16-08-2023

Deliverable D3.2
Governance and Sustainability Policy Paper

Deliverable D3.2

Contractual Date:	31-03-2023 (revised to 18-08-2023
Actual Date:	16-08-2023
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
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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 for use by policy makers and stakeholders. 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. The deliverable also presents the consortium's view of future activities from European, national and participant levels.

Table of Contents

Table of Figures

Executive Summary

This document is aimed at policy makers and stakeholders. It summarises the work in CLONETS-DS and outlines the advantages that the CLONETS research Infrastructure – Time & Frequency (T&F) dissemination network to European Research Area (ERA) can bring. In addition, it describes future activities at the European, national and participant level that must be undertaken to build such a network.

It also summarises 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**.

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.

In addition to providing background about T&F and the CLONETS-DS infrastructure, it is important to identify how functions and participants can be included in strategic decision making and planning as part of governance. As a result, 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, from rubidium and caesium clocks, hydrogen masers and caesium fountains in the 1950s, to the optical clocks that achieve unprecedented precision and signal stability under development today, 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.

GNSS threats that have emerged in recent years include GNSS jamming and GNSS spoofing [**GNSS-JAM**]. GNSS jamming (see Figure 1) can be caused by natural factors, either unintentionally or intentionally to jam the GNSS systems. There are military jammers, but also personal devices. Personal devices are forbidden in many countries, but can be obtained and used.

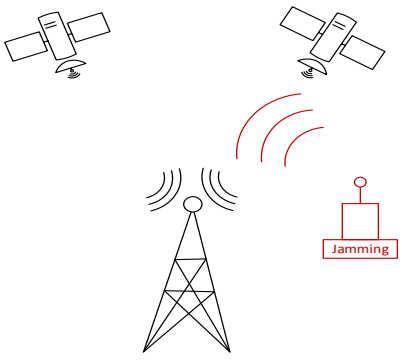

Figure 1. GNSS jamming

Although GNSS jamming is quite an inconvenience, a much more serious threat is GNSS spoofing (see Figure 2). GNSS spoofing involves the substitution of GNSS signals for others that the receiver analyses as correct. This results in an indication of the incorrect position and time to the GNSS user. The user is not aware that it is receiving incorrect GNSS signals.

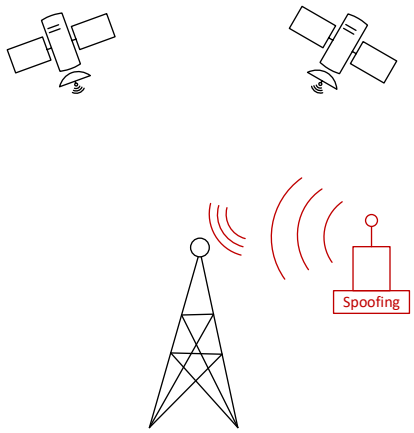

Figure 2. GNSS spoofing

Access to time and frequency signals via a fibre optic network will greatly improve the security of signals received by GNSS. Signals transmitted over a fibre optic network are very difficult to substitute, so they are able to provide a basis for detecting GNSS signal anomalies (GNSS spoofing), or, in the event of signal fading (GNSS jamming), provide reference signals.

In addition, GNSS system disruptions can also occur due to random failure, as was the case with Galileo in July 2019. The system failure lasted several days and was caused by a Grand Clock fault. [**FAILURE**]

Optical frequency and time distribution (OFTD) via optical fibre of such reference signals has several advantages over satellite transmission. It surpasses satellite technology by orders of magnitude on a continental scale, enabling significant reductions in measurement time and unprecedented signal uncertainty, which makes it more resistant to interference. It can serve as a reference system for GNSS systems and, at the same time, complement them in places of particular importance from the point of view of security (airports, financial institutions, strategic facilities, etc.).

Europe's reference time and frequency distribution network, CLONETS Research Infrastructure, can play a huge role not only as a complementary system to GNSS, but also as a platform for distributed scientific research in which time and frequency synchronization are vital. Scientific centres spread across Europe will be able to cooperate with each other based on CLONETS Research Infrastructure. Also, modern 5G telecommunications, banking, or energy networks could benefit from access to precise time and frequency signals.

