Fostering the Innovation Potential of Research Infrastructures

INFRAINNOV-2-2016: Support to Technological Infrastructures

CLONETS – CLOck NETwork Services
**Strategy and innovation for clock services
over optical-fibre networks**

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Disclaimer

This deliverable has been prepared under the responsible Work Package of the CLONETS Project in accordance with the Consortium Agreement and the Grant Agreement n° 731107. It solely reflects the opinion of the parties to these agreements on a collective basis in the context of the Project and to the extent foreseen in these agreements.

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LIST OF ACRONYMS AND ABBREVIATIONS

CLONETS	CLOck NETwork Services: Strategy and innovation for clock services over optical-fibre networks project
NMI	National Measurement Institute
NREN	National Education and Research Network
TF	Time and Frequency

LIST OF PROJECT PARTNER ACRONYMS

AGH / AGH-UST	Akademia Górniczo-Hutnicza im. Stanisława Staszica w Krakowie, Cracow, Poland
CESNET	CESNET, zájmové sdružení právnických osob, Prague, Czech Republic
CNRS[*]	Centre National de la Recherche Scientifique, Paris, France
INRIM	Istituto Nazionale di Ricerca Metrologica, Turin, Italy
GARR[#]	Gruppo per l'Armonizzazione delle Reti della Ricerca, Rome, Italy
Menlo	Menlo Systems GmbH, Martinsried, Germany
Muquans	Muquans, Talence, France
NPL	National Physical Laboratory, Teddington, United Kingdom
OBSPARIS[¶]	Observatoire de Paris, Paris, France
OPTOKON	OPTOKON a.s., Jihlava, Czech Republic
Piktime Systems	Piktime Systems sp z o.o., Poznan, Poland
PSNC	Instytut Chemii Bioorganicznej Polskiej Akademii Nauk – Poznańskie Centrum Superkomputerowo-Sieciowe, Poznan, Poland
PTB	Physikalsch-Technische Bundesanstalt, Braunschweig, Germany
RENATER	Groupement d'interêt Public pour le Reseau National de Telecommunications pour la Technologie, l'Enseignement et la Recherche, Paris, France
SEVENSOLS	Seven Solutions S.L., Granada, Spain
TOP-IX	Consorzio TOrino Piemonte Internet eXchange, Turin, Italy
UCL	University College London, London, United Kingdom
UP13	Université Paris 13, Villetaneuse, France
UPT AV CR (ISI)	Ustav Pristrojove Techniky AV, v.v.i., Brno, Czech Republic

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EXECUTIVE SUMMARY

This document describes the dissemination and exploitation plan of the CLONETS project, which has been put in place to ensure the maximal impact of the project. The dissemination and exploitation activities have continuously taken place throughout the project's duration with the plan being updated in accordance with the project's evolution, i.e. the progress made and the results obtained.

The project has utilized various different communication tools and channels. It has created a logo and project templates to facilitate the recognisability of the project's outputs, established a website as a communication platform and produced numerous materials with different levels of technical complexity depending on the targeted audience (posters, presentations, training materials, positioning paper, newsletters, etc.). (Section 2)

The project partners have attended a variety of different conferences and stakeholder meetings, at which they presented CLONETS and interacted with potential users and stakeholders. Additionally, the project has worked towards gaining support from stakeholder's consultative/executive bodies and committees and policy makers through presentations and discussions with international and European instances in metrology and science, as well as direct executive-level contacts with some research network providers. (Sections 3.1, 3.2, 3.3)

Acknowledging the importance of training, the project partners have participated in various training events, including seven regional training events organized by the project. The project has also supported the creation of a Master's Programme. Although the Master's Programme was cancelled at the last minute due to low enrolment together with visa rejections, the content and format of the programme remain relevant. Further, the contacts made during the preparation of the programme contributed to the impact of the project. (Section 3.4)

The interactions with potential user communities and stakeholders throughout the project have allowed the project partners to present the technological possibilities a fibre based TF service offers, provide technology recommendations regarding its implementation into a fibre network, better understand the needs of potential user communities, remain aware of the most recent developments in telecommunications and exchange good practices (Section 4).

The dissemination and exploitation plan of the project consists of five points aimed at maximizing the project's impact: knowledge management, dissemination to users and stakeholders, training, advice to policy makers and seeking resources for future development phases. These points remain relevant and serve as a guideline for the continued exploitation of the project's results beyond its duration. (Section 5)

The main direct economical and societal impact of the project will ultimately follow through the deployment, operation and exploitation of the TF optical fibre infrastructure and the consequent scientific advancements, innovations and technological developments that will be triggered. The project, however, has taken crucial first steps towards this goal and has produced some initial impact. In particular, the communication, dissemination and exploitation activities have benefited the TF community by giving it more visibility, strengthening collaborations and creating new synergies. The project has produced TF technology reviews and recommendations, which serve as a reference for anyone interested in TF services over optical fibre (Section 6).

