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White Paper:
GÉANT Core Time/Frequency Network (GÉANT C-TFN) Network Development Incubator Report (Public)

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Abstract

Following an 8-month time/frequency (T/F) incubator project, this report sets out recommendations for building a GÉANT Core Time/Frequency Network (C-TFN) comprising federated cross-border T/F links that interconnect existing national T/F networks. The report includes the proposed architecture of the GÉANT C-TFN, topology options, cost modelling, sustainability, funding, operation and maintenance, recommendations for GN5-2, and areas requiring further investigation.

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Executive Summary

Work Package 6 Network Development (WP6) has run an eight-month Network Development incubator project known as the time/frequency incubator. This involved extensive outreach to European National Metrology Institute (NMIs) and weekly calls to develop a way forward. This incubator completed in January 2024 and the results of the team's investigations are summarised in this document.

WP6 found universal support among the NMIs surveyed for funding the GÉANT Core Time/Frequency Network (C-TFN). Further, many have provided strong letters of support (please see Appendix F for more details).

This report sets out a number of recommendations about how GÉANT can use funds available in GN5-2 to build federated cross-border time/frequency links to interconnect existing national time/frequency networks.

In addition, the document identifies the areas requiring further investigation and preparation in 2024 so that the C-TFN network can be commenced in GN5-2. The success of this work will be measured using the existing GÉANT Product Lifecycle Management (PLM) process.

The intended audience for this document is the GÉANT governance involved in preparing the GN5-2 work plan, and the GÉANT management team, to help prepare for the C-TFN network in GÉANT.

1 Introduction

To provide context, this section outlines the primary frequency standards and the recommendations of the Clock Network Services Design Study (CLONETS-DS) project with regard to transmitting time and frequency. It then introduces the objectives, users and use cases for a Core Time/Frequency Network (C-TFN) and presents the proposed roadmap for building a GÉANT C-TFN.

1.1 Background

1.1.1 Primary Frequency Standards

Since 1968 the second has been defined by the Cs hyperfine transition at 9.2 GHz and realised by Caesium atomic clocks. In recent years, optical clocks have proven to be a more precise technology for the realisation of the SI second. An example technique for optical clocks is to stabilise a laser onto a single trapped ion or an ensemble of neutral atoms. In this case, the frequency of the light emitted is measured and forms a reference source.

Figure 1.1 below shows the improvements in the uncertainty of clocks over the past seventy years.

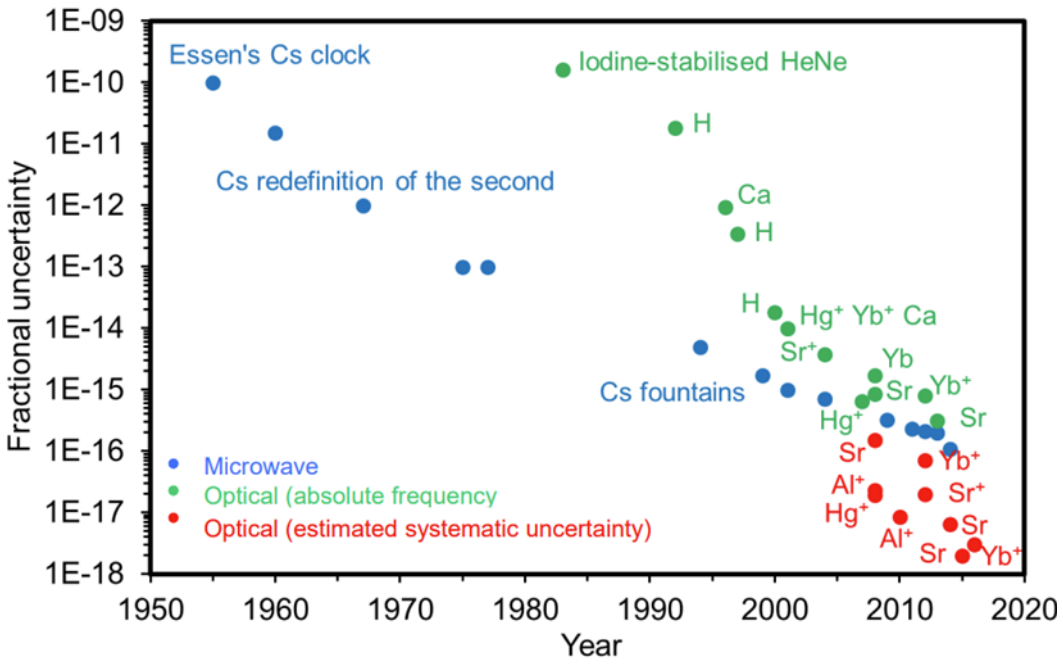

Figure 1.1: Improvements in clock uncertainty over the last 70 years

A significant number of optical atomic reference transitions based on electromagnetically trapped single ions or multiple atoms trapped in optical lattices have surpassed the performance of today's primary frequency standards. In consideration of this, in November 2022, the 27th General Conference on Weights and Measures (CGPM) [CGPM] approved Resolution Five towards the redefinition of the second [CGPM27 Res5], with a

preferred scenario leading to a redefinition at the 29th CGPM (2030), and invited 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.

1.1.2 CLONETS-DS and Transmitting Time and Frequency

Given that Europe will need optical fibre to meet the stability objectives to set the soon-to-be redefined SI second, it is important to begin work on this infrastructure in the coming years. Some national time/frequency networks are well progressed in this work; in particular, the REFIMEVE network has built frequency distribution links between major French cities. However, there are gaps in the Europe-wide infrastructure, partly because of the lack of investment in some countries, but most importantly because there is no centralised European organisation to interconnect the existing national time/frequency networks.

Following on from the Clock Network Services Design Study project (CLONETS-DS) recommendations for a unified European network (documented in the reports available at [CLONETS-DS_Reports]), GÉANT has engaged with many of the European National Metrology Institutes (NMIs) to understand their views on the proposed Core Time/Frequency Network (C-TFN).

1.2 Objectives

The broad objectives of the C-TFN are as follows:

- Complement the Global Navigation Satellite System (GNSS) with more reliable and accurate fibre cable frequency distribution between NMIs for measuring global Coordinated Universal Time (UTC).
- Support the redefinition of the SI second by frequency comparisons being carried out between now and 2030 by NPL, PTB, SYRTE and INRIM.
- Perform fundamental physics research, e.g. relativistic geodesy, gravity wave and anti-matter experiments.
- Enable NMIs (and other metrology organisations) to either enhance existing services or create new commercial services such as very accurate time stamps for banks to validate high-frequency trading.

