04-04-2023

Deliverable D3.2
Governance and Sustainability Policy Paper

Deliverable D3.2

Contractual Date:	31-03-2023
Actual Date:	04-04-2023
Grant Agreement No.:	951886
Work Package	WP3
Task Item:	Task 3.1
Nature of Deliverable:	R
Dissemination Level:	PU
Lead Partner:	PSNC
Document ID:	CLONETS-M30-001
Authors:	Wojbor Bogacki (PSNC), Artur Binczewski (PSNC), Krzysztof Turza (PSCN), Maciej Stróżyk (PSNC), Michał Blacerkiewicz (PSNC)

© GÉANT Association on behalf of the CLONETS-DS project.
The research leading to these results has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 951886 (CLONETS-DS).

Abstract
This deliverable summarises the work of the CLONETS-DS project. It presents the requirements of scientific users for accuracy and stability of time and frequency, and describes the topology of the proposed European T&F dissemination network.

Table of Contents

Table of Figures

Executive Summary

This deliverable summarises the work of the CLONETS-DS project. It presents the requirements of five groups of scientific users for accuracy and stability of time and frequency (T&F), based on data obtained during a stakeholder workshop held from 13 to 15 September 2021 in Bad Honnef, Germany. The document also describes the topology of the proposed European T&F dissemination network.

The project's overall policy with regard to providing access to high-performance time and frequency signals is reflected in its aims and objectives. Its primary aim is to **establish a sustainable, pan-European T&F reference system, based on transmitting ultra-precise T&F information via optical fibre**, that is ready for continuous multi-user operation, **to serve the European science community**.

Its specific objecitve is to **define and address the needs of the scientific user community, as representing the most demanding requirements**, thus allowing the less demanding requirements of other user groups to be met in parallel. To do this, the envisaged research infrastructure must:

- **Define an architecture that supports this service at the highest, most advanced level of the stability, accuracy, reliability and security of the delivered signals**.
- **Design an engineering model and strategies to implement a sustainable research infrastructure**, including the creation of a common data platform.
- **Define roadmaps and a deployment strategy that assure compatibility with and interoperability of already existing implementations in Europe and possible future extensions**.
- **Strengthen the European research area by elaborating plans for the integration of the necessary environment into the European landscape**.

Optical frequency and time distribution (OFTD) complements, and offers a viable alternative to, satellite transmission of T&F signals. Indeed, OFTD of such reference signals outperforms satellite-based technology by orders of magnitude over a continental scale. The T&F dissemination network proposed by CLONETS-DS will provide T&F signals for a wide range of users to enhance Europe's scientific and economic potential, as well as improve the security of time and frequency synchronisation in critical infrastructures such as telecommunications, energy and banking networks.

This deliverable should be considered together with deliverable D3.1 *Governance and Sustainability*, which summarises the work on governance structure and the sustainability model for the services undertaken by Work Package 3 Governance and Sustainability (WP3).

1 Introduction

The development of atomic clocks, which began in the 1950s – through rubidium and caesium clocks, hydrogen masers and caesium fountains to the optical clocks currently under development, which achieve unprecedented precision and signal stability – provide researchers with highly sophisticated time measurement instruments. However, these devices are available only to a small group of researchers in national metrology institutes (NMIs) or time laboratories. The demand for precise time signals has prompted the development of satellite-based time transmission methods using global navigation satellite systems (GNSSs). Today, access to high-performance time and frequency is almost exclusively provided by radio signals, in particular those of GNSSs such as Global Positioning System (GPS), the Russian navigation satellite system GLONASS, Europe's GNSS Galileo, or more recently the Chinese GNSS BeiDou, which have well-known vulnerabilities. However, optical frequency and time distribution (OFTD) via optical fibre of such reference signals outperforms satellite-based technology by orders of magnitude over a continental scale, allowing significantly reduced measurement time and unprecedented uncertainty.

