tnc25
Brighton, UK | 9-13 JUNE 2025
BRIGHTER TOGETHER

Time, Frequency and White Rabbits

Supporting Science and Society with Precision Timing

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TNC25

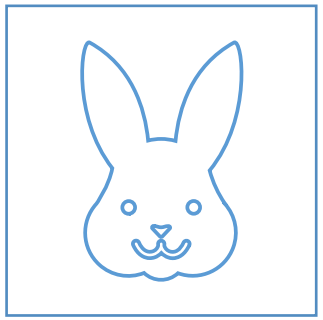
Wednesday, 11th June 2025

Co-funded by the European Union

GÉANT

Content

Importance of Time Services and Opportunities for NRENs



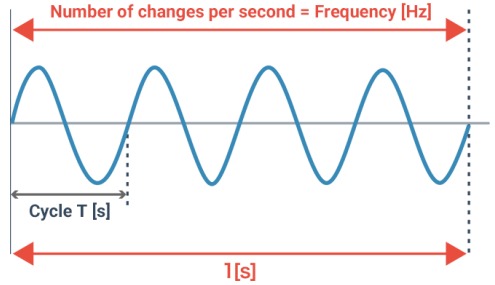
Low-Cost High-Accuracy Time Service with White Rabbit

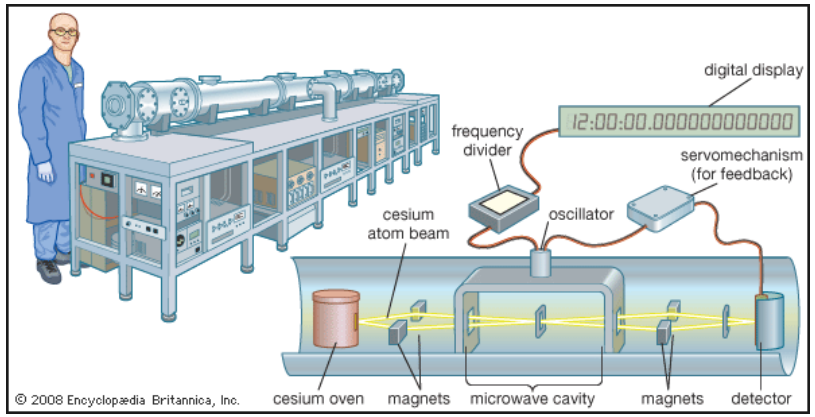
Activities in GEANT and NRENs

Importance of Time Services and Opportunities for NRENs

Time and Frequency in a Nutshell

- **Time** is how long something takes, and **Frequency** is how often it repeats.





Source: Encyclopedia Britannica

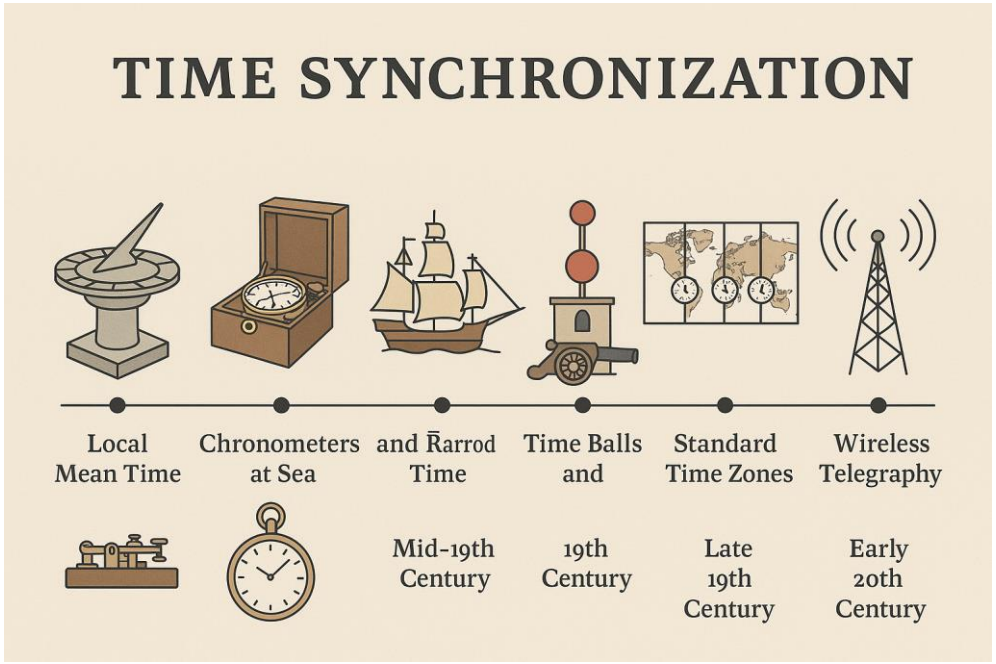
1500 B.C.

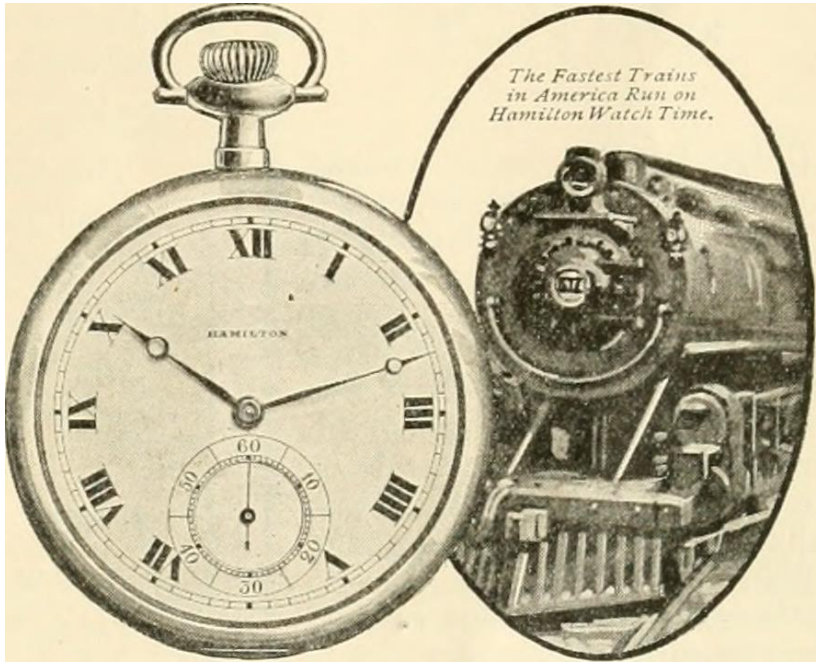
17th Century
Pendulum f=50Hz

Louis Essen's 1955 invention of the first practical atomic clock
1968 definition of second f= 9,192,631,770Hz

Time and Frequency in a Nutshell

- How did we “know” the time when moving in different geographical locations?



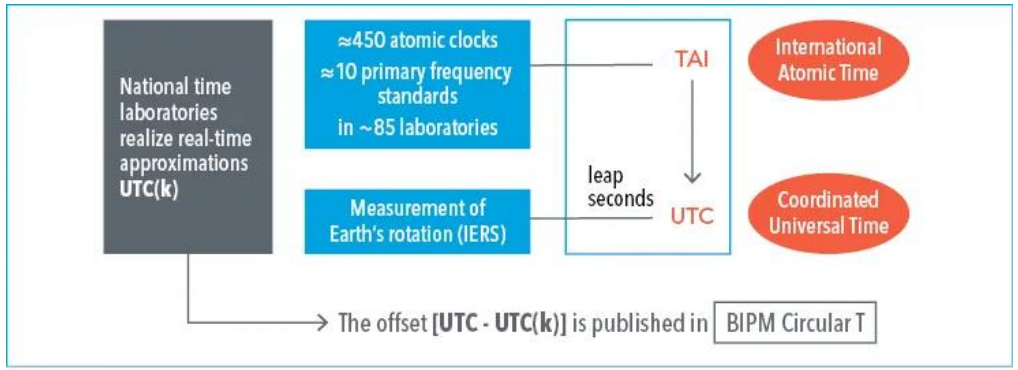


Src: Zmodal, How Railroads Created Standardized Time Zones

How Do We Measure and Maintain Time Now?

- Coordinated Universal Time (UTC) is the worldwide reference time scale computed, maintained and improved by the Bureau international des poids et mesures (BIPM) − the international organization focused on measurement science and standards.
  - National Metrology Institutes (NMIs) maintain and distribute the national timescale.
  - Their clocks provide regular measurement data to BIPM, as well as the local real-time approximations of UTC, known as UTC(k), for national use. BIPM compares and gives the NMIs the offset.

