GÉANT Infoshare: European Time and Frequency Services - Principles, Challenges and Use Cases

Current T&F situation in NREN networks

Josef Vojtěch, CESNET
josef.vojtech@cesnet.cz

WP6 T1 OTFN
9 March 2021

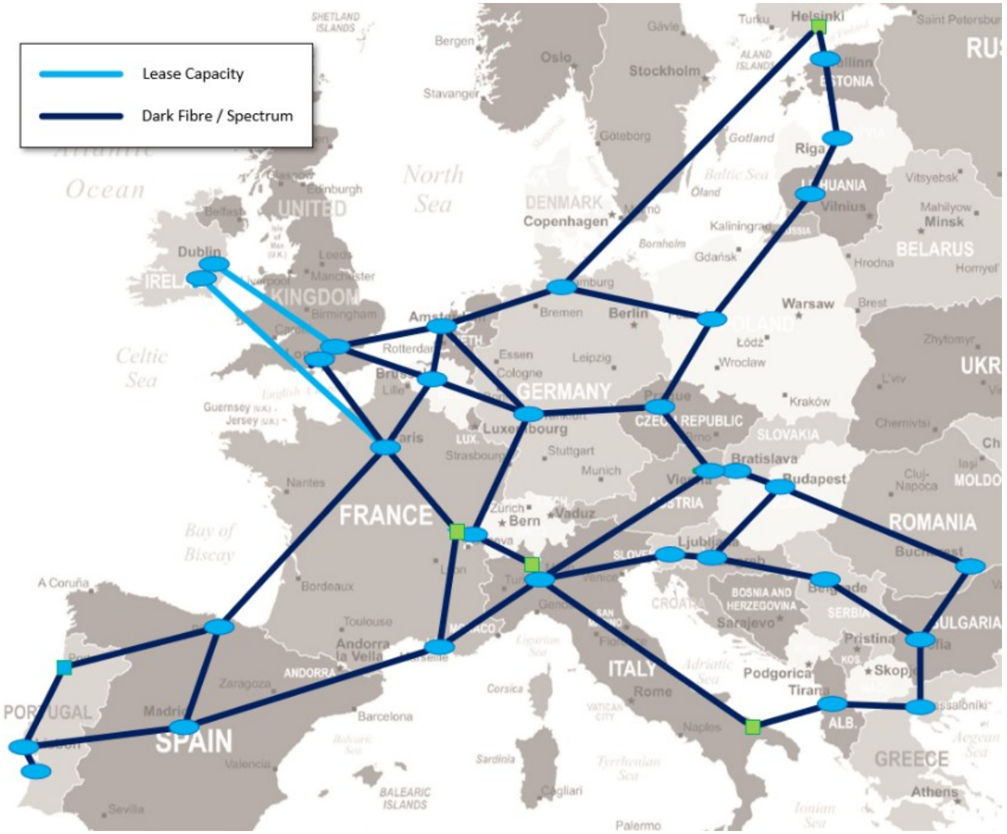
Agenda

Current T&F situation in (N)REN networks

• GEANT	Guy Roberts
• CESNET CZ	Josef Vojtech
• FUNET FI	Jani Myyry
• GARR IT	Gloria Vuagnin
• PSNC PL	Wojbor Bogacki
• RENATER FR	Nicolas Quintin
• SUNET SE	Magnus Bergrot
• SURFnet NL	Rob Smets, Erik Dierikx
• SWITCH CH	Konstantinos Chaloulos
• UNINETT NO	Kurosh Bozorgebrahimi

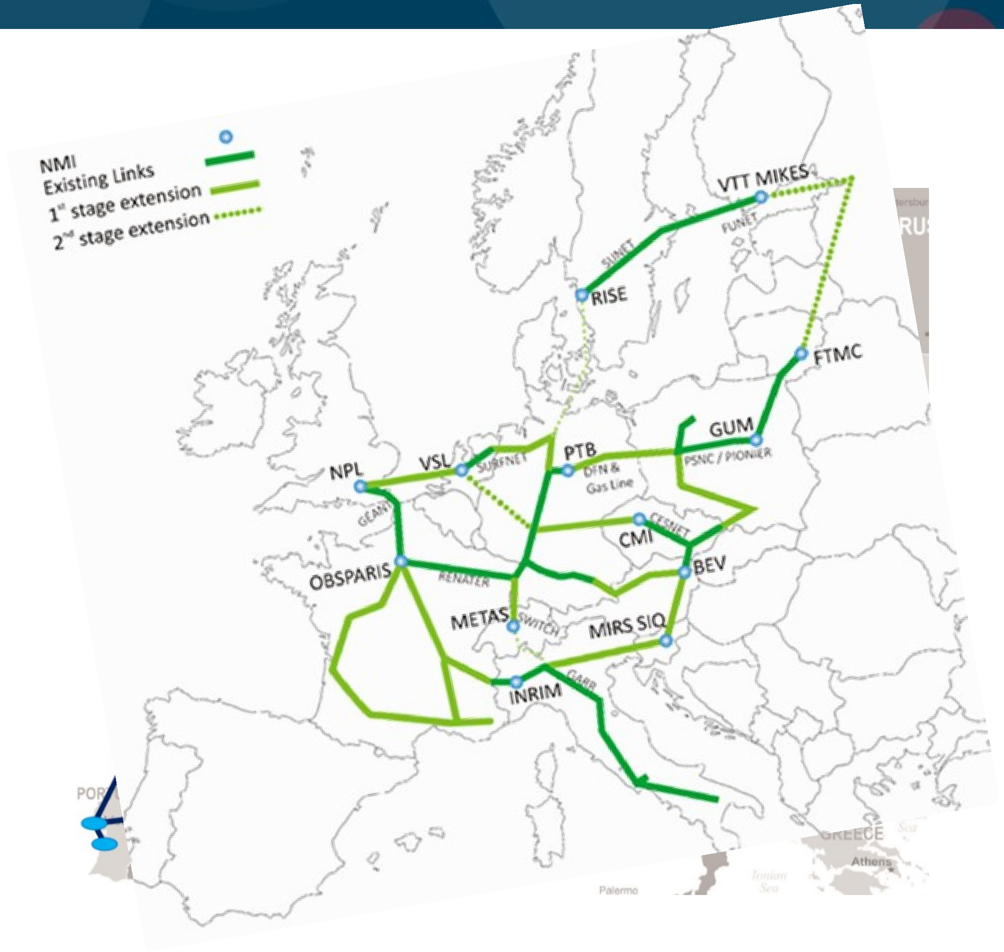
GÉANT
T/F and the new GEANT network

- GEANT would like to support the emerging T/F distribution in Europe. Where possible this is best served with dedicated dark fibre.
- If dedicated dark fibre is not achievable, it will be possible to carry T/F on some links in GEANT's new network.
- This new network is to be completed early 2023 and will have a 15-year IRU on dark fibre.
- C-band is reserved for up to 20Tbps of Internet traffic.
- GEANT will add an L-band on some links to carry T/F along with Internet traffic.



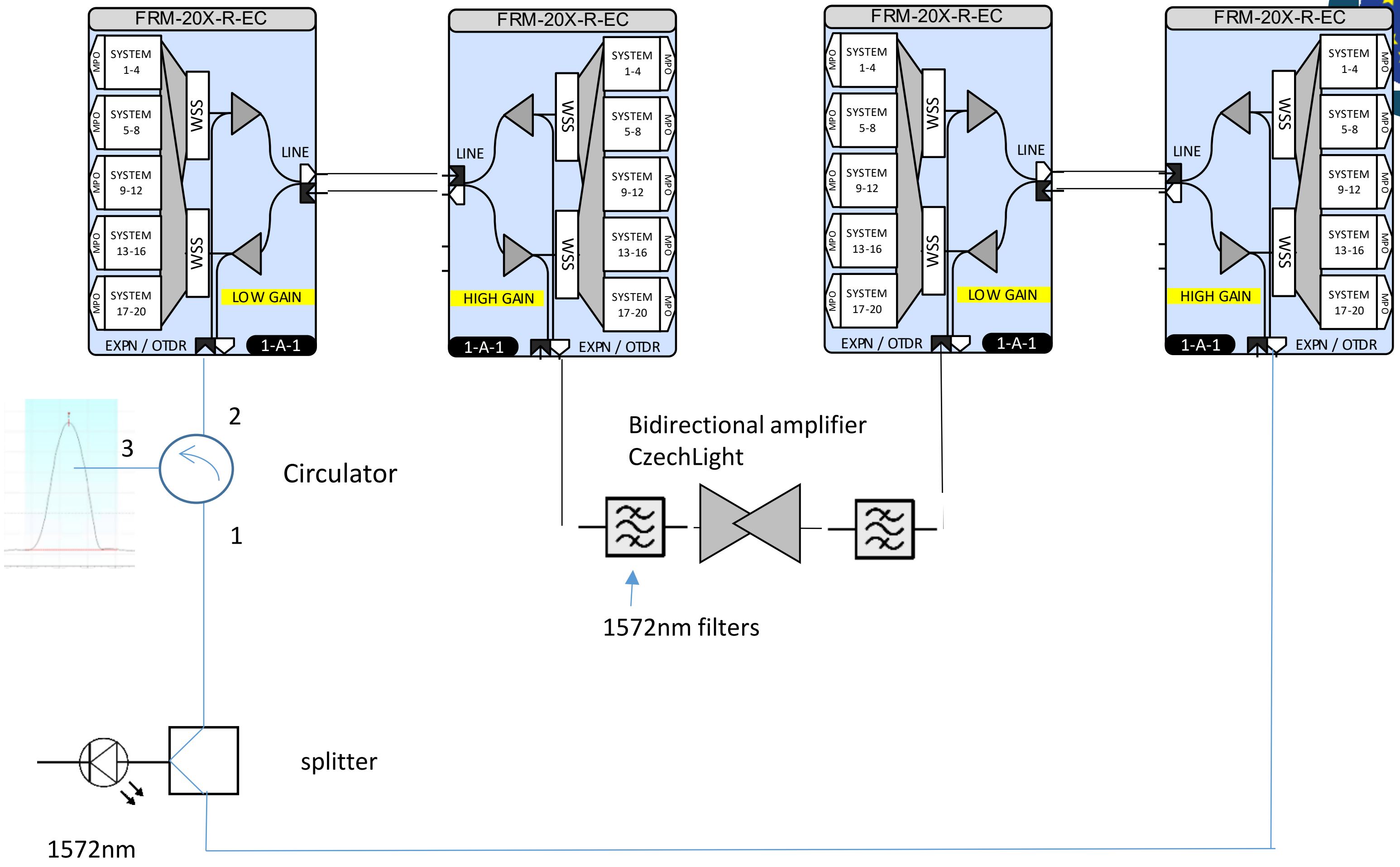
GÉANT
T/F and the new GEANT network

- GEANT would like to support the emerging T/F distribution in Europe. Where possible this is best served with dedicated dark fibre.
- *GEANT footprint has significant overlaps with Metrology requirements as identified in CLONETS study*



