POLITECNICO DI TORINO
Repository ISTITUZIONALE

Experimental Demonstration of Vibration Sensing and Positioning on Multiple Metropolitan Fibers

Original
Experimental Demonstration of Vibration Sensing and Positioning on Multiple Metropolitan Fibers / Pellegrini, Saverio; Gaudino, Roberto; Crognale, Claudio. - ELETTRONICO. - (2023), pp. 1-2. (Intervento presentato al convegno 2023 IEEE Photonics Society Summer Topicals Meeting Series (SUM) tenutosi a Sicily, Italy nel 17-19 July 2023) [10.1109/SUM57928.2023.10224504].

Availability:
This version is available at: 11583/2981379 since: 2023-08-29T15:20:23Z

Publisher:
IEEE

Published
DOI:10.1109/SUM57928.2023.10224504

Terms of use:

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

Publisher copyright
IEEE postprint/Author's Accepted Manuscript

©2023 IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other uses, in any current or future media, including reprinting/republishing this material for advertising or promotional purposes, creating new collecting works, for resale or lists, or reuse of any copyrighted component of this work in other works.

(Article begins on next page)

21 September 2024

Experimental Demonstration of Vibration Sensing and Positioning on Multiple Metropolitan Fibers

1st Saverio Pellegrini
Dipart. di Elettronica e Telecomunicazioni
Politecnico di Torino, Torino, Italy
saverio.pellegrini@polito.it

2nd Roberto Gaudino
Dipart. di Elettronica e Telecomunicazioni
Politecnico di Torino, Torino, Italy
roberto.gaudino@polito.it

3rd Claudio Crognale
CISCO Photonics
Vimercate, Italy
ccrognal@cisco.com

***Abstract*—We investigate on simultaneous polarization sensing on multiple fibers to detect and time-position anomalous vibration events. We experimentally demonstrate that our "threshold and cross-correlate" algorithm obtains timing with 40 ms rms accuracy when tested on deployed fibers (35km and 10km) in Turin urban area.**

***Index Terms*—Optical fiber sensing; optical polarization.**

I. Introduction

In recent years, many research groups worked on the idea of using installed telecom fibers for sensing applications, particularly on undersea optical links [1], [2]. This general idea is anyway interesting also on terrestrial optical networks where fiber mechanical vibrations sensing can be very relevant for anomalous "man-generated" events early warning, such as cable cuts or fiber tampering, particularly in urban areas. Traditional fiber sensing solutions, such as distributed acoustic sensors (DAS), are quite expensive and they should be properly engineered to run in parallel to an already deployed DWDM transmission. A much more economical option that has recently been discussed is to sense mechanical vibrations by measuring time variations on received state of polarization (SOP) in PM-QAM coherent trasmission systems through the DSP algorithms that are implemented in standard coherent receivers. This approach is particularly attractive since it only requires a proper firmware added to the receiver DSP that would allow to extract the SOP time-signal, at rate in the 100-1000 Hz range (thus much smaller than the PM-QAM baud rate). In this paper, we elaborate on SOP sensing focusing on the following innovative research aspects:

- Automated processing of the informations to be delivered, for instance, to optical network higher layer controllers;
- Reduction of the enormous amount of data that a continuous time-domain monitoring would generate;
- Approximated localization informations indirectly gained through the different positioning in time of the SOP variations on multiple fibers;

In particular, in this paper we experimentally measure the time-domain SOP evolution in two different metropolitan fibers (35 km and 10 km SMFs) deployed along two different cable ducts running in the city of Turin, Italy, and terminated in our labs. To emulate anomalous vibrational events hitting the two fibers, we use a commercial mechanical shaker driven

