



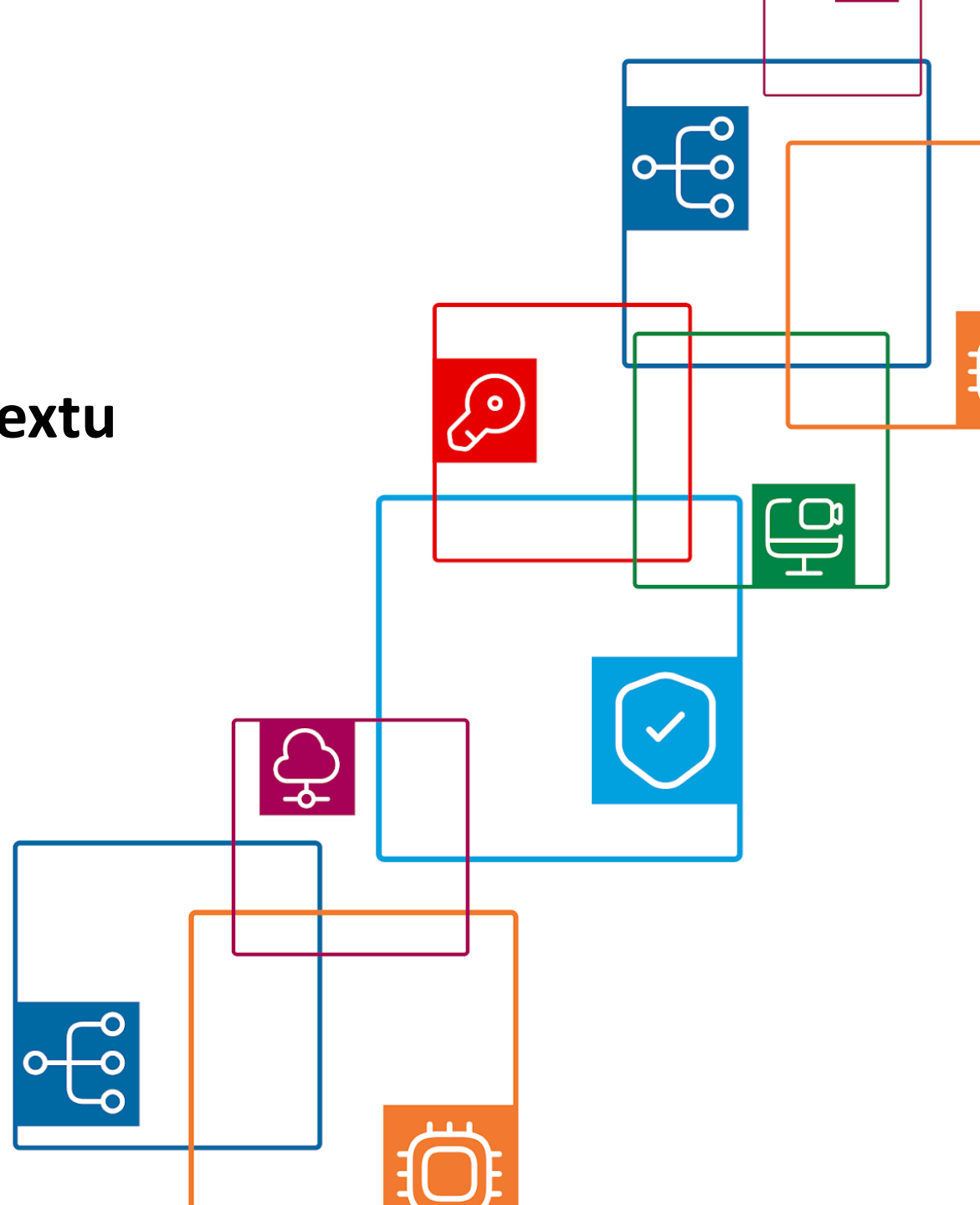
Ultrastabilní přenosy v evropském kontextu

Josef Vojtěch

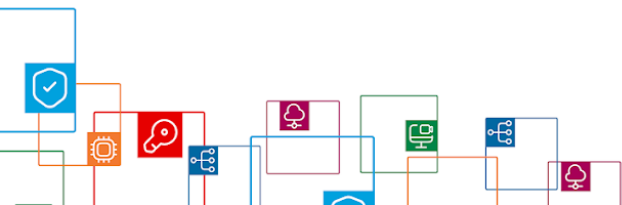
Oddělení Optických sítí

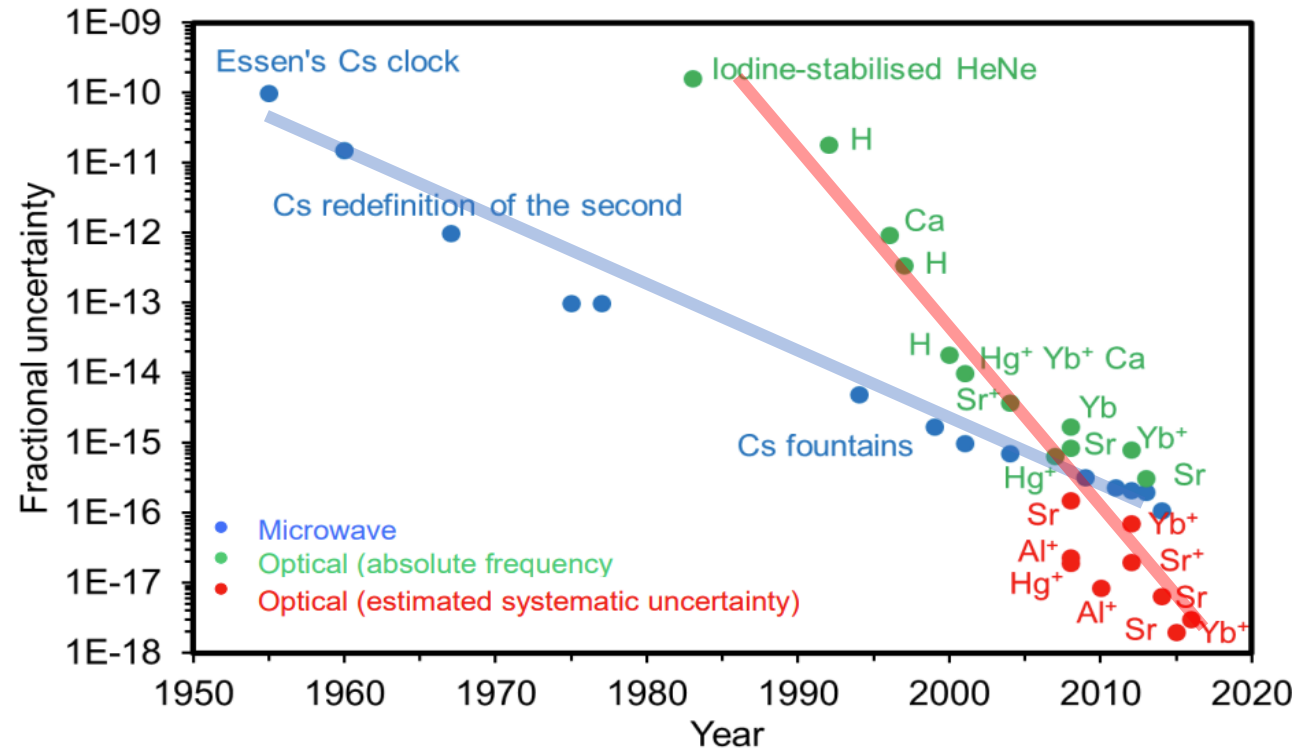
CESNET z.s.p.o.