For more than a decade, work has been underway on time and frequency transmission using fibre optic links. Researchers have already demonstrated that orders of magnitude performance improvements are provided by signals transported over optical-fibre networks, over distances up to continental scale (thousands of kilometres). Parallel work is being carried out on the development of atomic clocks, T&F transmission technology, and T&F dissemination networks. Research work is carried out under various programmes such as the European Metrology Programme for Innovation and Research (EMPIR) [**EMPIR**] and Horizon 2020 (H2020) [**H2020**] (see Figure 1).

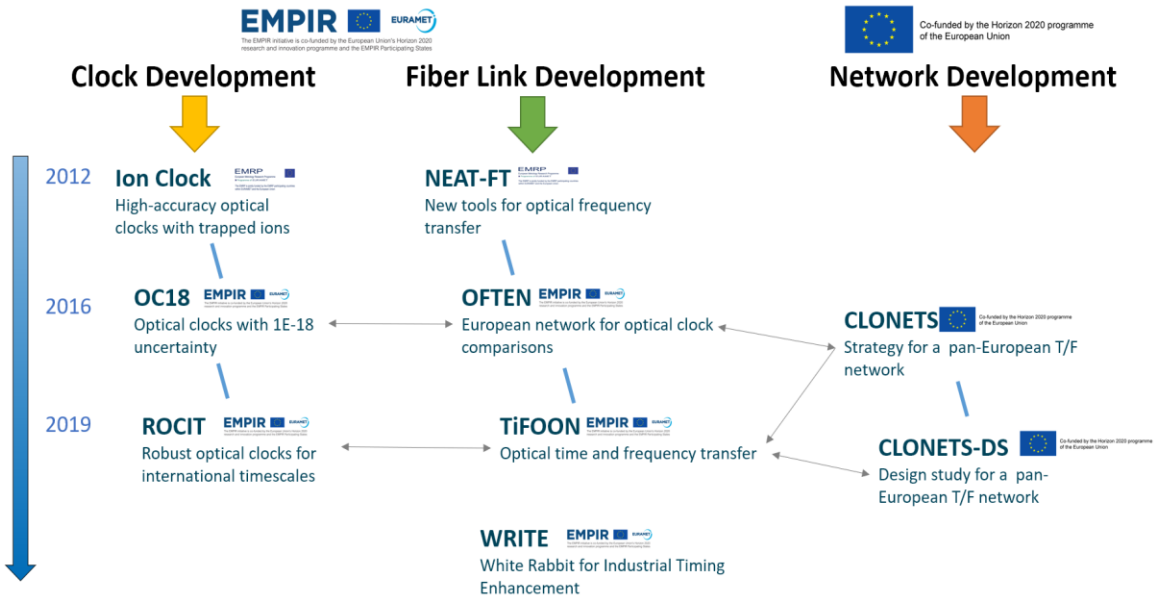

Figure 1. European projects focused on T&F work

Projects developing atomic clocks are: [ION CLOCK], [OC18], [ROCIT]. Projects focusing on T&F transfer technology are: [NEAT-FT], [OFTEN], [TiFOON], [WRITE]; projects working on transmission networks are [CLONETS] and [CLONETS-DS].

Research institutions are developing several T&F technologies, adapted to specific projects and applications. However, these solutions are not always compatible with each other and require additional resources for signal transfer. Several European national metrology institutes, in cooperation with National Research and Education Networks (NRENs) and other network operators, are installing and operating experimental long-distance links to compare optical clocks, which are leading the way to a new definition of the unit of time and to greatly improved timescales, or to transfer T&F signals to remote scientific users (Figure 2).

