



Time-Frequency Workshop

CERN Feb 2024

Guy Roberts, Richard Lui
GEANT

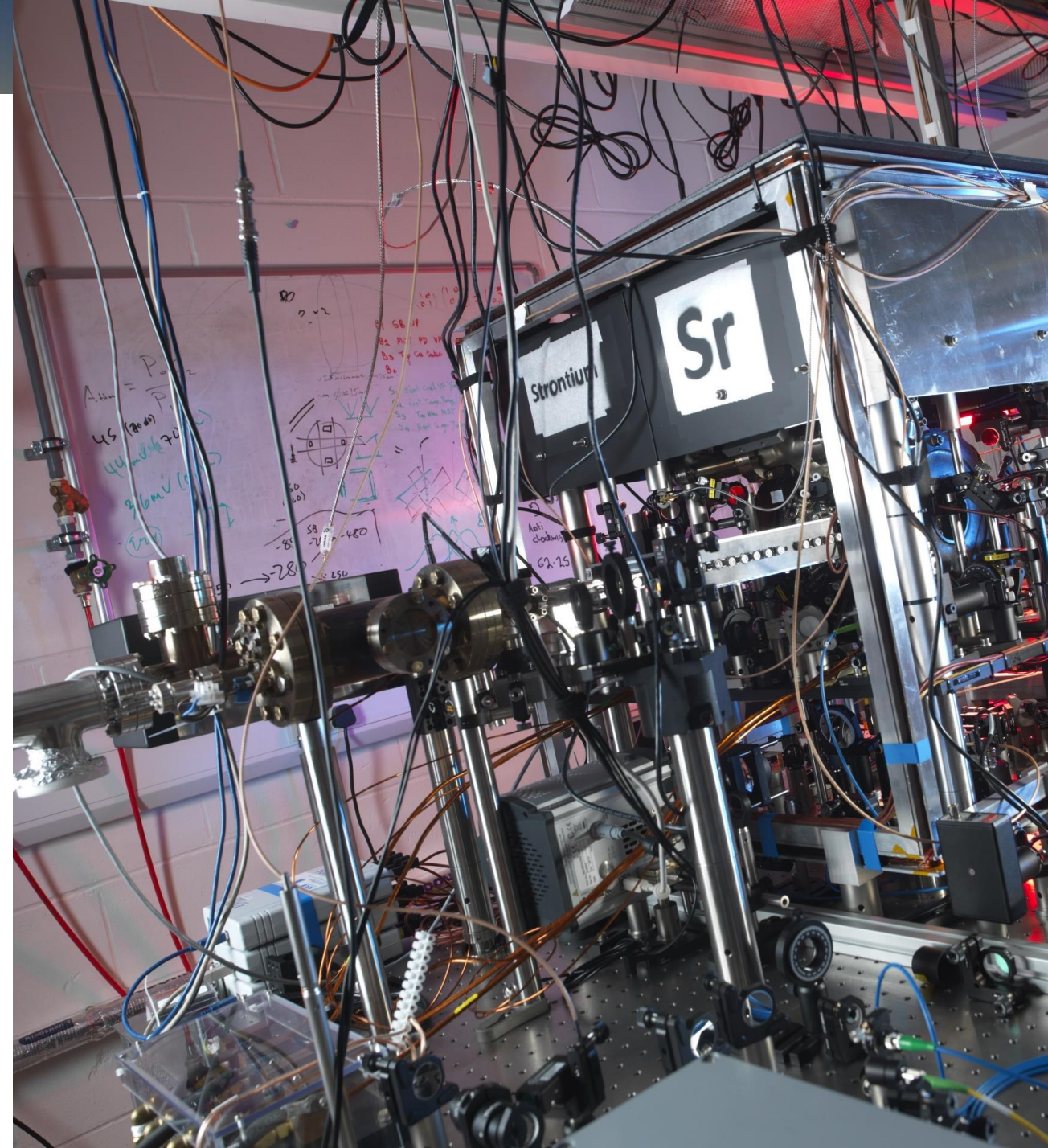
Feb 2024

Public

Optical clocks

- In 2022, the 27th CGPM approved Resolution 5 towards the redefinition of the second
- The target date for redefinition of the second is 2030
- *'Member States to support the development of national and international infrastructures mandatory for optical frequency standard comparisons'*.
- As of today, only comparisons mediated by **optical fibre** links provide the required stability and accuracy for comparing optical clocks

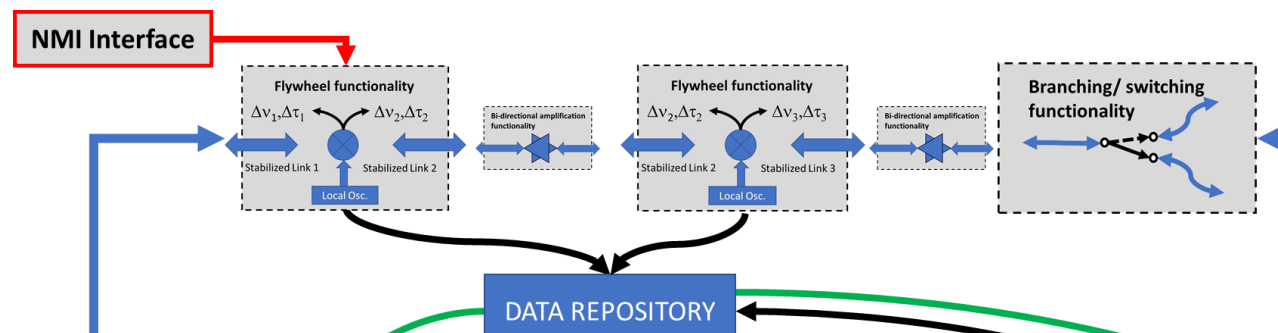
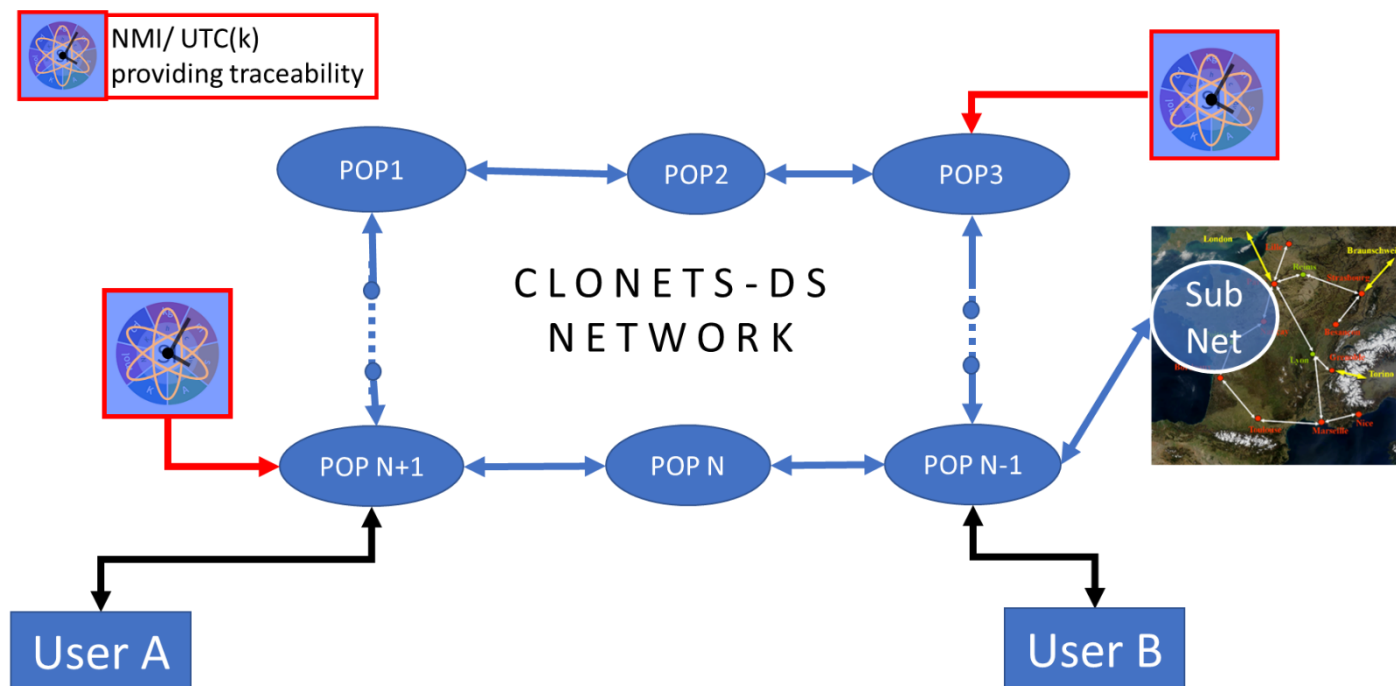
GEANT is really good at this bit!



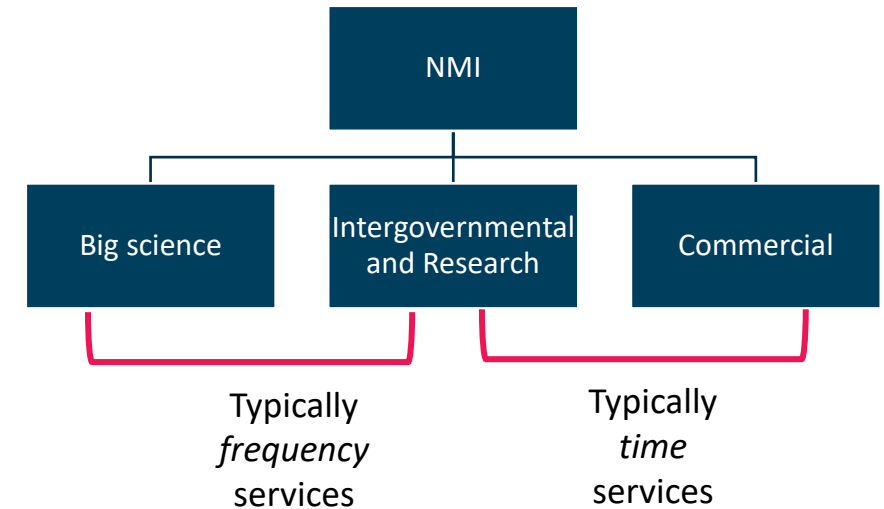
- CLONETS-DS project has completed and published its findings https://clonets-ds.eu/?page_id=98
- CLONETS-DS recommended the building of a European-wide time-frequency network (C-TFN)
- GEANT T/F incubator has explored using GEANT funds for this purpose
- Goal of GN5-2 funding: Prepare a GEANT funding proposal to build a core time-frequency network (C-TFN)



- CLONETS proposes to build a European-wide time frequency distribution network
- Architecture is defined in DS2.1
- Built on rings with NMIs reference clocks
- PoP flywheels and comparators used as access points for local providers



- NMI will be primary customers of the GEANT C-TFN links
- Also, some NRENs plan to run flywheels (PSNC / SURF / CESNET / RENATER)
- Big science users e.g. CERN
- Large intergovernmental organisations e.g. ESA.
- Existing national consumers of frequency services that are already connected via the NMI will benefit from the international links.
- National consumers of time services can use existing connectivity provided by their NMI or NREN to access international services – existing relationships maintained



The use-cases for the T/F network are very wide-reaching and can be broadly broken down into the following categories:

- Replace GNSS with more reliable and accurate fibre cable frequency distribution between national NMIs for measuring global UTC.
- Support the redefinition of the SI second being carried out between now and 2030 by NPL, PTB, Syrte and INRIM.
- Perform fundamental physics research e.g. gravity wave experiments.
- Improved accuracy and stability of geolocation for organisations such as ESA
- Provide very accurate time stamps for banks to validate high-frequency trading.

