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PROACTIVE PROTECTION OF DWDM INFRASTRUCTURES

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OUTLINE

- Introduction
- Application Requiring Photonic Services
- Detection of Fibre Infrastructure Threats
  - Outages
  - Interferometric and Polarisation Based Methods
  - Phase Sensitive OTDR
  - Parallel Operation
- Conclusion and Acknowledgement

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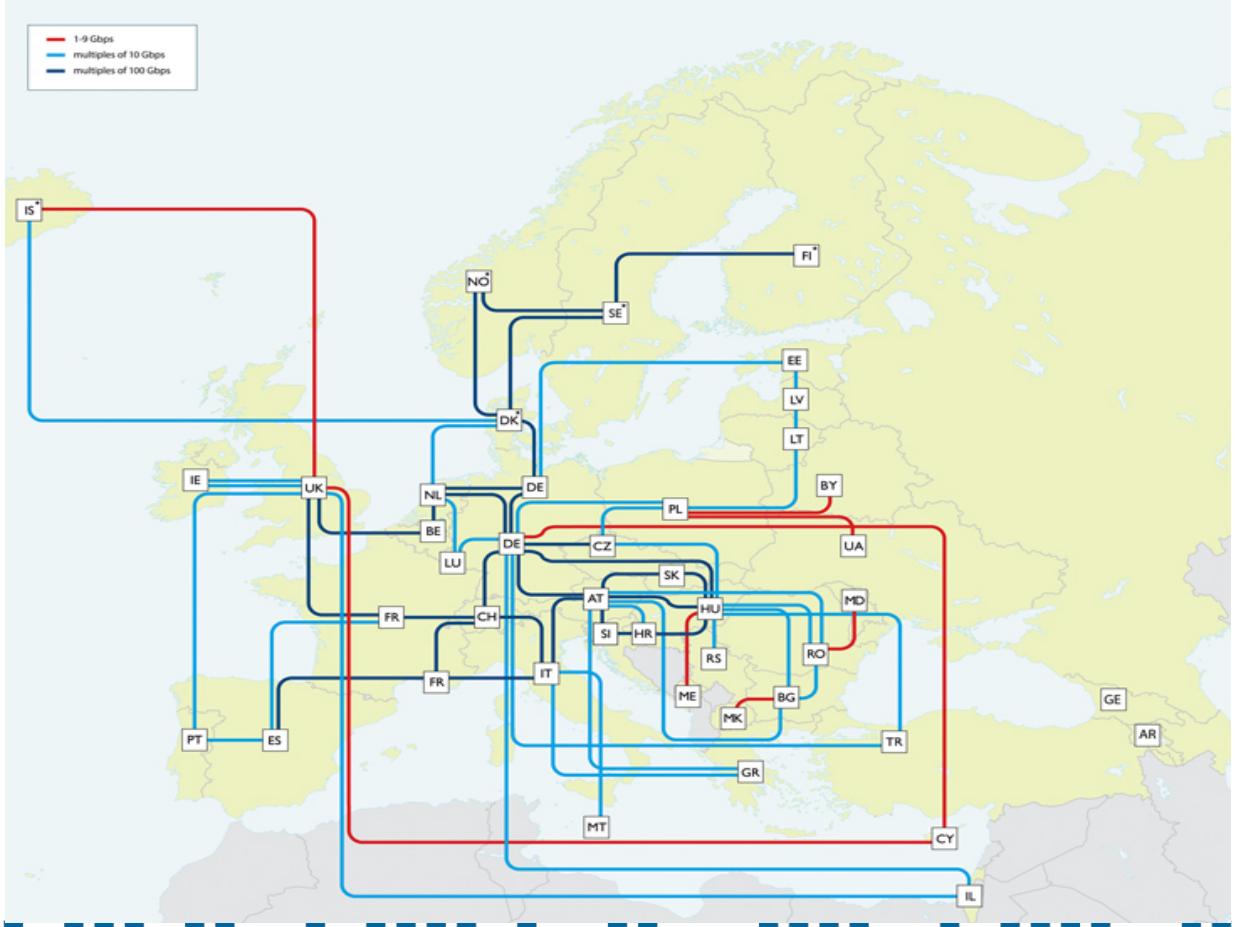
INTRODUCTION