1.3 Users of the C-TFN

CLONETS-DS identified a wide range of users of the C-TFN. These have been reviewed and corroborated by the incubator study and the users include the following organisations:

- National Metrology Institutes (NMIs), as users/providers of national time/frequency services.
- National Research and Education Networks (NRENs):
  - As users of time/frequency signal in their own networks.
  - National providers of time/frequency services to public institutes. For example, Funet provides time to EISCAT in Norway.
- International research organisations (e.g. CERN), international research projects, and community research facilities bringing together metrologists, scientists and NRENs working with other partners using the second fibre in a fibre pair for fundamental physics experiments.
- Large intergovernmental organisations, e.g. ESA.
- Commercial network providers:

- National providers of time/frequency services to commercial users. E.g. NPLtime is a service sold by NPL to banks in the UK.
- Consumers of time/frequency in their own networks, e.g. accurate time stamps to replace GPS in 5G networks.

1.4 C-TFN Use Cases

The CLONETS-DS project developed a strong set of use cases for time/frequency infrastructure. The use cases include commercial, scientific and network operator users. In addition, the time/frequency incubator project carried out its own market analysis.

In summary, the use cases for enhanced fibre connectivity in Europe can be grouped into the following categories:

- **Metrology**: the primary use case is the planned project to redefine the second using a new generation of optical clocks. Secondary cases include improving International Atomic Time (TAI).
- **Geodesy**, including improvements to the measurement of national height reference systems by measurement of gravity potential differences.
- **Research**:
  - Precision spectroscopy with traceability to primary standards.
  - Tests of fundamental physics via optical clock comparisons, including the growing field of quantum sensing.
  - Quantum research.
  - Astronomy use cases, including the detection of dark matter.
- **Commercial** uses cases, typically consumed by national users:
  - Finance.
  - GNSS backup.
  - Transport.
  - Communication.

All commercial use cases will continue to be delivered by the NMIs.

See Appendix E for more detailed use cases.

1.5 Roadmap

Considering the requirements of the metrology community and the recommendations documented in the CLONETS-DS reports [CLONETS-DS_Reports], GÉANT proposes the following roadmap (Figure 1.2) to build a GÉANT C-TFN comprising federated cross-border time/frequency links that interconnect existing national time/frequency networks. The dates shown here are indicative only and are subject to funding and manpower resources.

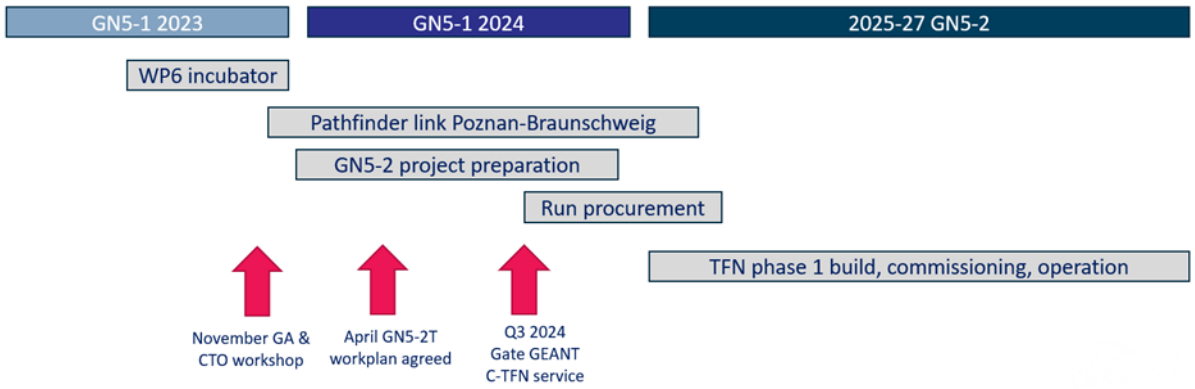

Figure 1.2: Roadmap for building GÉANT C-TFN

2 GÉANT C-TFN Architecture

In this section, a set of design architecture principles are stated that build on the architecture proposed in the CLONETS-DS project. Specifically, the incubator team has taken into consideration the implications of the GÉANT funding and how to manage the federation and sustainability of the solution.

2.1 Design Principles

The community has agreed that a federated model is needed to integrate the existing national time/frequency networks. For this reason, the design principles described below assume a federated model of operation.

GÉANT as a European backbone provider between national networks

- A monolithic Europe-wide organisation to connect all European institutions will not scale. NRENs and 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**,[1] 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.

Support for both research and commercial users

- NRENs, intergovernmental organisations and commercial providers should all be able to connect to the GÉANT C-TFN and build the national time/frequency services needed in their country/region. It is expected that NRENs will primarily offer services to research and education networks. Commercial providers will sell services at commercial rates and at a profit.
- State aid rules should be understood and a business model needs to be agreed which will ensure that these rules are not contravened. For further discussion on this subject see Appendix B.

Interconnection and access

- The GÉANT C-TFN infrastructure should be primarily about interconnecting the NMIs into a mesh/ring architecture as proposed in the CLONETS-DS project.
- Where practical, GÉANT will include **access points**[2] in the GÉANT C-TFN. These will be sites where time/frequency providers and users are present. This will include national NMIs, NRENs and research institutes.
- These access points should have a formal physical definition to achieve a consistent and well-defined interconnect method for all users. This should include connector description, optical signals definition, and expected performance. This will enable GÉANT to have a clearly defined demarcation and contractual relationship with the C-TFN users.

[1] See definition of cross-border in the Glossary.
[2] See definition of access point in the Glossary.

Functional layer partitioning

Based on a top-down functional decomposition of the design requirements, the design can be segmented into two functions/layers. The solution should be split into a physical transport layer with an overlaid time/frequency (T/F) service layer. This layering principle will allow multiple service types to be independently carried over the transport layer. As new service types are developed, these can be added over the transport layer.

- **T/F transport layer**: the infrastructure needed to carry time/frequency services. This consists of dark fibre, amplifiers, and the operation and maintenance of such. Regenerator Laser Station (RLS) equipment may be included in this layer if it is needed to ensure the cross-border fibre link retains stable frequency services. This layer will be built by GÉANT.
- **T/F service layer**: the equipment needed to create time or frequency signals. This consists of flywheels, frequency combs, RLS equipment, White Rabbit (WR) [White Rabbit] and electronically stabilised fibre-optic time and frequency technology (ELSTAB) equipment, and the operation and maintenance of such. These services will be provided and owned by the NMIs or other organisations operating flywheels and reference clocks.

These two layers are depicted in the figure below.

