GÉANT Core -Time Frequency Network (GÉANT C-TFN)

Net Dev Incubator Report (Public)

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Executive Summary

WP6 has run an 8 month Net Dev Incubator project known as the time/frequency incubator, this involved extensive outreach to European NMIs and weekly calls to develop a way forward. This incubator completed in January 2024 and the results of the team's investigations are summarized in this document.

We found universal support among the NMIs we surveyed for funding the C-TFN, further, many have provided strong letters of support, please see Appendix 6 for further details.

This report sets out a number of recommendations about how GÉANT can use funds available in GN5-2 to build an 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. Success of this work will be measured using the existing GÉANT new-product gating process.

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

Glossary of terms

The following table provides a glossary of terms used in this document.

Table 1: glossary of terms

Term	Definition
CLONETS	CLOckNETworkS project. Horizon Europe funded project to build a use case and design for a time/frequency network in Europe. Reports of the CLONETS-DS are available here: https://clonets-ds.eu/?page_id=98
CLONETS C-TFN	CLONETS Core-Time/Frequency network. Note: the CLONETS C-TFN is made up of a federation of national time/frequency networks interconnected by international links built and operated by GÉANT.
GÉANT C-TFN	The GÉANT time/frequency network built as a back-bone to interconnect the European national time/frequency networks.
REFIMEVE	The French national time/frequency network
GÉANT	The European Research and Education Network
NREN	National Research and Education Network
NMI	National Metrology Institute. See appendix 6 for a partial list of European NMIs
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'.
Access point	Access points are locations where NMIs, or other customers interconnect to the GÉANT C-TFN
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.
GPS	Global Position System, satellite positioning network, this is one of the GNSS systems
GNSS	Global Navigation Satellite System (GNSS) refers to a constellation of satellites providing signals from space that transmit positioning and timing data to GNSS receivers.
RLS	Regenerator Laser Station
EISCAT	EISCAT is an international scientific association with member institutes in several countries. We conduct ionospheric and atmospheric measurements with radars.

UTC	Coordinated Universal Time or UTC is the primary time standard by which the world regulates clocks and time.
GÉANT	The European research and education Internet backbone provider.
SLA	Service Level Agreement

Introduction and Background

Background: primary frequency standards

Since 1968 the Second has been defined by the Cs hyperfine transition at 9.2 GHz and realized by Caesium atomic clocks. In recent years, optical clocks have proven to be a more precise technology for the realization of the SI-Second. An example technique for optical clocks is to stabilize 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 below shows the uncertainty of clocks over the past seventy years.