2 Works on T&F Transmission

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 EU programmes, such as the European Metrology Programme for Innovation and Research (EMPIR) [EMPIR] and Horizon 2020 (H2020) [H2020] (see Figure 3).

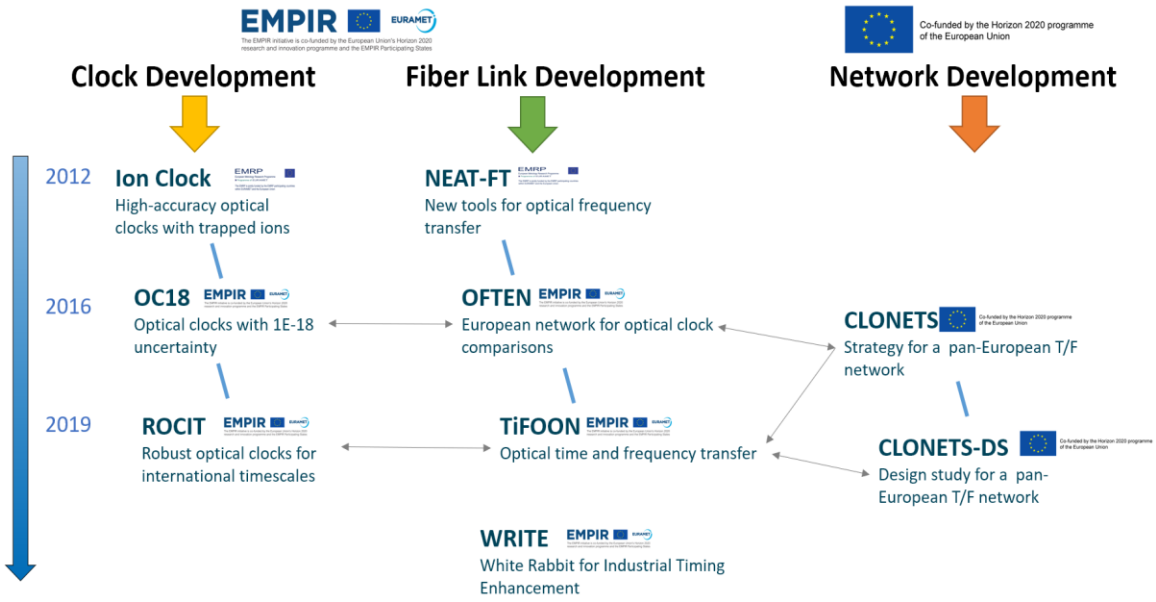

Figure 3. European projects focused on T&F work

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].

The need for precise time and frequency signals goes beyond scientific use cases. 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 4). 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.

