GEANT GN5-2 WP6 Incubator Project

Long-haul White Rabbit Time Distribution over Telecom Data Optical Networks

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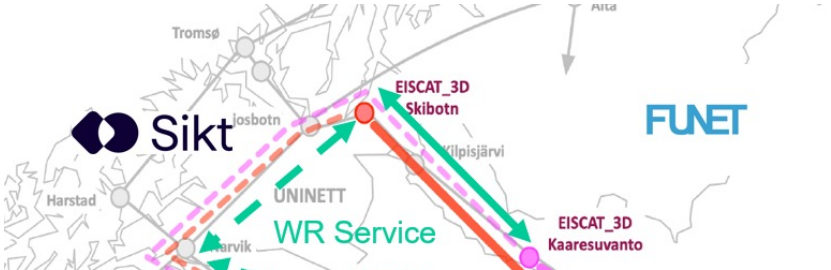
GNA-G Community VCs Q4 2025

2 and 3 Dec 2025

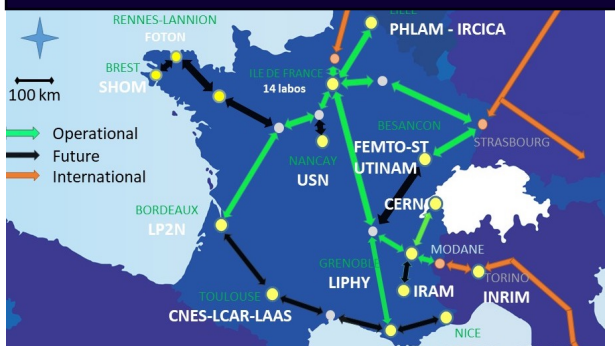
Multiple NRENs Already Deploy (National) WR Networks

A few examples

EISCAT 3D



What are the best practices and how do we solidify for future cross-border cross-NREN T&F?



CESNET, SUNET, FUNET, SURF, INRIM/GARR, SWITCH, NETNOD, RENATER/REFIMEVE, …..

GN5-2 WP6 NETDEV Incubator Project
(ongoing –> Feb.2026)

- GEANT (Guy Roberts) has initiated a GN5-2 WP6 NETDEV Incubator project led by SIKT on long-haul WR time service over DWDM networks.
  - Partners: GEANT, SIKT, CESNET, SUNET, FUNET, GARR
- Goals:
  1. Survey of current deployments in Europe
  2. Evaluate the available solutions, including field-trial on GEANT link Prague-Vienna
  3. Performance-cost analysis of the different solutions
  4. Best practice recommendation to NRENs on how to deploy WR in their long-haul DWDM networks.
- Key challenges for long-haul is the regeneration at In-line Amplification Sites (ILA). Competing solutions to be evaluated:
  - Bidirectional amplifiers
  - WR switches for regeneration
  - Optical-Electrical-Optical media converters.

Extending White Rabbit reach

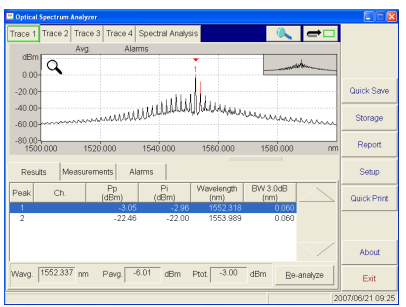
White Rabbit - sub ns time and RF frequency distribution, extension of IEEE 1588 Precision Time Protocol (PTP), based on OHW CERN project

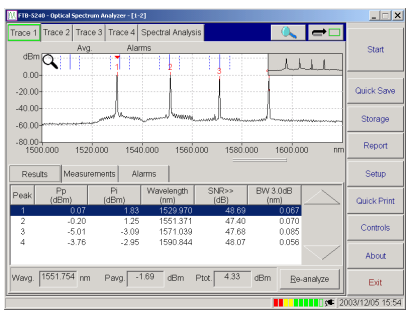
Dark fiber

- Powerfull BX SFPs (but not thermally stabilised laser, large offsets 1490 vs 1550 nm)
- More performant transceivers even with APDs (external component filter/circulator)
  - CWDM SFPs
  - DWDMs SFPs

Real long haul

- Telecom lambdas – assumption $t_{MS} = \mathbf{a} + t_{SM}$ is not valid
- Dark channel/fibre – with bidi propagation





GN5-2 Long haul WR Incubator

The Laboratory test

The laboratory setup included 4 x 100 km fiber spools to simulate a long optical link

The tests use two DWDM wavelengths ch9 (1570.42 nm) and ch8 (1571.24 nm) in a 100GHz grid.

Using external passive DWDM filters, these wavelengths from DWDM SFP 1GBE transceivers are coupled for bidirectional transmission onto a single fiber.

All tests use the same 1GE DWDM L-Band 120 km optical SFP transceivers

A grandmaster clock, locked to a Rubidium reference, served as the time source

A WR Switch at the end of this link operated as the slave

The time difference between the 1PPS (pulse per second) signals of the slave and grandmaster was measured using a Stanford Research Systems (SRS) SR620 Time Interval Counter (TIC) for subsequent evaluation of time and frequency distribution.

