CESNET3 OPTICAL NETWORK AND ITS ADVANCED SERVICES

SYNERGY OF CLASSICAL DATA, OPTICAL TIME AND FREQUENCY TRANSFERS AND QUANTUM APPLICATIONS IN REN

Josef Vojtech et al.

Optical networks department, CESNET a.l.e.

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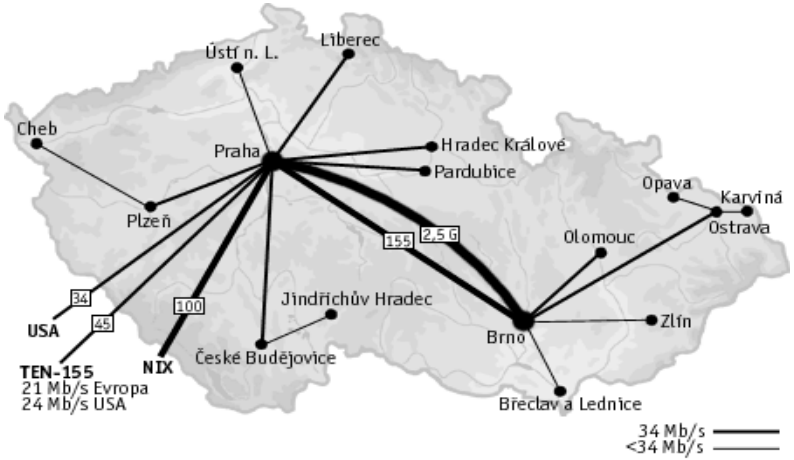
11th CEF networks workshop, Prague, Czechia

Lada Altmannová, Elizabeth Andriantsarazo, Ondřej Havliš, Michal Hažlinský, Tomáš Horváth, Jaroslav Jedlinský, Jan Kundrát, Tomáš Novák, Tomáš Pecka, Petr Pospíšil, Jan Radil, Vladimír Smotlacha, Martin Šlapák, Jaromír Šíma, Radek Velc, Rudolf Vohnout
Optical Networks Department
Vladimír Smotlacha
Network applications Department
Petr Adamec, Jan Růžička
Division of operations

Agenda

- Historical remarks to CESNET2
- CESNET3
- CITAF
- Quantum Key Distribution
  - Benefits from Time and Frequency transfers for QKD
  - Running projects
- Summary

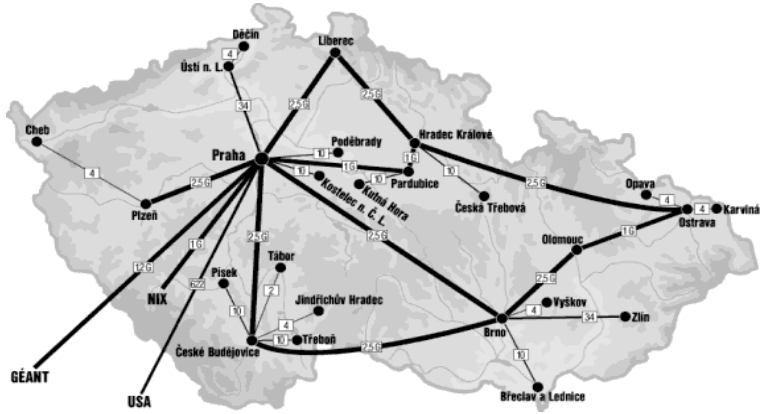
Optical Infrastructure Development and Used Concepts



1999 DFs

2003 CBF

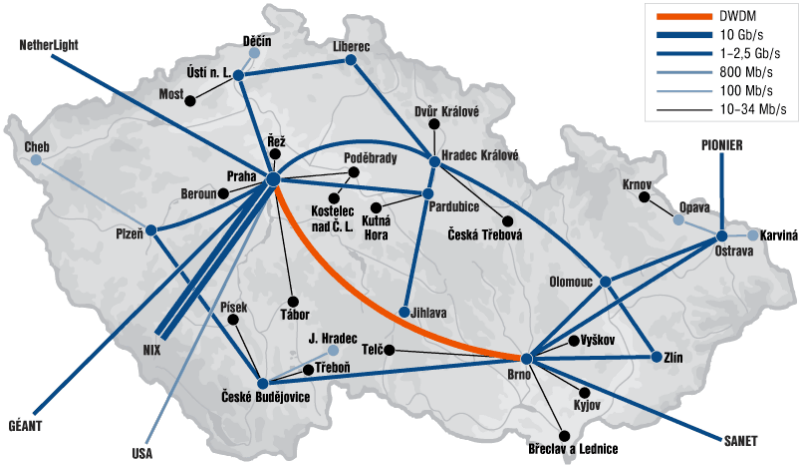
2004 DWDM, Open DWDM



2002

NIL

Bidi-transmission



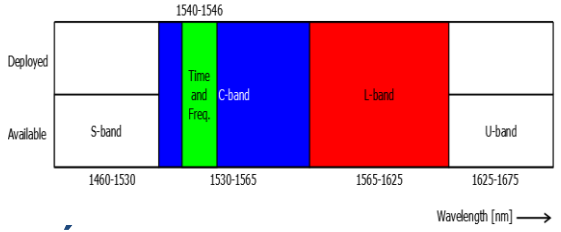
Stanislav Šíma

Promoter of many concepts important for RE networking:

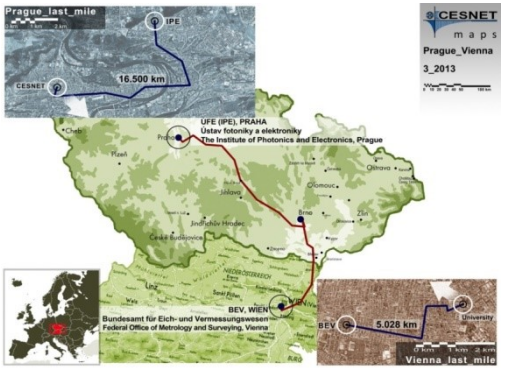
- Customer Empowered Networks and 1st CEF networks workshop 2004
- Open DWDM and intensive usage of Alien Waves
- Single fibre bidirectional transmission, Nothing in Line
- Photonic services delivering ultra low latencies
- ….

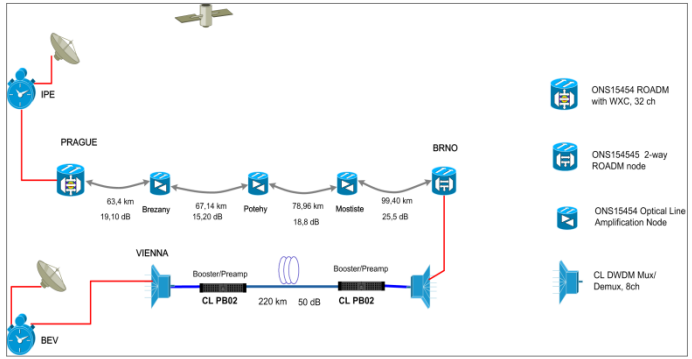
Photonic Services

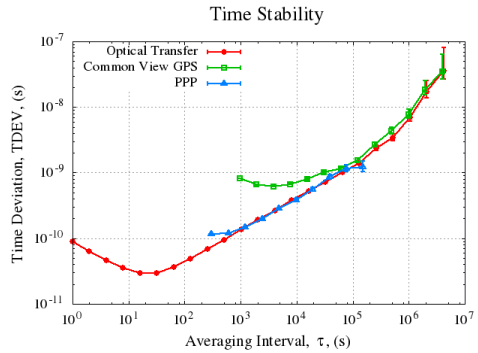
IPE/Prague –BEV/Vienna



- Since 2011, 550km, still in operation
- IPE Prague – Geodetic observatory (VUGTK) Pecný, 43dB, 2014
- Prague Brno – 306 km, 85 dB, 2014

