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Environmental Sensing and Localization via SOP Monitoring of IM-DD Optical Data Channels

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Abstract: We propose a low cost implementation of the state-of-polarization monitoring for environmental sensing on terrestrial telecommunication networks’ IM-DD optical signals. Experiment show feasibility of both event’s detection and localization with less than 100 meters accuracy. © 2023 The Author(s)

1. Introduction

Optical fiber are excellent mechanical stress sensors as signal phase and SOP are strongly affected by external strain. Distributed Acoustic Sensing (DAS) and Interferometric-based systems use optical fibers for accurate sensing of environmental events, though requiring expensive and dedicated hardware. Over the years, optical fiber communication networks based on wavelength-division multiplexing (WDM) have become a pervasive infrastructure with thousands of kilometers of fibers deployed. There is thus interest in exploiting such infrastructure as a wide environmental sensing network, as optical data signal already contain environmental information in their state of polarization (SOP) and phase evolution [3]. We propose to employ the SOP monitoring sensing technique [1, 2] on supervisory optical data channel [4] on intensity modulation- direct detection (IM-DD), as they are widely available in terrestrial networks. Thanks to the polarized nature of IM-DD signals, SOP variations can be observed by tapping some power to feed a polarimeter or even a simpler polarization beam splitter (PBS) followed by a pair of photodetectors [5] [6] [7]. In this experiment we prosecute the activity of [5] [6] [7], showing the localization feasibility of external perturbations with an accuracy below 100 meters using SOP monitoring on commercial IM-DD transceivers which simultaneously carry data.

2. Detection and Localization Experiment

The bidirectional setup implemented for the experimental validation of the environmental activity localization is depicted in Fig. 1a. Each node is composed by a commercial WDM card equipped with an IM-DD SFP+ TRX module generating an optical signal at 10 Gbps carrying data, and a commercial ROADM with an embedded EDFA and DWDM filter used as pre-amplifier and 10 Gbps drop node, respectively. A blue/red filter is placed in front of each node, in order to separate the two bidirectional signals. A small portion of the received optical power (-20 dBm) is dropped by means of a 10/90 optical splitter and collected by a commercial polarimeter (Novoptel PM1000) to monitor the Stokes parameters variations, although in [7] we have demonstrated the feasibility

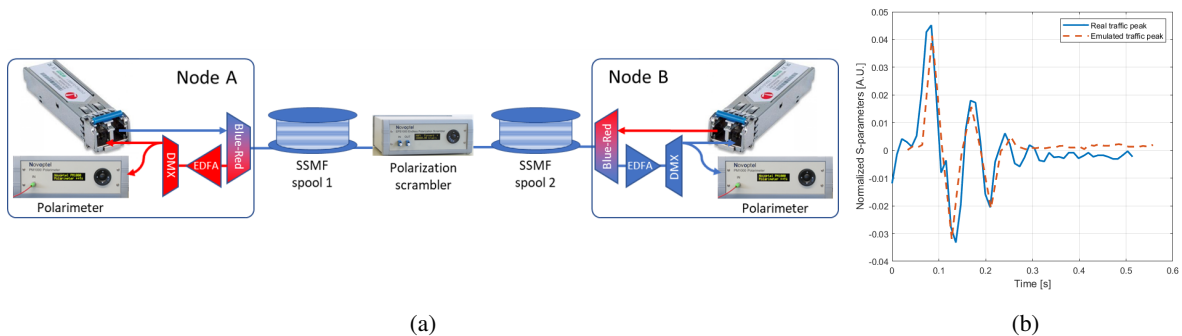


Fig. 1: (a) Experimental setup. On both ends an IMDD TRX and a polarimeter are present, being the opposite flows separated with blue/red filters. DMX: demultiplexer; EDFA: fiber amplifier; Blue-Red: multiplexer/demultiplexer. (b) Comparison of the Stokes parameters evolution generated by the real traffic (blue) and the laboratory polarization scrambler (red).

