GEANT GN5-2 WP6 Incubator Project

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

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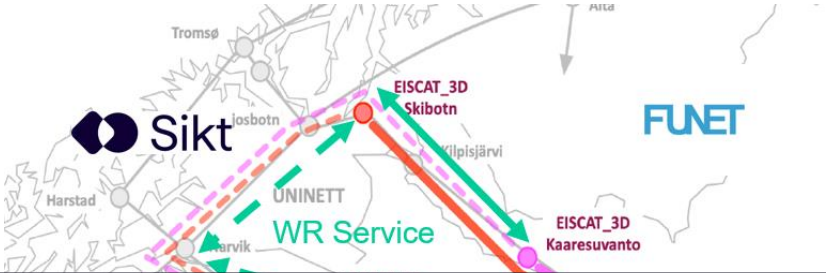
GNA-G Community VCs Q4 2025

2 and 3 Dec 2025

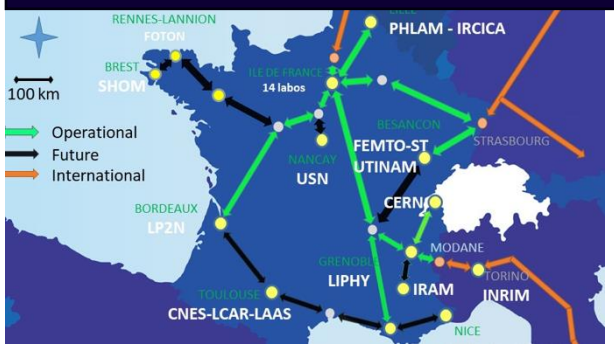
Multiple NRENs Already Deploy (National) WR Networks

A few examples

EISCAT 3D



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



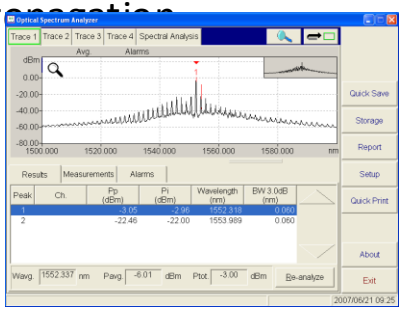
CESNET, SUNET, FUNET, SURF, INRIM/GARR, SWITCH, NETNOD, RENATER/REFIMEVE, …..

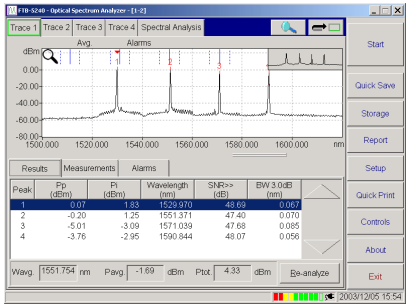
GN5-2 WP6 NETDEV Incubator Project
(ongoing –> Feb.2026)

- 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 $t_{MS} = \alpha + t_{SM}$ is not valid
  - Dark channel/fibre – with bidi pr[illegible]



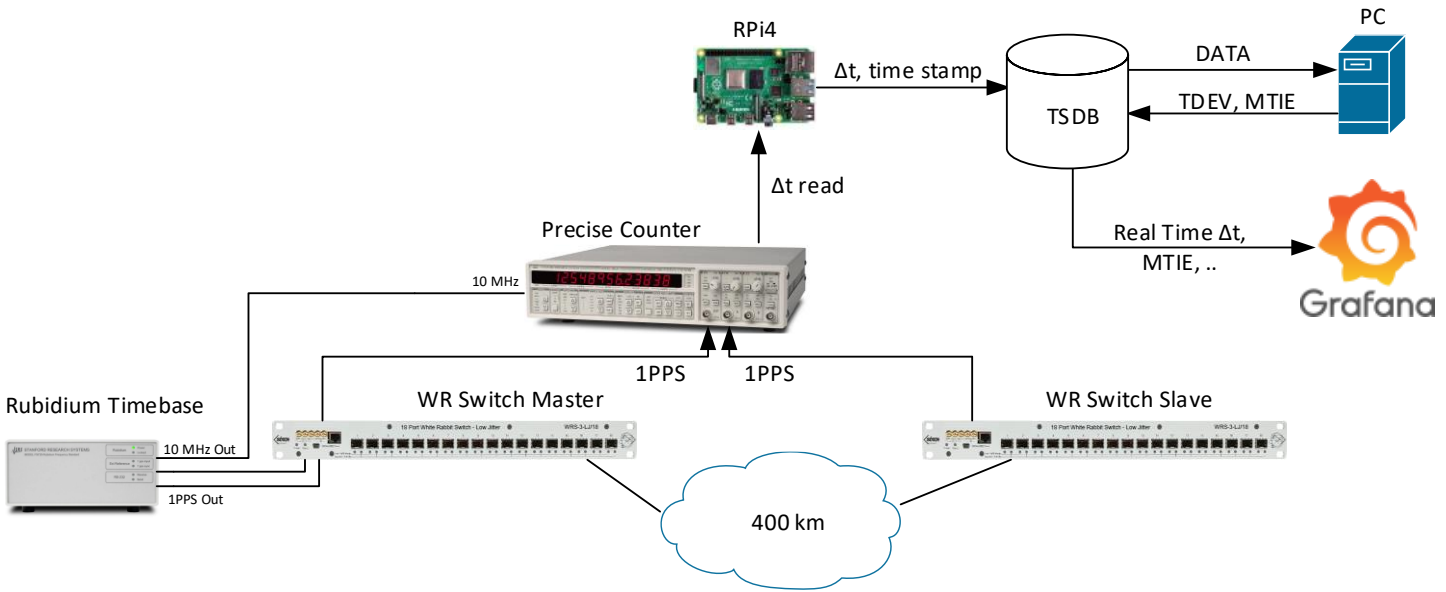


GN5-2 Long haul WR Incubator

- **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.