Konference CESNET, 1. 10. 2026

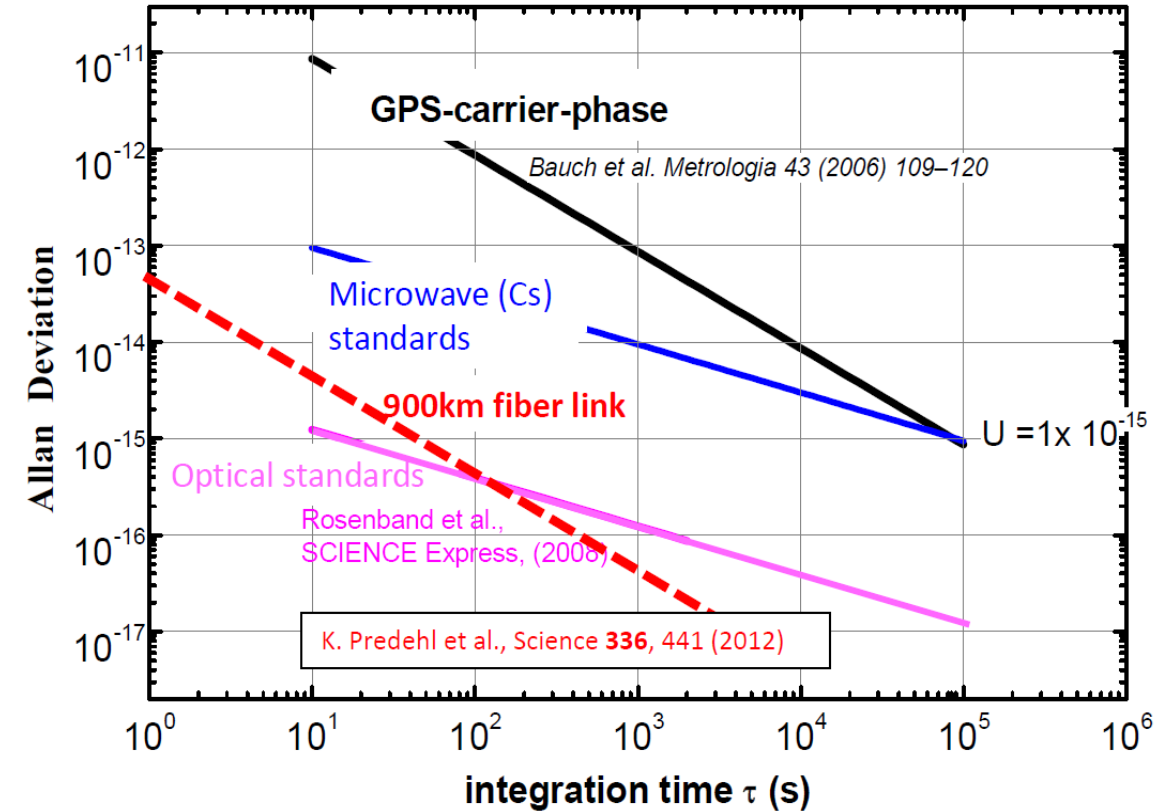


- TF projekty v Evropě
- FOREST
- GÉANT a Core-TFN
- Long-haul White Rabbit Incubator
- Závěr

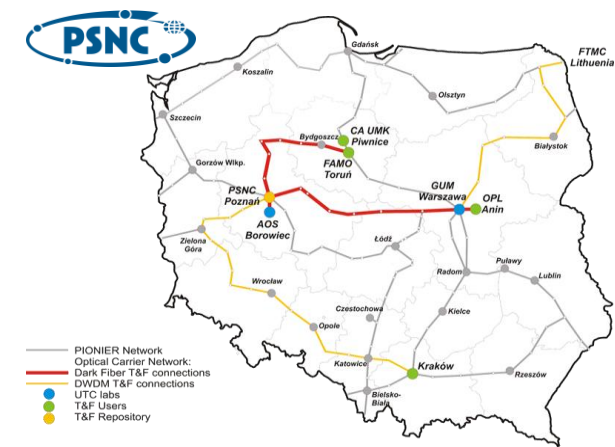
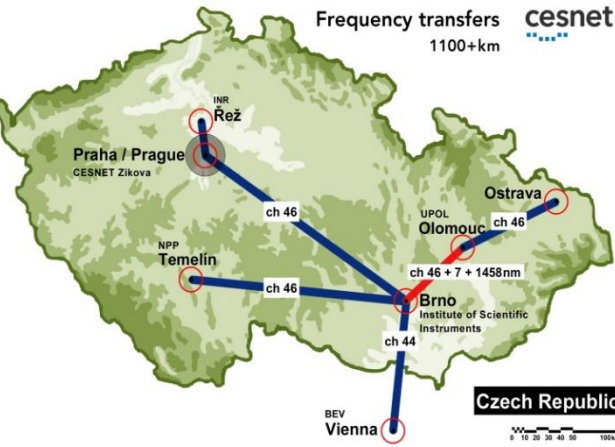
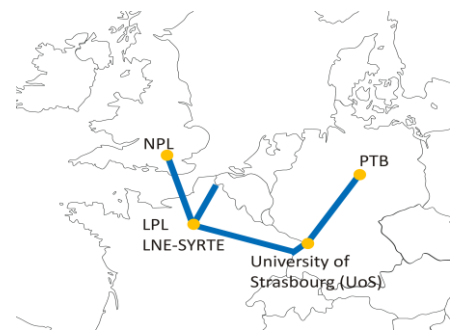
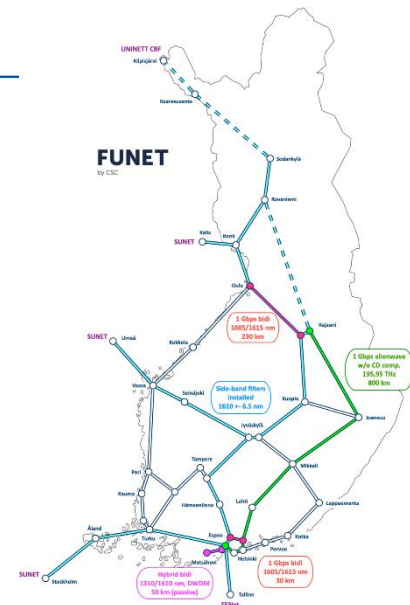
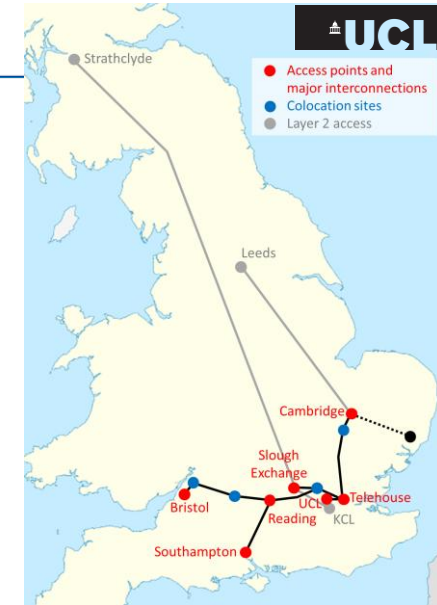
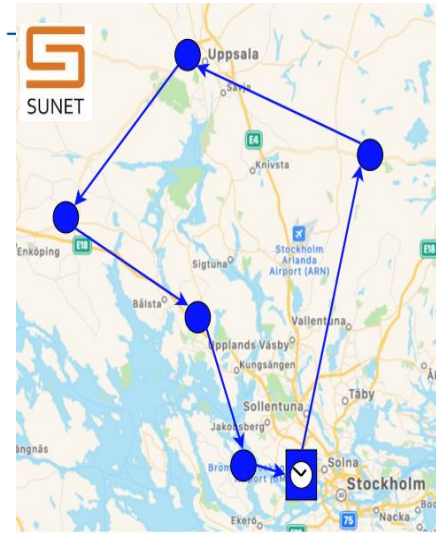