1 INTRODUCTION

The CLONETS project has brought together National Metrology Institutes (NMIs), university research groups, National Research and Education Networks (NRENs), an internet exchange and innovative high-technology companies, whose various fields of expertise are necessary for understanding the technical problematics of generating and disseminating time and frequency (TF) reference signals over long distances in optical fibre. It has made first strides towards the creation of high-performance, pan-European TF services over optical fibre networks - the ultimate goal of the project partners. The communication, dissemination and training activities of the project have contributed towards this goal.

2 COMMUNICATION AND DISSEMINATION TOOLS

2.1 Project Logo

The project logo is an essential tool in the communication and dissemination of the project and its results. It is a visual representation of the project and allows for an easy identification of the project's outputs. The logo was therefore designed and agreed on by Consortium partners within the first three months of the project. Subsequently, it has been used in all communication and dissemination materials, including reports, leaflets, posters and presentations, etc.

2.2 Project Templates and Information Materials

For consistency in style and format, various different templates (e.g. reports, presentations, posters and leaflets) incorporating the logo were created and made available to the Consortium through the internal file sharing tool for use in the project's communication and dissemination activities. The common presentation and poster templates were finalized in December 2017 in conjunction with the establishment of a repository of training, presentation and information materials (Section 3.4.1 and Deliverable D4.3).

Throughout the project, general materials for stakeholders' information (e.g. leaflets, posters, etc.) were prepared, updated and added to this shared repository, in accordance with the project's communication and dissemination activities and the targeted audiences. Additionally, a positioning paper has been prepared presenting the interest of TF over optical fibre services and providing more complete information for policy makers. The relevant informational material on CLONETS has been made available to the public through the project's website.

2.3 Website

A project website was created to facilitate the communication and dissemination of the project and its results to a wider public. The CLONETS website (http://www.clonets.eu) has been available since February 2017 and includes both a public and a restricted (internal) domain. The public part of the website provides general information on the project and its objectives and contains public documents and dissemination material produced throughout the project. Regular updates guarantee that interested stakeholders remain informed on the project's main activities and outcomes. The restricted internal area, accessible only by password-protected registered users, is dedicated to information share and exchange between consortium members and potentially other relevant stakeholders and communities (Deliverable D4.1).

2.4 Newsletters

The project has also produced a series of electronic newsletters, which summarize recent results of the project and announce the project's training events. The newsletters are made available on the project's website and sent out to interested parties (Deliverable D4.6).

3   COMMUNICATION, DISSEMINATION AND TRAINING ACTIVITIES

3.1   Conference Attendance Plan

Throughout the project duration, the project participants have attended a series of relevant stakeholder's conferences and workshops. A large number of conference presentations on the general subject of the project have been made, including at least eighteen presentations specifically on CLONETS, of which 8 have now been published as conference proceedings. Two conferences have shared the presentation slides ("12th Service and Technology Forum (STF)" and "ACES Workshop"). Through this activity, the project participants have been able to raise awareness of CLONETS, present its latest results, inform potential users on the possibilities a TF service over optical fibre can offer and encourage them to express support for the development of such a service. Additionally, it has provided CLONETS the opportunity to keep up to date with the latest developments not only in TF transfer but also in the potential user communities. Consequently, CLONETS has gained a better insight into the needs of potential users and the requirements they might impose on the establishment on of a pan-European TF service over optical fibres, for example in terms of type of signal, performance and geography.

The detailed conference attendance list is given in Table 1 in the Annex.

3.2   Dissemination Events

In addition to the attendance and participation to scientific conferences and workshops, the project partners also carried out a variety of communication activities focusing on stakeholders in technology and industry. The activities included participation in trade fora, lectures on TF over optical fibres and the presentation of the CLONETS project and its relevance for industrial applications.

Besides informing these potential stakeholders on CLONETS, it is also crucial for the Consortium to remain up-to-date on the latest trends in industry, in particular in the field of telecommunications. The increasing demand for data and the continuing advances in telecommunications technologies could potentially reduce the willingness to integrate TF services in an optical fibre network and possibly make current metrological TF techniques incompatible with data traffic. It requires a tremendous amount of work to anticipate these new trends.

The detailed list of dissemination events is given in Table 2 in the Annex.

3.3   Reporting to Consultative and Executive Bodies and Committees

The overall vision and the specific issues for an infrastructure of Time and Frequency (TF) distribution over optical fibre have been directly presented to Committees and National and International Bodies capable with their decisions and recommendations to boost the adoption of such an infrastructure and its uptake by different communities (scientific, technological, economical). This includes international and European instances in metrology and science, as well as direct executive-level contacts with some research network providers. A majority of these contacts have concerned scientific and technical bodies, and have undoubtedly contributed to making the CLONETS project conclusions better known and to preparing the way to taking them into account in procedures and recommendations to be adopted by these bodies. More recently, CLONETS members have sought to increase contacts with policy makers, at national end European levels. This aspect certainly needs to be emphasised in the

future, to prepare the way to adoption of a European Research Infrastructure, consideration for inclusion in the ESFRI roadmap and so on.