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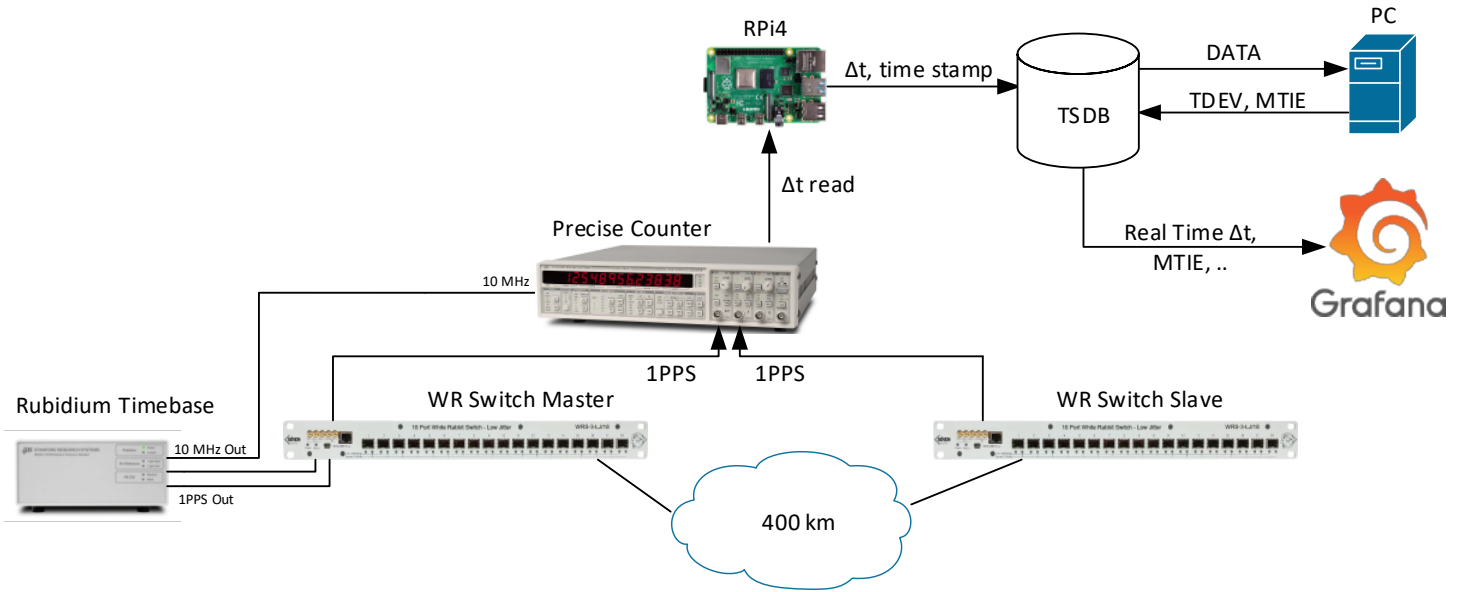
Time Deviation Comparison Between Two White Rabbit Switches

One WR switch is fed from Rubidium precise clock and serves as the master time source, while the other WR switch operates as the slave.

Due to the long distance and asymmetry of the fiber link, a time deviation will exist between the signals from the two switches. This deviation can be measured using a counter. The measured deviation, along with a timestamp, is stored in a Time Series Database (TSDB). The data can be retrieved from the TSDB for further processing.



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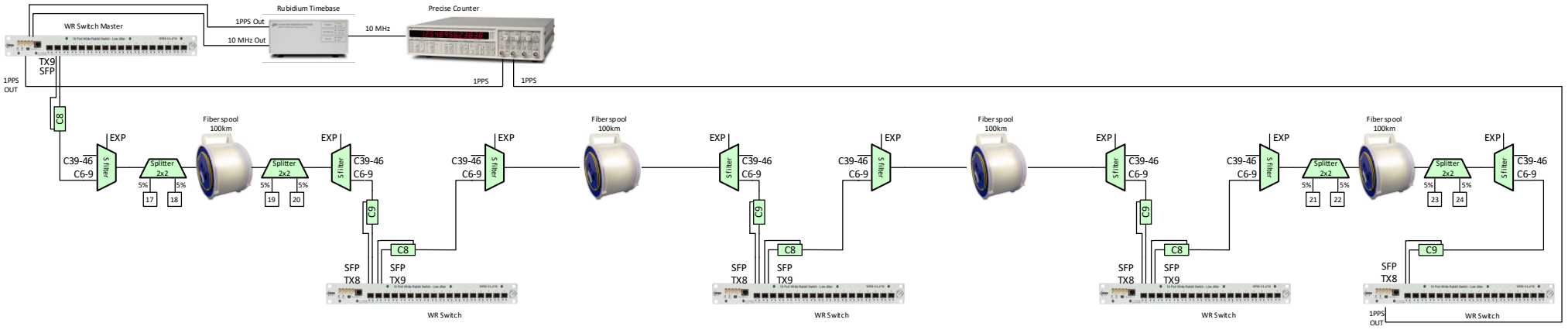
WR signal regeneration using chained WR Switches

In the WR regeneration chain, the link comprised three WR Switches arranged such that each acted as a slave to its predecessor and a master to its successor, interconnected by the same four 100 km fiber spools.



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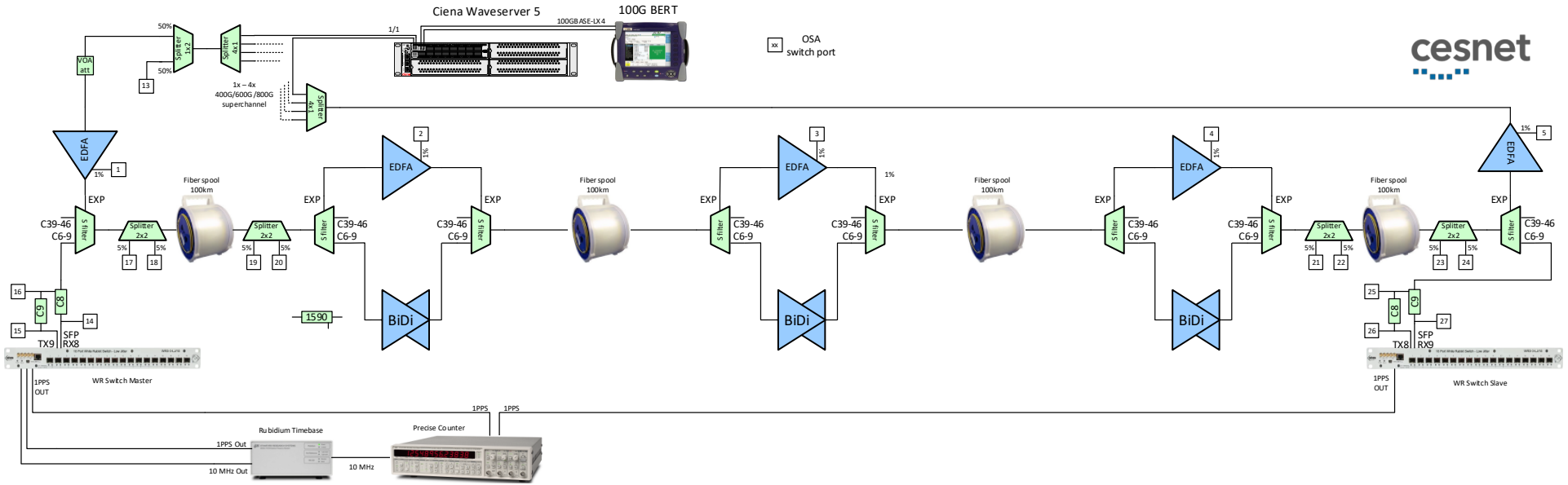
Optical amplification via an Bidirectional Erbium Doped Fiber Amplifier (BiDi EDFA)

