CLONETS-DS: Clock Network Services-Design study

Strategy and innovation for clock services over optical-fibre networks

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CloNetS DS
Clock Network Services Design Study

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Outline

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- Current needs
- Participants of CLONETS-DS, coordinator
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Introduction to the field

- Today, very common access to high-performance time and frequency is provided by Global Navigation Satellite Systems, such as GPS, GLONASS, Galileo, or more recently BEIDOU.
- However, **optical frequency and time distribution (OFTD) via optical fibre** of such reference signals **outperforms satellite-based technology** by orders of magnitude over continental scales with significantly reduced measurement time and unprecedented uncertainty.
- OFTD opens the way to novel applications in fundamental research and to many other also commercial fields.

Current needs for OFTD

- The **scientific potential** to be targeted by OFTD, e.g. :
  - optical clock comparisons
  - search for dark matter or the variation of fundamental constants
  - tests of Quantum Electro Dynamics (QED)
  - general and special theory of relativity
  - in applied science e.g. the novel field of chronometric levelling, detection of earthquakes, or environmental hazards and climate change
  - OFTD also performs the basis for novel applications with **social impact**, e.g.:
    - sustainable energy grids
    - financial markets
    - next generation mobile telecommunications networks
    - and more..

Current needs for OFTD

- Now, there is excessive dependence of critical infrastructures on GNSS, and radio signals and receivers are vulnerable and backup system is not in place.
  - This lack shown for example by almost week-long outage of the European GNSS Galileo incident on June 2019 due to a major technical error. As no European backup system is in place users had to be reverted to the US positioning system GPS.

- The OFTD benefits have already been demonstrated in a variety of ground-breaking experiments using dedicated point-to-point connections mostly on national level, however lacks resources for multi-user continuous operation on pan-european scale.

Current needs for OFTD

Navigation

Transport

Power Grids

Finance

Defence

Security

Telecommunication (ICT)

Science

Participants

- NMI
- NREN
- Academia
- Industrial
- Third parties

1 **NETHERLANDS**
- GEANT VERENIGING

2 **FRANCE**
- CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS
- RENATER
- UNIVERSITÉ SORBONNE PARIS NORD
- MUQUANS

3 **ITALY**
- INSTITUTO NAZIONALE DI RICERCA

4 **GERMANY**
- PHYSIKALISCH-TECHNISCHE BUNDESANSTALT
- MENLO SYSTEMS GmbH
- TECHNISCHE UNIVERSITAET MUENCHEN
- RHEINISCHE FRIEDRICH-WILHELMS-UNIVERSITAT BONN