The complete list of these activities is given in Table 3 in the Annex.

3.4 Training Activities

A sustainable TF optical fibre network across Europe requires researchers and engineers who are knowledgeable and capable in the field of TF transfer over optical fibre networks, in order to ensure not only continuing advancements and innovation in the field but also the deployment, maintenance and operations of the infrastructure. Additionally, it is essential that potential users are well informed on the opportunities a TF optical fibre network can offer them and that they learn how to best exploit such a network for their respective applications. Recognizing its importance, CLONETS has included a series of tasks explicitly focusing on the training of researchers, engineers and potential users. The corresponding training tasks, described in more detail below, serve as a valuable resource for future training activities and their impact reaches far beyond the project itself.

3.4.1 Common Training Materials

The groundwork for establishing common training materials was laid through the production of a training blueprint on the subject of time and frequency metrology and its applications (Deliverable D4.2). This training blueprint outlines a comprehensive training course, which provides a progressive learning pathway from entry to expert level. For the various different learning blocks, it identifies fundamental topics, desired learning outcomes and the target audience. Consequently, it serves as an effective guideline for training activities and allows for a continuing development of training solutions.

Based on this "Time and Frequency Training Blueprint", the Consortium has produced a variety of training materials targeting entry-level audiences as well as experts in time and frequency transfer methods (Deliverable D4.3) and has put in place a library of training presentations readily accessible to the Consortium through the internal file sharing tool. The training materials have been employed in various different training and dissemination events and continue to be a valuable resource for present and future such events, as existing materials are updated and new materials are added to the library.

3.4.2 Training Events

CLONETS has organized 6 regional training events dedicated to students, researchers, engineers and industrial users allowing them to gain a deeper insight into the current state-of-the-art TF transfer techniques over optical fibre networks and their applications. Besides teaching and raising awareness on TF issues, these events have allowed the project participants to interact with potential users, gain further insight into their TF needs and access the further need for dissemination and training activities. Project members have also contributed to other training events not organised within CLONETS itself.

Overall, the project partners have been involved in various different training activities in the field of TF transfer and optical fibre links. These activities are expected to continue after the end of the project. They will benefit from the work done and the experienced gained throughout the project.

The complete list of training activities is given in Table 4 in the Annex.

3.4.3 Master's Programme

One of the project's objectives is to ensure a permanent and effective knowledge transfer to engineers through the implementation of a Master's Programme (Deliverable D4.5). With this objective in mind, CLONETS has supported the creation of a well-structured training opportunity through the establishment of an international second level Specializing Master's Programme in "Photonics for Data Networks and Metrology", appropriate for training

professionals in TF transfer over optical fibre. This Pilot Master was organized by INRIM in close collaboration with the Politecnico of Torino, one of the leading universities in Italy, and in particular with the Department of Electronics and Telecommunications. The Pilot Master's Programme was ready to start in early 2019. The syllabus had been defined, the corresponding lecturers determined and a sufficient number of students were admitted. However, due to an unusually low enrolment rate combined with the rejection of student visa applications, the programme was finally cancelled. The content and format of the Master's Programme remain relevant and can serve as the basis for a future implementation.

4   EXCHANGE OF BEST PRACTICES

For the design of a realistic clock network service, it is important that the CLONETS members understand how telecommunication networks function. At the same time, for the integration of TF signals into a telecommunication network, it is essential that the network engineers and operators understand the technical requirements and challenges this brings and that they are knowledgeable of the existing technical solutions that exist.

Similarly, any end-user that would like to be connected to the clock network service envisioned by CLONETS will need to have a some understanding of the technical aspects of the TF service, as it is unlikely that a simple plug-and-play solution to disseminate metrological TF services will be deployed. Consequently, they will need to understand the type of signals they will receive, the overall necessary architecture to bring the signals to their institute, and more importantly the challenges these two parameters bring.

The communication, dissemination and training activities have enabled exchanges of knowledge, ideas and good practices between project partners and third parties (e.g. NMIs, research institutes, telecommunication networks, industry), that might be involved in future clock network services in some form (e.g. as a service provider, service enabler, end user, etc.).

4.1   Training events

The training events organised throughout the project were good opportunities to discuss directly with various audiences. It should be noticed that there was a high level of interest in the timing requirements for the finance sector and how these requirements are met by the current TF technology. There were even participant-led exchanges on the deployment of TF signals over standard telecoms fibre networks that showed a general awareness of the limitations of current technologies.

