TRANSMISSION OF PRECISE TIME AND ULTRA-STABLE OPTICAL FREQUENCY WITHIN TELECOMMUNICATION NETWORKS

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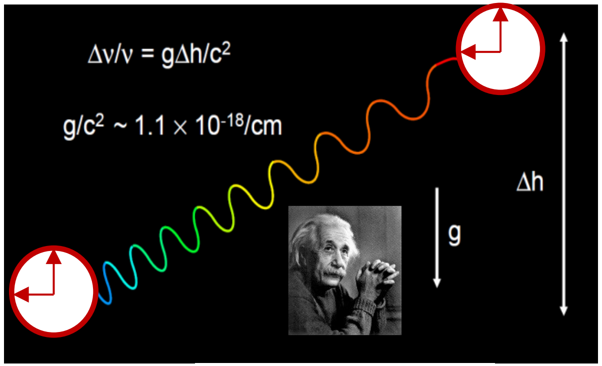
Outline

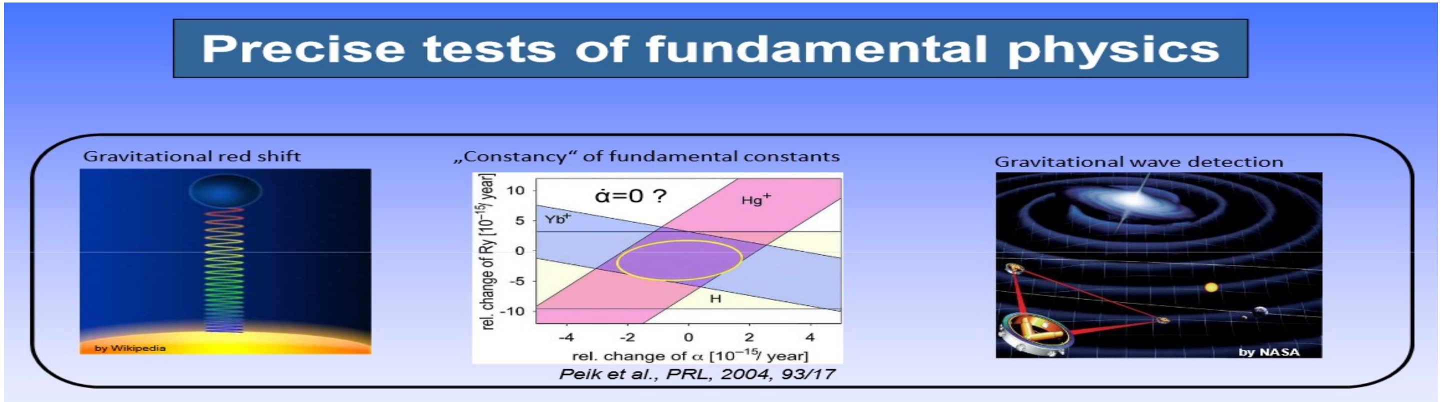
- Motivation for precise time and ultra-stable frequency transmission over fibers
- Overview of chosen national initiatives/project related to ultra-stable optical frequency / precise time transmission over telecom fibers: Czech Republic, Finland, France, Germany, Italy, Switzerland, United Kingdom
- Overview relevant projects
  - EURAMET EMRP, EMPIR: NEAT-FT, OFTEN, WRITE, TiFOON
  - HORIZON 2020: CLONETS, GN4-WP6-T1-OTFN, CLONETS-DS

Why Precise Time and Frequency?

- **Time and frequency** = quantities we are able to measure with the highest accuracy
- Represent ideal way how to measure tiny effects
- (Radio)astronomy: VLBI, SKA;
- Precise tests of fundamental physics:
  - Constancy of fundamental constants
  - Detection of gravitational wave
  - Tests of special & general relativity