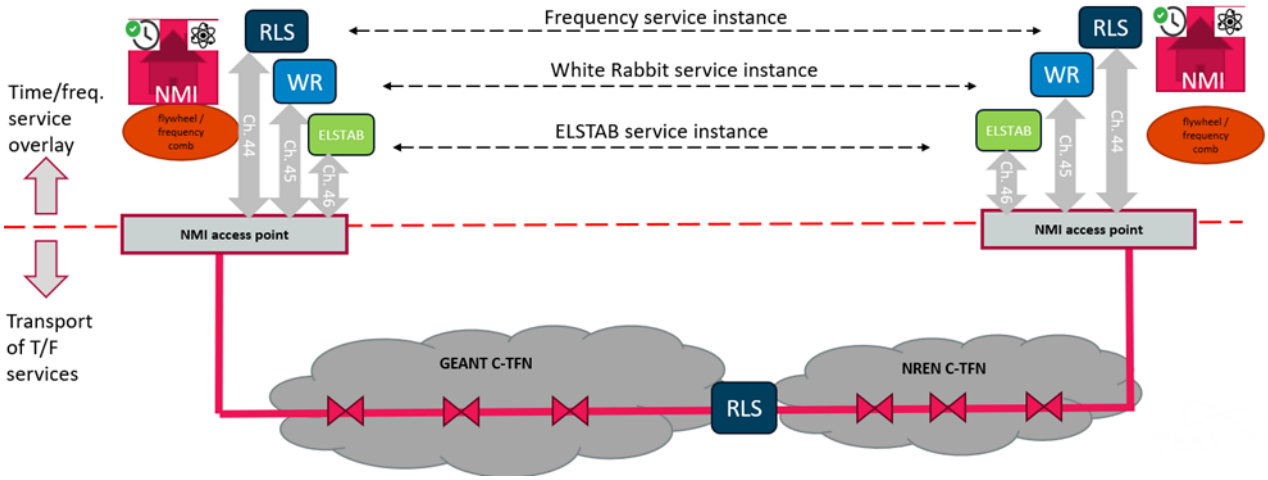

Figure 2.1: Separation of transport and services

Operation and management systems and processes

A single Operations Centre (OC) for the whole C-TFN is proposed. To support this, a set of functions is needed as follows:

- A federated management system to collect time/frequency measurements from each participating flywheel.
- A centralised archiving function for this data.
- Management software for monitoring and managing the bi-directional amplifiers.
- A ticketing system to act as a single point of contact for users.
- An API to allow users to collect data from the centralised archive.

It is expected that the experience gained through building and operating the pathfinder link (see Appendix D) will help give the GÉANT community better expertise in operating a time/frequency network.

2.2 Interconnect Agreement between GÉANT C-TFN and Users

As described in Section 2.1, the C-TFN will consist of two layers: the time/frequency service layer owned and operated by NMIs, and the dark-fibre transport layer owned and operated by GÉANT and NRENs.

It is proposed that there should be an interconnect agreement between NMIs and GÉANT. The details of this agreement are to be developed collaboratively by GÉANT and the NMIs/NRENs.

3 C-TFN Topology Options

A range of topology options for the C-TFN were investigated for the purposes of understanding the costs of building the proposed T/F network. These options are the result of the analysis conducted within the incubator project as well as several months of discussions with NRENs and NMIs on existing infrastructure, requirements and needs. Once funding for T/F is agreed in the GÉANT GN5-2 work plan, these options will be revisited by GÉANT and the NMI community.

Figure 3.1 shows one of the options considered. The final topology will be based on further consultation with the metrology community and the NRENs.

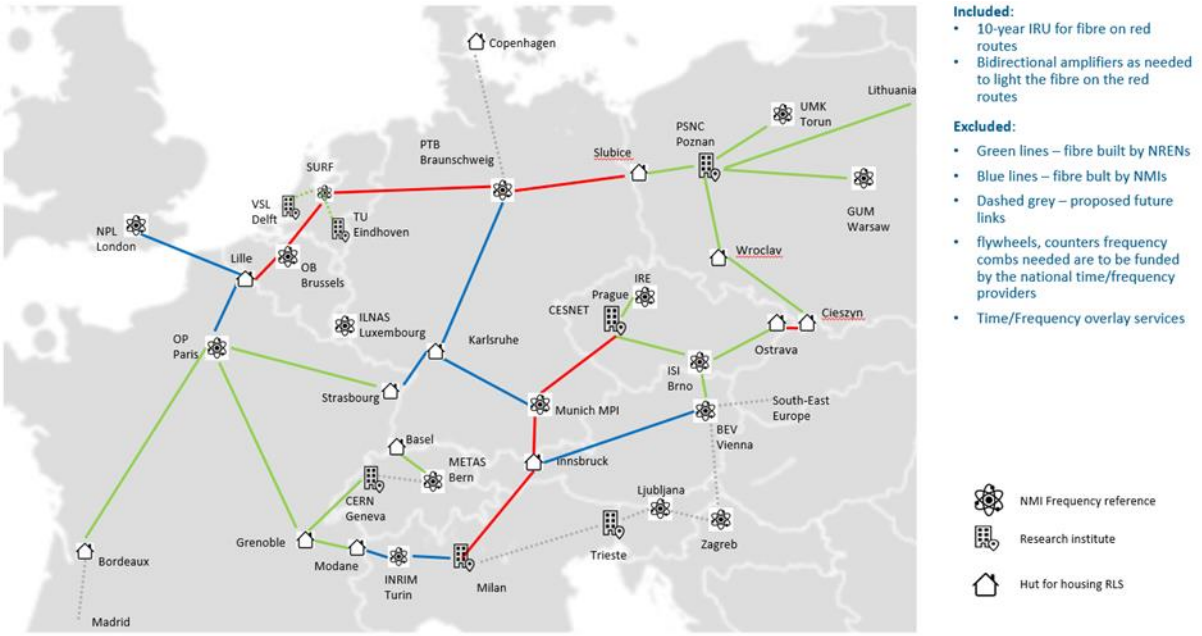

Figure 3.1: Proposed C-TFN Option A

4 Cost Modelling of Fibre for C-TFN Options

Work is ongoing to cost various topology options for the GÉANT C-TFN. The costs will vary depending on the fibre to be procured, the equipment (in particular, amplifiers) needed to be purchased, and the OC manpower required to operate and maintain the network.

In addition, there is the cost of the software management system.

Broadly, two sets of software tools are expected to be needed, as follows:

1. **Transmission hardware management**: the software to monitor and maintain the bi-directional amplifiers, RLS equipment, ELSTAB and White Rabbit hardware.
   a. It is expected that this software will be provided by the hardware manufacturer.
   b. The national networks and GÉANT are expected to pay for and host this software.
   c. In the case of GÉANT's C-TFN budget in GN5-2, this is expected to be provided by the provider of the bi-directional amplifiers as part of their turnkey build offering within the estimated hardware costs.
2. **Federated monitoring system**: the software to monitor time/frequency measurements from the flywheels. It should also show the link state for the whole federated network (both GÉANT C-TFN and each participating NREN's national time/frequency links) and present the results in a web based GUI for the OC and users to view. This system should also archive the time/frequency measurements in a centralised archive.
   a. It is expected that this will be developed by the GÉANT project.
   b. A pilot software solution is being developed by WP6 based on the existing TimeMap solution [TimeMap].
   c. It is recommended that the cost of this software solution be carried by WP6 in the GÉANT project.