Nevertheless the following questions and remarks were identified and we advise that when similar actions are organized in the future, lecturers (and more generally members from Consortium) should be prepared to answer them when interacting with trainees, stakeholders and industrial partners.

4.1.1   General remarks

Concerning the very motivations of the project, there are two recurrent general remarks. Although the significantly improved performances of TF dissemination over optical fibre compared to classical TF services presented in figures are well understood, members of the audience are interested in also hearing about the benefits for "common" people and industry.

⇨   This shows an essential aspect, which needs to be improved in future presentations as it deals with the essence of the project. It is very important that people can easily understand the current limitations of well-known TF services and learn how CLONETS can overcome them. We recommend that presentations should be more focused on the advantages of using metrological TF services instead of standard ones. We should also multiply the number of generic and/or civilian use-cases examples that would benefit from these new metrological

services, so that members of the audience can easily identify the extra value gained by their own application.

The other remark was on the financial aspects, when comparing a TF dissemination through optical fibre to multiple standalone local optical or time standards.

⇨ This key aspect of the TF dissemination should also be more detailed, as it seems that it confuses our audiences. We may want to develop the financial expenses that are required to deploy and operate day-to-day atomic clocks.

4.1.2 Specific remarks

We would like also to report that during the one-day training event "Introduction to time and frequency transfer over fibre networks" at the NPL, people asked questions regarding the calculation of statistical uncertainties that led to a short discussion on data handling. We therefore would like to draw attention to the fact that those two aspects should be addressed in future presentations.

4.2 Questions regarding the dissemination aspects of TF services

4.2.1 Additional hardware requirements to disseminate CLONETS T&F services in a telecommunication network

The project (Deliverable D2.2) has evaluated different types of scenarios for implementing a pan-European optical fibre network. It can be based either on existing optical networks, e.g. NRENs and other optical networks such as GEANT, or on dark fibres. In the eventuality that the first option is preferred or locally implemented, CLONETS members have drafted a document detailing the technical aspects for disseminating the three types of services: optical frequency, RF frequency + Time and White Rabbit. For detailed technical information on these services and their performances, see Deliverable D1.5.

4.2.2 Q&A session with GEANT engineers

Because GÉANT has shown an interest in TF services, a Q&A session was organised as part of a workshop at GIP RENATER in Paris. We hereunder report the questions that were raised during this meeting as a good example of the questions a telecommunication network engineer or operator may have, regarding the possible interactions between data signals and CLONETS metrological TF signals.

1. What is the risk of 4-wave mixing and other forms of cross-talk?
The cross-talk between two signals is proportional to the frequency difference between them and their power level. As spectral occupation in the optical carrier technique is less than 10kHz and the output power is kept below 3dBm, the TF signal power is much lower than telecom signals and there is much lower risk of cross-talk between TF signals and data signals than between data signals themselves. If time transfer is added (through a modulation of the optical carrier), the amplitude modulation would be limited to about 10%, so that cross-talk again would be kept very low. However, experts from CESNET suggested that when the number of transmitted wavelengths is high (almost 90% of the C-Band), the data traffic channels could be affected.

2. What size of guard band do we need to be comfortable?
DWDM (Dense Wavelength Division Multiplexing) engineers from CESNET and RENATER agree on the fact that a 100GHz guard band would be preferred. RENATER has proved that this is not a mandatory prerequisite, but only a recommendation. Data traffic has

indeed been sent in RENATER network for almost 2 years in a neighbouring channel without any impact.

3. How can we shut down the TF signals?
Any TF equipment could be monitored through the OSC (Optical Supervisory Channel) in ILAs (In-line Amplifiers) and can be connected to routers in extremity sites and can therefore be shut down.

4. Raman is unidirectional, so it will make the bi-directional TF signal asymmetric, how do you plan to cope with this?
TF signals are not impacted by asymmetric amplification.

5. How can we detect and prevent self-lasing oscillations in a bidirectional amplifier when Raman amplification is present?
In REFIMEVE, the first generation of amplifiers integrated 1/99 couplers with a photodiode to monitor metrological signals output power in both outputs. The tests were not conclusive and we suspect that fast and random oscillations due to the amplification of random spontaneous emission cannot be easily detected. We could use very narrow (expensive) optical filters and insert a photodiode but even this may not be conclusive. Nevertheless, oscillations are filtered by OADMs (Optical Add Drop Multiplexers) (25/35dB rejection ratio) and do not affect neighbouring channels.

6. How can we detect and prevent lasing oscillations when Raman amplification is present?
The issue with Brillouin-Stokes induced signals due to a high Raman gain has been already addressed in Deliverable D1.3 "Best Practice Guide Alien Wavelength Services" (Section 6 Recommendations). In the document, we propose some best practices to prevent this induced effect from happening. We recommended to:
- inject a low metrological signal power into the fibre (<5 dBm), such that the first order Brillouin-Stokes signal is low and is not sufficiently amplified with the Raman pump to generate a second order Brillouin-Stokes signal and to
- if possible, lower the Raman output power restricting the gain, so that the first order Brillouin-Stokes signal cannot be sufficiently amplified to generated a second order Brillouin-Stokes signal.