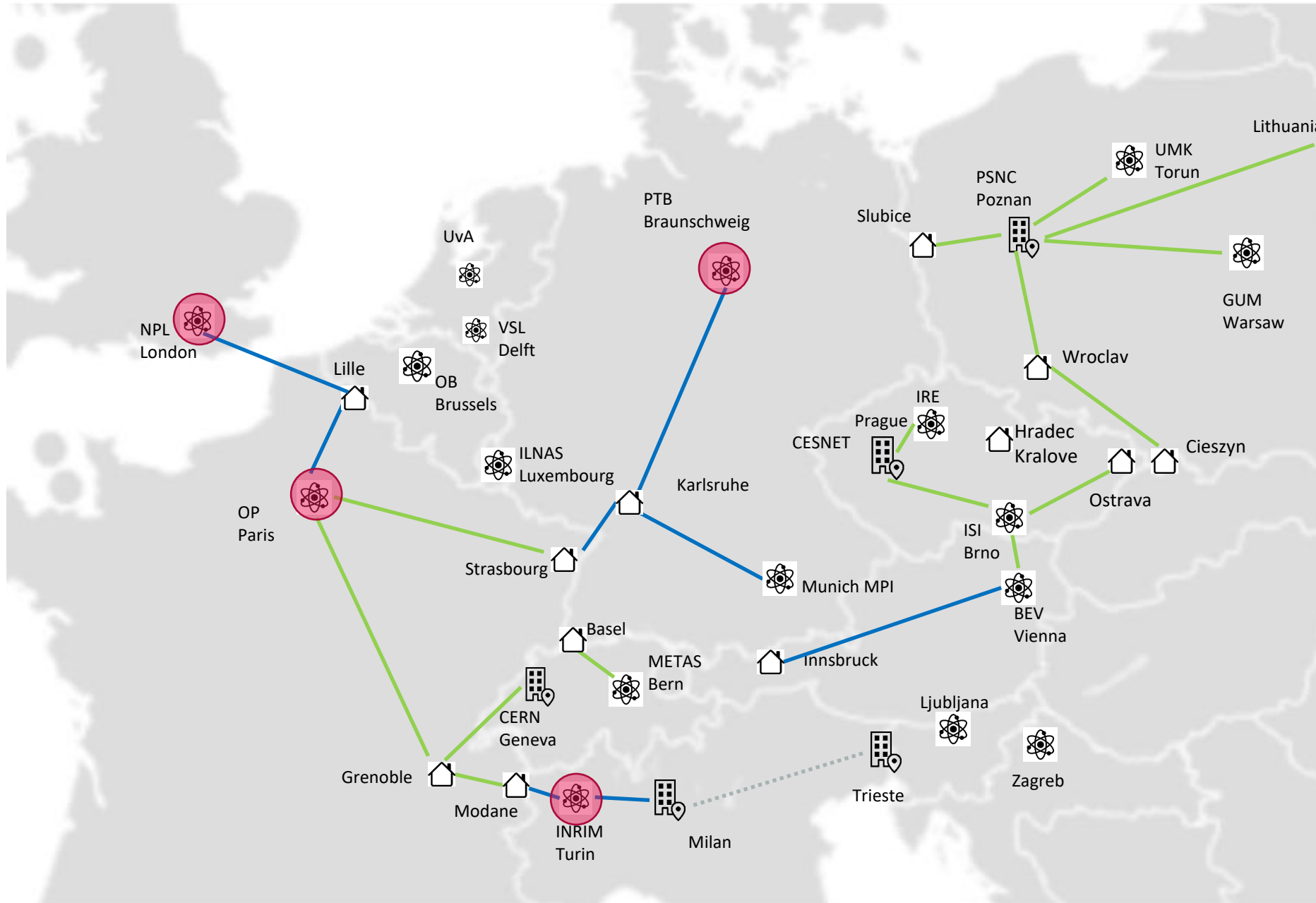


- Higher accuracy compared to satellite methods which have a frequency instability limit of 10^{-15}
- Optical clocks have a better instability limit of 10^{-16} and beyond, for example a clock with an instability limit of 10^{-18} would drift less than one second over 13.8 billion years, the age of the universe
- REFIMEVE have proven that the accuracy of distribution of optical carrier waves on fibre can achieve a stability greater than the $1e-19$ needed.
- Quantum science is rapidly growing e.g. EC quantum flagship
- More countries are developing optical clocks
- Optical fibre is harder to spoof or jam



- The high accuracy possible with optical frequency distribution is need by NMIs and for fundamental physics research e.g. geodesy.
- Frequency requires a very high accuracy transfer over fibre to be useful i.e. $1e-19$ per second.
- This requires feedback to filter out phase noise from fibre acoustic vibration, it also requires bidirectional amplifiers.
- Once a stable underlying frequency infrastructure built, time services can be built as an overlay.
- Time services have more users, but their accuracy requirements are less stringent
- The frequency network will form a high-accuracy foundation upon which all other time/frequency services can be built.



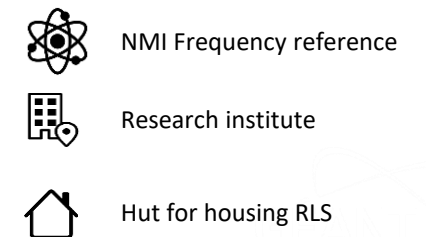


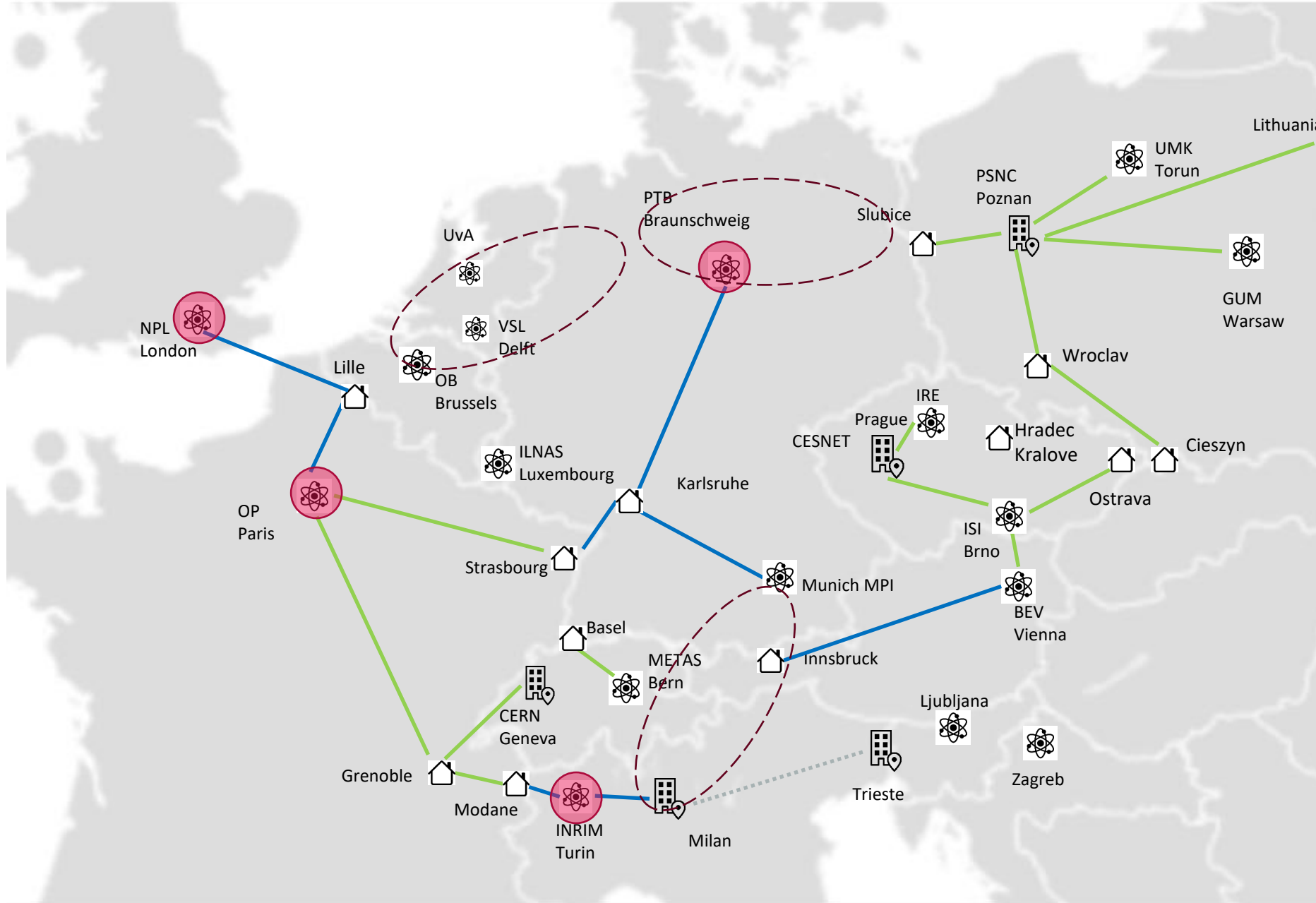
Frequency network:

- Green links built by NRENS in collaboration with national NMIs
- Blue links built by local NMIs/researchers

NMIs:

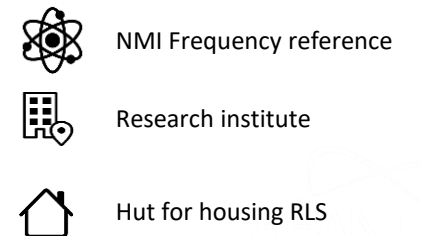
- Four big NMIs are involved in redefining the SI second highlighted in red

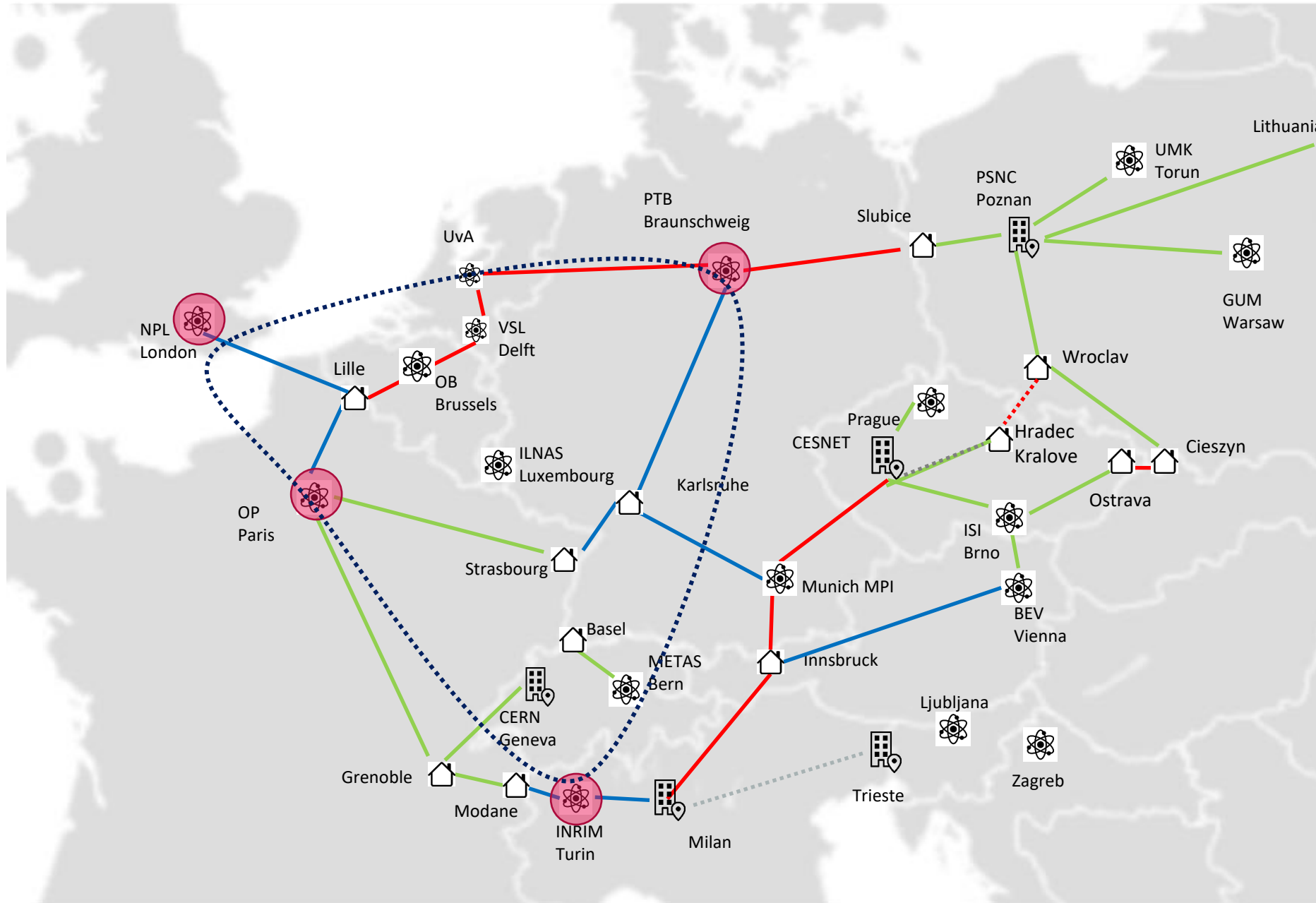




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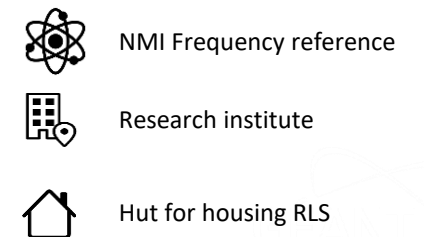
- National based networks need to be interconnected
- Eastern and Western islands of frequency services are not linked
- A full ring/mesh of the big four NMIs will enable them to complete definition of the SI second
- Link will also be needed to Nordics, SE and SW Europe as they develop Optical clocks





Solution:

- Red lines are proposed for GN5-2
- These will interconnect national 'islands' of frequency networks
- Support redefinition of the SI second
- Primary users are national frequency reference providers
- Secondary users are research institutes that connect via their national frequency provider