5 Time and Frequency Services

The following matrix shows the existing and planned frequency services on the C-TFN. Green services already exist; yellow and red services are planned to be built in the future, yellow services during the GN5-2 funding cycle.

Frequency Services								B-End								
	Amsterdam UvA	Basel	Bern METAS	Braunschweig PTB	Brno ISI	Brussels OB	Delft VSL	Ljubljana	London NPL	Luxembourg ILNAS	Munich MPI	Paris Syrte	Poznan PSNC	Prague CESNET	Prague IRE	S
Amsterdam UvA	ch44 2026															
Basel																
Bern METAS		ch7	ch7 now													
Braunschweig PTB	ch44			ch44 now												
Brno ISI																
Brussels OB						ch44 in 2025										
Delft VSL	ch44					ch44										
Ljubljana								ch44 2026								
London NPL									ch44 now							
Luxembourg ILNAS						ch44										
Munich MPI				ch44 2024												
Paris Syrte						ch44			ch44			ch44 now				
Poznan PSNC				ch44 2024	ch47 to Olomouc								ch44 ?			
Prague CESNET					ch46											
Prague IRE					ch46						ch44 2026			ch46 2024		
Strasbourg				ch44								ch44				N
Torun UMK				ch44 2024									ch44			
Turin INRIM											ch44	ch44				
Vienna BEV					ch44											
Warsaw GUM													ch44			
Zabreb								ch44								

Figure 5.1: Matrix of frequency services on C-TFN

Please note that this matrix is partially populated, and further services will be added over time. A similar matrix of time services should be developed by the community.

It has not yet been agreed how each frequency service should be funded. This will likely be by bilateral agreement between GÉANT and the two NMIs being connected.

6 Future Liabilities and Sustainability

Future Liabilities

The GÉANT C-TFN fibre topology described in Option A (see Figure 3.1 on page 9) will result in a small annual unfunded liability for fibre maintenance payments starting in July 2027. It is recommended that the Indefeasible Right of Use (IRU) contracts should include a clause that limits the duration of these fibre maintenance payments if the C-TFN network is no longer needed and is to be shut down.

Sustainability

As per the costing (see Section 4), Option A has an ongoing operating cost if the T/F links are to be kept running. An agreement needs to be reached between GÉANT, the NRENs and the NMIs on a contingency plan for how these costs will be funded in the case that GÉANT is unable to secure continuity funding in GN5-3.

7 Building, Funding and Procuring the GÉANT C-TFN Links

Many of Europe's optical time/frequency links have already been built by NRENs. These existing links should be integrated into the C-TFN. The resulting solution will be a federated one, with GÉANT owning and operating the cross-border links and the NRENs owning and operating the national links.

While strawman topology options have been considered, including Option A (shown in Figure 3.1 on page 9), details of the final topology of the C-TFN will be further developed based on NMI and NREN community consultation.

It is proposed that the GÉANT C-TFN links be funded and procurements conducted as follows:

Funding the GÉANT C-TFN Links

GÉANT project funding is proposed to be used to build the C-TFN according to the following principles:

- GÉANT will put in place 10-year IRUs with fibre providers to secure the dark fibre needed to build the GÉANT C-TFN.
- GÉANT will prepare a design specification to allow going to tender to build the GÉANT C-TFN. This needs to be ready by mid-2024 in time to launch a procurement by Q3 2024.
- Based on this specification, GÉANT will go to tender for an integrator to install and commission the equipment needed on the dark fibre to create the GÉANT C-TFN infrastructure.
- The integrator will work with equipment providers to provide a turnkey build.
- The 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.

Procurement

Procurement of the dark fibre will be run by GÉANT using the existing fibre Dynamic Purchasing System (DPS) procurement process.

Procurement of the equipment to light the dark fibre should follow the guidelines set out in Appendix A Public Procurement Procedure for Contracting the Build of a Time/Frequency Network.

8 Operation and Maintenance

This section outlines recommendations and principles for the following aspects of operating and maintaining the C-TFN: metrology community forum; adding services and modifying the topology; operation of time equipment; federated model of operation; and T/F and network management.

Metrology Community Forum

During GN5-2, GÉANT should invest in manpower to work with the NMIs and NRENs to facilitate the creation of a metrology community forum for agreeing operation and usage of the federated infrastructure.

This forum, comprising NMIs, NRENs and GÉANT, will aim to make recommendations on how best to invest future funds on behalf of the community, and will have an advisory role on the rules of how the GÉANT C-TFN should be operated.

Adding Services and Modifying the Fibre Topology

- When an NMI or other user requests a new time/frequency service over the C-TFN, this request should be raised with the GÉANT OC who will act as a single point of contact for the request.
- GÉANT should be responsible for allocating new wavelengths for each new service. GÉANT will need to ensure that the wavelengths have suitable guard bands and do not overlap.
- If an NMI requests to be connected to the C-TFN and there is no existing link, this request should be presented at the metrology community forum for consideration.
- GÉANT should have an ultimate veto on what changes are made to the topology of the GÉANT C-TFN, such as adding links to or removing links from the GÉANT C-TFN.

Operation of Time Equipment

- The NMIs operate the time sources, flywheels (when located in an NMI) and any associated equipment such as frequency combs.
- Where a flywheel is needed in a location with no NMI, this should be operated by the local NREN (for example PSNC in Poznan, CESNET in Prague, REFIMEVE in Strasbourg).
- GÉANT and the NRENs build, own and operate the fibre links between NMIs. GN3-2T funding will be used to buy fibre that is owned and operated by GÉANT. Existing fibre links will be owned and operated by NRENs, such as PSNC and REFIMEVE.

Federated Model of Operation

- GÉANT should act as the first-line support for the whole C-TFN. This includes all transport and time/frequency functions, including those operated by NRENs that are deemed to be part of the C-TFN.
- In the case where the first-line support finds the problem to be located in GÉANT fibre, GÉANT will be responsible for contacting the fibre provider or amplifier/RLS provider to fix the problem.
- In the case where the problem is deemed to be in a flywheel or clock source, GÉANT will contact the relevant NMI.

- In the case where the fault is deemed to be in an NREN fibre, GÉANT will contact the OC of the relevant NREN.
- If GÉANT is unable to resolve the issue, it will be escalated to second-line support.
- The expertise for the second-line support will come from the metrology community, either NMIs or the NRENs.

T/F and Network Management

- GÉANT has two paths for developing a time/frequency network management system: either developing it in-house or outsourcing development to an equipment vendor.
- During the procurement process, GÉANT should investigate the cost/benefit of outsourcing the development of a monitoring solution for the time/frequency network compared with a GÉANT in-house-developed solution.
- NRENs and NMIs have existing software solutions (such as REFIMEVE) that already solve this problem, which could be repurposed and further developed.
- WP6 is also updating the TimeMap software [TimeMap] as a trial network management solution. This will be evaluated in the pathfinder project (see Appendix D).
- Each NMI/NREN that deploys a flywheel will be expected to interoperate with the centralised management software solution.
- A centralised archive (possibly cloud based) needs to be financed and operated for the C-TFN. This work could be outsourced to an NREN.
- The following figure shows a possible architecture for the network management system.