> **UTC is based on about 450 atomic clocks, which are maintained in 85 national time laboratories around the world.**

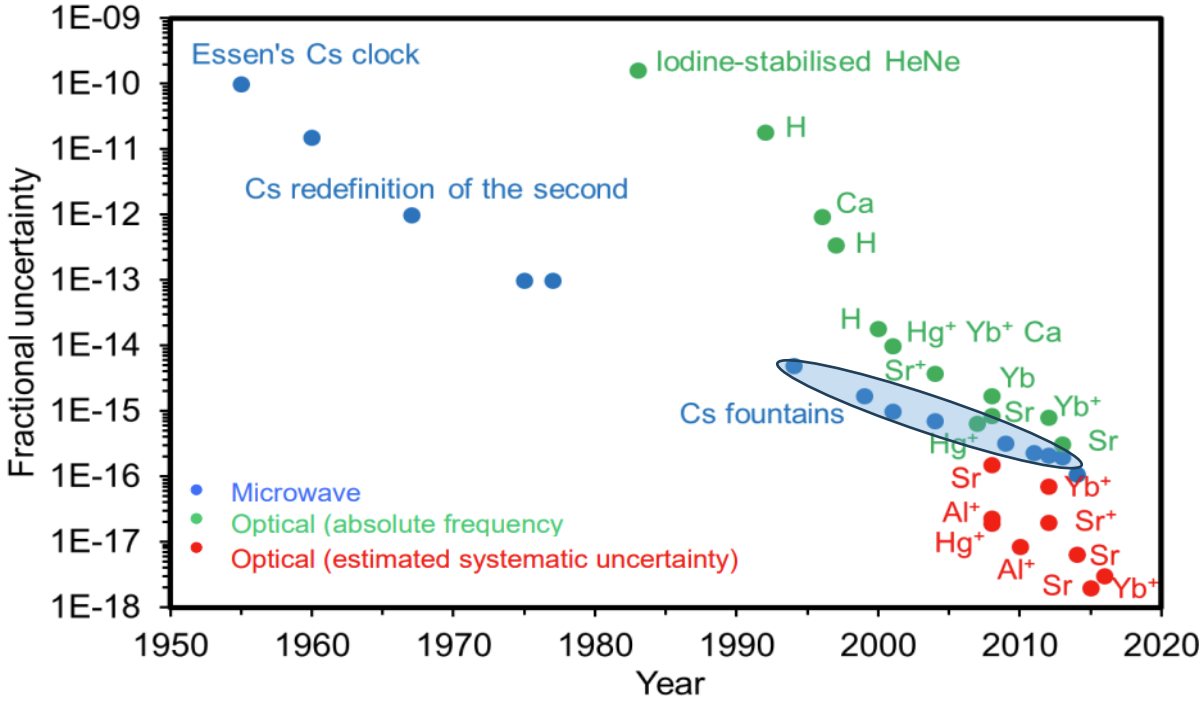


Source: BIPM

Precision timing underpins many features of our daily lives: mobile phones, financial transactions, electric power grids and global navigation satellite systems all rely on time and frequency standards.

Optical Atomic Clocks
The Future of Time

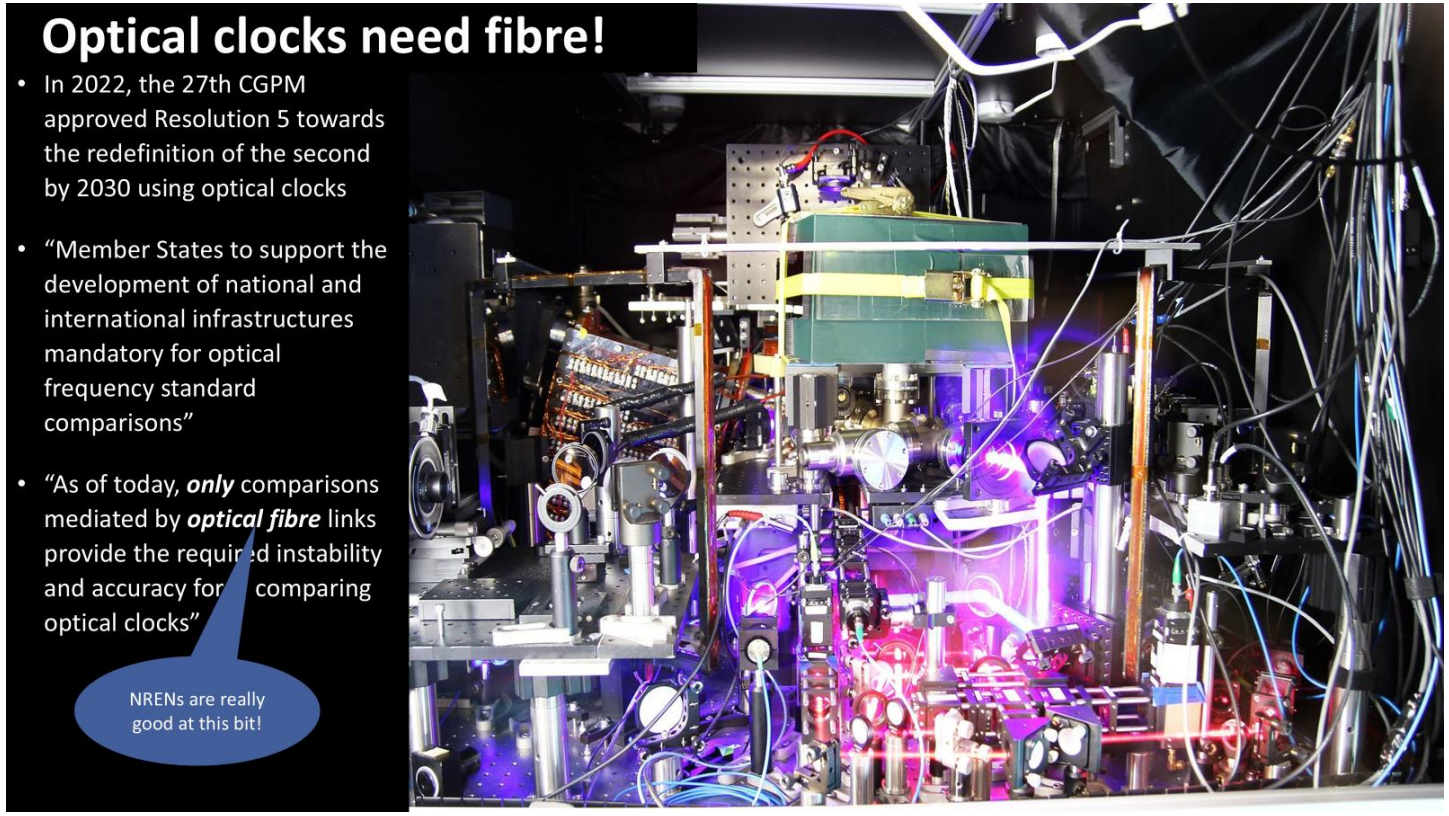
- Since 1968 the second has been defined by measurement using Cesium ‘RF’ atomic clocks.
  - E.g. an atomic clock with a fractional uncertainty of 1E-16 will drift by one second in 300 million years.
- Optical atomic clocks are now a better technology for measuring time at 1E-18.
  - ~ 31.7 billion years, less than 1 second drift since the Big Bang.



Courtesy: Guy Roberts, TNC 2024

Redefinition of the SI Second and the Role of NRENs

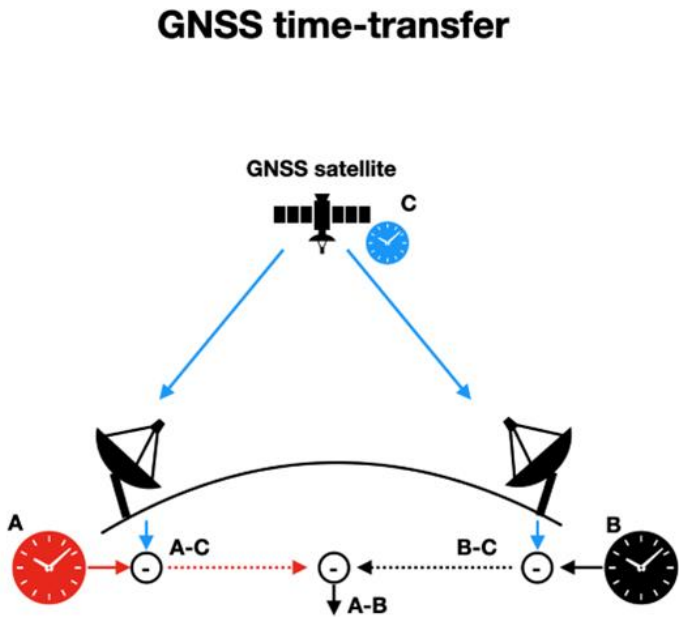
- **Support the redefinition of the SI second** being carried out between now and 2030+ by NPL, PTB, Syrte and INRIM and other NMIs.
- GEANT GN5-2 C-TFN project ongoing for fibre-based time and frequency distribution in Europe.



Courtesy: Guy Roberts, SIG-TFN Workshop, Ispra, 2025

Maintaining the Coordinated Universal Time (UTC)

- BIPM organizes the international network of time links to compare national/local realizations of UTC(k) from contributing laboratories.
- The network of time links used is non-redundant and relies on observation of Global Navigation Satellite System (GNSS) and two-way satellite time and frequency transfer.
    - Need to compensate for the delay due to e.g. the ionosphere, the gravitational field, movement of satellites, etc.
- Future: complement with reliable and high-precision distribution through optical fibres.