5 **UNITED KINGDOM**
- UNIVERSITY COLLEGE LONDON

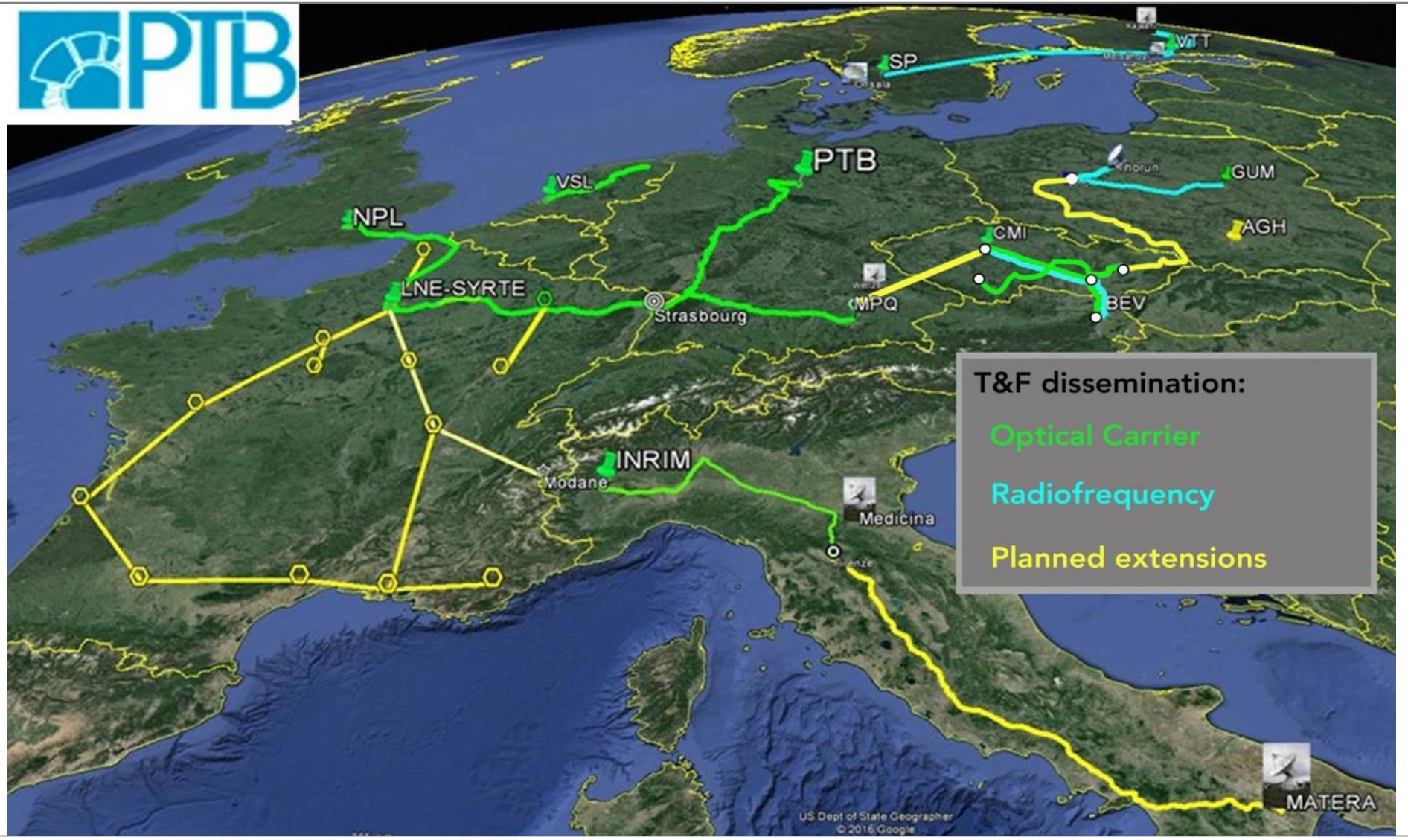
6 **CZECH REPUBLIC**
- CESNET, z.s.p.o.
- USTAV PRISTROJOVE TECHNIKY AV CR, v.v.i.

7 **POLAND**
- POZNANSKIE CENTRUM SUPERKOMPUTEROWO-SIECIOWE
- PIKTIME SYSTEMS sp. z o. o.
- AKADEMIA GORNICZO-HUTNICZA IM. STANISLAWA STASZICA W KRAKOWIE

8 **SPAIN**
- SEVEN SOLUTIONS S.L.
- UNIVERSIDAD DE GRANADA

Participants

- NMI
- NREN
- Academia
- Industrial
- Third parties



Participants coordinator: GÉANT

CloNetS DS
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Conjunction with other projects

- CLONETS-DS builds on several joint European projects such as EMRP projects NEAT-FT, Ion Clock, Surveying and ITOC, the EMPIR projects OFTEN, TIMEFUNC, OC18, and TiFOON, the Horizon2020 project ICOF.

- Direct precursor: CLONETS project (Jan 2017- Sept 2019)
  - The former project addressed the technical performance and explored the limits of the technology.
  - CLONETS-DS (Oct 2020 - Sept 2022): focuses on strengthening the coordination among research infrastructures (RI), NREN and industrial partners.