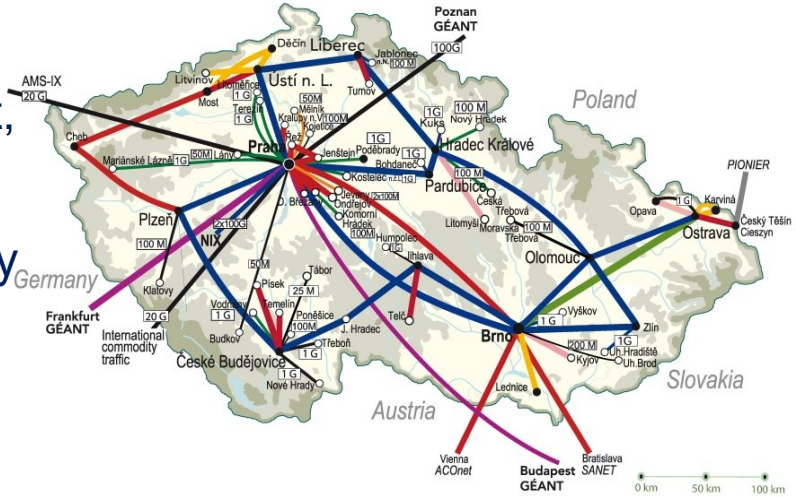






CESNET3 Network

- **Concept of three layers**
  - **Physical - more than 5800 km leased fibers (G.652, one G.655 route)**
  - **FlexWDM - effective use of the fibers, dedicated optical channels and services + dark channels for precise time, frequency, QKD)**
    - **400Gbps coherent system (blue in 2023 map)**
  - **IP/MPLS**
    - IPv4/v6 dual stack, unicast, multicast,
    - without limits on legitimate traffic,
    - ready for high throughput, low latency apps
    - external connectivity over 400Gb/s



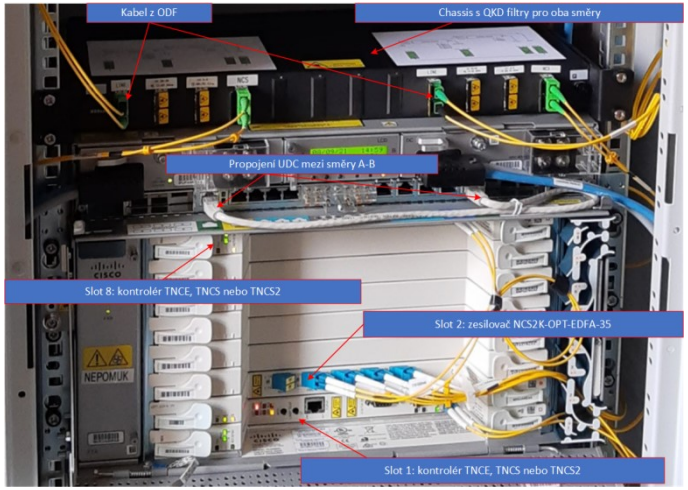
cesnet

lines with capacity 25Mb and more
March 2023

- Czech Light transmission system n x 100G
- Czech Light transmission system n x 10G
- Czech Light transmission system n x 10G started by 1G
- Czech Light transmission system n x 1G
- Cisco transmission system n x 100G
- Infinera transmission system n x 100G
- Infinera transmission system n x 10G
- Single colour transmission system
- Leased capacity
- Microwave
- Optical and Microwave
- PoP
- User Point

CESNET3 – FlexWDM0 – BACKBONE

- Complete refresh (DWDM + IP/MPLS) of main ring DWDM system, under e-INFRA CZ project LM2018140
  - Flexgrid C+ band (up to 96 50GHz channels) with flex spectrum allocation
  - Native support for coherent channels: 100 Gbps - 1.2 Tbps (superchannels)
    - IP/MPLS runs on 400 Gbps channels
  - Support of alien spectrum. Limited non coherent transport possible (White Rabbit)
  - Directionless
  - Contentionless
  - Colorless
  - Central management system EPNM
- Reservation of dark spectrum for TF services
- DWDM upgrade finished 2021

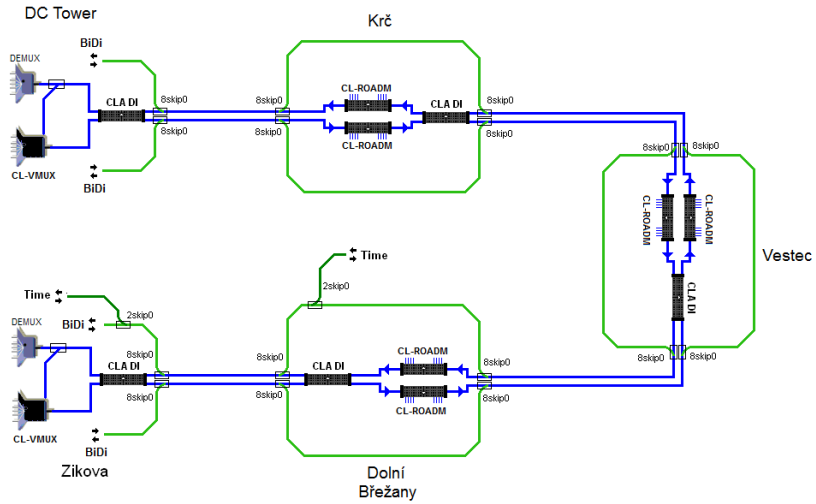


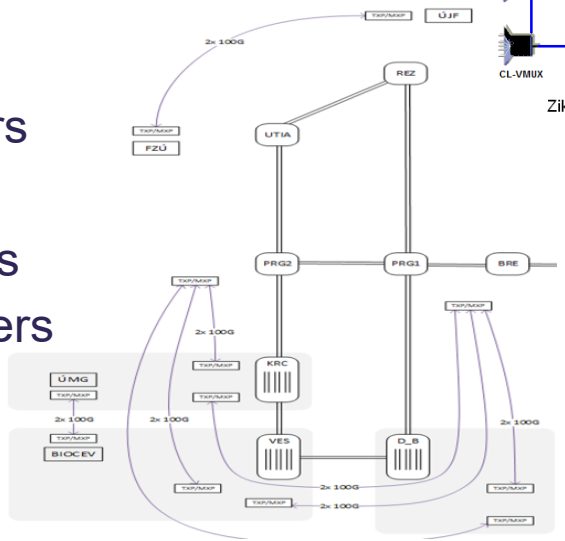
CESNET3 – FlexWDM1 – Access DWDM

- Suppports (but not limited to) main user sites around Prague - transport of 100+ Gbps channels with backup (Březany - ELI, Vestec - BIOCEV, Krč, CAS campus at Slovanka, INR Rež, etc.)
- Requested features
  - Flexgrid, Colorless a Directionless technologies
  - Starts at 100 Gb/s upgradable to 400 Gbps
  - Support of TF and QKD, reservation of dark spectrum
  - Diversification of transmission and transponder sub-layers
  - Support of SDN a central monitoring and management
- Tendered via negotiation process, bid offered by 6 subjects, winner is implementing Ribbon DWDM system.
- TBF June 2023

CESNET3 – FlexWDM1 – Access DWDM

- TBF July 2023
  - 100Gb/s speeds with redundancy
  - Prepared for future capacity upgrades
- IP and non data services from day 0
  - alien spectrum
  - TF spectrum
- Connecting users and partners
  - through main backbone
  - through GEANT and CBFs
  - through other external peers





Share Spectrum or not to Share

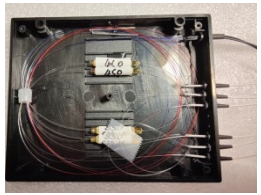
- **Alien Waves or actually Spectrum Connection Service work well for data**
- **Unique applications Time and Frequency can't use them only at cost of performance degradation**
  - **Need reciprocal path there and back to compensate disturbances**
- **Fibres rental p.a. cost (based on average price*) 1 MEUR p.a. for 2000 km of fibre and 15y contract (CESNET)**
- **SWITCH 240 km @ 100k CHF p.a.**
- **Housing is about 15% of total (e.g. determined during CLONETS-DS)**
- **Share infrastructure for T+F with data is attractive, add only up to 15% extra cost**

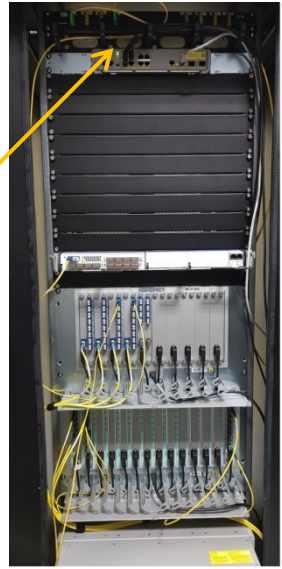
Approach	Advantage	Disadvantage
Dark channel	• Mutualise fibre and housing facilities. • Implementation of the T&F service can start immediately as no extra fibre is required.	• Adds complexity in the network due to the bidirectional signals propagating in a telco architecture. • Setting up the spectra-sharing architecture may be traffic impacting - reduced capacity for data traffic. • Optimising T&F service takes more time in order not to interfere with data traffic. • Each OADM adds up to 0.8dB of extra attenuation which degrades OSNR. • Is not ideal when attenuations/span > 25dB.
Dark fibre	• Data traffic and T&F services are using dedicated fibres and cannot interact (safest option).	• Additional high costs for fibre rent. • More fibres and the two dedicated networks need to be monitored and managed simultaneously (more manpower required).