GN5-2 Long haul WR Incubator

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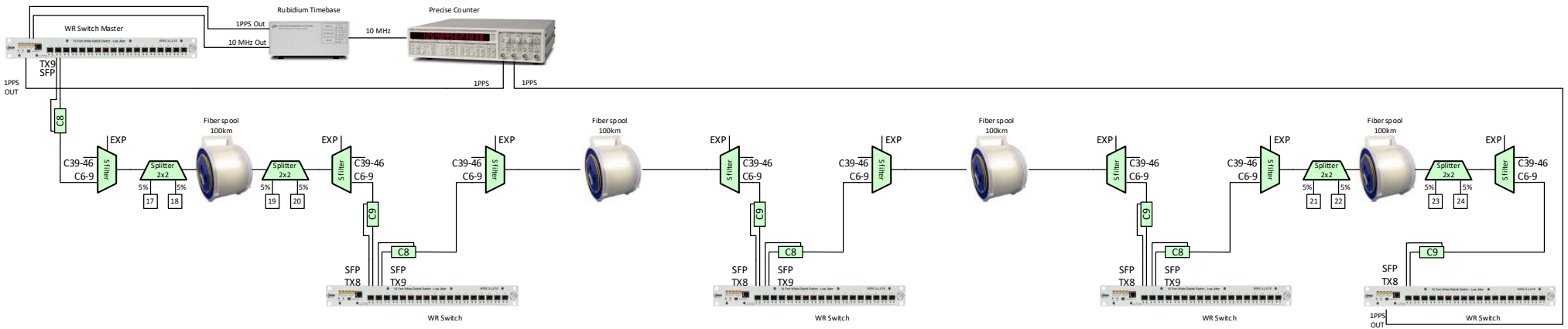
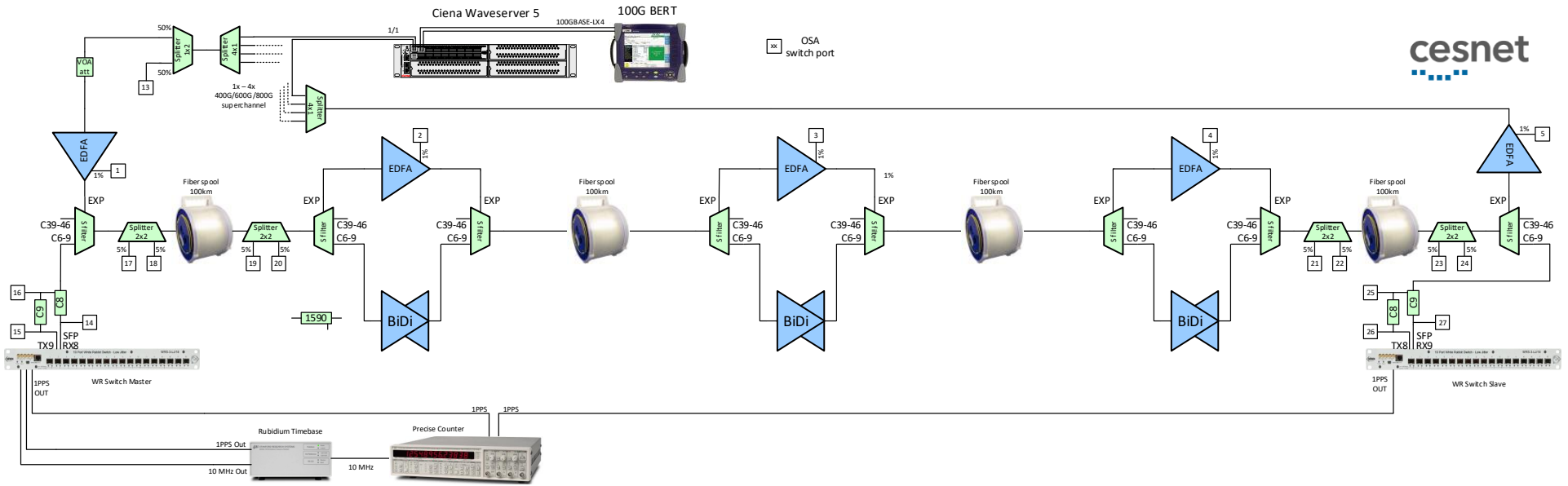
- **WR signal regeneration using chained WR Switches**
  - In the WR regeneration chain, the link comprised three WR Switches arranged such that each acted as a slave to its predecessor and a master to its successor, interconnected by the same four 100 km fiber spools.