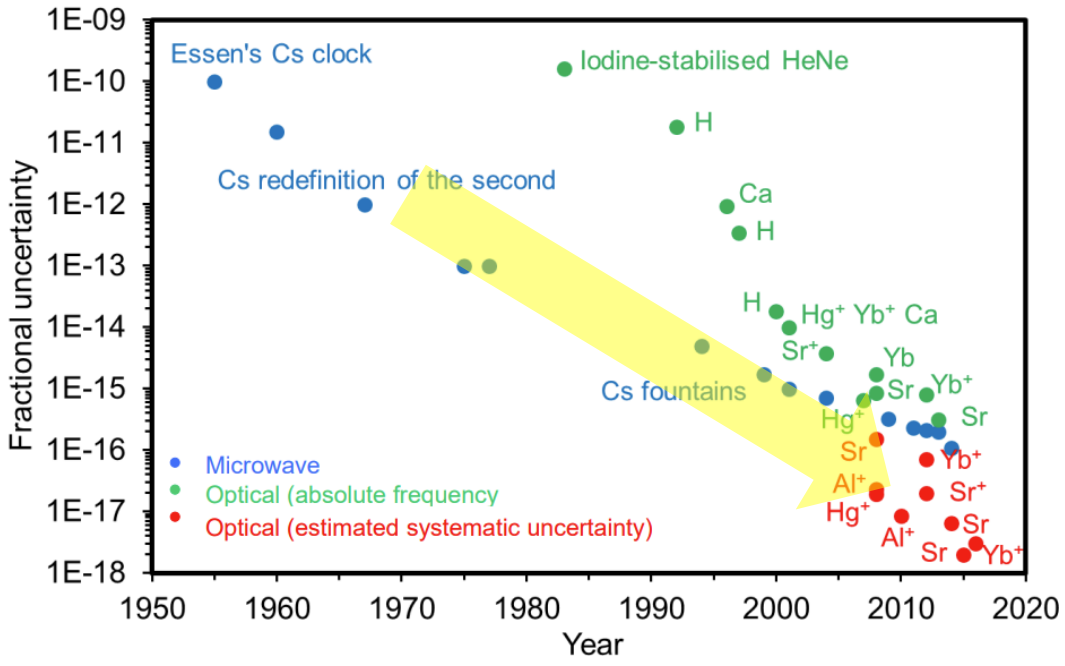

Figure 1: improvements in clock uncertainty over the last 70 years

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. Considering this, in November 2022, the 27th CGPM[1] approved Resolution Five [2] towards the redefinition of the second, 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

[1] The General Conference on Weights and Measures, CGPM, is the intergovernmental organization established in 1875 under the terms of the Metre Convention through which member states act together on matters related to measurement science and measurement standards. @ https://en.wikipedia.org

[2] Resolution 5 of the 27th CGPM (2022) "On the future redefinition of the second" https://www.bipm.org/en/cgpm-2022/resolution-5

of today, only comparisons mediated by optical fibre links provide the required instability and accuracy.

Background: CLONETS-DS and transmitting time and frequency

Given that Europe will need optical fibre to meeting the stability objectives to set the soon-to-be re-defined SI second, it is important to begin work on this infrastructure in the next years. Some National 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 European-wide infrastructure, partly because of the lack of investment in some countries, but most importantly because there lacks a centralized European organization to interconnect the existing national time/frequency networks.

Following on from the CLONETS-DS recommendations for unified European, GÉANT has engaged with many of the European NMIs to understand their views on the proposed C-TFN.

Objectives

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

- Complement GNSS with more reliable and accurate fibre cable frequency distribution between national NMIs for measuring global 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 national NMIs (and other metrology organizations) to either enhance existing services or create new commercial services such as very accurate time stamps for banks to validate high-frequency trading.

Users of the CLONETS C-TFN

CLONETS-DS identified a wide range of users, these have been reviewed and corroborated by the incubator study and the uses include the following organizations:

- National Metrology Institutes, NMI, as user/providers of national time/frequency services
- NRENs:
    - as user of time/frequency signal in their own networks.
    - national providers of time/frequency services to public institutes. E.G. 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.

CLONETS C-TFN use-cases

The CLONETS-DS developed a strong set of use cases for time-frequency infrastructure. The use cases include commercial, scientific and network operator users. In addition, the incubator task 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 5 for more detailed use cases.

Roadmap

Considering the requirements of the metrology community and the recommendations of the CLONETS-DS report, GÉANT proposes the following roadmap to build a CLONETS C-TFN network, in which the C-TFN network interconnects existing national time frequency networks. The dates shown here are indicative only and are subject to funding and manpower resources.