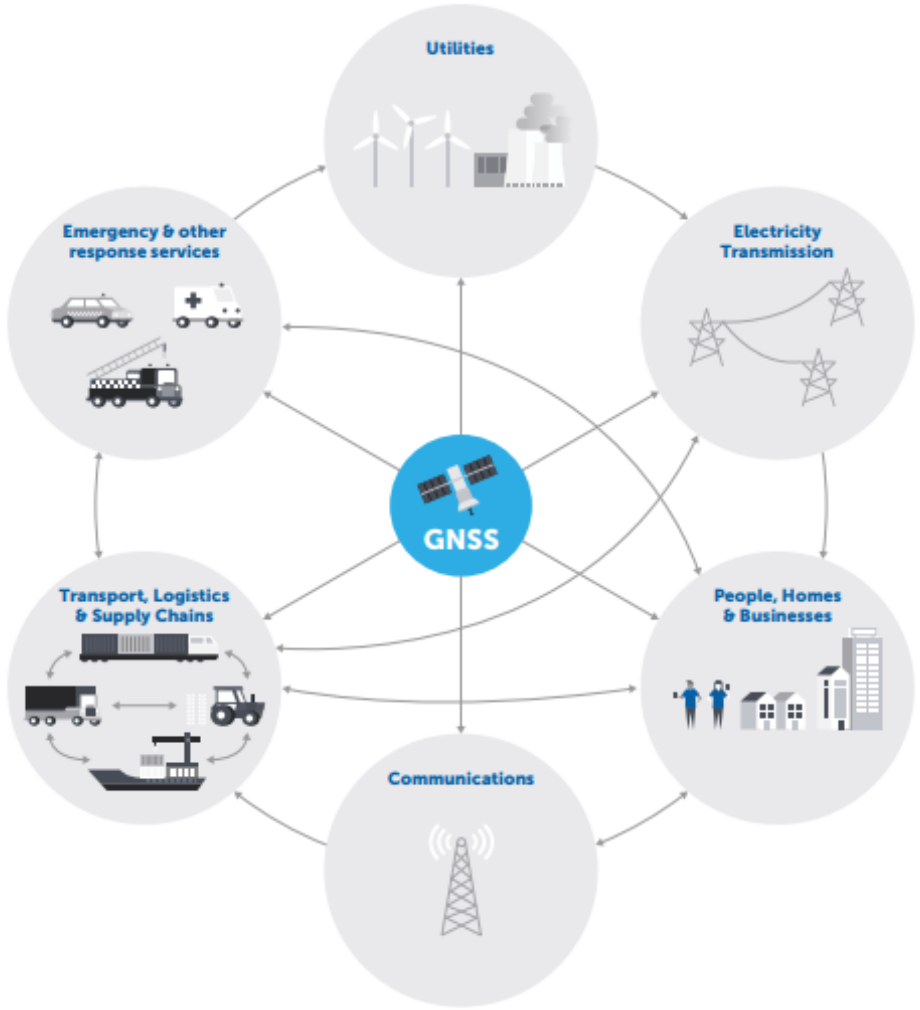


Common View GNSS Time Transfer *Source: NIST*

Comparing remote clocks, A and B with a common GPS clock (C). The time differences are computed using measurements logged by GNSS receivers that are referenced to local clocks A and B.

GNSS for Positioning Navigation and Timing (PNT)

- Ubiquitous in today's society :
  - Your mobile phones (mobile networks)
  - Financial services
  - Electric power networks (smart grids)
  - Automotive
  - Aviation
  - Emergency services and public safety
  - ….



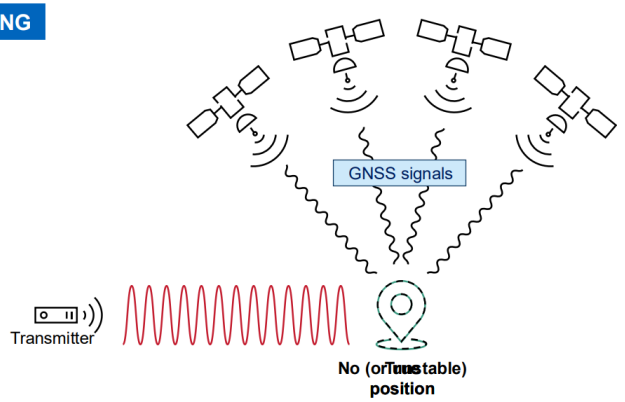
Source: UK Government Office for Science Report
Satellite-derived Time and Position: A Study of Critical Dependencies

GNSS Vulnerability

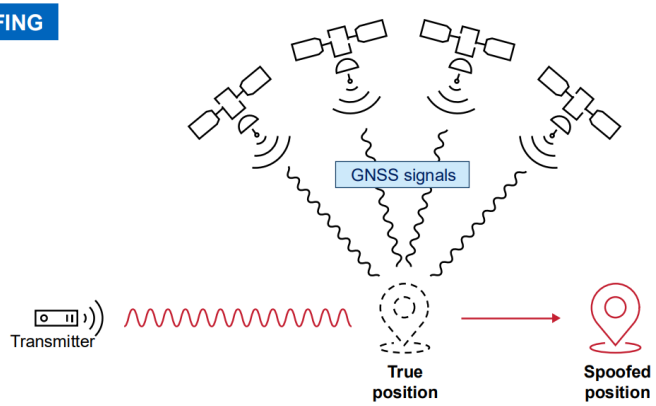
Achilles' heel: low power system at Rx

- Multiple type of attacks possible with cheap and accessible devices one can buy easily.

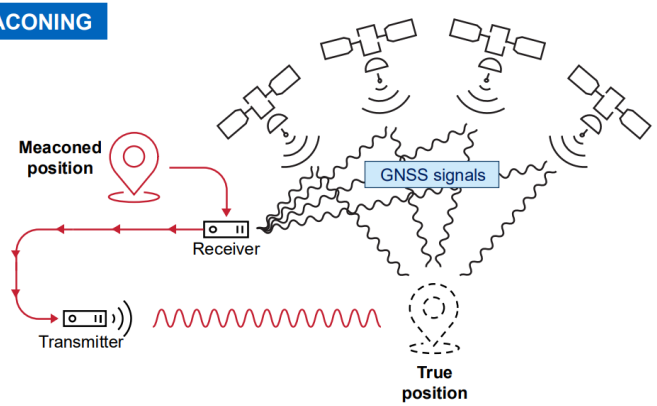
JAMMING



SPOOFING

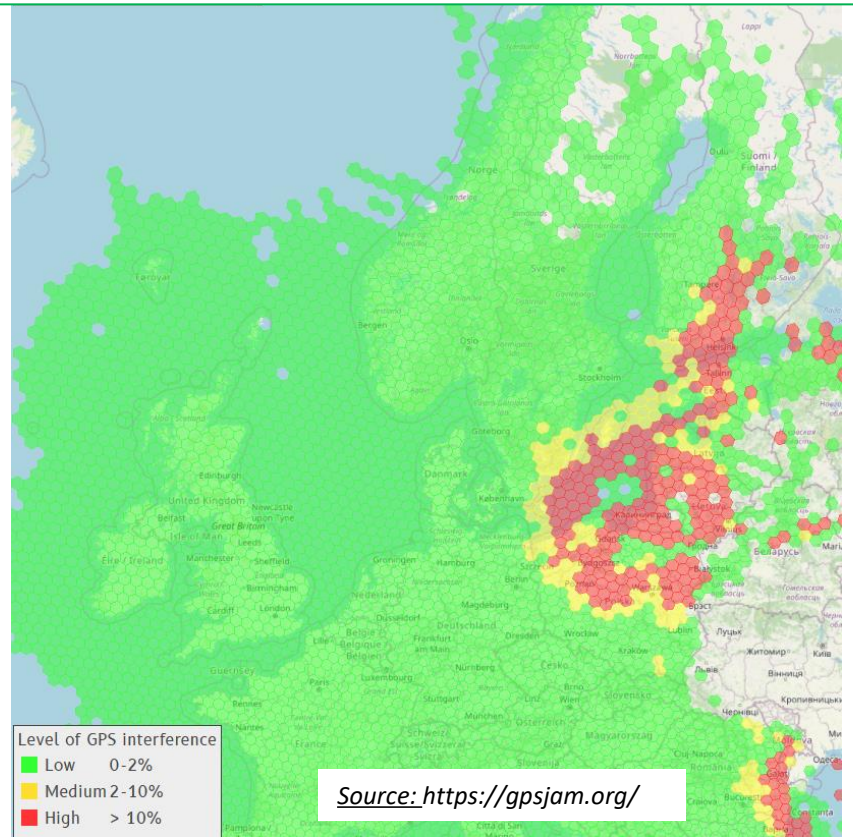


MEACONING



Source: Jammertest 2025 Information Meeting.