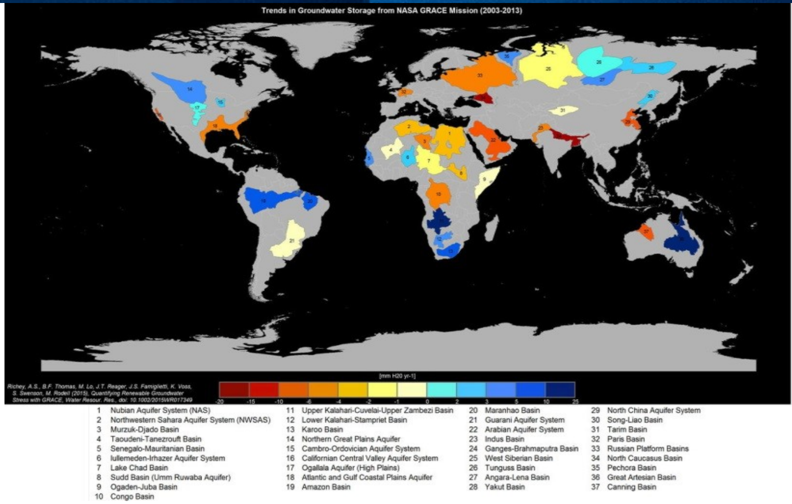


Credit: Schnatz14



Credits: Newbury14, Barr10

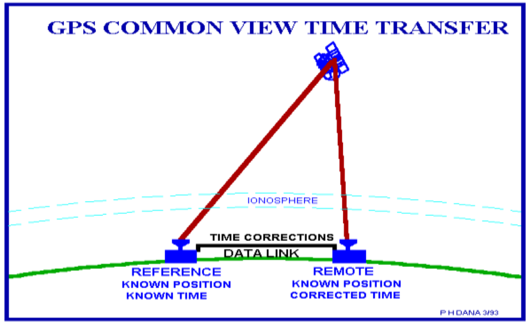
Why Precise Time and Frequency?

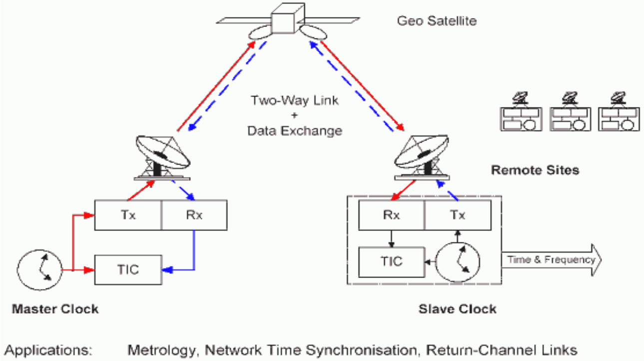


Earth sciences, remote sensing

- Land – geodesy, seismology, water resource and other natural resources inventory, etc.
- Atmosphere – climate modelling and changes monitoring, etc.
- Oceans – circulation, geoid monitoring etc.

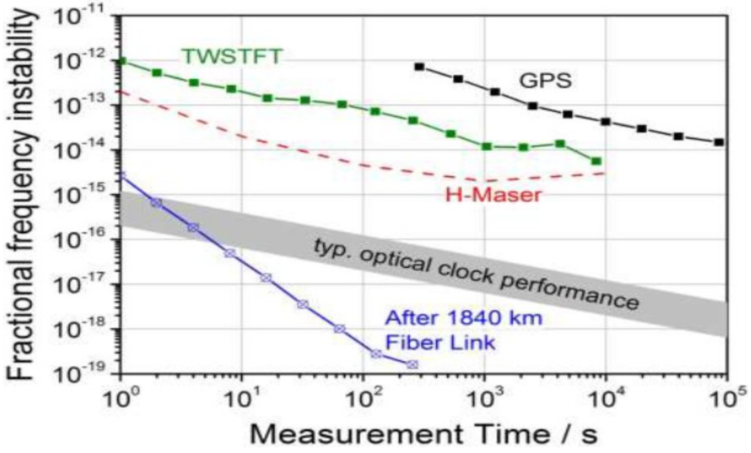
Traditional RF Based Transfer





- CV GNSS (GPS, GALILEO, GLONASS, …) accuracy 3 – 50 ns
- GNSS PPP (Precise Point Positioning) 0.1 ns
- TWSTF 0.1 ns