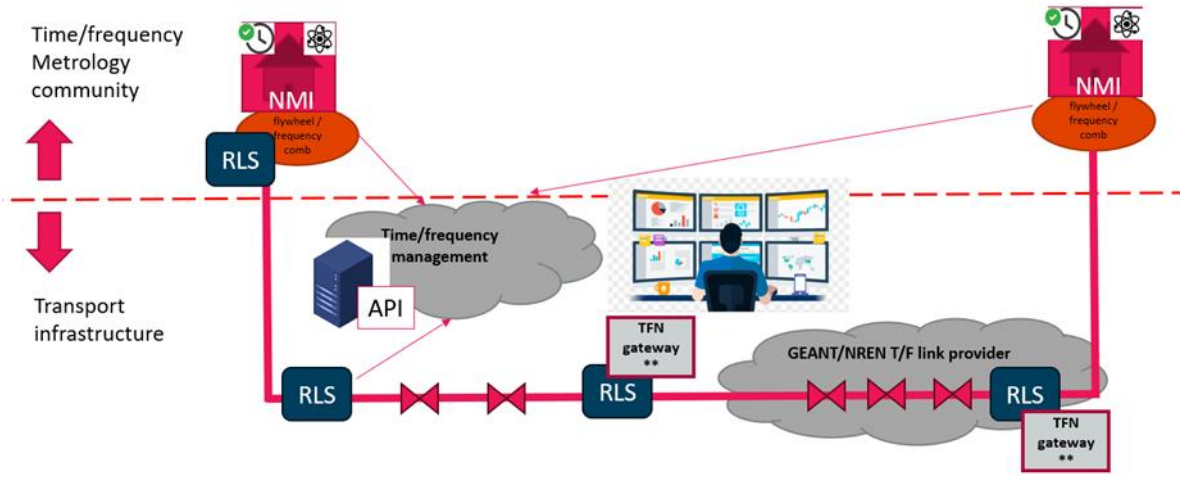

Figure 8.1: Possible architecture of a federated T/F network management system

9 Challenges for 2024 and Beyond

This section discusses the areas that need to be resolved before building the GÉANT C-TFN can commence, namely, defining the T/F services; metrology community forum; governance and contractual commitments; future funding; and developing a network management model.

Defining the C-TFN Time/Frequency Services

GÉANT does not have the expertise in time and frequency to be able to define the services to be built over the fibre. It is proposed that a forum of NMIs and NRENs be created to define and agree these services.

Metrology Community Forum

The question of how to create and sustain a metrology community forum, and the role of this forum, need further work.

It is recommended that the forum should include representatives from NRENs and NMIs that participate in the C-TFN network. It should be open to including members that are interested in joining the forum regardless of whether they currently participate in providing or using any of the services.

There are three possible ways in which such a forum can be organised:

1. **Special Interest Groups (SIGs)**. One option is to follow the model of Special Interest Groups (SIGs) well known in the GÉANT community, where participation would be open to any interested party; participation and contribution would be self-funded; and the modus operandi would include, but does not need to be limited to, organising onsite or online events for information sharing.
2. **Task Forces**. This option is similar to SIGs: participation would be self-funded and open to anyone interested, and events would be organised to share information. However, Task Forces would define a set of tasks with specific goals and deadlines by when predefined results would need to be completed.
3. **C-TFN Port Managers (PMs)**. This option is similar to the existing model of NREN access port managers, which serve as an NREN main point of contact for topics related to connecting NRENs to the GÉANT network. This group would include individuals appointed by their organisation with the purpose of working on topics needed for the operation and maintenance of the established C-TFN. This group will be closed, and might include more operational time- and objective-bound tasks. Participation might be self-funded by the organisations, or some model for funding as a part of the GÉANT project or of a potential C-TFN fee might be considered.

The final model for the forum needs to be discussed and decided.

Governance and Contractual Commitments

The following questions around C-TFN governance and contractual commitments are unresolved:

- GÉANT will use Horizon Europe funds to build the cross-border fibre links in the C-FTN network. While the cross-border fibre and associated amplifier equipment will be owned by GÉANT, the question of whether there is scope for GÉANT to purchase RLS equipment and hand this over to an NMI to operate and maintain should also be considered.

- What contract should be put in place between the NMIs to interconnect with GÉANT? Should any fees be payable for this interconnect, and if so how much?
- What SLA commitments should be made between interconnecting parties?
- How do existing time/frequency links interwork with the new GÉANT time/frequency links?
- What should the acceptable usage policy be?
- Who can access the time and frequency data produced by the C-TFN?
- Should there be a fee to access this data?
- How are decisions made on changes to the C-TFN? For example, if a new NMI wishes to join, how would the cost of this interconnection be funded? Who needs to agree to this?

Future Funding

GÉANT, the NRENs and the NMIs need to find a way to fund the GÉANT C-TFN after 2027.

Developing a Network Management Model

The GÉANT community should learn from the experience of the pathfinder link and the trial TimeMap software to develop a model for managing the entire C-TFN in a federated way. It is expected that there will be challenges of manpower and timescales to get a minimum viable product ready.

10 Recommendations for GN5-1 and GN5-2

Given the strong support among NMIs and NRENs for the GÉANT C-TFN proposal, the following recommendations are made for the remainder of GN5-1 and for GN5-2:

Item	Recommendations
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 a community forum for T/F services (metrology community forum)
GN5-2	
1	In GN5-2, GÉANT should fund the sum of €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 C-TFN should be further refined based on community agreement and should be built in line with the ambitions of Option A shown in this report (see Figure 3.1 on page 9)
5	The fibre IRUs are recommended to be 10 years duration, with a low annual charge to ensure a small ongoing liability in case 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, operation and further development of the C-TFN as a technical support to the GÉANT Operations team in WP7

Table 10.1: List of recommendations for GN5-1 and GN5-2

11 Conclusions

The GÉANT time/frequency incubator ran for eight months from May 2023 to January 2024. The incubator built on the results of the CLONETS-DS reports to find a solution to building the C-TFN using GÉANT GN5-2 funding.

This report has provided a set of recommendation on how to fund the GÉANT C-TFN network and identified the follow-on actions needed to achieve the desired network operations and ensure a suitable level of performance.

Appendix A Public Procurement Procedure for Contracting the Build of a Time/Frequency Network

The general procedure for procurement using Competitive Dialogue to build a time/frequency network is proposed as follows:

Prior Information Notice (PIN)

At the initial stage, a Prior Information Notice (PIN) is issued on Tenders Electronic Daily (TED). The purpose of the PIN is to inform the market of the upcoming procurement.

