# DISTRIBUTED SENSING AS A NEW TOOL FOR FIBRE INFRASTRUCTURE PROTECTION

M.Sc. Munster P. PhD.[1,2], M.Sc. Horvath T. PhD.[1,2], M.Sc., M.Sc. Vojtech J. Ph.D.[1]
Department of optical networks – CESNET, the Czech Republic [1]
Faculty of Electrical Engineering – Brno University of Technology, the Czech Republic [2]

munster@cesnet.cz

**Abstract:** *Distributed fibre optic sensing is well known in defence or oil industry in use as acoustic sensing. Telecommunication networks are threatened by fibre cuts mainly caused by digging activity or theft. Many network operators seeking appropriate solution for self-protecting infrastructure system. Most commercially available solutions of distributed sensing systems allow sensing only on dedicated fibres. Sharing the same infrastructure for data transmission and sensing is, however, more advantageous. On the other hand, it is necessary to solve the possible interaction of both services and thus the interference. We have developed our own sensing systems and we have made several measurements to evaluate the suitability of the most widely used distributed sensing techniques - interferometric, reflectometry and polarization for using in existing data infrastructures on optical fibres with active data traffic.*

**Keywords**: DISTRIBUTED SENSING, FIBRE INFRASTRUCTURE PTROTECTION, INTERFEROMETRY, POLARIZATION, REFLECTOMETRY, NREN

## *1. Introduction*

Fibre optic infrastructure is essential for all data transmissions because optical fibre is only medium which can satisfy requirements for large bandwidth, high speed, low insertion loss, low cost, and which allows signal multiplexing. Fibre optic infrastructure may be threatened by digging activity which causes an interruption of a signal transmission and also additional costs. Protection of fibre infrastructure may save not only costs but also time necessary for repairs and increase quality of the network, on the other hand.

National research and education networks (NREN) like CESNET (Czech National Research and Education Network) transfer except standard data also non-data services such as precise time or stable frequency. Distributed sensing is a new and highly demanded service which enables secure of fibre infrastructure itself on one hand, and for example, monitoring of seismic activity, train positions, or aircraft landings, on the other hand.

Structure of this paper is follows. Section 1 provides an introduction. Section 2 shortly describes basics of distributed sensing systems. In Section 3 we present some measurement results and Section 4 concludes the paper.

## *2. Distributed sensing*

Distributed fibre optic sensing is known for a long time, but rapidly decreasing costs of main components increase their availability. The paper describes the most used techniques and compare their sensitivity and suitability for use in fibre infrastructure protection.

***Fibre-optic interferometers***

The light interference is used in many fields of industry for a precision measurement. For acoustic or mechanical vibrations detection mainly two basic configurations are being used – the Mach-Zehnder and the Michelson interferometers. Both configurations mostly use two optical fibres – one is a reference arm and second one is a sensing arm. Except high sensitivity their big advantage is very fast response and possible multiplexing thanks to use of narrow linewidth lasers and relatively low output power. On the other hand, localization of event is complicated and mostly combination of two techniques is necessary which is also associated with the requirement for a special demultiplexing [1].

Main application of interferometers is perimeter securing thanks to the costs of these systems.

***Polarization based sensing***

Special group of interferometers are polarization interferometers. Standard single mode fibre supports two degenerate modes of orthogonal polarizations. The polarization state of light in a single-mode optical fibre is very similar to that of a plane light wave in free space. It could be linear, circular, or elliptical. Whereas the polarization state is influenced by temperature or strain we can evaluate the polarization changes and based on this we can obtain information about an event [2].

Sensitivity of polarization interferometers is not so high compare to standard dual path interferometers mentioned above however the lower sensitivity can be advantage in use for fibre infrastructure protection because standard telecommunication fibres are always terminated in central offices where are many sources of vibrations resulting in noise.