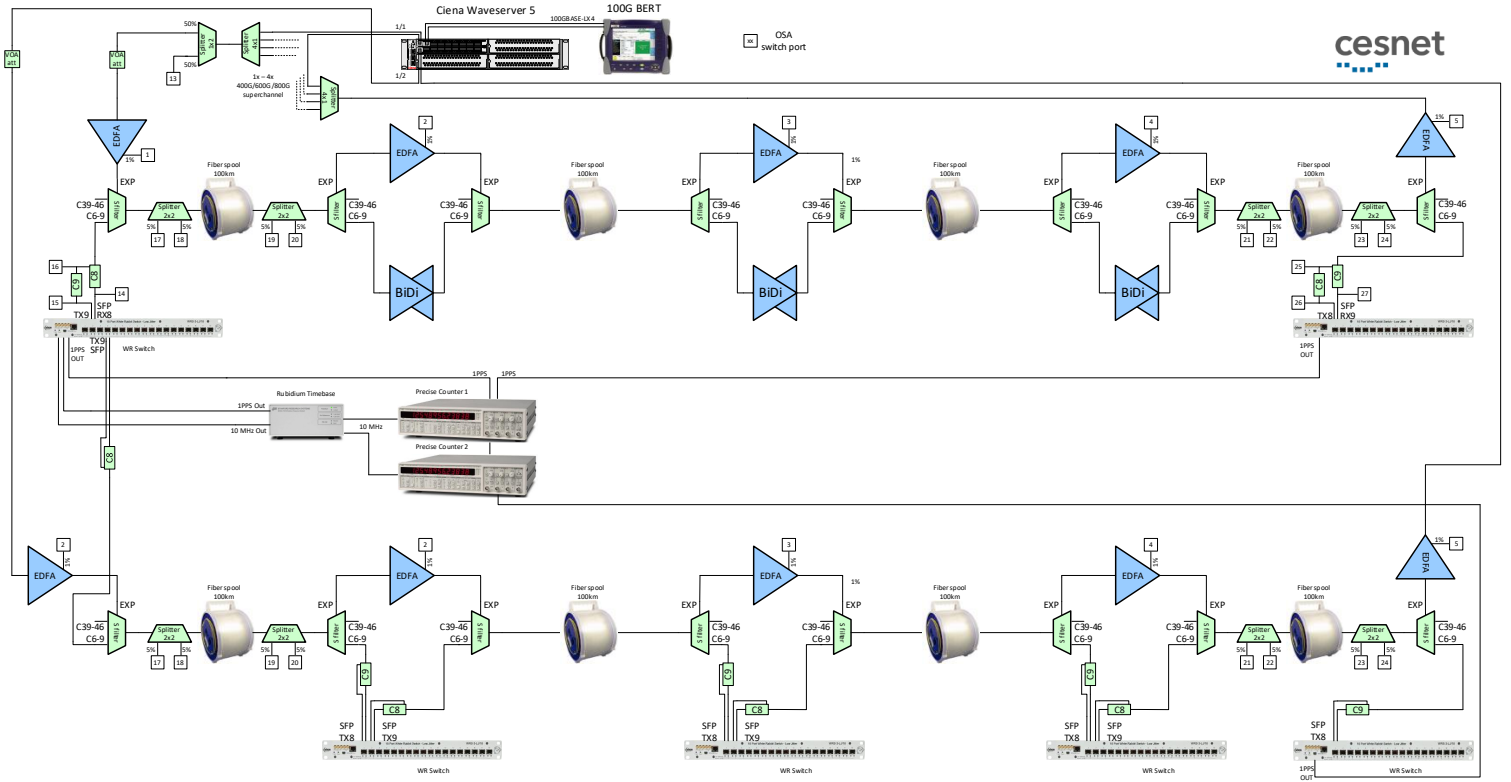
GN5-2 Long haul WR Incubator

- **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



GN5-2 Long haul WR Incubator

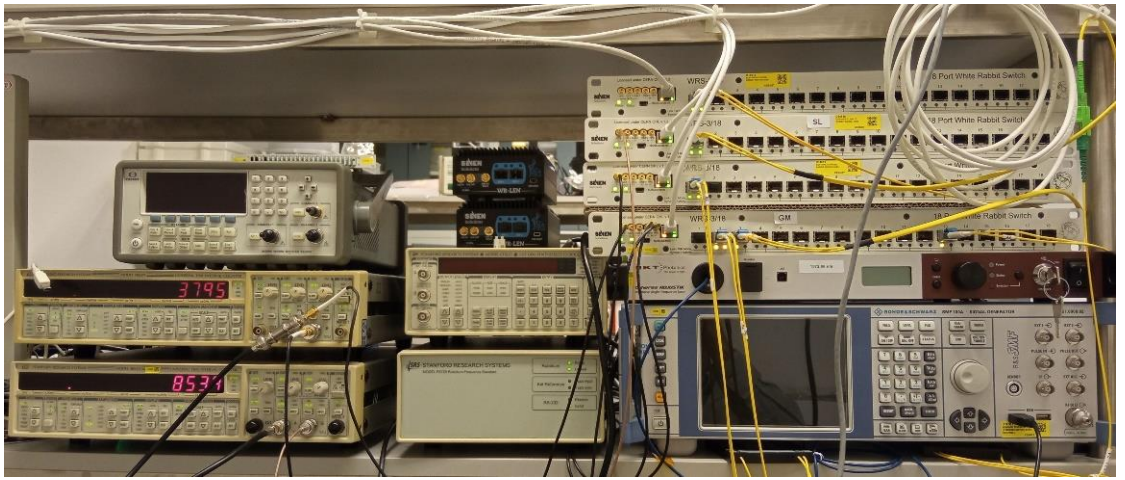
White Rabbit lab test setup, both variants - BiDi EDFA and WR repeaters