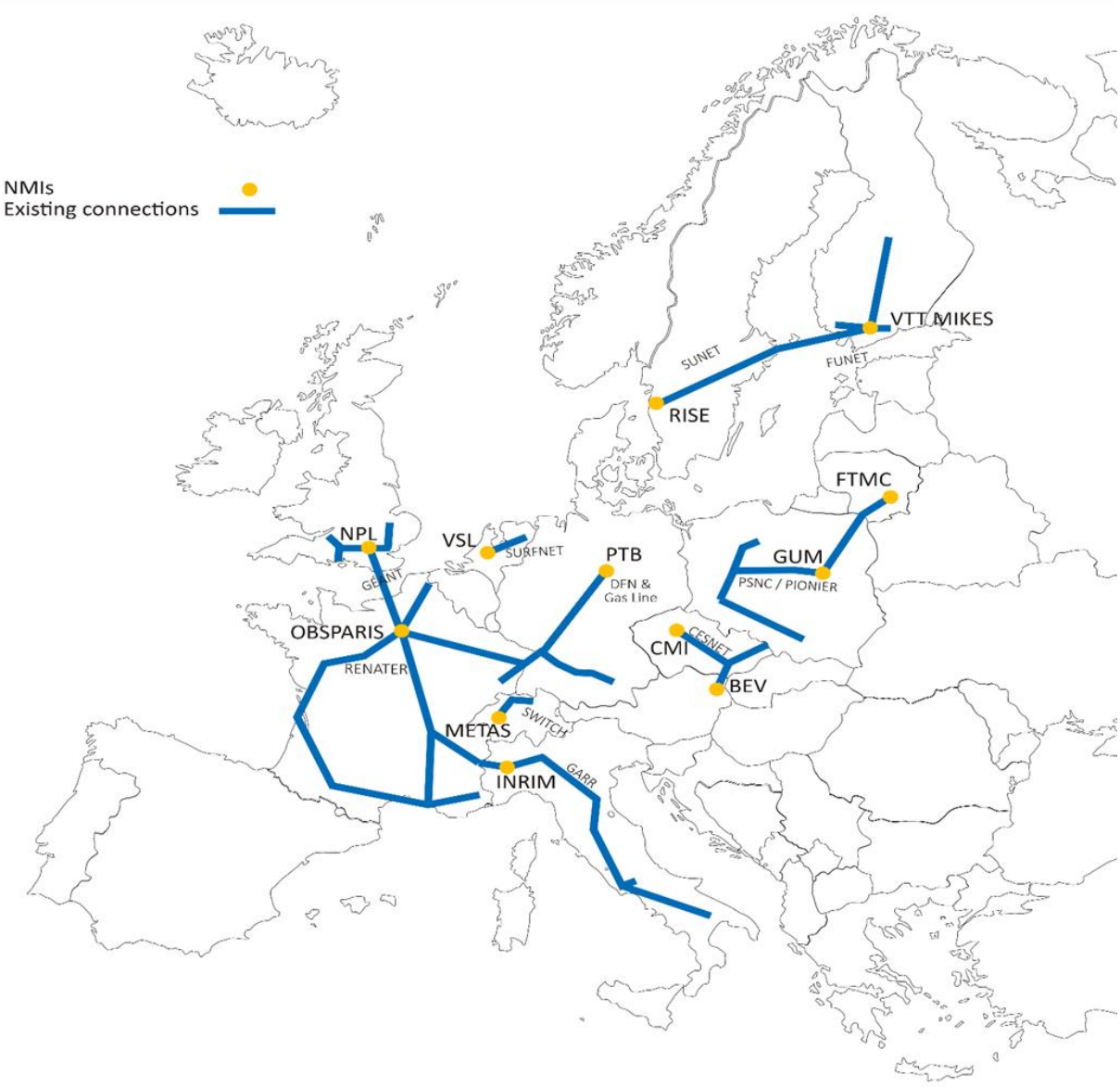

Figure 2. Existing T&F connections between NMIs

Beyond these long-distance links between NMIs, in many countries national networks are being established to expand high-performance time and frequency transmission for diverse scientific applications such as in France [**REFIMEVE**], Italy [**LIFT**], Poland [**OPTIME**], and the Czech Republic [**CITAF**]. Note that REFIMEVE was labelled as national research infrastructure in 2021.

The need for precise time and frequency signals goes beyond scientific users. In many fields, access to precise T&F signals is extremely important, such as: ICT, Power Grids, Navigation, Transport, Finance, Security, Defence, and more (Figure 3). In addition to precise T&F signals, these users also require reliability and security of the delivered signals. In these fields, fibre T&F transfer can be a viable alternative to satellite transmission.

