An advanced Dark Fiber Monitoring System for Next Generation Ring–and-Spur Long-Reach Passive Optical Networks

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Among different topologies proposed for Long-Reach Passive Optical Networks (LR-PONs), "ring and spur" is currently receiving an extensive investigation due to its low infrastructure cost and high reliability. Meanwhile, most of the existing PON monitoring systems are specially designed for tree-based topology and cannot be directly applied for ring-based networks. Therefore, an adequate monitoring system is highly required. In this paper, we propose a fast and simple monitoring system for LR-PONs using "dark fiber" and multi-wavelength bi-directional Transmission Reflection Analysis (TRA) approach. Both experimental and simulation results have demonstrated that the proposed scheme can reach high accuracy for fault localization.

Introduction

Long-Reach Passive Optical Networks (LR-PONs) allows for extending the distance between the central office (CO) and end users from a few kilometers to several tens of kilometers and beyond, which offers high capacity and large coverage [1]. Among different topologies proposed for LR-PONs, the "ring and spur" approach, in which a ring is employed as the feeder section while several sub-trees are employed for distribution segments, is currently receiving an extensive investigation due to its low infrastructure cost and high reliability [2]. However, this novel network configuration comes with some challenges for most of the existing PON monitoring systems. In particular, the new architecture requires the monitoring of the feeder ring in addition to the traditional tree-based topology. A conventional OTDR measurement is not adequate in this case due to the long measurement time (several minutes) required to obtain a sufficient SNR for such long distances. Moreover, in LR-PONs, optical amplifiers may need to be installed in the feeder ring to compensate the optical power loss caused by the long distance fiber. These devices may block the monitoring signals in the dedicated bands (e.g., U-band) [3].

In order to address the aforementioned problems, a novel monitoring system using a "dark fiber" and a multi-wavelength bi-directional Transmission Reflection Analysis (nλ-BD-TRA) approach is proposed in this paper. The technique is based on the measurement of the transmitted and backscattered powers at multiple wavelengths in both clockwise and counter-clockwise directions of the feeder ring.

Operation principle

As mentioned above, our system proposes the use of a "dark fiber" (i.e., a fiber that has been deployed in the same cable as the data fibers but does not carry any data) for monitoring purposes. This configuration addresses the monitoring wavelength limitation issue previously mentioned. Moreover, the dark fiber monitoring can cover the major faults (e.g. cable cut, bending, etc.) and perform the monitoring for all the fibers in the cable at the same time. This novel idea also makes the monitoring system more precise and flexible since one can choose any set of monitoring wavelengths for supervision without affecting the data signals.

Among different monitoring techniques, transmission reflection analysis (TRA) approach, which only requires to measure the power of transmitted and backscattered monitoring signals, outperforms the other solutions (e.g. optical time domain reflectometry OTDR). It is mainly because the TRA approach is characterized by a superior detection speed and a simple system configuration [4]. In our system, we use a single-wavelength TRA solution for non-reflective events (fiber bending, fiber seepage) monitoring. Regarding reflective events (fiber break) monitoring, a multi-wavelength TRA technique (which is defined in [5]) is utilized as the monitoring solution [6]. Let us note that for the case of long distance (e.g., fiber length >20 km), the TRA technique may present a relatively low localization accuracy especially close to the remote fiber end. In order to improve its accuracy, we propose a bi-directional (BD) configuration adequate for the monitoring of the feeder ring of LR-PONs [6].

The schematic diagram of the proposed monitoring scheme is shown in Fig. 1, where a two-wavelength TRA is taken as an example. Each time, a continuous-wave light is launched in the dark fiber passing the feeder cable ring of the LR-PONs through an optical circulator and a 2×2 optical switch. An optical isolator is implemented to minimize the reflections from the fiber end. The transmitted power (P_T) and the integrated Rayleigh-backscattered/reflected power (P_B) are both measured by the dual-channel lightwave meter.