CESNET

- 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

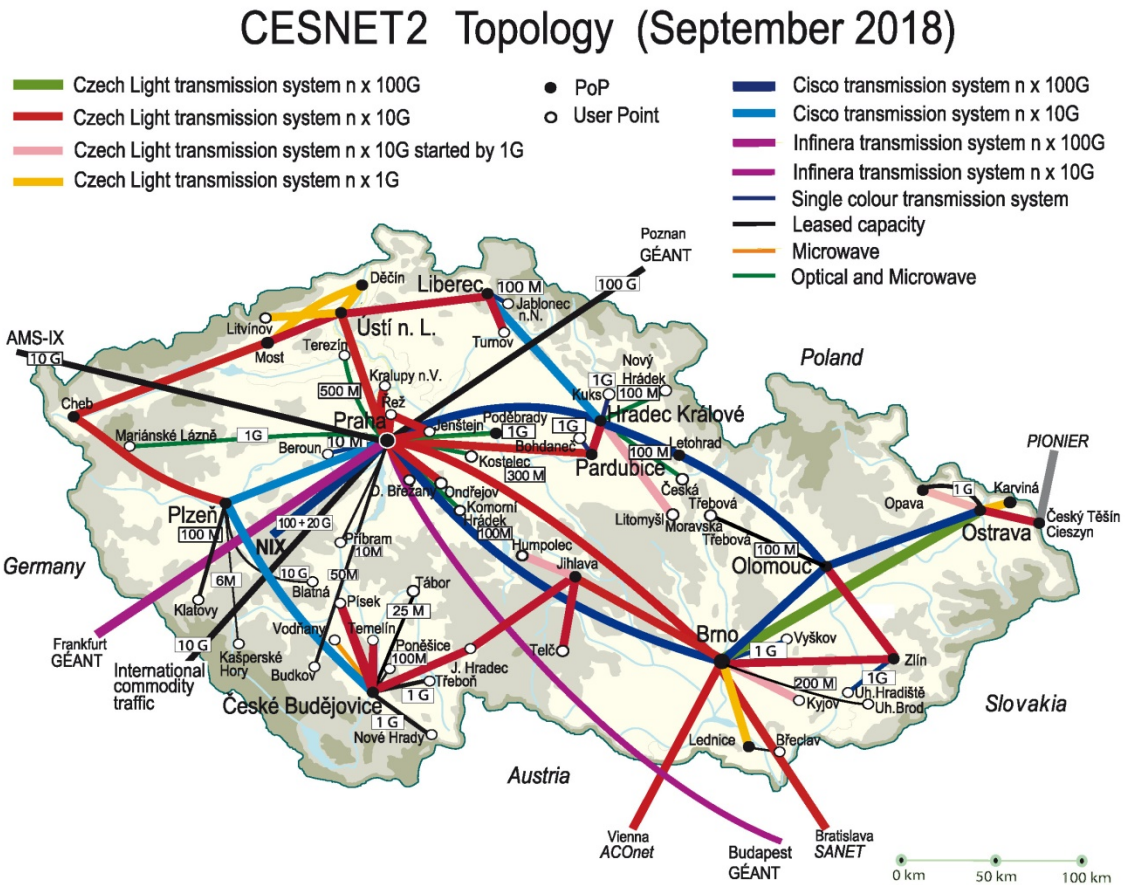
GÉANT

- Part of GÉANT project
- GN4-2 and GN4-3



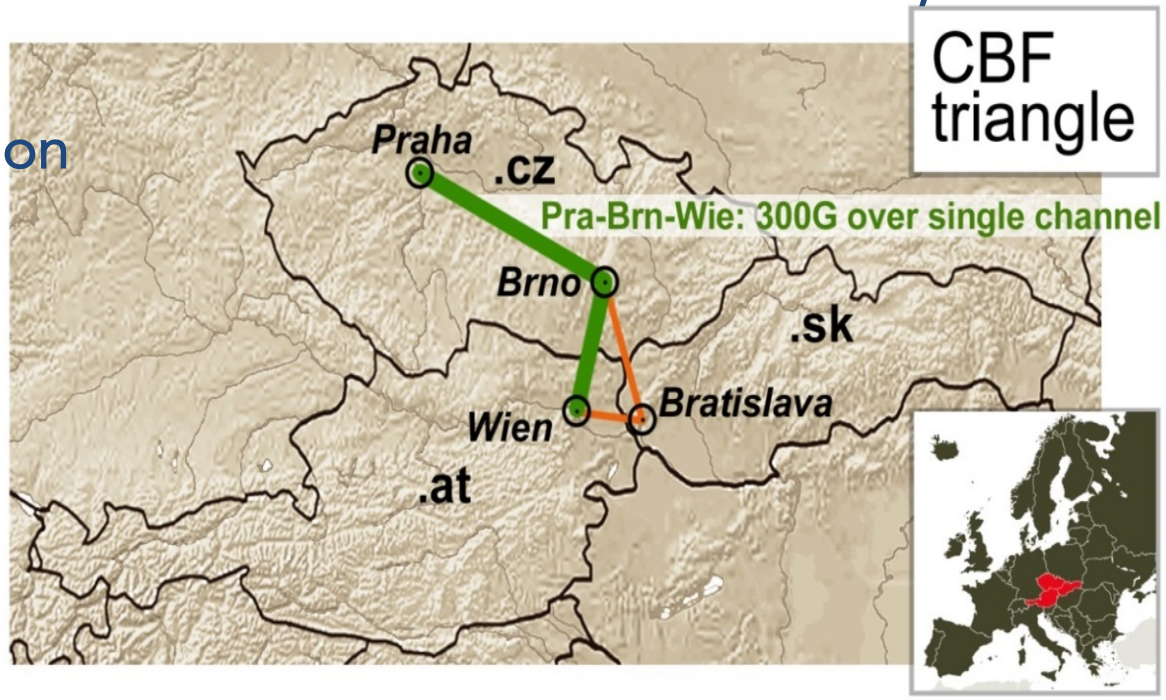
CESNET2 Network

- 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



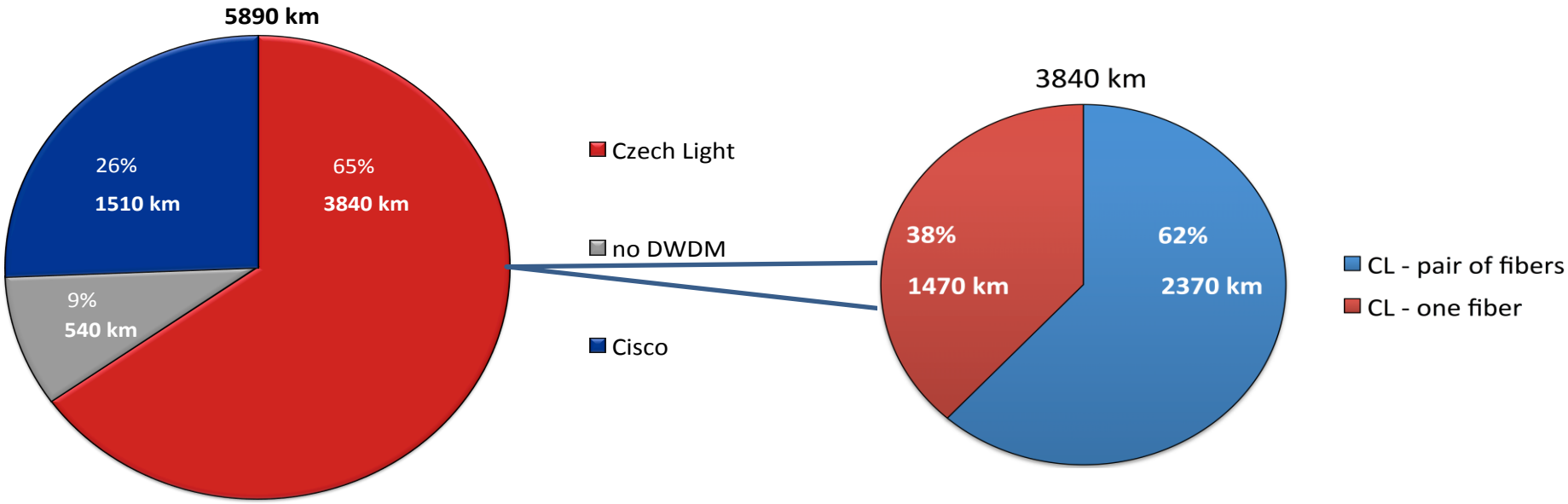
400G Field Trial

- 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



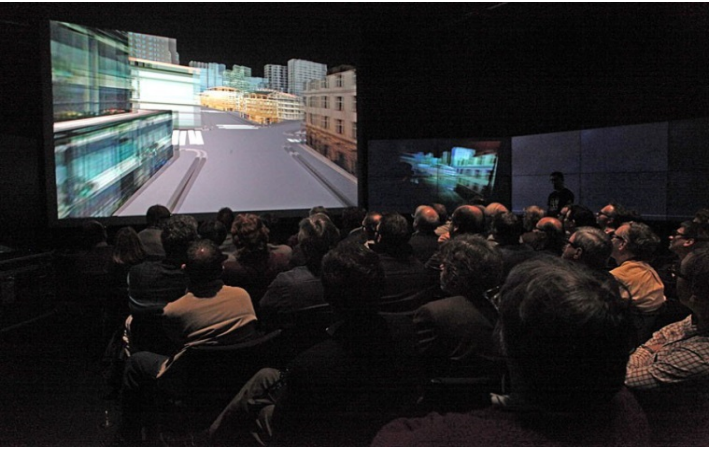
CESNET2 Network

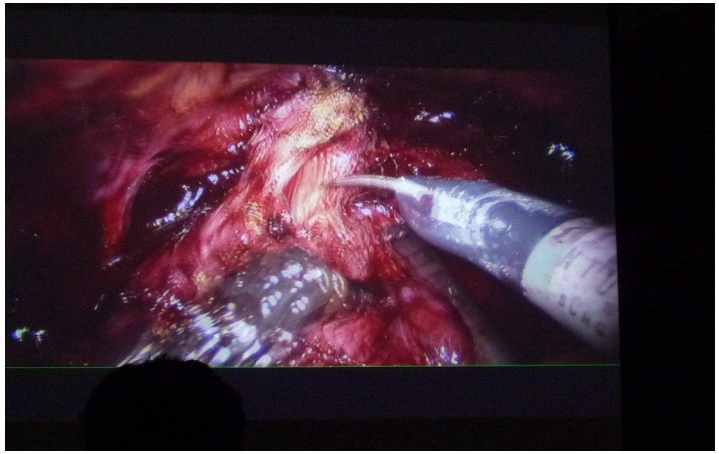
- Over 1470 km of single fibre lines with bidirectional transmission
- Two DWDM systems:
  1510 km Cisco ONS 15454 MSTP