Credits: Colorado, Timetech, Droste13

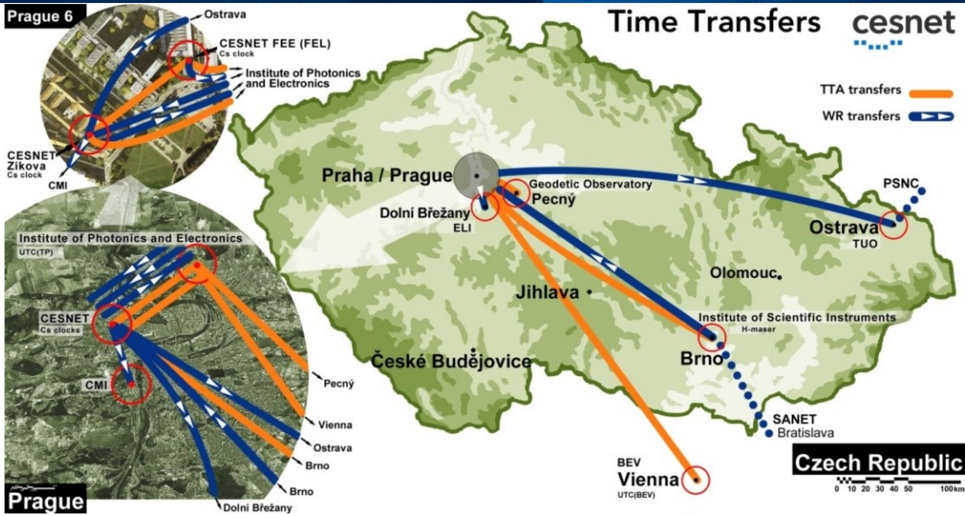


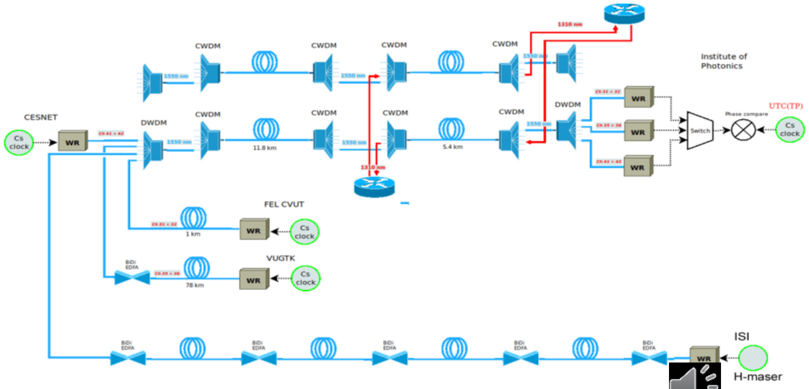
Specific situation in Europe

- Every country has own NMI, runs own approximation of UTC
- Distance between neighboring NMI is in order of hundreds kilometers
- Fiber utilization is necessary due to increasing number of optical clocks
- Cooperation between NMIs is supported by international projects

Czech Republic

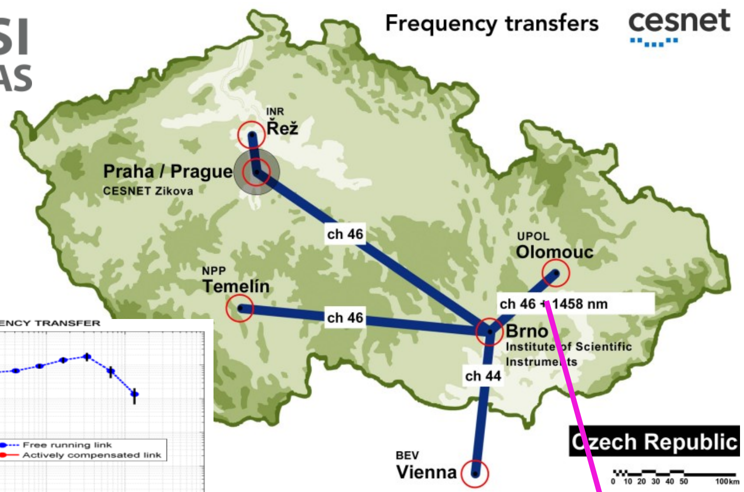
- CITAF
- Fibers shared with data
- Bidi + unidirectional telco lambdas
- Time+RF – Time Transfer Adapters + White Rabbit – over 1800+ km
- Stability (TDEV) down to 2ps
- Comparison of UTCs
  - UTC(TP)
  - UTC(BEV), planned UTC(PL/AOS)
- Distribution
  - ELI
- Synthetized Time Scale
  - Cs and H maser operators