The benefits of GNSS to the UK economy were estimated to be £13.62 billion per annum.
The impact of a loss of GNSS for 7-days was estimated to be £7.64 billion and impact of a loss for 24 hours was estimated to be £1.42 billion.
Report: The economic impact on the UK of a disruption to GNSS



Source: https://gpsjam.org/

Positioning Navigation and Timing (PNT)
Terrestrial High-Accuracy Time Service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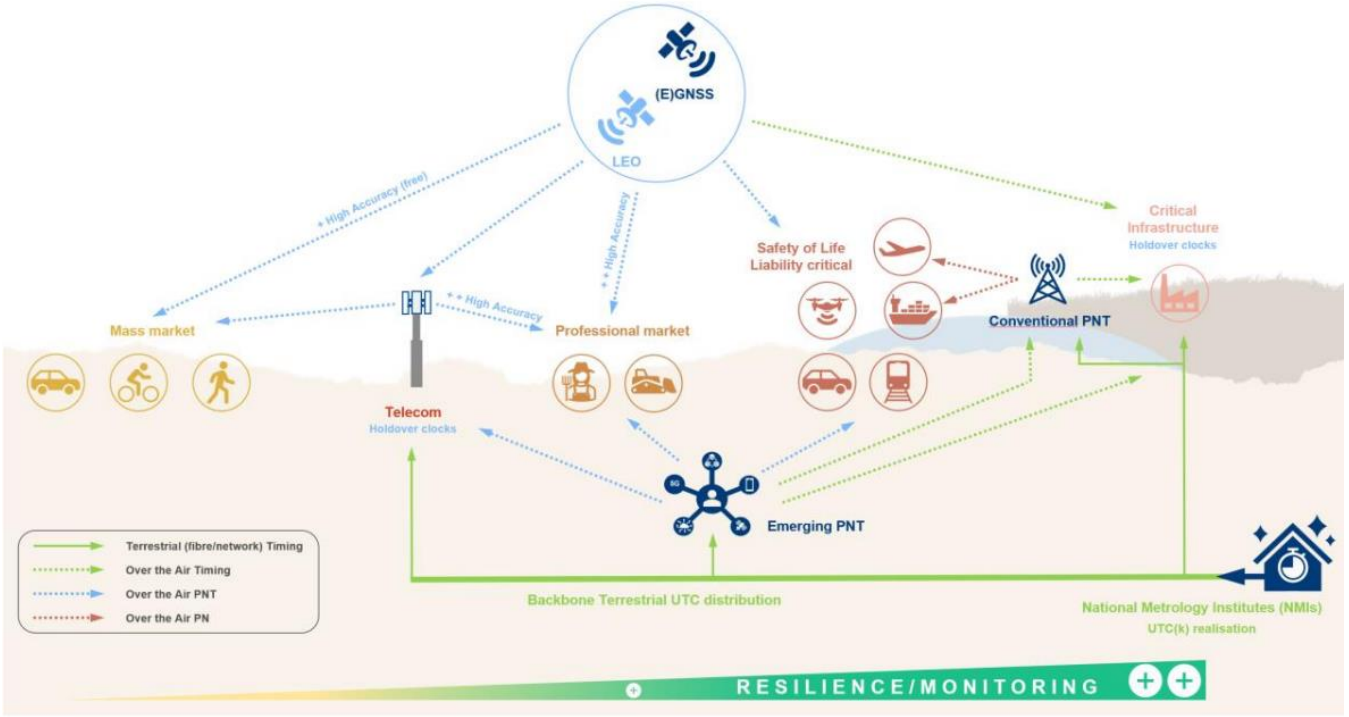
Europe moving toward a "timing backbone" and looking for input

November 13, 2024 - By Dana Goward
Est. reading time: 2:30

Citing a need for better "positioning, navigation and timing (PNT) resilience, availability and continuity," a market consultation document from the EU's Joint Research Center (JRC) says establishing a resilient PNT ecosystem is essential for "...EU autonomy, the economy's overall

Source: https://www.gpsworld.com/europe-moving-toward-a-timing-backbone-and-looking-for-input/



Such a backbone would:

- Interconnect existing Member States (MS) National Metrological Institutes (NMI) and National Research and Education Networks (NREN) architectures into a pan-European network.
- Maintain and (if possible) enhance the existing use cases (NMI, NREN and their existing commercial customers) and enable time

Source:European Commission, European Radio Navigation Plan 2023 and JRC136355

GNSS Attack Tests in Andøya, Norway

Test and Develop Resilient Systems

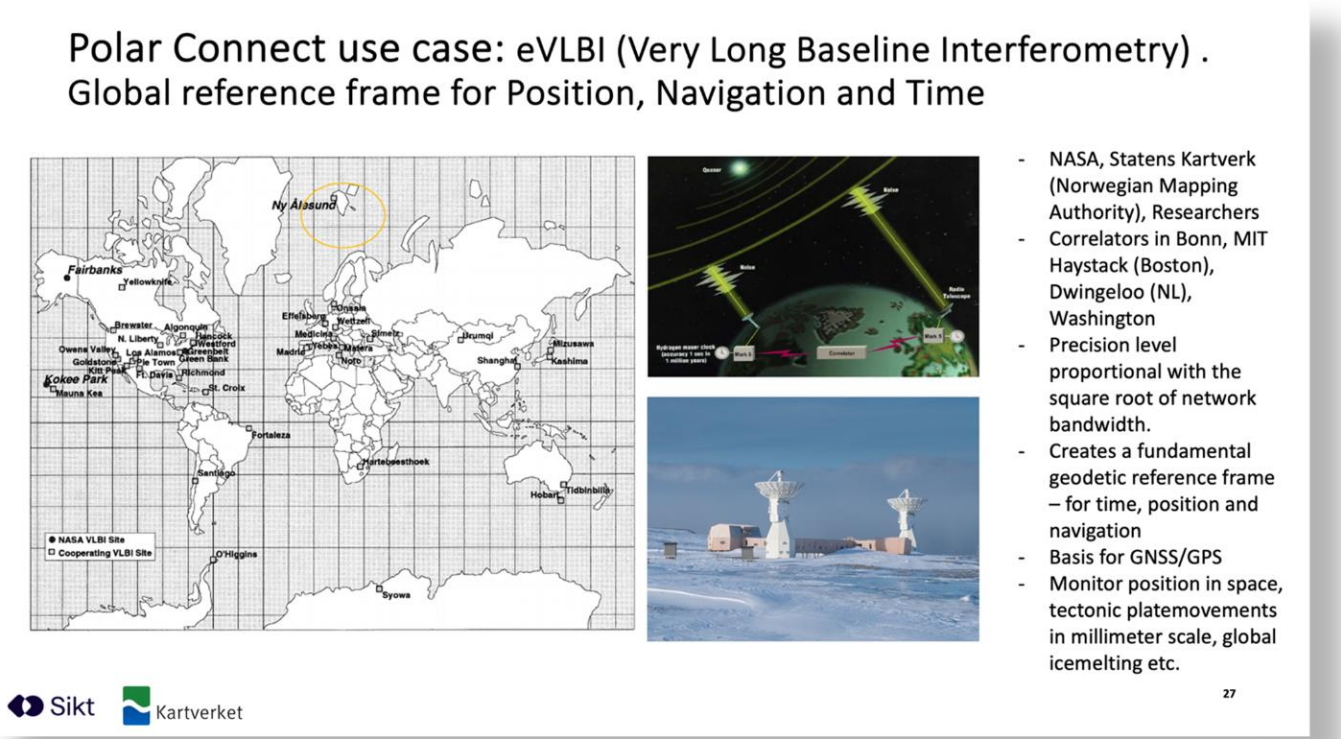
- Jammertest is the largest open satellite signal resilience test in the world.
- Facilitate industry and authorities to test their systems and products for potential weaknesses against realistic and extreme signal disturbance attacks.
  - Organized yearly in September by the Norwegian Communication Authority NKOM and Norwegian NMI Justervesenet.
  - Record applications in 2025 from 150 organizations and 24 countries.

SIKT providing terrestrial time and frequency service with White Rabbit

Opportunities for GEANT and NRENs
High-Accuracy Core Time and Frequency Network (C-TFN)

Use cases for T&F services are very wide-reaching and can be broadly broken down into the following categories:

- Redundancy to GNSS and terrestrial T&F
- Support the redefinition of the SI second being carried out between now and 2030.
- Support fundamental physics research.
- Opportunities for new services and applications.
- Contributing to European scientific leadership.



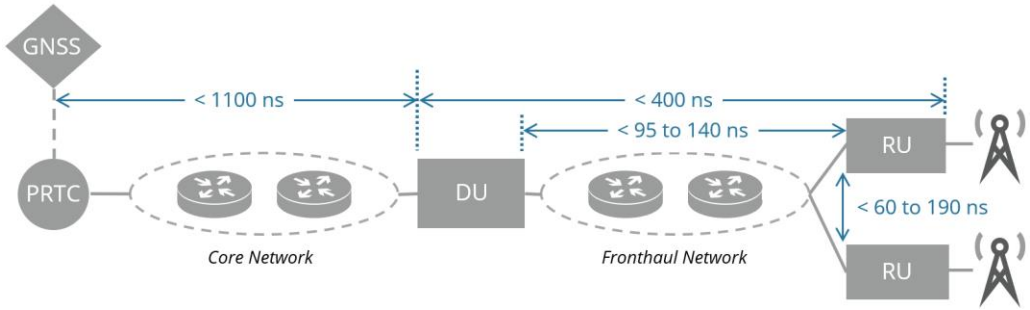
Courtesy: Olaf Schjederup, Bright Cables Session Thursdat 11:00am, TNC 2025