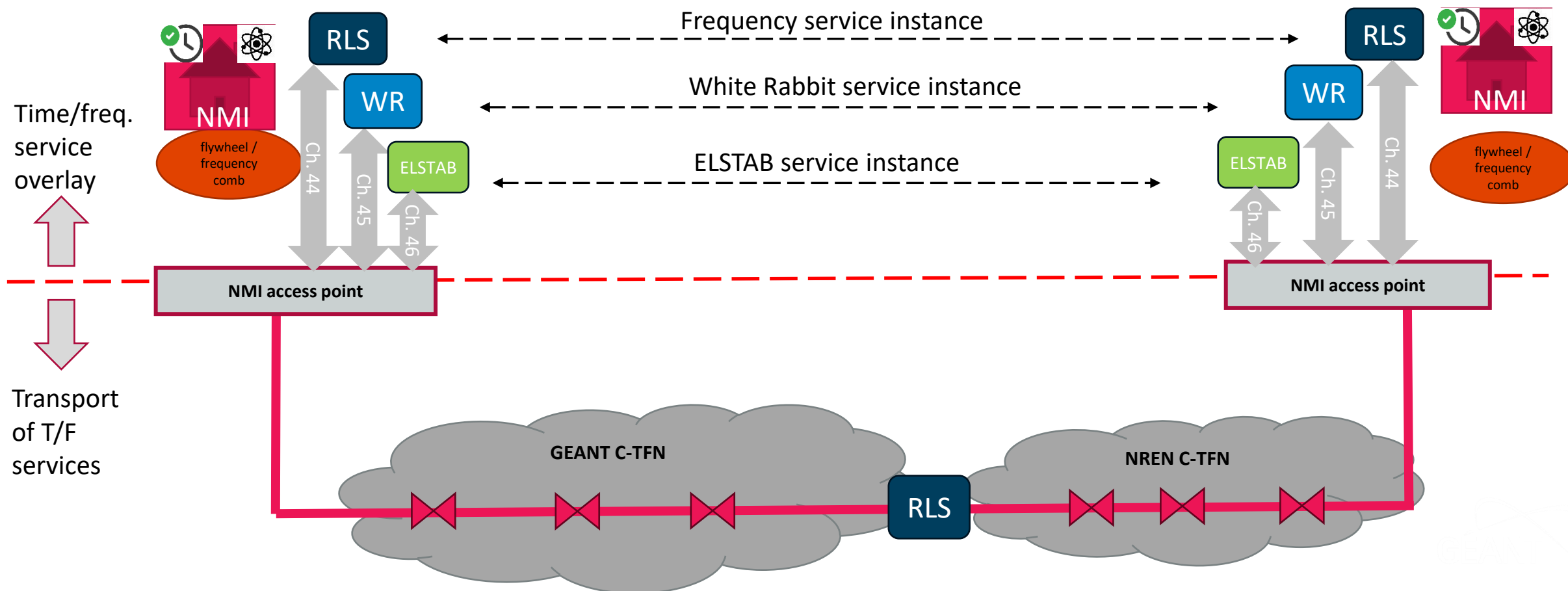


NMIs

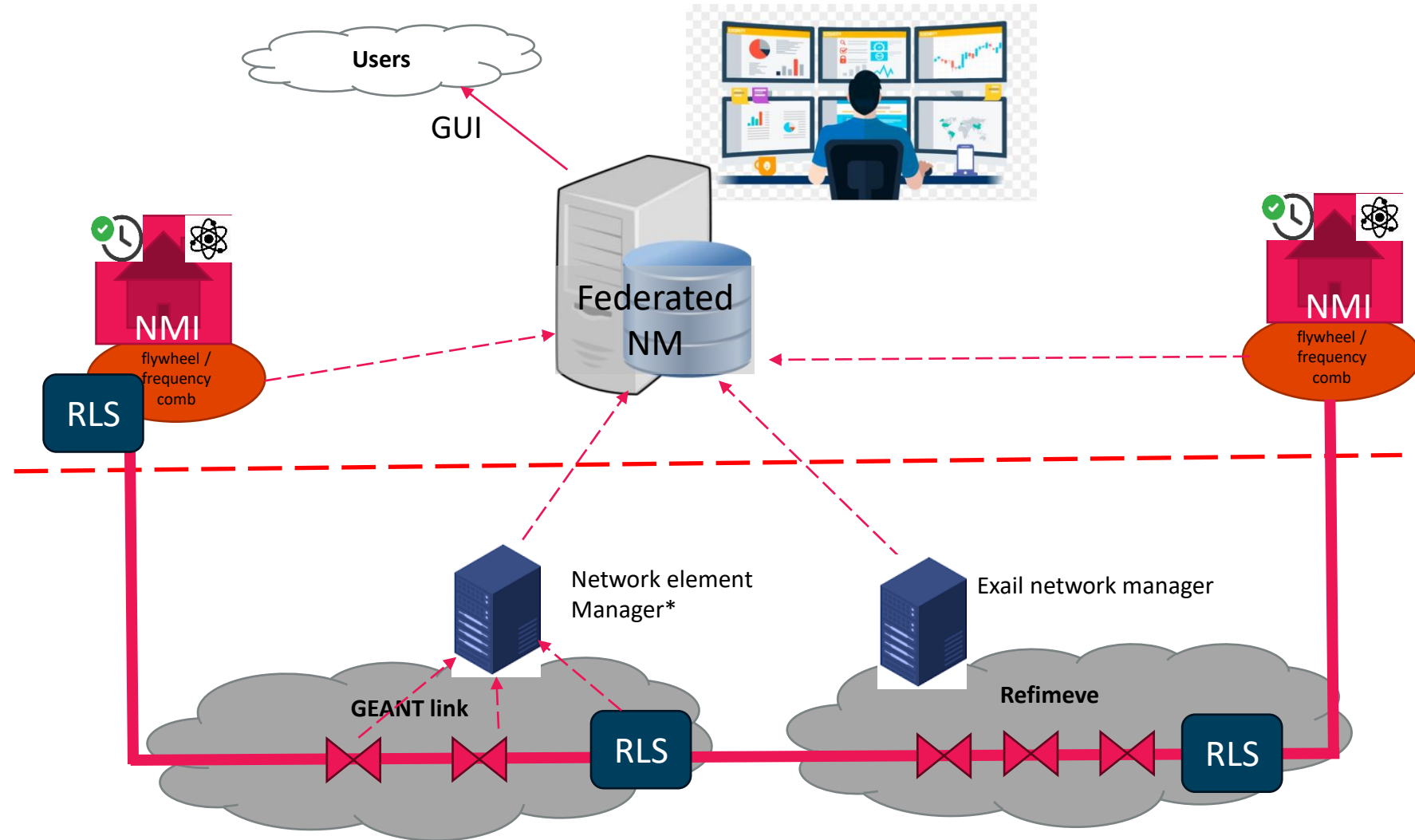
- Build, own and operate the T/F equipment:
 - Flywheels, counters, frequency combs
- Retain ownership of time/frequency
- Generate and measure time/frequency
- Terminate T/F services

GEANT, NRENs

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



- The management of the C-TFN should be federated
- Each European provider of time/frequency will manage their own national infrastructure.
- It is recommended that the GEANT OC act as a single point of contact for the federated C-TFN.
- A network management system will need to be developed for this purpose.
-



NMIs/NREN/GEANT T/F transport

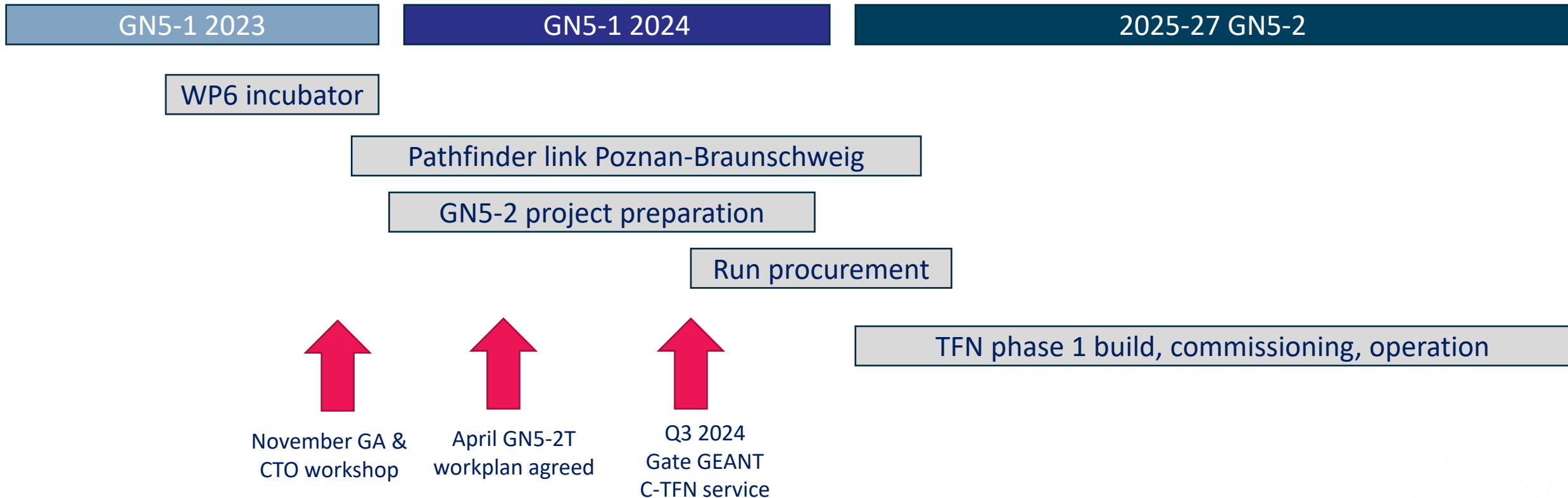
- NMIs, GEANT and NRENs should run a management system to operate their own time/frequency distribution networks.
- They should also provide a network interface to their local management system that can be monitored by the NOC

GEANT NOC

- GEANT operates a centralized NOC
- GEANT will operate a centralized server (in the cloud?)
- GEANT WP 6 will develop a prototype network management system in GN5-1. This will be based on TimeMap
- The GEANT NOC will use this software to aggregate the time/frequency information from all federated partners.
- TimeMap will also collect link status from each of the participating T/F distribution networks.



- May-Dec 2023: Incubator study
- Jan 2024 to June 2025: Pathfinder link
- Jan 2025- July 2027: Build TFN Phase 1
- After July 2027: TFN Phase 2 (funding not yet identified)



- Propose to use GN5-2 funds for *all* initial costs
- Total operational cost for scenario A is €335,000 from 2027
 - Add to cost share
 - Categorise service as “a la carte” with ten organisations paying €35,000 each or €17,500 with 50% cost share
 - Identify EC funding from 2027
 - Cease operation
- In the costing scenarios we have proposed that IRUs will be 75% up-front funded, this means that each year the annual recurring maintenance fee for the dark fibre will be 2.5% of the NRC. The objective is to prioritise sustainability.

Time/Frequency network projected costing

TCO Period	2.5	years
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Item	Scenario A	
	Capex	OPEX (support/yr)
Fibre	6,041,700	201,390
RLS (NMIs)	-	-
RLS (mid-route)	-	-
Amplifiers	120,000	30,000
Flywheels	not inc	not inc
Comparators	not inc	not inc
Other (IP/racks/install)	not inc	not inc
Housing	not inc	not inc
Installation (all)	256,000	
Insurance		360
Project Management	150,000	
Geant OC manpower		100,000
Servers+Software	20,000	3,000
Total	€ 6,587,700	€ 334,750

TCO € **7,424,575**

GÉANT as a European backbone provider between national networks

- A monolithic European-wide organization to connect all European institutions will not scale, NRENs, NMIs (or other providers of time/frequency) need to be local service providers for the time/frequency needs within their countries.
- The GÉANT C-TFN should complement rather than compete with the national time/frequency networks.
- The links in the GÉANT C-TFN should only be **cross-border**. I.e will cross national borders within Europe. Any exceptions to this will require a consensus among all NMI and NREN funders of the C-TFN.
- See definition of cross-border in the glossary.



- GEANT should work with the metrology community to prepare a specification for a turn-key build of the GEANT C-TFN links.
- GÉANT should go to tender for a vendor/integrator to install and commission the equipment needed on the dark fibre to create the GÉANT C-TFN infrastructure.
- The vendor/integrator will also be asked to quote for a maintenance wrap for the hardware, in particular this would include holding spares and delivering these to site as needed.
- The cost of support will be highly dependent on the Service Level Agreement (SLA) that GÉANT puts in place with the fibre providers and any equipment providers/integrators. A high level of SLA will require spares in every country and will be expensive, a lower level of SLA will be cheaper. For this reason it is important to agree maintenance targets with the NMIs/NRENS.