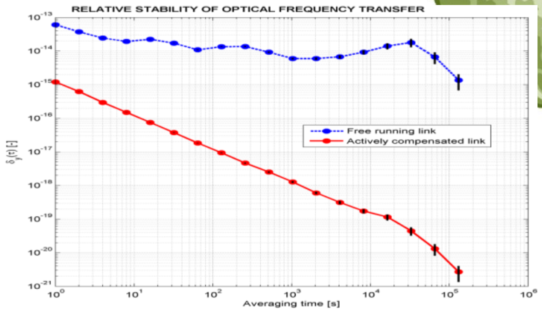


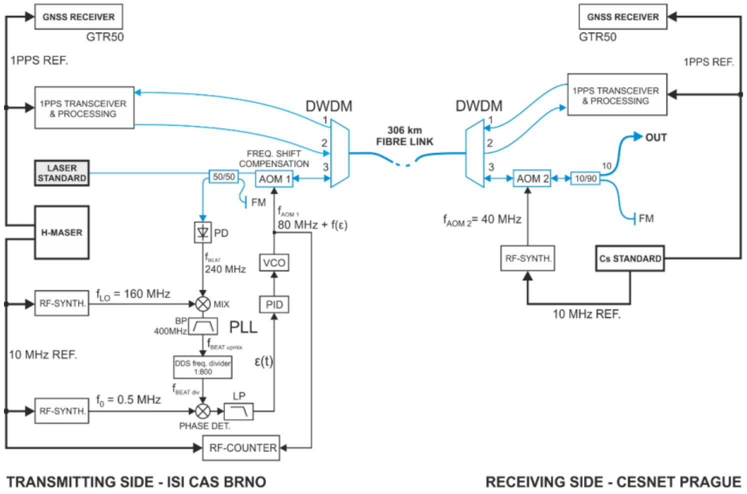


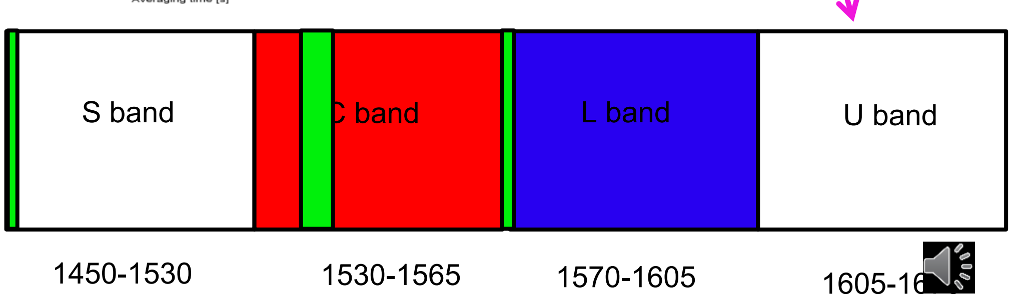
Czech Republic

- Coherent optical frequency – COF bidirectional transmission within single fiber – 1100+ km
- Preferably dedicated all-optical sub band 800/400 GHz (includes 1540.5 and 1542.1 nm)
- bidiEDFAs C+1570nm, SOAs for 1458



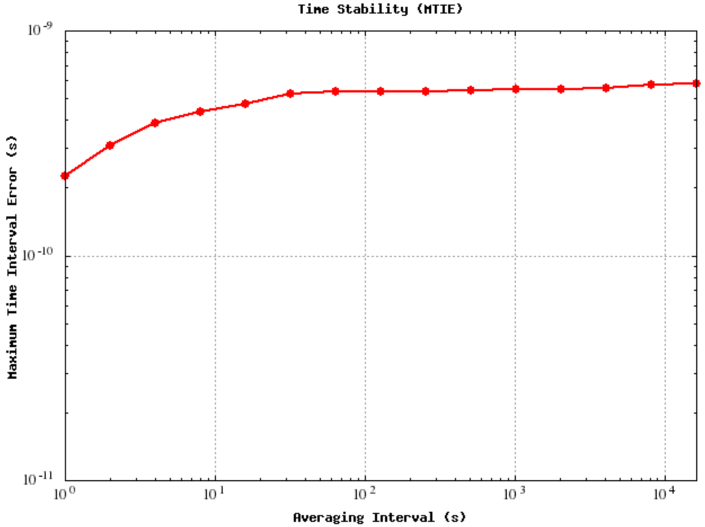


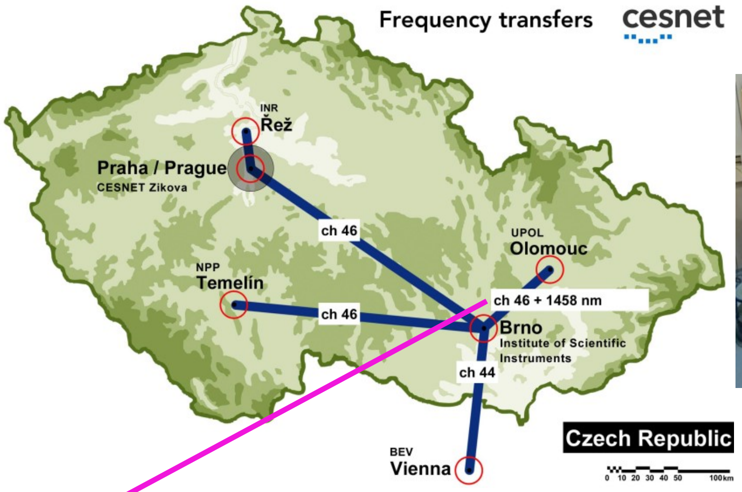


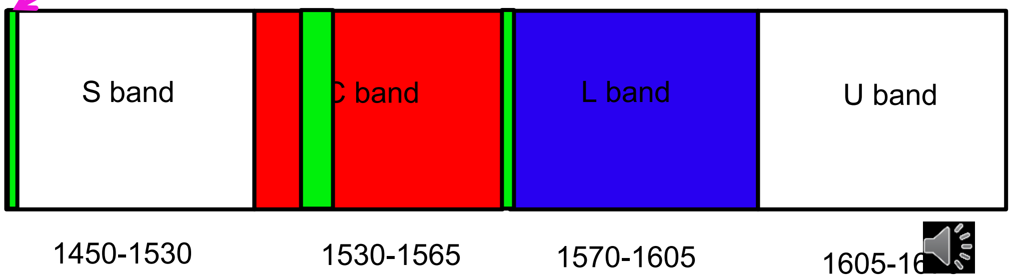


Czech Republic

- White Rabbit in 1460 nm band
- 26+20 dB line (90km field+ 100km lab fiber)
- WR MTIE < 600ps