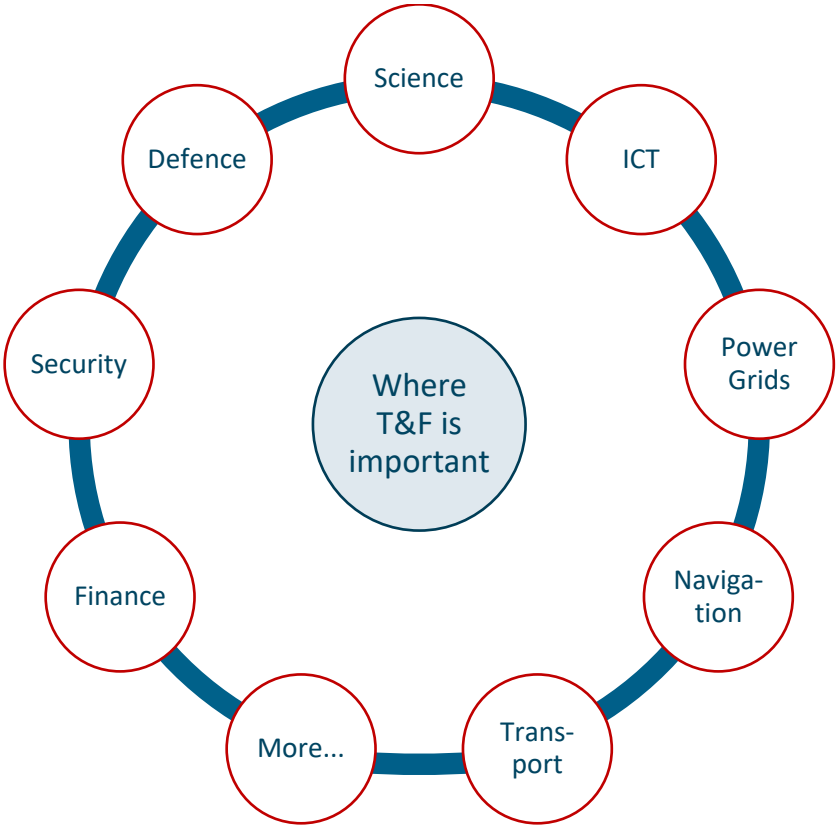

Figure 3. T&F users

The benefit of OFTD has already been demonstrated in a variety of groundbreaking experiments using dedicated point-to-point connections. However, there are no European T&F dissemination systems which can cover a huge part of Europe and will be ready for multi-user continuous operation.

The CLONETS-DS project aims to establish a pan-European time and frequency reference system as a European research infrastructure to serve the European science community. It is based on transmitting ultra-precise time and frequency information via optical fibre. CLONETS-DS builds on several joint European projects (such as those shown in Figure 1) and its direct precursor project CLONETS. The project now goes far beyond previous efforts by designing a sustainable, pan-European, ultra-precise time and frequency reference system available to the European research community. This research infrastructure considers user needs; designs the required architecture, engineering models and roadmaps; and develops a sustainability model for the future service, thus strengthening the European research area.

The specific objective of the CLONETS-DS project is to elaborate the needs of the scientific community for ultra-precise timing and frequencies in various fields of research and the corresponding definition of user requirements. To achieve this, the envisaged research infrastructure has to address the following points:

- Define an architecture that supports this service at the highest, most advanced level of stability and accuracy.
- Design an engineering model and strategies to implement a sustainable research infrastructure, including the creation of a common data platform.

- Define roadmaps and a deployment strategy that assure interoperability of already existing implementations in Europe and possible future extensions.
- Strengthen the European research area by elaborating plans for the integration of the necessary environment into the European landscape.

A research infrastructure achieving all of these objectives will enable first-class research previously not even conceivable and foster the collaboration between time and frequency stakeholders across Europe, thereby putting Europe's research community into a leading position.

2 CLONETS-DS Project Work

Work in the CLONETS-DS project focused on many aspects, but among the most important were defining the science cases and the requirements of advanced users, proposing a T&F network topology, and defining governance structure and sustainability measures.