Item	Recommendations for GN5-1
1	Transition the incubator into development allowing the implementation of the pathfinder link
2	Continue to work with NMIs and NRENs to foster community forum for T/F services (Metrology community forum)
Item	Recommendations for GN5-2
1	In GN5-2 GÉANT should fund the sum of Euro 7.5 million to build the first phase of the GÉANT C-TFN
2	The funds provided should be primarily used for purchasing cross-border fibre IRUs and associated amplifier equipment.
3	The cross-border fibre links should be owned and operated by GÉANT to support time and frequency links between NMIs.
4	The Topology of the GÉANT C-TFN should be further refined based on community agreement and should be built in line with the ambitions of options A and B shown in this report.
5	The fibre IRUs are recommended to be 10 years duration, with a low annual charge to ensure a small ongoing liability in case of funding for maintenance is not available after GN5-2
6	The fibre IRUs should have a clause that allows GÉANT to terminate the fibre contract during the IRU with a well-defined and low liability to GÉANT and its NREN shareholders.
7	GÉANT should also use GN5-2 funds to cover the maintenance cost of the fibre and associated equipment.
8	GN5-2 should work with NMIs and NRENs to build and sustain a community forum (Metrology community forum) for agreeing operation and usage of the federated infrastructure.
9	For sustainability purposes, GÉANT should initiate a process to find funding after GN5-2 ends.
10	It is recommended that in GN5-2 WP6 continues developing a monitoring solution based on TimeMap.
11	It is recommended that resources are provided in GN5-2 WP6 to continue NREN (and possibly NMI) collaboration and discussion around management, operations and further development of the GÉANT C-TFN as a technical support to the GÉANT operations team in WP7

- First proof-of-concept link for the CLONETS core-TFN.
- Target completion: early 2025
- GÉANT fibre from PTB to the polish border.
- PSNC will provide access to their existing fibre from the border to Poznan
- Purpose is to prove the technical concept
- Both frequency and time will be tested.



Bi-directional amp



Regenerator laser station



ELSTAB

- The T/F incubator is now **complete** and has set a vision that will further the science of metrology in Europe.
- The incubator has generated genuine **enthusiasm** in the research community, letters of support have been received from nine NMIs.
- GEANT can make a real **difference** to the metrology community by interconnecting national time/frequency networks
- A significant **improvement** in the European infrastructure can be achieved for a relatively small investment.
- We have strong **engagement** from the NMIs and NRENs who support of this work.
- Synergies with quantum research have been shown and time-frequency will form a **complementary infrastructure** with quantum research.





Topology and service roadmap

CERN Feb 2024

Guy Roberts, Richard Lui
GÉANT

Feb 2024

Public

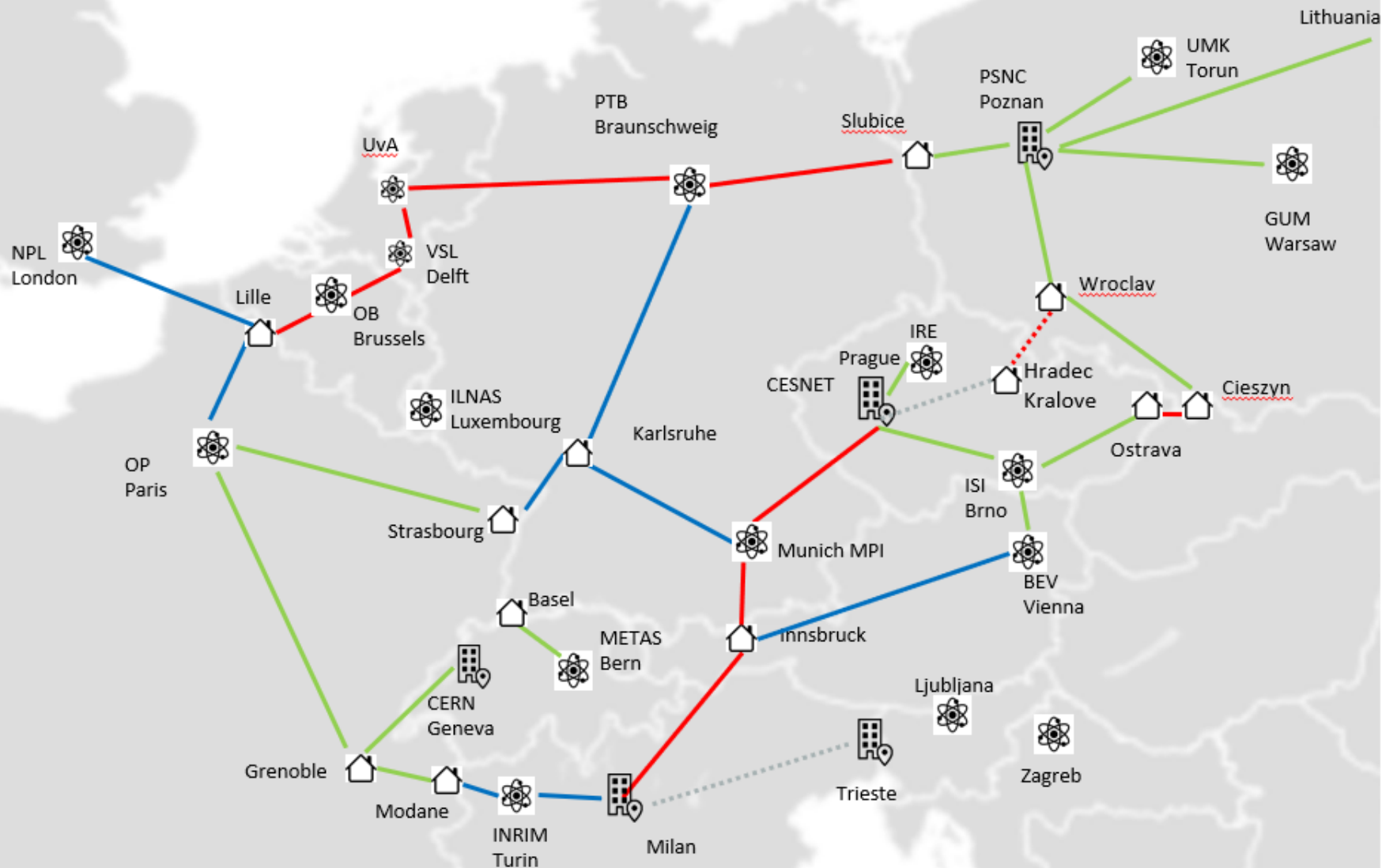
Proposed C-TFN: Option A




Included:

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

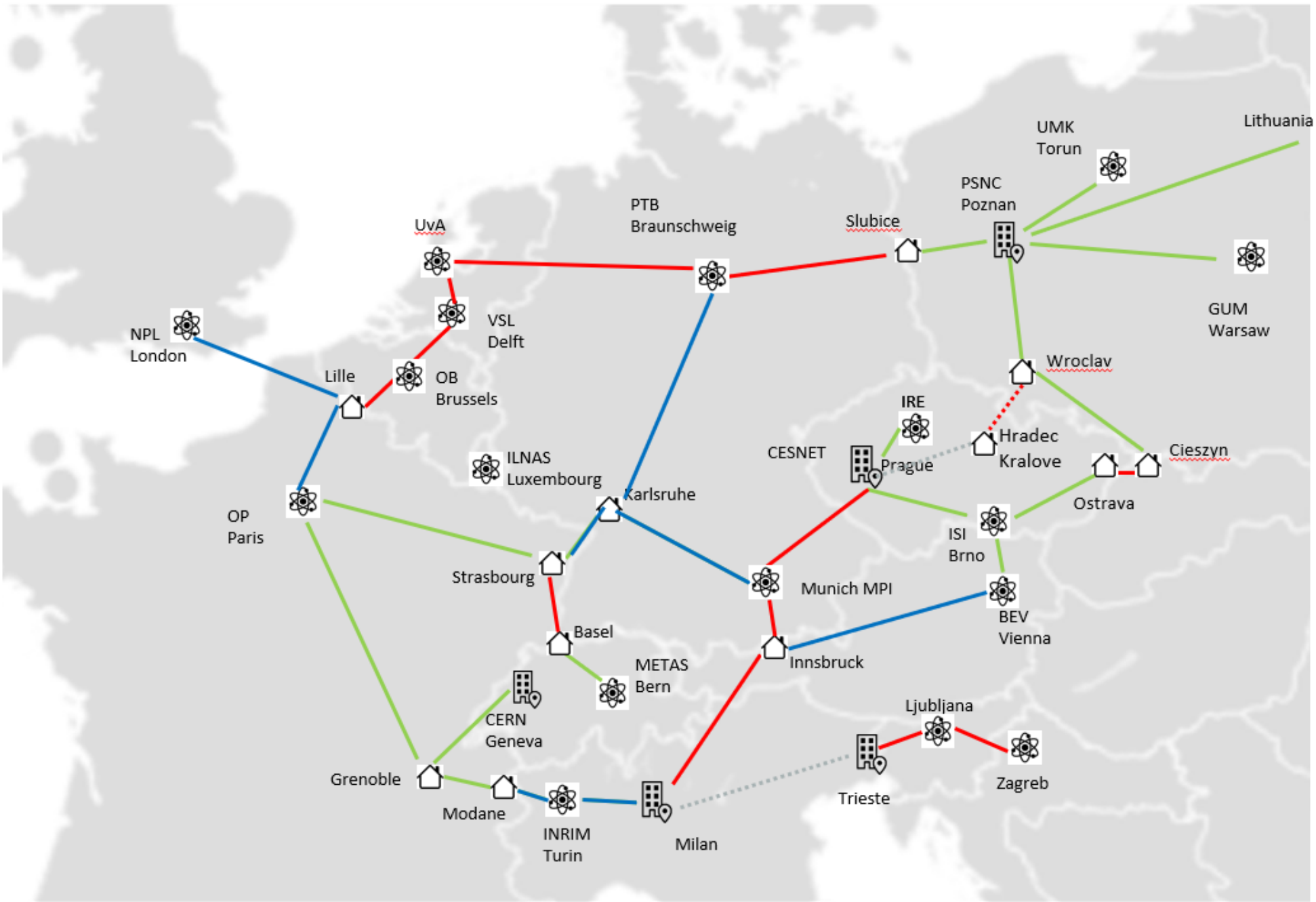
Excluded:

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



-  NMI Frequency reference
-  Research institute
-  Hut for housing RLS

Proposed C-TFN: Option B

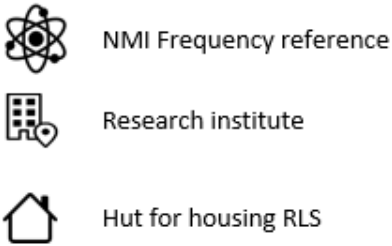


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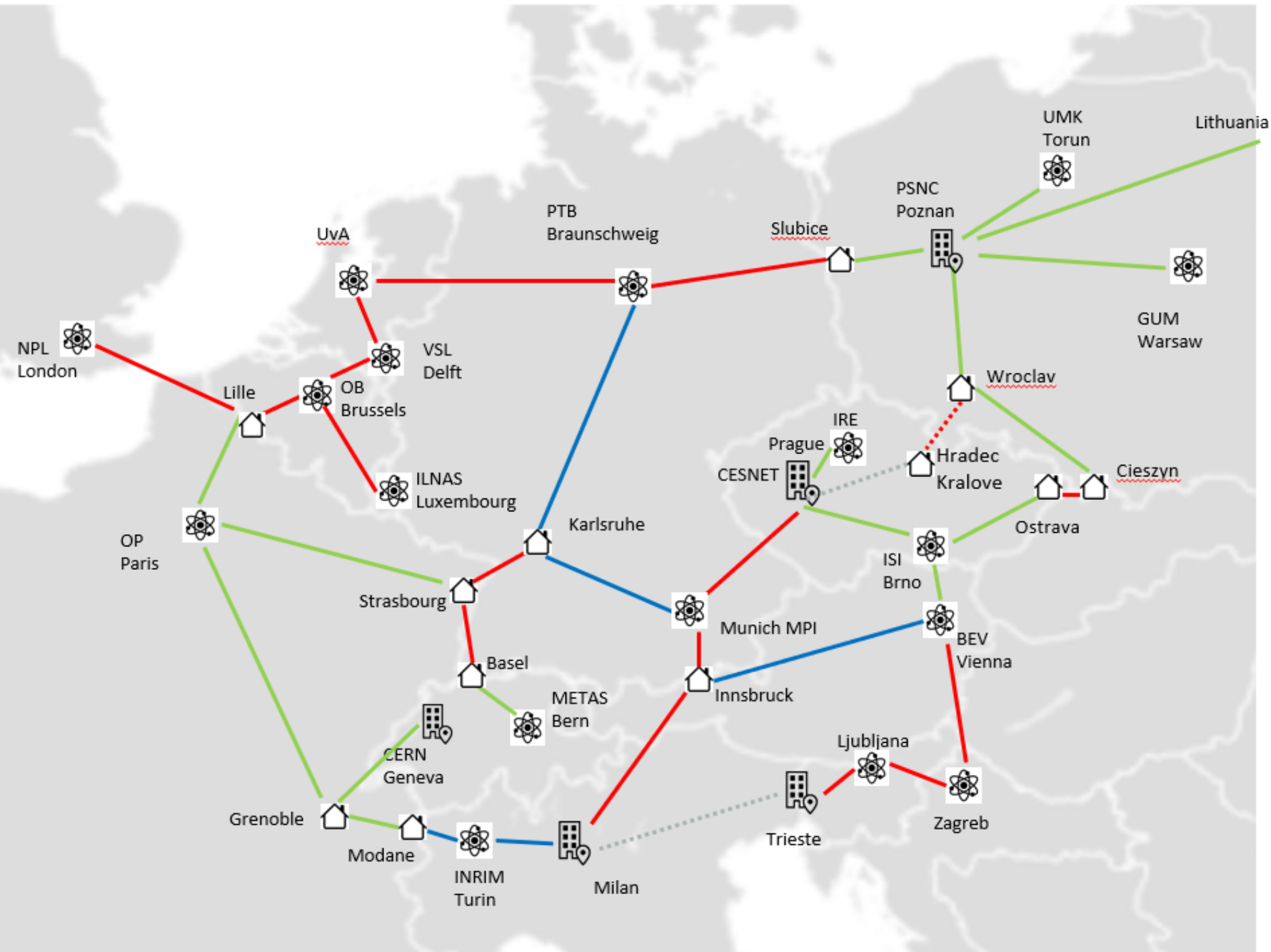
Proposed C-TFN: Option C