- 3x BiDi EDFA in the middle of the route 4x 100 km
- 4skip0 filters for separation of DWDM C-Band and 1572 nm L-band
- Bisi EDFAs used for 1100km of coherent reference transfer, since 2016 with very good operation experiences
- Standard EDFAs C-Band for simulating the operation of coherent signals N x 400/600/800Gbit/s



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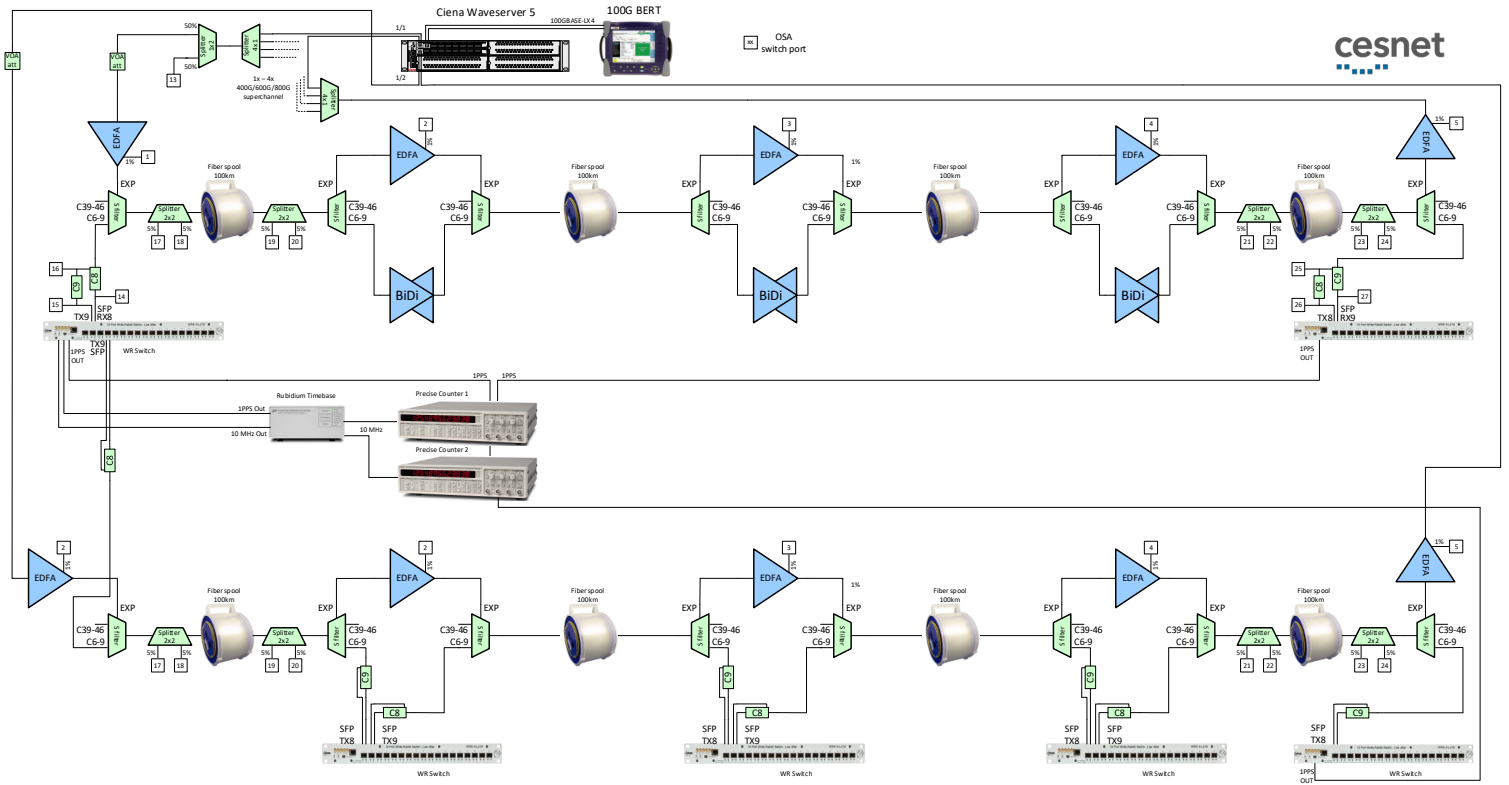
White Rabbit lab test setup, both variants - BiDi EDFA and WR repeaters



4x 100 km Cesnet Test White Rabbit / Superchannel 400/800G – BiDi EDFA version plus repeater version

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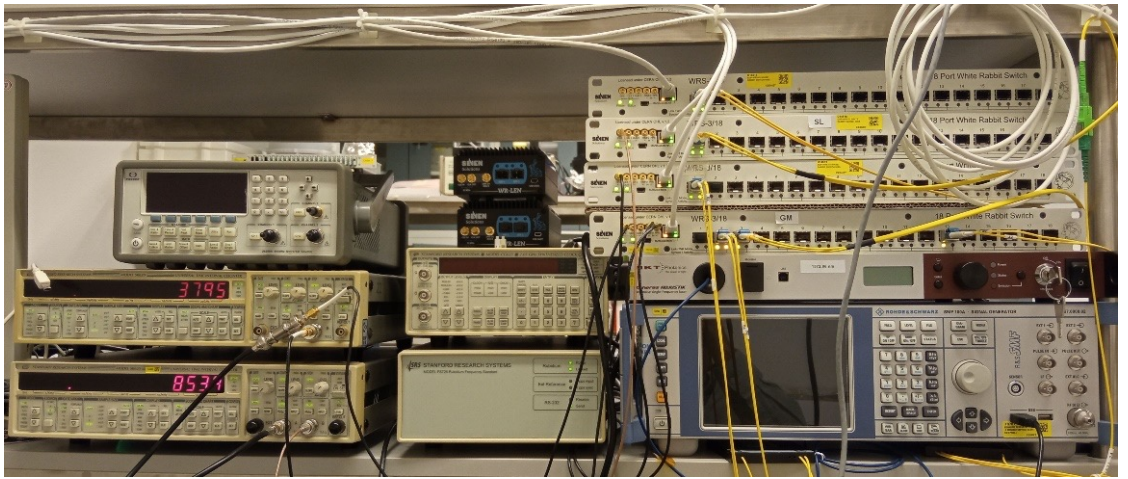
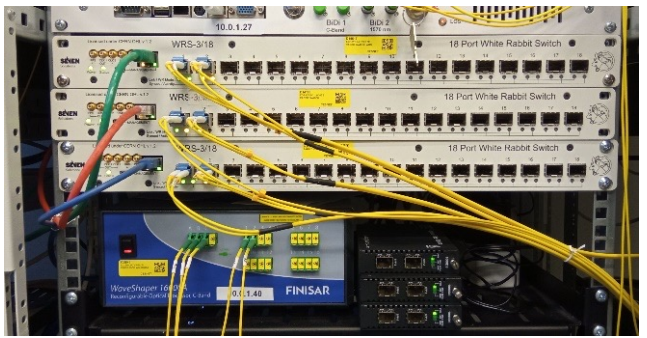
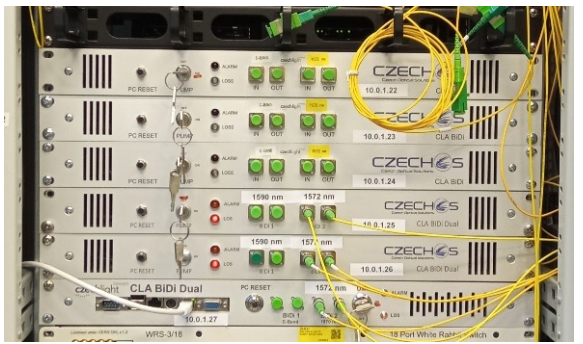
Photos of the laboratory setup