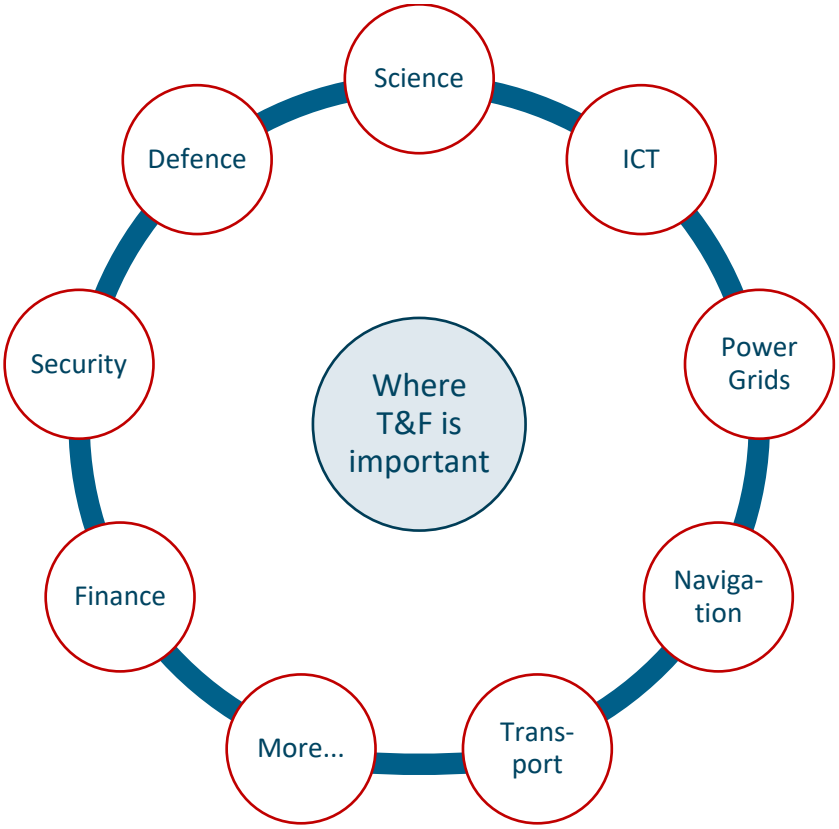

Figure 4. T&F users

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 that can cover a huge part of Europe and will be ready for multi-user continuous operation.

The CLONETS-DS project aim was 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 3) and its direct precursor project, CLONETS. CLONETS-DS successfully designed a sustainable, pan-European, ultra-precise time and frequency reference system available to the European research community. It considered user needs, designed the required architecture, engineering models and roadmaps; and developed a sustainability model for the future service, thus strengthening the European research area.

The specific objective of the CLONETS-DS project was 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 had 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 ensuring the lead of Europe's research community.

3 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.

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)

Stakeholder requirements for stability and accuracy of frequency (Figure 5) and timing (Figure 6)were also defined. More information can be found in deliverable D1.2 *Requirements and Definitions* [D1.2].

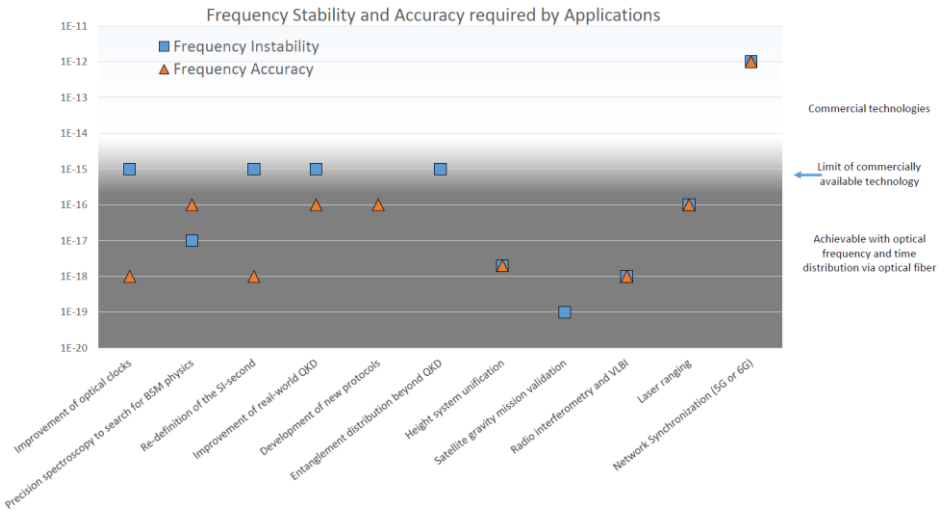

Figure 5. Frequency stability and accuracy requirements mostly surpass currently commercially available technology