Low-Cost High-Accuracy Time Service with White Rabbit

Time Distribution in Data Networks

Protocols for packet-based time transfer

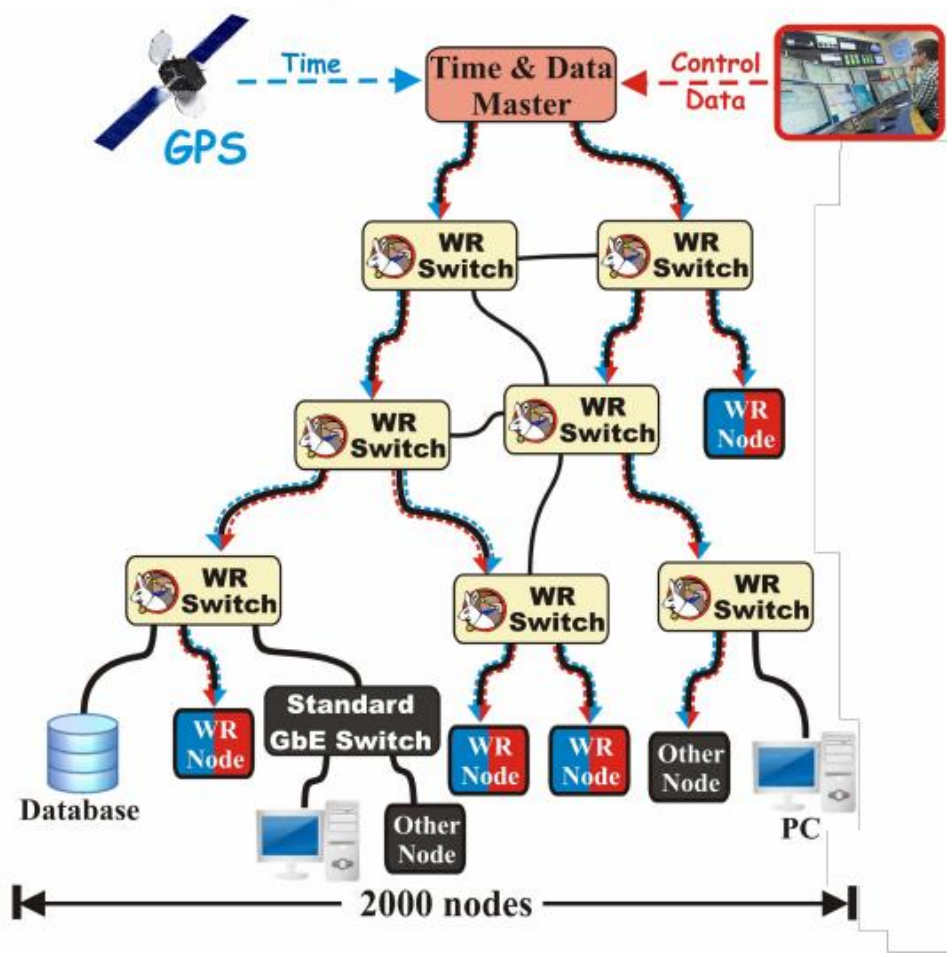
- 1985: Network Time Protocol NTP (your PC time) on Layer 7 (UDP)
  - Time accuracy in the tens of milliseconds on average
  - Heavily affected by delay variation as you are contending for capacity with other IP data packets
- 2002: Precision Time Protocol PTP (IEEE1588-2008, ITU-T profiles) on Layer 2 (Ethernet)
  - Time accuracy in the range of 1millisecond down to hundreds of nanoseconds
  - Heavily affected by transmission path asymmetry, devices have free-running oscillators, etc.
  - Most “legacy” networks partially support it and not good enough for most use cases
    - E.g. Most mobile network operators had big issues during 5G roll out of Time Division Duplex Frequencies(e.g.3.5GHz) requiring end-to-end time accuracy < 1.5µs.



White Rabbit Protocol for Sub-Nanosecond Accuracy

IEEE1588-2019 High Accuracy Profile

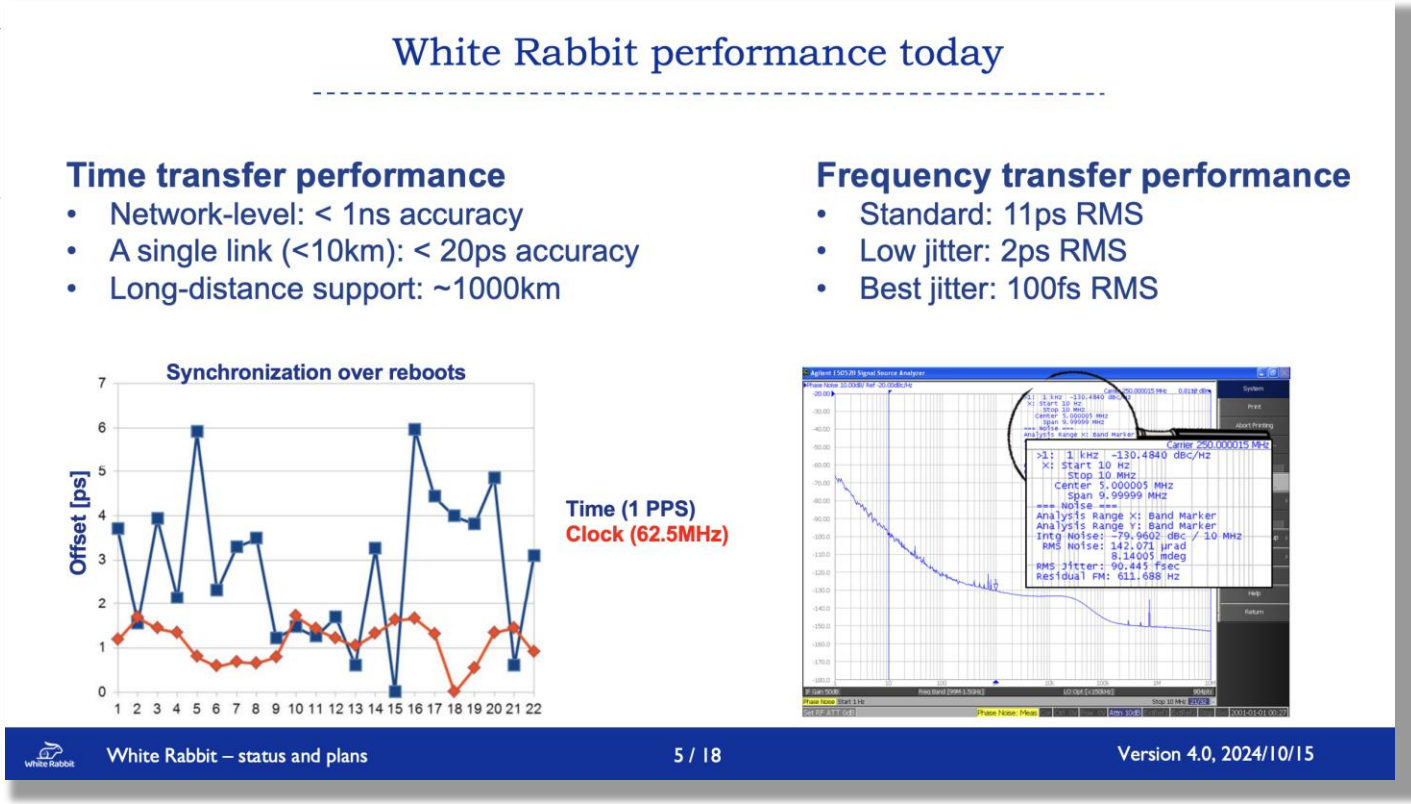
- First developed at CERN in 2008, meant for Big Physics facilities, e.g. CERN, GSI, NIKHEF
- Combination of IEEE1588-2008 with further extensions:
  - Clock syntonization over the physical layer L1Sync (similar to SyncE).
  - Enhancement of timestamps precision through phase measurement.
  - Automatic precise evaluation and compensation of transmission link asymmetry.
  - Backward compatible with PTP IEEE1588-2008.
    - No ITU-T profile.
- Open Source and commercially available
- Initial specs for links < 10km and scalable to 2000 nodes, but for maintaining sub-ns accuracy up to ~20 WR nodes in a chain.



Refer to White Rabbit Collaboration Source: Javier Serrano, GEANT Time and Frequency Workshop

Why is White Rabbit Important?

- WR offers a solution that is unmatched by other technologies
- Gaining rapid acceptance among network operators
- Several system vendors are providing carrier-grade WR switches
- Continuous development with research and industry partners (WR Collaboration).
  - Further possibilities for development, e.g. an ITU-T telecom profile in the future?



Courtesy: Guy Roberts, SIG-TFN Workshop, Ispra, 2025

White Rabbit Asymmetry Compensation

Rule of thumb: speed of light in optical fibre ~4.9 ns/1 meter -> 1ns ~20cm

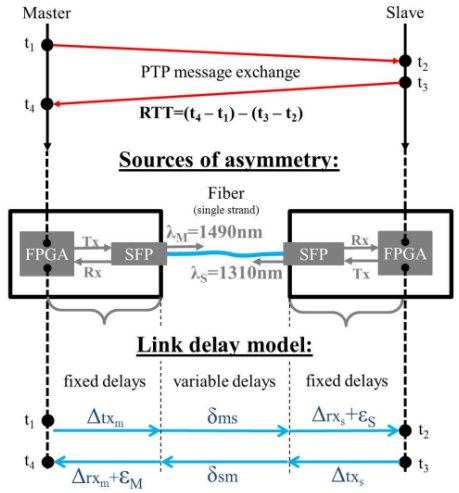
- “Traditional” optical fibre communication uses fibre pairs, one fibre per direction (Tx Rx) using the same wavelength:
  - In practice fibres have different lengths even in the same cable from few to tens of meters. Different transmission time introduces delay variation/time error
  - Pre-calibration is difficult for in-situ as every “fix” of a fibre break will introduce unknown Δ fibre length.
- Single fibre with different wavelengths per direction:
  - Asymmetry is introduced because of chromatic dispersion: different wavelengths travel at different speeds in the fibre medium (e.g. higher wavelengths travel faster).
  - Compensated with calibration.

