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Stakeholder Workshop

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Abstract
This document summarises the CLONETS-DS "Workshop on Time and Frequency for European Science" that took place from 13 to 15 September 2021.

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Executive Summary

After 12 out of 24 months of the CLONETS-DS project, an in-person workshop and meeting took place from 13 to 15 September 2021 at the Physikzentrum (physics center) in Bad Honnef, Germany. The aim of the meeting was to bring together as many members of the CLONETS-DS consortium as possible, which consists of 18 partners from 8 countries, as well as stakeholders from a variety of fields that would benefit from a European time and frequency network.

Thanks to the advancing Covid-19 vaccinations in Europe, most of the consortium partners managed to attend in person, with a total of 22 people making it to the workshop. An additional 25 stakeholders managed to travel to Bad Honnef, with several short notice cancellations. Up to 10 additional consortium members or external stakeholders attended virtually in a hybrid format whenever possible.

Over the course of three days, the members and stakeholders discussed eight science cases that would benefit from an ultrastable time and frequency network: fundamental science, quantum technology, optical clock research and SI units, geodesy, astronomy, navigation/Global Navigation Satellite System (GNSS), telecom, and dissemination of reference frequencies to the general scientific community.

Through discussions in sub-groups, topics for which no existing solutions or alternatives are available were identified. These sub-topics of the eight science cases emphasise the need for an ultrastable time and frequency network in Europe to enable further advancements.

On the final day, delegates from the European Strategy Forum on Research Infrastructure (ESFRI) were invited to learn about CLONETS-DS and discuss future possibilities. The discussions resulted in valuable outcomes about funding possibilities and next steps.

1 Introduction

This document reports on the first CLONETS-DS project workshop, which was held from 13 to 15 September 2021 in Bad Honnef, Germany. The objective of the workshop was to bring together the CLONETS-DS consortium, consisting of 18 partners from 8 countries, along with stakeholders from a variety of fields such as fundamental science, quantum technology, geodesy, and so on.

Section 2 provides an overview of the workshop preparation, including the science cases that were identified to benefit significantly from a stable time and frequency network.

Section 3 details the three days of the workshop and highlights the outcomes of the discussions of the science cases.

Finally, Section 4 draws conclusions on the workshop and its findings.

2 Preparation

Project participants spent several months preparing for the CLONETS-DS project workshop. The time and location of the workshop was chosen to allow as many people as possible to attend in person despite the constraints of the COVID-19 pandemic. However, remote access via a video transmission was also available to anyone who could not attend in person.

Project participants selected the participants of the CLONETS-DS workshop from a list of more than 100 external time and frequency stakeholders. Each person received an email invitation and attendee form. The template of the email was prepared by CLONTES-DS participants. The project participants also decided to invite ESFRI [ESFRI] delegates to gain insights into the next steps of such a European-wide project.

The workshop was scheduled to begin on the afternoon of 13 September and end on 15 September [Workshop].

In the months leading up to the workshop, the CLONETS-DS consortium met virtually to discuss potential beneficiaries of a time and frequency network, and eight science cases were defined that need precise time and frequency signals:

- Fundamental Science
- Quantum Technology
- Optical clocks and SI units
- Geodesy
- Astronomy
- Navigation and GNSS
- Next Generation Telecom Networks
- Dissemination of reference frequencies to the general scientific community

The workshop program was prepared based on these science cases.

Figure 2.1: Workshop program page 1

Figure 2.2: Workshop program page 2

3 Workshop

The workshop took place at Physikzentrum Bad Honnef in Bonn.

3.1 Day One

After the registration, Dr. Ronald Holzwarth, managing director of Menlo Systems, welcomed the workshop stakeholders. Next, Dr. Harald Schnatz, head of the Quantum Optics and Unit of Length Department at the German national metrology institute PTB, gave a presentation on "Time & Frequency Transfer via optical fibre and current plans for CLONETS architecture". After that the eight science cases that were identified by the CLONETS-DS project as needing precise time and frequency signals were briefly presented:

- Fundamental Science – by Dr. Ronald Holzwarth (Menlo Systems, Germany)
- Quantum Technology – by Dr. Cecilia Clivati (INRIM, Italy)
- Optical clocks and SI units – by Dr. Harald Schnatz (PTB, Germany)
- Geodesy – by Prof. Simon Stellmer (University of Bonn, Germany)
- Astronomy – by DR. Philip Tuckey (Observatoire de Paris, France)
- Navigation and GNSS – by Prof. Urs Hugentobler (Technical University of Munich, Germany)
- Next Generation Telecom Networks – by DR. Łukasz Śliwczyński (AGH, Poland, via video conference)
- Dissemination of reference frequencies to the general scientific community – by Dr. Vladimir Smoltacha (CESNET, Czech Republic)

3.2 Day Two

Day two of the CLONETS-DS workshop focused on science case development with stakeholders. In the first half of the day, participants were divided into eight teams, one for each science case. The groups discussed how CLONETS-DS could benefit their research field, as well as next-generation applications with CLONETS-DS. In the afternoon, summaries of the various discussion groups were prepared, and the results presented by the leaders of each group.

The discussions with the stakeholders were very valuable. The sub-topics of the eight science cases were considered in detail, to find out whether a time and frequency network would be essential, nice to have, or unnecessary since existing technology already meets the requirements.

3.2.1 Science Case: Fundamental Science

The team discussing Fundamental Science soon realised that a time and frequency network would be essential to answering some of the universe's biggest questions. For example, current precision spectroscopy, which is being performed on anti-matter at CERN, is nearly at the limit of commercially available frequency sources such as masers and Cesium clocks. Therefore, a time and frequency network with absolute frequencies at levels several orders of magnitude better than these atomic clocks would allow much higher precision in the spectroscopy. Such fundamental experiments are needed to confirm theories. Furthermore, dark matter research would benefit greatly from a network of optical atomic clocks, with comparisons between the clocks being carried out. Tests of relativity would be greatly enhanced. High-resolution molecular spectroscopy requires frequency references that are better than those commercially available, and new physics with isotope shifts could reveal changes in the nuclei of atoms if such a network were available in the future.

3.2.2 Science Case: Quantum Technologies

The past years have brought quantum technology into the foreground – especially the four pillars of quantum communication, quantum simulation, quantum computing, and quantum sensing and metrology. In the discussion it became clear that various use cases would greatly benefit from a stable time and frequency network. A phase-stable optical reference via fibre would allow the labs to avoid local ultrastable cavities, thereby improving scalability, and improving synchronisation between sites for higher detection rates in quantum communication. Some new cryptographic primitives (e.g., in blind computing) take advantage of superior phase coherence, making a stable network necessary. A shared use of dark fibres for quantum communication and stable time and frequency transfer would be ideal in terms of setting up the infrastructure.

3.2.3 Science Case: Optical Clock Research and the SI-Unit "Second"

This science case is one of the driving forces of time and frequency links between remote laboratories. Since optical clocks that are based on various species of atoms are still being researched worldwide, it is critical to analyse their behavior at the highest level via clock comparisons. Even smaller labs that work on developing their own optical clocks could benefit from a more stable clock laser derived from the CLONETS-DS signal. The future re-definition of the SI-second will require in-depth analysis of all current and future candidates (e.g., Strontium lattice, Ytterbium-ion, and many more). The measurements will include comparisons between similar and vastly different clocks using ratio measurements in many labs at remote locations.

3.2.4 Science Case: Geodesy

The field of geodesy has become interested in ultrastable clocks, since these are within the 10^{-18} level of accuracy, which means that the gravitational red-shift of a 1 cm height difference can be measured in the gravitational potential of earth. Stable frequencies in a network can thus be used for important applications such as height system unification – as even countries within Europe do not have a unified height system with the same zero-level. Absolute height measurements and a unified system would eliminate these problems. Furthermore, satellite gravity missions that measure the Geoid could be verified and improved greatly with a dense network of ground measurements based on these measurements, which are critical for monitoring climate change as well as sea-level changes.

3.2.5 Science Case: Astronomy

Initial experiments have been conducted by consortium members on highly accurate very long baseline interferometry (VLBI) setups [VLBI]. VLBI experiments require high short-term and long-term synchronisation between remote sites. Here a stable time and frequency network is crucial to really benefit from all the individual sites. Additionally, long-term radioastronomy measurements of the times of arrival (dating) of pulsar pulses give access to the physics of the sources, tests of general relativity, search for low-frequency stochastic gravitational wave backgrounds, and pulsar timescales. In gravitational wave detection, ultrastable radio frequencies and optical frequencies are required. Some ideas that were brought up included synchronisation between distant sites, which would allow multi-messenger type configurations and further enhance the measurement capabilities.