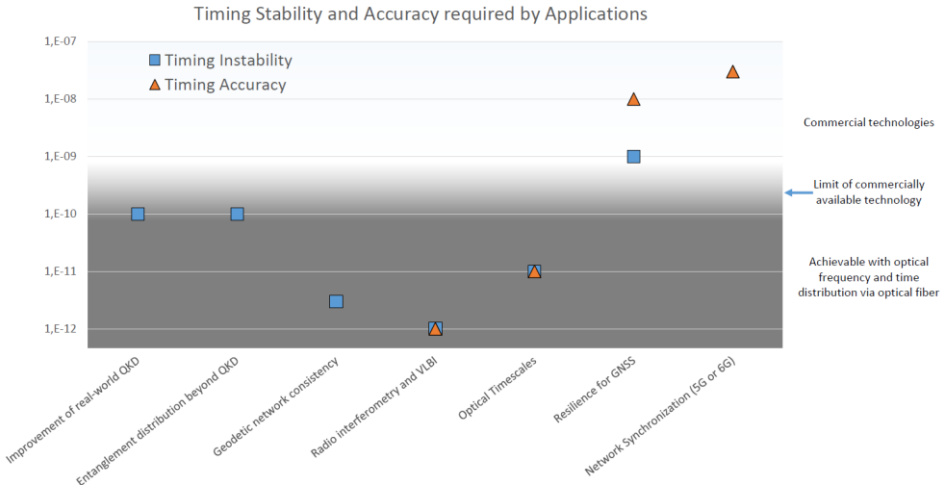

Figure 6. Timing stability and accuracy requirements also surpass currently commercially available technology

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.

4 Stakeholder / Policy Support and Future Activities

Providing precise time and frequency signals to end users regardless of their geographical location by CLONETS Research Infrastructure will influence the development of scientific research in the fields mentioned earlier, as well as enable remote research centres to collaborate on distributed experiments where synchronization of measurements plays an important role. The range of potential experiments is very broad and includes research work in physics, astronomy, earth sciences, metrology, security, electronics and telecommunications networks both wired and wireless.

The CLONETS Research Infrastructure can also support satellite systems. A natural space for cooperation between GALILEO and the CLONETS Research Infrastructure is to provide precise time and frequency data solutions for a large group of users, such as scientific & research users, but also power grids, financial systems, telecommunications systems 5G and beyond, as well as other users requiring access to precise and secure time and frequency signals. These solutions can be complementary for most applications. The GALILEO system covers a much larger territory, but the CLONETS network is able to provide synchronization signals with greater accuracy, and is protected from jamming and spoofing.

The CLONETS Research Infrastructure as a time and frequency dissemination network is a pioneering and unique project in the world. Currently, there are national T&F transmission networks in Europe, as well as unitary time and frequency laboratory connections using fibre optic transmission technology.

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 national European 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.