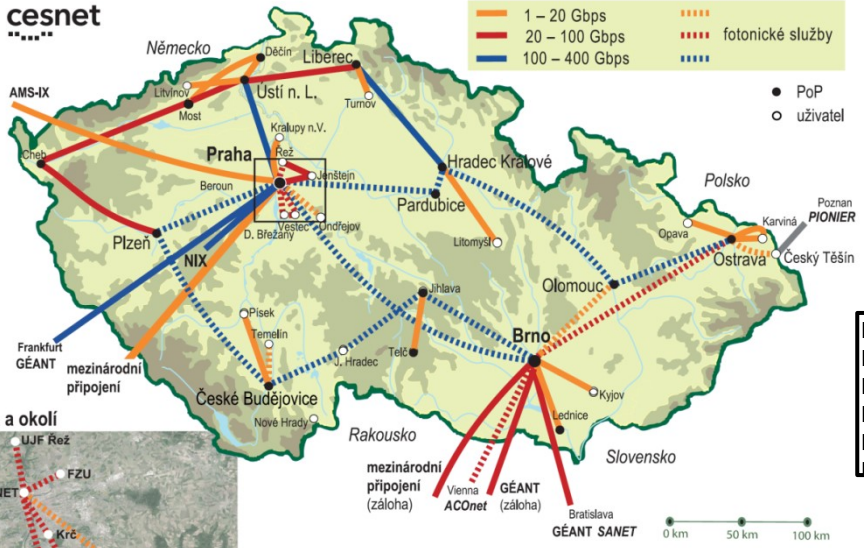
*Sima S. et al., Deliverable D3.2v3-Economic analysis, dark fibre usage cost model and model of operations, Porta Optica project

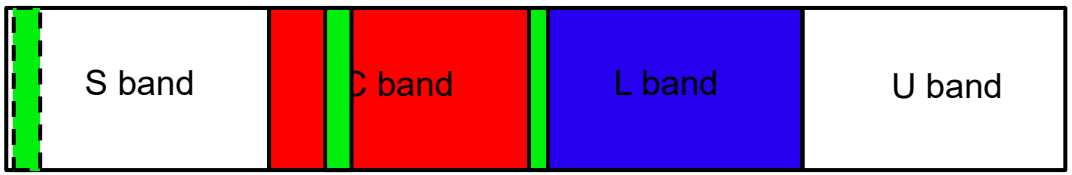
CESNET3

- **Major upgrade program 2020-2Q23**
- **Deployed 120+ OADMs for dark spectrum reservation**
  - **Dual(tri)-band, emphasis on minimal reflections and attenuation (<1 dB)**









Agenda

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- CESNET3
- CITAF
- Quantum Key Distribution
  - Benefits from Time and Frequency transfers for QKD
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Czech Infrastructure for Time and Frequency

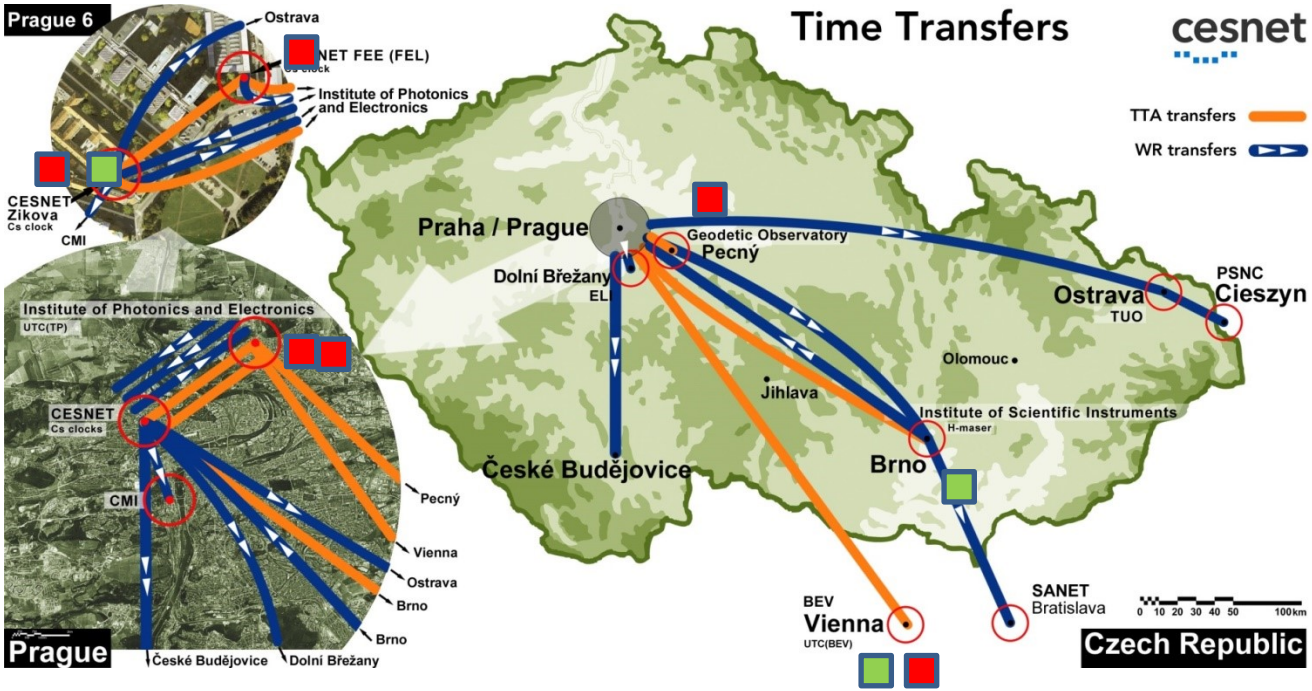
- CITAF is a **non-commercial and open activity** focused on the transfer of accurate time and very stable frequency using optical networks. It is used to **transmit time scales of atomic clocks** in involved organizations. Next application is the **transfer of ultra-stable optical frequency** over hundreds of kilometers of optical fiber with active noise cancellation.
- The CITAF infrastructure is the result of the research activities of the CESNET and partners:
  - Institute of Scientific Instruments, ASCR https://www.isibrno.cz/en
  - Institute of Photonics and Electronics, ASCR https://www.ufe.cz/en
  - Institute of Plasma Physics, ASCR
  - Faculty of Electrical Engineering of the Czech Technical University in Prague https://fel.cvut.cz/en/
  - Faculty of Nuclear Sciences and Physical Engineering of the Czech Technical University in Prague
- The achieved parameters and potential **corresponds to similar activities in other countries** and allow us to participate in international research in the field of time and frequency metrology.
- **https://citaf.org/en/index**

Connected Institutions

- Cs, H - CESNET (Prague, CZ)
- Cs, UTC(TP) - Institute of Photonics and Electronics Academy of Sciences (Prague, CZ)
- UTC(BEV) - Bundesamt für Eich- und Vermessungswesen (BEV) (Vienna, AT)
- H - Institute of Scientific Instruments Academy of Sciences (Brno, CZ)
- Cs - Faculty of Electrical Engineering of the Czech Technical University in Prague (Prague, CZ)
- Cs - Research Institute of Geodesy, Topography and Cartography (Pecný, CZ)
- Institute of Plasma Physics - Academy of Sciences (Prague, CZ)
- ELI/HiLase (Dolni Brezany, CZ)
- Czech Metrology Institute (length laboratory) (Prague, CZ)
- VSB-Technical University Ostrava (Ostrava, CZ)
- South Bohemian University (České Budějovice, CZ)
- SANET (Bratislava, SK)
- PSNC (Cieszyn, PL)