The PIN will include a document containing:

- Description of the scope of the project.
- A high-level system description, including a list of equipment needed.
- A reference topology.
- A procurement timetable.

Note that the main equipment providers of amplifiers/RLS/time equipment are believed to be Exail and PikTime Systems. They should be encouraged to register on TED.

Publication of a Contract Notice

This step initiates the procurement. GÉANT will announce its intention to award a contract to build the European Core Time/Frequency Network (C-TFN). The contract notice contains key information about the procurement and will be published in the Official Journal of the European Union (OJEU).

Pre-Qualification Stage

Interested companies submit a response to a Pre-Qualification Questionnaire (PQQ). This questionnaire is only used to assess the suitability of the applicants based on their economic and financial standing, technical and professional ability. It will not consider any technical issues.

Invitation to Participate in Dialogue

GÉANT will then shortlist the suitable candidates and invite them to participate in the dialogue phase. GÉANT will issue a description of the problem it is trying to solve, to give the candidates a chance to propose a solution. During this phase, any aspect of the contract can be discussed.

Competitive Dialogue Phase

In this phase, GÉANT will enter into a dialogue with the selected candidates to discuss all aspects of the contract. This stage is important as it allows GÉANT to explain to the candidates the technical scope of the time/frequency network. As the equipment and build are not off-the-shelf components, the bidders will need to gain an understanding of the engineering requirements.

This stage allows GÉANT to refine the requirements based on feedback from the candidates. The dialogue continues until GÉANT identifies the solution or solutions capable of meeting its needs.

Final Tender Stage

Once the dialogue phase is over, GÉANT informs the participants of the conclusion of this phase and issues an Invitation to Submit Final Bids (ITSFB) based on the solution or solutions presented and discussed during the dialogue phase. The ITSFB will include a guideline on how tenders will be scored.

Evaluation and Award

GÉANT will evaluate the final tenders received, and award the contract based on the previously disclosed evaluation criteria.

Standstill Period

After the contract award decision is announced, there is a mandatory standstill period of 15 days before the contract can be formally entered into. This allows unsuccessful bidders to challenge the decision if they believe the procurement process was conducted unfairly.

Appendix B Rules to be Met by the C-TFN as a Public Infrastructure Collaboration

It is proposed that Horizon Europe funding will be used to build the GÉANT C-TFN; in GN5-2, non-recurring costs will likely be 100% funded.

As a public infrastructure collaboration between GÉANT, NRENs and NMIs, further work is needed to agree the most appropriate business model for the C-TFN to ensure that state aid rules are met, including considerations of public goods and natural monopolies.

State Aid

Article 107 of the Treaty on the Functioning of the European Union (TFEU) addresses the issue of state aid, aiming to prevent distortions of competition within the European Single Market. State aid refers to any advantage granted by a Member State to undertakings or the production of goods that may distort competition and affect trade between EU Member States through the use of public funds. The primary objective is to ensure a level playing field among businesses across the EU.

Public Goods

Time/frequency has some characteristics of a public good: it is non-rivalrous and non-excludable. Non-rivalrous means that one person's use of time/frequency does not diminish its availability to others. Non-excludable means that it is difficult to prevent someone from using the infrastructure once it is provided. Due to these characteristics, private firms may be unwilling to invest in public goods, as they cannot easily prevent free-riders from using the infrastructure without paying. Therefore, governments typically step in to provide public goods such as roads and railways, funded through taxation.

Natural Monopolies

A public time/frequency network also exhibits some characteristics of a natural monopoly. A natural monopoly occurs when the fixed costs of providing a service are very high, while the marginal cost of serving additional users is relatively low. In the case of roads and railways, building and maintaining the infrastructure involves significant fixed costs, but once in place, the cost of adding more users is minimal. It is often inefficient to have multiple competing providers in such markets, as this would lead to duplicated infrastructure and higher overall costs. As a result, governments often either provide the infrastructure directly or regulate it to ensure fair access to all users.

Appendix C GÉANT C-TFN Funding Model

This appendix describes the preferred funding model for the GÉANT C-TFN.

GN5-2 Funding Period

- GN5-2 is the Horizon Europe funding cycle for the GÉANT project.
- The funding cycle starts January 2025.

GN5-2T Funding Model

It is proposed that in the GN5-2 funding cycle a funding vehicle, provisionally called 'GN5-2T', be created as follows:

- Name: GN5-2T.
- Duration: starting January 2025 for the duration of 2.5 years.
- Target budget: €7.5 million.
- Finance model: 100% funded model. The funds will be paid to GÉANT and GÉANT will make staged payments to the integrator on completion of link builds.
- This money can be used for both up-front infrastructure investment and for ongoing maintenance.
- However, the maintenance costs can only be paid for the duration of the GN5-2 funding cycle.
- Any future maintenance liabilities should be documented and understood. For example, if a 10-year IRU for dark fibre is put in place, then there will be an ongoing maintenance charge beyond the GN5-2 timeframe.
- It is expected that further funding will be allocated in GN5-3 and beyond for the continued maintenance of the GÉANT C-TFN. However, a fallback is needed in case funding is not available from GÉANT.
- If NMIs wish to claim funds from the GN5-2T then they will need to be a contractor to either the integrator or their local NREN.

Work carried out in the CLONETS-DS project identified a longer-term mechanism to fund the time/frequency network. A discussion on how to support the sustainability of a C-TFN can be found in these two documents: *Deliverable 3.1 Governance and Sustainability* [CLONETS-DS D3.1]and *Deliverable 4.2 Roadmap Towards an ESFRI Listing: Impact and Dissemination* [CLONETS-DS D4.2].

Appendix D T/F Pathfinder

In 2024 the first proof-of-concept link of the GÉANT C-TFN will be built. The target completion date is 2025. The pathfinder will use GÉANT fibre from PTB to the Polish border; the dark-fibre lease will be paid for from GN5-1 funds. PSNC will provide access to their existing fibre from the border to Poznan. PSNC will also provide the hardware for the link – amplifiers and RLS equipment – at their own cost.

The purpose is to prove the technical concept described in CLONETS-DS and show how a federated cross-border link can be built, operated, and maintained.