5   DISSEMINATION AND EXPLOITATION OF RESULTS

The dissemination and exploitation plan of the project was based on the following five points, in order to maximize the impact of the project. These points remain relevant and will serve as a guideline for the continued exploitation of the project's results beyond its duration.

5.1 Knowledge Management

The project being a support and coordination action has not produced any new scientific results. However, the project's outputs, amongst others, include the formulation of an overall vision of a TF service over optical fibre in Europe, the drafting of industrial technology roadmaps and the outlining of a strategy for deployment. The results produced by the project can be found in the deliverable documents, which have been made freely available through the project's website. They can consequently be exploited by any interested party in view of creating new TF services over optical fibre, the ultimate objective of this project.

5.2 Dissemination to users and stakeholders

Throughout the project's duration, communication and dissemination activities have taken place (Section 3) and it is the project partners' intention to continue informing and interacting with potential users and relevant stakeholders after the project. On the one hand, these activities ensure that potential user communities and stakeholders are made aware of the benefits of TF services over optical fibre networks and the scientific and technological advancements they can stimulate. On the other hand, they allow the project partners to receive feedback and consequently, to better assess the needs of users and possible constraints in the conceptualization of a TF service over optical fibre networks. The goal is to continue to develop user communities, to promote the exchange of ideas, to either create new or strengthen existing collaborations and to secure support for the implementation of a pan-European TF service over optical fibre networks.

5.3 Training

The project has carried out various different training activities (Section 3.4), which are expected to have an impact far beyond the project's duration. They have strengthened the community of engineers and researchers in the field of TF dissemination over optical fibre networks, and thus help ensure its further development. Additionally, the training materials produced and the experience gained throughout the project provide a solid foundation for future training activities, in which the project partners intend to continue to be involved in after the end of the project.

5.4 Advice to policy makers

The project has laid the groundwork for more actively engaging policy makers by preparing appropriate communication materials, such as the positioning paper. The overall vision and the specific issues of a TF distribution over optical fibre networks have been reported to consultative and executive bodies and committees (Section 3.3) increasing the visibility of the project and raising awareness of the opportunities a TF service of optical fibre networks can offer. This activity will be continued beyond the project's duration and will be increased in follow-up actions, as the vision of a TF service over optical fibre networks is refined.

5.5 Seeking resources for future development phases

The ultimate objective of CLONETS is the implementation of a pan-European TF service over optical fibre networks. This project has been an important step towards this objective through its various outputs (e.g. needs studies, market analysis, technology reviews, formulation of an overall vision, etc.). The project partners intend to exploit these results for future development phases. It has become clear that while the present Action, which was selected in the context of an INFRAINNOV Call, has clarified and developed many aspects such as technology transfer, user needs and possible implementation strategies, it has probably not allowed a sufficiently detailed preliminary design study to be carried out to support an immediate transition to the detailed design and implementation of the proposed infrastructure. Therefore it is likely that the proposed infrastructure will be proposed for a more detailed preliminary design study, for example in response to a call such as INFRADEV-01-2019-2020: Design Studies. Further, the CLONETS participants will use the results of the present project to prepare the adoption of CLONETS as a European infrastructure, through work with national and European policy makers and funding agencies, including the ESFRI forum.

6 IMPACT OF THE PROJECT

The project has taken crucial first steps towards the creation of a sustainable, pan-European optical fibre-based network providing high-performance TF services to research infrastructures as well as support to a wide range of industrial and societal applications. While the project has already had an impact (see below), the main direct economical and societal impact will ultimately follow through the deployment, operation and exploitation of the TF optical fibre infrastructure and the consequent scientific advancements, innovations and technological developments that will be triggered.

6.1 Community Impact

The CLONETS project has brought together different organizations with complementary fields of expertise: NMIs, NRENs, research laboratories and industrial partners, all with the common goal of implementing a pan-European TF service over optical fibre. The project has allowed the project partners to work more closely together, to exchange their ideas and interdisciplinary approaches and to strengthen their collaborations and thus the European TF community.

Through its communication, dissemination and training activities, the project has interacted with potential users and stakeholders (Section 3) leading to a larger awareness of the project. Additionally, the interactions and discussions of the project partners with third parties potentially interested in either being part of or benefitting from a future clock network service, have led to exchanges on good practices (Section 4) and have opened the door to collaborations and synergies beyond the project itself.

Potential users (e.g. in high precision spectroscopy, geodesy, quantum sensing) have expressed their interest in learning more on the opportunities and benefits a high performance TF reference signal through optical fibre could bring. And conversely, the project has asked potential users for more information on their TF reference signal requirements, through surveys (Deliverables D1.1 and D3.3) as well as direct discussions. This input will help guarantee that the overall vision of a TF service has a maximal impact on the potential user communities.