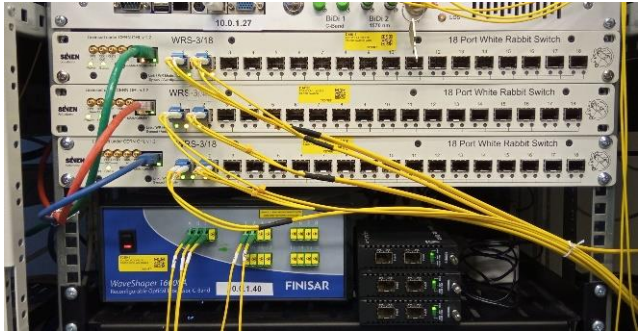


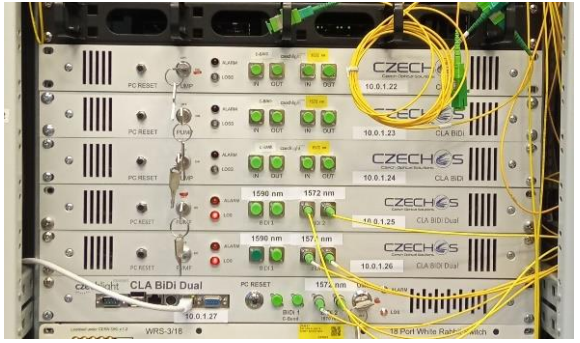
4x 100 km Cesnet Test White Rabbit / Superchannel 400/800G – BiDi EDFA version plus repeater version

GN5-2 Long haul WR Incubator

Photos of the laboratory setup







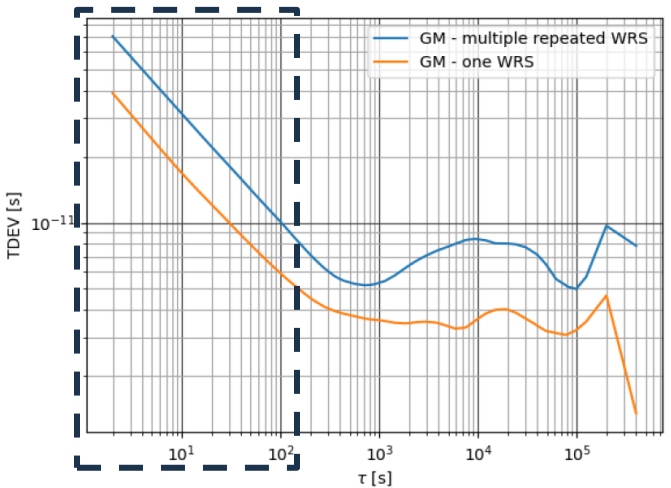
Lab Results

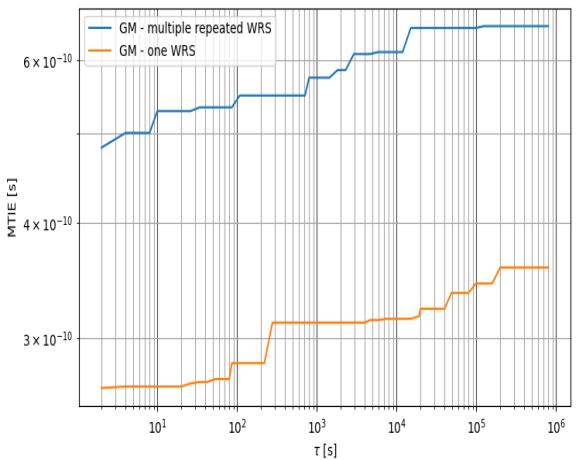
WR regeneration vs. bidi optical amplifiers