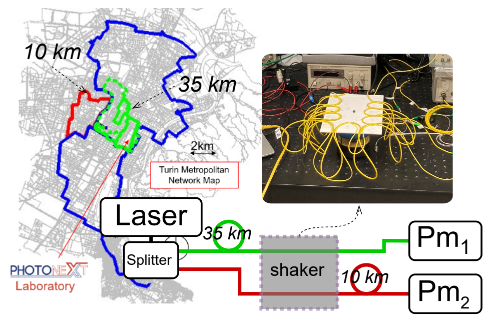

Fig. 1. Experimental setup scheme and map of the two deployed metropolitan fibers used for the experiments, in green (35 km) and red (10 km). At the fiber output, two polarimeters (Pm_1 and Pm_2) were used to retrieve the SOP samples. A picture of the fibers glued on the shaker is also reported.

by a low-frequency arbitrary waveform generator (AWG). We envision a post-processing algorithm that receives data from several coherent receivers able to evaluate the received signal state of polarization (SOP) evolution over a common time-reference (through the available common time-stamps), and can detect and possibly locate in time an anomalous vibration. Using triangulation algorithms, time positioning could in principle lead to events geographical positioning.

II. Proposed post-processing algorithm and experimental validation

Our experiments were carried out on the setup shown in Fig. 1, inducing vibrations on two metropolitan fibers (35 km and 10 km deployed in Turin urban area, Italy) by means of a mechanical shaker, placed right before the shortest metro span and after the longest one. The shaker was driven by an AWG generating Gaussian noise with 40 Hz bandwidth, with 30 s duration then repeated every 90 s. Two polarimeters (Pm_1, Pm_2) sampling at 95.4 Hz were used to retrieve SOP samples. Our focus was on studying a simple but effective processing of the SOP traces at the output of each fiber. The algorithm we propose works as follows:

1) The SOP angular speed (SOPAS, in [rad/s]) between two consecutive acquired SOP samples is evaluated. We will refer to it as $\omega(t_i)$, where t_i is the discretized time index. Since we are monitoring two different conditions, we will refer as "fiber quiet state" the condition when no shaking happens, with SOPAS mean value $\bar{\omega}_{quiet}$. The "event" state is instead the few seconds vibration

we induced on the fibers, with angular speed mean value $\bar{\omega}_{event}$.

2) A potential event is monitored by the condition $\omega(t_i) > \omega_{th}$, where ω_{th} is an heuristically chosen threshold. When this condition arises, we record the following samples on all fibers for a time window T_{warn}, together with its time-stamps. In a future real network system, a warning flag should be sent by a proper telemetry system to a central control unit (CCU), together with the stored samples. Figure 2a) shows recorded SOPAS traces $\omega(t_i)$ of the two fibers, over which we applied a moving average, in both “quiet” and “event” states. The histogram of the 35 km fiber SOPAS evolution is in Fig. 2b) and highlights the difference between $\bar{\omega}_{event}$ and $\bar{\omega}_{quiet}$, facilitating the selection of some working thresholds: in this case we chose $\omega_{th} = 2 \cdot \bar{\omega}_{quiet}$, so approximately 0.2 rad/s, to test the response of the algorithm to false alarms (FA).
3) If the CCU receives warning flags from more than one monitored fiber inside a properly selected time interval, we use it as an indication that an anomalous event has very likely occurred. The time cross-correlation (CC) between the two (or more) received SOPAS evolution is then evaluated. An example of some computed CC functions ($R(\tau)$) is in Figure 3b).
4) The time-positioning of the CC maximum peak, referred to common time-stamps, gives an indication of when the same mechanical vibration, after having propagated through the ground, hits the two (or more) fibers, which would perceive the vibration with a reltive delay τ.

We believe that the proposed algorithm could be effective to reduce the amount of stored data to be sent to a CCU, and moreover, to estimate the time delay between the sensing of the same event, perceived by different fibers. False alarms probability could also be reduced, since the warning flag should be triggered only when more than one fiber senses an event. In fact, results in Fig. 2a) show that the condition $\omega(t_i) > \omega_{th}$ happens several times for the green curve, but T_{warn} only triggers, according to our proposed algorithm, when the shaker induced events happen on both fibers. This confirms the correct operation of our algorithm, able to filter out everything that is not happening on both fibers, and thus reducing FA probability. For what concerns time delay estimation, CC is computed on the same T_{warn} of Fig. 2a), considering a margin of 4 seconds before and after its bounds. Since in our setup the vibration is simultaneously applied to both fibers, we expected a correlation peak centered around 0 seconds for all the events. We thus acquired $\omega(t_i)$ for several hours in different times of the day, always alternating quiet states with vibrations, recording around 600 hundred events. The estimate of the different τ for all the set is shown as histogram in Fig. 3a). These results show good accuracy in measuring the relative delay between the same vibrational event sensed by the two metro fibers, with standard deviation (rms) equal to 39.58 ms, which is of the same order of magnitude of a few SOP sampling