GÉANT
Mixing time/frequency with internet traffic

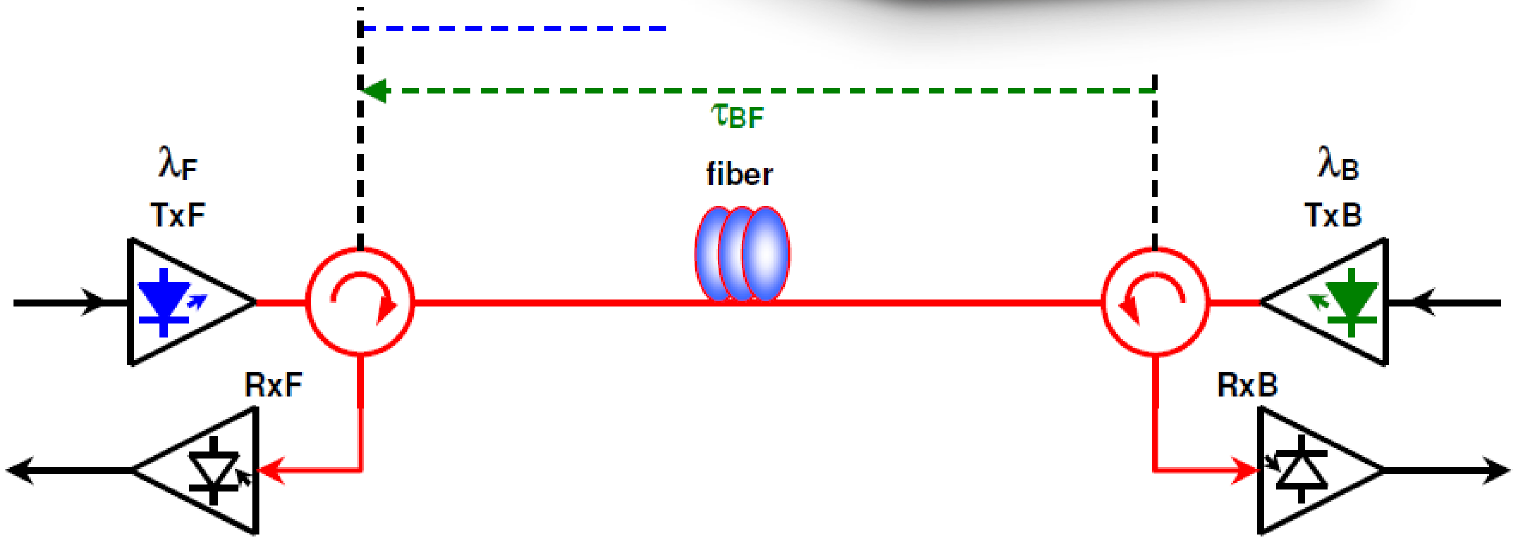
- GEANT uses DWDM system from Infinera
- C-band is unavailable for T/F due to lack of coupling of CH44 and other concerns
- L-band is being added to some core routes to support scientific needs such as time/frequency
- L-band access ports built into the switching and amplifier cards
- Lab testing has shown that time/frequency signals can be injected as a bi-directional signal on the L-band using these ports.



GÉANT
Regenerators in the L-band

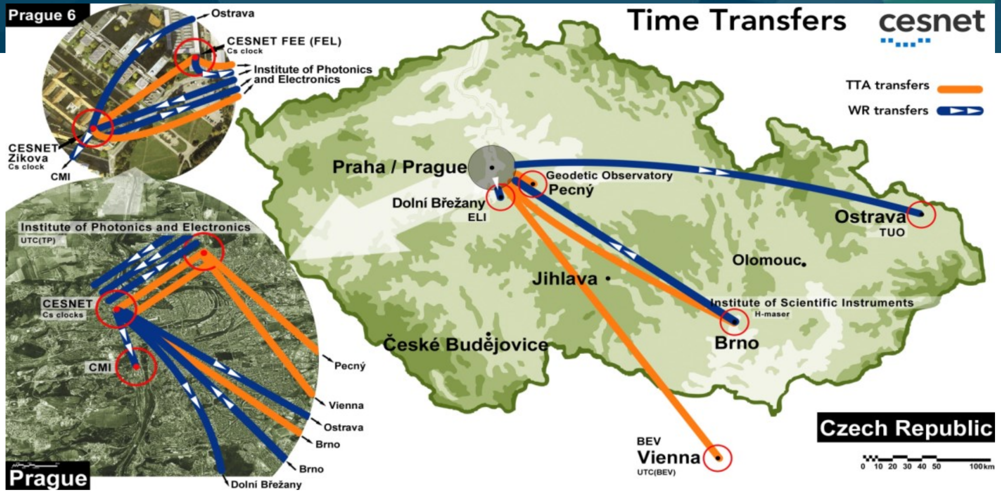
- Long-haul systems require T/F regeneration
- Existing system available from µQuans for ch 44
- Ongoing investigation into developing an L-band variant of this equipment for the GEANT network

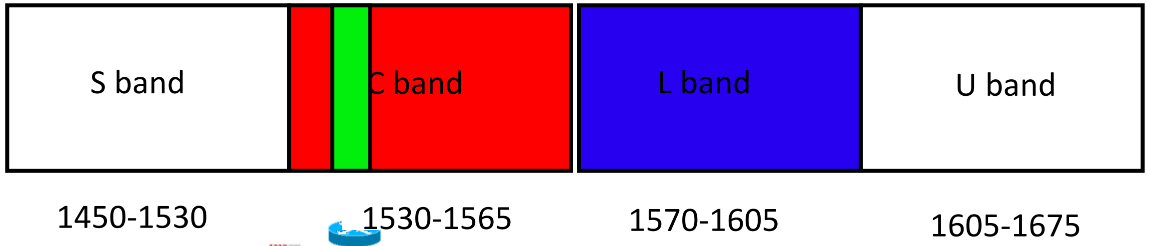
- Bidirectional feedback allows very stable frequency distribution

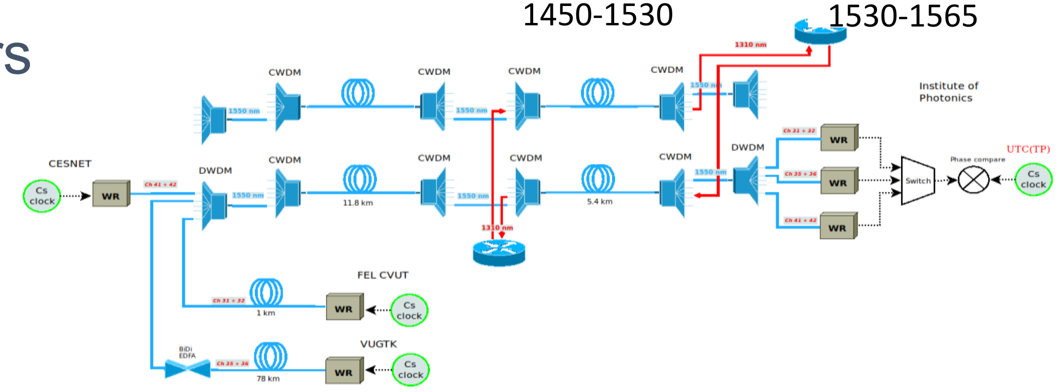


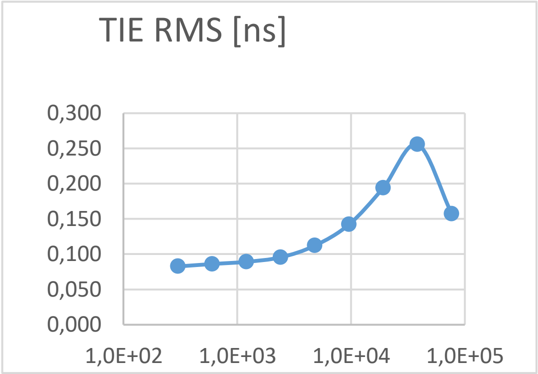
CESNET – Czech Republic
Czech Republic TF Infrastructure

- TTA – IPE Prague – BEV Vienna 550km **since 2011**
- TTA – bidi amplified transfer 2013
- Time and RF frequency - Time Transfer Adapters + White Rabbit over **1800 km**
- Fibres **shared with data** (fibre rental 1M€ p.a.)
- Comparison of UTCs
  - UTC(TP) - UTC(BEV) with ACOnet
  - UTC(TP) - UTC(PL)* with PSNC
- Distribution to demanding users
  - ELI, VUGKT
- Synthetic Time Scale
  - Multiple transfers between each Cs and H clock