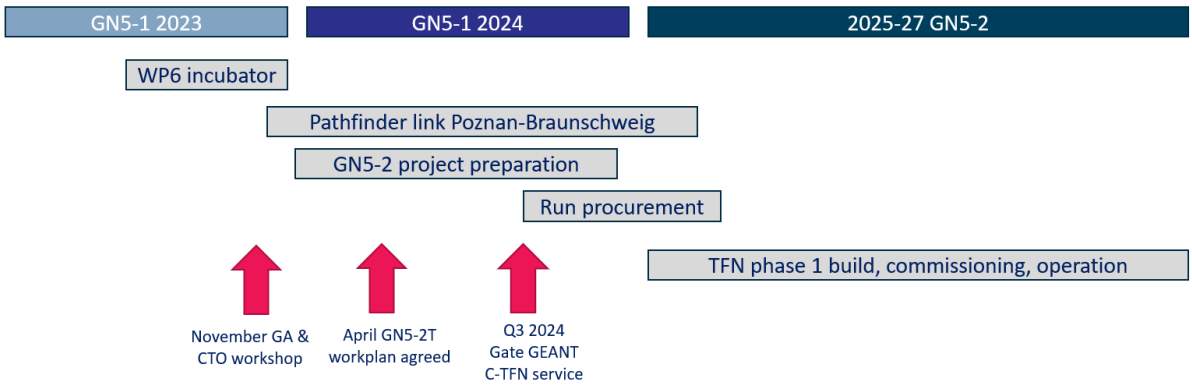

Figure 2: Roadmap for building GÉANT C-TFN

CLONETS C-TFN Architecture

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

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 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**[3]**.** 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 organizations and commercial providers should all be able to connect to the CLONETS 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 service at commercial rates 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 2.

[3] See definition of cross-border in the glossary.

Interconnection and access

- The CLONETS C-TFN infrastructure should be primarily about interconnecting the NMIs into a mesh/ring architecture as proposed in the CLONETS-DS
- Where practical, GÉANT will include **access points**[4] 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 between with our users.

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 overlayed time/frequency 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.

- The T/F transport layer: the infrastructure needed to carry time/frequency services. This consists of dark fibre, amplifiers, and operation and maintenance of such. 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: This consists of the equipment needed to create time or frequency signals. This consists of flywheels, frequency combs, RLS equipment, WhiteRabbit and ELSTAB equipment, and operations and maintenance of such. These services will be provided and owned by the NMIs or other organization operating flywheels and reference clocks.

These two layers are depicted in the figure below.

[4] See definition of access point in the glossary.

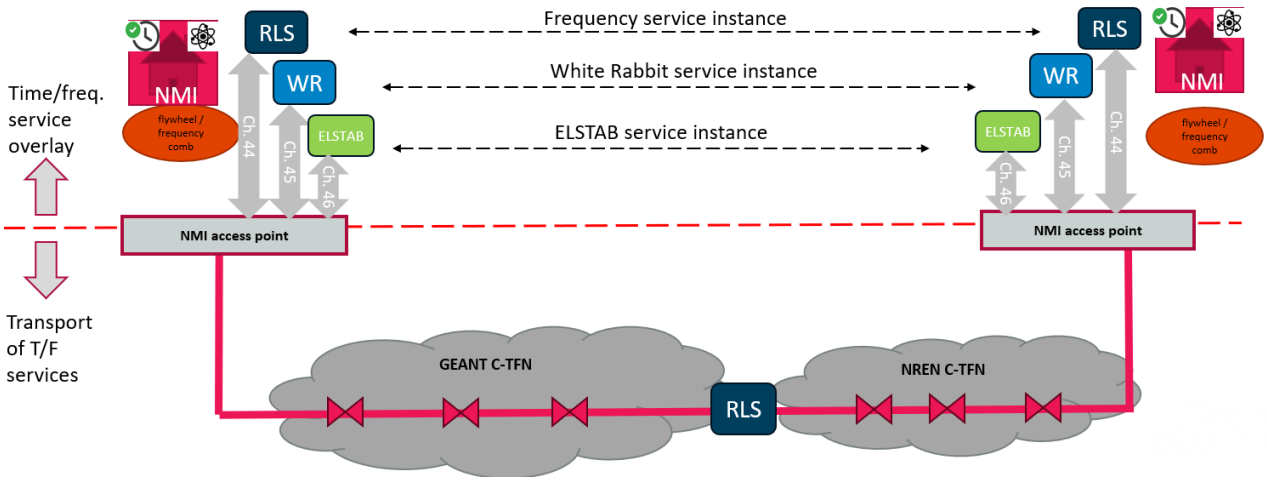

Figure 3: separation of transport and services

Operation and Management systems and processes

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

- A federated management system to collect time/frequency measurements from each participating flywheel
- A centralized 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 customers
- An API to allow users to collect data from the centralized archive.