***Phase sensitive OTDR***

Optical time-domain reflectometry (OTDR) is being widely used in telecommunications for detection faults in fibre optic networks. Since laser linewidth is relatively broad (GHz to THz) it is not possible to detect local changes caused by temperature or acoustic vibrations. Using an ultra-narrow linewidth laser enables detection of refractive index changes in the optical fibre caused by external events. These systems are knowns as φ-OTDR or DAS (Distributed Acoustic Sensing) and are mainly use for pipeline security or long perimeter intrusion detection. Ing. Fig. 1 is photo of our own developed system.

***Fig. 1*** *CESNET modular phase OTDR.*

## *3. Measurement results*

In this part we present some measurement results from distributed sensing systems. First, interferometry-based sensing system is evaluated. Fig. 2 shows measurement when walking around the cable lying on the floor in our laboratory. Total length was about 10 km.

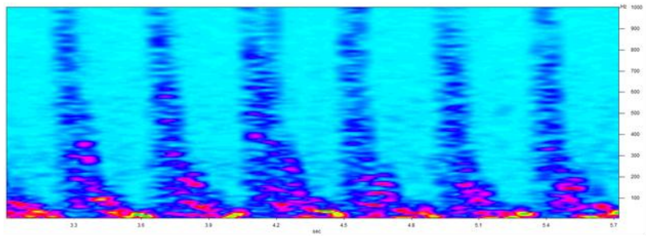

*Fig. 2* *Interferometry system. Calculated spectrograph, walking.*

The response of the system was good and detected very small events. However, there were no other sources of noise which can influence the measurement. The second measurement was made in a real network on fibres leading across the Brno city. The signal was noisy but still strong events like for example touching the fibre caused strong response of the system. Fig. 3 shows spectrograph of the received signal when knocking the cable.

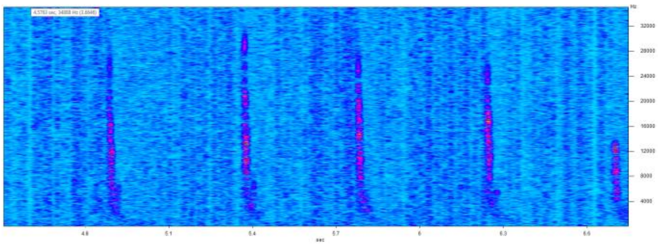

*Fig. 3* *Interferometry system. Calculated spectrograph, knocking the cable.*

In case of polarization sensitivity of the system was lower. In Fig. 4 is depicted Poincar sphere and state of polarization change caused by shaking the fibre in laboratory conditions. Although the response of the system seems to be high enough it is necessary to realize that it is really a shaking with a cable. Response of the system on vibrations near the cable is show on Fig. 5. [3]

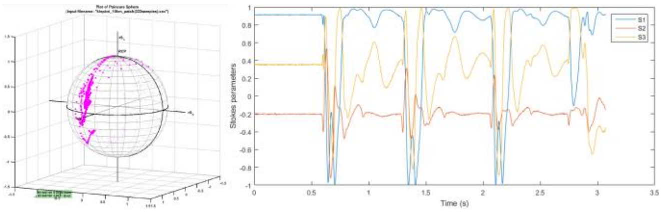

*Fig. 4* *SOP change caused by shaking the fibre. L: the Poincar sphere, R: Stokes parameters.*

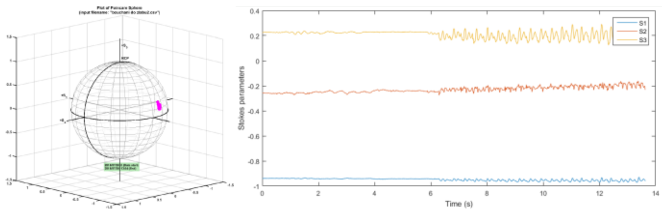

*Fig. 5* *SOP change caused by shaking the fibre. L: the Poincar sphere, R: Stokes parameters.*

We also tried to compare sensitivity of both systems mentioned above. In experimental measurement described in [1] the same conditions were applied. Both systems measured correctly the set frequency 1025 Hz, but power levels were different, as can be seen in Fig. 6. While intensity for interferometry-based system was −28 dB in case of polarization system the peak was about 55 dB lower, about −83 dB.