Link delay model

- Correction of RTT for asymmetries
- Asymmetry sources: FPGA, PCB, SFP electrics/optics, chromatic dispersion
- Link delay model:
  - **Fixed delays** – FPGA, PCB, SFP
  - **Variable delays** – fibre:

$$\alpha = \frac{\nu_g(\lambda_s)}{\nu_g(\lambda_m)} - 1 = \frac{\delta_{ms} - \delta_{sm}}{\delta_{sm}}$$

  - Calibration procedure to find fixed delays and α

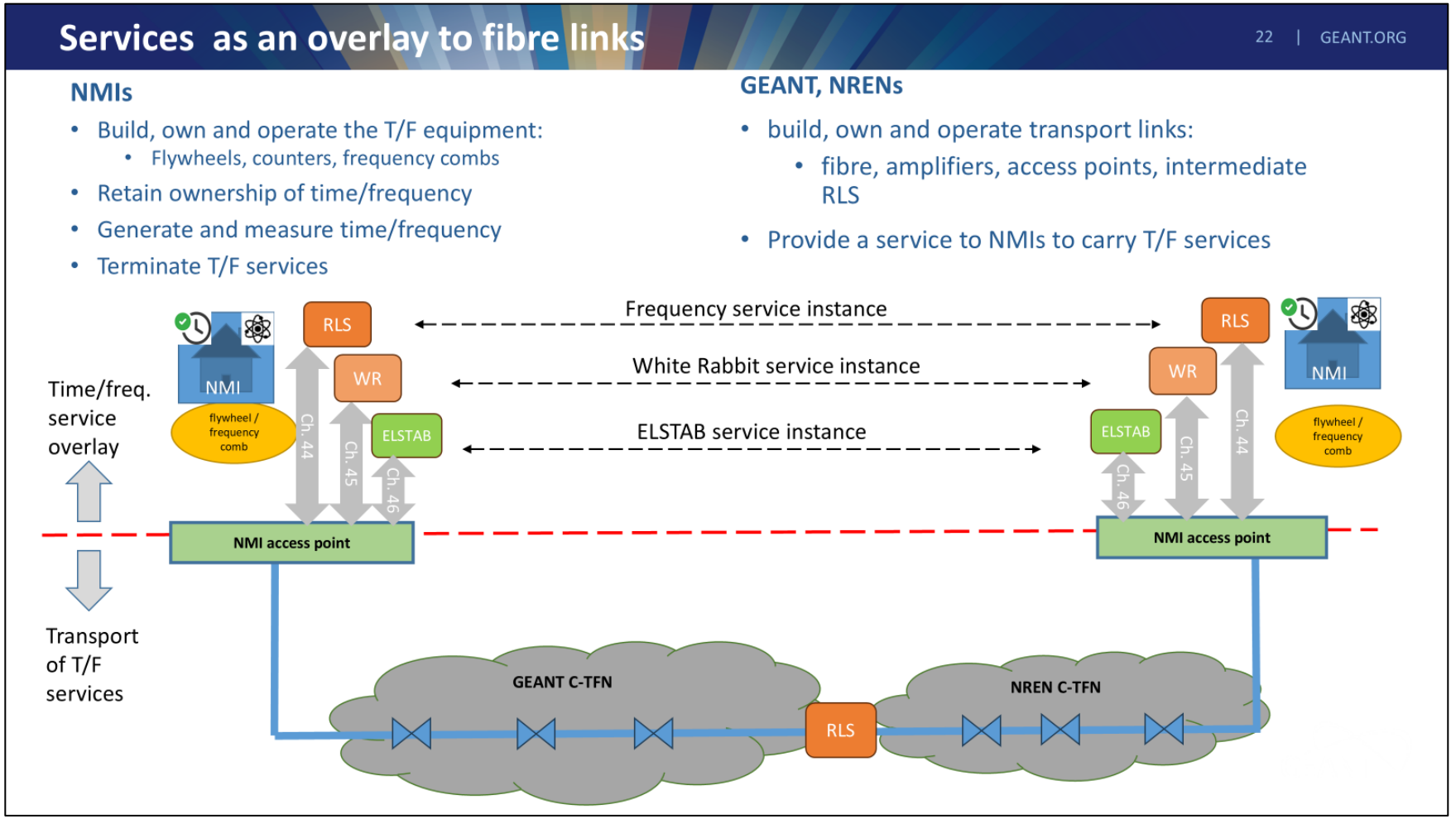


Source: M. Lipinski, GEANT 2022 SIG-TFN WS,

White Rabbit over Dedicated Single Fibre

See outcomes from CLONETS project

- 2024: Build Pathfinder link and prepare C-TFN.
- GN5-2: 2025-27: Build C-TFN northern route .
- GN5-3: 2027-29: continue C-TFN southern route.

