the same fiber. These differences in optical characteristics might lead to potential issues when fiber sensing and communication signals co-exist on the same network, no matter they are transmitted on the same piece of fiber or share the same switching node. One of the main issues is the crosstalk between the sensing signals and the communication signals. The higher peak power and pulsing characteristics of the sensing signals might reduce the optical signal-to-noise ratio (OSNR) of the communication channel and cause nonlinearity, which in turn will increase the BER and reduce the throughput. On the other hand, the existence of communication channels near the sensing signal might interfere with the backscattering signal and cause the sensitivity level to decrease.

Therefore it is important to understand the crosstalk between the fiber sensing signals and the optical communication signals to verify the feasibility of having both signals co-existing on the same optical network, especially over the new Open APN architecture. When considering the architecture of the connection to the Open APN, it is necessary to clarify how to use the communication optical fiber of the Open APN as a sensor medium and utilize the Open APN gateway, which is the switching function of Open APN. This PoC is designed to achieve this purpose.

1.2. Objectives

Since the probe light of fiber sensing interrogators mostly are high power pulse laser, the effects of crosstalk may be different from that of communication signals. Therefore it is important to verify the effects of fiber sensing signals on APN while using a wavelength-selective switch (WSS) with crosstalk. In this PoC, we plan to experimentally and quantitatively evaluate the effect of the crosstalk between the fiber sensing signals and the optical communication signals under different conditions, such as different crosstalk levels, different sensing signal characteristics, different communication channel modulation formats, different fiber distances, etc. The study will be conducted both in a laboratory setup and over an Open APN testbed. These results will help the network operators in the future to configure the Open APN with fiber sensing functions to achieve optimum performance between these two types of signals.

1.3. Scope

As described in reference document “Fiber Sensing for Open APN”, Version 1.0 [1], there are three types of fiber sensing architectures for connecting a fiber sensing network to the APN.

Type I:

1. The APN is only used to transmit the measurement data and the control signal of the interrogator.
2. The optical fiber and an external switch as a sensor medium, completely independent of the APN.

Type II-1:

1. The APN is used to transmit the measurement data and the control signal of the interrogator.
2. APN's fiber and switch are used for communication service and fiber sensing.
3. Communication and fiber sensing signals do not coexist in the fiber.
4. The switch is free off crosstalk.

Type II-2:

1. The APN is used to transmit the measurement data and the control signal of the interrogator.
2. APN's fiber and switch are used for communication service and fiber sensing.
3. Communication and fiber sensing signals do not coexist in the fiber.

4. The switch has non-negligible crosstalk. Optical fiber sensing signals can enter other fibers through the crosstalk of the switch.

Type III:

1. The APN is used to transmit the measurement data and the control signal of the interrogator.
2. APN's fiber and switch are used for communication service and fiber sensing.
3. Communication and fiber sensing signals simultaneously propagate in the fiber.

Since there is no fiber optic sensing signal that coexists with the communication signal in Type I and Type II-1 architectures, this PoC focuses on Type II-2 architectures, where the fiber optic sensing signals can enter other fibers through crosstalk from the switching node, potentially interfering with the communication performance. The PoC results of Type II-2 architecture will provide valuable techniques and experience for PoC of Type III architecture.

This PoC will focus on the effect of the crosstalk from the sensing probe light signal to the communication signals. The reverse crosstalk, i.e. the effect of the crosstalk from the communication channels to the sensing backscattering signal, will not be the focus on this PoC.

2. Reference Cases

2.1. Pulse laser sources for DFOS interrogators and DWDM OTDR

DFOS includes various types of sensing technologies based on different backscattering signals (Rayleigh, Brillouin and Raman) and different signal processing principles (such as time domain vs. frequency domain analysis, and intensity-based analysis vs. phase-based analysis), and the physical phenomena being monitored are also different (including vibration, acoustic signal, strain, temperature, attenuation, etc.). Therefore there are different types of optical system configurations among different DFOS systems.