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

Interconnect agreement between GÉANT C-TFN and users

As previously described, the CLONETS 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 in collaboration between GÉANT and the NMIs/NRENs.

CLONETS C-TFN Topology options

A range of topology options for the GÉANT C-TFN options were investigated for the purposes of understanding the costs of building the proposed T/F network. These options are 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 workplan, these options will be revisited by GÉANT and the NMI community.

The following diagram shows one of the options considered, the final topology to be build will be based on further consultation with the metrology community and the NRENs.

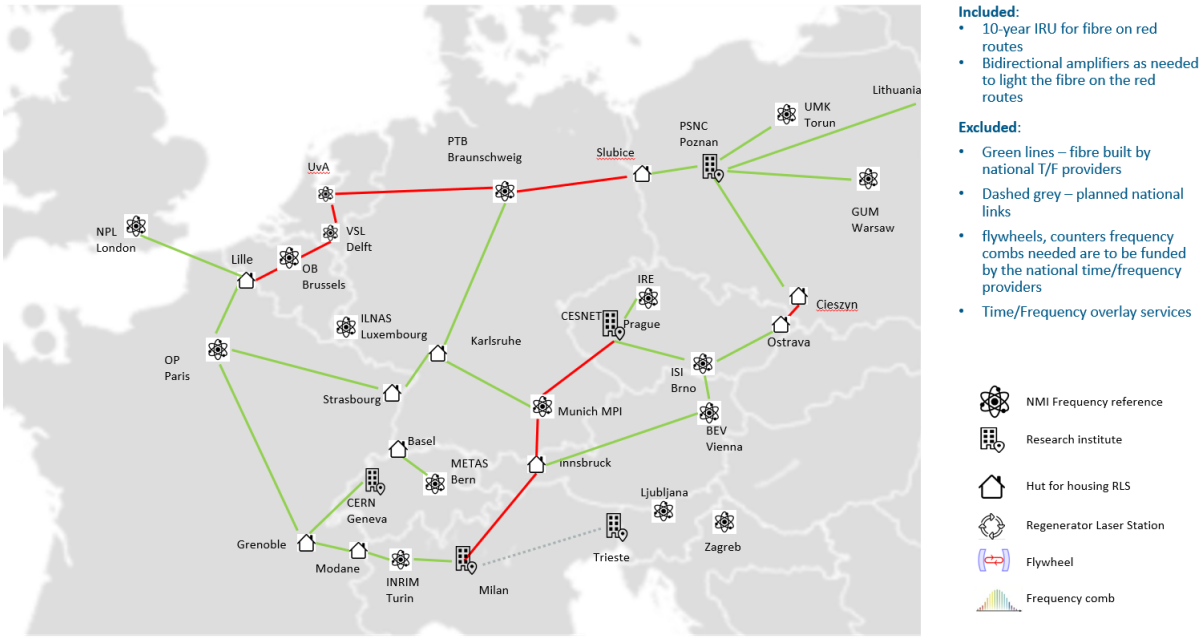

Figure 4: proposed C-TFN option A

Cost modelling of fibre for C-TFN options

Cost of fibre and amplifiers and OC manpower

Work is ongoing to cost various topology options for the GEANT C-TFN. The costs will vary depending on the fibre to be procured and the equipment needed to be purchased.

Cost of software

The costing above for the fibre and amplifiers does not include the cost of software management system. This cos is discussed here.