  3840 km Open line system Czech Light



Photonic Services

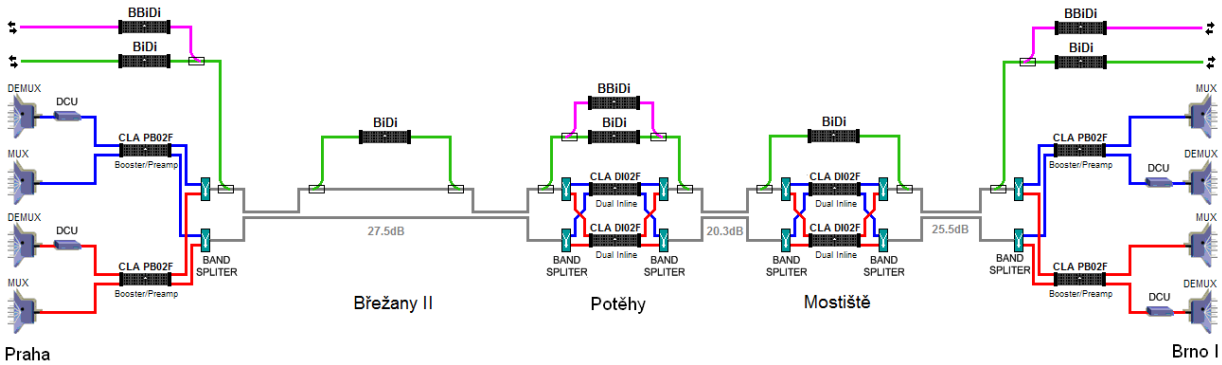
- High speeds (400Gbps or 1.2Tbps) cannot solve all challenges
- Low and stable latency is important
- Remote interactive cooperation (conferences, remote controll, art) - 3D, 4K
- Photonic service Prague Vienna 500 km3 ms
- IP Service Prague London 1000 km 30 ms

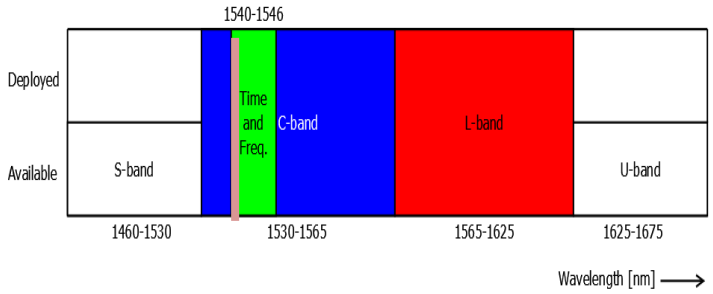


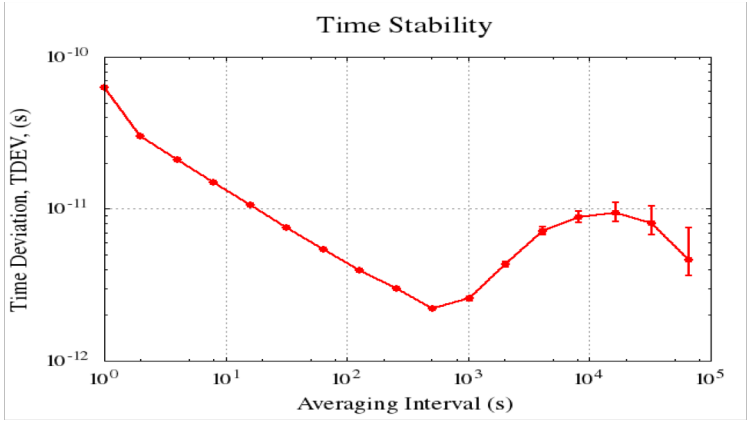


Photonic Services

- Modification: to C and L systems the bidirectional system is added
- Such path is necessary for increased stability