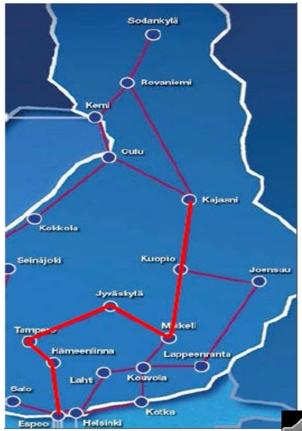






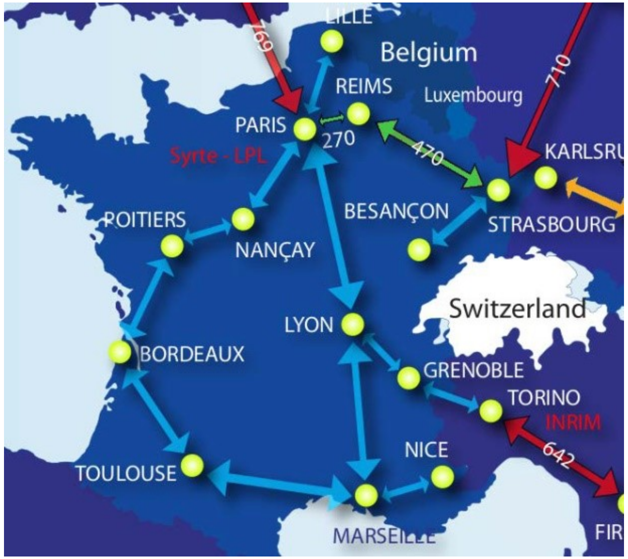
Finland

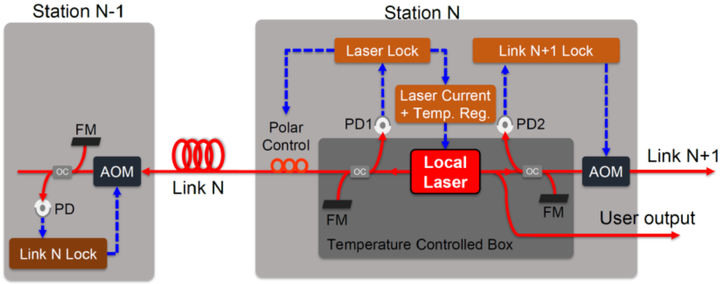
- T+RF - shared with data
- Espoo-Kajaani(800 km), WhiteRabbit, unidir telco lambdas
- Espoo-Helsinki (25 km), single fiber, WhiteRabbit 1605/1615nm in CWDM channel
- Espoo-Metsähovi observatory (60 km), single fiber, WhiteRabbit, pasive DWDM



FRANCE

- Shared Fibres
- COF 2400 km
  - Paris-Lille
  - Paris – Grenoble – Modanne
  - Paris - Strasbourg – Besançon
- Up to now, 8 labs connected
- 12 RLS, bidiEDFAs





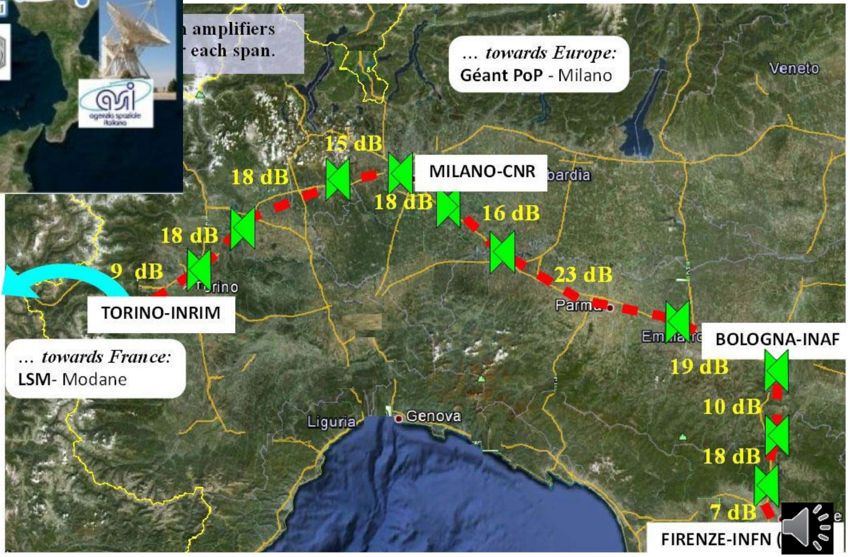
Chiodo et al, Opt Express 2015

Germany

- Dedicated Fibres
- COF
  - Braunschweig – Hannover: ca. 85 km
  - Braunschweig – Karlsruhe- Strassbourg: ca. 750 km, 3 inline FBAs
  - Karlsruhe – Garching: ca. 375 km 2 inline 1 FBA, 1 EDFA
- Time+RF - ELSTAB
  - Hannover – Frankfurt: ca. 390 km, 4 inlines
  - Planned Hannover – Berlin: ca. 300 km, 4 inline amps
  - Hannover – Bremen: ca. 140 km, 1 inline amps
  - PTB – Hannover: ca. 85 km
  - PTB – Bremen: ca. 225 km, 3 inline amps
  - Planned UTC(DLR) to UTC(PTB)/UTC (DTAG)
    - Hannover – DLR Oberpfaffenhofen/Weßling: ca. 800 km, 12 inline amps
    - Frankfurt – DLR Oberpfaffenhofen/Weßling: ca. 500 km, 7 inline amps