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

1. **Transmission hardware management**. This is the software to monitor and maintain the Bidirectional amplifiers, RLS equipment, ELSTAB and WhiteRabbit hardware.
    a. It is expected that this software is 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 bidirectional amplifiers as part of their turn-key build offering within the estimated hardware costs.
2. **Federated monitoring system**. This is the software to monitor time/frequency measurements from the flywheels. It should also show the link sate 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 centralized archive.

a. It is expected that this will be developed by GÉANT project.
b. A pilot software solution is being developed by WP6 based the existing TimeMap solution.
c. The cost of this software solution is recommended to be carried by WP6 in the GÉANT project.

Time and frequency services

The following matrix shows the existing and planned frequency services on the CLONETS 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: 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.

Sustainability and future liabilities

Potential Liabilities

The GÉANT C-TFN fibre topology described in Option A will result in a small annual unfunded liability for fibre maintenance payments starting in July 2027. It is recommended that the IRU contacts 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, 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.

Building 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 CLONETS 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 presented in this document, details of final topology of the GÉANT C-TFN will be further developed based on NMI and NREN community consultation.

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 us to go 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 turn-key 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 our existing fibre DPS procurement process.

Procurement of the equipment to light the dark fibre should follow the guidelines set out in Appendix 1: public procurement procedures.

Operations and Maintenance

Metrology community forum

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

This forum, comprising NMIs and GÉANT, will aim at making 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

Managing new network – adding services and modifying the fibre topology

- When an NMI or other user requests a new time/frequency services over the GÉANT C-TFN, this request should be raised with the GÉANT OC who will act as a single point of contact for this 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 links, 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 or removing links to 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 either 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 of the C-TFN

- GÉANT should act as the first-line support for the whole CLONETS C-TFN. This includes all transport and time/frequency functions including those operated by NRENs that are deemed to be part of the CLONETS 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 our 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 develop this in-house or outsourcing to an equipment vendor.
- During the procurement process GÉANT should investigate the cost/benefit out-sourcing the development of a monitoring solution for the time/frequency network compared to 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.
- WP 6 is also updating TimeMap software (https://network.GÉANT.org/timemap/) as a trial network management solution, this will be evaluated in the pathfinder project.
- Each NMI/NREN that deploys a flywheel will be expected to interoperate with the centralized 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.

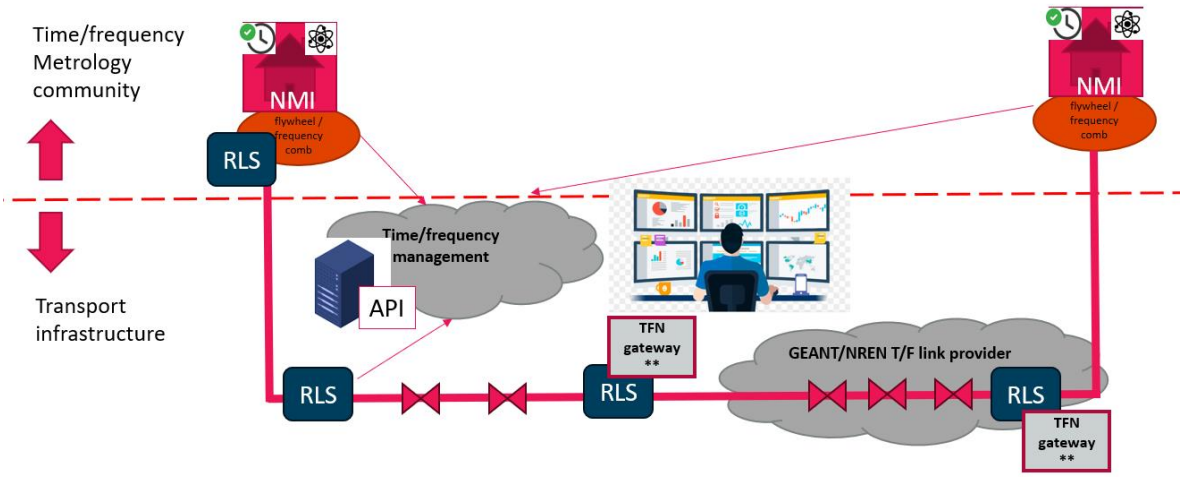

Figure 6: possible architecture of a federated T/F network management system

Challenges for 2024 and beyond

This section discusses the areas that need to be resolved before building the GÉANT C-TFN can commence.