Included:

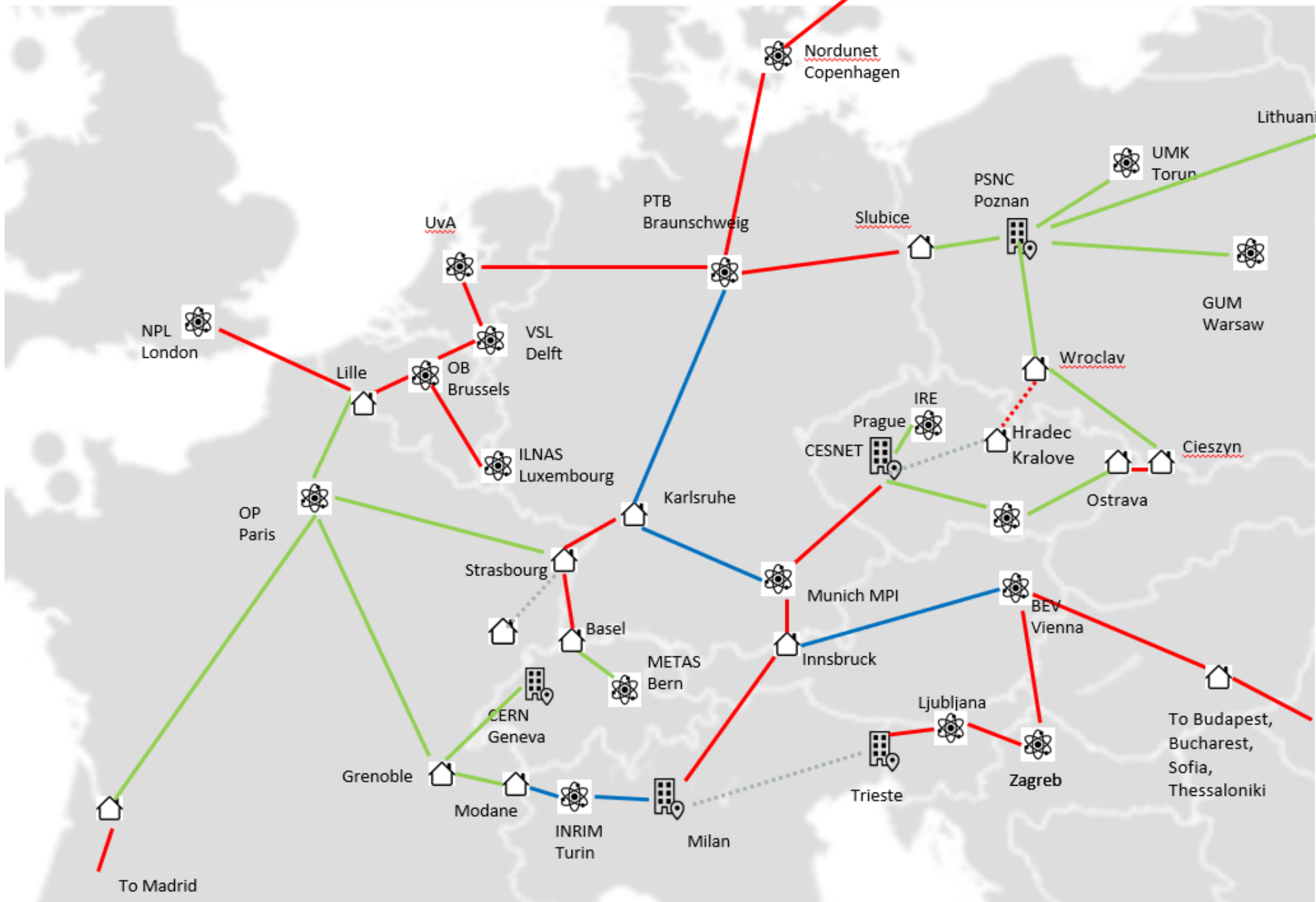
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- Time/Frequency overlay services



Proposed C-TFN: Future expansion (after 2027)






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 built by NMs
- Dashed grey – planned national links
- flywheels, counters frequency combs needed are to be funded by the national time/frequency providers
- Time/Frequency overlay services

 NMI Frequency reference
 Research institute
 Hut for housing RLS

Time/Frequency network projected costing

TCO Period	2.5	years
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Item	Scenario A		Scenario B		Scenario C		Scenario D	
	Capex	OPEX (support/yr)	Capex	OPEX (support/yr)	Capex	OPEX (support/yr)	Capex	OPEX (support/yr)
Fibre	5,735,940	191,198	7,518,168	250,606	12,095,412	403,180	26,140,485	871,350
RLS (NMIs)	-	-	-	-	-	-	-	-
RLS (mid-route)	-	-	-	-	-	-	-	-
Amplifiers	114,000	28,500	147,000	36,750	252,000	63,000	486,000	121,500
Flywheels	not inc	not inc	not inc	not inc	not inc	not inc	not inc	not inc
Comparators	not inc	not inc	not inc	not inc	not inc	not inc	not inc	not inc
Other (IP/racks/install)	not inc	not inc	not inc	not inc	not inc	not inc	not inc	not inc
Housing	not inc	not inc	not inc	not inc	not inc	not inc	not inc	not inc
Installation (all)	243,200		313,600		537,600		1,036,800	
Insurance		342		441		756		1,458
Project Management	150,000		150,000		150,000		150,000	
Geant OC manpower		100,000		100,000		100,000		100,000
Servers+Software	20,000	3,000	20,000	3,000	20,000	3,000	20,000	3,000
Total	€ 6,263,140	€ 323,040	€ 8,148,768	€ 390,797	€ 13,055,012	€ 569,936	€ 27,833,285	€ 1,097,308
TCO	€ 7,070,740		€ 9,125,760		€ 14,479,853		€ 30,576,554	

Scenario A should be the Minimum viable network for the community

- The TCO covers both NRC and ARC for the duration of GN5-2.
- GÉANT will use horizon Europe funding to cover 100% of NRC and ARC costs between January 2025 and July 2027.
- The dark fibre IRUs includes: 10-year IRU on fibre, amplifier hut space, and power at the huts
- After the July 2027 the solution is unfunded and another source of funds is required for continuity. See discussion on sustainability and future liabilities.
- In this costing we have assumed a 40% uplift in costs compared to the most recent GÉANT procurement. This uplift is due to inflation and expensive fibre tails to the NMI sites.
- In this costing we have assumed that IRUs will be 75% up-front funded, this means that each year the annual recurring maintenance fee for the dark fibre will be 2.5% of the NRC.
- In this costing no RLS equipment is included in these cost as these need to be added on a per-service basis. See the service section below for further discussion of the time and frequency service overlays.





Recap of day 1 CERN Feb 2024

Guy Roberts
GEANT

Feb 2024

Public

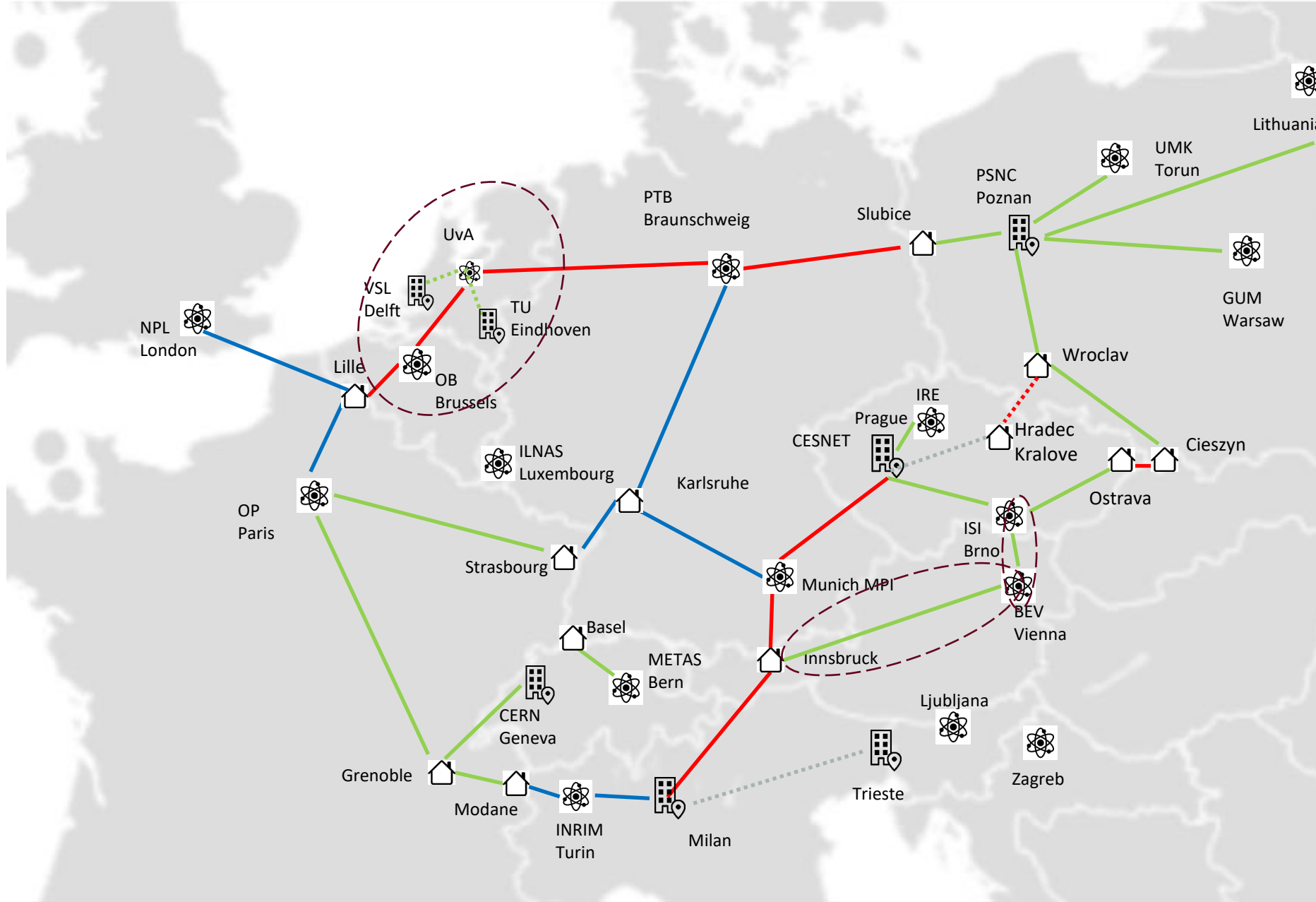
CERN workshop 8th February 2024

Zoom: <https://cern.zoom.us/j/61172090928?pwd=RGVlOXhLVCTyRDdOUHFIZUI6MHpBQT09>

- 9:30-10:00 update on the discussions from day 1 (Guy)
- 10:00-11:00 Speakers
 - White Rabbit, Maciej Lipinski and Javier Serrano, CERN (20 minutes + Q&A)
 - T/F and fundamental Science, Michael Doser, CERN (20 minutes +Q&A)
- 11:00-11:30: Coffee
- 11:30-12:30 Speakers
 - Applied Science, Jeroen Koelemeij, Vrije Universiteit Amsterdam (20minutes +Q&A)
- 12:30-13:30: Lunch
- 13:30- 14:00: Round table discussion on use cases
- 14:00- 14:30: Sustainability and cost modelling
- 14:30-15:00: Wrap-up and next steps
- 15:00-15:30 coffee break
- 16:00-17:00 optional tour of CERN (pre-registration only)



Corrections to map

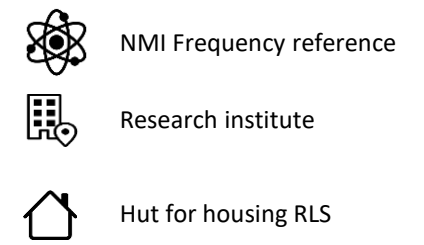


Included:

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

Excluded:

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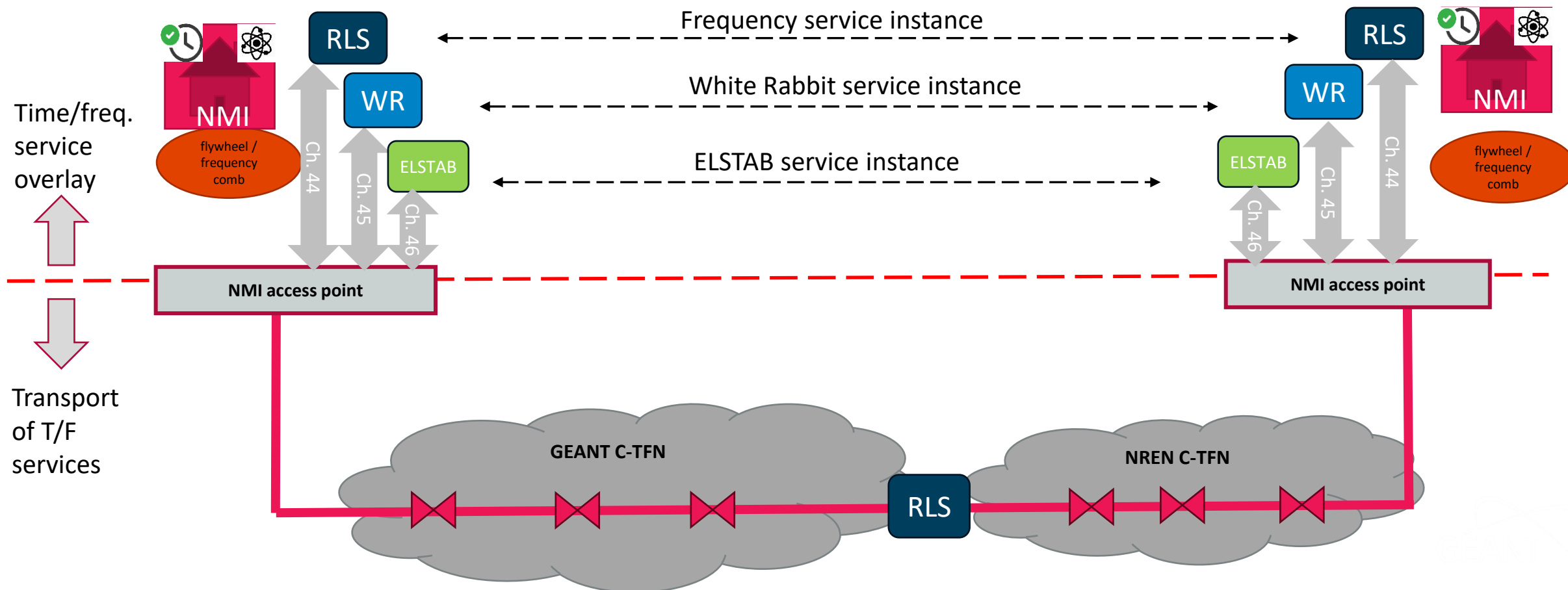


NMIs

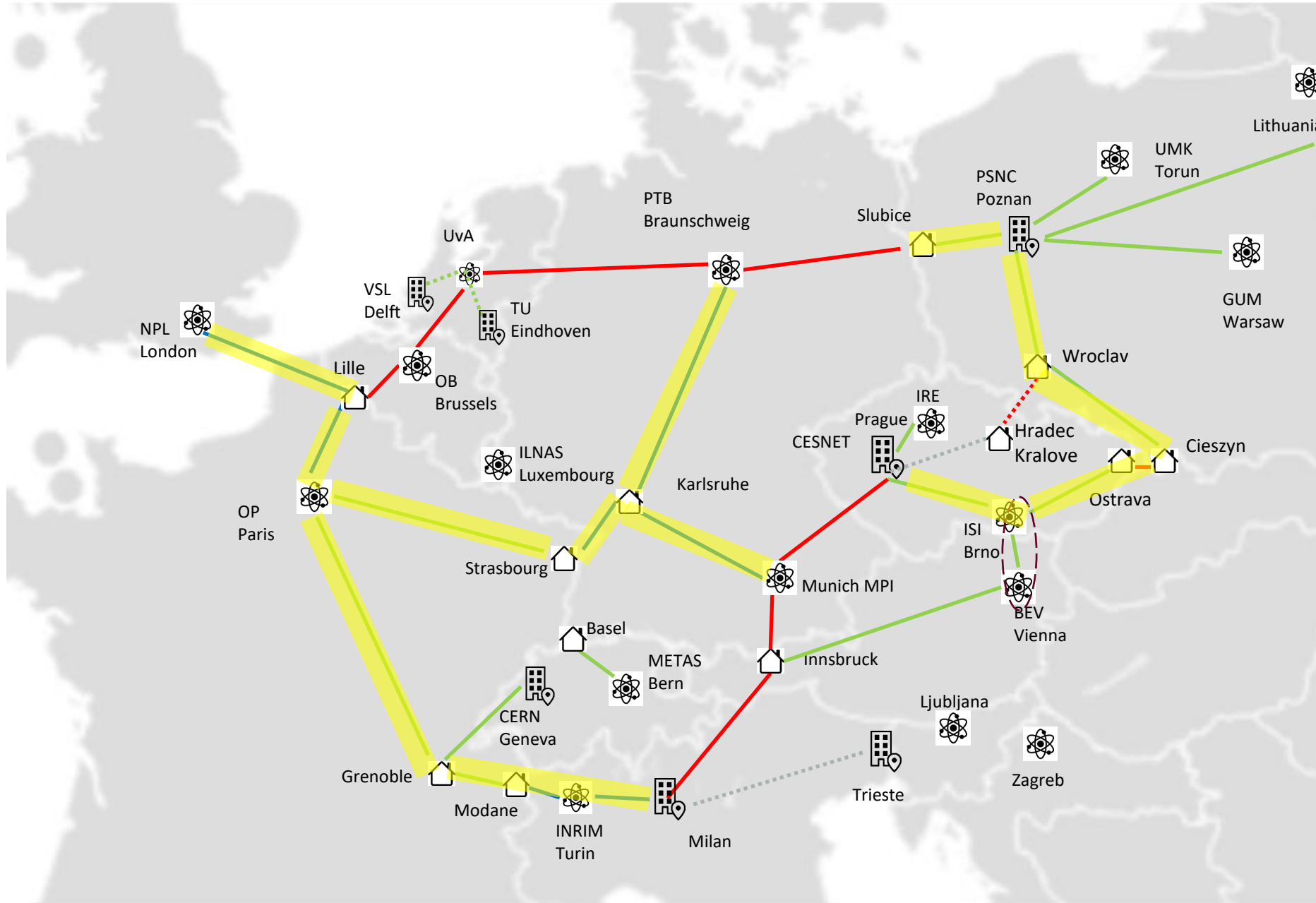
- Build, own and operate the T/F equipment:
 - Flywheels, counters, frequency combs
- Retain ownership of time/frequency
- Generate and measure time/frequency
- Commit to operating a **persistent** frequency service

GEANT, NRENs

- build, own and operate transport links:
 - fibre, amplifiers, access points, intermediate RLS
- Provide a service to NMIs to carry T/F services
- Need to future-proof the fibre/amps for future time services



Persistent service requires sustainability model for NREN links

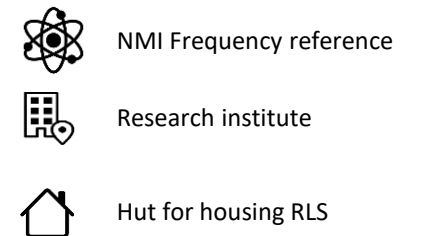


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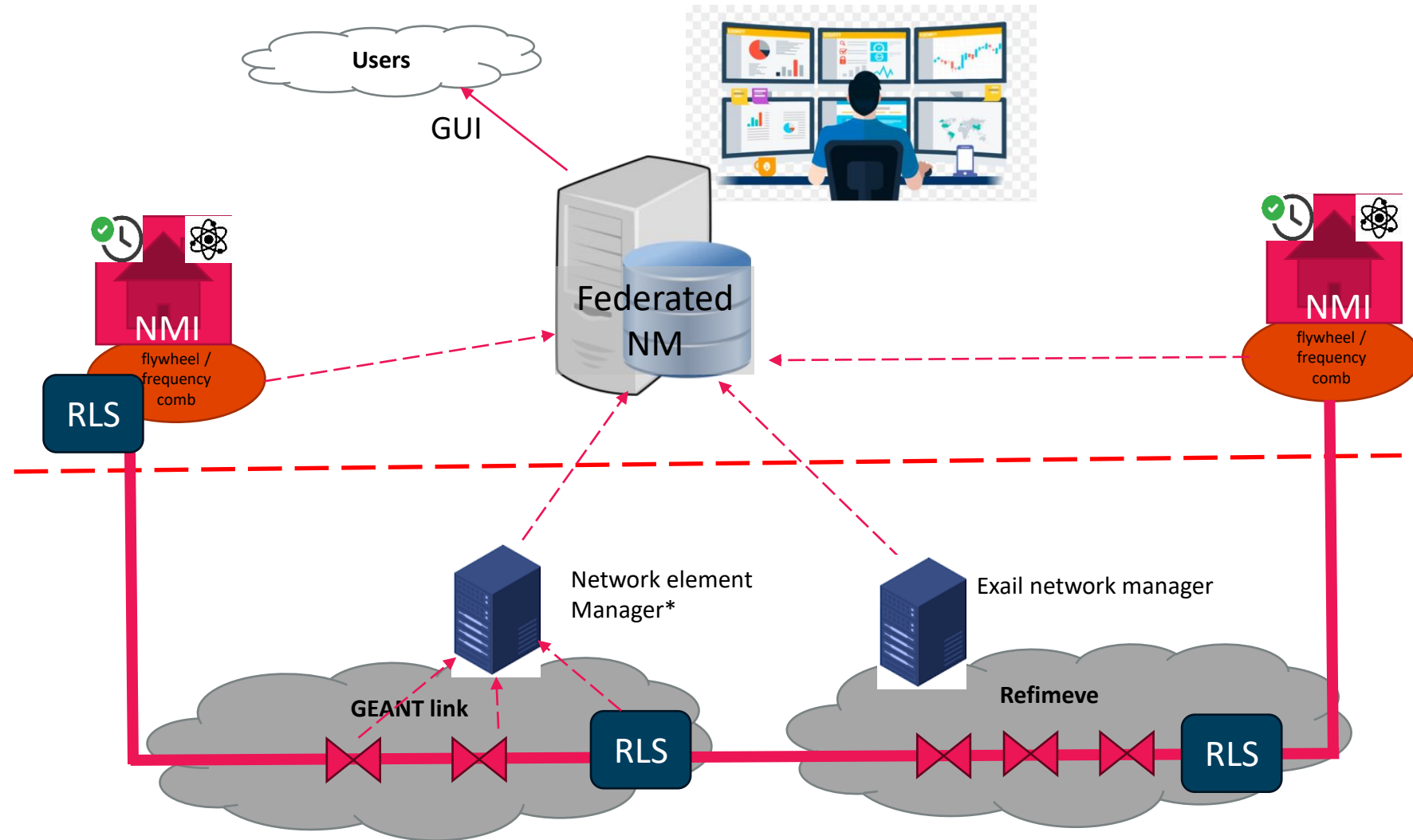
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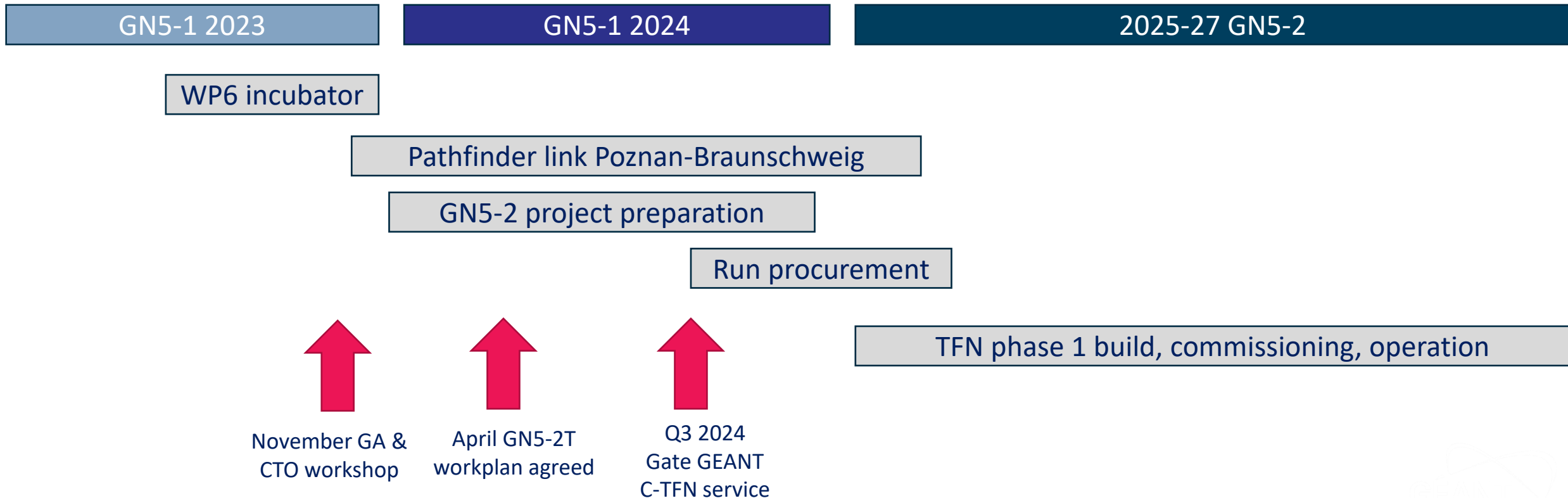
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- Each European provider of time/frequency will manage their own national infrastructure.
- It is recommended that the GEANT OC act as a single point of contact for the federated C-TFN.
- A network management system will need to be developed for this purpose.
- *Further work needed to explore software costs and reuse of existing solutions*