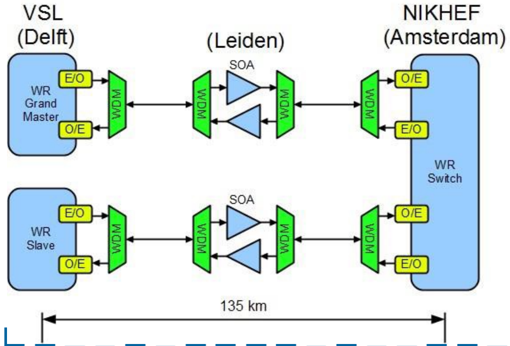
Italy

- Dedicated Fibres
- NMI INRIM - COF
  - 650 +100km
  - bidirectional, bidiEDFAs
- NREN White Rabbit - tests



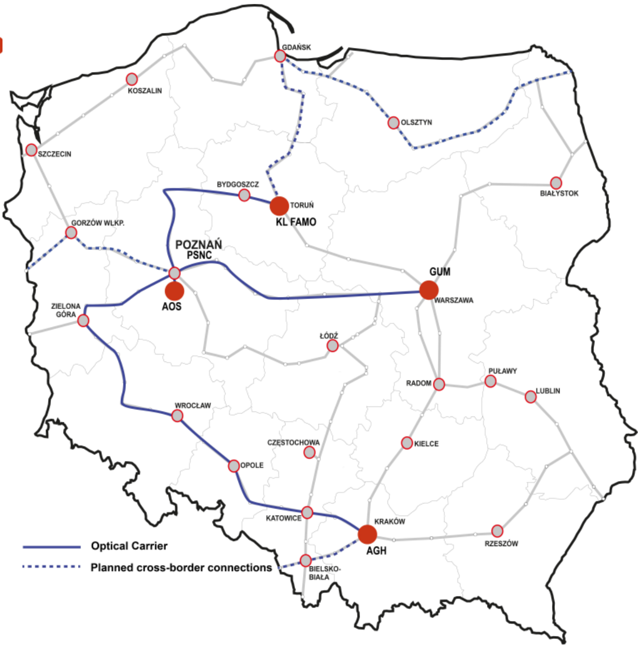
Netherlands

- Shared Fibres
- T+RF - White Rabbit
- 1470+1490, quasi bidi SOA, NIKHEF – VSL 2014, 137 km
- Change to 100 GHz offset declared



Poland

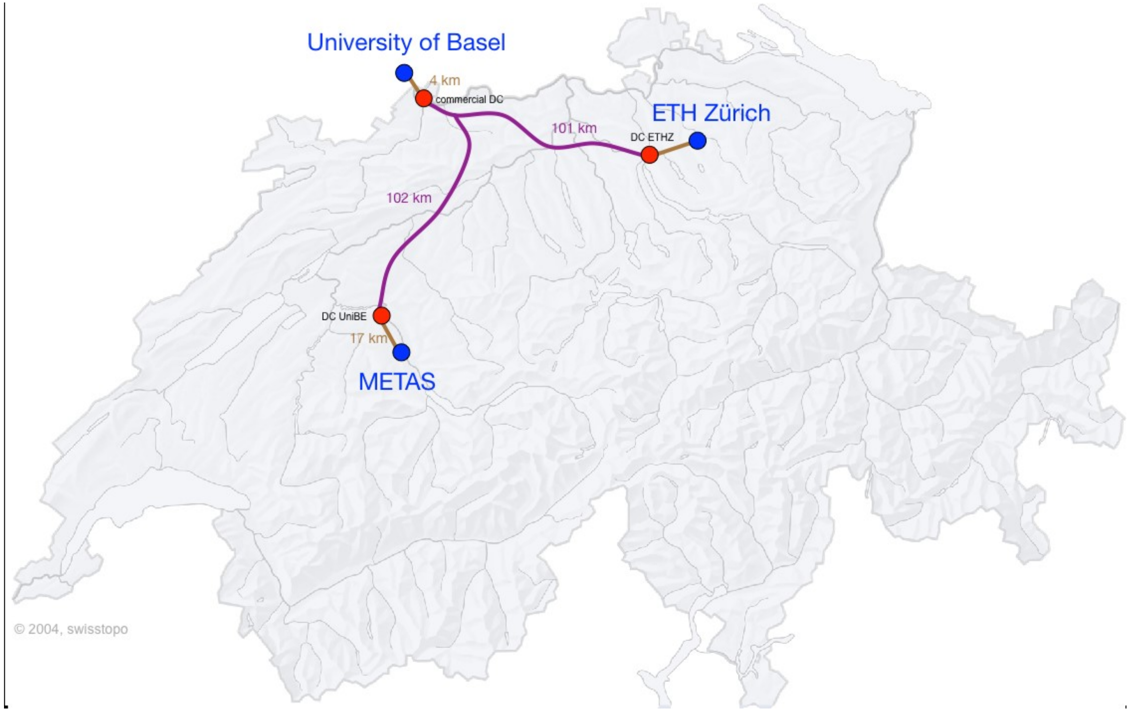
- Dedicated Fibres
- T+RF - ELSTAB
  - red bidirectional, bidiEDFAs
  - orange - unidirectional telco lambda DWDM
- COF – blue, under development