Furthermore, because the DFOS industry does not have any common technical standards, even with the same type of DFOS (such as the distributed acoustic sensor), different vendors develop products with their own proprietary specifications and settings. Therefore there are no “standard” DFOS interrogators to be used for this PoC. As a result, it is not feasible to study one particular DFOS interrogator product from a specific vendor.

Instead, we plan to use some generic probe laser signals to represent and emulate the DFOS in general, since these DFOS interrogators share the same general optical operation principles (i.e. analyzing the backscattering light of the probe laser from the sensing fiber).

The typical values for DFOS probe lasers according to Table 2.2 of the reference document "Fiber Sensing with Open APN" version 1.0 are listed in Table 1.

Table 1: Typical values for DFOS Probe lasers

	DWDM-OTDR	C-OTDR	OFDR	B-OTDR
Center wavelength [nm]	DWDM grid	1550.12 nm *typical		
Spectral linewidth	1MHz to 10MHz	<= ~1 kHz		~1 MHz
Output power	>=4mW peak	100~200 mW peak	Tens of mW	100~200 mW peak
Pulse / CW	10-200ns	~100 ns	CW	~50 ns

DWDM-OTDR: Dense wavelength division multiplexed optical time domain reflectometer

C-OTDR: Coherent optical time domain reflectometer

OFDR: Optical frequency domain reflectometer

B-OTDR: Brillouin optical time domain reflectometer

CW: Continuous wave

In order to perform PoC experiments, the key specifications of the DFOS probe laser should conform to the values listed in Table 1. Two types of pulsed laser sources are designed and will be assembled, and the expected characteristics are listed in Table 2. Compared to the DFOS Probe lasers in Table 1, the pulsed laser sources in Table 2 are expected to be suitable for PoC experiments.

Table.2: Pulsed laser sources for Interrogators and DWDM OTDR

	Pulsed laser sources for DFOS interrogators	Pulsed laser sources for DWDM OTDR
Center wavelength	1550.92 nm	1530nm ~ 1630 nm (DWDM grid)
spectral linewidth	≤ 1 kHz	≤ 0.2 MHz
Output power	1 to 400mW(Adjustable)	1 to 400mW(Adjustable)
Pulse / CW	CW, 10-1,000ns	CW, 10-1,000ns

More details of these two types of pulsed laser sources are described below:

(1) DFOS Probe laser source

The first type has narrow linewidth and fixed wavelength, and can be used as probe light for various types of DFOS Interrogators such as C-OTDR, OFDR, and B-OTDR. Note that the R-OTDR (Raman optical time domain reflectometer) light source is not included in this study for the following reasons:

- The spectral linewidths of Raman light source and scattering light are too broad to pass the switch.
- The frequency shift of about 100nm requires two switch wavelength channels.

This type of probe laser can be generated by narrow linewidth laser (NLL), Acoustic optical modulator (AOM), arbitrary waveform generator (AWG), Erbium doped fiber amplifier (EDFA), filter and adjustable optical attenuator, as shown in Figure 1.