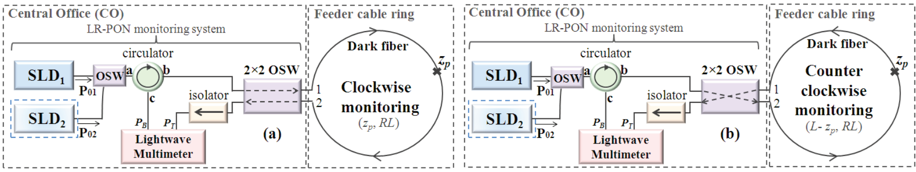

Fig. 1. Schematic diagram of the proposed TRA based monitoring solution. (a) Clockwise direction. (b) Counter clockwise direction

The proposed monitoring procedure is discussed hereafter. If a fault occurring in the feeder cable ring is detected by the by the logical/network layer, one of the two light sources in the monitoring system will be first triggered. The next step consists in measuring the transmitted monitoring power (P_T) detected by the powermeter at the central office (CO). If the powermeter shows a null output of P_T, it indicates the occurrence of a fiber break. In such a case, the other light source will also be triggered to realize a 2λ-BD TRA solution and localize the break. If the powermeter only shows a decrease of P_T, it indicates that the fiber is still connected but an event with big loss introduced, which implies either a fiber bending or a seepage. The 1λ-BD TRA measurement will then be activated to localize the bending or seepage.

The calculation model of fiber break measurement is described in [6]. As mentioned before, for fiber break monitoring the 2λ-BD TRA technique will be utilized [6]. For fiber bending/seepage monitoring, only one light source will be used and the calculation model is described in [7].

Localization accuracy analysis

In this section, the simulation results dedicated to the localization accuracy for fiber break and fiber bending/seepage are provided. This study is conducted under two wavelengths (i.e., λ_1: 1550nm with an attenuation coefficient (α) of 0.2 dB/km and a Rayleigh scattering coefficient ($S{\cdot}\alpha s$) of 0.0026; λ_2: 1310nm with a α value of 0.35 dB/km and a $S{\cdot}\alpha s$ value of 0.0055) [6]. Using a similar methodology as presented in [6] and by considering the inaccuracy of the powermeters (the measurement uncertainty coefficients for measuring P_B and P_T are both 0.1% according to our previous repeatability test), we can plot the expected localization error (see Fig. 2(a) for fiber break and Fig. 3(a) for fiber bending) and the corresponding standard deviations (STD) (see Fig. 2(b) for fiber break and Fig. 3(b) for fiber bending) versus the event location z_p along a 50 km-long fiber (10000 samples have been considered in our simulation).

For fiber break monitoring, we consider two different configurations of the monitoring system (configuration 1 describes the case of using two monitoring wavelength ($\lambda_1+\lambda_2$) for a single directional measurement; in configuration 2, the bi-directional methodology has been employed in the 2λ-TRA ($\lambda_1+\lambda_2$) monitoring solution). Here the event is introduced with a RL_a (clockwise direction) of 50 dB and a RL_b (counter-clockwise direction) of 53 dB.

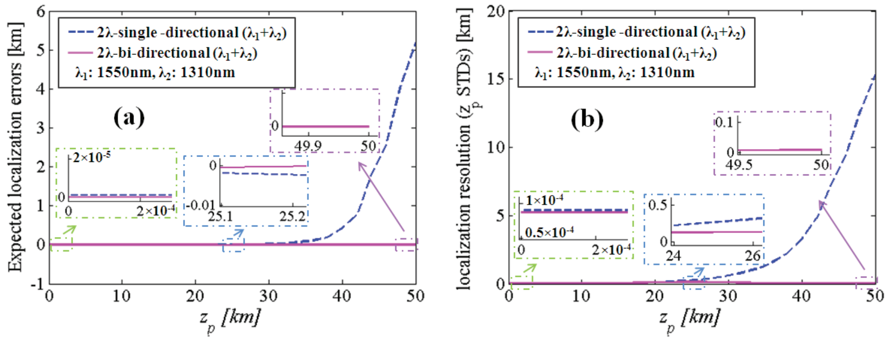

Fig. 2. (a) Calculated expected localization errors and (b) Corresponding STDs when a fiber break is introduced along the feeder ring.