Switzerland

- Shared fiber
- Ca. 250 km COF

  to be deployed 2020
- 1572 nm, bidiEDFAs



United Kingdom

- Dedicated Fibres
- Time+RF 155 km
  - NPL (Teddington) - Telehouse North (London), 75 km fibre, NPLtime (PTP)
  - NPL (Teddington) - Daisy (Reading), 80 km fibre, NPLtime (PTP) and White Rabbit
- COF
  - NPL (Teddington) - LPL (Paris), 760 km fibre, bidiEDFAs

HORIZON 2020

Horizon 2020 is the biggest EU Research and Innovation programme

- €80 billions of funding
- 7 years (2014 to 2020)
- follower of FP7

https://ec.europa.eu/programmes/horizon2020

CLONETS
CLOCK NETWORK SERVICES

CLONETS

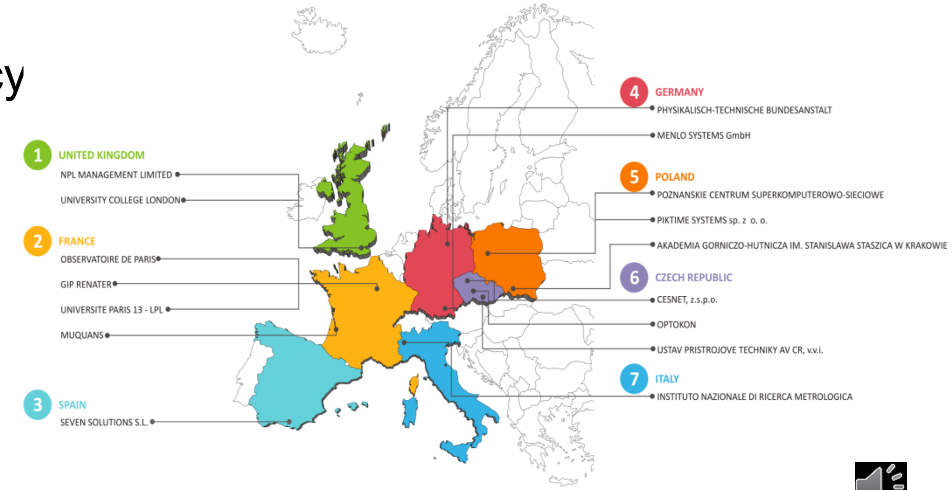
“Clock Network Services”

- European Union funded project: Horizon 2020 European Research and Innovation programme - coordination and support action.

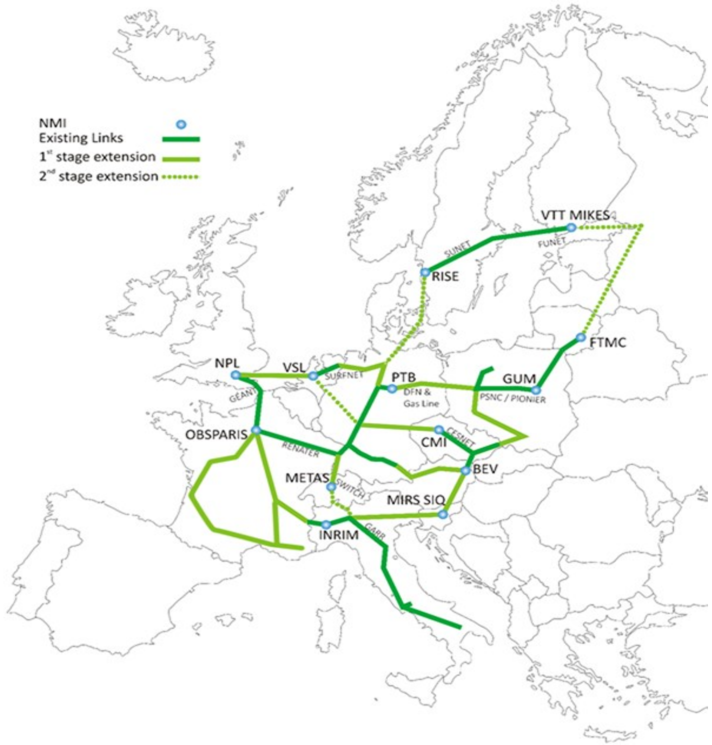
- No budget for research or infrastructure

- Aims to prepare the transition of time and frequency services to permanent, pan-European, optical fibre-based network.