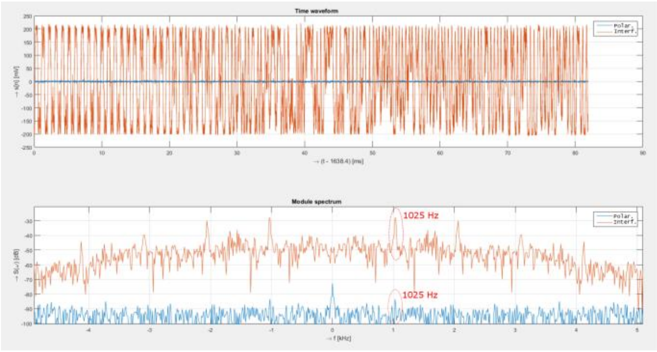


*Fig. 6* *Received signals from both sensing systems (interferometer – red signal, polarization – blue signal) and their spectra (below) for 1025 Hz.*

The last system is a phase sensitive OTDR and it is the most complex setup with a very difficult signal post-processing. Moreover, since the back-reflected signal is very weak it is necessary generate high power pulses which can influence other signals in the fibre if WDM is applied. On the other hand, the system enables single-end measurement with precise localization of event. Fig. 7 shows waterfall plot from the fibre where the detected event is located at 61 km from the beginning.

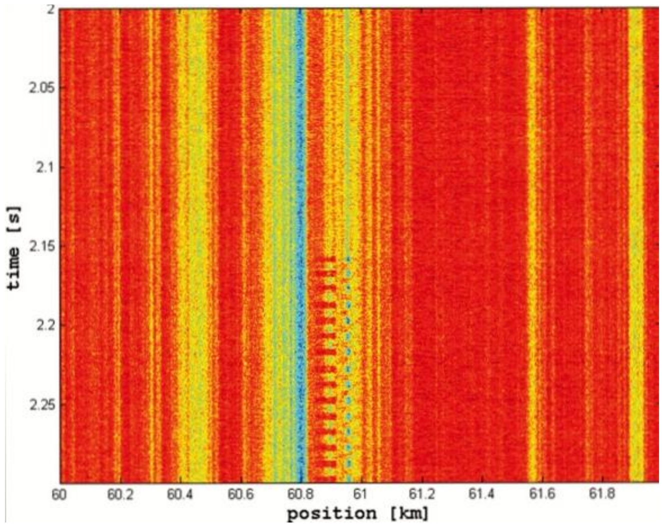


*Fig. 7* *Waterfall plot from phase sensitive OTDR.*

Table 1 lists basic comparison of distributed sensing systems. For all systems only, basic configuration is considered to allow for a suitable comparison [4].

***Table 1:*** *Comparison of distributed sensing systems.*

| | **Phase sensitive OTDR** | **Polarization based sensing** | **Interferometers** |
|---|---|---|---|
| **Sensitivity** | ++ | + | +++ |
| **Number of required fibres** | 1 | 1 | 2 |
| **Single-ended measurement** | Yes | No (passive mirror at least) | No (passive mirrors at least) |
| **Measurement range** | Tens of km | Tens of km | Tens of km |
| **Localization of event** | Yes | No (in basic configuration) | No (in basic configuration) |
| **Price** | High | Low | Moderate |

| | |
|---|---|
| **Special requirements** | Elimination of reflections in optical route, channel spacing >200 GHz away from data. |

## *Conclusion*

We presented description and comparison of interferometric, polarization and reflectometry sensing systems in both, laboratory and real conditions. Interferometry-based system has great sensitivity however in the real network the received signal is very noisy, and it is very difficult to extract useful information. Polarization system sensitivity is lower and detects only mechanical vibrations however the signal is not so noisy and hence the post-processing is easier. The best results can be obtained using phase sensitive OTDR. Compare to previous systems enables also localization. Unfortunately, because of its complex setup, complicated post-processing and high costs this system is unusable for fibre infrastructure protection.

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