T + F transfers

- **Precise time transmission over 2200+ km**



- **Time Transfer Adapters**

  Own developed FPGA based, TDEV ~ 20-30ps at 1E3s

- **White Rabbit**

  Commercially available, based on CERN OHWR project

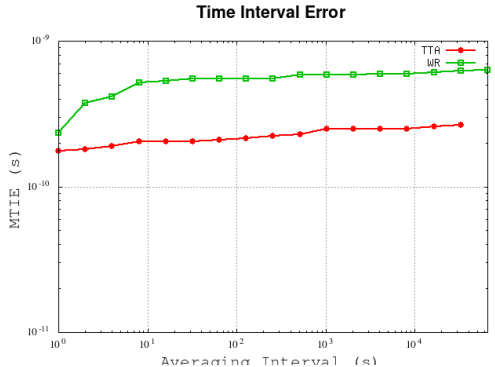
- **Cs clock 5071A**

- **Active H - maser**

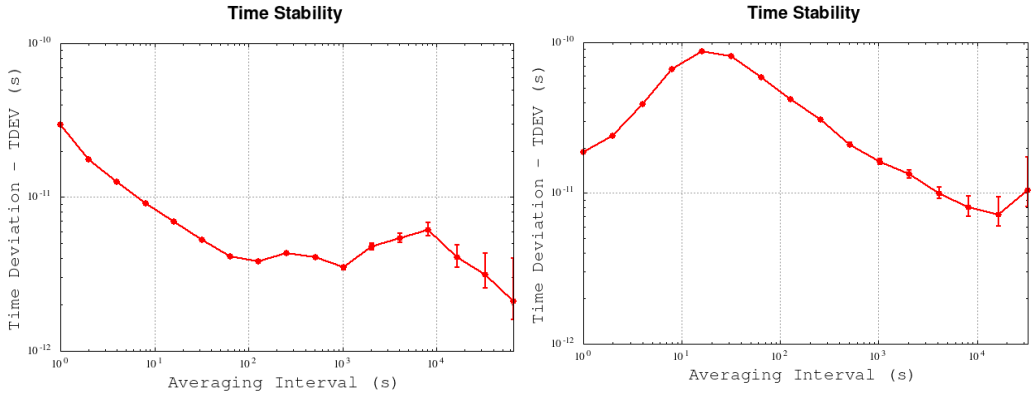
Infrastructure for Time and Frequency

- (Cs clock generated) time scale comparison using multiple optical methods deployed
  - TTA + WR
    - CESNET – IPE
    - FEE CTU – IPE

Details: Smotlacha V., Vojtech J., EFTF 2022

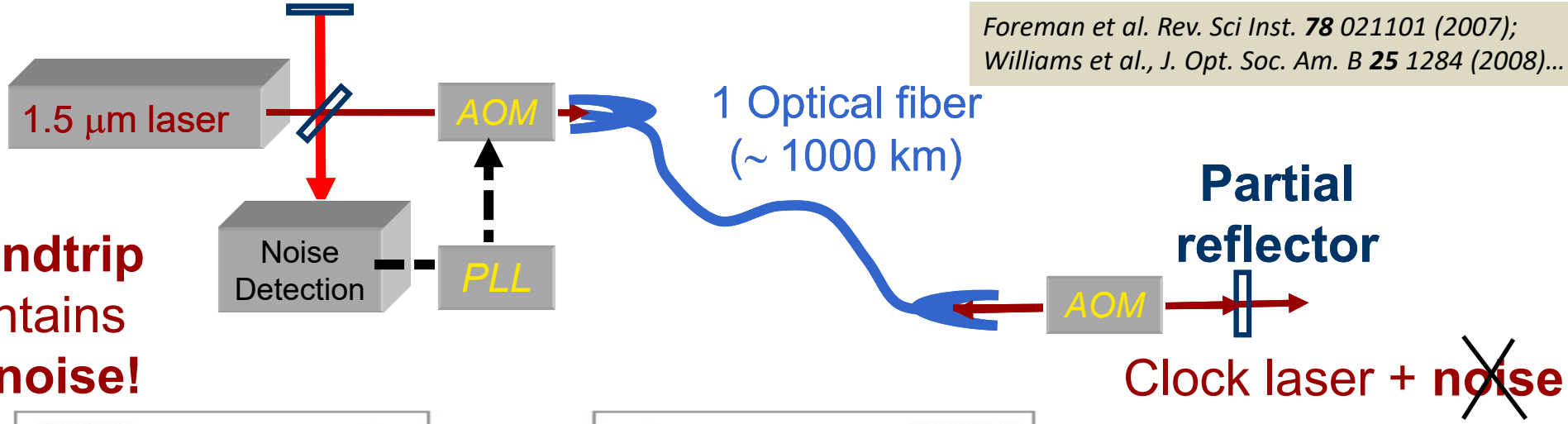


Comparison of Maximum Time Interval Error



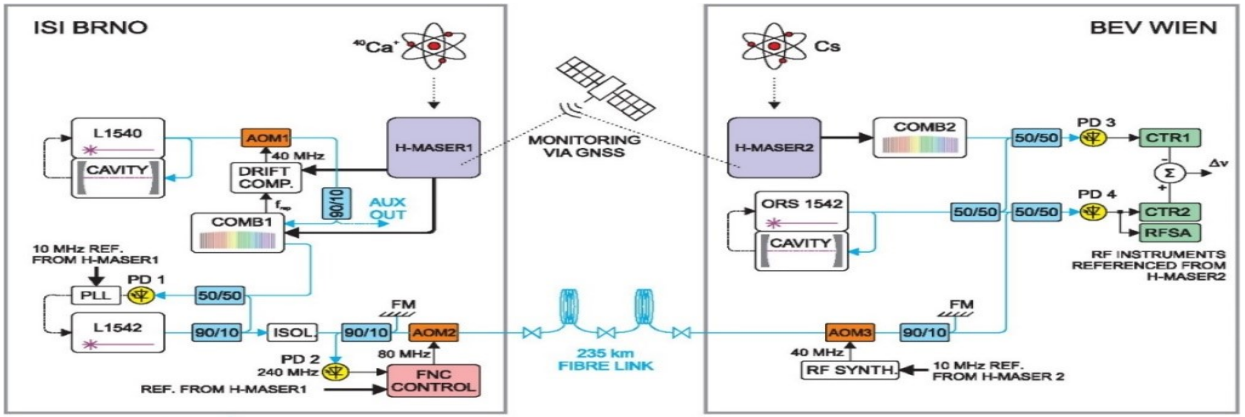
TDEV comparison for TTA and WR transfers over 180 km of field deployed fibre