- The plan for CLONETS-DS: to go far beyond and expand existing fibre link technology by new concepts of supporting simultaneous measurement by multi-user, multi-service technology.

The precursor: CLONETS project

- European Union funded coordination and support action intended to facilitate the vision of a sustainable, pan-European optical fibre network for precise time and frequency reference dissemination.

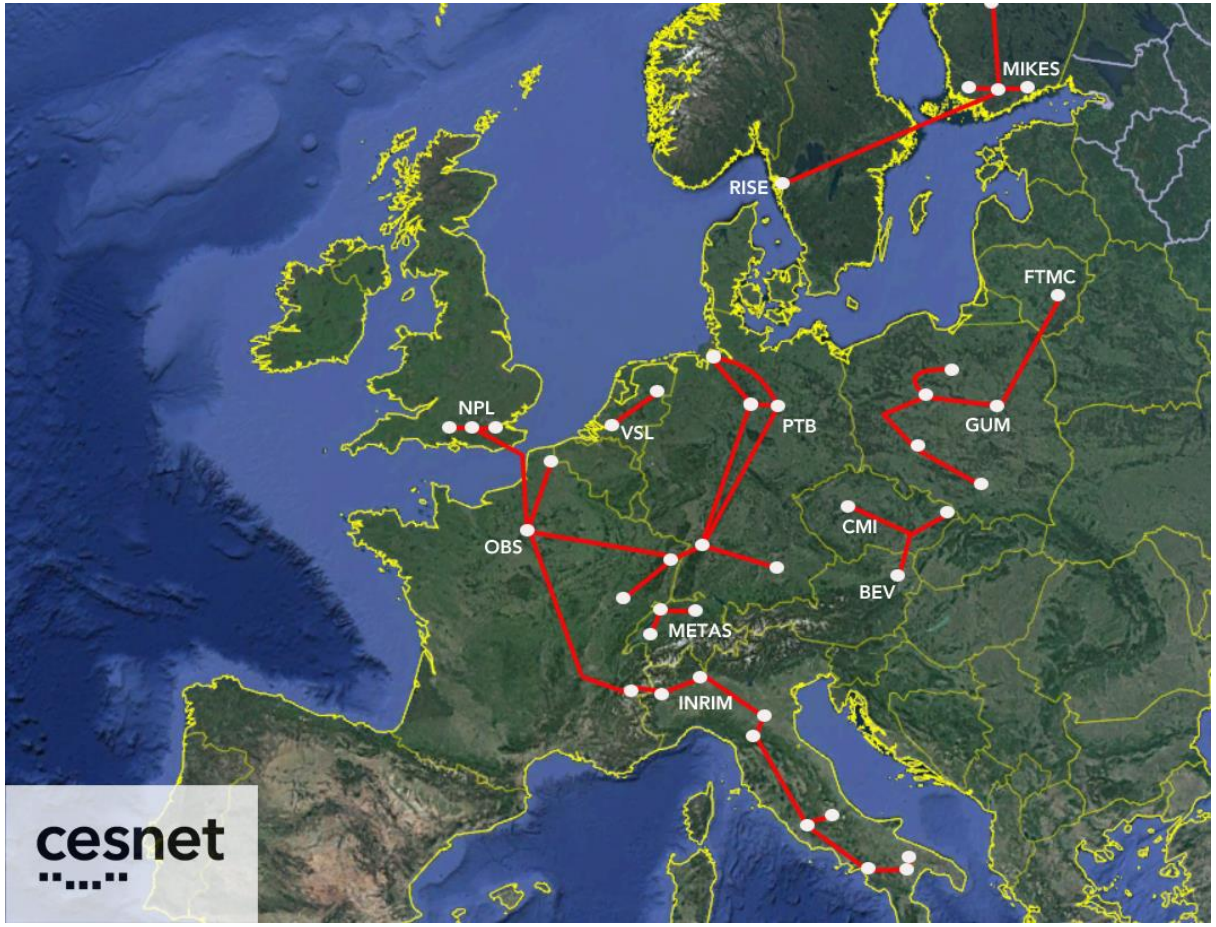
- It was the first step to create a long-term operating framework for interconnection of a number of fibre links for time and frequency transmissions which have been developed and are separately operational in several countries in Europe.