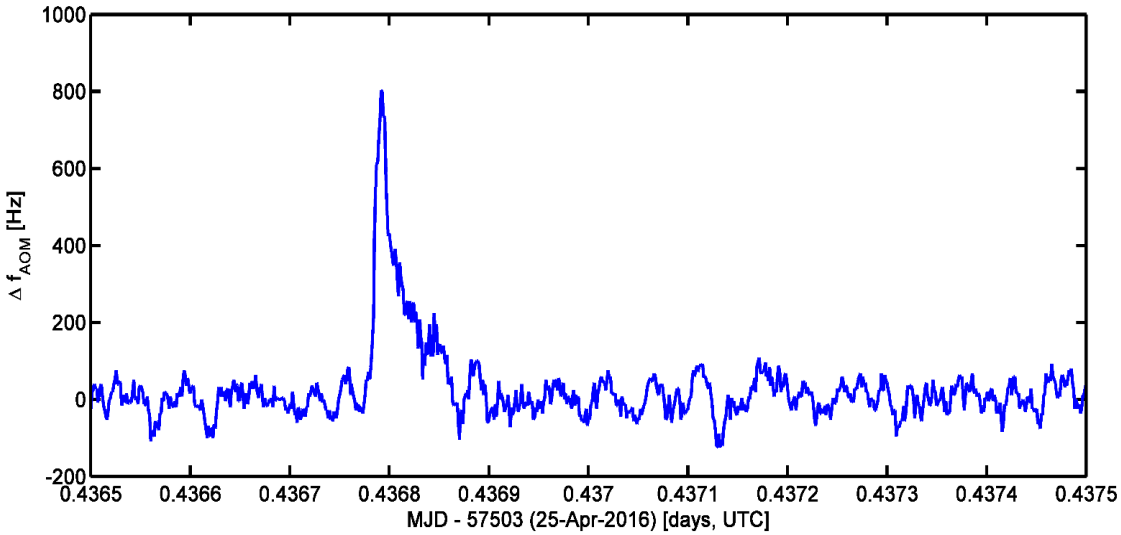


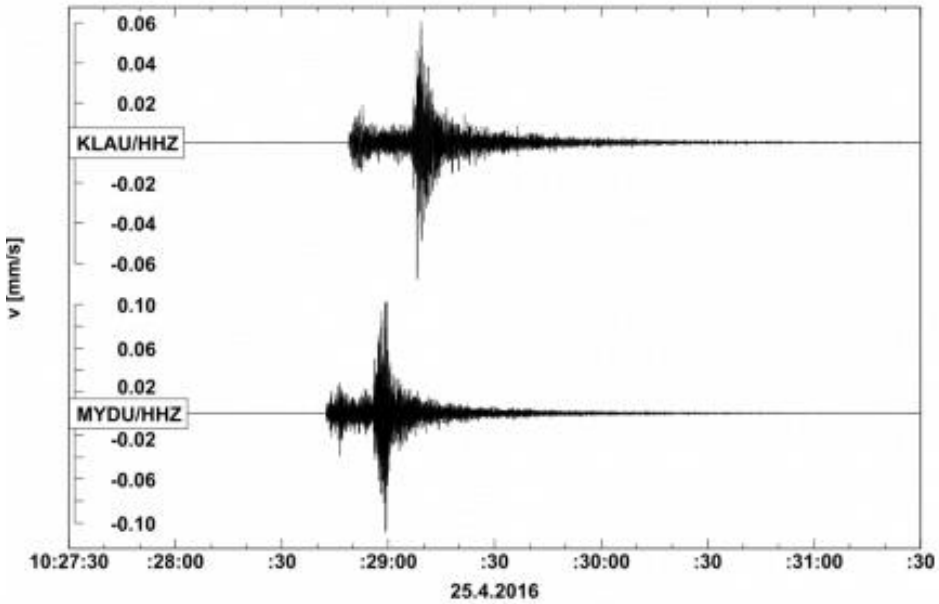


J. Vojtech et al., “Joint accurate time and stable frequency distribution infrastructure sharing fiber footprint with research network,” Opt. Eng., vol. 56, no. 2, p. 27101, Feb. 2017.