Coherent Optical Frequency Transfer



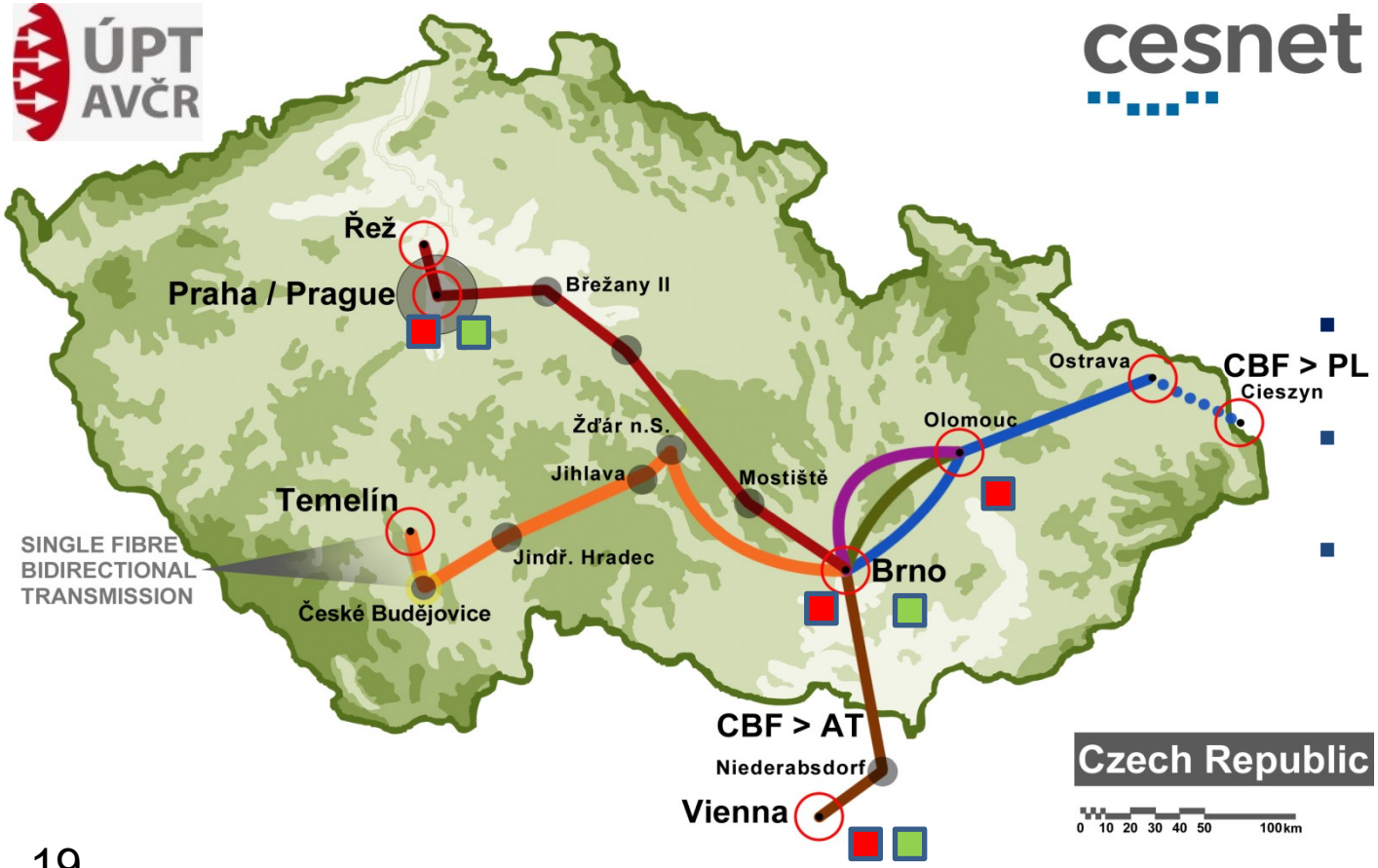
Foreman et al. Rev. Sci Inst. ***78*** *021101 (2007);*
Williams et al., J. Opt. Soc. Am. B ***25*** *1284 (2008)…*

roundtrip contains **2× noise!**



Cizek et al. ***Opt. Express. 30,*** *5450 (2022)*

Infrastructure for Time and Frequency

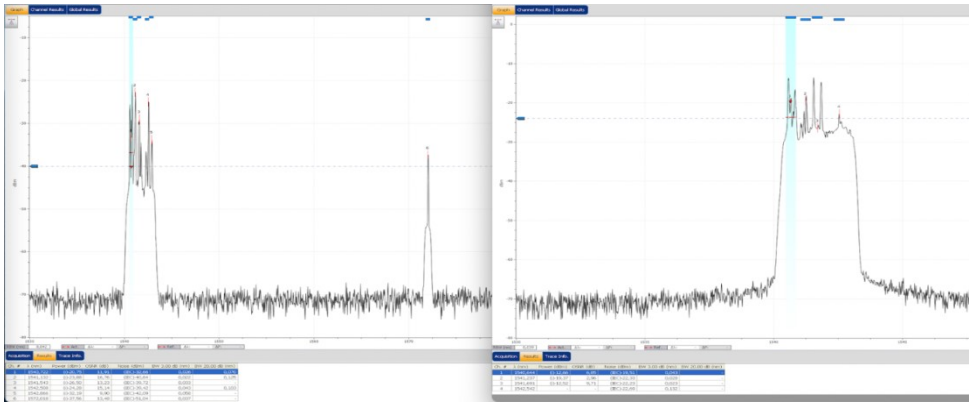


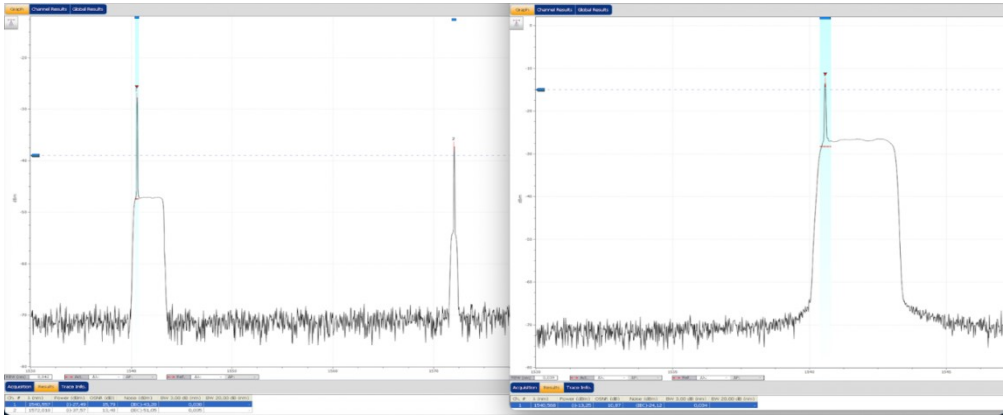
- **Optical clock (under development)**
- **Metrology laser for length purposes**

- 1100+ km, developed in cooperation with ISI
- 700 km **bidirectionaly lit as a service** (since 2015)
- 29 BiDi EDFAs, avail. from 3 vendors

Bidi All Optical Amplification

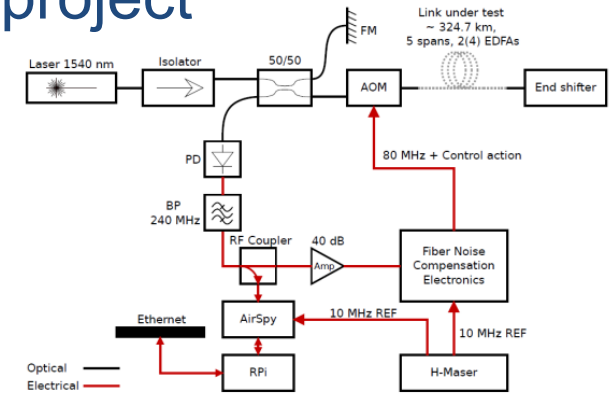
- Need reciprocal/bidirectional path to cancel slow changes $\tau AB = \tau BA$
- Bidirectional amplification
- Hi gain medium + feedback - We are trying to avoid it!!
- $G^2R_1R_2 << 1$
- R composes from Rayleigh backscattering and reflections from splices, connectors etc.
- Only with limited gain up to 20-21 dB
- But we have lossy spans:
- 24, 27.7, 26 and 28.6 dB?