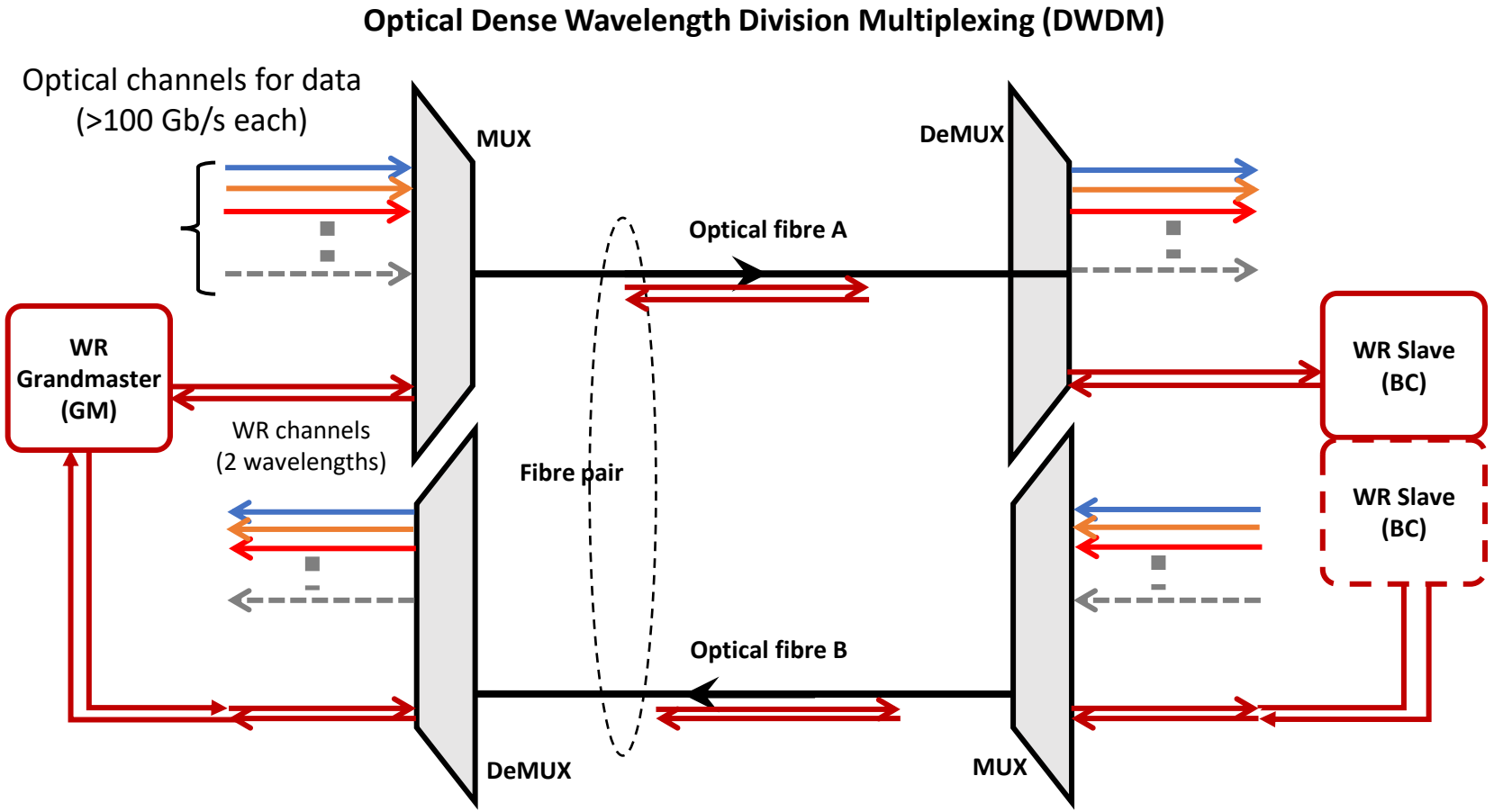


Courtesy: Guy Roberts, SIG-TFN Workshop, Ispra, 2025

White Rabbit over Fibre Shared with Telecom Data

Using existing fibre-optic infrastructure in parallel with telecom data

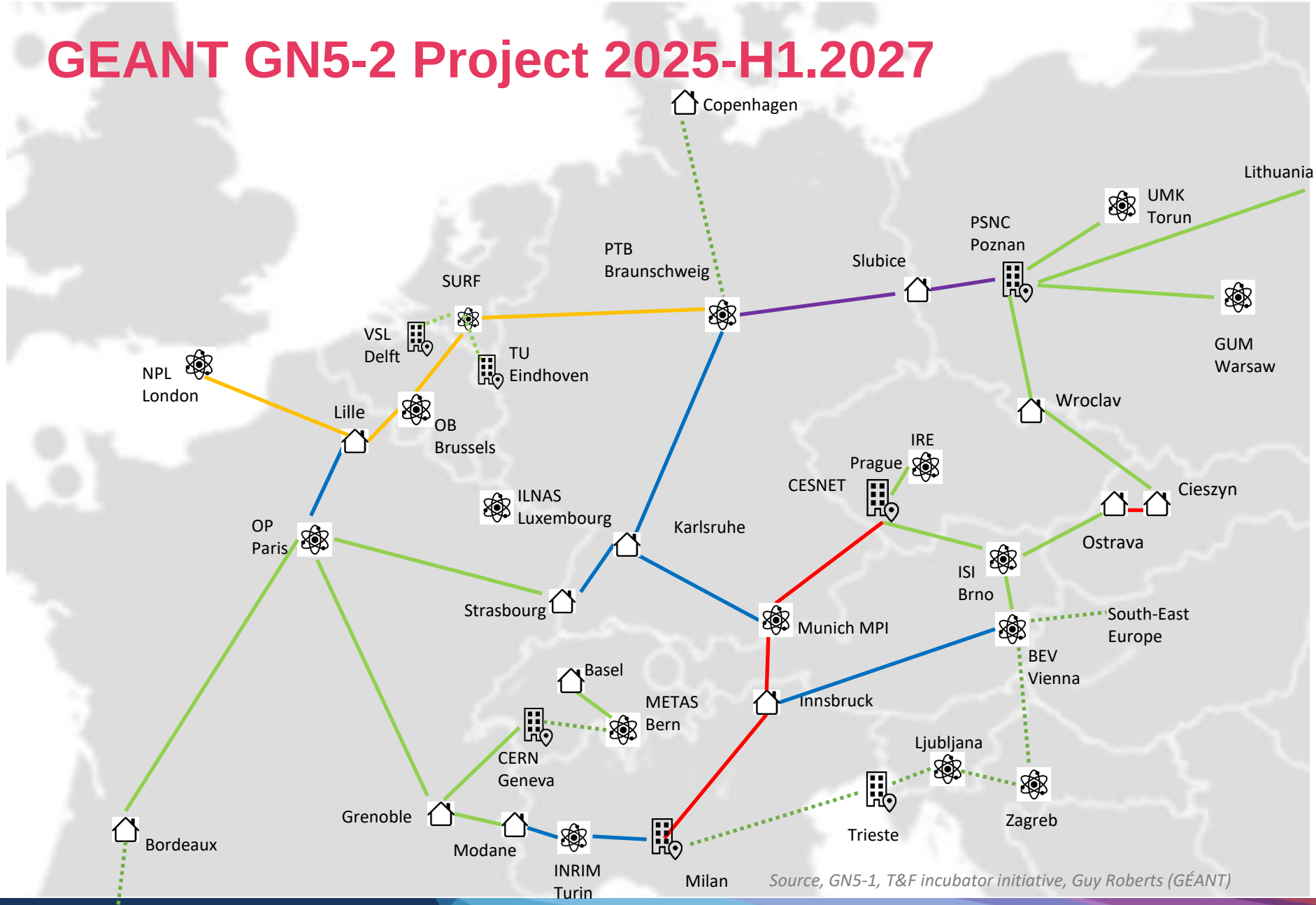
- Low cost of deployment of telecom equipment
- No dedicated fibre required facilitates acceptance by network operators
- In long-haul transmission, at amplification sites solutions are required for the WR bidirectional optical path,



WR time error can be measure if deploying a loop (i.e. from Grandmaster to slave on fibre a and from slave to grandmaster on fibre b)

Activities in GEANT and NRENs

GEANT GN5-2 Project 2025-H1.2027



Source, GN5-1, T&F incubator initiative, Guy Roberts (GÉANT)

Included:

- 10-year IRU for fibre on red routes
- Bidirectional amplifiers as needed to light the fibre on the red routes

Excluded:

- Green lines – fibre built by NRENs
- Blue lines – fibre bult by NMIs
- Dashed grey – proposed future links
- flywheels, counters frequency combs needed are to be funded by the national time/frequency providers
- Time/Frequency overlay services

New established link

NMI Frequency reference

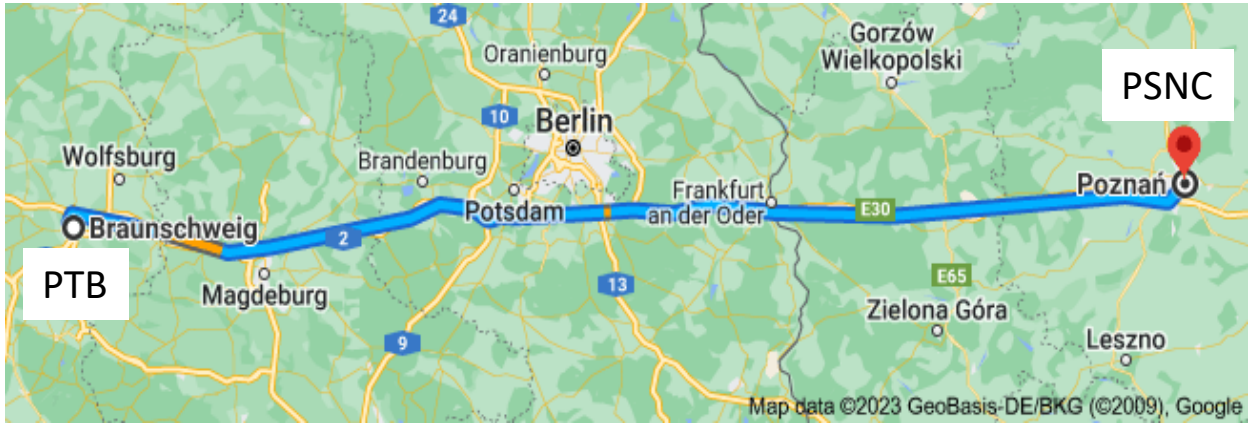
Research institute

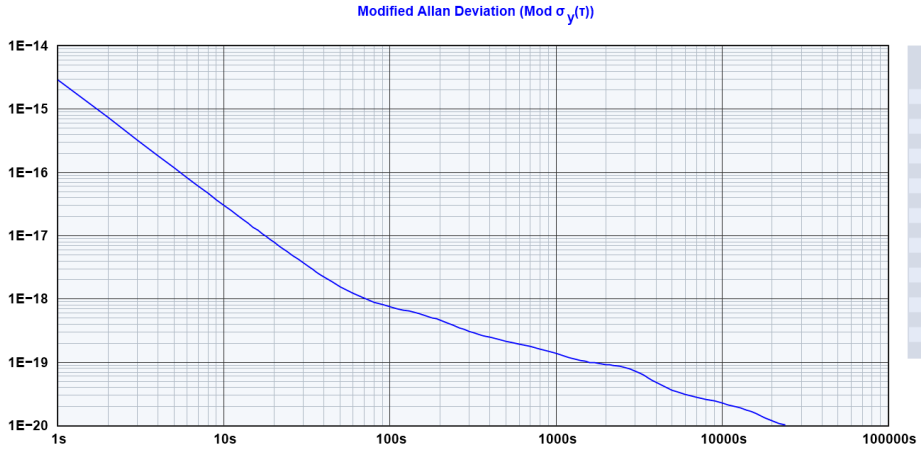
Hut for housing RLS

Pathfinder: Blaizing a Trail

- First proof-of-concept link for the CLONETS core-TFN.
  - GÉANT fibre from PTB to the polish border.
  - PSNC provides access to their existing fibre from the border to Poznan
- Purpose is to prove the technical concept
- Both frequency and time tested.