- 16 international participants, 3 partners. Heterogeneous environment, various needs.

- Results: Available techniques, and also other very information has been gathered about any possibilities, and within the surveys the needs have been summarized, not only for NRENs but also for commercial market.

The precursor: CLONETS project

- http://www.clonets.eu/clonets-summary.html



			Existing advanced techniques	Performances Frequency (instability) Time (precision, Time Deviation TDEV)	TRL	Distances
FREQUENCY	Optical Carrier (Carrier Wavelength)		Active cancellation	10^{-15} @1s ; 10^{-20} @1d	8	>1000 km
	RF Carrier (Modulated Wavelength)		Active cancellation with optical delays	10^{-14} @1s ; 10^{-18} @1d	4	0-100 km
			Active cancellation with electronic delays (ELSTAB)	10^{-13} @1s ; 10^{-17} @1d	8	500-1000 km
				10^{-16} @1d (unidirectional)	8	>1000 km
			White Rabbit PTP	10^{-15} @1d (unidirectional)	8-9	>1000 km
			Phase conjugation	10^{-19} @1d	5-6	0-100 km
TIME	Two-way comparison			TDEV ≈ 2 ps	5-6	100-500 km
				TDEV ≈ 30ps calibration through GPS (unidirectional)	6	100-500 km
	Optical frequency comb			Calibration uncertainty <40 ps TDEV 500 fs @1s	4-5	0-100 km
	Active cancellation with electronic delays (ELSTAB)			TDEV < 1ps calibration uncertainty <40 ps	8	>1000 km
	Protocol based (White Rabbit PTP)			Verified with GPS disagreement ±2 ns	8-9	>1000 km
				Calibration uncertainty <10 ns	8-9	0-100 km

The precursor: CLONETS project

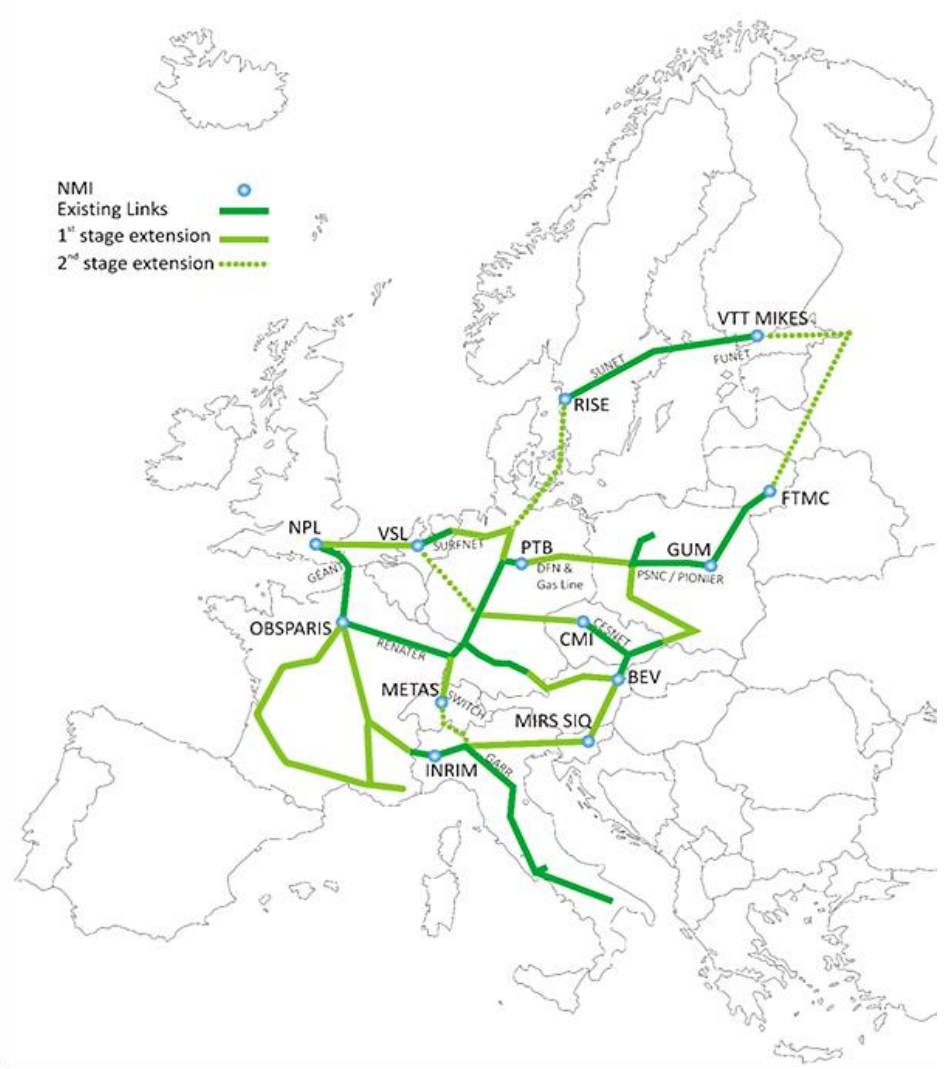
- Potential extension of existing links, see map:

- The communication link layer:
  - *'dark fibre'*
  - *'dark channel'*
  - *'DWDM channel*

- Alien Wavelength/Spectrum Services

  (for DWDM channel and dark spectrum)

- Among other things, the project produced best practice guide by involved NRENs with the utilization of "Alien Wavelength" or "Alien Spectrum" methods for time and frequency transfer over *'DWDM channel'* and *'dark spectrum'.* It also summarizes constraints and considerations for deployment of such techniques in other networks.



CLONETS-DS, intentions, aims

- The project aims to prepare the deployment of OFTD technology to create a sustainable, pan-European time and frequency reference system for European research infrastructures in the first place, that in parallel will allow to support to a multitude of lower-performance.

- We will extend these activities and prepare a design study that considers user needs, designs the required architecture, engineering models and roadmaps, and develops a sustainability model for the future service (including costs, prices, and potential clients), thus strengthening the European research area. In a parallel effort we will add this project to the ESFRI listing of the EU.

- **http://clonets-ds.eu/**

Objectives, work plan

- Elaborating the needs of the scientific community for ultraprecise timing and frequencies distinct fields of research (tests of fundamental physics, metrology and optical clock comparisons, geodesy and/or very long base line interferometry (VLBI), telecommunication, and navigation.

- Defining an architecture that supports T&F services at the highest, most advanced level of stability and accuracy without interdependencies to allow parallel use by various scientific communities and multiple users at the same time.

- Designing an engineering model as well as a deployment strategy that assure interoperability of already existing implementations at European level and possible future extensions including the creation of a Data Management Plan to ensure that all envisioned users profit from a common data platform in an appropriate way.

Objectives, work plan

- Defining roadmaps and strategies to implement a sustainable research infrastructure including a costing model, a proposal for governance, plans for efficient dissemination and exploitation in order to estimate potential future economic and societal impact.

- Strengthening the European research area by elaborating plans for the integrations of the necessary environment into the European landscape. Taking the necessary steps towards the implementation into the ESFRI strategy.

Work packages

- **Work package 1** focuses on the scientific work as Time and Frequency use-cases. With this input requirements are extracted, and operation models are defined. Finally, the time and frequency service provided by the proposed Research Infrastructure to the scientific community are defined.