The CLONETS 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. A forum of NMIs and NRENs is proposed to 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 needs further work.

It is recommended to create a forum that would include representatives from NRENs and NMIs that participate in the C-TFN network. The forum should be open to including members that are interested to join the forum regardless if 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. **SIGs**: An option is to follow the model of Special Interest Groups (SIGs) well known in the GÉANT community where participation would be open for 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 for 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-PM**: 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 individual appointed by their organisation with a purpose to work on topics needed for operations and maintenance of the established TFN. This group will be closed, might include more operational time- and objective- bounded tasks. Participation might be self-funded by the organisations, or some model for funding as a part of the project or the C-TFN fee might be considered.

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

GÉANT C-TFN Governance and contractual commitments

The following questions around governance and contractual commitments are unresolved.

- GÉANT will use Horizon Europe funds to build the network, while the fibre and associated equipment will be owned by GÉANT, is there scope for GÉANT to purchase RLS equipment and hand this over to an NMI to operate and maintain?
- What contract should be put in place between the NMIs interconnect with GÉANT? Should any fees be payable for this interconnect, if so how much?
- We need to agree what SLAs commitments are 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 CLONETS 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 and the NMIs need to find a way to fund the C-TFN after 2027.

Developing a network management model

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

Recommendations for GN5-2

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

Table 2: List of recommendations for GN5-2

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

Conclusions

The GÉANT Time Frequency Incubator ran for 8 months from May 2023 to Jan 2024. The incubator built on the results of the CLONETS-DS report to find a solution to building the CLONETS C-TFN using GÉANT GN5-2 funding.

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

Appendix 1: 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:

PIN Prior Information Notice.

At the initial stage a PIN (Prior Information Notice) is issued on TED (Tenders Electronic Daily). 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 Pik Time Systems. We should encourage them to register on TED.

Publication of a Contract Notice:
This step initiates the procurement. GÉANT will announce our 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 shortlists the suitable candidates and invite them to participate in the dialogue phase. GÉANT will issue a description of the problem we are 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 our requirements based on feedback from the candidates. The dialogue continues until GÉANT identifies the solution or solutions capable of meeting our 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 2: C-TFN as a public infrastructure collaboration between GÉANT, NRENS and NMIs

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

Further work is needed to agree the most appropriate business model for the C-TFN to ensure that state aid rules are met.

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 Good: Time and frequency have 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 like roads and railways, funded through taxation.

Natural Monopolies: A public time-frequency network also exhibits some characteristics of 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 3: Time-Frequency Core network, 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 GN5-2 funding cycle we create a funding vehicle provisionally called 'GN5-2T' as follows:

- Name: GN5-2T
- Duration: starting January 2025 for the duration of 2.5 years
- Target budget: 7.5 Million Euros
- 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 GN5-2 funding cycle.
- Any future maintenance liabilities should be documented and understood, for example if we put in place a 10 year IRU for dark fibre, 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 Core-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 either be a contractor to the integrator or their local NREN.

Work was carried out in the CLONETS-DS identified a longer-term mechanism to fund the CLONETS network. A discussion of the how to support the sustainability of Core-TFN can be found in these two documents: Deliverable 3.1 – Governance and Sustainability.pdf and Deliverable 4.2 – Roadmap Towards an ESFRI Listing.pdf .

Appendix 4: T/F Pathfinder

In 2024 the first proof-of-concept link of the CLONETS 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.