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11	It is recommended that resources are provided in GN5-2 WP6 to continue NREN (and possibly NMI) collaboration and discussion around management, operations and further development of the GÉANT C-TFN as a technical support to the GÉANT operations team in WP7

1. Metrology community forum

Domenico Vicinanza and Enzo Capone

2. Sustainability and Business model

Richard Lui and Paul Rouse

3. Interconnect agreement

Bram Peeters and Ivana Golub

4. Technical requirements

Guy Roberts and Jochen Kronjaeger

- A new community metrology forum is needed
- Should bring NMIs and NRENs together
- GEANT is able to facilitate this group events
- Euramet is active, so the new group should not overlap with its functions
- Group should have an advisory role to GEANT giving a united view of the NMIs requirements
- Group should set up mini task-forces to tackle specific well-defined questions, such as ‘What is the specification for a flywheel’

- Sustainably after mid-2027 is important and needs to be addressed now
- Euramet has a Horizon Europe framework program to fund metrology research, but is not likely to be the right organization to fund time/frequency links
- A united approach to lobbying the EC for funds is needed between GEANT, the NRENs, NMIs and Euramet.

- There is a need for an interconnect agreement between GEANT and the connected NMI
- The sample interconnect agreement text between GEANT and an NMI was reviewed and was considered in principle to be acceptable.
- The interconnect agreement will need to identify the commitments made by both GEANT and the NMIs.
- In follow-up discussions some NMIs indicated that the ‘always up’ service will require considerable investment and manpower for maintenance by the organization providing it.
- There is also a need for a wider agreement among all NMIs participating in the C-TFN, even if they are not connected directly to GEANT.
- An MOU was discussed as a suitable method of bring together all participating NMIs. A draft MOU has been created by CLONETS-DS team and is under review.



- A clear set of technical requirements for flywheels needs to be documented.
- These should define the performance of the flywheels in terms of instability and availability.
- Flywheel will need to have high short-term stability and high availability
- More than one level of flywheel performance will need to be specified:
 - Flywheel in an NMI that is 'steered' to a local UTC reference, eg fountain clock
 - Flywheel in an NREN/research establishment that is not steered.
- GEANT links should be engineered in such a way as to support both frequency and time with no disruption to frequency services if/when new time services are added.
- To ensure frequency transfer is verifiable it recommended that both fibres in the pair are used.
- An in-band management solution is needed for amplifiers





Sustainability and cost modelling

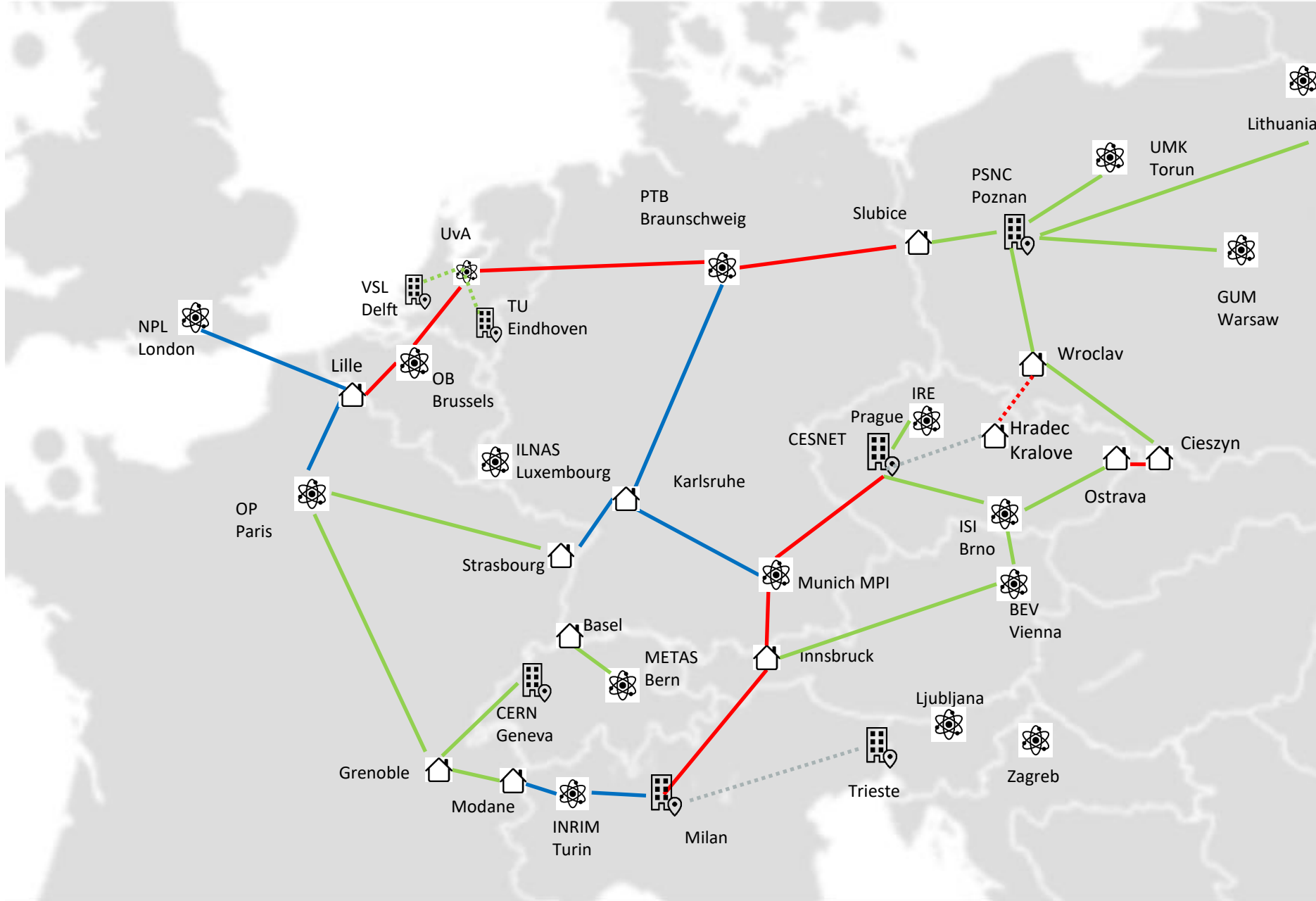
CERN Feb 2024

Guy Roberts
GEANT

Feb 2024

Public

Corrections to map

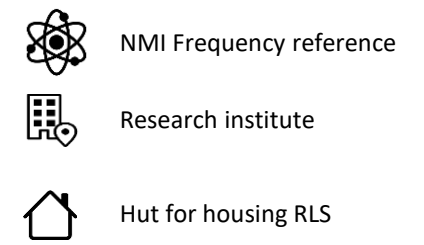


Included:

- 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 built by NMIs
- Dashed grey – planned national links
- flywheels, counters frequency combs needed are to be funded by the national time/frequency providers
- Time/Frequency overlay services



Time/Frequency network projected costing

TCO Period	2.5	years
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Item	Scenario A		Scenario B		Scenario C		Scenario D	
	Capex	OPEX (support/yr)	Capex	OPEX (support/yr)	Capex	OPEX (support/yr)	Capex	OPEX (support/yr)
Fibre	5,735,940	191,198	7,518,168	250,606	12,095,412	403,180	26,140,485	871,350
RLS (NMIs)	-	-	-	-	-	-	-	-
RLS (mid-route)	-	-	-	-	-	-	-	-
Amplifiers	114,000	28,500	147,000	36,750	252,000	63,000	486,000	121,500
Flywheels	not inc	not inc	not inc	not inc	not inc	not inc	not inc	not inc
Comparators	not inc	not inc	not inc	not inc	not inc	not inc	not inc	not inc
Other (IP/racks/install)	not inc	not inc	not inc	not inc	not inc	not inc	not inc	not inc
Housing	not inc	not inc	not inc	not inc	not inc	not inc	not inc	not inc
Installation (all)	243,200		313,600		537,600		1,036,800	
Insurance		342		441		756		1,458
Project Management	150,000		150,000		150,000		150,000	
Geant OC manpower		100,000		100,000		100,000		100,000
Servers+Software	20,000	3,000	20,000	3,000	20,000	3,000	20,000	3,000
Total	€ 6,263,140	€ 323,040	€ 8,148,768	€ 390,797	€ 13,055,012	€ 569,936	€ 27,833,285	€ 1,097,308
TCO	€ 7,070,740		€ 9,125,760		€ 14,479,853		€ 30,576,554	

Scenario A should be the Minimum viable network for the community

- The TCO covers both NRC and ARC for the duration of GN5-2.
- GÉANT will use horizon Europe funding to cover 100% of NRC and ARC costs between January 2025 and July 2027.
- The dark fibre IRUs includes: 10-year IRU on fibre, amplifier hut space, and power at the huts
- After the July 2027 the solution is unfunded and another source of funds is required for continuity. See discussion on sustainability and future liabilities.
- In this costing we have assumed a 40% uplift in costs compared to the most recent GÉANT procurement. This uplift is due to inflation and expensive fibre tails to the NMI sites.
- In this costing we have assumed that IRUs will be 75% up-front funded, this means that each year the annual recurring maintenance fee for the dark fibre will be 2.5% of the NRC.
- In this costing no RLS equipment is included in these cost as these need to be added on a per-service basis. See the service section below for further discussion of the time and frequency service overlays.





Thank You

Any questions?

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Co-funded by
the European Union

Keeping time

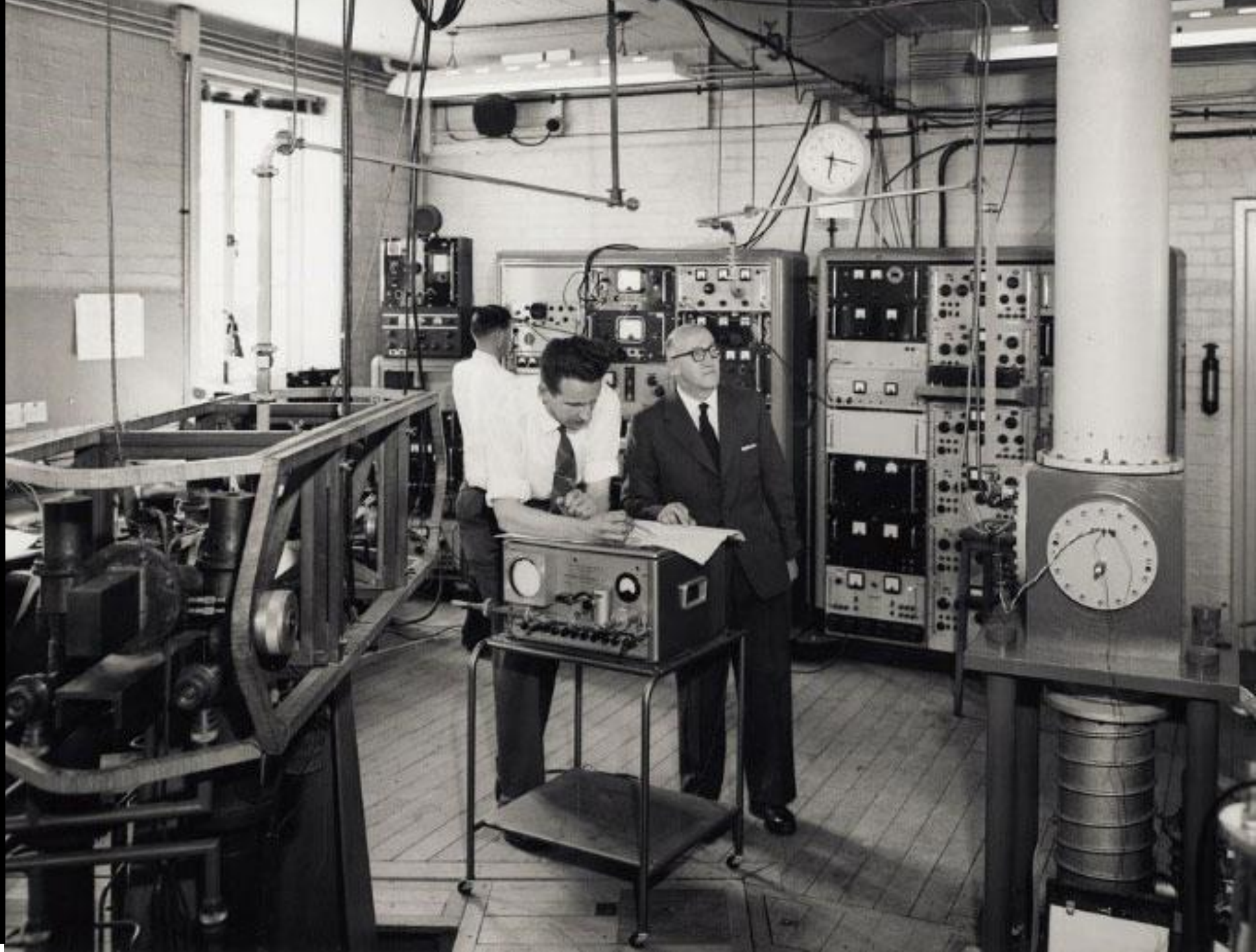
- Keeping track of time has been important to humans since the beginning of civilization
- Most modern systems need some element of time to synchronize events
- Time is especially important for geolocation