Concerning synergies with European optical fibre network infrastructures, the project partners have been in active contact with GEANT and other European NRENs. This has allowed the project to, on the one hand, raise interest in TF as a service and provide technology recommendations (Section 6.3), and on the other hand, better understand how NRENs operate their networks and be aware of the current and future networking technologies and their compatibilities with a TF service (Deliverable D1.2).

6.2 Training

6.2.1 Short training and dissemination events

The impact of the training and dissemination events has mainly been to reinforce links of the project partners with potential user communities (in both academia and industry) and network engineers and technicians. The exchanges with the different relevant communities have contributed to strengthening the TF community.

6.2.2 Master's Programme

The preparation and organization of the Master's Programme has had an impact despite being cancelled at the last minute due to a low enrolment rate combined with visa rejections. Firstly, it has produced a Master's Programme appropriate for training professionals in TF transfer over optical fibre. The content and format of the programme remain relevant and both INRIM and Politecnico of Torino continue to be interested in implementing the Master's Programme in the future. Secondly, it has also raised awareness of the importance of TF to a wider community outside of the Consortium. The collaboration with the Department of

Electronics and Telecommunication of Politecnico of Torino has strengthened the link between TF metrology over fibre and the large field of optical networking and data traffic providing new opportunities and synergies. Additionally, the Master's Programme has led to the engagement of a new stakeholder Open Fibre, a major Italian telecommunications company, which has expressed its interest in training their employees through the Master's Programme. The value of the Master's Programme as an excellent training opportunity has also been recognized by Compagnia di San Paolo, the main bank foundation in Italy. In support of the Master's Programme, the bank foundation offered 8 student grants. This support is a testament to the quality and relevance of the created Master's Programme.

6.3 Technology recommendations

The project has produced a comprehensive overview of key high performance TF transfer techniques, their TRLs and the performances achievable (Deliverable D1.5). This report has allowed the Consortium to gain a better insight into current state-of-the-art TF techniques, assess their relevance for high performance TF services, identify potential technological gaps in TF transfer techniques and outline the corresponding technology development roadmap (Deliverable D1.6, D2.3). The overview of key TF transfer technologies together with the roadmap serve as a guide to showing the current possibilities of TF transfer techniques and the developments necessary for the implementation of a fully integrated TF service over optical fibre networks. They are an important support in the dissemination and exploitation activities of the Consortium and impact the choice of technologies in the design of TF services over optical fibre networks.

The production of these technology-focused reports has additionally enabled the project's partners to provide recommendations regarding the implementation of a TF service in an extended optical fibre network. In fact, the project has been in active contact with a GEANT JRA concerning the preparation of the next version of the GEANT network, in order to facilitate compatibility with the vision for time and frequency services over fibre being developed in CLONETS. The collaboration has led to the production of a recommendations document outlining the current specifications for a TF service over an optical fibre network (Section 4.2.1).

6.4 European landscape

The project has allowed the project participants to foster exchanges and interactions across Europe, survey the diverse landscape of TF technologies and approaches present in Europe and establish new collaborations. Through these activities, the project has worked towards the coordination and harmonization of the different developments and interests across Europe. A challenge that will need to be met, in order to ensure Europe's leading role in the dissemination of TF services over optical fibre.

Additionally, the TF community has been interacting with the Quantum Key Distribution (QKD) community and is collecting information on the feasibility of mutualizing an infrastructure, i.e. a pan-European dark fibre network providing novel and innovative services, such QKD and high-performance TF services.

7 CONCLUSION

The communication, dissemination and training activities of CLONETS have helped the project gain visibility and have opened the door to new collaborations and synergies. The project partners plan to capitalize from this dynamic and continue the dissemination and exploitation of the project's results. It is their intention to continuing taking steps towards the realization of a pan-European fibre-based TF service, which is expected to bring significant scientific, social and economic impact.

