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Introduction

Application Requiring Photonic Services

Detection of Fibre Infrastructure Threats
- Outages
- Interferometric and Polarisation Based Methods
- Phase Sensitive OTDR
- Parallel Operation

Conclusion and Acknowledgement
INTRODUCTION
Czech Education and Scientific NETwork

Established in 1996 as Association of Legal Entities, non-profit organisation

26 Universities (24 public and 2 state) and Academy of Sciences (54 research institutes)

NREN – National Research and Educational Network. Other NERNs e.g.: GARR, ACONet, DFN, JISC, NORDUnet, PSNC, SURFnet, RENATER, SWITCH,

e-Infrastructure provider in the Czech Republic for science and research
- Part of GÉANT project
- GN4-2 and GN4-3
- Based on 5890 km of dark fibre lines / 78 867 km²
- Italy 13 000 km / 301 338 km²
- Mixed IM-DD 10G and coherent DP-QPSK 100G
- Tested 32 Gbaud 200G @ 50 GHz
2017 – field trial of 64 GBaud system together with Ciena and GÉANT, 200/300/400 Gbit/s @ 60 GHz

300G Prague – Vienna, all optical transmission over 513 km/134 dB, five spans, CD compensated

Crossborder triangle - cooperation among ACONet, CESNET and SANET
- Over 1470 km of single fibre lines with bidirectional transmission

- Two DWDM systems:
  1510 km Cisco ONS 15454 MSTP
  3840 km Open line system Czech Light
High speeds (400Gbps or 1.2Tbps) cannot solve all challenges

Low and stable latency is important

Remote interactive cooperation (conferences, remote controll, art) - 3D, 4K

Photonic service Prague Vienna 500 km 3 ms

IP Service Prague London 1000 km 30 ms
Modification: to C and L systems the bidirectional system is added.

Such path is necessary for increased stability.

- Ultra-stable optical frequency dissemination
- 25 Apr 2016 – 4.1 degree, epicentre located 20 km SW from Vienna

- Ultra-stable optical frequency dissemination
- 3rd party equipment – 1540.56 nm, <100 Hz linewidth laser stabilized using saturated absorption in $^{13}$C$_2$H$_2$
- Rel. line stability $10^{-14}$ uncompensated, $10^{-18}$ compensated at 10 000 s averaging
DETECTION OF FIBRE INFRASTRUCTURE THREATS
Metro networks experience 13 cuts annually for every 1000 miles of fibre.

The most common causes of fibre cuts – digging activities (58%).

How can that be done?

Most fibre cuts: machinery within constructions/thefts.

Heavy machines digging near a fibre shakes a cable before breaking it.

Active monitoring of vibrations near a fibre cable.

 Mostly based on evaluation of phase/polarization/backscatter of light.

In combination with SDN and NetOS allows to reduce outage times.

Multiple works put vibrations as predecessor of breakage, e.g.:

Vibration sensing methods using fibre/fibres, basic setups

Requirement: Without installation works along fibres

<table>
<thead>
<tr>
<th></th>
<th>Phase sensitive OTDR</th>
<th>Polarization based sensing</th>
<th>Interferometers</th>
</tr>
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<tbody>
<tr>
<td>Sensitivity</td>
<td>++</td>
<td>+</td>
<td>+++</td>
</tr>
<tr>
<td>Number of required fibers</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Single-ended measurement</td>
<td>Yes</td>
<td>No (passive mirror at least)</td>
<td>No (passive mirrors at least)</td>
</tr>
<tr>
<td>Measurement range</td>
<td>Tens of kilometers</td>
<td>Tens of kilometers</td>
<td>Tens of kilometers</td>
</tr>
<tr>
<td>Localization of event</td>
<td>Yes</td>
<td>No (in basic configuration)</td>
<td>No (in basec configuration)</td>
</tr>
<tr>
<td>Price</td>
<td>High</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>Special requirements</td>
<td>Elimination of reflections in optical route, channel spacing &gt;200 GHz away from data.</td>
<td></td>
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</tbody>
</table>
SENGING METHODS USING FIBRES

Lab comparison of polarisation and interferometric methods (Michelson)

10km of G652.D fibre on spool
Artificial vibrations generated by speakerphone

Polarisation method in the field

City line 13km of G652 fibre

SOP change caused by mechanical vibration near the cable. L: the Poincare sphere, R: Stokes parameters.

SOP change caused by shaking the cable. L: the Poincare sphere, R: Stokes parameters.
Interferometric method in the field

City line 13km of G652 fibre

Michelson interferometer, knocking on duct Response in time and corresponding spectra (below).
Sensitivity of interferometric method
Polarisation and interferometric method comparison

Interferometric system has great sensitivity, however in the real network the received signal is very noisy, and it requires a lot of effort to extract useful information.

Polarisation system sensitivity is lower and detects only mechanical vibrations of the fibre however the signal is not so noisy and hence the post-processing is easier.
### Phase sensitive OTDR
- For acoustic/mechanical vibrations detection own back-scatter based fibre-optic sensors based on the Rayleigh scattering
- Ultra narrow spectral width stable laser source and high-power signal

Rayleigh back-scatter signal is about 60 dB lower compared to the input – high-power optical input signal is necessary.
Backscatter is measured while pulse propagates.

Based on signal intensity change, localisation of event is possible in order of tens of meters.
SENSING METHODS USING FIBRES

Phase sensitive OTDR

Sawing

Hammer strokes in distance of about 12 km
For long distances sharing of fibre is highly desirable (100 km single fibre rental ~ 40 kEUR annually [1])

Intensive verification of parallel operation with coherent data and also precise time and ultra stable optical frequency

All in one: time, phase sensitive OTDR, 100G DP-QPSK data, optical frequency [2]

[1] Sima S. et al., Deliverable D3.2v3-Economic analysis, dark fibre usage cost model and model of operations, Porta Optica project
[2] T. Horvath et al., “Simultaneous transmission of accurate time, stable frequency, data, and sensor system over one fibre with ITU 100GHz grid” Optical Fibre Technology, 2018
Parallel operation of phase sensitive OTDR with coherent data

[1] T. Horvath et al., “Simultaneous transmission of accurate time, stable frequency, data, and sensor system over one fibre with ITU 100GHz grid” Optical Fibre Technology, 2018
CONCLUSION AND ACKNOWLEDGEMENT
Down time is expensive - built-in OTDR functionality allows limiting it by remote fault location.

Built-in OTDR is becoming standard part of DWDM transmission systems.

However, much more effective way would be to locate the potential place of fault in advance, and to try avoiding it.

The sensing features built into DWDM are expected soon.

Additional usage:
- Early warning systems
- Transportation
- Monitoring of infrastructures
- ...

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Thank You Very Much for Kind Attention

QaA

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Demo available: Telecom Infra project summit

October 16 and 17, London, UK