- Since 1968 the second has been defined by measurement using Cesium 'RF' atomic clocks.
- Optical atomic clocks are now a better technology for measuring time



Adopted from Harald Schnatz



Vývoj hodin



2012

Ion Clock

High-accuracy optical clocks with trapped ions

2016

OC18

Optical clocks with 1E-18 uncertainty

2019

ROCIT

Robust optical clocks for international timescales

Linkové technologie



NEAT-FT

New tools for optical frequency transfer

OFTEN

European network for optical clock comparisons

TiFOON

Optical time and frequency transfer

Návrh sítě



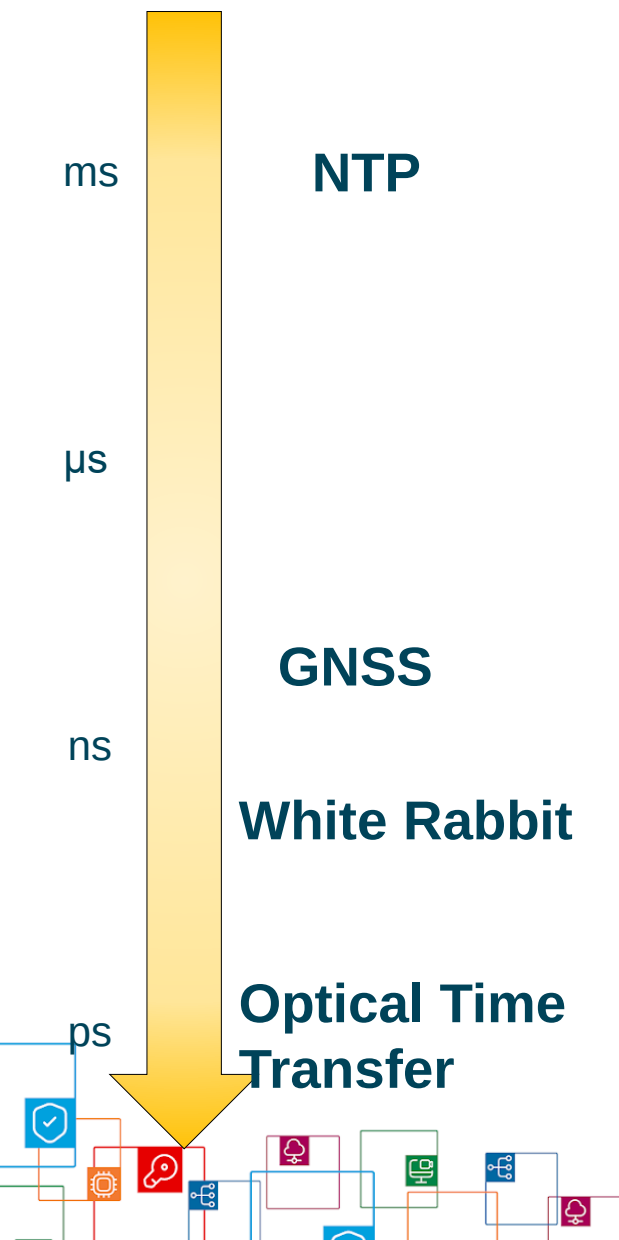
CLONETS

Strategy for a pan-European T/F network

CLONETS-DS

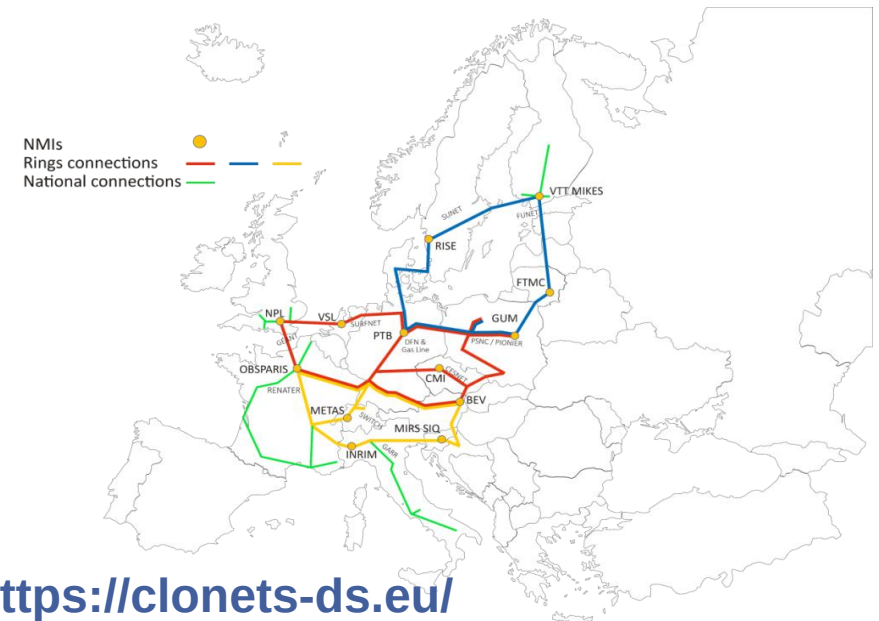
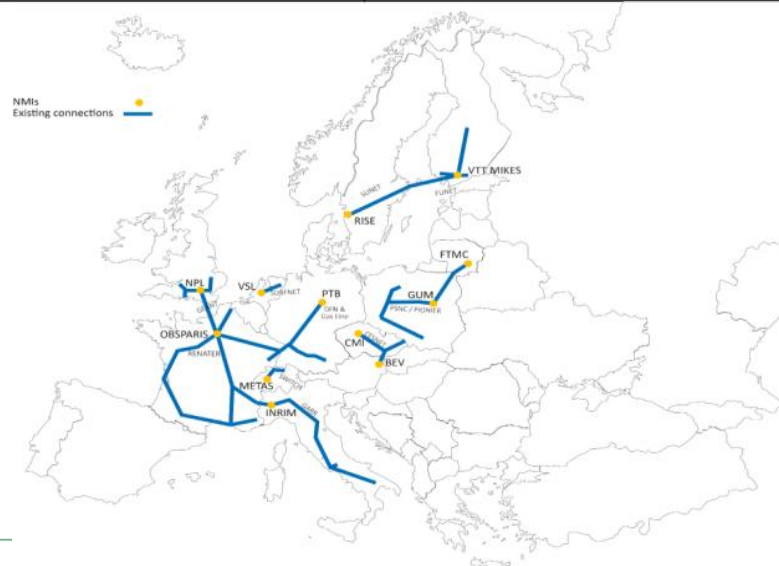
Design study for a pan-European T/F network