Photonic Services

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

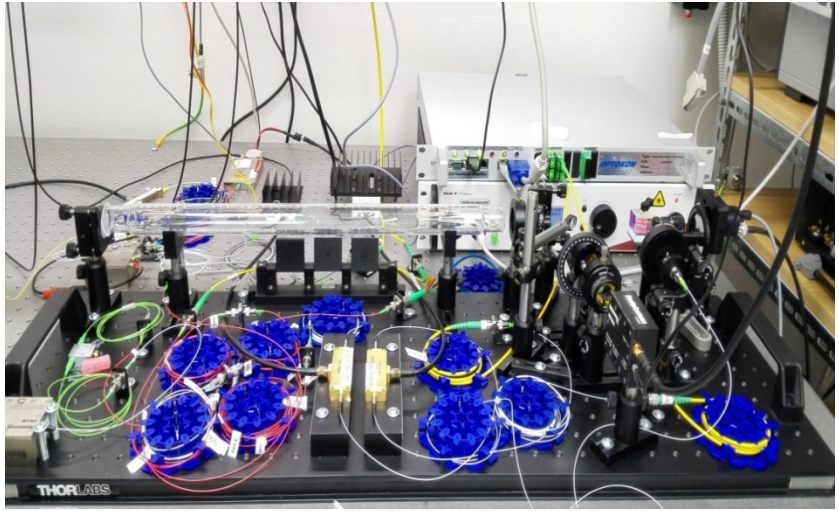


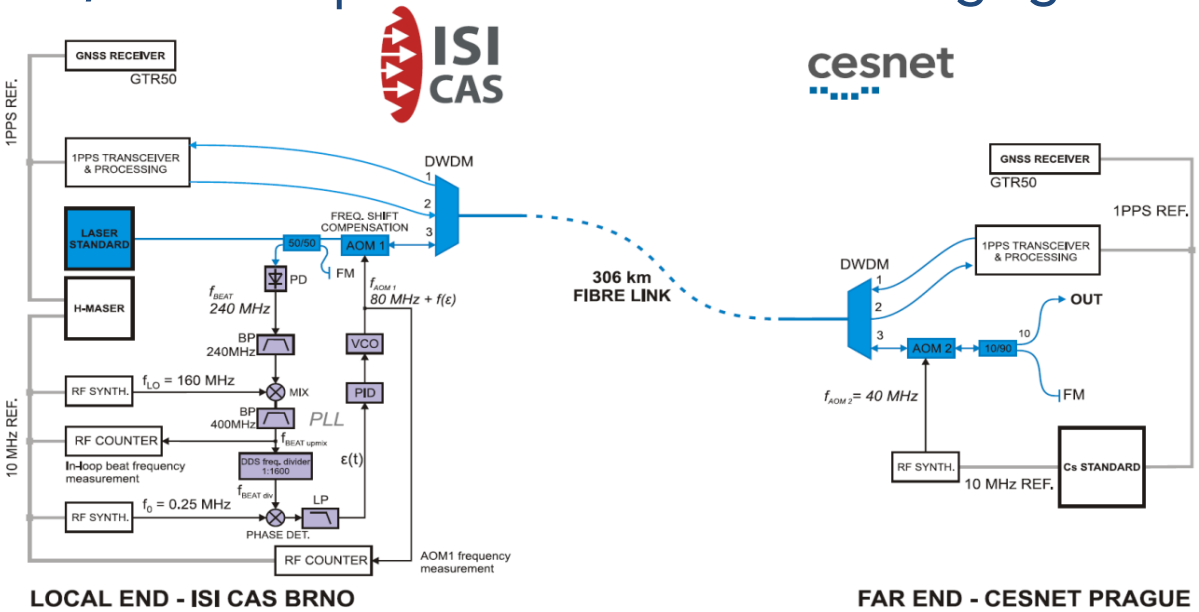


M. Cizek et al., "Transfer of stable optical frequency for sensory networks via 306 km optical fiber link," 2016 European Frequency and Time Forum (EFTF), York, 2016

Photonic Services

- Ultra-stable optical frequency dissemination
- 3rd party equipment – 1540.56 nm, <100 Hz linewidth laser stabilized using saturated absorption in $^{13}C_2H_2$
- Rel. line stability 10^{-14} uncompensated, 10^{-18} compensated at 10 000 s averaging





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DETECTION OF FIBRE INFRASTRUCTURE THREATS

FIBRE CUT BASED OUTAGES

CESNET
12 fibre cut based outages last year
2.04 /Mm/y

CDT
19 fibre cut outages per 3500 km last year
5.4/Mm/y

Metro networks experience 13 cuts annually for every 1000 miles of fibre [1]
8.08/Mm/y

The most common causes of fibre cuts – digging activities (58%) [2]

[1] W. D. Grover, “Mesh-Based Survivable Networks: Options and Strategies for Optical, MPLS, SONET and ATM Networking”, PrenticeHall PTR, Upper Saddle River, 2004.
[2] Orange (France Telecom) in France (January 2010-March 2011).

PROACTIVE PROTECTION

- 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.:

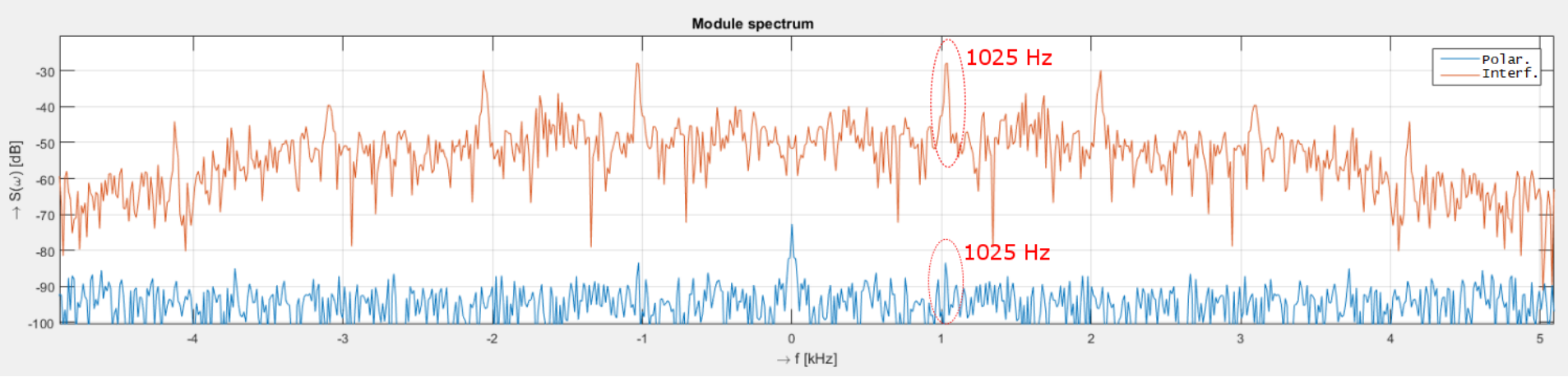
[1] J. E. Simsarian and P. J. Winzer, "Shake before break: Per-span fibre sensing with in-line polarization monitoring," 2017 Optical fibre Communications Conference and Exhibition (OFC), Los Angeles, CA, 2017, pp. 1-3

Vibration sensing methods using fibre/fibres, basic setups

Requirement: Without installation works along fibres

	Phase sensitive OTDR	Polarization based sensing	Interferometers
Sensitivity	++	+	+++
Number of required fibers	1	1	2
Single-ended measurement	Yes	No (passive mirror at least)	No (passive mirrors at least)
Measurement range	Tens of kilometers	Tens of kilometers	Tens of kilometers
Localization of event	Yes	No (in basic configuration)	No (in basec configuration)
Price	High	Low	Moderate
Special requirements	Elimination of reflections in optical route, channel spacing >200 GHz away from data.		

Lab comparison of polarisation and interferometric methods (Michelson)