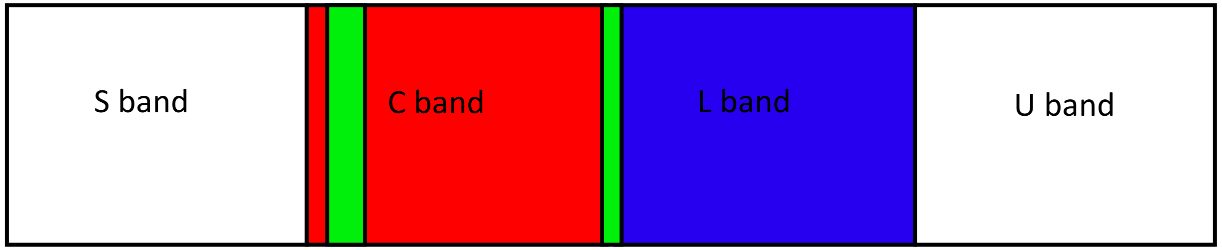


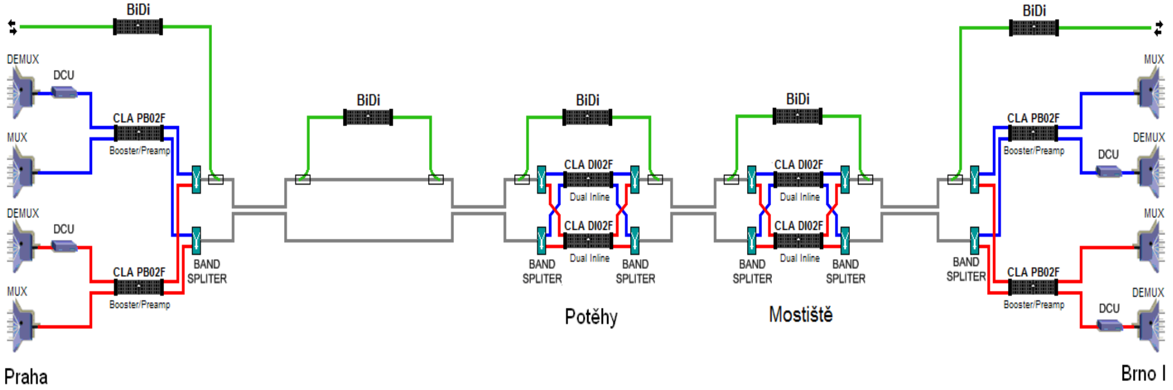




CESNET – Czech Republic
Czech Republic TF Infrastructure

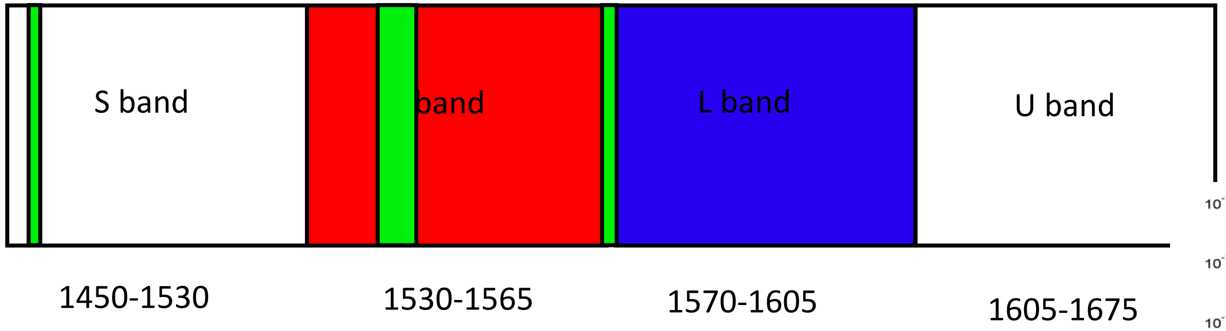
- Coherent optical frequency - 305 km Prague Brno since 2015
- Deployment band OADMs 800/400 GHz (incl. ch 46 1540.5 and ch 44 1542.1 nm)
- Now **1100 km**, developed in cooperation with ISI
- 700 km **bidirectioaly lit as a service** (since 2015)
- 21 BiDi EDFAs, > 29 in 2021 (avail. from 3 vendors)
- L band DWDM in EF since 2011
- New coherent 400G backbone roll out 2021
  - Filters deployed for **ch 46-39, ch 9-6**

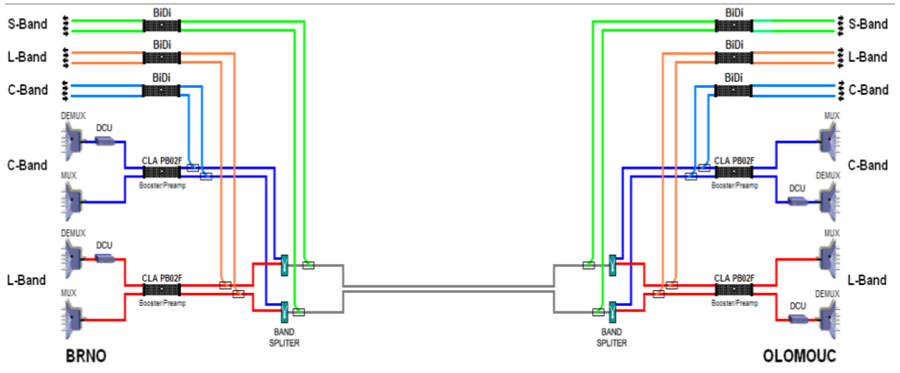


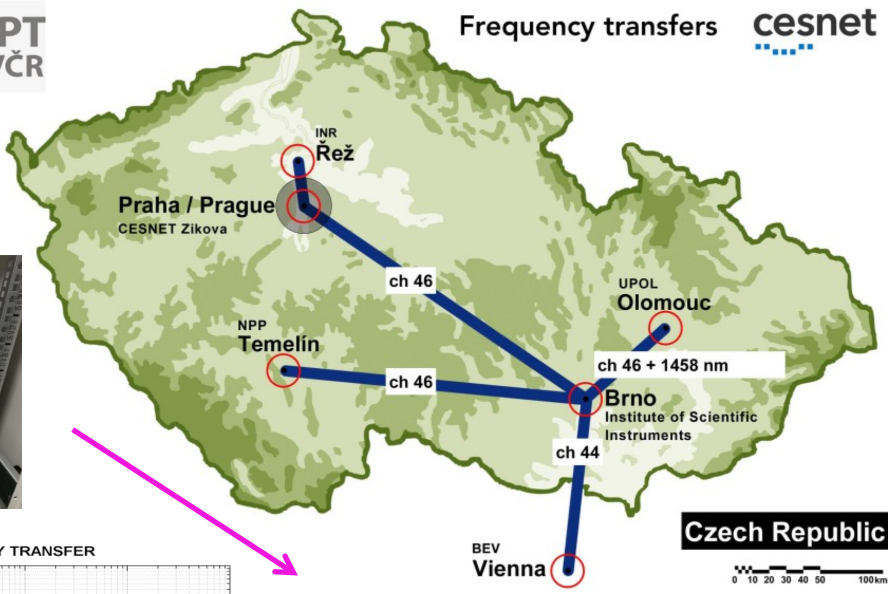


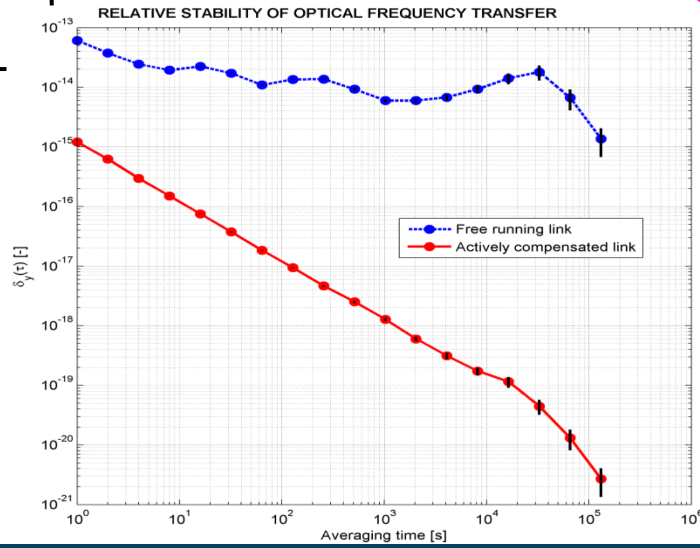
CESNET – Czech Republic
Czech Republic TF Infrastructure

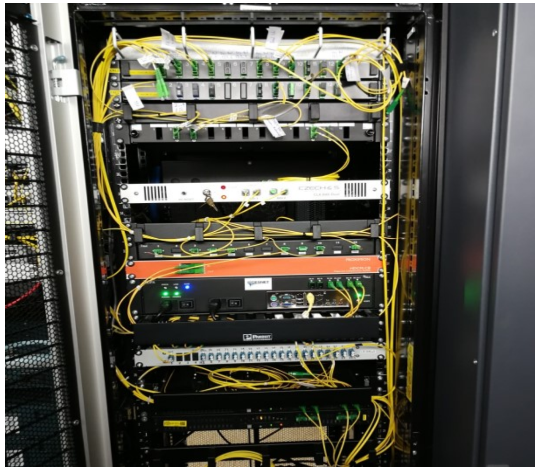
- 1458 nm transfer requested for Ca+ clock comparison without optical comb
- C+L+S transmissions
- PTTI21: Active Fully Bidirectional Precise Time Transmission Outside the Telecommunication Bands Over 200 km of Single Mode Fiber