- Přehled dostupných metod a jejich přesností



Existing advanced techniques			Performances Frequency (instability) Time (precision, Time Deviation TDEV)	TR L	Distance
Frequency	Optical Carrier (Carrier Wavelength)	Active cancellation	10^{-15} @1s; 10^{-20} @1d	8	>1000 km
	RF Carrier (Modulated Wavelength)	Active cancellation with optical delays	10^{-14} @1s; 10^{-18} @1d	4	0-100 km
		Active cancellation with electronic delays (ELSTAB)	10^{-13} @1s; 10^{-17} @1d	8	500-1000 km
			10^{-16} @1d (unidirectional)	8	>1000 km
		White Rabbit PTP	10^{-15} @1d (unidirectional)	8-9	>1000 km
		Phase conjugation	10^{-19} @1d	5-6	0-100 km
Time	Two-way comparison		TDEV $\approx$ 2ps	5-6	100-500 km
			TDEV $\approx$ 30ps calibration through GPS (unidirectional)	6	100-500 km
	Optical frequency comb		Calibration uncertainty <40ps TDEV 500 fs @1s	4-5	0-100 km
	Active cancellation with electronic delays (ELSTAB)		TDEV < 1ps calibration uncertainty <40 ps	8	>1000 km
	Protocol based (White Rabbit PTP)		Verified with GPS disagreement $\pm$ 2ns	8-9	>1000km
			Calibration uncertainty <10ns	8-9	0-100 km

Science Case	Application	User Need	European Impact	Required Service	Locations	Frequency		Timing	
						Instability	Accuracy	Instability	Accuracy
1 Telecommunication and Networks / Position, Navigation, and Timing	Resilience for GNSS based on PNT	High	High	Absolute Timing Service				1,E-09	1,E-08
	Network Synchronization (5G or 6G)	Low	Low	Frequency & Timing	Bremen (DE)	1,E-12	1,E-12		3,E-08
	Optical Timescales	High	High	Absolute Timing Service	Braunschweig (DE), Paris (FR), Amsterdam (NL), Pr			1,E-11	1,E-11
2 Quantum Technologies	Improving real-world QKD	Medium	High	Frequency & Timing	For sure the nextcoming secu	1,E-15	1,E-16	1,E-10	
	Development of new protocols	Medium	High	Absolute Frequency Service			1,E-16		
	Entanglement distribution beyond QKD	Medium	High	Frequency & Timing		1,E-15		1,E-10	
3 Fundamental Science	Precision spectroscopy to search for BSM physics	High	High	Absolute Frequency Service	Garching (DE), Paris (FR), Mai	1,E-17	1,E-16		
	Improvement of optical clocks	High	High	Frequency & Timing	L, Prague (CZ), Zagreb (HR), T	1,E-15	1,E-18		
	Redefinition of the SI-second								
4 Earth Observation / Geodesy	Height system unification	High	High	Absolute Frequency Service	Bonn (DE), Wettzell (DE)	2,E-18	2,E-18		
	Satellite gravity mission validation	Medium	High	Relative Frequency Service	Wettzell (DE)?	1,E-19			
	Geodetic network consistency	Medium	High	Relative Timing Service				3,E-12	
5 Astronomy	Radio interferometry and VLBI (reference frame realization)	High	High	Frequency & Timing	Nancay (FR), IRAM (FR), Effels	1,E-18	1,E-18	1,E-12	1,E-12
	Laser ranging	High	High	Frequency & Timing	(https://ilrs.gsfc.nasa.gov/network/stations/active/index.html): Grasse (France),	1,E-16	1,E-16		

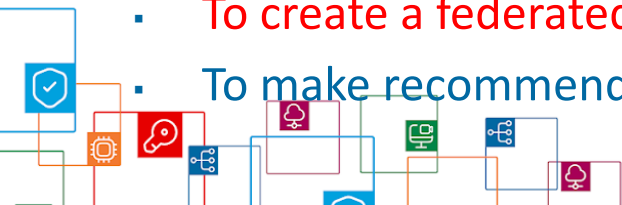


CLONETS-DS deliverables on the web: <https://clonets-ds.eu/>

- GN4-3 WP6 (2019-22) and GN5-1 WP6 OTFN (23-24)
 - <https://wiki.geant.org/display/NETDEV/OTFN>
 - **T/F knowledge exchange platform:** <https://wiki.geant.org/display/NETDEV/TF+Gateway>
- **Core TF Network** defined - Time/ Frequency service and infrastructure incubator study
- **Support the redefinition of the SI second** being carried out between now and 2030+ by NPL, PTB, Syrte and INRIM and other NMIs.
- Perform **fundamental physics research** e.g. gravity wave experiments.
- **Supplement GNSS** with a fibre network to increase reliability of time distribution
- Support **European-wide commercial services** such as very accurate time stamps for banks to validate high-frequency trading.



- **Special Interest Group for the Time and Frequency Network (SIG-TFN) 2024,**
<https://wiki.geant.org/spaces/SIG/pages/735051873/SIG-TFN+Homepage>
- Dvě pracovní skupiny SIG-TFN:
 - C-TFN technical specification (Led by Guy Roberts)
 - T/F Sustainability (led by Richard Lui)
- Aims:
 - To provide a forum for gathering and exchanging experiences, ideas and knowledge on the development, deployment, testing and standardisation of Time and Frequency distribution across R&E networks and between NMIs, with a particular focus on interoperability; This will be achieved through group meetings (online and face-to-face), the use of online collaborative tools, collating and dissemination of information or organising pilot projects;
 - To define agreed objectives and commitment levels related to the operation and management of a Time and Frequency Network;
 - To define an agreed data management plan and having a common repository for information and data;
 - To create a federated access to repositories and data;
 - To make recommendations and play the role of a technical adviser.