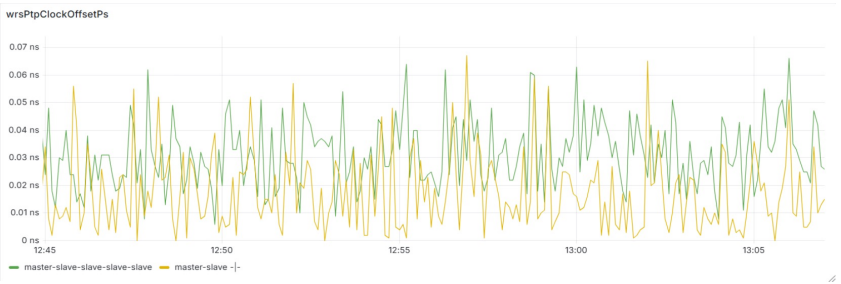




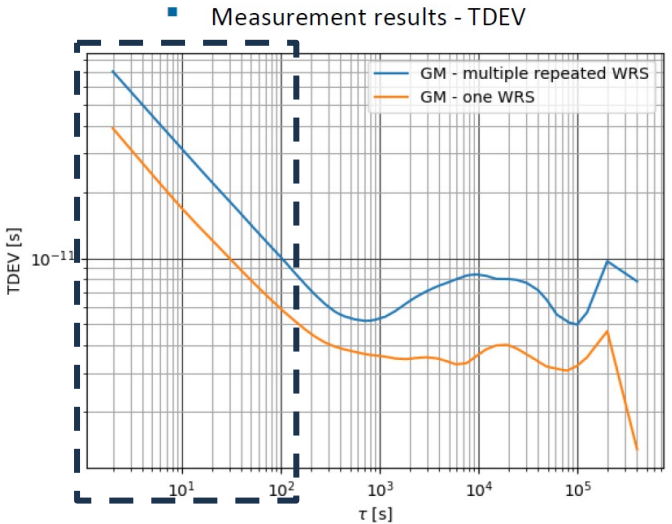
Lab Results

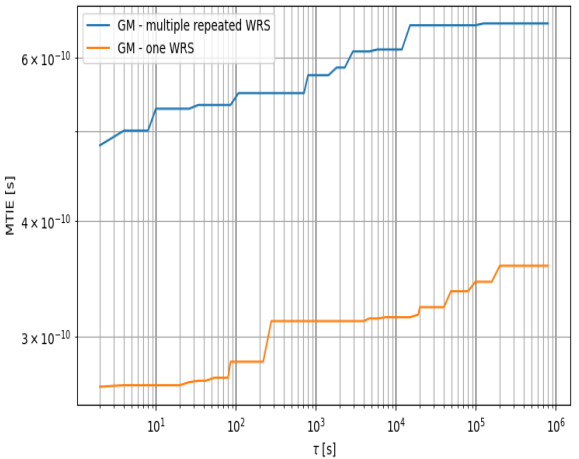
WR regeneration vs. bidi optical amplifie

Time Deviation (TDEV): measures the stability of a clock signal by quantifying the root-mean-square (RMS) timing error over various observation intervals.



Clock Offset from WRS





Analysis of the 1PPS signal data clearly indicates that the **optical amplification method offers better time stability**.

Regeneration with White Rabbit Switches
Regeneration with bidi amplifiers

Field-Trial over GEANT DWDM system Prague-Vienna

On GÉANT route Prague – Vienna: Prague – Kouřim – Šachotín – Ivančice and back

Test is on one fiber in loop – stability measurement with CLA BiDi SDN controlled EDFA used in new gen of CESNET TF network