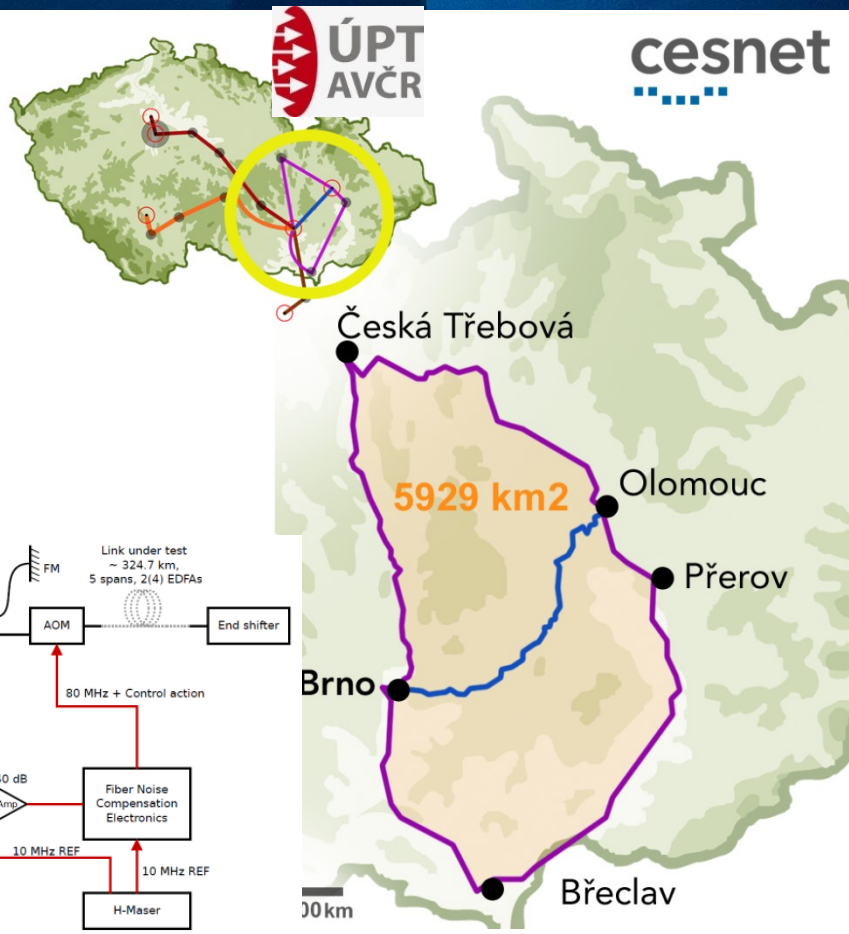




Large Dual Wavelength Sagnac Loop

- ISI, UPOL, CDT
- Length 352 km, area 5929 km^2
- 6 amplification points around loop
- Automatic bi-EDFA balancing deployed
  - Beat acquisition via simple SDR
  - Major outcome of TiFOON project
- To be used on remaining lines





Agenda

- Pre-CESNET3
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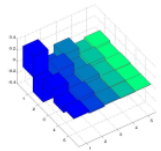
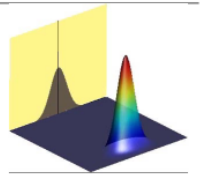
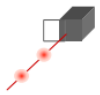
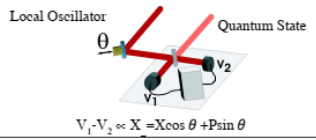
- Quantum Key Distrubution
  - Benefits from Time and Frequency transfers for QKD
  - Security increase: QKD + Sensing
- Summary

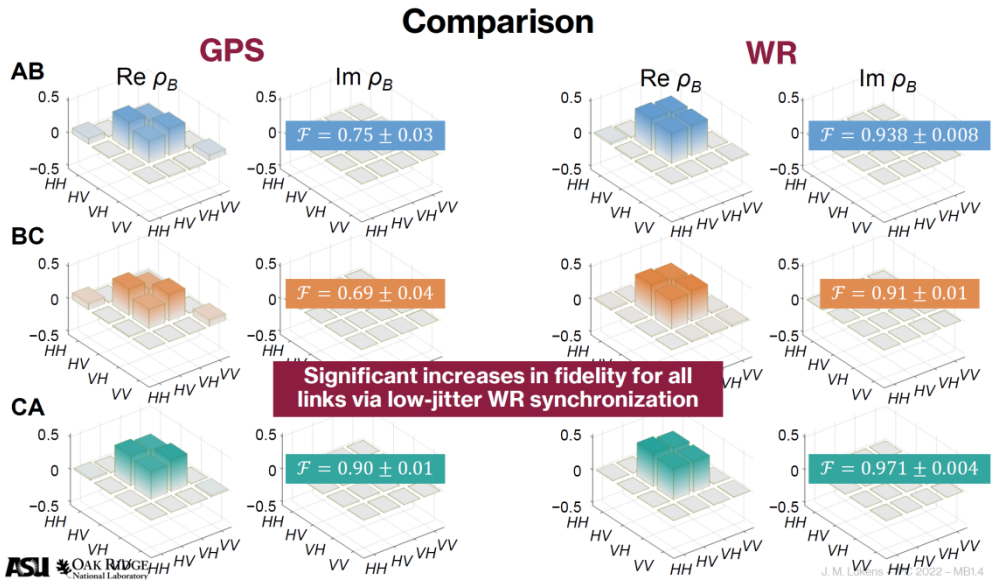
Benefits from Time and Frequency transfers for QKD

Discrete variable QKD - precise timing is must (transition from APDs to Super-conducting Nanowires SP detectors (improvement in jitter). GPS is no more enough.

« Discrete » vs « continuous » Light

Light is :	Discrete Photons	Continuous Wave
We want to know :	their Number & Coherence	its Amplitude & Phase (polar) its Quadratures X & P (cartesian)
We describe it with :	Density matrix $\rho_{n,m}$ 	Wigner function W(X,P) 
We measure it by :	Counting: APD, VLPC, TES... 	Demodulating : Homodyne Detection 
« Simple » States	Fock States	Gaussian States

Credit: Grangier P.,http://gdriqfa.unice.fr/IMG/pdf/Grangier.pdf



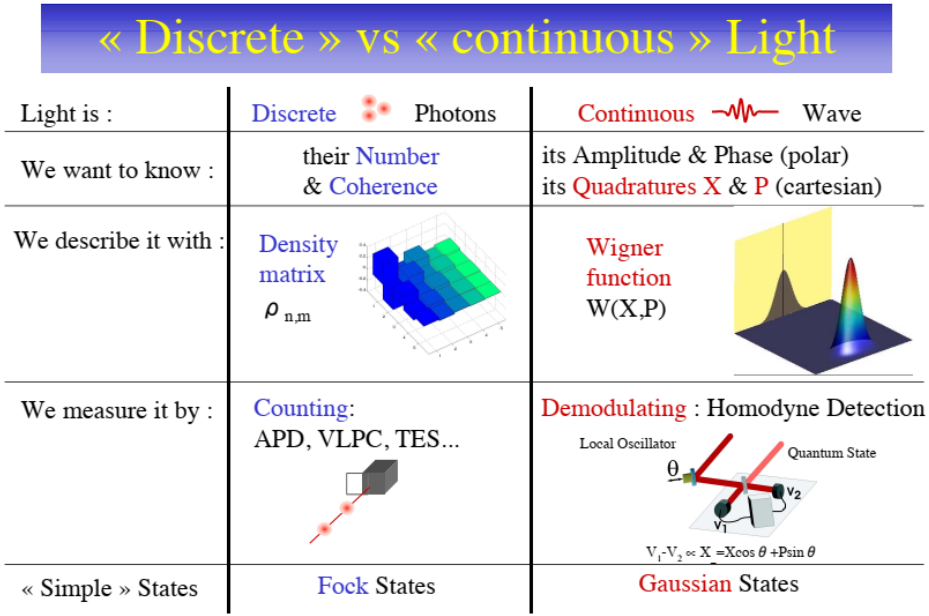
Credit: Lukens. J. et al. ***Scalable and secure architecture for quantum networks, IPC 2022, MB1.4***

Benefits from Time and Frequency transfers for QKD

Continuous variable QKD clearly benefits from providing ultrastable reference and coherent optical frequency transfer as source of phase noise correction (via line stabilization for optical frequency transfer)

Clivati, C., Meda, A., Donadello, S. et al. Coherent phase transfer for real-world twin-field quantum key distribution. Nat Commun 13, 157 (2022). https://doi.org/10.1038/s41467-021-27808-1

Meda et al., "QKD and frequency distribution cooperation: the Twin-field QKD case," 2022 IEEE 15th Workshop on Low Temperature Electronics (WOLTE), 2022, pp. 1-4, doi: 10.1109/WOLTE55422.2022.9882601.