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

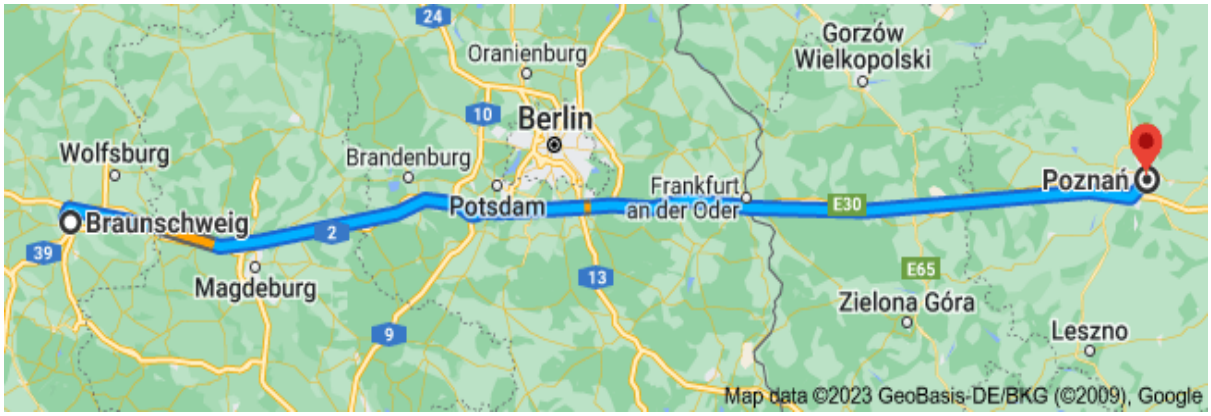

Figure 7: Map of the T/F pathfinder route

Figure 8: PIK Time Systems Bidirectional amplifier

Figure 9: PIK Time Systems Regenerator Laser Station

Figure 10: PIK Time Systems ELSTAB equipment

Appendix 5: T/F Detailed use-cases

CLONETS

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.pdf and Deliverable 1.2 – Requirements and Definitions.pdf for the complete documentation.

NPL

NPL indicated 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, the project can be found here National Timing Centre. 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
  - Test-bed 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

4.1.3 Justervesenet

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

- Public safety; Emergency radio networks. Detection and mitigating timing and positioning failures/attacks in telecommunications/satellite-based services. Detection and investigating events.
- Financially 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 sync, 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, LOFAR radio telescope project
- Navigation, experimental high accuracy GPS with TUdelft and VU University

SURF STF presentation

SIKT like NPL confirm 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

- National 5G operations looking for better solution to calibrate 5G base stations, at the moment they use a mobile caesium clock.
- Astronomy, EISCAT, the Norwegian radio telescope project Digital twins.
- SINTEF mentioned a use case where real-time digital twins in their new Ocean Space Center will require high precision timing between the physical observation location and the HPC resource facility. SINTEF also operates a drone lab. It has been mentioned the importance of robust and high-precision timing, beyond GPS.
- Fiber optical sensing. Synchronising multiple DAS units. Bidirectional sensing with SOP and Phase requires high timing synchronisation between the end-point in order to geo locate 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 project including country wide deploying WhiteRabbit technology into all major nodes in order of provide time and radiofrequency references.

Appendix 6: NMI consultation and Letters of Support

Letters of support have been provided by the following institutions:

- FAMO Consortium including Nicolaus Copernicus University (Torun / Poland)
- GUM Poland
- Belnet Belgium
- ROB Belgium
- IPE/UFE
- PTB
- INRIM

Copies of these letters can be found here:
https://wiki.GÉANT.org/display/gn43wp6/Supporting+documentation

Table 3: outreach meetings between GEANT 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 Nov
Nomios	no	Netherlands	15 Nov
Real Instituto y Observatorio de la Armada (ROA)	no	Spain	5 Dec
Institute of Physics (IFZg) National Laboratory for TF	no	Croatia	5 D