- Started in January 2017, scheduled for 30 months



CLONETS



Existing advanced techniques			Performances Frequency (instability) Time (precision, Time Deviation TDEV)	TRL	Distances
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 ≈ 2 ps	5-6	100-500 km
			TDEV ≈ 30ps calibration through GPS (unidirectional)	6	100-500 km
	Optical frequency comb		Calibration uncertainty <40 ps 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 ±2 ns	8-9	>1000 km
			Calibration uncertainty <10 ns	8-9	0-100 km

Topology proposal, performance overview, some from CLONETS outcomes

GEANT GN4-3 OTFN TASK

OTFN task

begin Apr 2019 - scheduled for 24m

- participant NRENs:
    - RENATER
    - PSNC
    - CESNET
    - SWITCH

GEANT

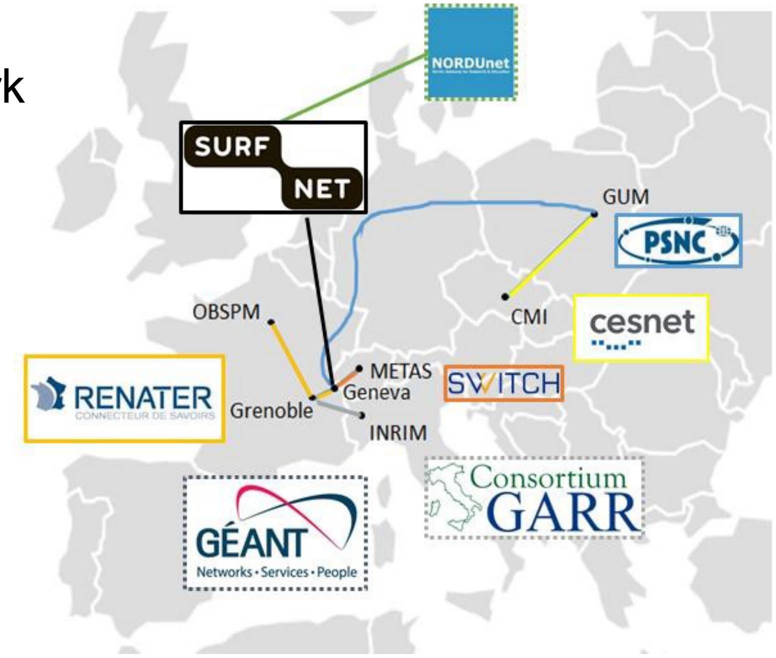
European academic network interconnecting 38 national research and education networks (NREN)

50 mil. users in 10000 institutions

links up to 500 Gbps

GEANT GN4-3 OTFN TASK

- Builds on results of CLONETS project.
- Create an engineering design to allow time and frequency generated by atomic clock to be disseminated over next generation of GÉANT network
- Carry out lab verification of non influence of time and frequency service within new generation of GÉANT network
- Proposed TF testbed on the right
- White paper „Distributing New Performant Time and Frequency Services over NREN Network“: https://www.geant.org/Resources/Documents/GN4-3_White-Paper_Time_and_Frequency.pdf



Credit to GEANT

CLONETS-DS

“Clock Network Services – Design Study”

- Elaborating the needs of the scientific community for ultraprecise timing and frequencies in various fields of research leading to the definition of user requirements the envisaged system has to address in its service at selected points of presence.
- Defining an architecture that supports this service at the highest, most advanced level of stability and accuracy.
- Designing an engineering model and strategies to implement a sustainable research infrastructure including the creation of a common data platform.
- Defining roadmaps and a deployment strategy that assure interoperability of already existing implementations in Europe and possible future extensions.
- Within parallel effort, it is being planned to list this project in upcoming revisions of the ESFRI roadmap of the EU.

- Start postponed to Oct 2020, scheduled for 24 months

Summary

- COF transmission scheme clear (excl. different channels)
- Significant effort do address operational issues (stand alone operation, calibration, resiliency)
- Significant effort do squeeze both T and F into narrowband spectrum (optical)
- Optical time and frequency transfer infrastructure will share fiber infrastructure with research network rather than utilize commercial fibers.
- Stability frequency transfer and uncertainty of time transfer improves 10x (NEAT-FT vs- TiFOON)

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Thank You Very Much for Kind Attention!

Questions Please?

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