Existing DWDM Infinera, L-band acess, CWDM OSC channel 1590 nm

Verification for possible future deployment for GÉANT routes

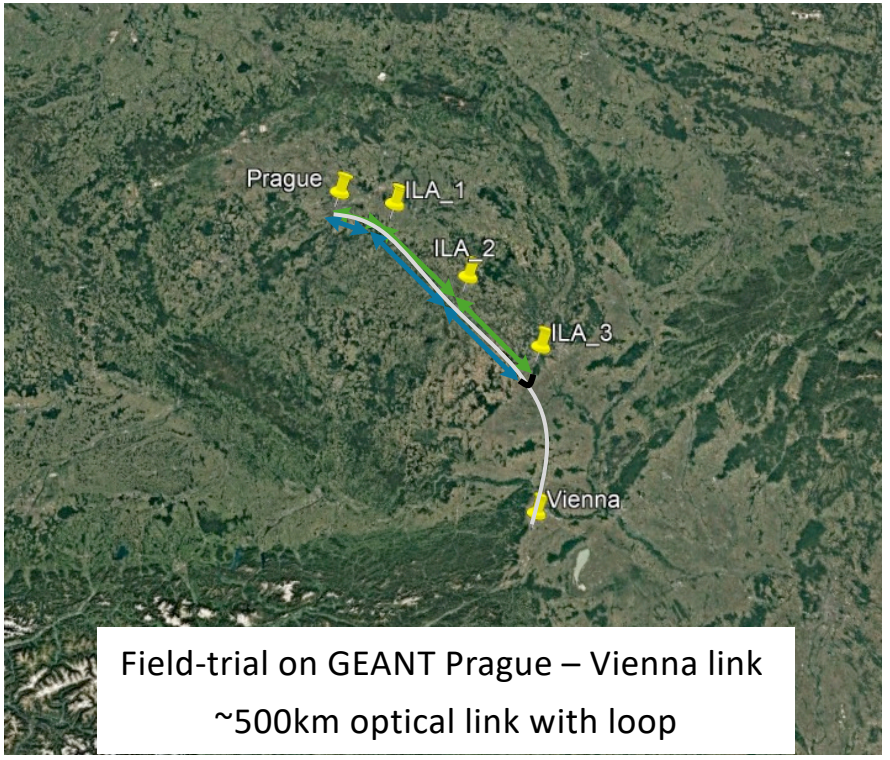
1. step: 3x BiDi EDFA, 322 km

2. step: 5x BiDi EDFA, 498 km

    1GBE DWDM L-Band 120 km optical SFP transceivers (Ch.8 and 9)

Loopback on the 2nd fiber and measure performance

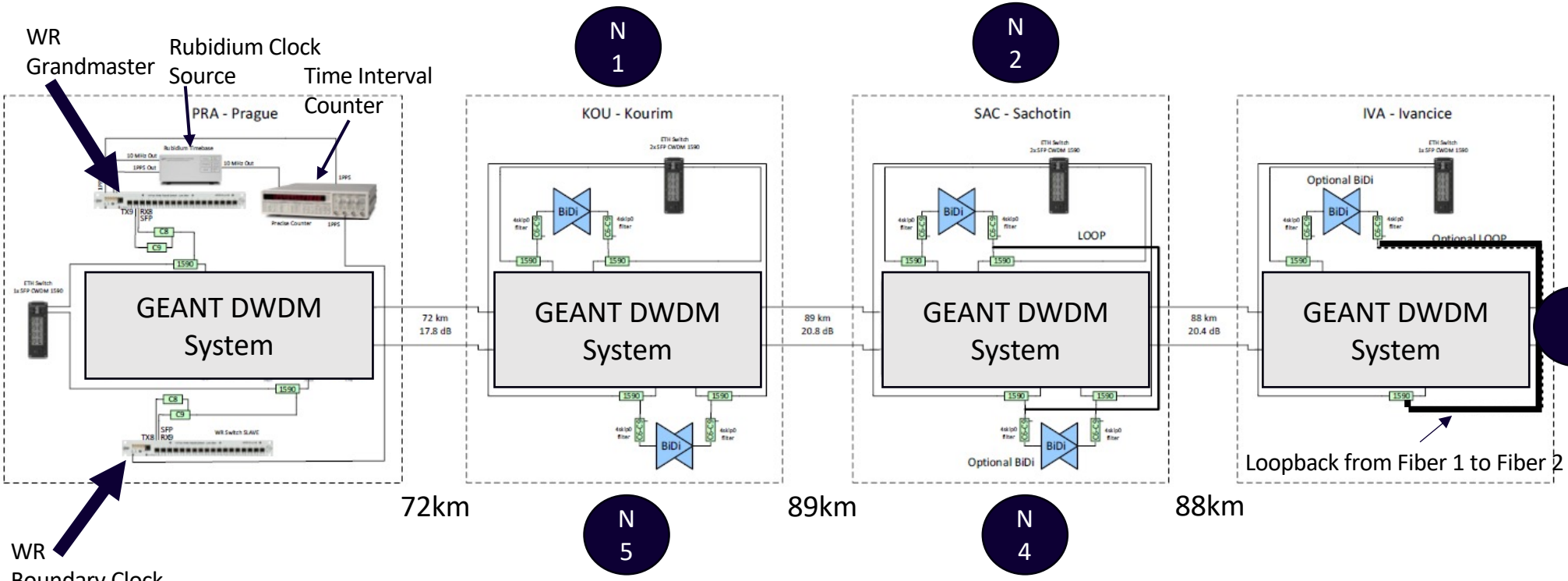
    Total fiber path end-to-end ~ 500km



Field-trial on GEANT Prague – Vienna link

~500km optical link with loop

Field-Trial Setup



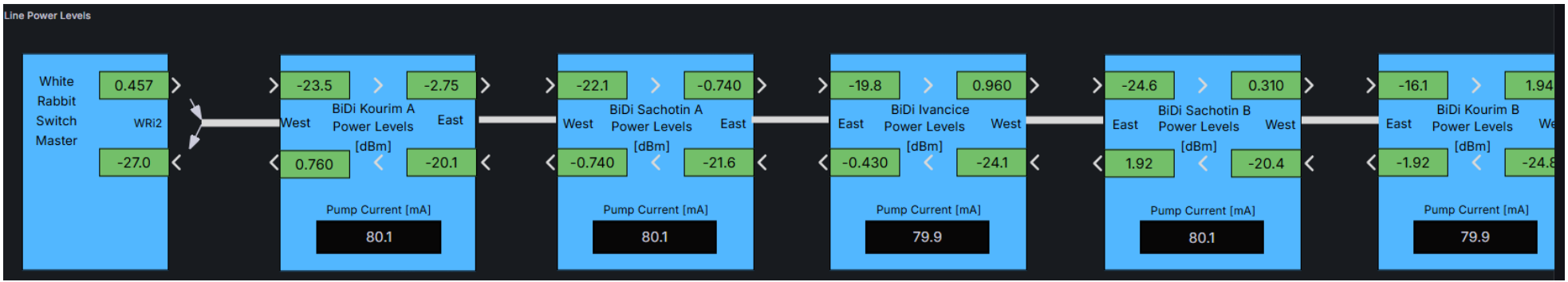
End-to-End WR grandmaster to WR slave is 498km

Sikt

Field-Trial Results – No Impact on Data Channel

2 x 400G channels (in C-band) running in parallel with the white rabbit T&F service (in L-band)