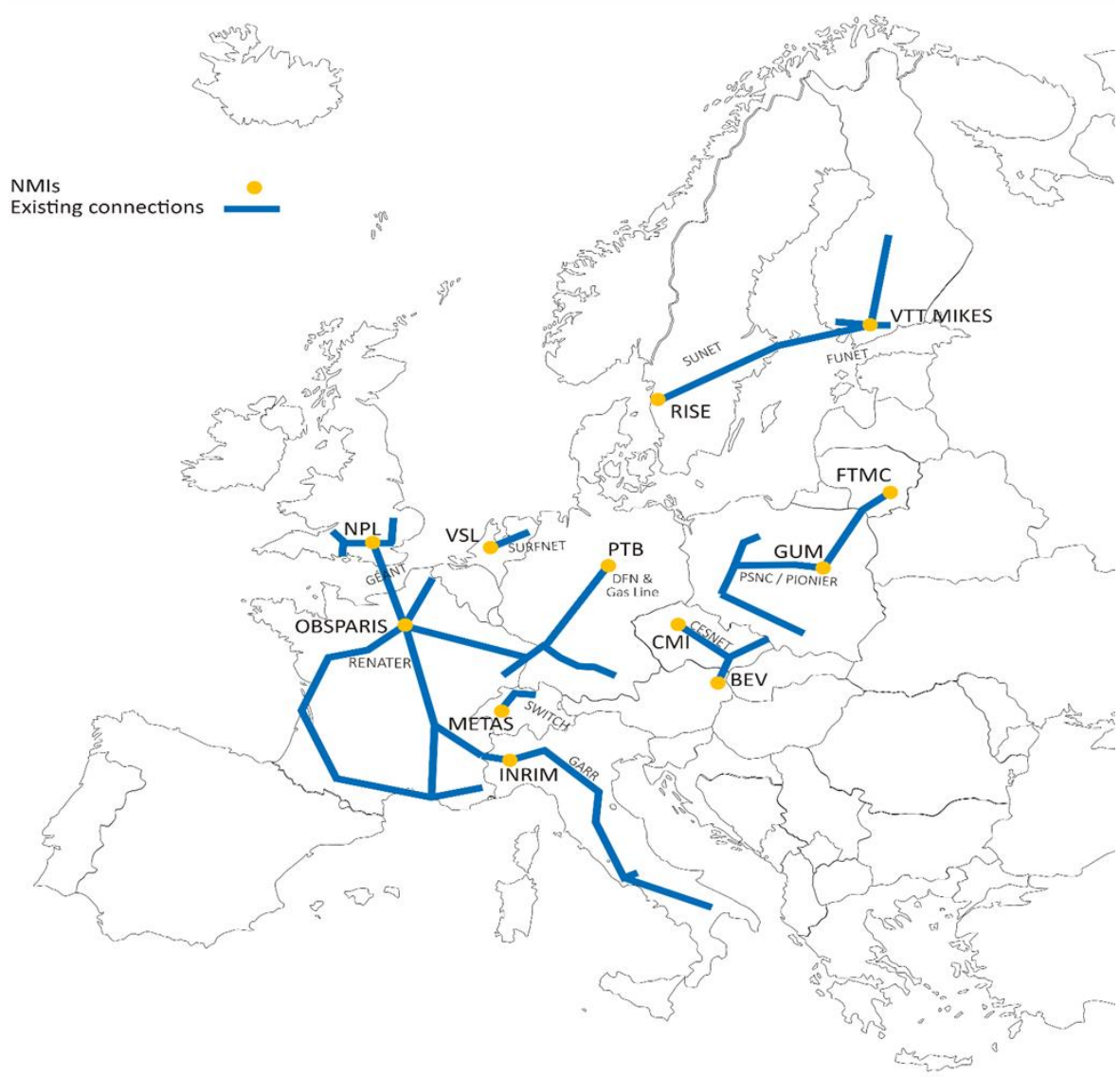

Figure 7. Existing T&F connections between NMIs

Beyond these long-distance links between national metrology institutes (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 a National Research Infrastructure in 2021.

However, there is no unified European network. When such a network is established, it will cover most European countries and will be the largest T&F infrastructure in the world. Based on the input data and several discussions across the CLONETS-DS consortium during the technical work carried out in WP3, we set up an organisational diagram of the Pan-European Research Infrastructure for Time and Frequency Signal Dissemination. As a distributed research infrastructure, the pan-European Infrastructure is formed of:

1) National Research Infrastructures for Time and Frequency Signal Dissemination at the national level in each participating country; and

2) The CLONETS Research Infrastructure (European Core Network) for time and frequency dissemination and overall synchronisation of National Research Infrastructures for Time and Frequency Signal Dissemination over the whole continent (see D3.1 for more information on NRIs as well as the legal arrangement of the future CLONETS [**D3.1**]).

Its planned length is more than 11 500 km. (Figure 9). The network will connect existing and under construction national T&F networks, creating a European research environment, bringing together researchers from all over Europe, enabling them to collaborate on a new level related to T&F synchronization. It should be noted that the network's topology allows for expansion. However, the estimated cost of building such a network can reach EUR100 000 000.