Fiber-based Optical network for European Science and Technology (FOREST)

<https://www.cesnet.cz/pro-media/ceska-stopa-v-evropske-infrastrukture-budoucnosti-cesnet-pomaha-budovat-sit-pro-prenos-extremne-presneho-casu-86>

-Mezinárodní metrologie a experimenty s extrémní přesností v základní a aplikované fyzice

-Kvantové komunikace (QKD)

-Vláknové snímání pro geovědy a dohled infrastruktur

- Konsorcium 60 institucí ze 17 států EU, 13 NMI a 13 NREN
- Pro start je ustanoveno Steering Committee
 - SC shall include experts:
 - from countries that have expressed a financial commitment to FOREST, ie. France, Italy and the Czech Republic;
 - from the GEANT consortium, in light of its major role in interconnecting national networks;
- Podpora:
 - 13 odpovědných ministerstev z 10 států
 - Ostatní výzkumné infrastruktury a další organizace: EPOS, JIVE, LOFAR, ESRF, GEANT, JRC, BIPM, EURAMET, CERN
 - 105 podpůrných dopisů od dalších institucí, včetně >20 průmyslových partnerů

forest-ri.eu

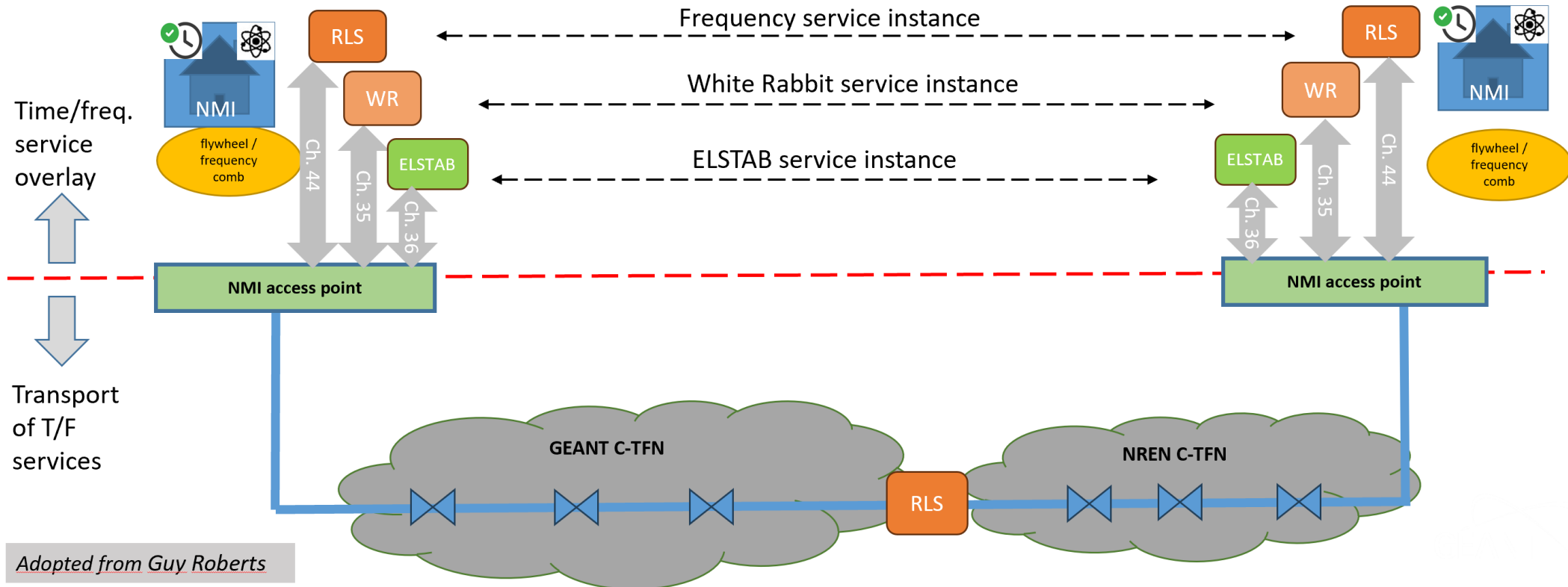


NMIs

- Build, own and operate the T/F equipment:
 - Flywheels, counters, frequency combs
- Retain ownership of time/frequency
- Generate and measure time/frequency
- Terminate T/F services

GEANT, NRENs

- build, own and operate transport links:
 - fibre, amplifiers, access points, intermediate RLS
- Provide a service to NMIs to carry T/F services



- Coherent Optical Frequency

- Channel 44 -1542.14 nm will be used across Europe as the agreed wavelength for frequency services
- A high-level design needs to be agreed among all NMIs to ensure a coherent frequency distribution strategy (note that this contrasts to the bilateral arrangements between peering NMIs for time distribution).

- Time services – discussion

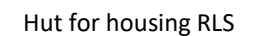
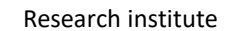
- Time services should be agreed bilaterally between peering NMIs. Once the service type and technology are agreed, GEANT will allocate a separate wavelength channel for each individual time service request
- The time services should be deployed in agreement between the NMIs at each end of the link
- Time services will be built on the GEANT fibre on a wavelength to be agreed between GEANT and the NMIs at each end of the time link
- White Rabbit seems to be the preferred technology for time distribution