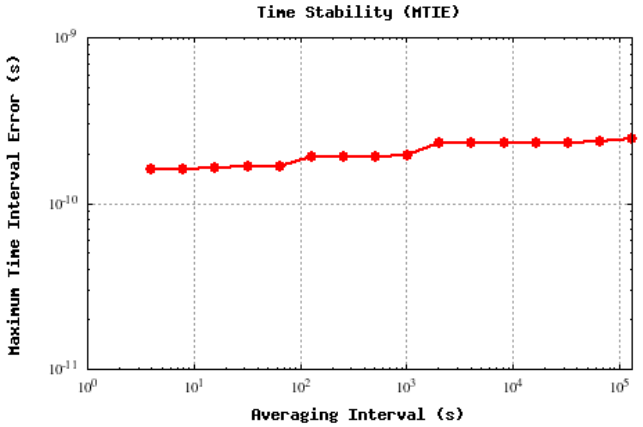
Both pre-FEC-BER and Q-margin before and after White Rabbit activation, are at the same level

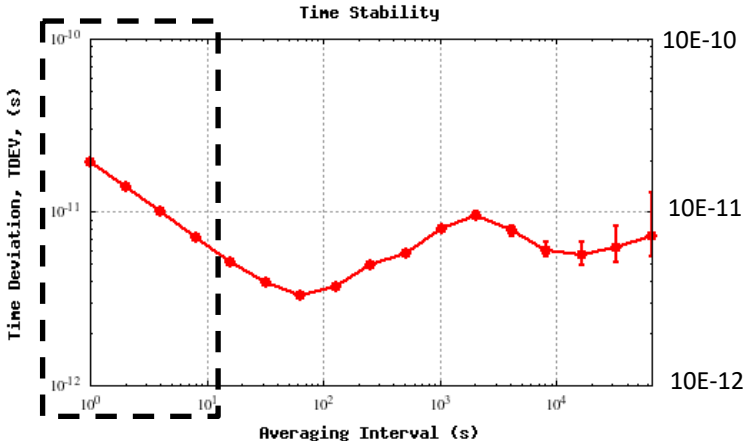


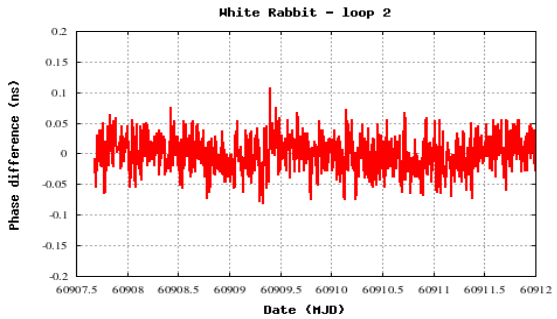
Field-trial Results of T&F Performance

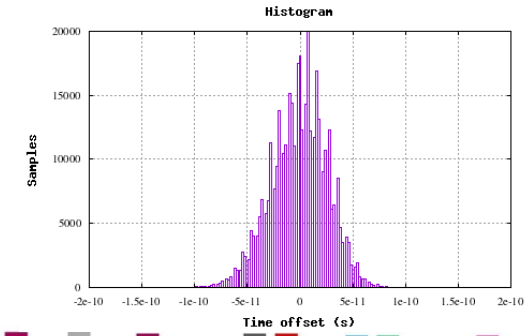
Longer 500 km loop

MTIE < 200ps, TDEV <10ps (1-1000s)









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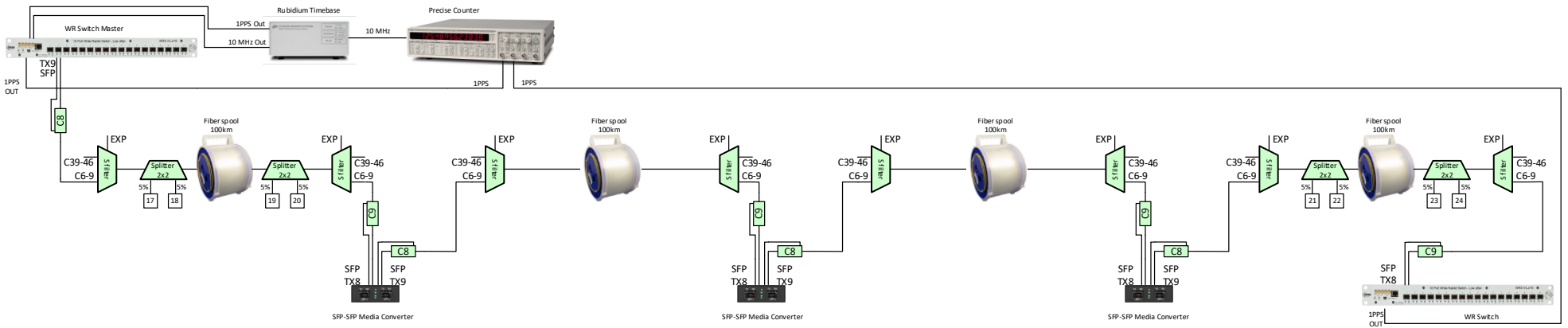
OEO Regeneration Evaluation

- Despite it requires per segment (re) calibration
- FUNET & SUNET have already deployed such a solution
- NPL in design stage of an OEO unit (product requirements gathering)
- OPNT has developed an OEO unit

Actuall work

- Laboratory test of signal regeneration using SFP-SFP media converters (CTC Union interruped, because of overheating of converters in simple pasively cooled chassis)
- Will continue with rack mountable chassis with fans
- Tests of regens provided by OPNT



Next Steps

Survey ongoing – please reach out raimena.veisllari@sikt.no

Performance-cost analysis of the different solutions

Whitepaper on best practices for NRENs both for intra- and inter-borders

Interested in precise timing?☺ Consider participation in:

Precise Time and Time Interval Meeting
January 26-29, 2026
Anaheim, CA

cesnet

Thank You very much for kind attention!

Questions?

We are open for cooperation and experience exchange.