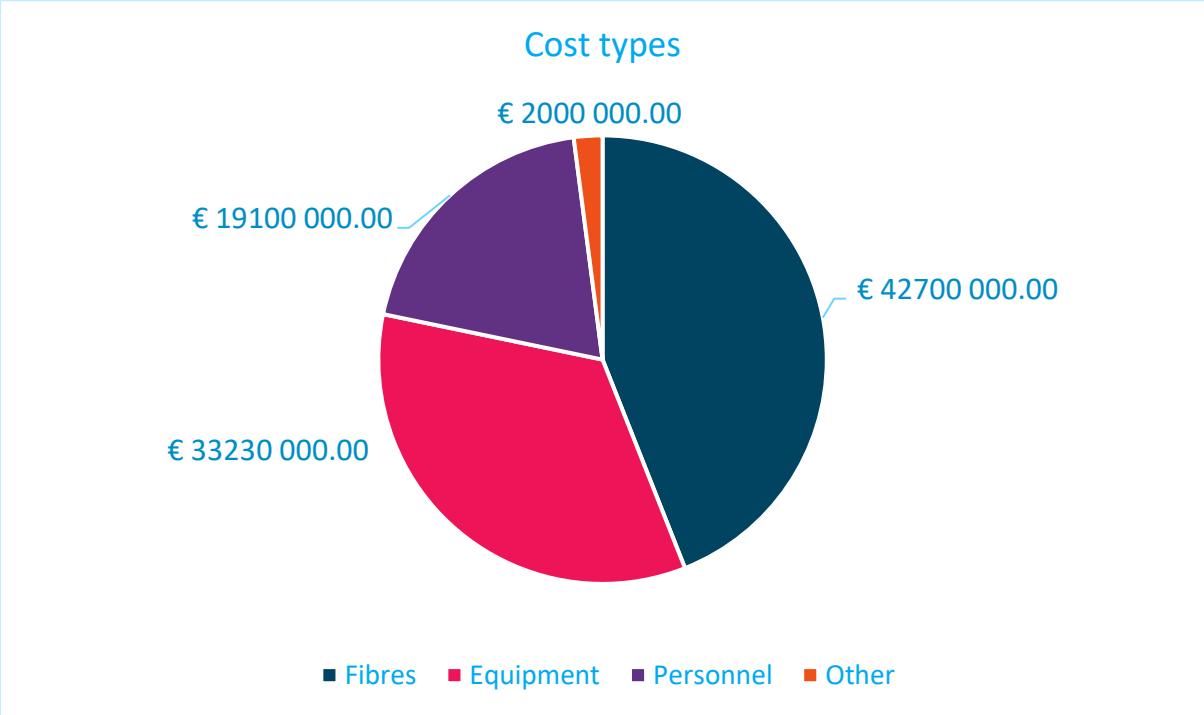

Figure 8. Cost types

The CLONETS-DS project has proposed an advanced T&F network that will cover most of Europe consisting of three rings. Each ring will distribute time and frequency signals (1 PPS, 10 MHz) and an optical carrier for comparing optical clocks.