- **Work package 2** focuses on the technical realization, based on the findings of WP1, on implementing the time and frequency reference system, working out a system architecture and covering all related technical aspects. This includes hardware considerations, conceptual considerations, cooperation with national networks, as well as processing, analysing data provided by the system.

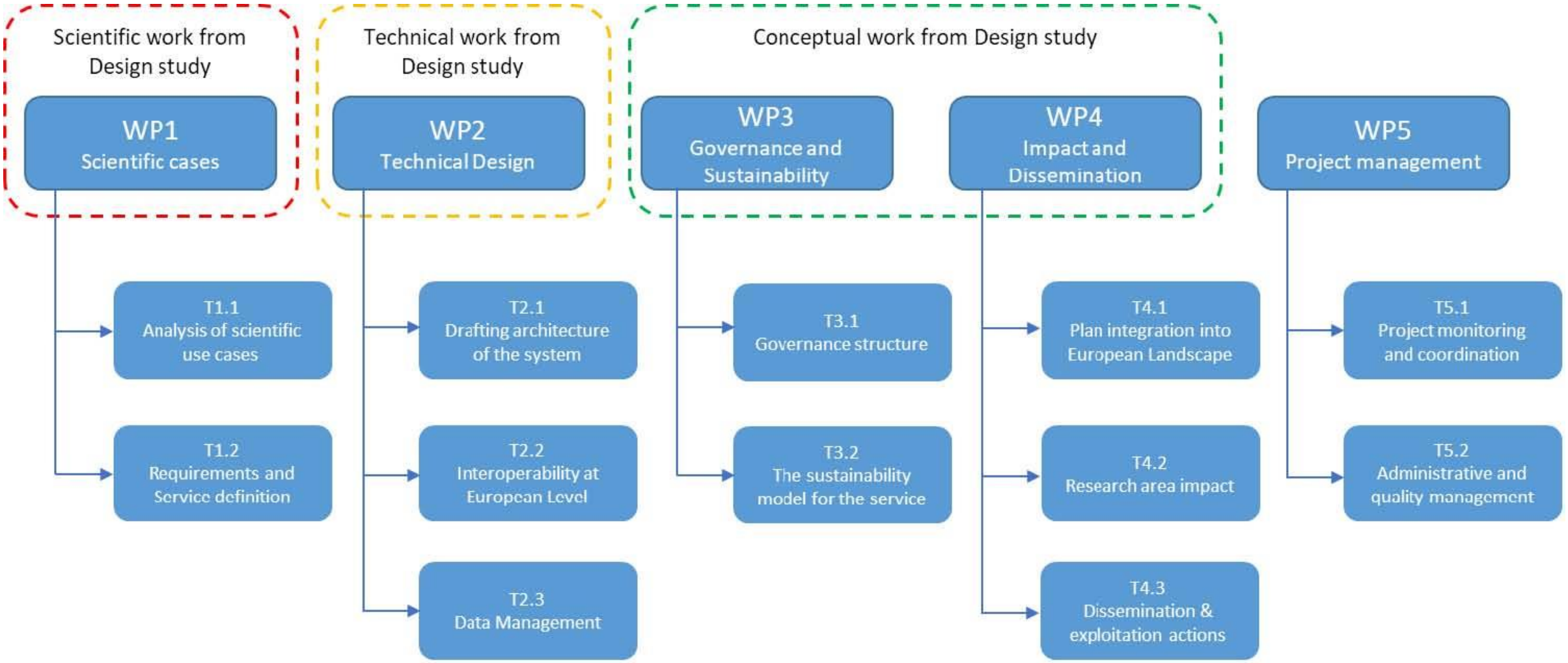
- **Work Package 3** concentrates on all governance issues related to the proposed research infrastructure.

Work packages

- **Work Package 4** focuses on creating impact and disseminating the results of this project and thereby promoting the proposed research infrastructure in the best possible way. It covers the governance structure of the system, sustainability model for the services, and plans the integration into the European Landscape.