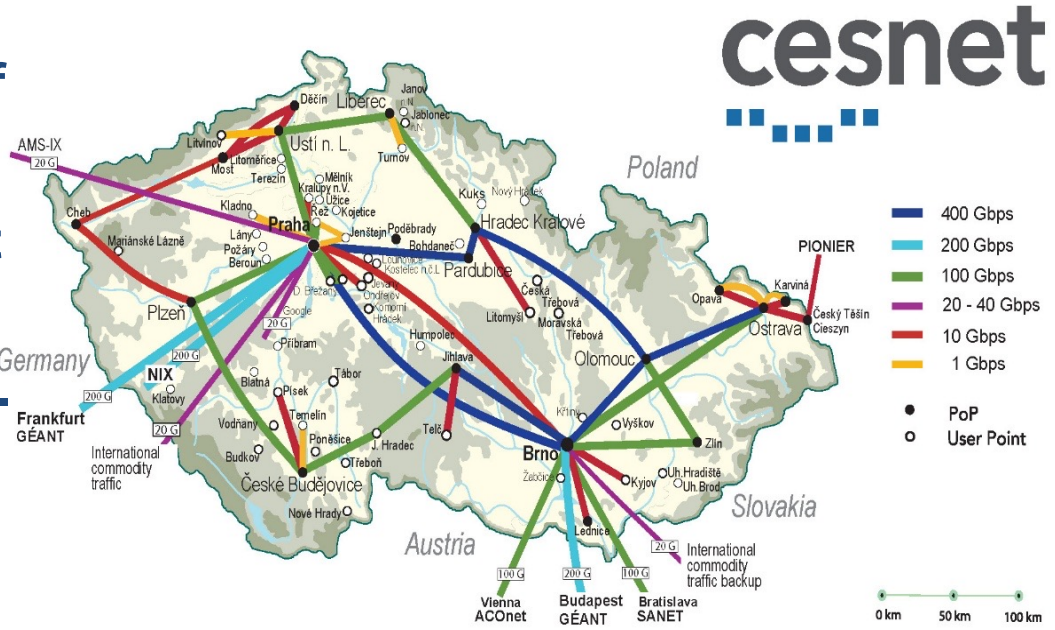
vojtech@cesnet.cz

cesnet

Time Distribution in CESNET Network
National White Rabbit Network

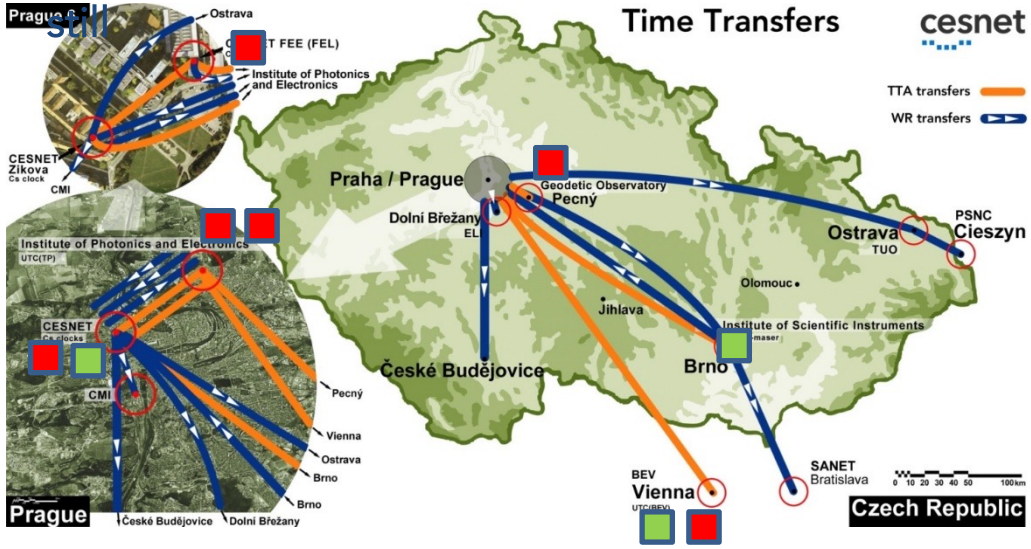
CESNET3 network

- **CESNET3 network almost 5800 km of fiber routes**
- **Based on coherent transmission, but some non-coherent service remains**
- **For time and frequency dedicated all-optical bidirectional bandwidth reserved (skip telecom equipment)**
  - 120 pcs. of OADMs deployed Dual window OADMs installed



TF transfers

- Since 2009, now precise time transmission over 2200+ km
- Shared with data services
  - Bidirectional transfer over dark channel in operational DWDM on shorter routes
  - Some services over bidi amplified dark channels, some over telecom lambdas



Time Transfer Adapters

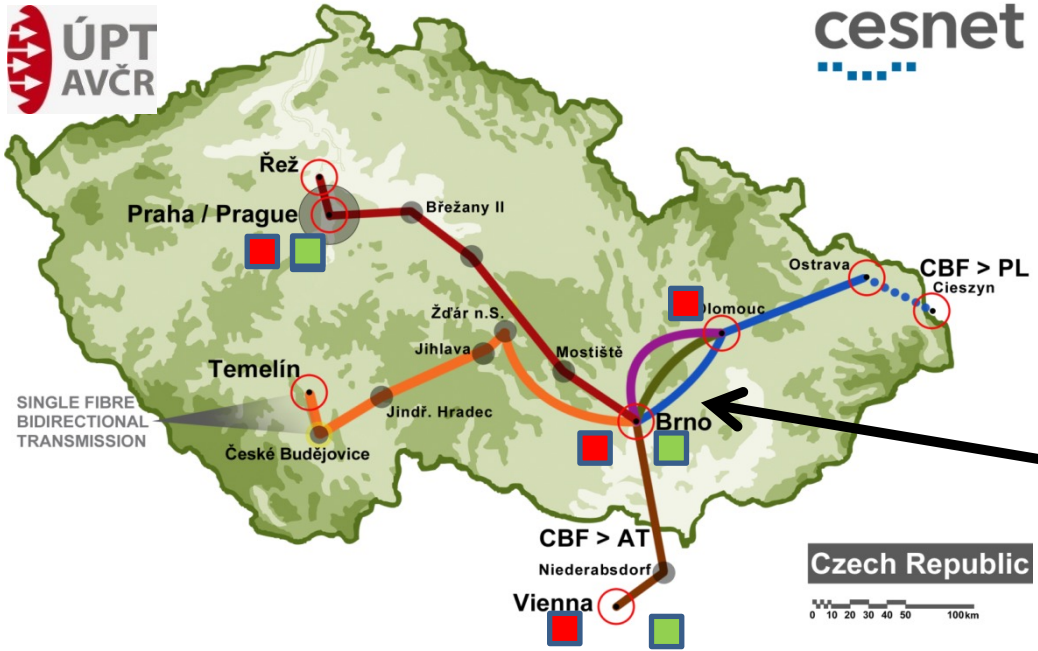
Own developed FPGA based, TDEV ~ 20-30ps at 1E3s