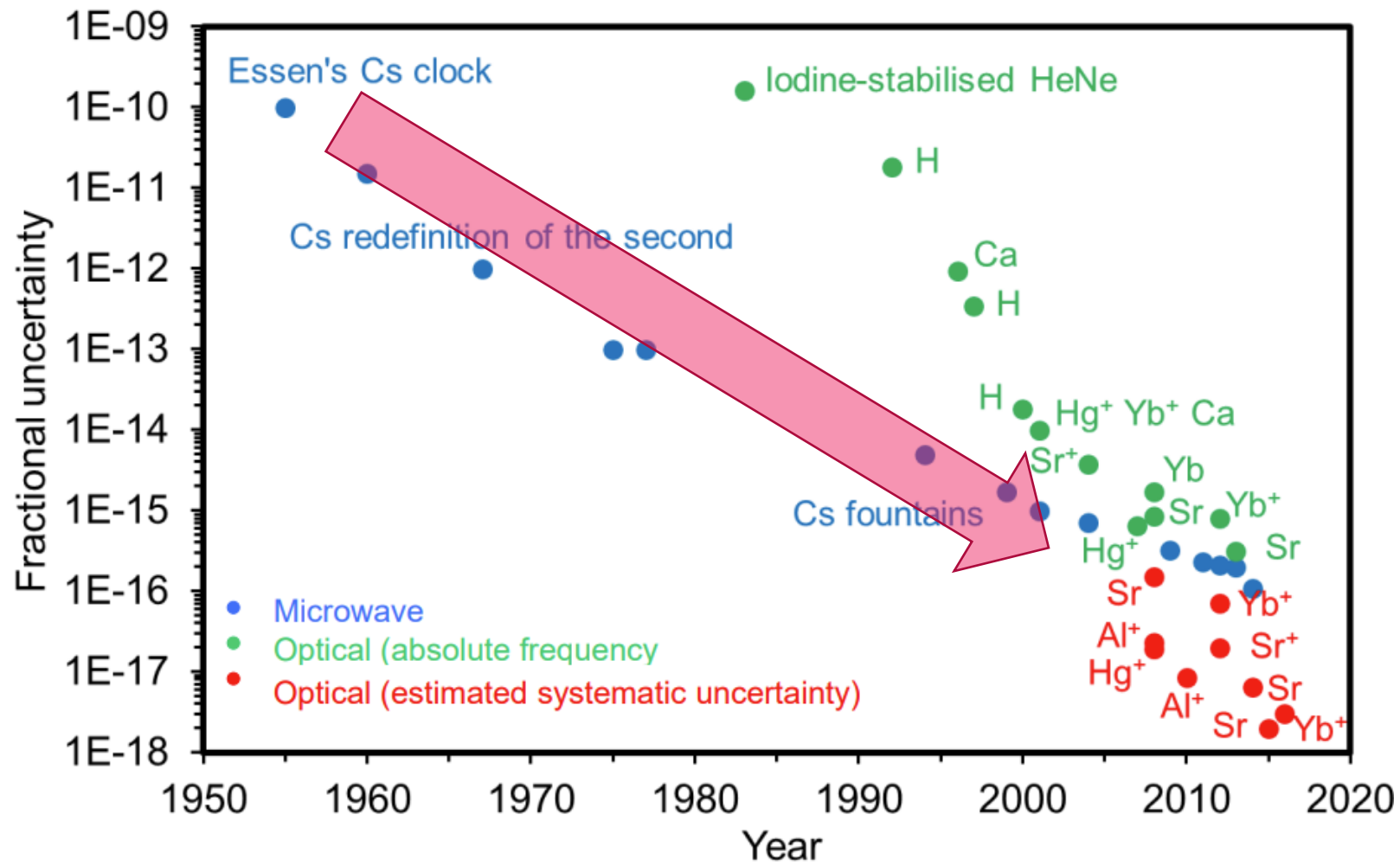
First working atomic clock,
NPL 1955

Since 1968, the SI second
defined as the duration of
9192631770 cycles of
radiation from transition
between two energy levels
in a caesium-133 atom.

Atomic clocks are no longer
the most accurate way to
measure time



- Since 1968 the second has been defined by measurement using Cesium atomic clocks.
- Optical clocks are now a better technology for measuring time
- A laser is shone onto a single trapped ion of strontium and the frequency of the light emitted is measured
- Traditional atomic clocks can be compared using satellite links



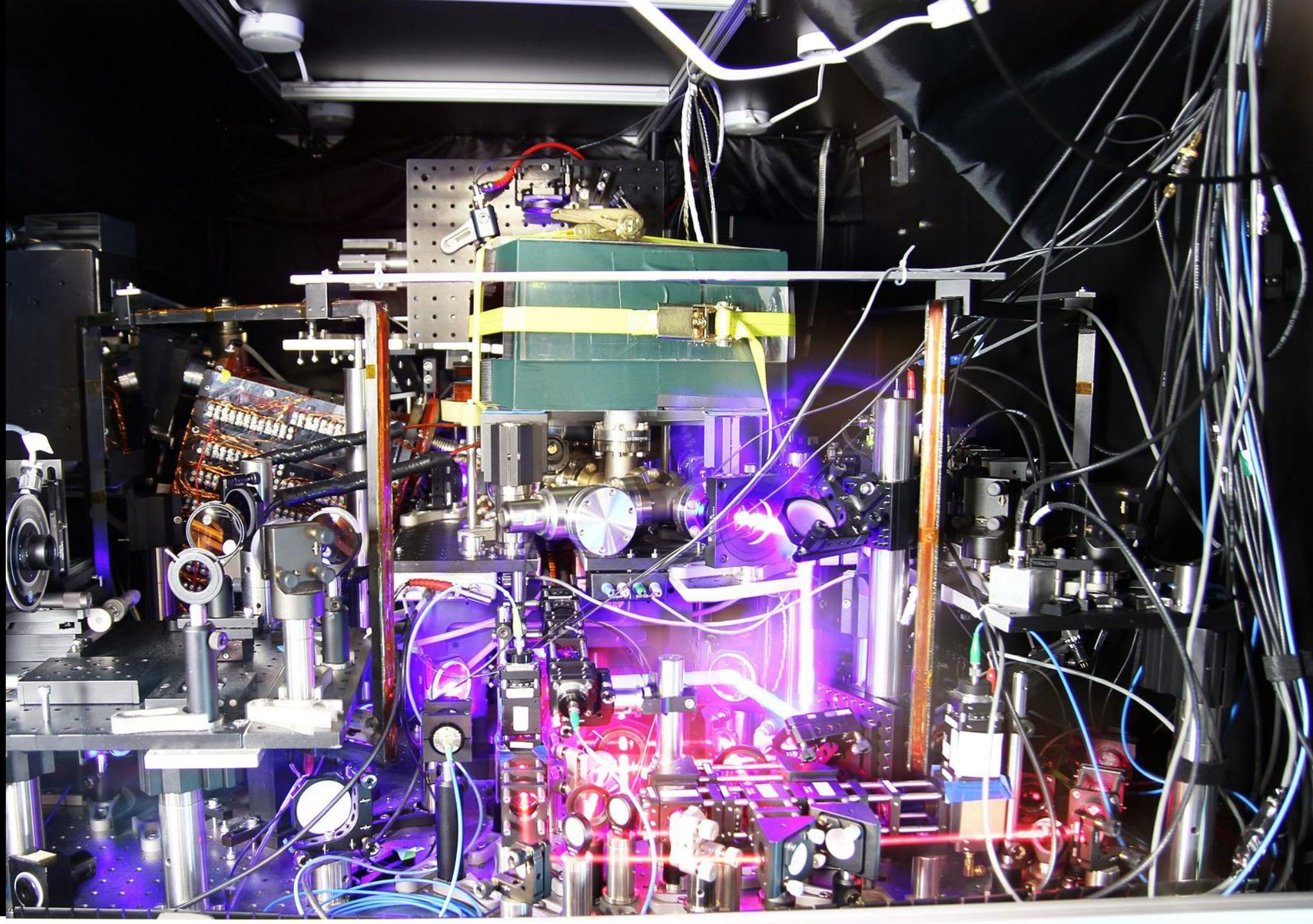
National measurement institutes (NMIs) play a crucial role in the accurate measurement and dissemination of Coordinated Universal Time (UTC).

- **Atomic Clocks:** Traditionally NMIs maintain 'radio frequency' atomic clocks, cesium or rubidium atoms with an uncertainty is up to $1e-16$. New 'optical' atomic clocks are now being developed.
- **Calibration:** A single atomic clock is not sufficient to ensure a time scale is calibrated as a drift will remain undetected. For this reason, at least three atomic clocks are compared to establish a common time reference. This helps ensure that the time scale is stable and accurate.
- **UTC Adjustment:** UTC is adjusted to account for discrepancies between atomic time and the Earth's rotation, leap seconds are added or subtracted to keep UTC within 0.9 seconds of mean solar time.
- **Certification and Traceability:** NMIs provide certification and traceability services, allowing other institutions and laboratories to calibrate their own clocks and instruments against the NMI's primary standards. GPS and other satellite services are commonly used to carry out international comparison of time scales.
- **Dissemination of Time:** NMIs are responsible for disseminating accurate time to the public, scientific institutions, industries, and other users. This done via radio broadcasts, internet services and other means

Optical clocks are now
the best technology
available

This Strontium clock is
operating in NPL

A laser is shone onto
a single trapped ion of
strontium and the
frequency of the light
emitted is measured



Objectives

We need a basic framework to allow GÉANT project to fund the infrastructure:

- Set budget and target network to build
- High-level C-TFN architecture and topology
- Roadmap for implementation
- Business model – infrastructure ownership and sustainability
- Governance model

Scope

- Build on CLONETS-DS work (do not repeat work already done)
- Provide guidance to GEANT governance on funding objectives
- Work with NMIs to set out ownership, usage, sustainability models
- Define relationships between stakeholders
- Set foundations for procurement process
- Initiate a pathfinder link to prove the technology

5. Market analysis

- Extensive interviews conducted with end-users (NMI and big science)
- Regular calls with NRENs and NMIs during the incubator, f2f symposium
- Expressions of interest from nine countries and end-consumers
- Letters of support provided by:
 - FAMO Consortium including Nicolaus Copernicus University Poland
 - GUM Poland
 - Belnet Belgium
 - ROB Belgium
 - IPE/UFE Czech Republic
 - PTB Germany
 - IMRIM Italy
 - CERN

4b. Benefits to NRENs

- **Enhanced Knowledge Exchange and development expertise**
By sharing knowledge and best practices with NRENs, this initiative fosters the development of specialized expertise in time and frequency network deployment and management. This collaborative approach elevates the technical proficiency across the NRENs, enabling NRENs to build and maintain technically complex national T/F networks.
- **Strengthened Collaboration between NMIs and NRENs**
The initiative acts as a bridge, enhancing the flow of information and support between National Metrology Institutes (NMIs) and NRENs. This collaboration is crucial for supporting NRENs in developing their own national time and frequency networks, ensuring a more integrated European T/F infrastructure.



4c. Benefits to NRENs (cont.)

- **Direct Engagement with the Research Community:**

By working closely with researchers, GÉANT and NRENs can contribute significantly to the development of science data repositories and scientific workflows. This direct involvement not only enhances the quality of research outputs but also ensures that the infrastructure meets the needs of the scientific community.

- **Opportunities for New Services and Applications:**

The expanded capabilities of the C-TFN will enable NRENs and GÉANT to explore and offer new non-data services, potentially opening new opportunities for collaboration in diverse scientific and commercial sectors.

- **Contribution to European Scientific Leadership:**

By fostering an integrated European T/F network, this initiative significantly contributes to Europe's standing as a global leader in high impact scientific research and technology. It underscores Europe's commitment to advancing scientific infrastructure and collaboration.