ANNEX: DETAILED TABLES OF DISSEMINATION ACTIVITIES

	Conference / Workshop				CLONETS Participation				
Date(s)	Abreviation	Full Name of the Conference	City	Country	Name(s)	Unity	Type of Participation	Title	Time Slot
29 May - 2 Jun 2017	**TNC 2017**	TNC17 Networking Conference - GEANT	Linz	Austria	Vladimir Smotlacha	**CESNET**	Booth + Poster	Poster 06 - CLONETS – Clock Network Services	Poster #6
29-30 Jun 2017	**ACES Workshop**	ACES Workshop	Zurich	Switzerland	Harald Schnatz	**PTB**	Invited Talk	Progress towards a European metrological fiber network: current status and prospects	29 Jun 2017, 15:00-15:30
2-6 Jul 2017	**ICTON 2017**	International Conference on Transparent Optical Networks	Girona	Spain	Josef Vojtech	**CESNET**	Poster	Tu.P.1 CLONETS – Clock network services: Strategy and innovation for clock services over optical-fibre networks	4 Jul 2017, 13:30-15:30
10-13 Jul 2017	**EFTF 2017 - IFCS 2017**	European Frequency and Time Forum	Besancon	France	Philip Tuckey	**OBSPARIS**	Poster	ID 1173 - CLONETS – Clock Network Services: Strategy and Innovation for Clock Services Over Optical-Fibre Networks	12 Jul 2017, 16:00 - 18:00
19-26 Aug 2017	**URSI GASS 2017**	International Union of Radio Science General Assembly & Scientific Symposium	Monteal	Canada	Paul-Eric Pottie	**OBSPARIS**	Talk	DA12-1: (Invited) INTERNATIONAL OPTICAL AND MICROWAVE CLOCK COMPARISONS VIA LONG-HAUL COHERENT FIBER LINKS	22 Aug 2017, 9:40–10:00

18-19 Oct 2017	**12th STF**	12th Service and Technology Forum (STF)	Rome	Italy	Nicolas Quintin	**GIP-RENATER**	Talk	CLONETS - CLOck NETwork Services	19 Oct 2017, 11:30
14-17 Nov 2017	**JRES 2017**	Journées Réseaux de l'Ensignement et de la Recherche	Nantes	France	Nicolas Quintin, Emilie Camisard	**RENATER**	Booth + Poster	83 - RENATER, partenaire du projet CLONETS pour l'étude de la construction d'un réseau métrologique européen	Poster #83
29 Jan - 1 Feb 2018	**PTTI 2018**	Precise Time and Time Interval Meeting	Reston, VA	USA	Vladimir Smotlacha	**CESNET**	Talk	CLONETS – Clock Network Services	31 Jan 2018, 11:30
10-12 Apr 2018	**EFTF 2018**	European Frequency and Time Forum	Torino	Italy	Davide Calonico	**INRIM**	Poster	The H2020 European Project CLONETS: Clock Services Over Optical-Fibre Networks in Europe	Paper 7203
10-12 Apr 2018	**EFTF 2018**	European Frequency and Time Forum	Torino	Italy	Robert Urbaniak	**PIKTIME**	Booth		Exhibition Table 20
13-17 May 2018	**CLEO 2018**	CLEO Laser Science to Photonic Applications	San Jose, CA	USA	Josef Vojtech	**CESNET**	Poster	The H2020 Project CLONETS: Clock Services over Opticla-fibre Networks in Europe	16 May 2018, 11:30-13:00
10-14 Jun 2018	**TNC 2018**	TNC18 Networking Conference - GEANT	Trondheim	Norway	Josef Vojtěch	**CESNET**	Poster	24 - Project CLONETS	Poster #24
14-15 Jun 2018	**GRAM 2018**	Les Journées Scientific du Programme National GRAM	Besancon	France	Eva Bookjans	**OBSPARIS**	Poster	The H2020 European Project CLONETS: clock services over optical-fibre networks in Europe	_
14-15 Jun 2018	**GRAM 2018**	Les Journées Scientific du	Besancon	France	Paul-Eric Pottie	**OBSPARIS**	Talk	REFIMEVE+ : towards a wide optical fiber network for optical	14 Jun 2018, 9:55-10:35

		Programme National GRAM						frequency standard dissemination	
23-27 Sep 2018	**ECOC 2018**	44th European Conference on Optical Communication	Rome	Italy	Jiri Stefl	**OPTOKON**	Poster at booth		Stand 449
11-16 Nov 2018	**SC18**	SuperComputing Conference	Dallas, TX	USA	Wojbor Bogacki Artur Binczewski Krzysztof Turza Aleksander Weinert	**PSNC**	Poster at booth		Booth 1015
28-31 Jan 2019	**PTTI 2019**	Precise Time and Time Interval Meeting	Reston, VA	USA	Josef Vojtěch	**CESNET**	Poster	The CLONETS – Clock Network Services Strategy and Innovation for Clock Services Over Optical-Fibre Networks	29 Jan 2019, 17:30-18:30
30 Jan - 1 Feb 2019	**SOK 2019**	Seminar on Optical Communications	Ljubljana	Slovenia	Jiri Stefl	**OPTOKON**	Lecture and presentation	Optical links and their perspectives for transmission of precision time and frequency	31 Jan 2019, 11:15-12:00
18-22 Feb 2019	**EQTC 2019**	European Quantum Technology Conference	Grenoble	France	Eva Bookjans	**OBSPARIS**	Poster	The H2020 European Project CLONETS: An optical- bre network for clock services in Europe.	18-19 Feb 2019, Poster 1.16