Bi-directional amp



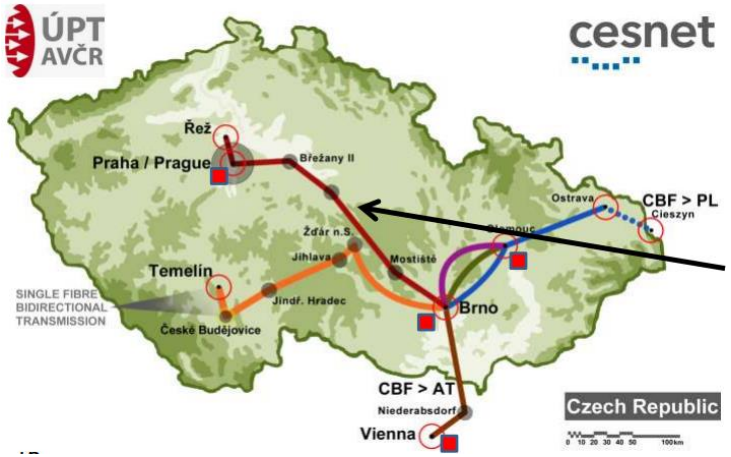


Tau	Sigma(Tau)
1s	2.93E−15
2s	7.33E−16
4s	1.85E−16
8s	4.71E−17
10s	3.03E−17
20s	7.93E−18
40s	2.25E−18
80s	8.96E−19
100s	7.54E−19
200s	4.63E−19
400s	2.48E−19
800s	1.64E−19
1000s	1.38E−19
2000s	9.29E−20
4000s	4.83E−20
8000s	2.60E−20
10000s	2.28E−20
20000s	1.19E−20

Trace	Sample Interval	Duration
PSNC -> PTB -> PSNC (2 x 690 km)	1 s	3d 7h 11m 45s

Multiple NRENs Already Deploy National WR Networks

A few examples



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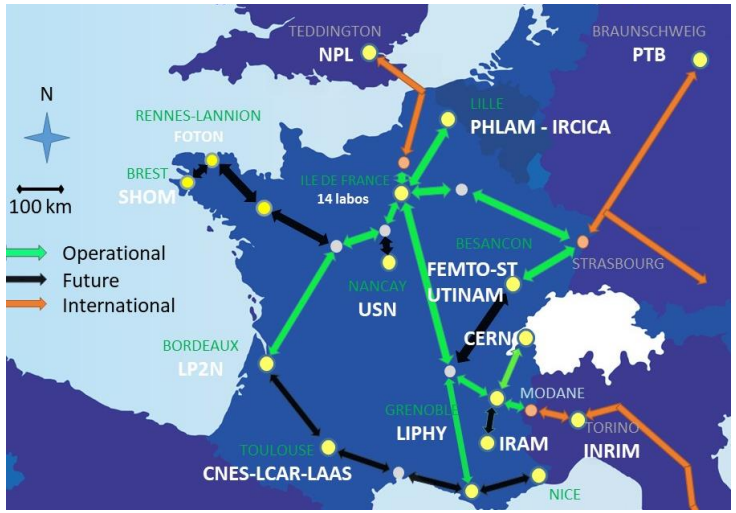
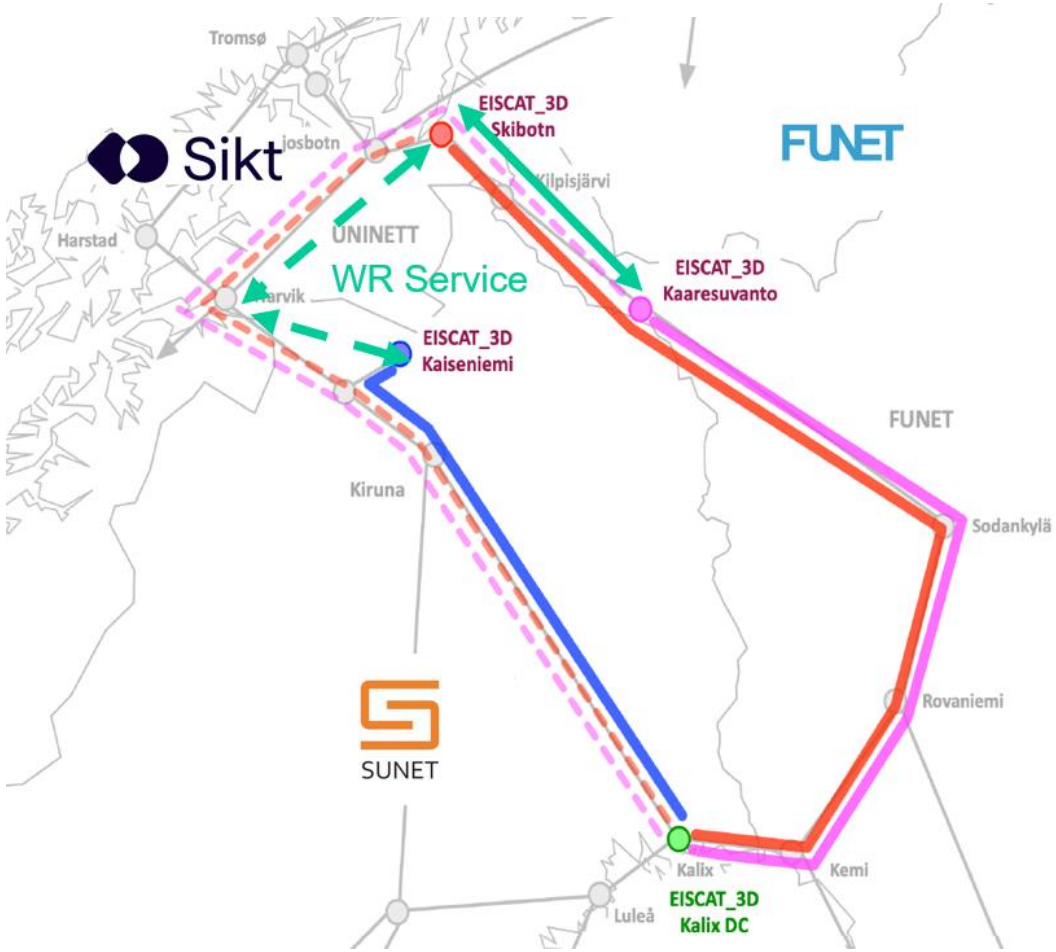
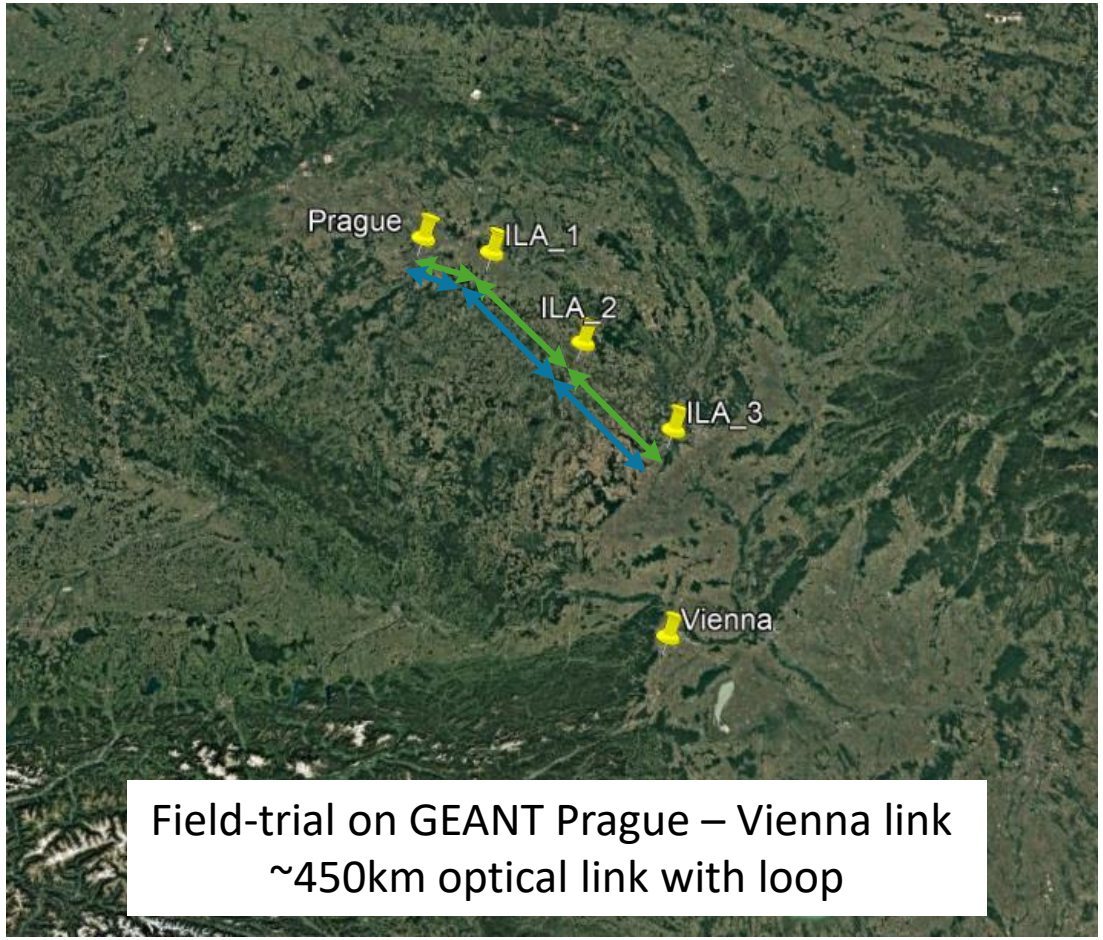


EISCAT 3D



Long-haul White Rabbit Time Distribution

- GEANT has initiated a WR incubator led by SIKT (Norwegian NREN) on long-haul WR time service over DWDM networks.
- Aims to evaluate the available solutions, compare the performance/cost ratio, and make recommendations to NRENs on how best 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, and Optical-Electrical-Optical media converters.
- Partners: GEANT, SIKT, CESNET, SUNET, FUNET, GARR
- If you would like to participate, please reach out raimena.vesillari@sikt.no



Field-trial on GEANT Prague – Vienna link
~450km optical link with loop

Thank you

Any questions?

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