- **Work Package 5** – Project management runs parallel with the others work packages and is responsible for management, coordination and reporting during the project.

Work packages



The survey, current needs

We have made a survey of needs, regarding the stakeholders and all the participants at all, and these are the results at the moment:

Ambition

- This project is dedicated to lay the foundations for the implementation of high-performance, pan-European time and frequency (T&F) service using an optical fibre infrastructure.
- On a worldwide scale, Europe has the highest density of the best atomic clocks and is leading in time and frequency related research and applications with cutting edge industrial leaders.
- Europe is in a unique position to play a leading role in redefining the SI second, and novel uses in a wide range of scientific disciplines, from tests of fundamental physics to earth observation.

    - This excellent basis should be used and secured in order to boost Europe in its current leading position in research and bring its industry to the highest level, in order to respond to the future challenges of the next generation industry for the benefit of European society and its industry by setting up the necessary infrastructure.

Ambition

- The provided time and frequency information available at the strategic end points will be used by national countries, private consortia and companies, or other organizations according to their priorities.
- This will create synergies, harmonize the developments and increase the efficiency of implementation of an effective T&F-service over fibre networks.

  - available clock signals from world class optical atomic clocks to every researcher
  - proposing a network architecture with a clear choice of technologies and a strategy for the deployment
  - providing the opportunity for training on the job, enabling engineers and technicians to lead the necessary industrial developments and system deployment
  - giving advice to policy makers how to guide industry and public authorities towards the strategic development of new commercial products and how to achieve a sustainable infrastructure that guarantees European leadership in this field and meets today's and tomorrow's societal challenges

Ambition

- The establishment of a pan-European time and frequency dissemination over a fibre-optic network infrastructure, linking not only NMIs but bringing the performance of state-of-the art frequency standards as well as traceable, robust timing at a level of performance exceeding that of GNSS to the wider scientific community and to demanding industrial users.

- The reliable T&F fibre infrastructure is considered to stimulate European industry in various ways:

  - completely independent back-up system secures infrastructure vital to industry in general
  - enables new products and services
  - increases Europe's market share in the development of network-grade commercial T&F devices

Impact

- Impact on fundamental research
- Quantum technology
- Optical Clock research
- Dissemination of reference frequencies to the general scientific community
- Redefinition of the SI second
- More accurate and efficient dissemination of the SI second
- Improving established satellite techniques
- Impact on geodesy, chronometric levelling and height systems
- VLBI applications in Geodesy and Radio astronomy
- Environmental impact
- Impact on navigation
- Enabling technology for innovation

Impact

- **Impact on fundamental research, e.g.:**
  - Quantum Electro-Dynamics (QED), anti-Hydrogen (CERN), many measurements will greatly benefit from the availability of our proposed European time and frequency reference system.
  - Possible violations of the equivalence principle of General Relativity
  - Lorentz symmetry breaking while the earth rotates around the Sun
  - Possible time variation of the electron-to-proton mass ratio or the fine structure constant.

  - The list of stakeholders covers many of Europe's leading scientific institutes, e.g. the European particle accelerator facility CERN (Geneva, Switzerland/France), the Max-Planck-Institute of Quantum Optics (Garching, Germany), or the European Laboratory for Non-linear Spectroscopy (*LENS*) in Florence.

Economic impact

- The Global Navigation Satellite System (GNSS) market
- The telecommunications market
- The energy market and Smart Grid Technology
- Nuclear power plants (NPP)

  e.g. very precise measurements of the containment stability is operated in NPP Temelín, Czech Republic utilizing stable frequency transmission from ISI to the NPP via dedicated DWDM channel

Any questions?

Thank you for your kind attention!

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Project Information
CLONETS-DS
Grant agreement ID: 951886
Status: Ongoing project
Start date: 1 October 2020
End date: 30 September 2022
Funded under H2020-EU.1.4.1.1.