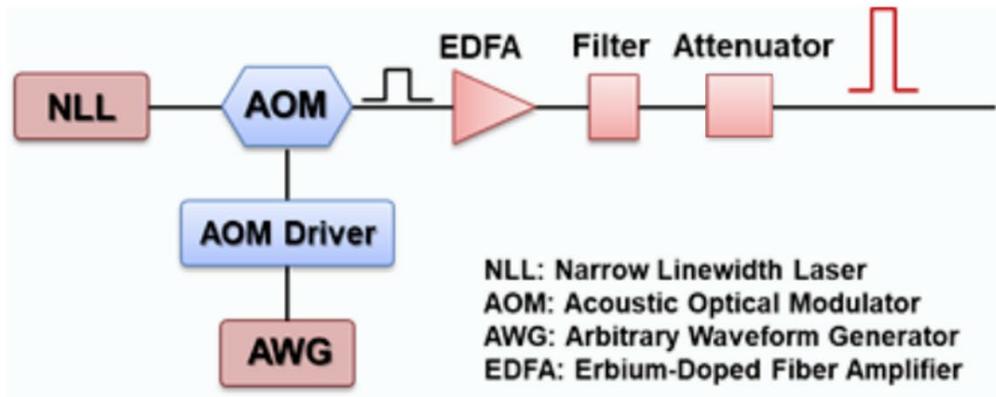


Figure 1: Probe lasers for C-OTDR, OFDR, and B-OTDR

(2) DWDM OTDR Pulse laser source

The second type is tunable laser source (TLS) for DWDM OTDR. It can be generated by Tunable laser source (TLS), Acoustic optical modulator (AOM), Optical-to-Electrical Converter, OTDR, EDFA, filter and adjustable optical attenuator, as shown in Figure 2.

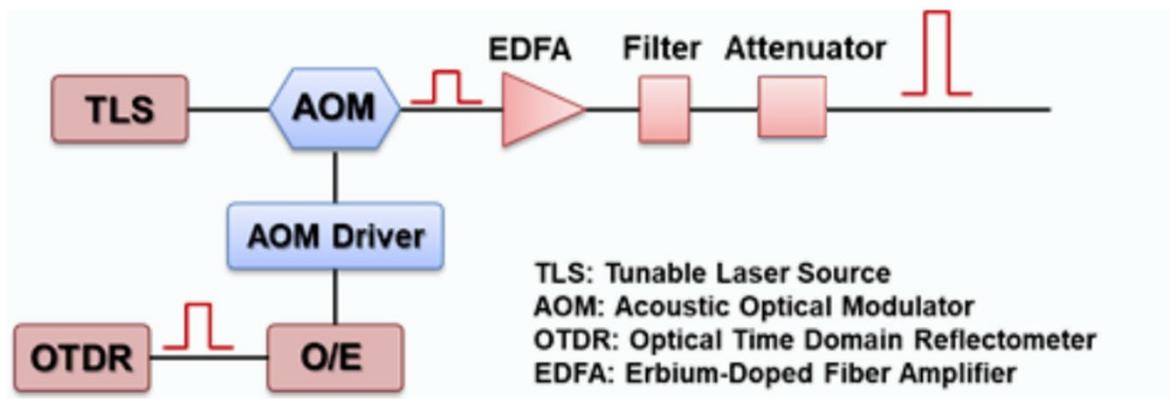


Figure 2: DWDM OTDR Pulse laser source

2.2. Evaluate effects of crosstalk on communication

In sensing architecture type II-2, the switch has crosstalk. Many studies, such as the evaluation of crosstalk, the evaluation of mutual interference between communication and sensing signal, and the study of noise immunity of communication signals, are

necessary for adopting this type as fiber sensing architecture with the APN since fiber sensing light may affect the communication service due to crosstalk of the switch.

Two proposed test architectures for crosstalk effects evaluation are shown in Figure 3 and Figure 4. The effect of crosstalk on communication is measured by a bit error rate tester (BERT) and eye diagram in Figure 3 and evaluated by the performance of monitored Open APN in Figure 4.