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

- Measurement results - TDEV



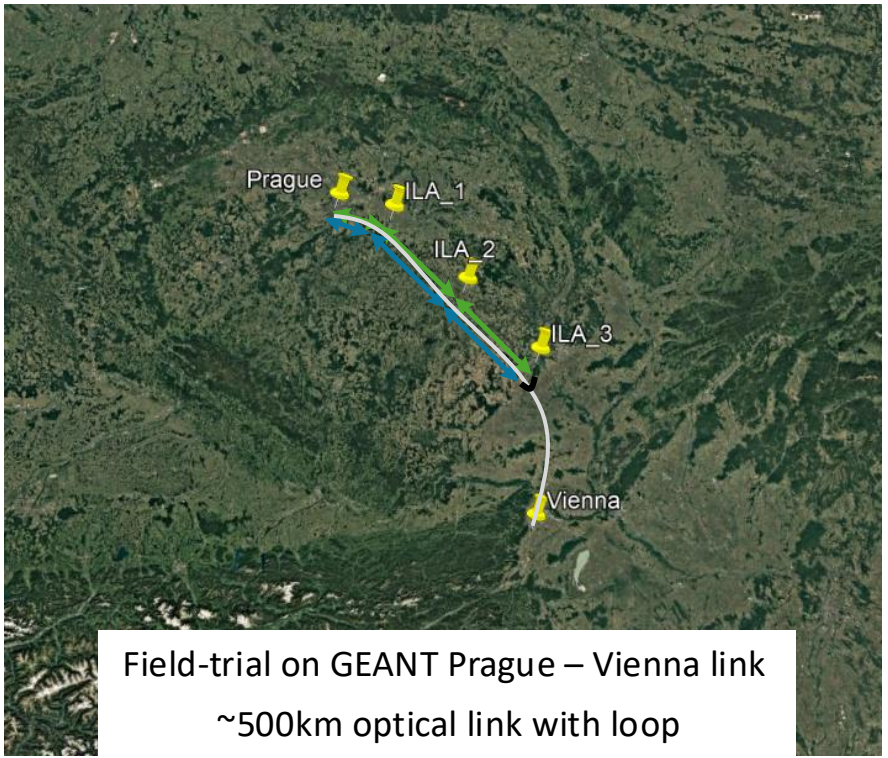


Analysis of the 1PPS signal data clearly indicates that the **optical amplification method offers better time stability**.

Regeneration with White Rabbit Switches
Regeneration with bidi amplifiers

Field-Trial over GEANT DWDM system Prague-Vienna

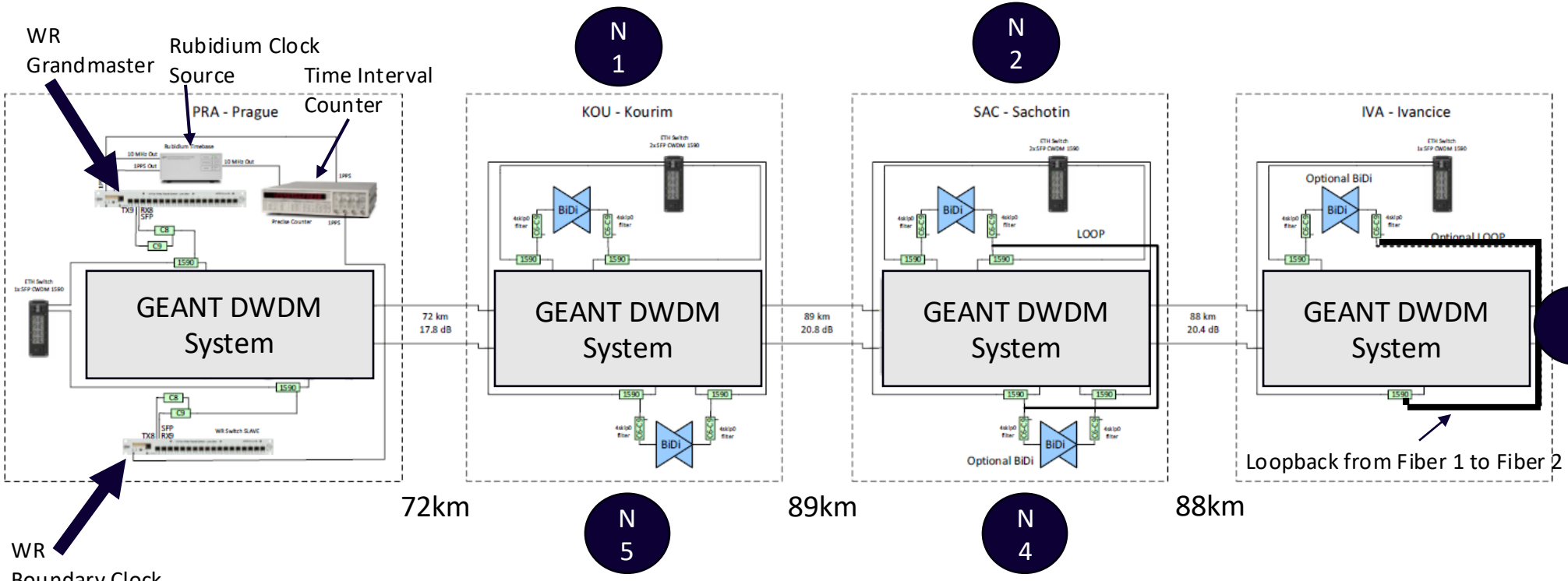
- On GÉANT route Prague – Vienna: Prague – Kouřim – Šachotín – Ivančice and back
- Test is on one fiber in loop – stability measurement with CLA BiDi SDN controlled EDFA used in new gen of CESNET TF network
- Existing DWDM Infinera, L-band acess, CWDM OSC channel 1590 nm
- Verification for possible future 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

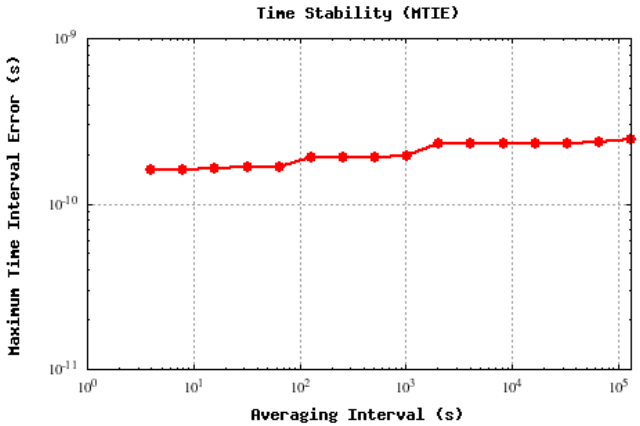
Field-Trial Results – No Impact on Data Channel