3.2.6 Science Case: Navigation

Satellite-based navigation systems require very precise ground-stations with reference clocks at the 10^{-16} level. Improved comparisons of another order of magnitude better than that are necessary for ideal operation. For the future, optical clocks are foreseen, making 10^{-18} comparisons vital. Reference frames for both time and frequency are needed, and for creating them the network would be ideal. Other concepts that were discussed were a GNSS backup for sea navigation by transmitting very precise time signals from the ground for triangulation and crucial navigation, especially in low visibility environments.

3.2.7 Science Case: Telecom

For high-speed telecommunication, both time and frequency from a single source is compulsory. With ever-increasing data rates, data transmission, and 6G and beyond, requirements are getting more stringent. Traceability to UTC is also required in most cases. Since a telecom is a service provider, telecommunication requires high reliability, robustness, resilience, management, and operability. The immediate use of a time and frequency network would be the supervision of the current synchronisation network.

3.2.8 Science Case: General Reference Frequencies

Many other fields and applications would benefit from the CLONETS-DS network. This could include accelerator timing, where long-term stable timing and time stamping is valuable for applications such as x-ray-based experiments. Laser calibration in laser development would benefit from a stable and accurate source to compare systems to, as well. Other fields such as length metrology, atmospheric sensing and greenhouse gases, microwave optics, and interferometry are currently not necessarily limited by the references available.

3.2.9 Poster Session

Participants were invited to bring posters about their field of research to the conference, which around 20 people did. This resulted in hours of interesting discussions about the benefits of a stable time and frequency network which lasted all evening.

Figure 3.1: Poster session

3.3 Day Three

The third day was dedicated to presentations and discussions with delegates from the European Strategy Forum on Research Infrastructure (ESFRI). These were invited a few weeks before the workshop using the flyer shown in Figure 3.2.

Figure 3.2: ESFRI Delegate Invitation Flyer

The three ESFRI delegates or associated people that joined (one in-person, two virtually) were Martin Vyšinka (Ministry of Education, Youth and Sports, CZ), Jean-Marie Flaud (French Ministry of Research, FR), and Marc Hempel (DESY, DE).

After a welcome of the ESFRI Delegates, Dr. Harald Schnatz from PTB gave a presentation about "European projects on Time and Frequency Transfer via optical Fibers", followed by a summary of the science cases by Dr. Ronald Holzwarth. The discussion with ESFRI delegates started next.

Some interesting insights and ideas were gained from this discussion with the delegates. Discussion about such a time and frequency network and its benefits on the national level should be enforced. Preparation of national parts of the infrastructure for national roadmaps for different scenarios should be considered by the CLONETS-DS consortium. The delegates also recommended that strong emphasis should be placed on the cooperation with stakeholders, highlighting the benefits to their applications. For an ESFRI application, particular sections should be strengthened (e.g., excellence, social impact, financial, and so on). A survey of other ways of funding this would be beneficial (e.g., structural funds, recovery funds, or other national options). CLONETS-DS will need to emphasise that the planned infrastructure network is much more than just a collection of atomic clocks.

Figure 3.3: Plenary session

4 Conclusions

In spite of the limitations due to COVID-19, the CLONETS-DS workshop was very successful. Discussion with stakeholders helped the CLONETS-DS project team to understand the issues related to access to time and frequency signals from the stakeholders' point of view.

Also, a discussion with the ESFRI delegates showed what requirements CLONETS-DS must meet to apply to ESFRI.

The in-person discussion, and several days of joint meals and social aspects helped strengthen the relationships between consortium members and the scientific community.

The next steps in the CLONETS-DS project include a detailed summary of the science cases based on the discussions and findings from this workshop, as well as technical discussions of how the requirements of the stakeholders can be met and how the infrastructure could be implemented.

References

[ESFRI]	www.esfri.eu
[Workshop]	https://clonets-ds.eu/?p=205
[VLBI]	"Common-clock very long baseline interferometry using a coherent optical fiber link," Clivati et al., *Optica* **7**, 1031 (2020)

Glossary

ESFRI	European Strategy Forum on Research Infrastructure
GNSS	Global Navigation Satellite System
SI	International System of Units
UTC	Coordinated Universal Time
VLBI	very long baseline interferometry