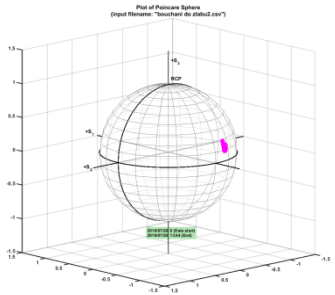


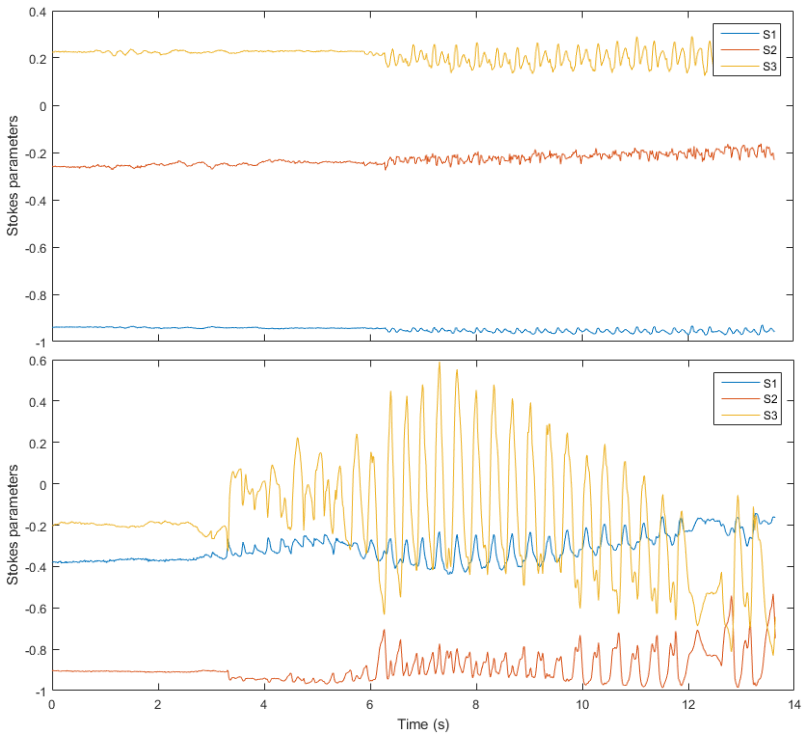
10km of G652.D fibre on spool
Artificial vibrations generated by speakerphone

[1] P. Munster, T. Horvath, P. Sysel, J. Vojtech and R. Velc, "Comparison of interferometry based and polarization based sensing systems for use in fiber infrastructure protection," 2017 International Workshop on Fiber Optics in Access Network (FOAN), Munich, 2017

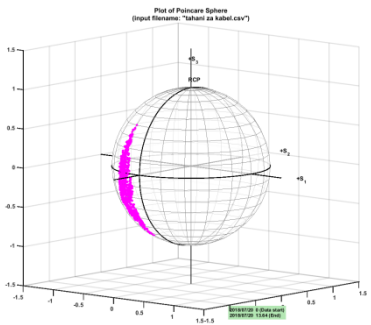
Polarisation method in the field

City line 13km of G652 fibre





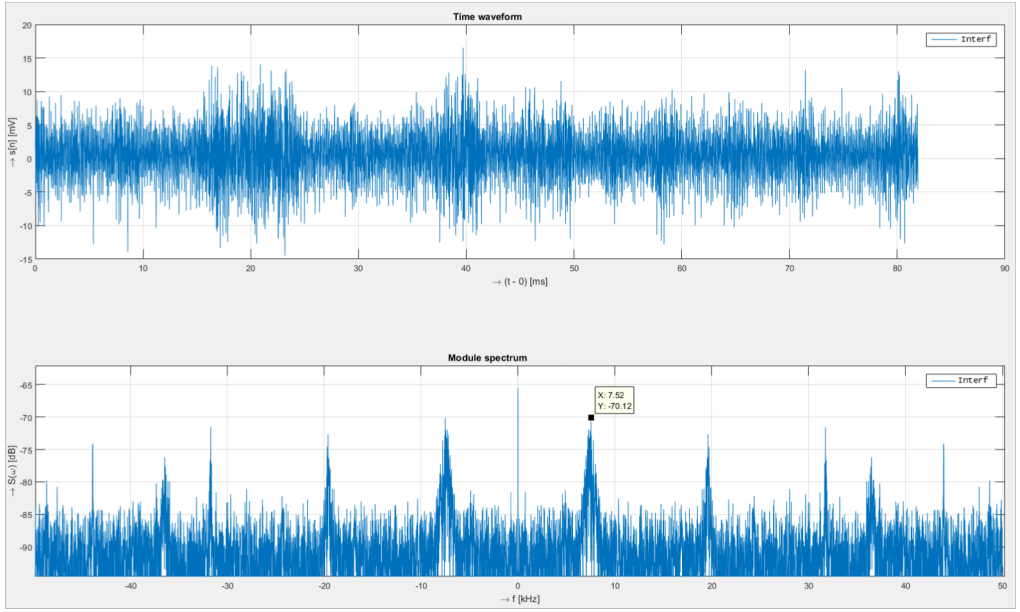
SOP change caused by mechanical vibration near the cable. L: the Poincare sphere, R: Stokes parameters.



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).

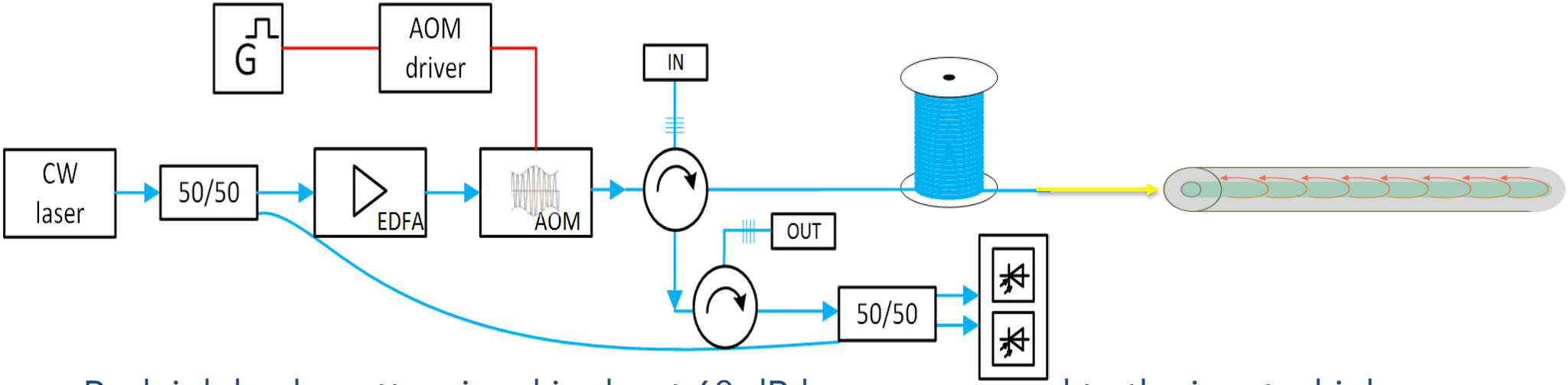
Sensitivity of interferometric method

SENSING METHODS USING FIBRES

- 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



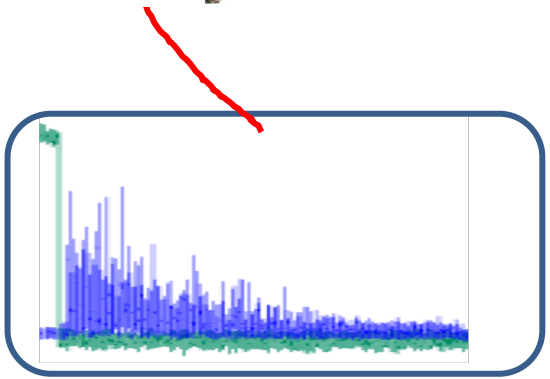
- Rayleigh back-scatter signal is about 60 dB lower compared to the input – high-power optical input signal is necessary.