2.1 User Needs

One of the main tasks of the project was to determine the needs of users. The project focused on scientific users for two reasons: first, one of the goals of the project is to strengthen the scientific community in Europe, and second, the scientific community has the highest, most demanding requirements in terms of accuracy and stability of time and frequency signals. If the requirements of the scientific community can be met, the requirements of users outside the scientific community will also be achieved. During a stakeholder workshop held from 13 to 15 September 2021 in Bad Honnef, Germany (described in more detail in [D1.1]), five science cases and their requirements were identified:

Science Case 1: Fundamental Science

- Improvement of optical clocks
- Precision spectroscopy to search for beyond standard model (BSM) physics
- Redefinition of the SI unit second

Science Case 2: Quantum Technologies

- Improvement of real-world Quantum Key Distribution (QKD)
- Development of new protocols
- Entanglement distribution beyond QKD

Science Case 3: Earth Observation / Geodesy

- Height system unification
- Satellite gravity mission validation
- Geodetic network consistency

Science Case 4: Astronomy

- Radio interferometry and Very-Long-Baseline Interferometry (VLBI) in astronomy
- Laser ranging

- Pulsar timing

Science Case 5: Telecommunication and Networks / Position, Navigation, Synchronisation, and Timing

- Optical timescales
- Position, navigation and timing (PNT)
- Resilience for GNSS
- Supervision of telecommunication networks and synchronisation (5G or 6G)

Requirements for stability and accuracy of frequency (Figure 4) and timing (Figure 5) stakeholders expect were also defined. More information can be found in deliverable D1.2 *Requirements and Definitions* [D1.2].

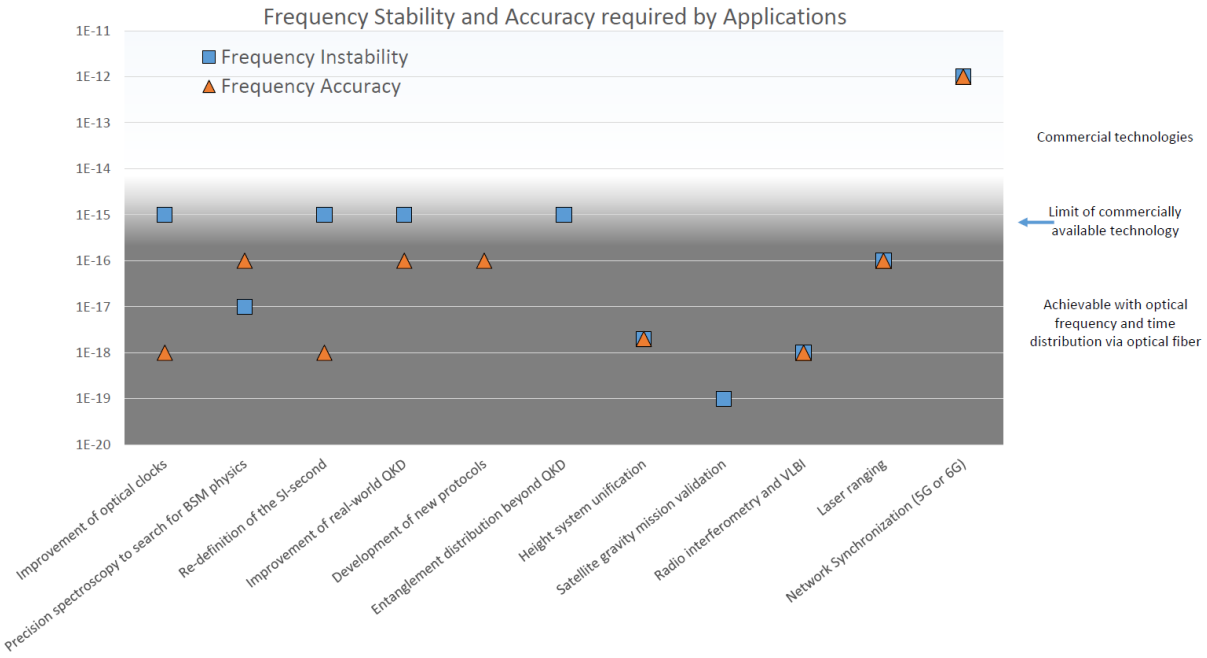

Figure 4. Frequency stability and accuracy requirements mostly surpass currently commercially available technology