Credit: Philippe Grangier - http://gdriqfa.unice.fr/IMG/pdf/Grangier.pdf

Running QKD projects

Network Cybersecurity in Post-Quantum Era – NeSPoQ (BUT, TUO, CESNET)

- **2021-2025, provider: Ministry of interior CZ**
- Practical applicability of QKD and PQC for links with 100Gbps+ traffic
- PQC (post-quantum cryptography) into FPGA hardware
- Application sponsor: Nation Cybersecurity Burro - **NÚKIB**

Running QKD projects

CZ-QCI

ISI, CESNET, CTU, MU, UPOL, TUO, BTU

DIGITAL-2021-QCI-01-DEPLOY-NATIONAL

Connecting: Prague-Brno-Ostrava

Project starting date: 1 March 2023

Project end date: 31 August 2026

Credit: Philippe Grangier - http://gdriqfa.unice.fr/IMG/pdf/Grangier.pdf

QCI 01- INDUSTRIAL – SEQRET, lead by KEEQuant

7.6 Mrd € Digital Europe

1.6 Mrd € Cybersecurity

170 M€ Quantum Comm.

3 calls

Call 3: DIGITAL-2021-QCI-01-EUROQCI-QKD
2M€, Planning group for future QCI deployment

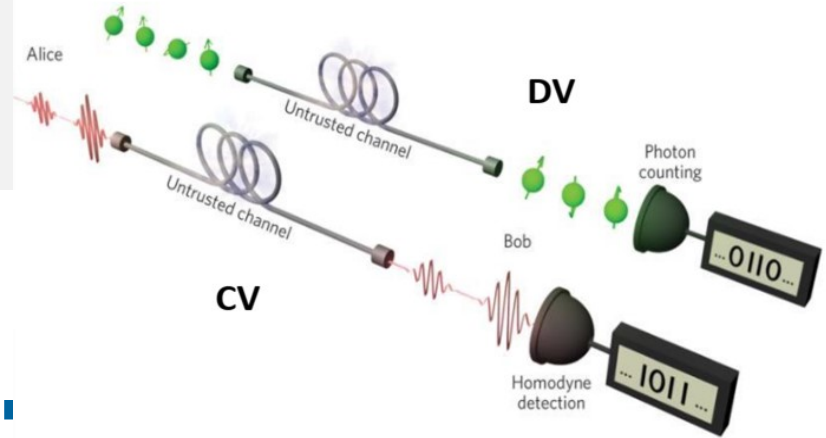
Call 2: DIGITAL-2021-QCI-01-DEPLOY-NATIONAL
108M€, 5M€ per member state to establish first QKD test-beds

Call 1: DIGITAL-2021-QCI-01-INDUSTRIAL

„Create a European Industrial Ecosystem for Secure QCI technologies and systems'

- 44M€ Total (5-15M€ per project/consortium)
- FR: 50% (75% SME)
- secure (>EAL4), standardized (ETSI, etc.), industrialized QKD-system at TRL 8-9
- integration in existing telecom networks

- EU based telecom components
- Expected price drop of QKD HW 70%



Running QKD projects

CZQCI

ISI, CESNET, CTU, MU, UPOL, TUO, BTU

DIGITAL-2021-QCI-01-DEPLOY-NATIONAL

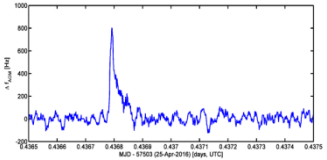
Project starting date: fixed date: 1 March 2023

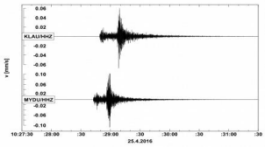
Project end date: 31 August 2026

Credit: Philippe Grangier - http://gdriqfa.unice.fr/IMG/pdf/Grangier.pdf

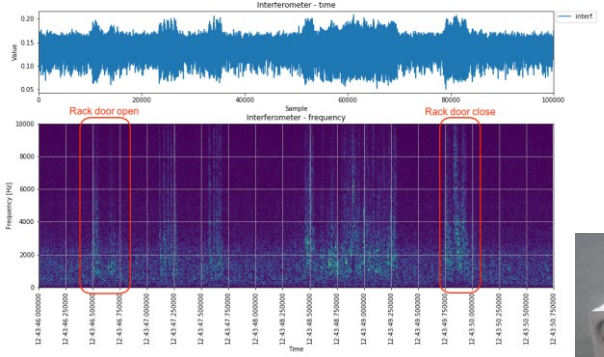
Running QKD projects

- Quantum encrypted communication with enhanced physical layer security“ – NUCRYPT (ISI, CESNET, CDT)
- 2023-2027, provider: Ministry of interior CZ
- Security of QKD enhanced by fibre sensing - QKD attacks target implementation and require physical access
  - Coherent Frequency Transfer uses Michelson Interferometer for noise detection





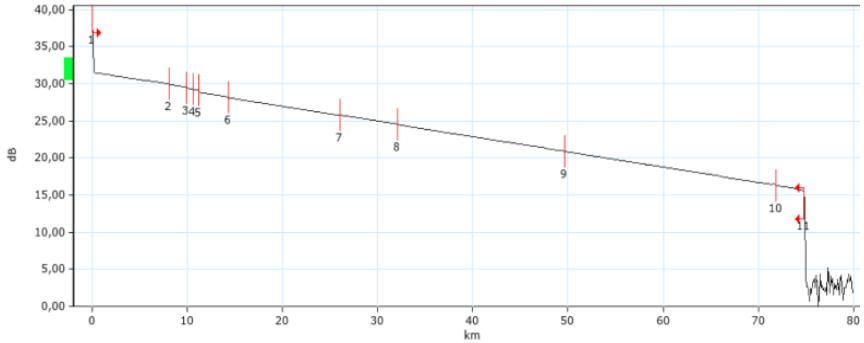
25. Apr 2017 4.1 deg, 20 km SW from Vienna

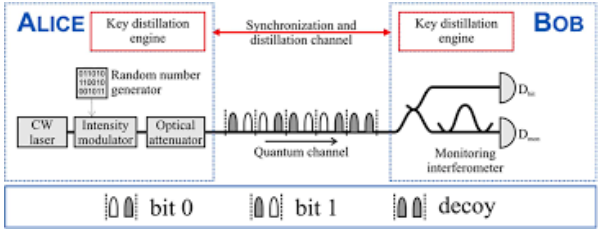


  - Polarimetry – works very well when fibre touched

Shared QKD Line

- Real use case - urban cross border fiber pair – 65 km, 16 dB@1550 nm
- Cooperation with OpenQKD (TUO, PSNC)
- Line used by IM – DD 10 Gbps traffic and
- Existing WhiteRabbit precise time transfer
- Available QKD system
  - Coherent One Way protocol (Nicolas Gisin et al. 2004)
  - Max performance 75km / 18 dB



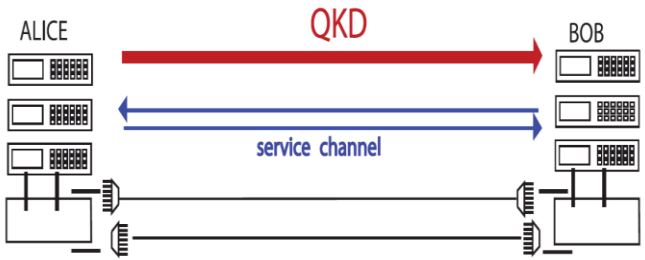


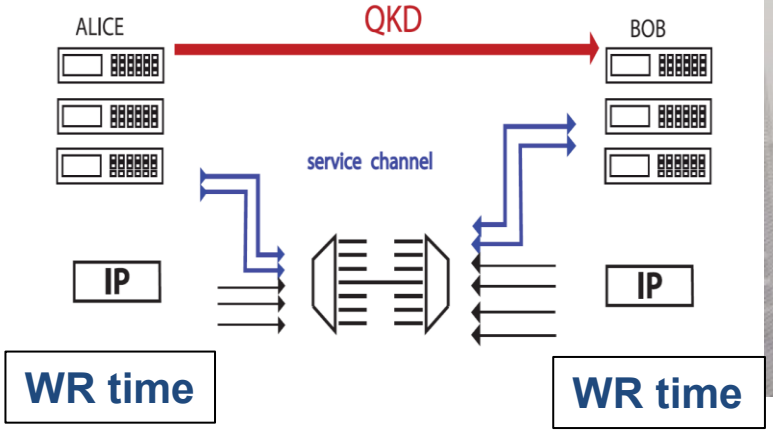
Credit: Gisin N. ***Coherent One Way protocol, 2004***

Shared QKD Line

- System intended for dedicated fibers = „fiber hungry“

  by default: 3 fibers + IP connectivity
- System performance on the edge: 18 dB vs 16 dB
- Prevents use high rejection OADMs
- No additional fibers available
- QBER 2%, far from 11% limit, secret key rate 2kbps





Summary

- OADMs should be installed at day 0, otherwise it is quite complicated
- Keep fibres spans short (in dB), APC connector - avoid reflections (TF, QKD)
  - ULL fibres helps
  - ?Hollow core fibers
- Service works demanding, staff needs to be well trained
    - TF - signal presented in both directions
    - QKD - no chance to confirm presence of Q signal without SPAD
    - QKD fibre to be marked along way (seems to be unused) - avoid using OTDR
    - QKD working on „edge“ - influence of light from environment at Bob side
- QKD definitely benefits from parallel T&F transfer, sharing of fibers seems important for long term sustainability -> need QKD system tolerant to parallel signals and also broadband noise
- Looking forward to CV system developed within QCI-Industrial project SEQRET
- Looking for cooperation and experience exchange in the field with very high dynamics of development

Acknowledgment

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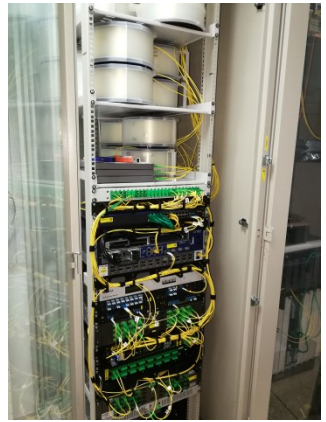
Jaroslav Roztořil
Alexander Kuna
Miroslav Vozňák

Thank You Very Much for Kind Attention!