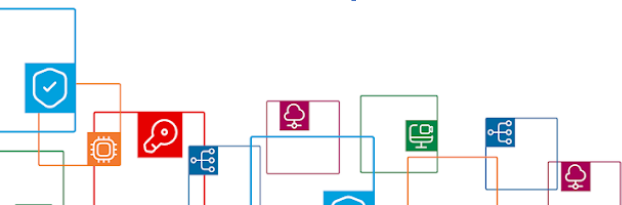
- Excluded:**

- NMI Frequency reference

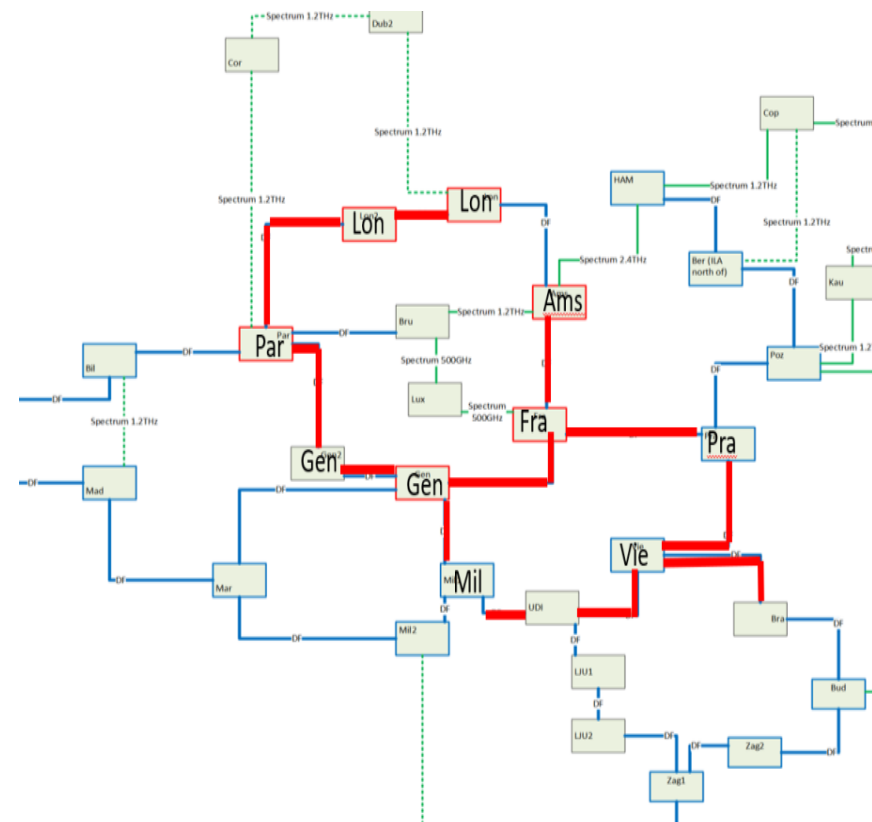


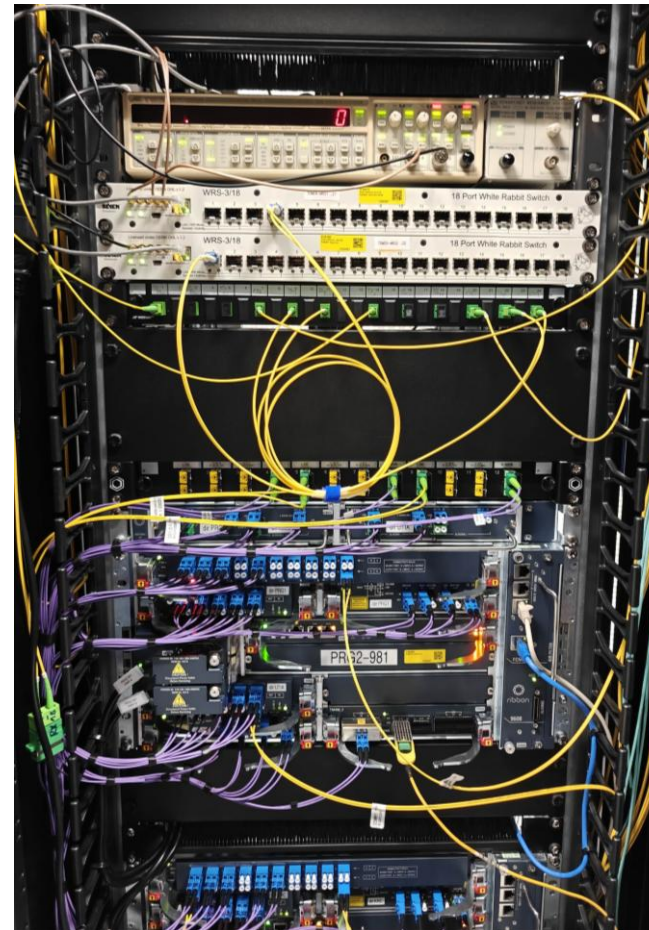
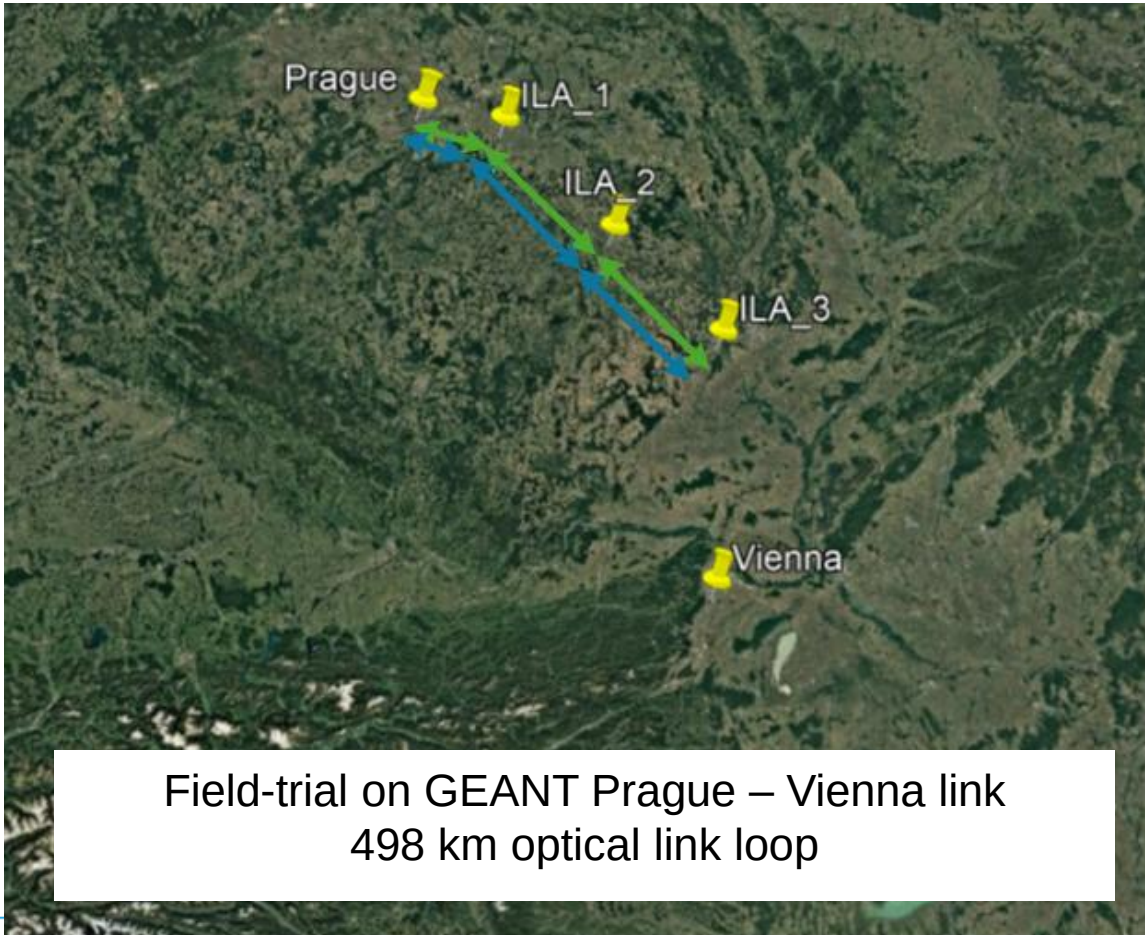
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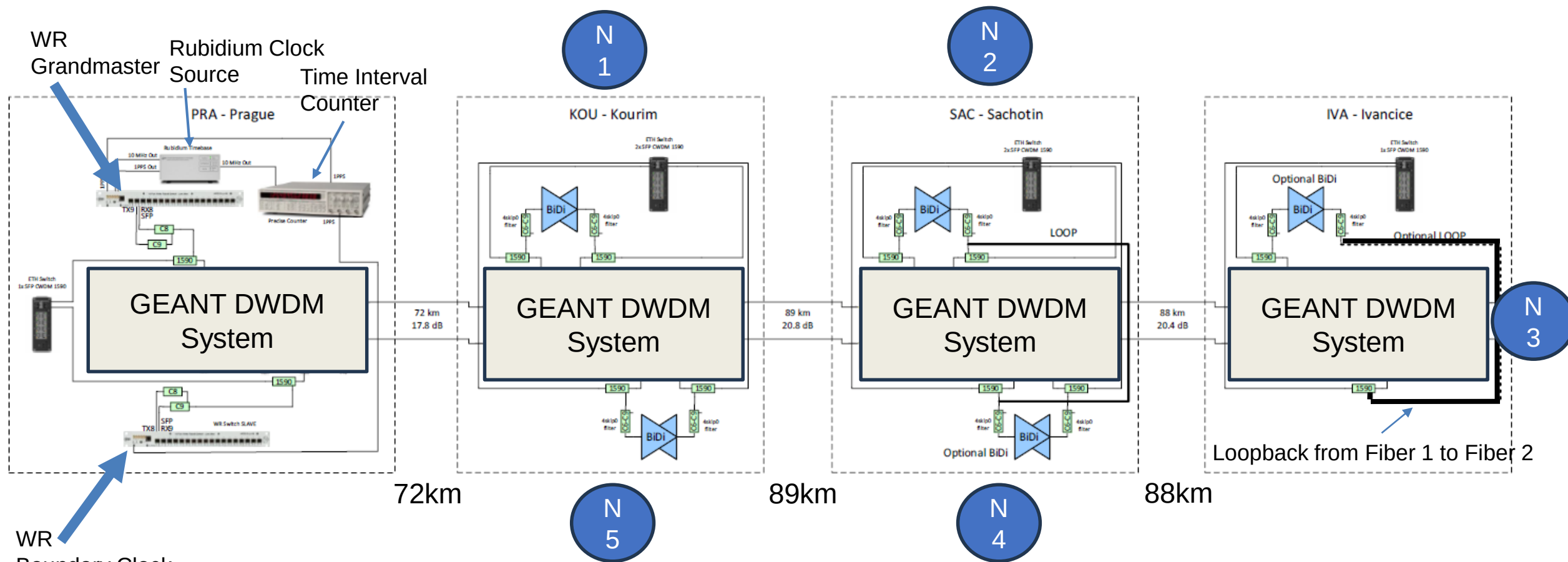
- GN5-2 WP6 NETDEV Incubator project led by SIKT on long-haul WR time service over DWDM networks. (Sept 25 – Feb 26)
Partners: GEANT, SIKT, CESNET, SUNET, FUNET, GARR
- Key challenges for long-haul is regeneration at In-line Amplification Sites (ILA). Solutions to be evaluated:
 1. Bidirectional amplifiers – 1R
 2. WR switches for regeneration – 3R
 3. Optical-Electrical-Optical media converters – 2R
- Goals:
 1. Survey of current WR 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.