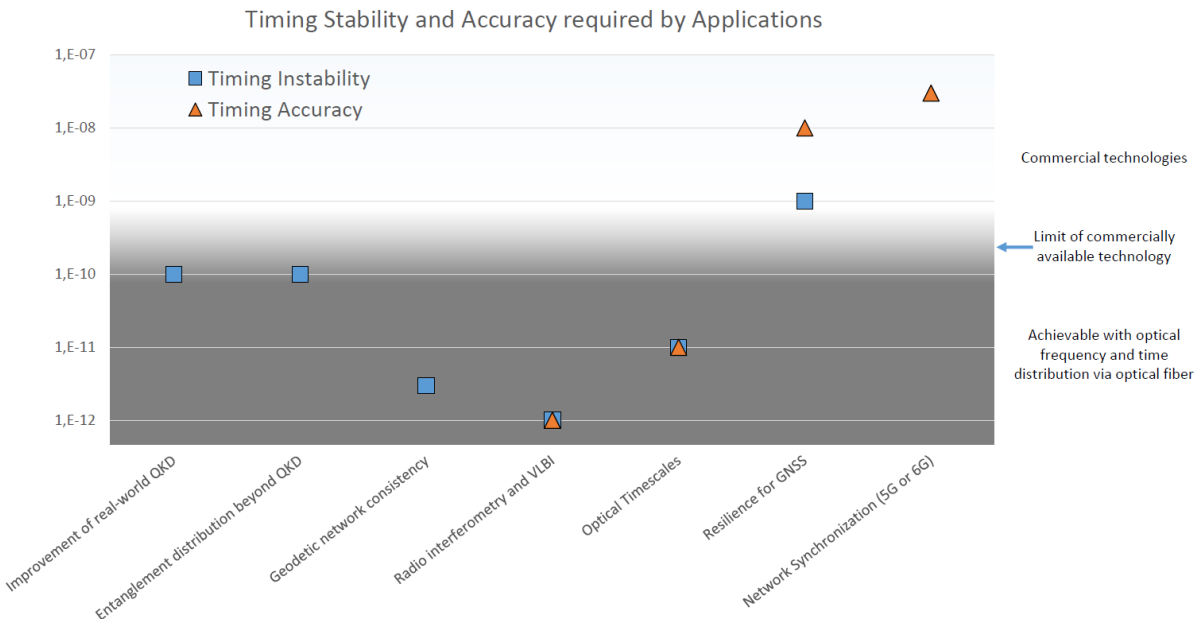

Figure 5. Timing stability and accuracy requirements also surpass currently commercially available technology

Not all requirements of scientific users for stability and accuracy of time and frequency signals can be met by available commercial solutions. A larger group of scientific users requires more precise signals. These signals can be provided by the T&F network proposed by the CLONETS-DS project.

2.2 European T&F Dissemination Infrastructure

To meet the requirements for the T&F network, the CLONETS-DS project has proposed a network consisting of three rings. Each ring will distribute time and frequency signals (1 PPS, 10 MHz) and an optical carrier for comparing optical clocks. The network will cover most of Europe. The planned span of the network is more than 11,500 km, and the length of the combined fibre links is almost 20,000 km (Figure 6).