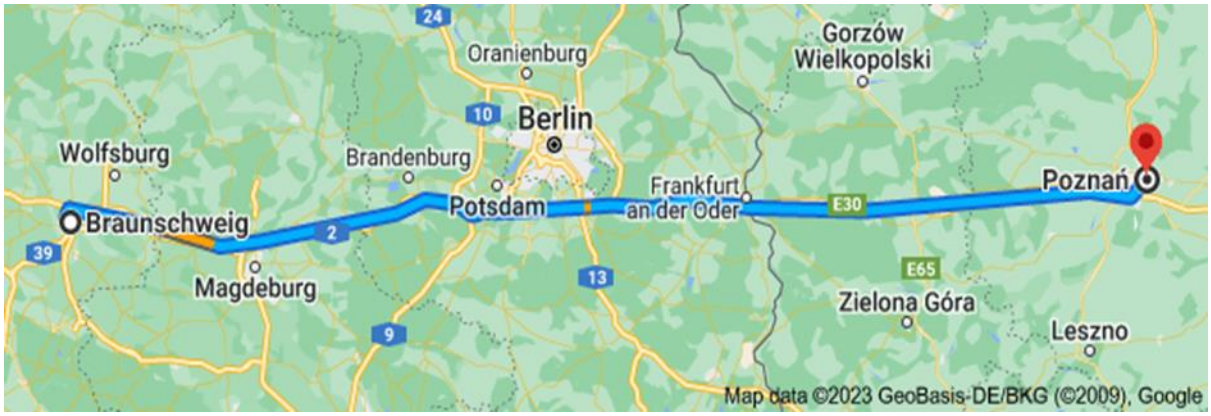

Figure D.1: Map of the T/F pathfinder route

Figure D.2: PikTime Systems bi-directional amplifier

Figure D.3: PikTime Systems Regenerator Laser Station

Figure D.4: PikTime Systems ELSTAB equipment

Appendix E T/F Detailed Use Cases

This appendix provides details of use cases identified by the following: CLONETS-DS project, NPL, Justervesenet and NRENs.

CLONETS-DS

The CLONETS-DS project analysed requirements for accurate time in the following areas:

- Fundamental science.
- Quantum technology.
- Optical clocks and SI units.
- Geodesy (geometry, gravity, and spatial orientation of the Earth).
- Astronomy.
- Navigation and GNSS.
- Next-generation telecom networks.
- Dissemination of reference frequencies to the general scientific community.

Please see *Deliverable 1.1 Stakeholder Workshop* [CLONETS-DS_D1.1] and *Deliverable 1.2 Requirements and Definitions* [CLONETS-DS_D1.2] for the complete documentation.

NPL

NPL indicated that a UK project called the National Timing Centre (NTC) programme has just started with the aim of setting up the Resilient Enhanced Time Scale Infrastructure (RETSI) based on fibre across a limited number of locations in the UK [NTC]. NPL have indicated three use-case areas for the planned network:

- Metrology:
  - Verification of optical clock performance for redefinition of the SI second.
  - Comparing Coordinated Universal Time(k) signals via optical links between NMIs to improve stability of International Atomic Time, and allowing comparisons of optically steered time scales using electronically stabilised fibre-optic time and frequency technology (ELSTAB) initially, White Rabbit may also be useful longer term.
  - Using optical links as an independent test of GPS / Two-Way Satellite Time and Frequency Transfer (TWSTFT) link performance.
  - Testbed for trialling improvements in European optical clocks.
- Geodesy using optical clock comparisons:
  - Verification of national height reference systems.
  - Monitoring temporal variations in gravity potentials.
- Academic research:
  - Precision spectroscopy with traceability to primary standards.
  - Tests of fundamental physics via optical clock comparisons.
  - Fibre-optic acoustic sensing (FOAS) and large-area fibre-optic gyroscopes.

Justervesenet

The Norwegian NMI, Justervesenet, has a list of high-level needs for a reference high-precision clock network and positioning services:

- Public safety: emergency radio networks. Detecting and mitigating timing and positioning failures/attacks in telecommunications/satellite-based services. Detecting and investigating events.
- Financial systems: stability (correct time stamping of transactions).
- Power grid (both robustness and high precision).
- Military operations: sovereignty.
- Protection of nature and environment due to correct navigation.
- Transport: air, sea, road and railway.
- Weather forecast: very dependent of earth observation and navigation satellites. A terrestrial network will detect and possibly help to mitigate jamming, attacks and failures.
- Oil and gas: dynamic positioning.
- Electronic/optical communication: time synchronisation, base station positioning, etc.

NRENs

SURF, with the help of VSL, is providing a pilot timing service based on White Rabbit technology to end users.

- Astronomy: Low-Frequency Array (LOFAR) radio telescope project.
- Navigation: experimental high-accuracy GPS with TUDelft and VU Amsterdam.

For more information, see the SURFtime&frequency Pilot Service presentation [SURFT&F].

Sikt, like NPL, has confirmed that providing an alternative to GPS is now on the Norwegian political agenda and that Sikt might be selected to build a national timing network. Their feedback also includes the following:

- National 5G operations are looking for a better solution to calibrate 5G base stations. At the moment they use a mobile caesium clock.
- Astronomy: EISCAT and the Norwegian radio telescope project digital twins.
- SINTEF mentioned a use case where real-time digital twins in its new Ocean Space Centre will require high-precision timing between the physical observation location and the HPC resource facility. SINTEF also operates a drone lab. It has mentioned the importance of robust and high-precision timing, beyond GPS.
- Fibre-optical sensing: synchronising multiple DAS units. Bi-directional sensing with SOP and phase requires high-precision timing synchronisation between the end points in order to geolocate origins of perturbations.
- Each Norwegian university and physics lab should in principle have a high-precision timing source for instrument calibration and research. A frequency reference is also very useful for calibrating spectroscopic instruments.

CESNET submitted a project including country-wide deployment of White Rabbit technology into all major nodes in order of provide time and radio frequency references.

Appendix F NMI Letters of Support and Consultation

Letters of support have been provided by the following institutions:

- FAMO Consortium, including Nicolaus Copernicus University (Toruń, Poland).
- GUM, Poland.
- Belnet, Belgium.
- ROB, Belgium.
- IPE/UFE, Czechia.
- PTB, Germany.
- INRIM, Italy.

Copies of these letters can be found here: [LoS].

Table F.1 summarises the outreach meetings that have taken place between GÉANT and the NMIs.

NMI Organisation	Optical clock today?	Country	Meeting dates (2023)
PTB	yes	Germany	regular attendance at weekly calls
NPL	yes	UK	21 June / 25 October / 16 November
Observatoire de Paris	yes	France	22 June
INRIM	yes	Italy	11 September
VSL	no	Netherlands	10 August / 25 September / 3 November / 16 November
METAS	no	Switzerland	4 September with Switch only
GUM	no	Poland	5 October
CERN	no	Switzerland	13 July
UFE	no	Czechia	
ISI	no	Czechia	regular attendance at weekly calls

NMI Organisation	Optical clock today?	Country	Meeting dates (2023)
The Royal Observatory of Belgium (ROB)	no	Belgium	27 September / 7 November
Vrije Universiteit Amsterdam	no	Netherlands	10 August / 25 September
ESA	no	Netherlands	28 September
Exail	no	France	17 November
Nomios	no	Netherlands	15 November
Real Instituto y Observatorio de la Armada (ROA)	no	Spain	5 December
Institute of Physics (IFZg) National Laboratory for T/F	no	Croatia	5 December