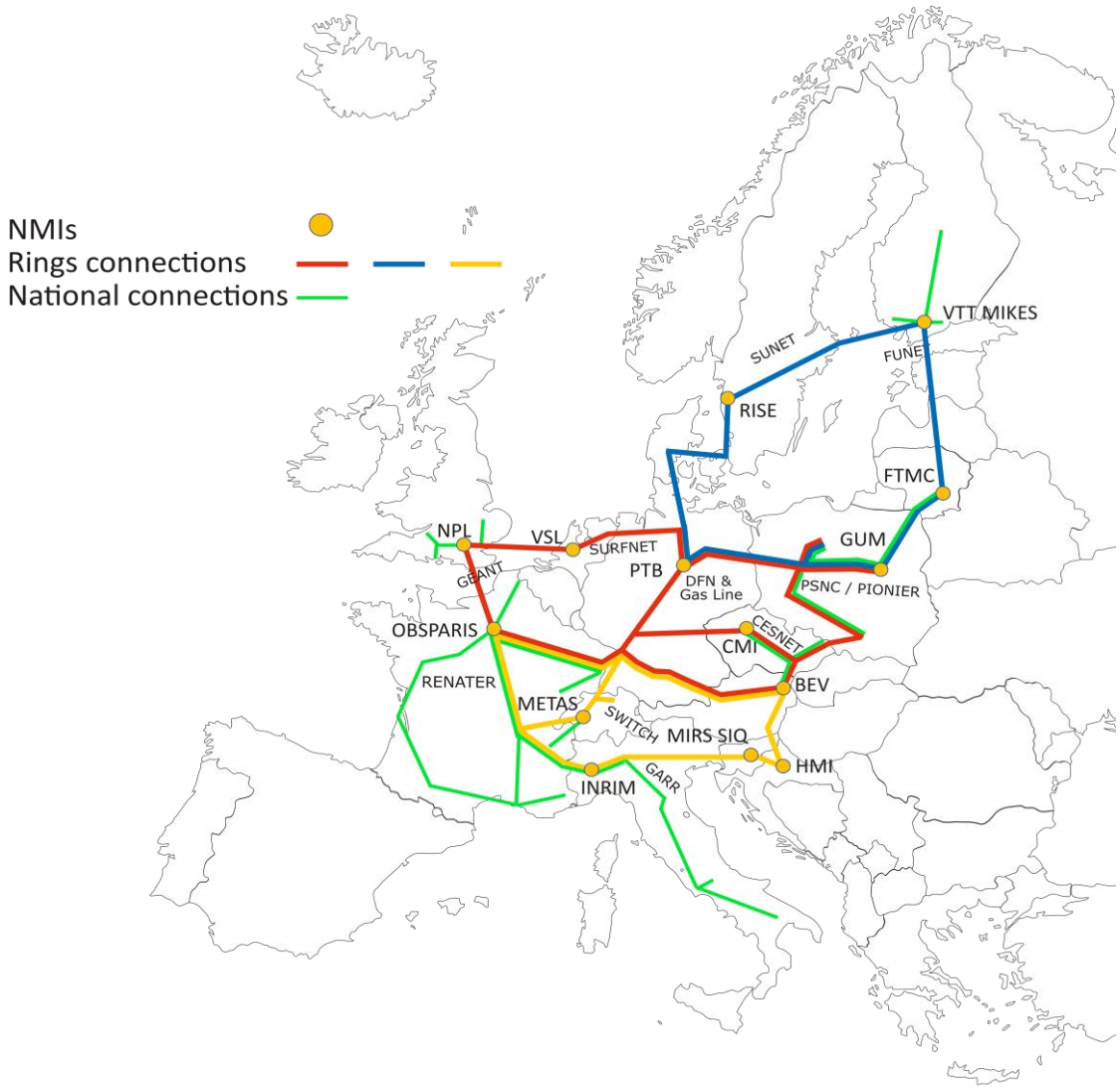

Figure 9. Proposed T&F dissemination infrastructure

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* [**D2.1**], [**D2.2**].

To build such an advanced T&F dissemination network, three basic elements are required (Figure 10) – knowledge, technology, and funds.

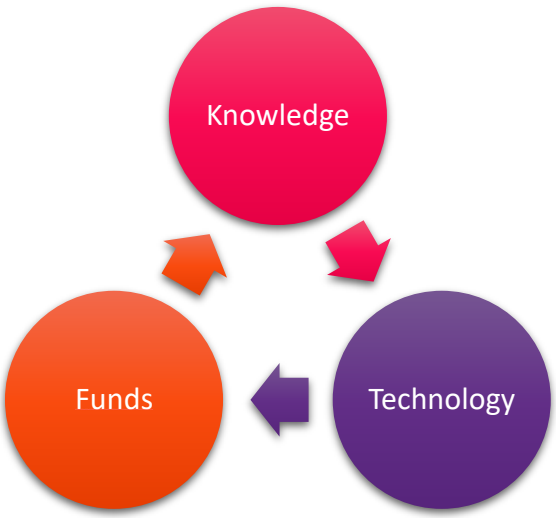

Figure 10. Basic T&F network elements

Participants are able to provide both the relevant technology (which is being developed and improved all the time) and the knowledge and experience related to T&F systems and fibre optic networks. NMI participants will be responsible for T&F signals, NREN participants will be responsible for the network, industry and academia participants will be responsible for T&F dissemination technology. However, a major issue is raising funds for construction, maintenance, management of the T&F dissemination network. Activities on three levels are required for the proposed network to exist:

- European level
- National level
- Participant level.

Figure 11. Cooperation is needed on three levels

4.1 European Level Activities

The potential cost of building and maintaining a T&F network can reach EUR100 000 000 in a 10-year period, which far exceeds the capabilities of consortium members, sources of funding are sought. CLONETS-DS Deliverable *D3.1 Governance and Sustainability* [D3.1] has described funding opportunities for the construction of the CLONETS Research Infrastructure.