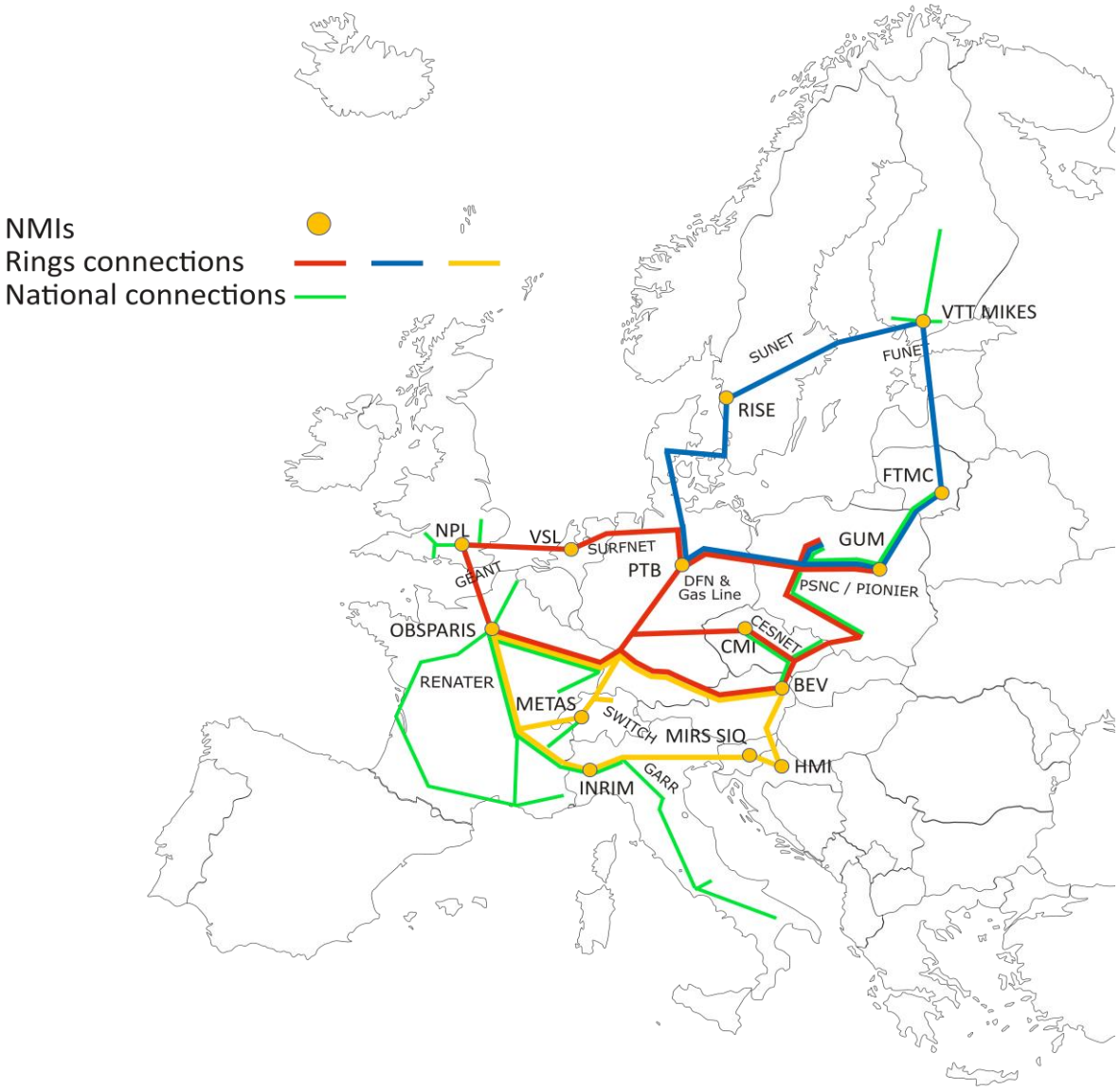

Figure 6. Proposed T&F dissemination infrastructure

Each country will have at least one point of presence (PoP). A PoP is a point of delivery of time and frequency signals to the network, and also a point where national networks or users can connect to the backbone network. If possible, the network will rely on already existing national infrastructure and will also rely on NRENs/GÉANT for cross-border connections. The operational responsibility should remain at the national level. The main benefits of the CLONETS-DS network topology are to allow incorporation of national implementations, allow the implementation of different techniques, realise an open, expandable, adaptable structure, and easy implementation of novel concepts, as well as access to T&F signals for a wide range of users. More information about the topology can be found in deliverables D2.1 *Technical Design Report* and D2.2 *Roadmap for technical implementation of the T&F-reference system* (not yet published at the time of issue of the present deliverable).