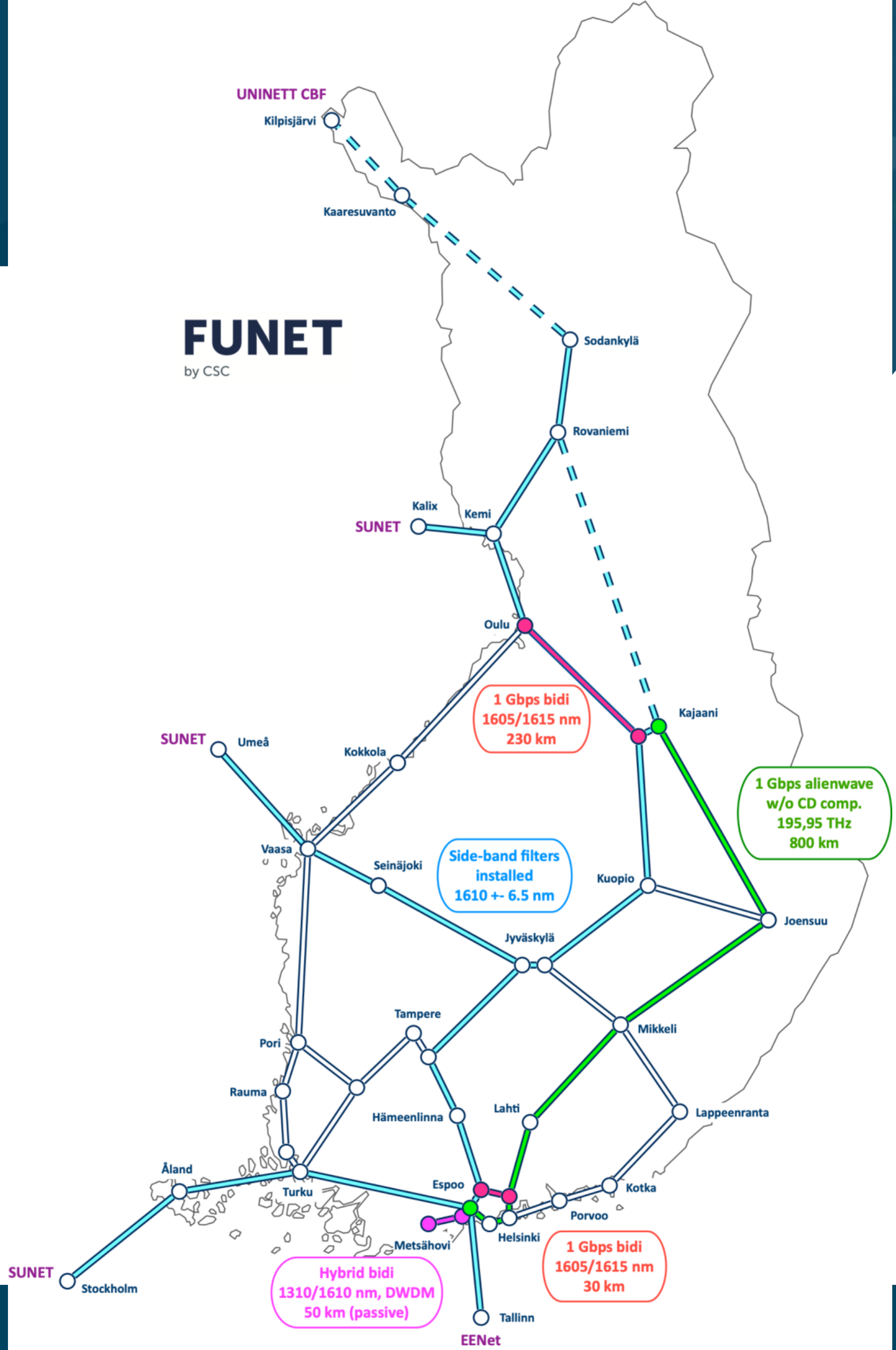






FUNET - Finland

- Side-band channel (1610 +- 6.5 nm) support
  - Filters planned together with SUNET, Netnod and FI&SE time labs
  - Most important backbone and all CBF connections ready to support
- Implementations:
  - **Espoo-Kajaani** White Rabbit link (800 km)
    - 1 Gbps **alienwave** 195.95 THz, without CD compensation
  - **Kajaani-Oulu** White Rabbit link (230 km, 2021/Q1)
    - 1 Gbps 1605/1615 nm, bidi, side-band filters
    - **Raman** amplification on some spans
  - **Espoo-Helsinki** White Rabbit link (30 km)
    - 1 Gbps 1605/1615 nm, bidi, side-band filters
  - **Espoo-Metsähovi**
    - Bidi DWDM (100 GHz spacing), 1310/1610 nm planned
    - Aalto University Metsähovi Radio Observatory
    - Finnish Geospatial Research Institute, National Land Survey
- Potential implementations?
  - Sodankylä Geophysical Observatory
  - EISCAT-3D stations
  - CBF links to Sweden, Norway and Estonia



GARR - Italy
Ultra accurate T&F distribution in Italy

The Italian **reference model** for high-demanding T/F distribution is a dedicated (IRU) dark fibre pair, which is exclusively used by INRIM (i.e. the Italian NMI) and whose maintenance is managed by GARR.

The fibre pair topology follows the same route of a portion of GARR infrastructure

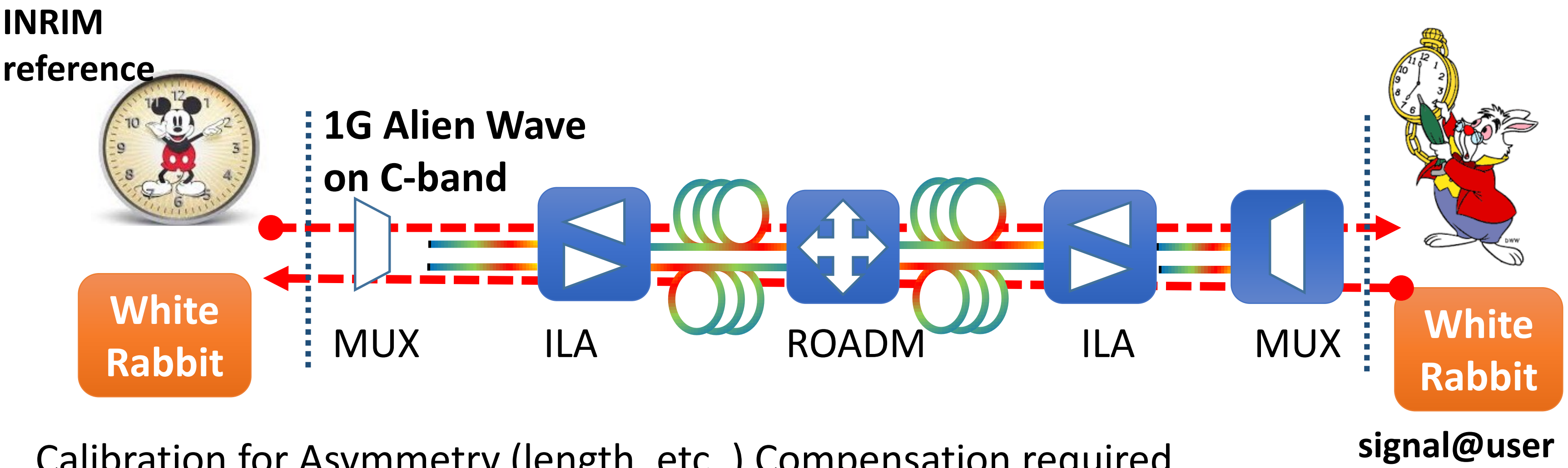
- 1850 km; built 2012-2018, operational since 2013
- 1 fibre dedicated to frequency distribution ultrastable frequency 1542 nm
- 1 fiber dedicated to pre-production trials, research and pilots including Quantum Tech (sensing, QKD)

Funding: Inrim, MIUR, Euramet (programs EMRP and EMPIR), EU-H2020, ASI, Regione Piemonte

GARR - Italy
White Rabbit explored for users with less stringent time requirements (ns)

GARR in collaboration with INRIM started to test White Rabbit over production GARR (unidirectional) DWDM infrastructure. The aim is:

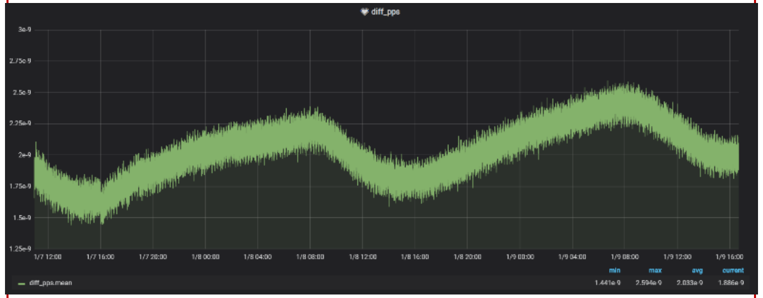
- to check which accuracy we can reach at user site
- to measure the average accuracy/stability we can get in different parts of GARR network
- to understand the complexity of operating the WR devices



Calibration for Asymmetry (length, etc.) Compensation required

Result over a 60 km path of GARR DWDM system

- diff_pps order of 10^{-9} *s*
- Night-day variation in the range of 2ns



GARR - Italy
T/F Italian Research Infrastructure Pillars

Dedicated Dark Fiber

- High demanding users
- A pair of fibers enables to separate production from R&D (prototypes, Quantum sensing, QKD)

GARR-INRIM Operational Independence

- T/F signal needs specific tuning and maintenance
- No impact on each other service during operations

Infrastructure lifecycle Independence

- Avoids dependencies in network evolution/update
- Free to innovate and deliver service without mutual constraints

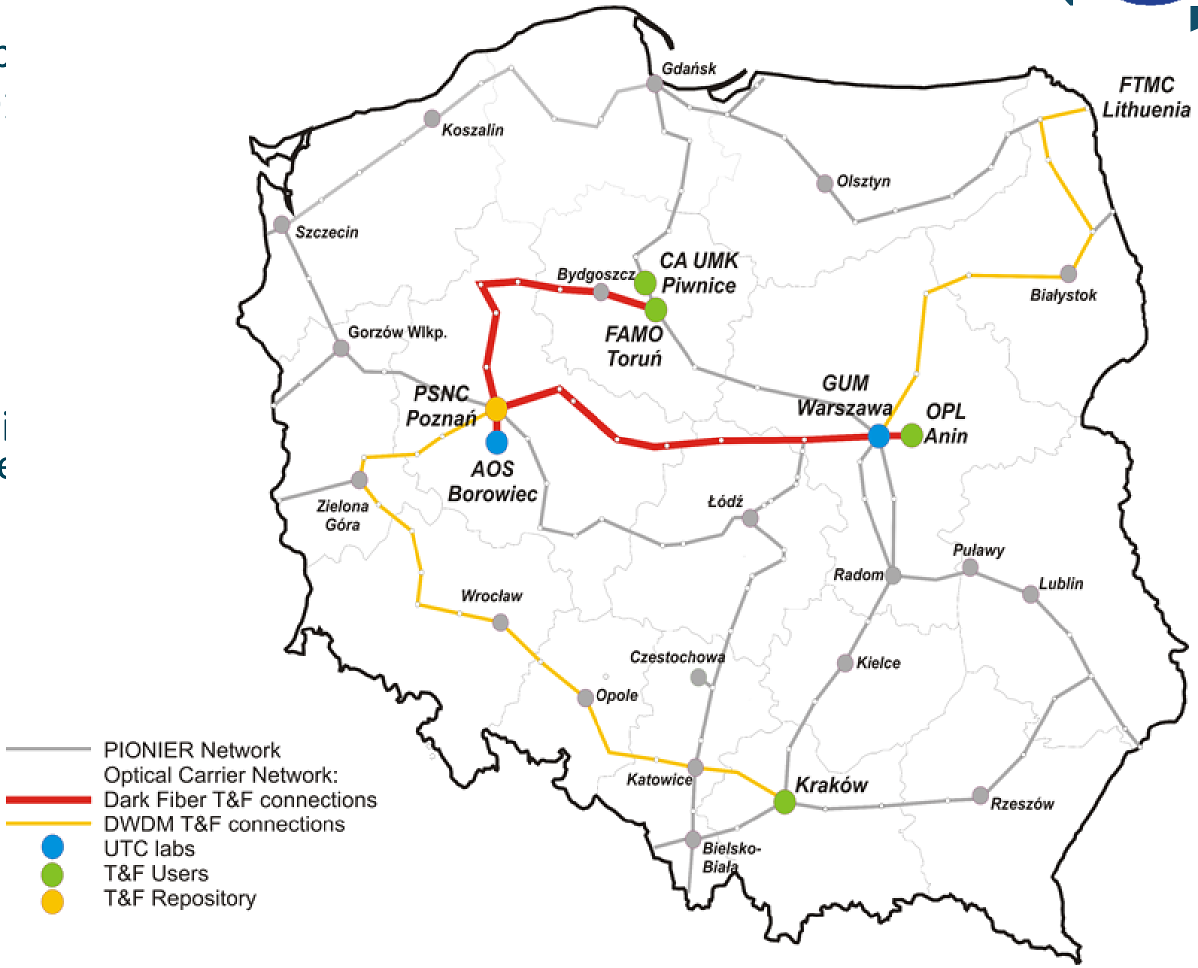
Work in progress in collaboration GARR-INRIM

- To offer a T&F service less accurate but more widely distributed

PSNC – Poland
PSNC T&F networks

PSNC T&F networks

- 4 fiber optical Dark Fiber links 800 km long:
    - the first 420 km long is operational continuously since Decemb
    - the second one 330 km long is operational since December 20 UTC k laboratories with the Polish laboratory of optical clocks,
    - the next two are 40 and 15 km long and were built in 2015.
- 2 fiber optical DWDM links 1600 km long:
    - Poznan – Krakow (750 km)
    - Warsaw - Vilnus (850 km – 550 km in Poland)
- 2 Time and Frequency Laboratories the first one is located in GUM i and generates UTC (PL), the second one is located in AOS in Borowie generates UTC (AOS);
- Optical clocks in KL Famo – Toruń
- 2 Cesium fountains – AOS Borowiec, PSNC Poznan
- Local Repository located in PSNC in Poznan with passive H-Maser and direct fiber connection to both Polish UTC(k) scales.