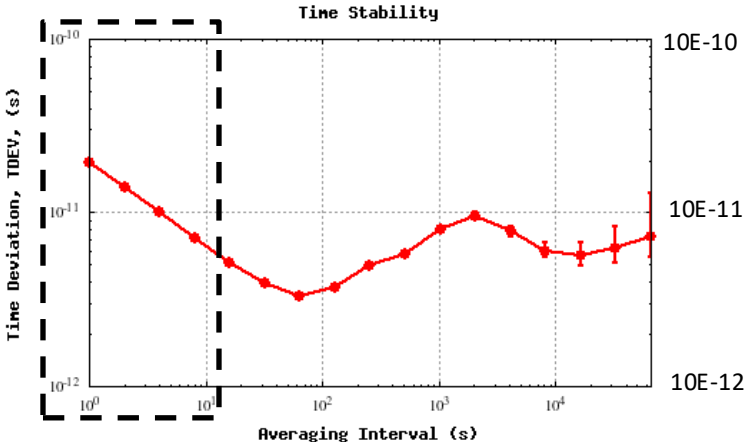
- 2 x 400G channels (in C-band) running in parallel with the white rabbit T&F service (in L-band)
- Both pre-FEC-BER and Q-margin before and after White Rabbit activation, are at the same level

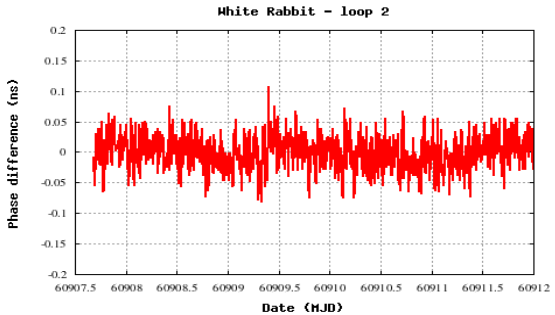
Field-trial Results of T&F Performance

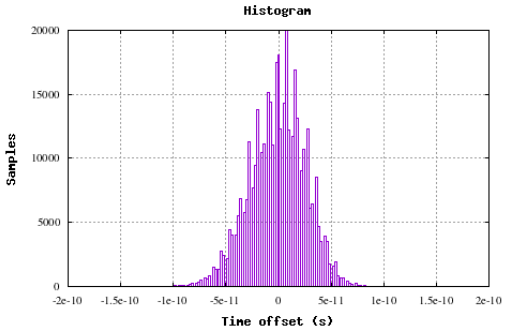
Longer 500 km loop

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



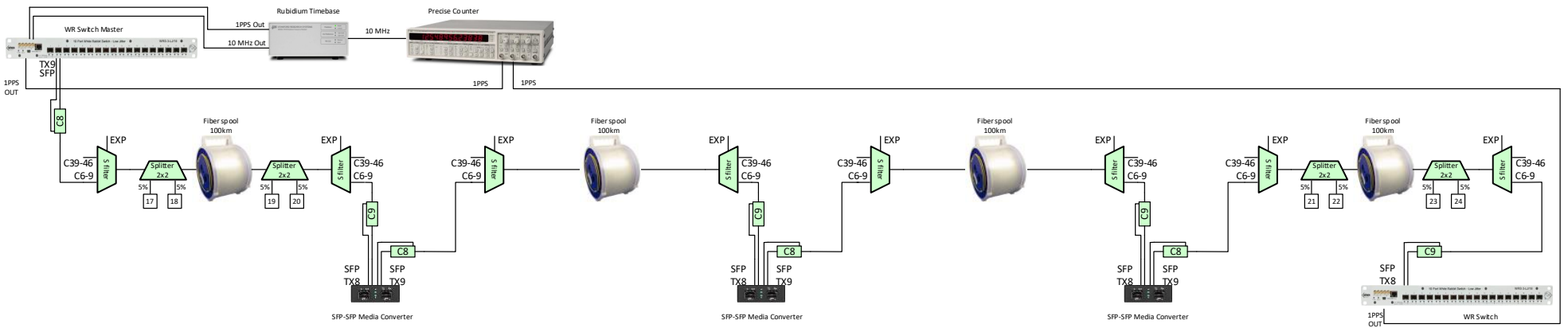






GN5-2 Long haul WR Incubator

- 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.