Table F.1: Outreach meetings between GÉANT and the NMIs

References

[CGPM]	https://en.wikipedia.org/wiki/General_Conference_on_Weights_and_Measures
[CGPM27_Res5]	https://www.bipm.org/en/cgpm-2022/resolution-5
[CLONETS-DS_D1.1]	https://clonets-ds.eu/wp-content/uploads/2022/07/Deliverable-1.1-Stakeholder-Workshop.pdf
[CLONETS-DS_D1.2]	https://clonets-ds.eu/wp-content/uploads/2022/07/Deliverable-1.2-Requirements-and-Definitions.pdf
[CLONETS-DS_D3.1]	https://clonets-ds.eu/wp-content/uploads/2023/07/Deliverable-3.1-Governance-and-Sustainability.pdf
[CLONETS-DS_D4.2]	https://clonets-ds.eu/wp-content/uploads/2023/05/D4.2_Roadmap-Towards-an-ESFRI-Listing.pdf
[CLONETS-DS_Reports]	https://clonets-ds.eu/?page_id=98
[LoS]	https://wiki.GÉANT.org/display/gn43wp6/Supporting+documentation [restricted access]
[Measure_Sci]	https://en.wikipedia.org/wiki/Metrology
[Measure_Stds]	https://en.wikipedia.org/wiki/Standard_(metrology)
[Metre_Conv]	https://en.wikipedia.org/wiki/Metre_Convention
[NTC]	https://www.npl.co.uk/ntc/resilient-time-for-the-future
[SURFT&F]	https://wiki.geant.org/download/attachments/592773341/SURFtime%26frequency%20Pilot%20Service%20External%20Presentation%20GEANT%20STF%20by%20Sander%20Klemann.pptx?api=v2
[TimeMap]	https://network.geant.org/timemap/
[White_Rabbit]	https://white-rabbit.web.cern.ch/

Glossary

Access point	Access points are locations where NMIs, or other users, interconnect to the GÉANT C-TFN
API	Application Programming Interface
C-TFN	Core Time/Frequency Network. The whole federated European time/frequency network made up of links from GÉANT and the NRENs and flywheels from the NMIs and other research institutions.
CERN	European Organisation for Nuclear Research
CGPM	The General Conference on Weights and Measures / Conférence générale des poids et mesures (CGPM) is the intergovernmental organisation established in 1875 under the terms of the Metre Convention [Metre_Conv] through which member states act together on matters related to measurement science [Measure_Sci] and measurement standards [Measure_Stds].
CLONETS-DS	CLOckNETworkS Design Study project. Horizon Europe-funded project to build a use case and design for a time/frequency network in Europe. Reports produced by the CLONETS-DS project are available at [CLONETS-DS_Reports].
CNRS	Centre National de la Recherche Scientifique
Cross-border	When a time/frequency link spans multiple countries it is referred to as 'cross-border'. The fibre is described as 'cross-border fibre'.
Cs	Caesium
DAS	Distributed Acoustic Sensing
DPS	Dynamic Purchasing System
EISCAT	EISCAT is an international scientific association with member institutes in several countries. It conducts ionospheric and atmospheric measurements with radars.
ELSTAB	Electronically Stabilised Fibre-Optic Time and Frequency Technology
ESA	European Space Agency
FAMO	Consortium of Atomic, Molecular and Optical Physics
FOAS	Fibre-Optic Acoustic Sensing
GÉANT C-TFN	The GÉANT-built and -owned parts of the C-TFN
GÉANT	The European research and education Internet backbone provider
GÉANT	The European Research and Education Network
GN5-1	GÉANT Network 5, Phase 1, a project funded by the European Union's Horizon Europe research and innovation programme under Grant Agreement No. 101100680 and one of the projects implementing the actions defined in the GN5-FPA
GN5-2	GÉANT Network 5, Phase 2, a project for which a proposal is being developed at the time of writing, to be funded by the European Union's Horizon Europe research and innovation programme and one of the projects implementing the actions defined in the GN5-FPA
GNSS	Global Navigation Satellite System refers to a constellation of satellites providing signals from space that transmit positioning and timing data to GNSS receivers
GPS	Global Position System, satellite positioning network, this is one of the GNSS systems
GUI	Graphical User Interface
GUM	Główny Urząd Miar / Central Office of Measurements, the Polish National Metrology Institute
HPC	High-Performance Computing
IFZg	Institute of Physics
INRIM	The Italian national time/frequency network
IPE/UFE	Institute of Photonics and Electronics / Czech Academy of Sciences

IRU	Indefeasible Right of Use
ISI CAS	Institute of Scientific Instruments of the Czech Academy of Sciences
ITSFB	Invitation to Submit Final Bids
LOFAR	Low-Frequency Array
METAS	Federal Institute of Metrology, the Swiss National Metrology Institute
Metrology community forum	A forum of NMIs, NRENs and GÉANT yet to be created. This forum will be responsible for making recommendations on how best to invest future funds on behalf of the community. It will also have an advisory role on the rules of how the GÉANT C-TFN should be operated.
NMI	National Metrology Institute. See Appendix F for a partial list of European NMIs.
NPL	National Physical Laboratory, the UK's National Metrology Institute
NREN	National Research and Education Network
NTC	National Timing Centre
OC	Operations Centre
OJEU	Official Journal of the European Union
PIN	Prior Information Notice
PLM	Product Lifecycle Management
PM	Port Manager
PQQ	Pre-Qualification Questionnaire
PTB	Physikalisch-Technische Bundesanstalt, the National Metrology Institute of Germany
REFIMEVE	The French national time/frequency network
RETSI	Resilient Enhanced Time Scale Infrastructure
RLS	Regenerator Laser Station
ROA	Real Instituto y Observatorio de la Armada / Royal Institute and Observatory of the Navy
ROB	Royal Observatory of Belgium
SI	International System of Units
SIG	Special Interest Group
SINTEF	Stiftelsen for industriell og teknisk forskning / Foundation for Industrial and Technical Research
SLA	Service Level Agreement
SOP	State of Polarisation
SYRTE	Systèmes de Référence Temps-Espace, l'Observatoire de Paris, l'Université Paris Sciences & Lettres (PSL)
T/F	Time/Frequency
TAI	International Atomic Time
TED	Tenders Electronic Daily
TFEU	Treaty on the Functioning of the European Union
TuDelft	Delft University of Technology
TWSTFT	Two-Way Satellite Time and Frequency Transfer
UTC	Coordinated Universal Time or UTC is the primary time standard by which the world regulates clocks and time
VSL	National Metrology Institute of the Netherlands
VU	Vrije Universiteit Amsterdam
WR	White Rabbit (WR) is a fully deterministic Ethernet-based network for reliable data transfer and sub-nanosecond accuracy of synchronisation for large distributed systems
WP	Work Package
WP6	Work Package 6 Network Development
WP7	Work Package 7 Network Core Infrastructure and Core Service Evolution and Operations