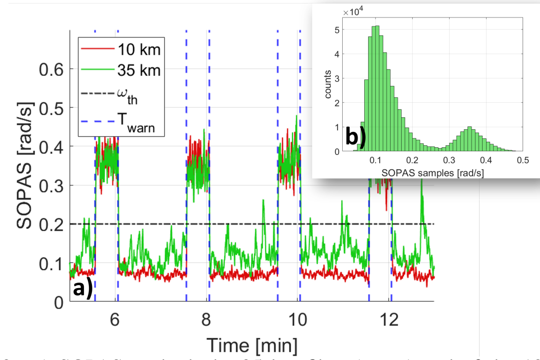

Fig. 2. a) SOPAS on both the 35 km fiber (green) and of the 10 km (red) one, in 8 minutes of acquisition, with T_{warn} window (blue) and ω_{th} (black), b) histogram of the 35 km fiber SOPAS, over about 2 hours.

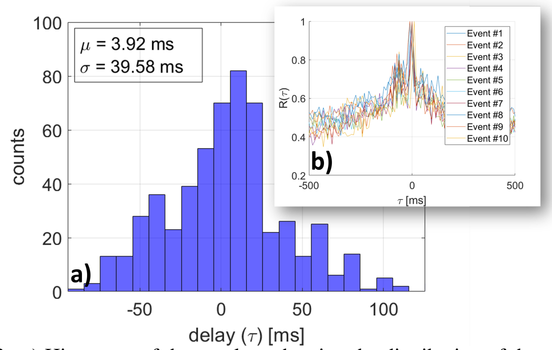

Fig. 3. a) Histogram of the τ values showing the distribution of the measured delays between the same event occurring on simultaneously on both fibers, b) Examples of CC functions for 10 events.

times (approx. 10 ms in our experiments). This result provides information on the accuracy in estimating time delays which, using triangulation techniques, can then give indications on vibrations geographical positioning. In fact, propagation speed for mechanical vibrations is in the order of 1 km/s (with large variations depending on the soil structure), and thus our time-positioning accuracy in the $\pm$100ms peak-to-peak range may lead to about 100 meter positioning accuracy.

III. Conclusions

We presented a preliminary but effective algorithm to detect (with low FA probability) and time-position (with about 40 ms rms accuracy) anomalous vibration hitting deployed metropolitan fibers in the city of Turin. We are currently researching on more sophisticated processing algorithms, applying them to even longer SOP acquisitions.

Acknowledgments*: this work was carried out in the PhotoNext Center facilities at Politecnico di Torino (www.photonext.polito.it) under a research contract with Cisco Photonics. This work was partially supported by the European Union under the Italian National Recovery and Resilience Plan (NRRP) of NextGenerationEU, partnership on “Telecommunications of the Future” (PE00000001 - program “RESTART”).*

References

[1] G. Marra, C. Clivati, R. Luckett, A. Tampellini, J. Kronjäger, L. Wright, A. Mura, F. Levi, S. Robinson, A. Xuereb, B. Baptie, and D. Calonico, “Ultrastable laser interferometry for earthquake detection with terrestrial and submarine cables,” *Science*, vol. 361, no. 6401, pp. 486–490, 2018.

[2] A. Mecozzi, M. Cantono, G. C. Castellanos, V. Kamalov, R. Muller, and Z. Zhan, “Polarization sensing using submarine optical cables,” *Optica*, vol. 8, no. 6, pp. 788–795, June 2021.