White Rabbit

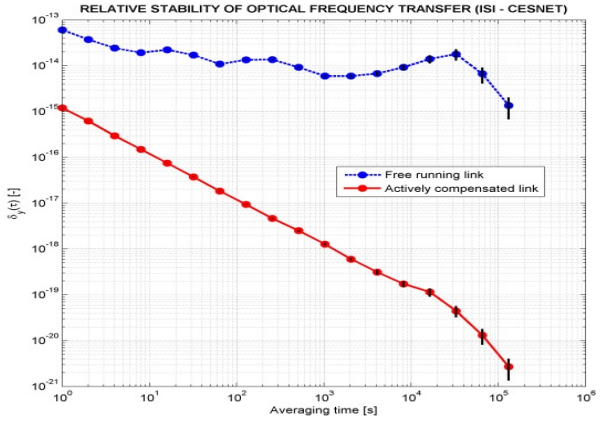
Cs clock 5071A

Active H - maser

Infrastructure for Time and Frequency



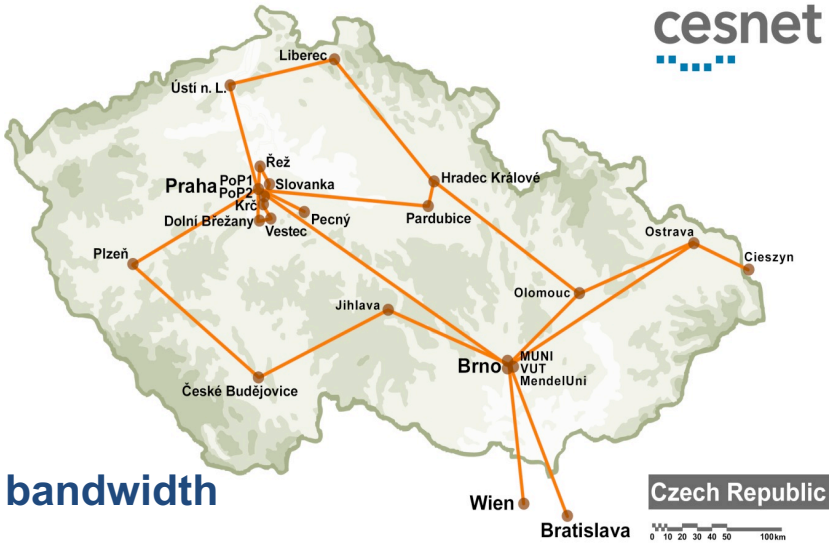
- Optical clock (under development)
- Metrology laser for length purposes

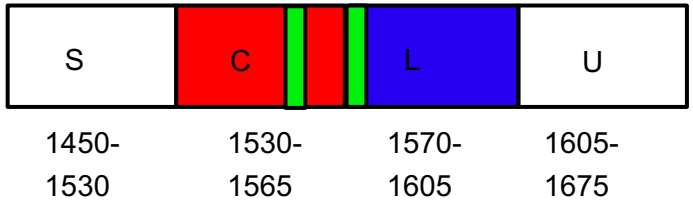


CESNET Praha - UPT Brno 306 km, ADEV 10^{-18} @10^{3} s

Large national e-Infrastructure project - modernization of CESNET optical network running

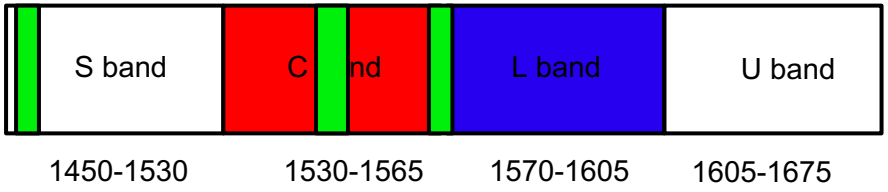
- **Sub-goal: Infrastructure for accurate time distribution**
- **Operate a reliable distributed WR system is a challenge**
  - monitoring
  - resilience
- **2500+km with 20 Points-of-Presence with WR switches**
  - WR PoPs in neighboring countries: AT (Vienna)
  - Poland (Cieszyn), SK (Bratislava)
- **Bidi transfer over dark spectrum using special OADMs for bandwidth**
- **Dedicated dual band bidirectional amplifiers**
- **Two independent sources of accurate time traceable to UTC(TP)**
  - H-masers in Cesnet (Prague) and UPT (Brno)

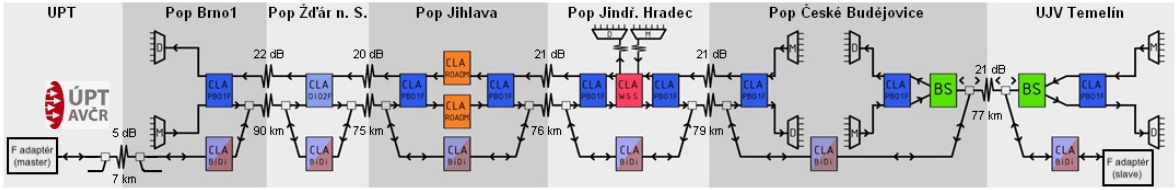




Shared Spectrum

- Total fibre infrastructure 5800 km approx., coherent 100-400Gbps per lambda
- For time and frequency dedicated all-optical bidirectional bandwidth reserved (skipping telecom equipment)
- 120 pcs. of OADMs deployed Dual window OADMs installed: 46-39 ch and 9-6 ch
- TF: 9-6, Coherent optical frequency (COF): channels 44+46
- One line with 1458nm COF transfer (Ca+ clocks)
- Dual band Bidi EDFAs used to compensate losses (about 40 new dual band to be added)





Long-hauls in CESNET

- Long reach
  - Use telecom lambdas (unidirectional, now coherent systems – need of guardbands)
  - Our first long haul line 300km 69 dB, dark spectrum, parallel transfer with data
  - Fully bidirectional EDFA amplifiers, no need for calibration
    - 2014 TTAs with SFPs based on Virtex 7
    - 2015 coherent optical transfer in parallel
    - 2017 change model into bidirectionally lit channel using CzechLight bidi amps, still in operation