SENSING METHODS USING FIBRES

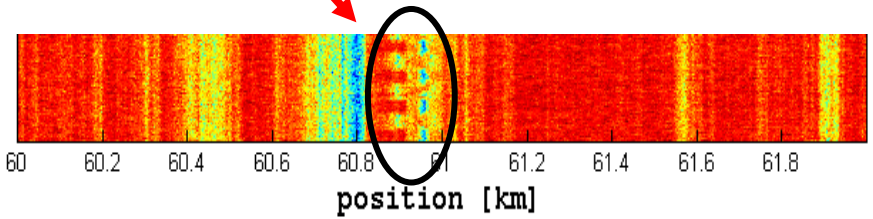
Phase sensitive-OTDR

Vibrations

Transmission fibre



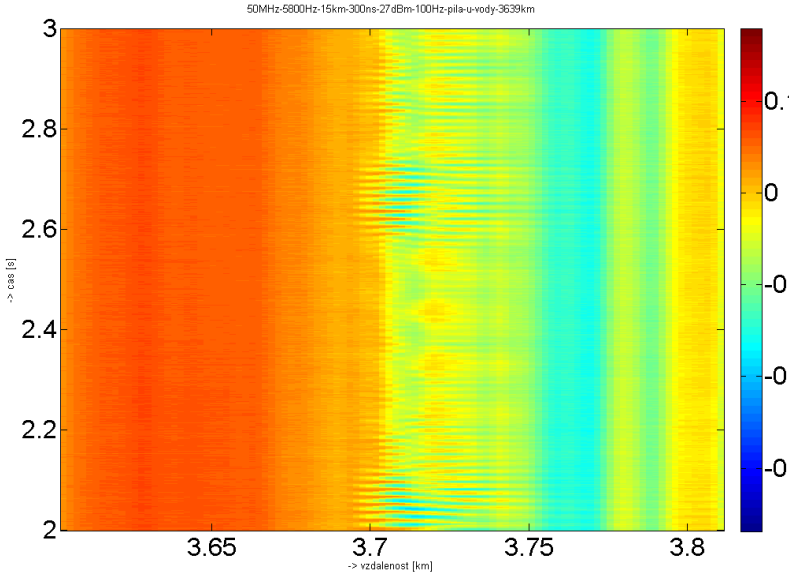
Backscatter is measured while pulse propagates

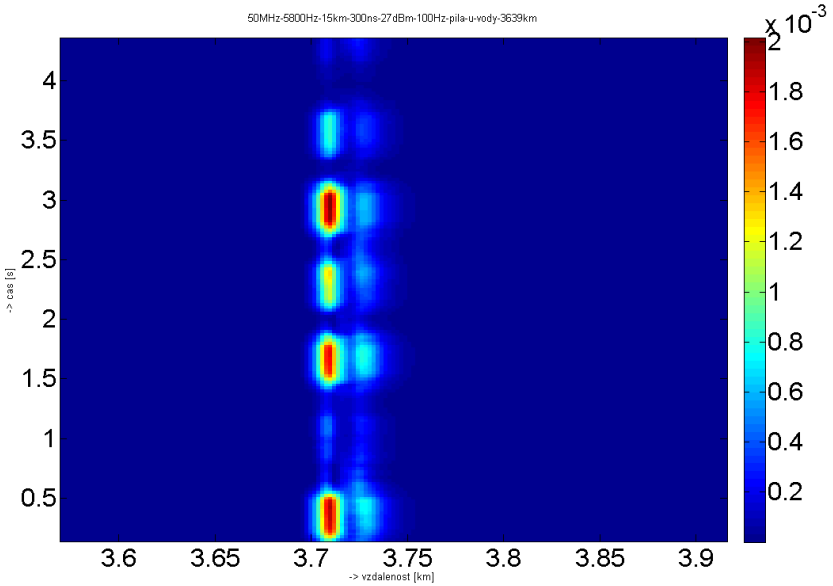


Based on signal intensity change localisation of event is possible in order of tens of meters

Phase sensitive OTDR

Sawing



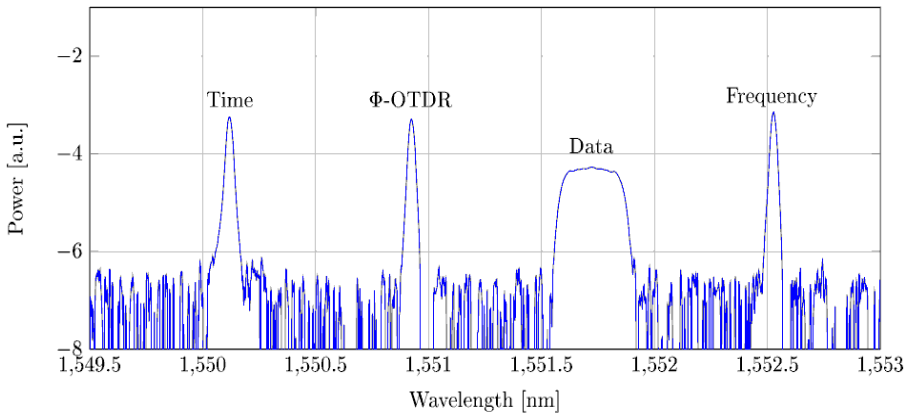


Hammer strokes in distance of about 12 km

PARALLEL OPERATION WITH DATA

- 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]