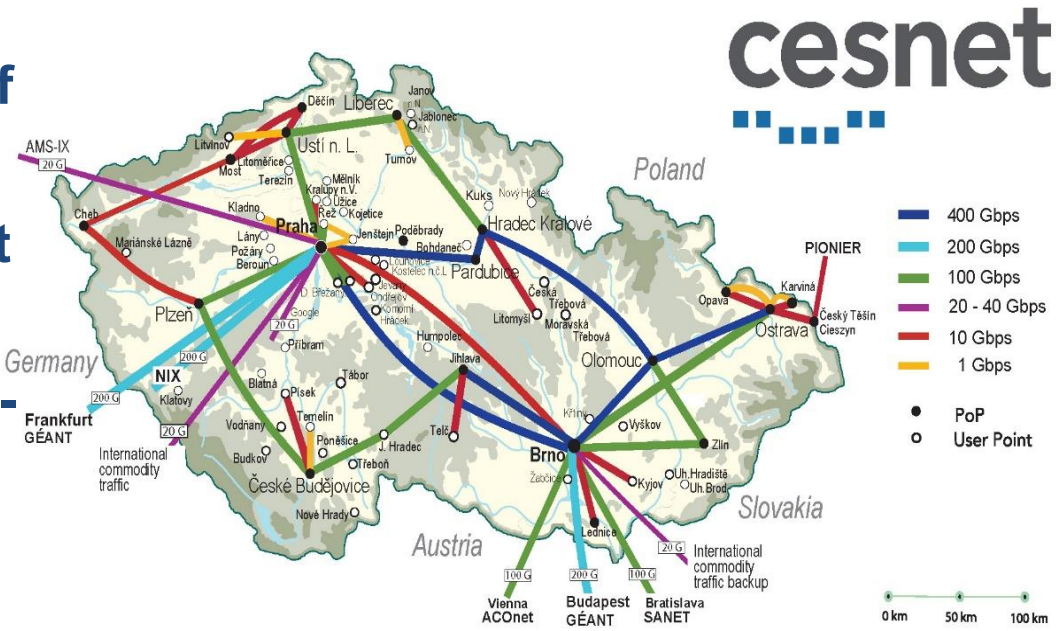
vojtech@cesnet.cz

cesnet

Time Distribution in CESNET Network
National White Rabbit Network

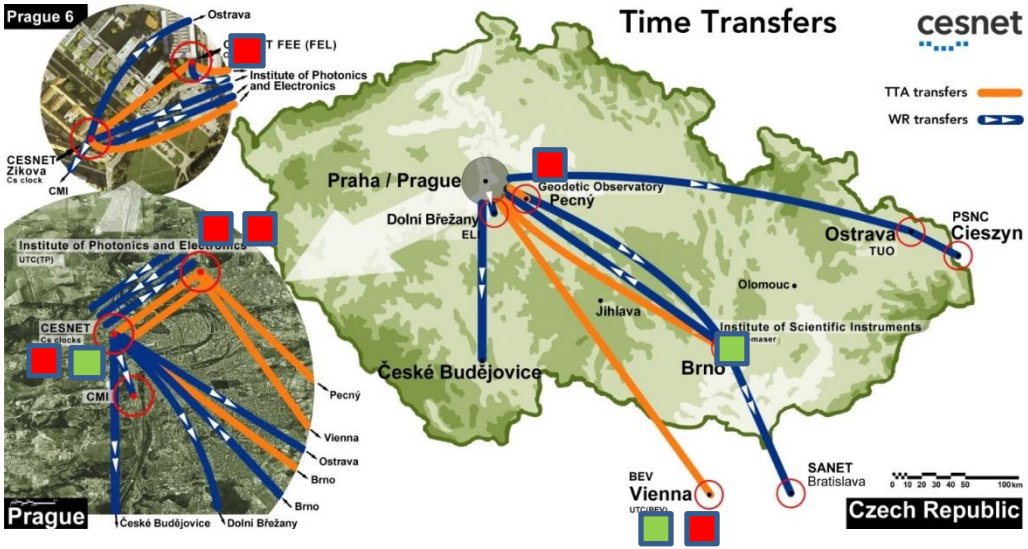
CESNET3 network

- **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

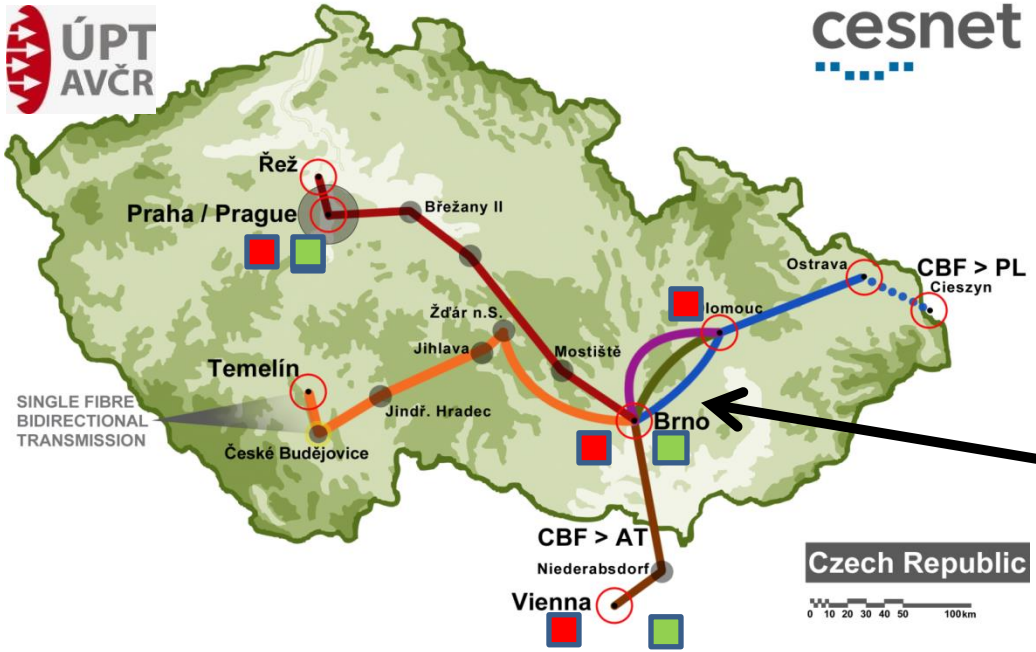
- Since 2009, now precise time transmission over 2200+ km
- Shared with data services
  - Bidirectional transfer over dark channel in operational DWDM on shorter routes
  - Some services over bidi amplified dark channels, some over telecom lambdas still