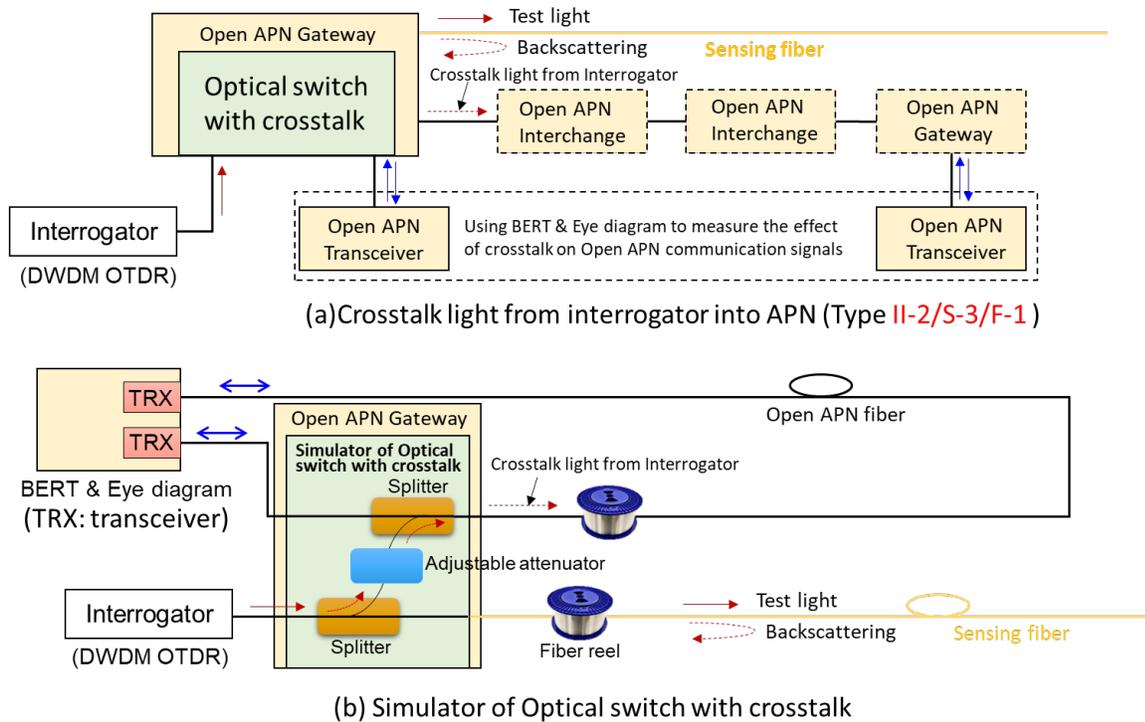


Figure 3: Evaluate crosstalk effects by BERT and eye diagrams test sets

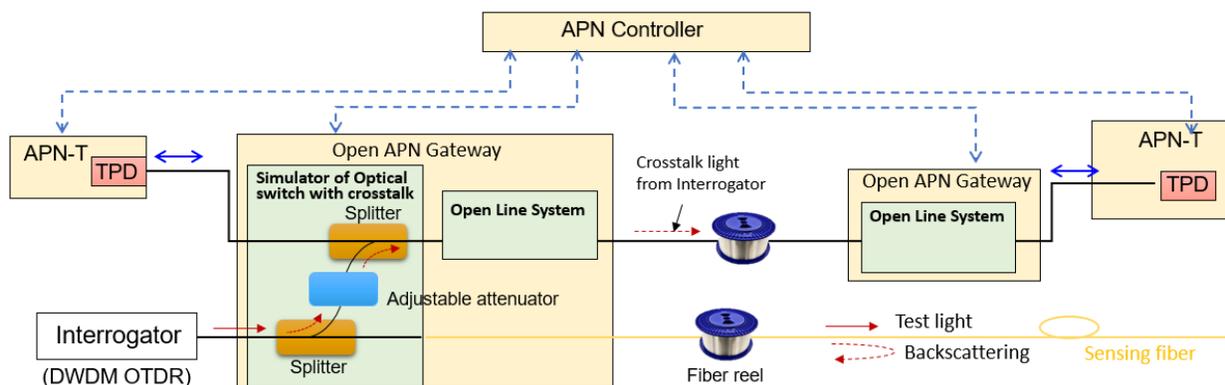


Figure 4: Evaluate crosstalk effects by the performance of monitored Open APN

The features and functions of both test sets are:

- (1) Emulate a switch with crosstalk using two splitters and an adjustable attenuator
 - Crosstalk value can be adjusted by various split ratio splitters and an adjustable attenuator
 - The crosstalk value using two 20/80(%) split ratio splitters can be calculated by the following formula and 14 dB minimum without attenuator:

$$\text{Crosstalk (dB)} = -10\log (20/100) \times 2 + \text{Attenuation amount of attenuator}$$

- (2) Distance of fibers
 - Using various length fibers to evaluate crosstalk effects
- (3) Light sources
 - DFOS Probe laser source

Evaluating the impact of ultra-narrow linewidth laser interference on communications.