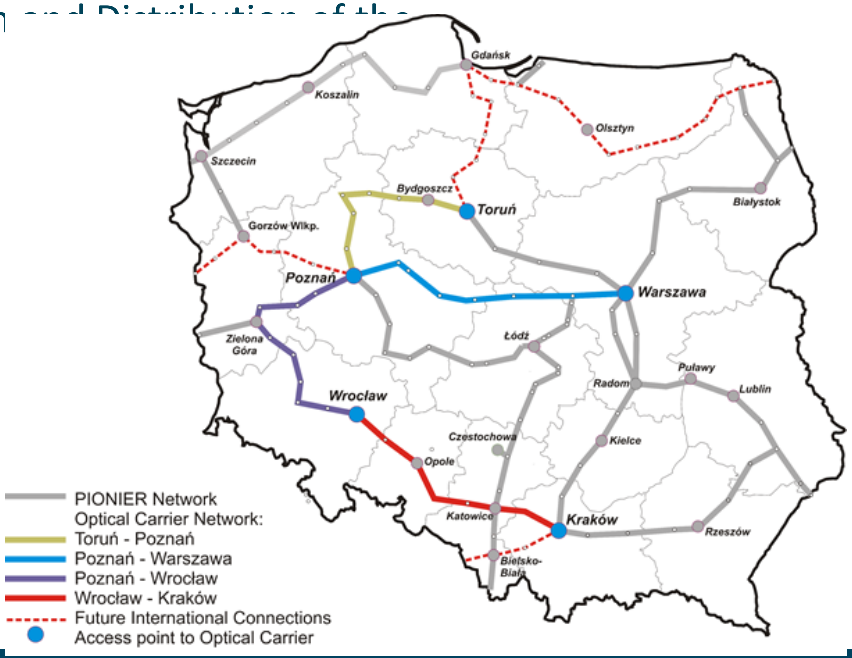


PSNC - Poland

- **PSNC T&F networks – under development**

NLPQT Project -

The main goal of the project is development of modern infrastructure in the fields of photonics and quantum technologies, with particular attention paid to the needs of industry. One of the subproject is development of National System for Generation
Reference Optical
Carrier.

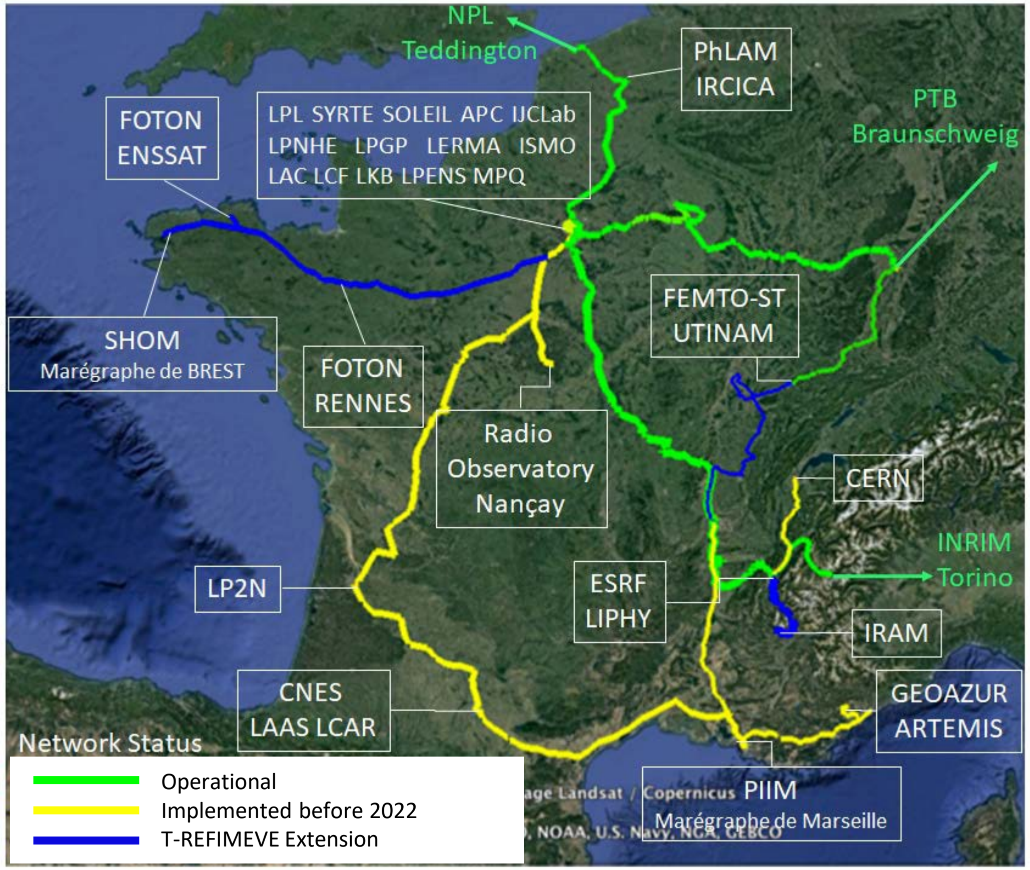


PIONIER-LAB Project -

The PIONIER-LAB project - National Platform for Integration of Research Infrastructures with Innovation Ecosystems assumes construction of research laboratories integrated with the national fiber optic network PIONIER. The PIONIER-LAB project aims in creating 8 specialized laboratories: One of the laboratories is Distribut
Time and Frequency Laboratory.

RENATER – France
French T/F network

- **French T/F network**



T/F techniques

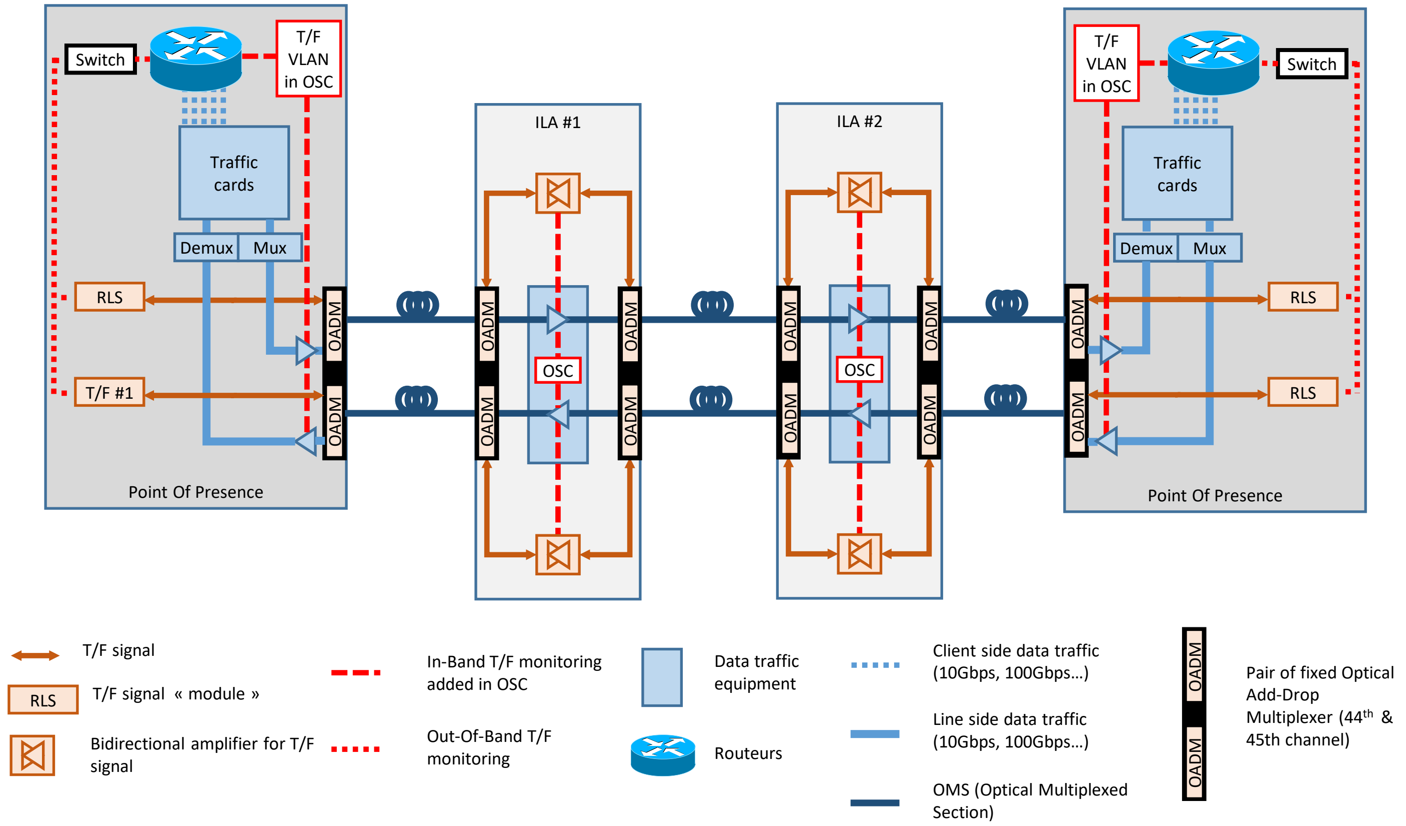
Current setup	• Optical carrier (unmodulated light) bidirectionnal, @1542,14nm, dark channel = shared fibres
Future setup (additional)	• White Rabbit Unidirectional, C-Band, alienwave • RF modulation over T/F signal @1542,14nm