According to Figs. 2(a) and 2(b), it clearly appears that using the bi-directional monitoring configuration provides a better localization accuracy, especially at the remote end (compared with configuration 1 and 2, when z_p=49.9km, the expected localization error changes from 5.3 km to 0.1 m and the corresponding STDs changes from 15 km to 5 m).

Similar with fiber break, for fiber bending/seepage measurement, two different configurations are also considered. The expected localization errors and corresponding STDs are depicted in Figs. 3(a) and 3(b).

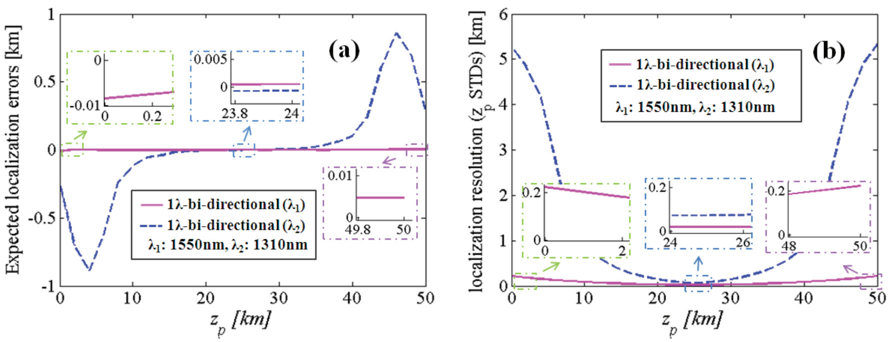

Fig. 3. (a) Calculated expected localization errors and (b) Corresponding STDs when a fiber bending/seepage is introduced along the feeder ring.

Configuration 1 depicts the case of using λ_1 as the monitoring wavelength. In configuration 2, λ_1 is replaced by λ_2. In the simulation model, we assumed an insertion loss (*IL*) and a return loss (*RL*) of the bending/seepage are 25dB and 95dB @ λ_1, 10dB and 105dB @ λ_2, respectively. Note that typically, if an event is characterized by a *RL* higher than 75 dB, it can be seen as a non-reflective event since no reflection peak can be found in the OTDR trace. As shown in Figs 3(a) and 3(b), using longer wavelength (1550nm) provides better localization accuracy for non-reflective events measurement.

Experimental validation and discussion

The experimental set up is shown in Fig. 1. In this experiment, a fiber break is introduced at five different locations along a 56.03 km-long standard single-mode fiber. The SLDs used in our experiment are operated at 1307.5nm (SLD_1) and 1564.6 nm (SLD_2) with an 80.4 nm and an 57.9 nm bandwidth respectively. The input power (P_0) was 10.73 mW for SLD_1 and 12.79 mW for SLD_2. For comparison purposes, the events localization has also been measured by a commercial OTDR, which has a localization accuracy of 30 m (a pulse duration of 300 ns has been selected in order to get a necessary dynamic range). The experimental results are presented in Tab. 1.

Tab. 1: Comparison of the event localization (z_p) measured by OTDR and the proposed TRA based approach

	z_{p1} [km]	z_{p2} [km]	z_{p3} [km]	z_{p4} [km]	z_{p5} [km]
OTDR	-0.001	1.726	26.44	51.12	56.03
2λ-TRA	0	1.727	26.42	51.13	56.02
Difference	1m	1m	20m	10m	10m

As depicted in Tab.1, the proposed monitoring solution gives very similar results, proving that a good localization accuracy for a long reach fiber system can be obtained. In addition, since our proposed multi-wavelength TRA technique only requires the measurement of power variations, the measurement time can be reduced significantly down to 2~3 seconds per line (several minutes are needed for OTDR). Moreover, the TRA technique uses an un-modulated light source that could make the overall monitoring system simple and low cost.

Conclusion

A dark fiber based monitoring system for Ring–and-Spur LR-PON has been proposed. The capability of localizing different kinds of faults along the feeder ring has been theoretically analyzed and experimentally verified. Compared to OTDR, the proposed nλ BD-TRA system provides better localization functionality for LR-PON monitoring.

Acknowledgements

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