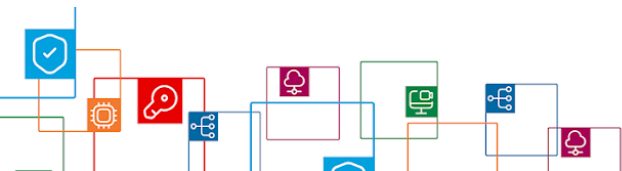
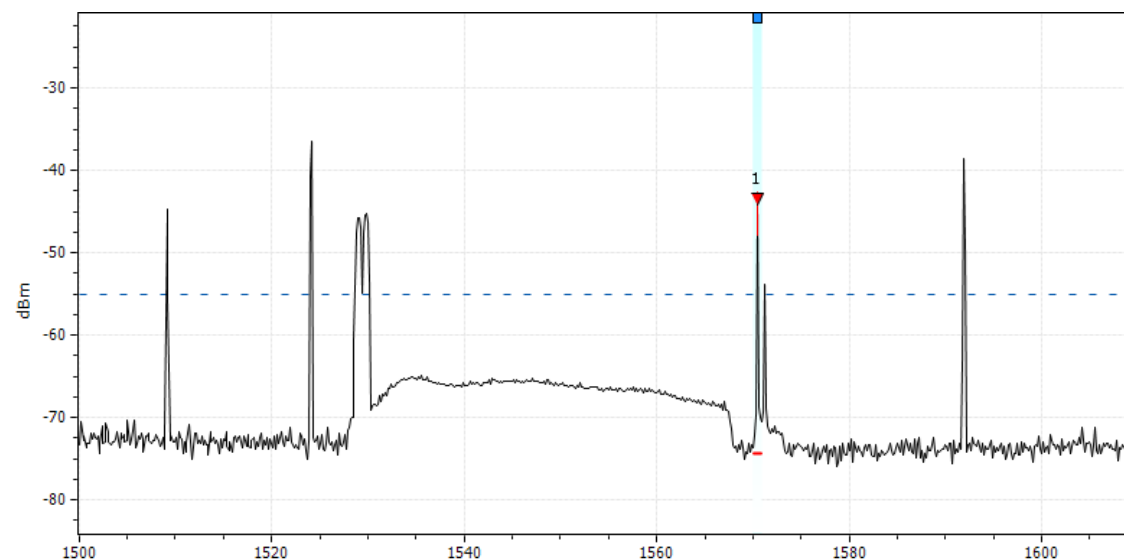
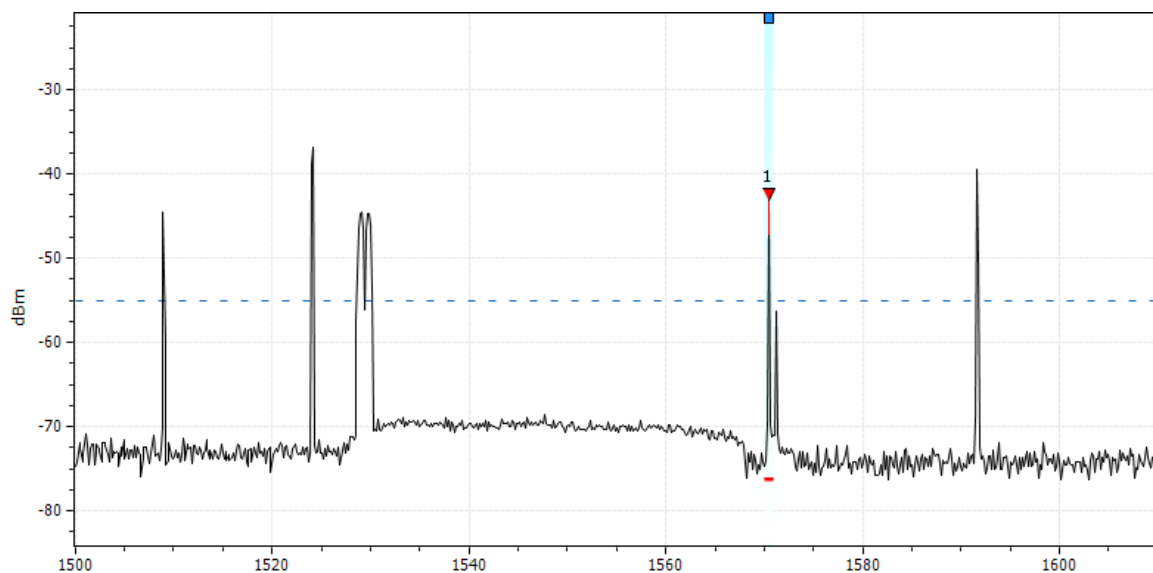
- dedicated bio