Test	OTDR Length [km]		SOP Length [km]	
	Spool 1	Spool 2	Spool 1	Spool 2
1	20.006	0.957	19.938	1.025
2	20.006	6.045	20.083	5.968
3	20.006	9.515	19.934	9.587
4	20.006	10.473	20.105	10.374
5	20.006	15.560	20.079	15.487
6	20.006	16.518	20.044	16.480

Table 1: Experimental results: measured spool lengths using the OTDR and the SOP method

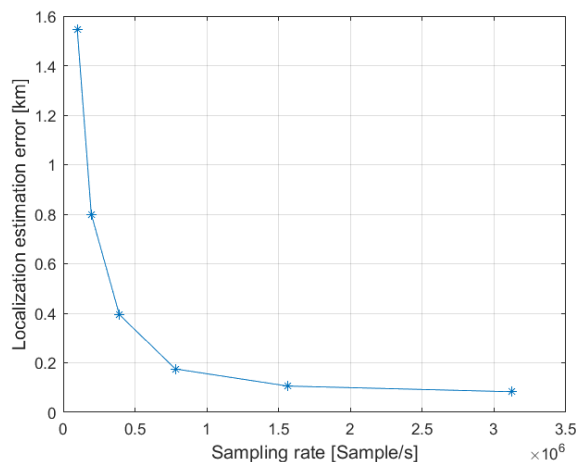


Fig. 2: Localization estimation error as a function of the polarimeter's sampling rate.

with a simpler PBS-based setup. The bidirectional link is composed of two standard single mode fiber (SSMF) spools with a polarization scrambler (Novoptel EPS1000) between them, emulating fast Stokes parameters variations, caused by the local birefringence modulation induced by vibration/pressure produced by the passage of the front and rear car's axle on roadway [6]. The original and emulated IMDD Stokes parameters peak time profile corresponding to this event are reported in Fig. 1b. The difference between the two polarimeters timestamps corresponding to the peak detection is evaluated and translated in spatial difference, by means cross-correlation after proper low-pass filtering of the acquired Stokes parameters to exclude fast variations introduced by the scrambler. The polarimeters are properly connected themselves with a BNC cable in order to share the same time reference during peak detection. The polarimeter sampling rate is set at 3.1 MSample/s is used (320 ns sampling time), corresponding to a spatial resolution of about 64 m. In order to validate the peak localization method, we used different fiber spools. While the first fiber spool length was kept constant, we varied the second spool length to emulate a mechanical stress happening at six different positions in the overall fiber length. Spools are first precisely characterized using an OTDR and their length is then compared to the estimation obtained using SOP technique. Tab. 1 show a great SOP technique estimation accuracy always below 100 meters. We then fixed the spool configuration to the sixth (16 km of 2nd spool) and explored the estimation accuracy varying the polarimeter sampling rate from 0.1 MSamples/s to 3.1 MSamples/s. For each sample rate we have calculated the localization estimation error as the difference between the value obtained with the OTDR and the one obtained with the SOP technique. The results are reported in Fig. 2, showing that it decreases from around 1.5 km at 0.1 MSamples/s to less than 100 m at 3.1 MSamples/s, although it reaches similar low values at 1.0-1.5 MSamples/s. This result suggests that acceptable estimation errors can be obtained with reasonably low cost/complexity ADC circuits and PBS-based circuits (as shown in [7]) in order to replace the expensive polarimeters. From our experiment we found out that the polarization detection equipment requires a time synchronization accuracy of the order of tens of microseconds. Implementation of adequate time synchronization protocols such as the Precision Time Protocol (PTP) or GPS-based timing systems modules, whose accuracy scales down to the sub-microsecond regime, is thus needed.

3. Conclusion

In this paper, we have proposed and demonstrated the possibility to detect and localize environmental events on existing optical networks for telecommunications by means of SOP monitoring technique of bidirectional data signal generated by commercial IM-DD transceivers widely available in metro and access terrestrial network segments. The proposed solution can be scaled down to low cost implementation replacing polarimeters with PBS and adequate time synchronization protocols.

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