- DWDM OTDR Pulse laser source

Evaluating the influence of various wavelengths on communication, especially the wavelengths that are close to or the same as the communication signal wavelength.

- (4) Laser source power
 - Output power of DFOS Probe laser source and DWDM OTDR Pulse laser source are adjustable from 1 to 400mW
- (5) Both transmission directions of communication light are evaluated

3. Desired Features

In the Open APN system with fiber sensing, it is desirable to achieve good sensing performance while not affecting the regular optical communication signals' performance. Therefore the desired feature from this PoC is to quantitatively analyze the effect of cross on the sensing performance and the communication performance, and use the finding to determine the optimum optical characteristics settings for the sensing signal (such as the pulse width, pulse repetition rate, peak power, wavelength, etc.) and the optical spectrum arrangement, so that the effect from the crosstalk between the sensing signal and the communication signal will be kept minimum, and that both types of signal can operate properly and deliver expected performance.

4. Key Benchmarks

In this PoC, we plan to experimentally investigate and verify the following items:

- The effect of the crosstalk from the sensing probe light signal to the communication signals at different crosstalk levels.
- The difference in the crosstalk for communication signals with different modulation formats.
- The difference in the crosstalk effects from different probe light laser sources.
- The difference in the crosstalk effects from different wavelength separations between the sensing signal and the communication channels.
- Any effect of fiber length on the crosstalk between the communication channels and the sensing signals.

There are several test parameters to be used to evaluating the effect of crosstalk on communication performance:

- (1) Crosstalk value
- (2) Wavelength: 1530nm ~ 1630 nm, 1550.92 nm
- (3) Spectral linewidth: ≤ 0.2 MHz, ≤ 1 kHz
- (4) Output power: 1 to 400mW
- (5) Pulse / CW: CW, 10-1,000ns
- (6) Fiber length: ≤ 100 km

For communication system the crosstalk should be greater than 25dB to achieve 1 dB penalty at 10^{-9} BER for Not-return-to-zero (NRZ) [2] and the “W 100G Optical Spec” of Open ROADMs MSA has the same requirement [3]. Using two 20/80(%) split ratio dividers and an adjustable attenuator to simulate a switch with crosstalk, the crosstalk value can be adjusted from 14dB to no crosstalk.

5. Other Considerations

As described above, this PoC consists of experiments in the laboratory and experiments on the Open APN testbed. For the laboratory experiments, it is planned to be conducted in the research lab of Chunghwa Telecom. And for the experiment on Open APN testbed, we plan to collaborate with other task forces in IOWN GF, such as OAA Task Force, and utilize the Open APN testbed developed by them. Therefore it is likely that these experiments will be conducted in Japan.

The timeline of this PoC work is shown below.

- By July 2022: The planning of this PoC.
- By October 2022: Execution of the laboratory part of the PoC.
- By December 2022: Execution of the testbed part of the PoC.
- By March 2023: Finalizing the PoC and developing with a report.
- By June 2023: Reporting the results to the deliverable report.

References

- [1] “Fiber Sensing for Open APN”, Version 1.0, IOWN Global Forum, 2022.
- [2] T. Zami, B. Lavigne, and E. Balmeffrezol, “Crosstalk analysis applied to wavelength selective switch,” in Proc. OFC 2006, , vol. , p. 3.
- [3] “Open ROADM_MSA_Specification_ver5.0”, Available:
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History

Revision	Release Date	Summary of Changes
1.0	October 21, 2022	Initial Release