The long-term strategy for CLONETS Research Infrastructure is its inclusion on the European Strategy Forum on Research Infrastructures [ESFRI] roadmap. This consortium plan is developed in more detail in deliverable *D4.2 Roadmap Towards an ESFRI Listing* [D4.2]. ESFRI is an advisory body to the European Commission that evaluates the needs for unique services for European Research Area (ERA) that can significant improved scientific cooperation at European level and cannot be implemented individually at the national level [ESFRI], [ERA]. CLONETS Research Infrastructure has the potential to become such an European infrastructure.

The CLONETS-DS consortium has been working for a long time to create closer links to the EuroQCI [EuroQCI] community. The infrastrucute of EUROQCI will provide a secure communication between government, companies and EU citizens through Quantum Key Distribution [QKD]. The EUROQCI infrastrucutre requires dark optical fibers which is similar requirements for CLONETS Reaserch Infrastructure. Estimates of the cost of acquiring dark fiber settle at around 50% of the cost of building the entire T&F dissemination network, so building a shared infrastructure based on dark fiber seems very attractive. Possible synergy scenaroius was described in D3.1 [D3.1].

An interesting initiative that offers opportunities to support CLONETS Research Infrastructure seems to be the CEF-2 program, especially areas of support for the development of communications technologies, for which CLONETS Research Infrastructure may be a synchronization core network for 5G telecommunication networks.

It should be noted that without the support of the European Commission in programs that enable the development of modern, advanced services at the European level, it seems extremely difficult to build an advanced T&F dissemination network such as CLONETS Research Infrastructure.

4.2 National Level Activities

The CLONETS Research Infrastructure will be a core network for time and frequency dissemination and overall synchronisation of national research infrastructures for time and frequency signal dissemination over the whole continent. It is extremely important to cooperate with these NMIs to ensure that T&F signals are available to as many potential users as possible.

In countries where T&F networks have less coverage, work should be undertaken to expand and develop them. An important element to the development of these networks is the cooperation of NRENs with NMIs and time and frequency laboratories, since NRENs can provide access to the transmission network, and NMIs and labs can provide access to time and frequency signals. Without close cooperation between these entities, it seems impossible to build an extensive national time and frequency distribution network. National programs should be sought to enable funding for National Research Infrastructures for Time and Frequency Signal Dissemination.

Important is bilateral cooperation between countries and the construction of cross-border links for time and frequency transmission. Such connections can provide in the future, the basis for expanding CLONETS Research infrastructure. Such connections can be realized through cooperation between NMIs, or between NRENs.

4.3 Participant Level Activities

Cooperation between partners was very good during the Project. As a result, participants were able to deliver a Memorandum of Understanding (MoU) to establish ongoing cooperation after end of the CLONETS-DS project, with the long-term goal to build the CLONETS Research Infrastructure. New entities interested in developing the T&F dissemination network can also join the MoU in the future.

At this point, prior to further policy development, participants should focus on raising awareness of precision time and frequency services among users. It is necessary to conduct lectures, speeches or present the results of the CLONETS-DS project at scientific conferences. In addition, users interested in accessing precise time and frequency signals should be sought out and invited to join the growing community.

The partners are constantly working on improving transmission technologies and developing T&F distribution networks, as well as on developing the time and frequency sources themselves - atomic clocks. This work makes it possible to achieve ever greater precision in transmitted signals. In cooperation with the project leader, GÉANT, the launch of a T&F network demonstrator is planned, which will allow to test and validate the solutions developed in the CLONETS-DS project.

5 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, the CLONETS Research Infrastructure, 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, etc.

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. Practical steps towards building this network can be identified that are relevant to user needs and corresponding investment. Such relevance will only strengthen the impact of the future network and sustainability of this community.

References

[GNSS-JAM]	https://www.maritimeglobalsecurity.org/media/1043/2019-jamming-spoofing-of-gnss.pdf
[FAILURE]	https://insidegnss.com/lessons-to-be-learned-from-galileo-signal-outage/
[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
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[EMPIR]	https://www.euramet.org/research-innovation/research-empir
[ERA]	https://research-and-innovation.ec.europa.eu/strategy/strategy-2020-2024/our-digital-future/european-research-area_en
[ESFRI]	https://www.esfri.eu/
[EuroQCI]	https://digital-strategy.ec.europa.eu/en/policies/european-quantum-communication-infrastructure-euroqci
[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