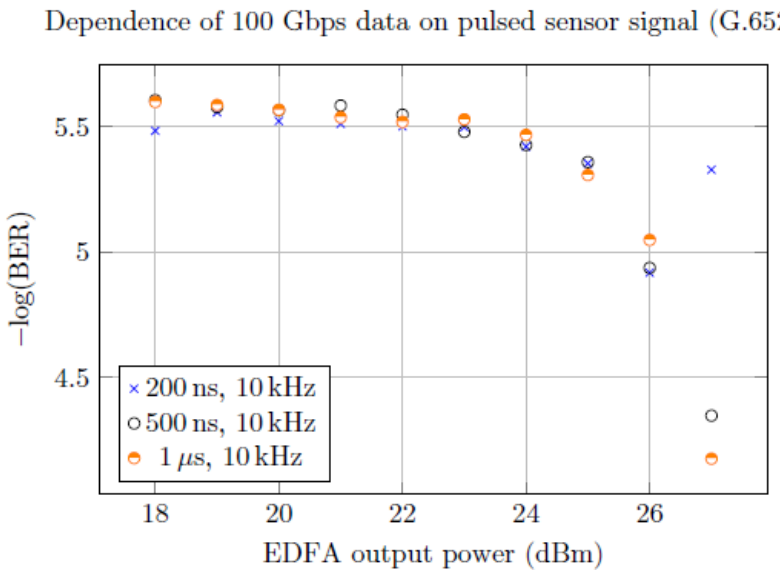


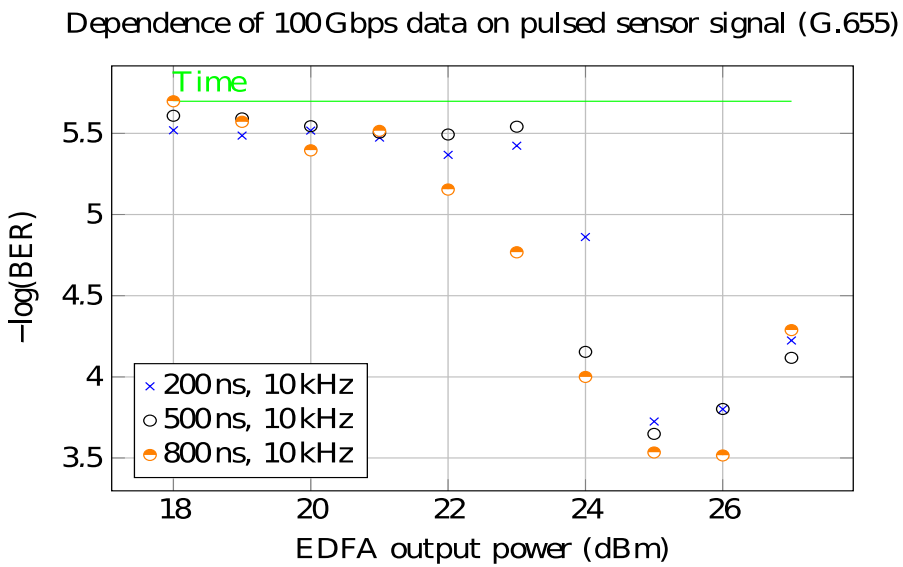
[1] Sima S. et al., Deliverable D3.2v3-Economic analysis, dark fibre usage cost model and model of operations, Porta Optica project

[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 WITH DATA

- **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

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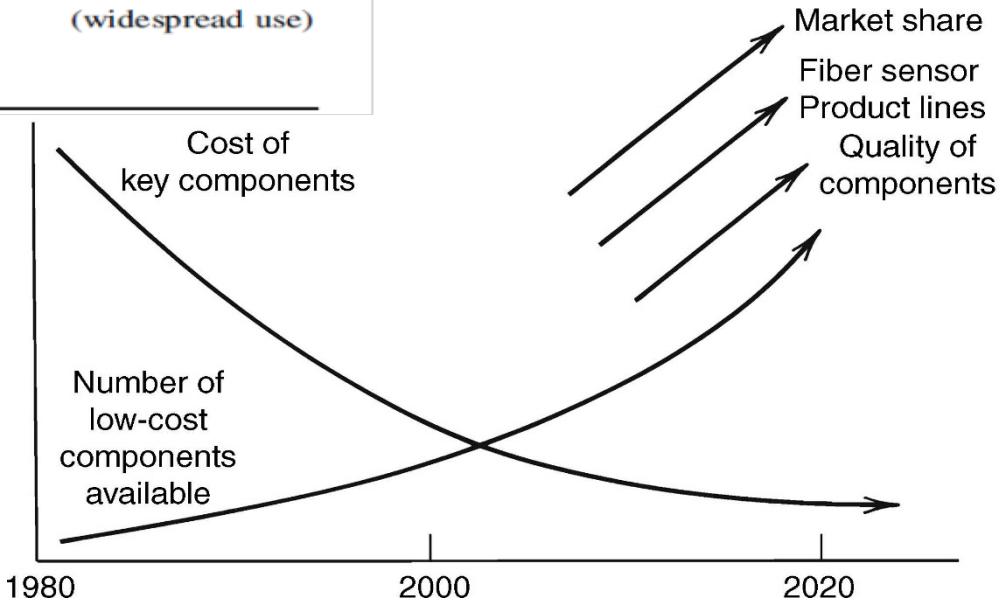
CONCLUSION AND ACKNOWLEDGEMENT

CONCLUSION

- 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

CONCLUSION

	1980	2000	2020
Laser diodes	$3000 each (prototypes)	$3 each (compact disc players)	<$1 each (CD and DVD players)
Single-mode fibers	$5–10 per meter (limited availability)	$0.10 per meter (standard telecom)	<$0.05 per meter (standard telecom)
Integrated optic modulators	Laboratory devices	$500 each	$50 each (fiber optic gyros)
Fiber optic gyros	Laboratory devices	$500–5000 each (low- to medium cost navigation, early use)	$500–1000 each (widespread use)



Techna Vio, Global fiber optic sensors market, London, United Kingdom, 2015.

E. Udd, E. and Wi B. Spillman Jr., Fiber optic sensors: an introduction for engineers and scientists, 2nd Ed., Hoboken, NJ, John Willey 2011

CONCLUSION

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

G. Marra et al., “Ultrastable laser interferometry for earthquake detection with terrestrial and submarine cables”, Science 10.1126/science.aat4458 (2018).

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CESNET E-Infrastructure - Modernisation, reg. no.

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Thank You Very Much for Kind Attention

QaA

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http://photonics.cesnet.cz

Demo available: Telecom Infra project summit

October 16 and 17, London, UK