General info

Contact nicolas.quintin@renater.fr

T/F fibre footprint	2 400km (2021) => 4 000km (2028) (30 labs to be connected)
Photonic layer	Infinera (Coriant) optical vendor | T Contra-Raman pumps, F-OADM, Coherent, QPSK or QAM modulations => Up to 6 wavelengths co propagating with T/F (sometimes without gardband)
Incidents	1 since 2012 didn't impact data traffic
Infos	Outsourced NOC fully able to shutdown any T/F equipment at any moment if required Industrial T/F equipment (Muquans and Lumibird)

RENATER – France
Current T&F situation in NREN networks

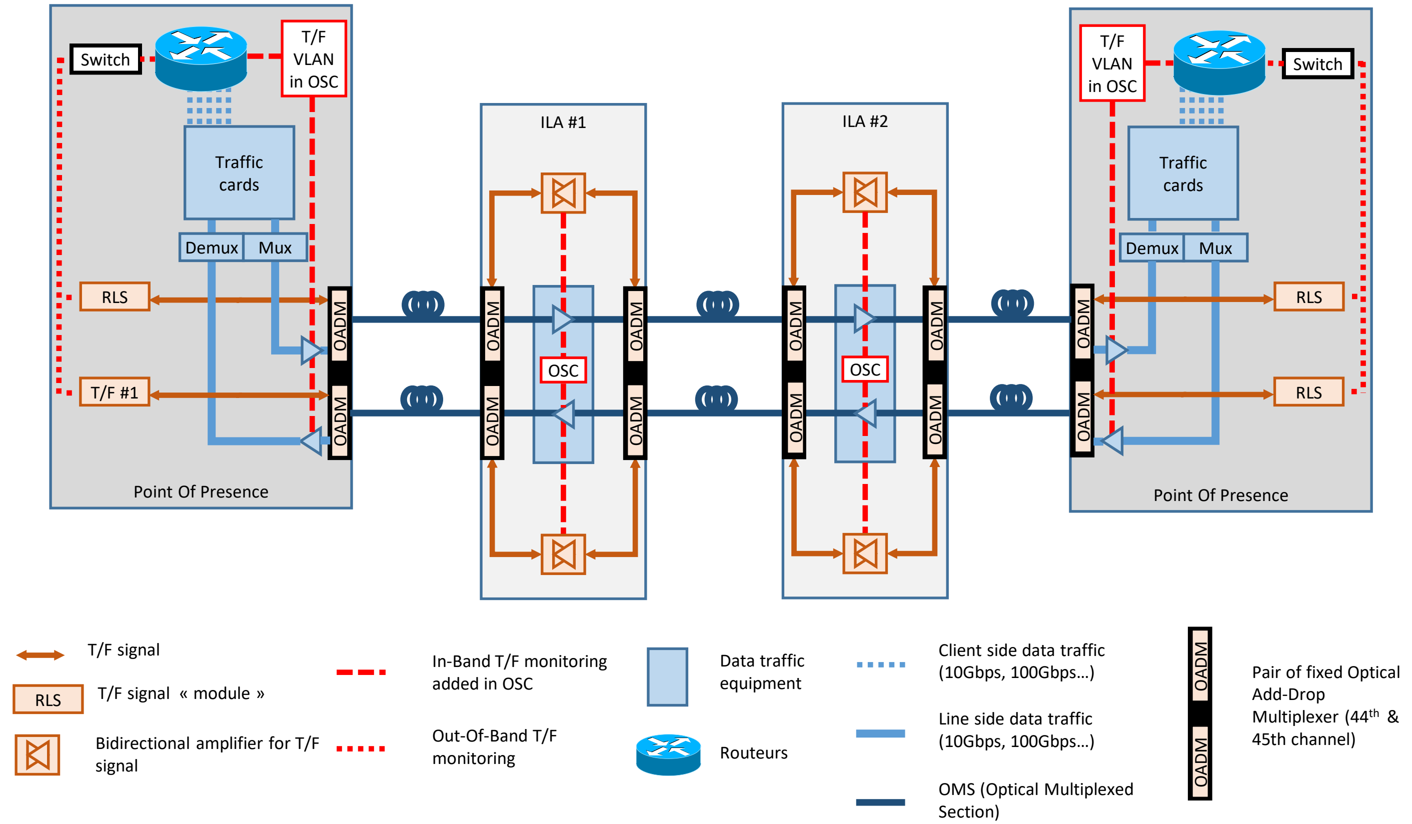


2 RLS in extremity sites

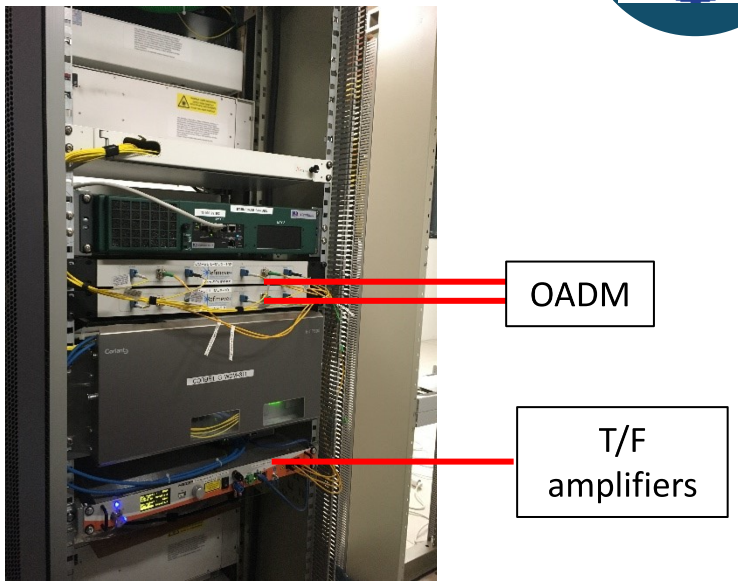
RLS

Optical	Wavelength (THz or nm)	194.4THz
	Spectral occupation	<5GHz
	max Output power (dBm)	3dBm
	min Input power (dBm)	-60dBm
	Connector type	FC/APC
Hosting	Typical Power consumption	120W
	Alimentation	220V AC
	Dimensions	19", 540mm, 7RU
	Weight (kg)	7kg

RENATER – France
Current T&F situation in NREN networks



Amplifiers and OADM in shelters

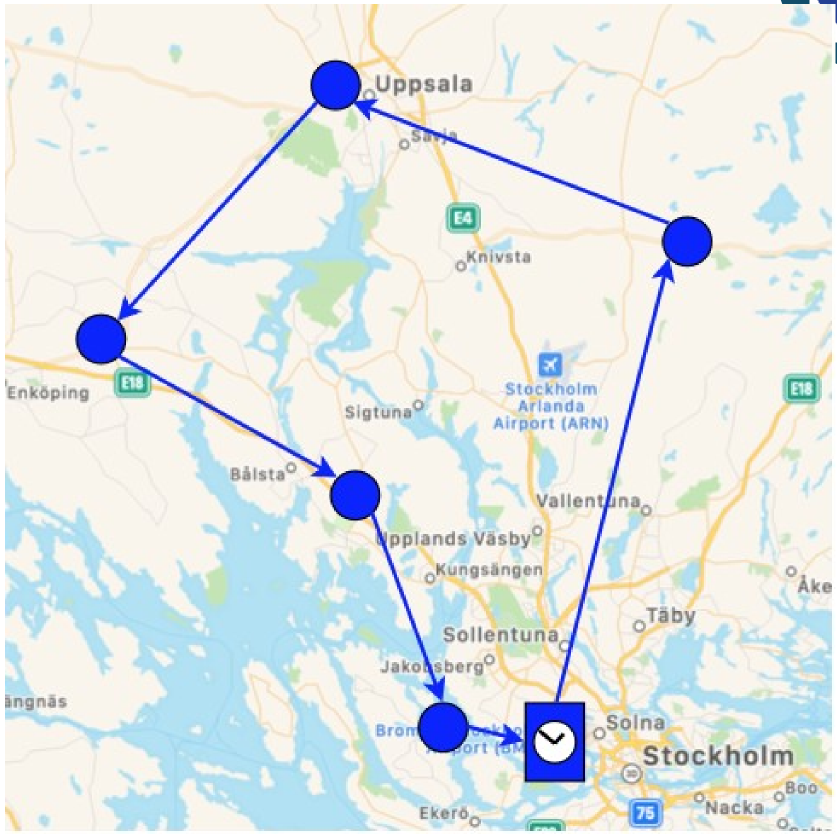


		T/F Amplifiers	OADM
Optical	max Output power (dBm)	3dBm	X
	min Input power (dBm)	-50dBm	X
	Typical gain (dB)	14dB	X
	Connector type	FC/APC	FC/APC and LC/PC
Hosting	Typical Power consumption (W)	<15W	0W
	Alimentation	-48V DC	X
	Dimensions	19", 240mm, 1RU	19", 240mm, 1RU
	Weight (kg)	2kg	0,5kg

Sunet – Sweden
Current T&F situation in Sunet

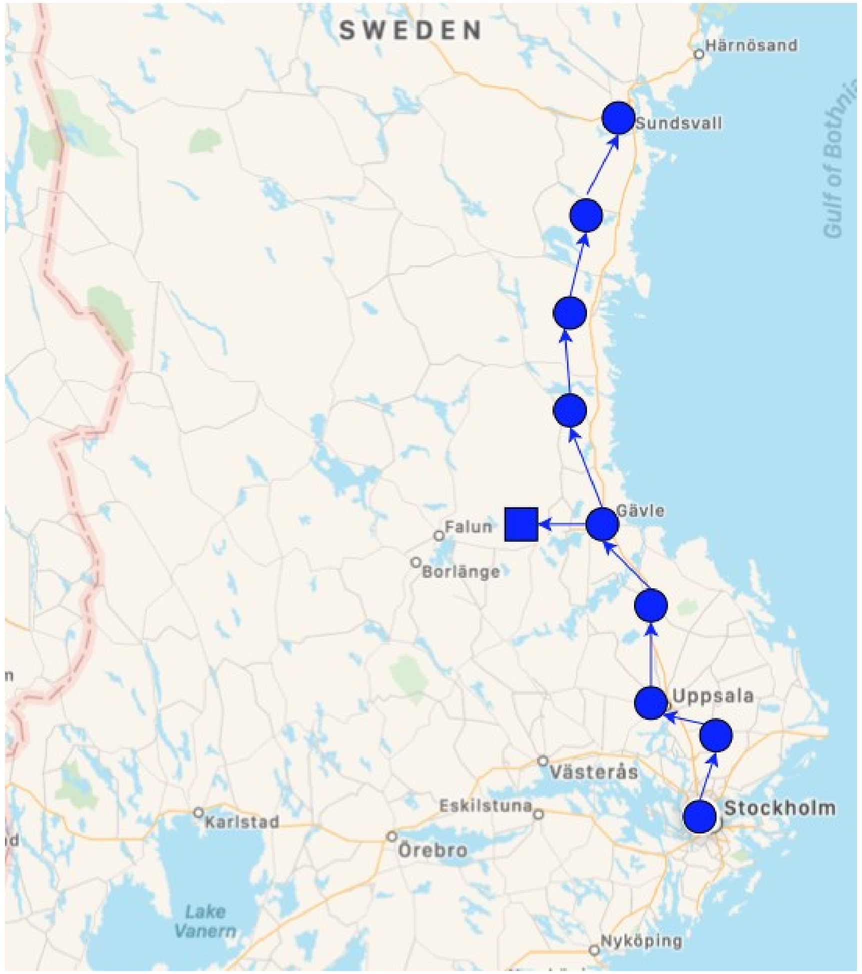
- **Sucess full loop test with WhiteRabbit 218km**
  - Together with Netnod for the national Time and Pace project
  - Financed by the Swedish Post and Telecom Authority, PTS
  - Long term stable time and frequency, also when GNSS is not available
  - Time nodes in 4 (soon 5) locations -node has two atomic clocks and can operate autonomously
  - Traceable to UTC(SP)
  - Operated by Netnod, supervised by RISE