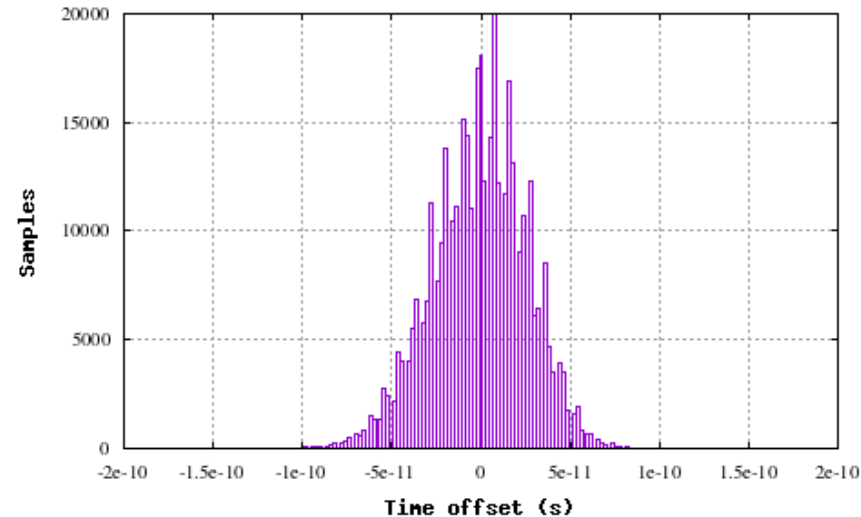
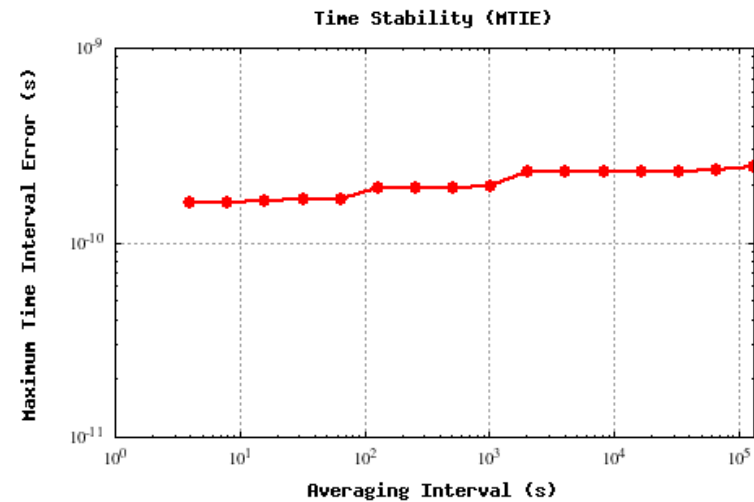
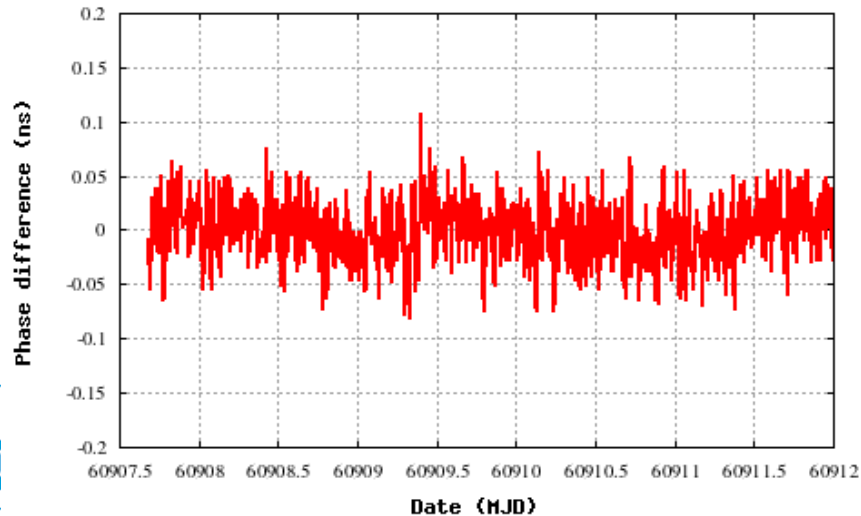
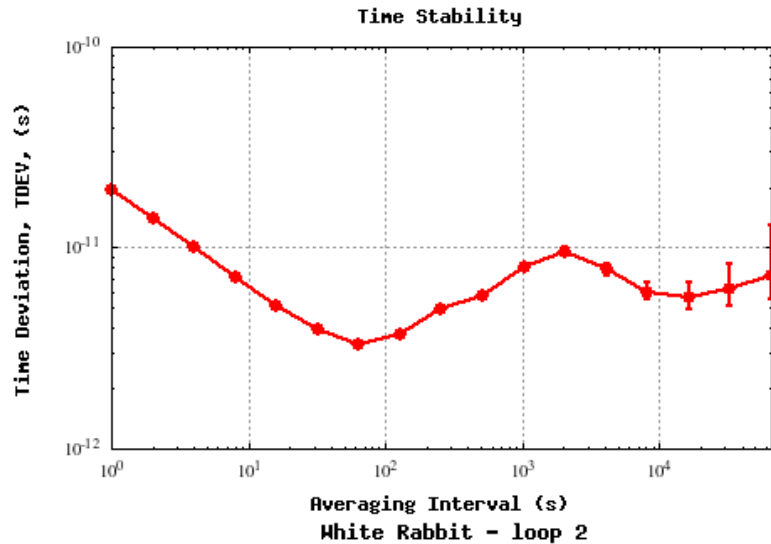






- Field-Trial Results – No Impact on Data Channels
- 2 x 400G channels (in C-band) running in parallel with the white rabbit T&F service (in L-band)
- Both pre-FEC-BER and Q-margin before and after white rabbit activation, are at the same level





Calculated parameters:

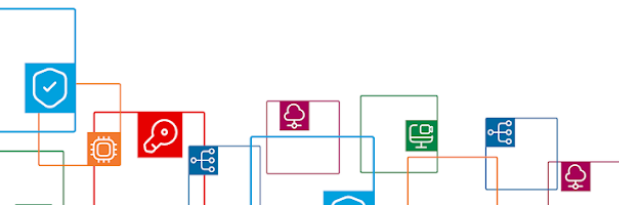
St. dev. $\sigma = 33\text{ps}$

MTIE < 250 ps

TDEV < 10 ps ($\Delta > 4\text{s}$)

https://www.gna-g.net/wp-content/uploads/2025/12/GNA-G_LongHaulWR-_incubator_Vojtech_short.pdf

- Optická frekvence a White Rabbit preferované aplikace
- CESNET je intenzivně zapojen do evropských aktivit GÉANT, SIG-TFN, WR collaboration a FOREST
- Zájem a tlak na integraci sensoriky a QKD





Děkuji za vaší pozornost!
Vaše otázky prosím?

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