Questions Please?

josef.vojtech@cesnet.cz



Lab tour: https://en.mapy.cz/s/bacevacama

Where precise time & frequency matters?

Transport

Telecommunication (ICT)

Qtec

Security

Finance

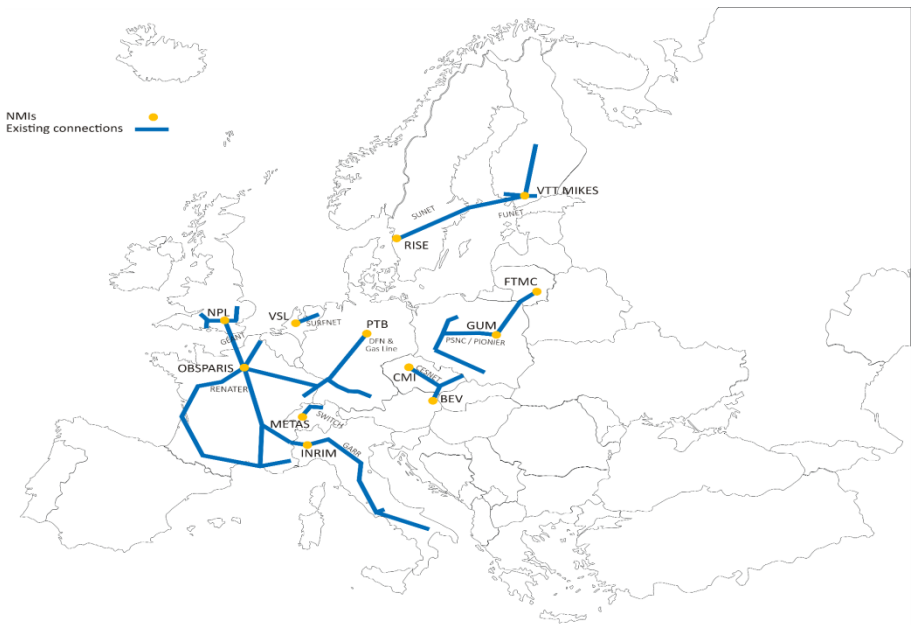
Navigation

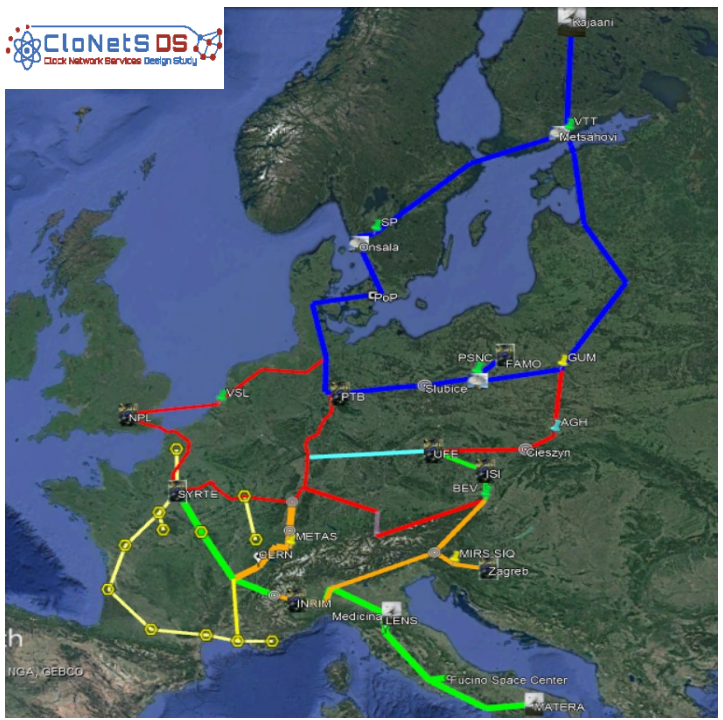
Science Needs Better
Clocks/Reference Signals

Power Grids

Defence

- H2020 project 2020-23 CLOck NETwork Services - Design Study
  - Study user needs
  - Design study for pan European network

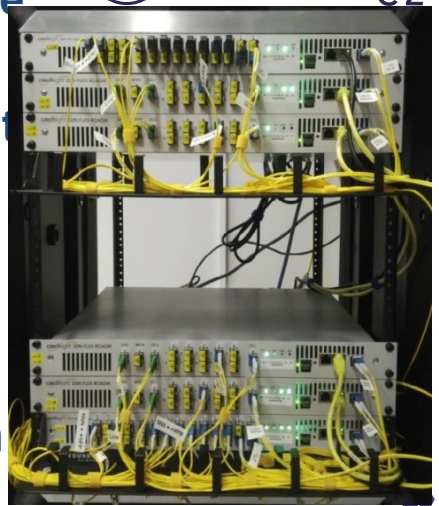


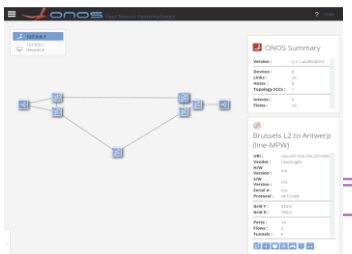


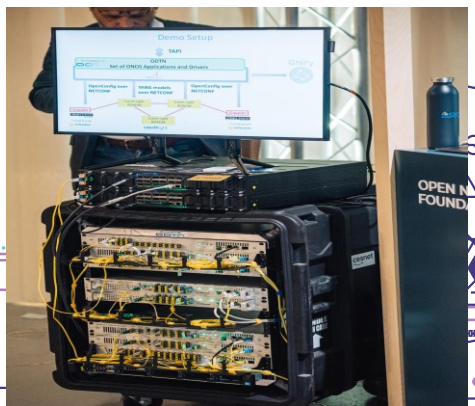
Source: W. Bogacki CLONETS- DS talk at TNC22

Open Line System Czech Light

- Určen pro efektivní využití vláknových kapacit (pásma C a L, obousměrné přenosy)
- Nasazován od roku 2004: „J Vojtech, J. Radil, ‘Czech Light & Czech Light Amplifiers‘, 17th TF-NGN, Zurych, 2005“
- Nasazeno více než 130 zařízení rodiny Czech Light v CESNET2 a dalších sítích, např. SWITCH
- Vyžádané demonstrace na předních akcích v oboru: Telecom Infrastructure Project 2018+19, Optical Fibre Conference 2020, European Conference on Optic Communications 2021 + pozvánka na rok 2022







Open Line System Czech Light

- Vše vzdáleně konfigurovatelné
  - NETCONF
  - RESTCONF + YANG - push telemetry
- Vše vzdáleně monitorovatelné
  - OpenMetrics (Prometheus)
  - Grafana
  - Odezva pod 1s (vs telekom standard 15 min)
  - Velmi jemná práce se spektrem pro super rychlé signály:
    - CL SDN ROADM zeleně, telekomunikační OSA černě)
- Výtečná prezentace J. Kundráta:
  - Chatty ROADMs: Streaming Telemetry with Open Source Software and Open Hardware (ECOC 2021)
  - https://www.youtube.com/watch?v=zPdA_GX4rPI