3 Conclusions

The modern economy requires access to precise time and frequency signals. Both scientific and commercial users need precise and secure time and frequency signals. GNSS is a common solution for T&F signals, but it does not meet all users' requirements, unlike the precision and security of the T&F signals distributed via optical fibre, which do meet all users' requirements. GNSS transmissions should not be the only source of T&F signals, especially in critical infrastructures.

The proposed T&F dissemination network will provide T&F signals for a wide range of users to enhance Europe's scientific and economic potential, as well as improve the security of time and frequency synchronisation in critical infrastructures such as telecommunications, energy and banking networks.

However, it should be noted that the cost of building such a network is significant and beyond the financial capabilities of the project partners. Building a time and frequency dissemination network will be very difficult, if not impossible without the support of European and national institutions.

References

[CITAF]	https://citaf.org/en/index
[CLONETS]	https://www.ptb.de/clonets/clonets-home.html
[CLONETS-DS]	https://clonets-ds.eu/
[D1.1]	https://clonets-ds.eu/wp-content/uploads/2022/07/Deliverable-1.1-Stakeholder-Workshop.pdf
[D1.2]	https://clonets-ds.eu/wp-content/uploads/2022/07/Deliverable-1.2-Requirements-and-Definitions.pdf
[EMPIR]	https://www.euramet.org/research-innovation/research-empir
[H2020]	https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/programmes/h2020
[ION-CLOCK]	https://www.ptb.de/emrp/ion-clocks-project.html
[LIFT]	https://www.refimeve.fr/images/stories/exposes/Calonico.pdf
[NEAT-FT]	https://www.ptb.de/emrp/neatft_home.html
[OC18]	http://empir.npl.co.uk/oc18/
[OFTEN]	https://www.ptb.de/emrp/often_home.html
[OPTIME]	https://optime.org.pl/
[REFIMEVE]	https://www.refimeve.fr/index.php/en/, labelled as national research infrastructure: https://www.enseignementsup-recherche.gouv.fr/fr/la-feuille-de-route-nationale-des-infrastructures-de-recherche-2021-84056
[ROCIT]	http://empir.npl.co.uk/rocit/
[TiFOON]	http://empir.npl.co.uk/tifoon/
[WRITE]	http://empir.npl.co.uk/write/

Glossary

BeiDou	Chinese Global Navigation Satellite System
BSM	Beyond Standard Model
CITAF	Czech Infrastructure for Time and Frequency
CLONETS	CLOck NETwork Services
CLONETS-DS	CLOck NETwork Services – Design Study
EMPIR	European Metrology Programme for Innovation and Research
Galileo	European Global Navigation Satellite System
GLONASS	GLObalnaya NAvigatsionnaya Sputnikovaya Sistema, Russian global navigation satellite system
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
H2020	Horizon 2020
ICT	Information and Communication Technology
LIFT	LInk ottico nazionale per la Frequenza e il Tempo / Italian Time and Frequency Optical Link Project
NEAT-FT	Network for European Accurate Time and Frequency Transfer
NMI	National Metrology Institute
NREN	National Research and Education Network
OC18	Optical clocks with 1×10^{-18} uncertainty
OFTD	Optical Frequency and Time Distribution
OFTEN	Optical Frequency Transfer – a European Network
OPTIME	High-Precision Dissemination of Time and Frequency Reference Signals
PNT	Position, Navigation and Timing
PoP	Point of Presence
PPS	Pulse Per Second
QKD	Quantum Key Distribution
REFIMEVE	Réseau Fibré Métrologique à Vocation Européene / Metrological Fibre Network with European Vocation
ROCIT	Robust Optical Clocks for International Timescales
SI	International System of Units
T&F	Time and Frequency
TiFOON	Time and Frequency over Optical Networks
VLBI	Very-Long-Baseline Interferometry
WP	Work Package
WP3	Work Package 3 Governance and Sustainability
WRITE	White Rabbit for Industrial Timing Enhancement