  - 1600nm window on passive dwdm filters
  - 6 hops, Stockholm - Uppsala and back
  - Bidirectional on single production fibre with breakouts at each hops.
  - 1600nm window on passive filters
  - 4 hops Custom built 1610.06 nm SFP:s with circulators
  - 2 hops ADVA BiDi SFP:s
  - White Rabbit on each hop
  - Stability +- 0.1ns over 10days



Sunet – Sweden
Sunet next step

- Connect Time Nodes in Stockholm and Sundsvall
  - 442km of fiber
  - 10 Sites
  - Combination of WhiteRabbit switches and O-E-O regen boxes
  - Installation done, waiting of first data

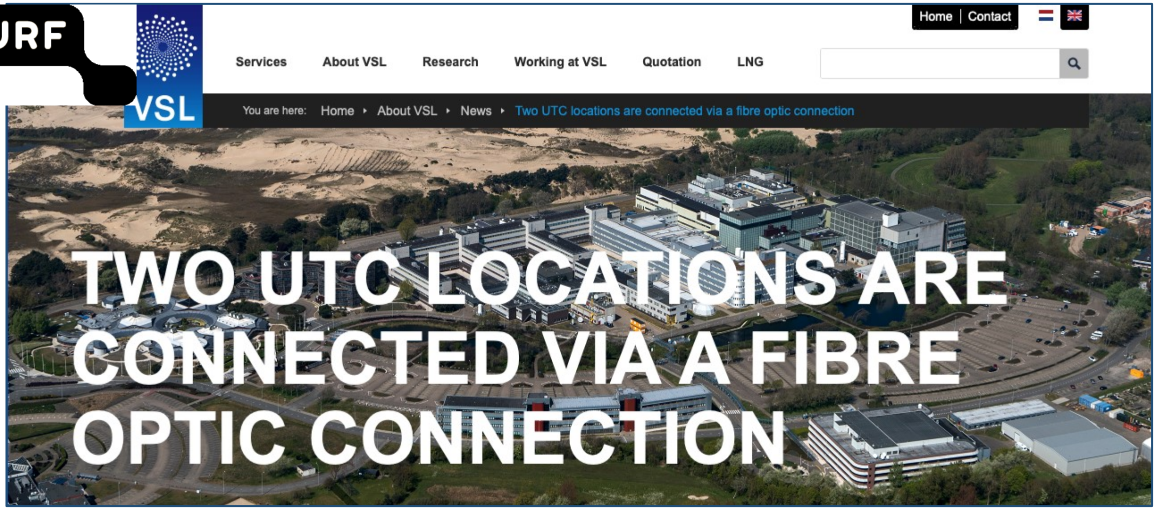


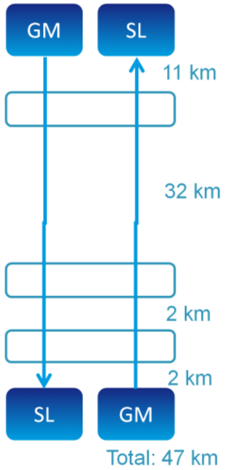
Sunet – Sweden
Goal for the project

- Connect all Swedish Post and Telecom Authority, PTS time nodes
- Connect to RISE - UTC(SP)
- Have redundant paths
- Connect to VTT, Finland?
- Dissemination in other locations, simpler time nodes?

SURF - Netherlands

https://www.vsl.nl/en/about-vsl/news/two-utc-locations-are-connected-fibre-optic-connection





USE CASE: TIME SYNCHRONISATION VIA A FIBRE OPTIC CONNECTION

01/08/2021

UTC is the international time reference: many applications, such as navigation equipment, use it to determine their time measurement. Normally via satellite connections, but fibre optic connections are also used, and are more accurate and reliable. In collaboration with SURF, a fibre optic connection between VSL and ESA ESTEC has been realised.

Reference for time: UTC

For all kinds of applications, it is important that there is a global reference for the exact time. Satellite navigation is of course a well-known and important application, but the exact time also plays a major role in industrial processes, stock exchange trading, telecommunications, astronomy, and medical research. The global reference for time measurements is UTC: the coordinated universal timescale. UTC is generated on the basis of atomic clock measurements of about 90 time centres worldwide, which are interconnected.

Realising the time standard

Erik Dierikx is researcher Time & Frequency at VSL, the Dutch metrology institute. "At VSL we maintain all relevant national measurement standards, including time, mass, length, etc. This is a task we perform for the government. When it comes to time: with 4 atomic clocks we realise the national time standard of the Netherlands. And like VSL, there is a total of about 90 time centres worldwide that realise a time standard. We compare our measurements with each other, and this results in the UTC. That is a kind of "weighted average" of the time measurements of those time centres."

Pierre Waller works as an engineer at ESTEC (European Space Research and Technology Centre), the ESA's technical centre in Noordwijk. This is where most of the ESA projects are developed. "ESTEC is also one of the time centres mentioned by Erik. We also have atomic clocks with which we can make very precise time measurements. Among other things, we need these for the monitoring of GALILEO, the civil satellite navigation system developed by ESA. But ESTEC is also the ESA's technical centre when it comes to time measurement. We need to have hands-on expertise in this area".

SURF - Netherlands

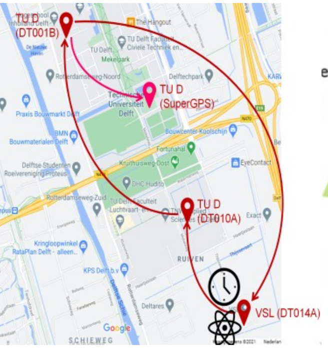
https://www.surf.nl/en/use-case-supergps-super-accurate-positioning-via-optical-network

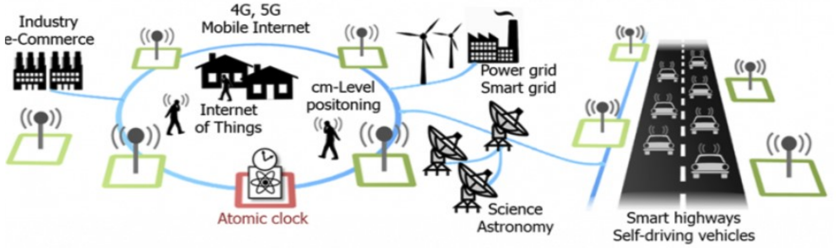
Use case: SuperGPS - super accurate positioning via optical network

GPS is good at positioning in large open spaces without obstacles, such as oceans and deserts. But in urban areas, with all their tall buildings, accurate positioning with satellite signals is more difficult. SuperGPS chooses a different solution: a combination of an optical fiber network and radio transmitters on buildings and along streets.

SURF

Christian Tiberius is a senior lecturer at the Faculty of Civil Engineering at Delft University of Technology. He is one of the project leaders of SuperGPS. "We started this project in 2016, in collaboration with VU Amsterdam, where Jeroen Koelemeij already worked on time and frequency distribution via fiber optics. We already had a lot of knowledge about the use of broadband radio signals. We were able to combine these two areas of expertise. The project now lies entirely with us, and I lead it together with my colleague Gerard Janssen from Electrical Engineering.





Accurate to 100 picoseconds

Christiaan Tiberius

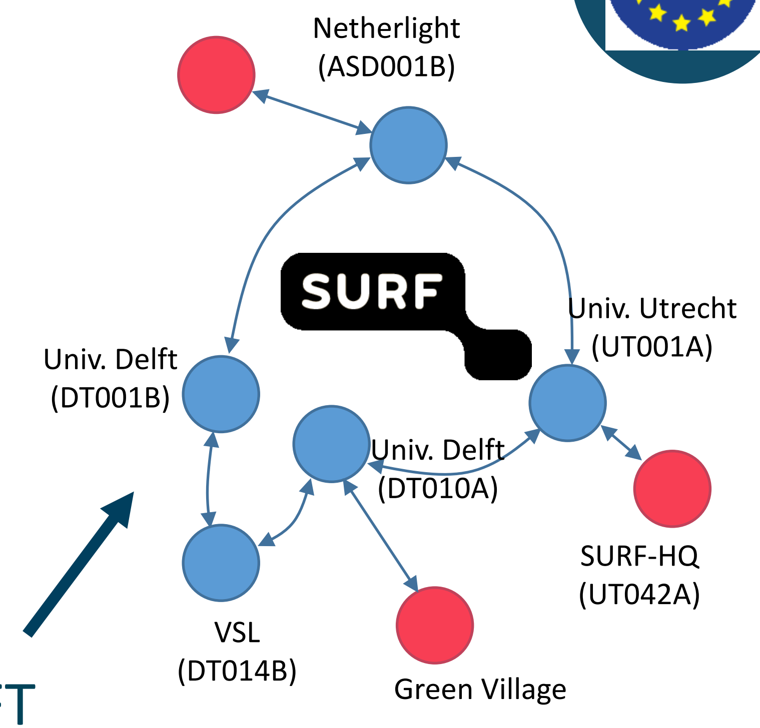
Experiments have already been conducted with SuperGPS. Tiberius: "Many projects result in papers, articles or other documents. We said at the beginning: we really want to make this work in a practical way. That's why we took the test in The Green Village - an existing experimental garden at TU Delft. We hung a transmitter box on 6 lampposts. Each transmitter was connected to the fiber optic network on which the atomic clock distributed the time. We then drove a car equipped with a receiver, and checked whether the system could determine the position of the car accurately enough, i.e. to 1 to 2 decimeters. This turned out to be the case!