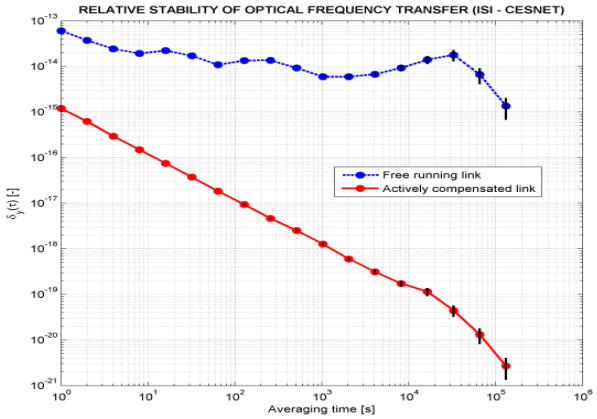
Time Transfer Adapters

- Own developed FPGA based, TDEV ~ 20-30ps at 1E3s
- **White Rabbit**
- **Cs clock 5071A**
- **Active H - maser**

Infrastructure for Time and Frequency



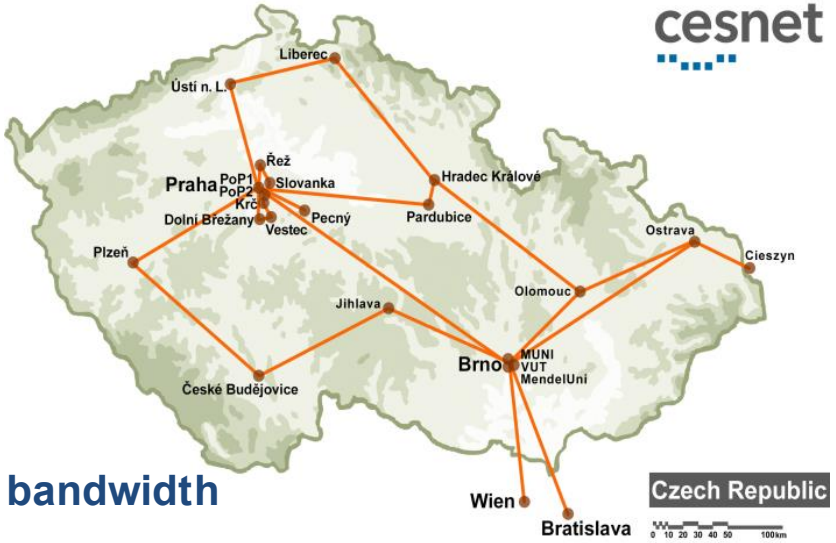
- Optical clock (under development)
- Metrology laser for length purposes

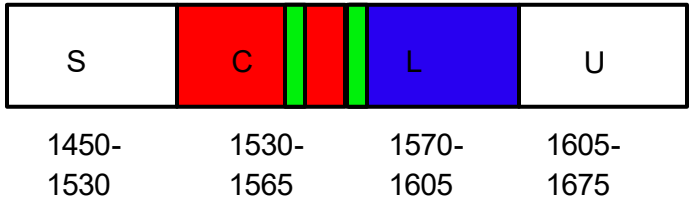


CESNET Praha - UPT Brno 306 km, ADEV 10^{-18} @10^{3} s

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

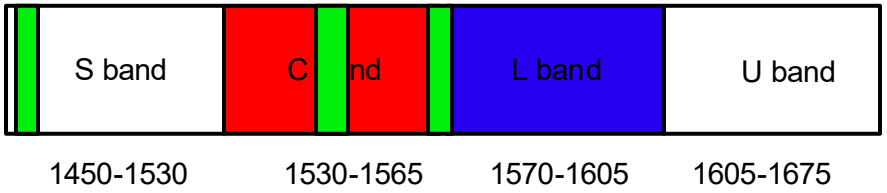
- **Sub-goal: Infrastructure for accurate time distribution**
- **Operate a reliable distributed WR system is a challenge**
  - monitoring
  - resilience
- **2500+km with 20 Points-of-Presence with WR switches**
  - WR PoPs in neighboring countries: AT (Vienna)
  - Poland (Cieszyn), SK (Bratislava)
- **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)

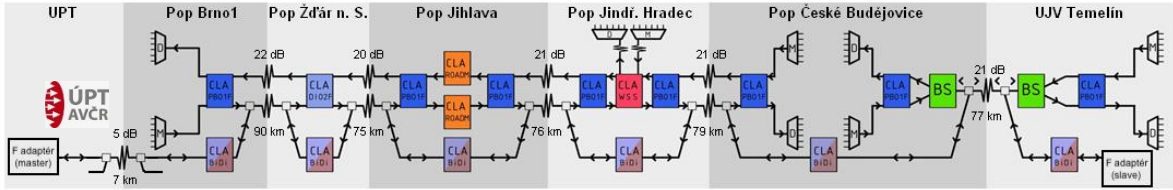




Shared Spectrum

- 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