The optical network delivered the time signal from VSL to each radio station with an accuracy of 100 picoseconds. The radio stations then transmitted their signals, which the car used to determine its position. A deviation of 100 picoseconds (1 picosecond = 1 trillionth second) corresponds to an error in the measured distance of 3 centimeters. However, there are other sources of error in the system (e.g. thermal noise in the electronics), which ultimately results in an accuracy of 1 to 2 decimeters".

SURF - Netherlands 2021

- TFT still seen as mainly a special service for researchers
  - Possibly application for indoor 4G and 5G timing

- Investigation into different business models is ongoing
  - Full service including equipment
    - SURF: all infrastructure owned and operated
  - Only fiber and spectrum resources, incl. transceivers
    - SURF: provides fiber, spectrum and SFP's
    - Researcher: provides White Rabbit Equipment
  - TFT as a service: PoC for a protected core ring in support of TFT
    - SURF: buy-in of the TFT service, provides fiber and spectrum resources
    - Vendor: provides equipment, and assures service,



SWITCH - Switzerland
Swiss ITU CH07 in L-band

Project «Sinergia»

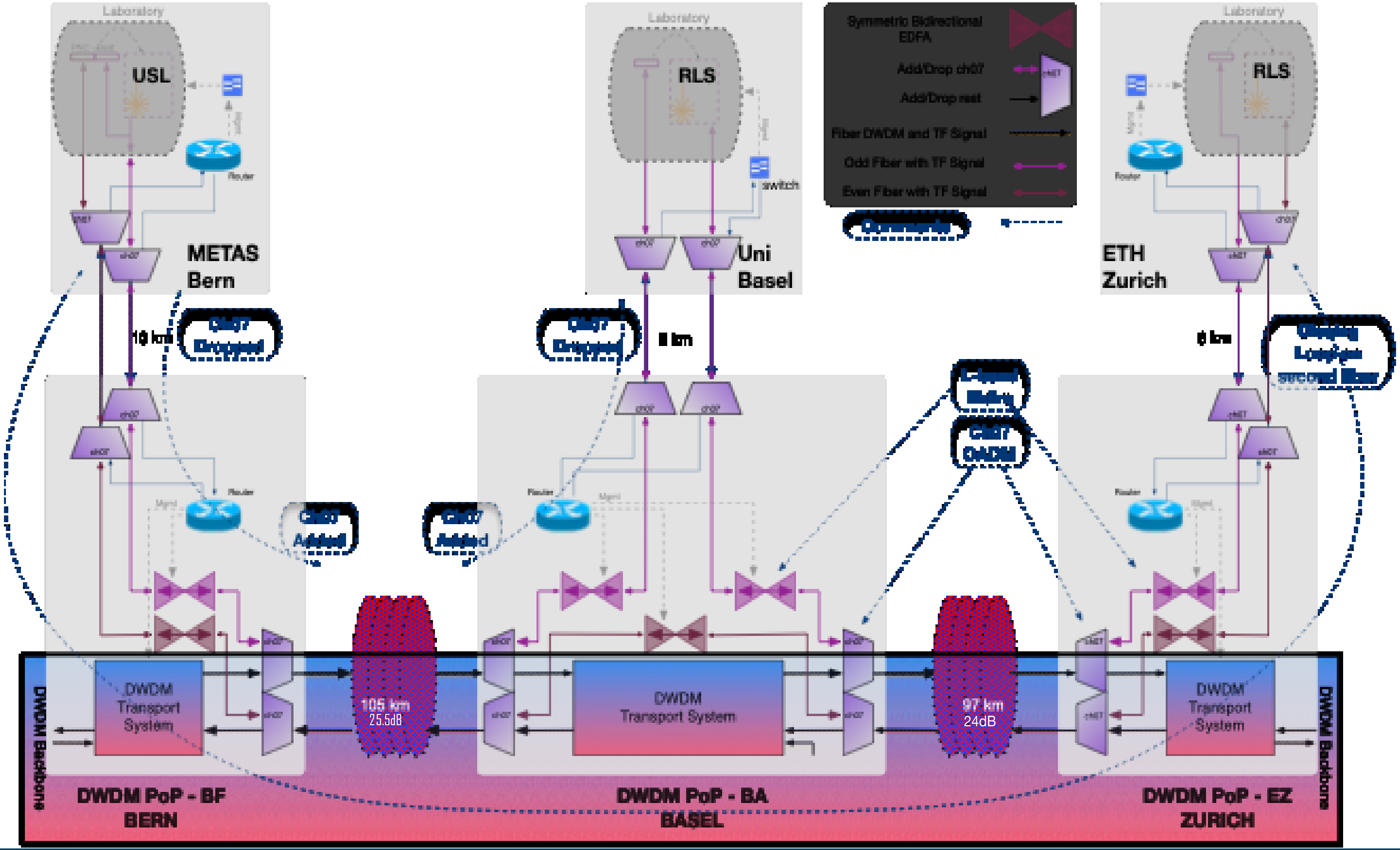
- METAS (NMI), ETH Zurich, Uni Basel
- Goal: High Precision Frequency ($<10^{-15}$)
- Applications:
    - Precision Spectroscopy
    - Ultra Narrowband THz Lasers

Implementation Specifics

- Single Fiber with Optical stabilization
- Dark Channel
    - Parallel to DWDM Data Transport
- ITU CH07 in L-band
- Future-proof
    - FlexGrid in C-band
    - Future Vendors in C-band

Equipment needed

- CH07 OADMs
- Symmetric L-band Bidir Amplifiers
- Metrological Signal in CH07
    - Ultra Stable Laser
    - Repeater Laser Station

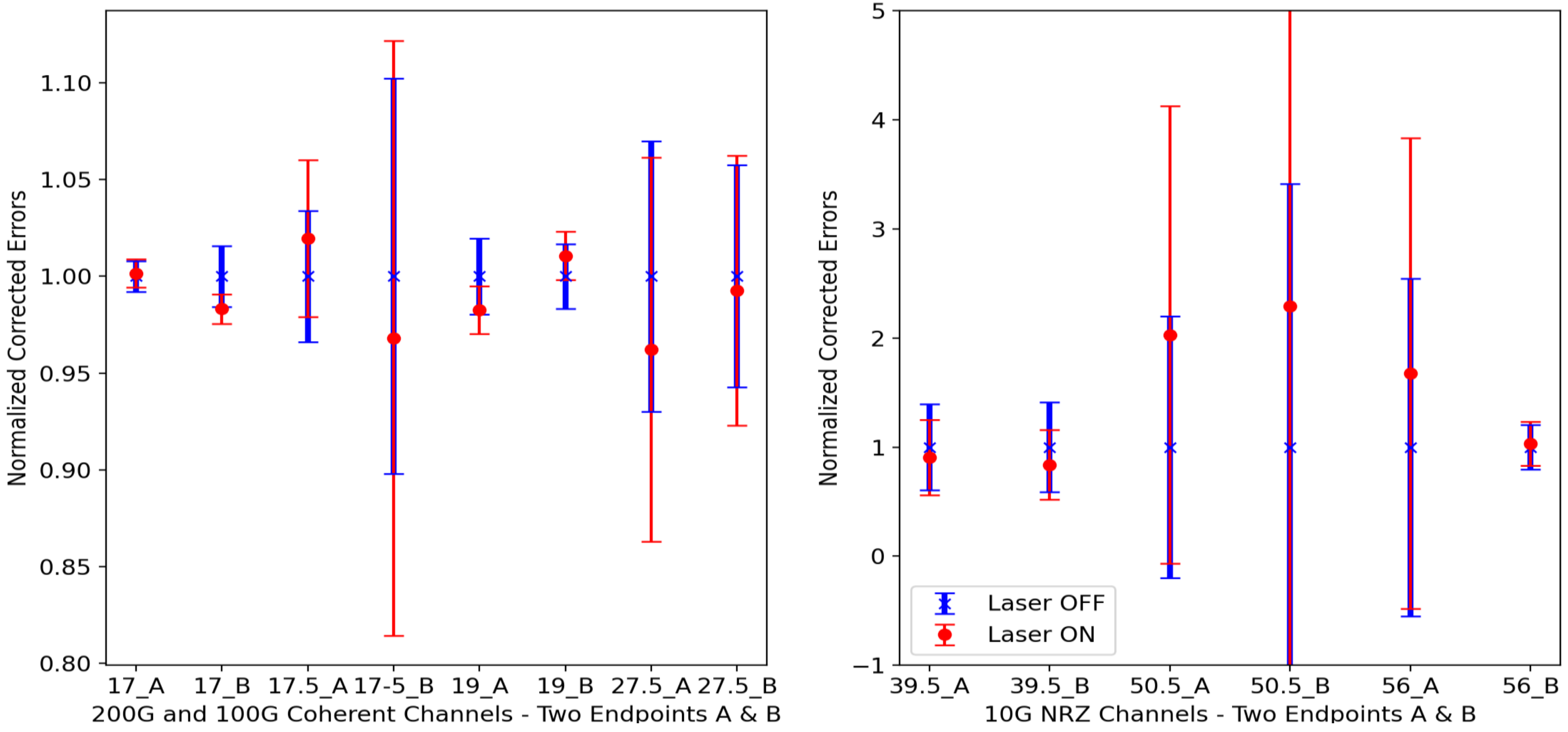


SWITCH - Switzerland
Parallel Transport - Interference

- Goal: Impact of Metrological Signal on DWDM channels
  - Transponders have Performance Data
    - Errored Sec (i.e. Out Of Frame, Background Errored sec)
  - Transponders have FECs
    - Corrected Errors
- Turn CH07 Lasers (& Amps)
  - OFF and ON
  - Any Impact to DWDM Channels?
- 8 backbone DWDM channels
  - **no errored seconds** in OUT signal
    - = No Impact for clients
- Let's look at the corrected errors
  - Increased Corrected Errors? ---->
    - No clear correlation
- **No Impact on DWDM Channels**

Data measurements:
120h Laser ON
38h Laser OFF

Average corrected errors per 15min devided by the average corrected errors when the laser ch07 was off.
>1 means more corrected errors, <1 less corrected errors.



UNINETT - Norway

- Don´t have so far real demands on T&F services
- But working with among other "Norwegian Metrology Service" to identify the needs
- About to build our next generation optical infrastructure and supporting T&F is considered in the design.
- We prepare the nodes with L/C filter in order to be able to support T&F and other special optical services at L-band area without interrupting the C-band data traffic.

Ackonowledgement

- Contributors
- Rest WP6 T1 OTFN team: Xavier Jeannin, Ivana Golub, Tim Chown

Thank you

Any questions?

josef.vojtech@cesnet.cz