1-4 Apr 2019		SPIE Optics and Optoelectronics 2019	Prague	Czech Republic	Josef Vojtech, Radek Velc, Rudolf Vohnout, Vladimir Smotlacha, Jan Radil	**CESNET**	Booth with Poster and Flyers		Booth 103
14-18 Apr 2019	**IFCS-EFTF 2019**	Joint Conference of the IEEE International Frequency Control Symposium & European Frequency and Time Forum	Orlando, FL	USA	Paul-Eric Pottie	**OBSPARIS**	Talk	CLONETS – Clock Network Services Optical-Fibre Network for Clock Services in Europe : Recent Progress	17 Apr 2019, 15:00-15:20
5-10 May 2019	**CLEO 2019**	CLEO Laser Science to Photonic Applications	San Jose, CA	USA	Josef Vojtěch	**CESNET**	Poster	The CLONETS – Clock Network Services Strategy and innovation for clock services over optical-fibre networks	9 May 2019, 11:30-13:00, Poster JTh2A.116

Table 1: Conference attendances

Dissemination Events					CLONETS Participantion				
Date	Abreviation / Type	Name of Event	City	Country	Name	Unity	Dissemination / Communication activity	Titel	Time Slot
3-6 Apr 2017	**WSTS 2017**	Workshop on Syncronization and Timing Systems	San Jose, CA	USA	Pablo Marin	**SEVENSOLS**	Booth + Talk	Bringing a global time reference to any time critical center through telecom optical fiber intrastructure	Session 4: Delivering Time
6-9 Nov 2017	**ITSF 2017**	The Internet of Time	Warsaw	Poland	Lukasz Sliwczynski	**AGH**	Talk	ELSTAB - electronically stabilized fiber optic system for time and frequency distribution with picoseconds accuracy	8 Nov 2017, 16:20
6-9 Nov 2017	**ITSF 2017**	The Internet of Time	Warsaw	Poland	Pablo Marin, Javier Diaz, Eduoardo Ros	**SEVENSOLS**	Booth + Talk	Ultra-accurate time transfer based on the IEEE-1588 High Accuracy Profile standard. A high scalability and resilience approach	8 Nov 2017, 16:00
9-10 Nov 2017		ICT's Proposers' Day	Budapest	Hugary	Jose Luis Gutierrez	**SEVENSOL**	Network event focused on looking for potential partners to create consortiums related to		

							time and frequency transfer to prepare submissions for the H2020 work programme.		
11-15 Mar 2018	**OFC 2018**	The Optical Networking and Communication Conference & Exhibition	San Diego, CA	USA	Jiri Stefl	**OPTOKON**	Booth		Booth no 5906
16-17 Mar 2017	**RUE 2017**	RUE 2017 (Rencontres Universités-Entreprises)	Paris	France	Nicolas QUINTIN, Emilie CAMISARD	**GIP-RENATER**	Information booth with a CLONETS poster and the first version of CLONETS flyers, CLONETS was selected as one of the ten most innovating project by the committee and was also given a 10 minutes slot to present the project to the largest employer federation in France (MEDEF).		
20 -23 Mar 2018	AMPERE 2018	AMPERE 2018	Brno	Czech Republic	Ondrej Cip	**ISI**	Review lecture - Presentation of the time and frequency metrology and utilization of optical fibre link for distribution of time and frequency for industry, general public, researchers and	Transmission of Precise Frequency and Time from Atomic and Optical Clocks Over Photonic Networks for Metrological and Industrial	21 March 13:30-14:00 in the Forum Optics

							students was done at 26th multinational fair trade of electrical engineering, energy, control, communication, lighting and security (fair trade AMPER)	Applications Overview	
20 -23 Mar 2018	Trade fair	AMPERE 2018	Brno	Czech Republic	Lenka Pradova	ISI	Review lecture - Presentation of the time and frequency metrology and utilization of optical fibre link for distribution of time and frequency for industry, general public, researchers and students was done at 26th multinational fair trade of electrical engineering, energy, control, communication, lighting and security (fair trade AMPER)	Comparison of Stability of Optical Frequency Standards Over Photonic Networks	21 March 14:00-14:30 in the Forum Optics
20 -23 Mar 2018	Trade fair	AMPERE 2018	Brno	Czech Republic	Ondrej Cip, Lenka Pradova	ISI	Meeting and interview with the company MIT Ltd during AMPER (booth 3,17 in Hall C of Brno Fair Trade) - Presentation of main CLONETS principles,		

							discussion about involving possibilities of distributed time and frequency signals over fibre links for industrial application.		
12 Apr 2018	Presentation for PROFIcomms	_		Brno	Czech Republic	Jan Radil	**CESNET**	Providing information about new photonic applications, CLONETS project and potential benefits for commercial companies working in networking/informatics /fibre optics/measurements.	
25 May 2018	Presentation for NetworkGroup			Brno	Czech Republic	Jan Radil	**CESNET**	Providing information about new photonic applications, CLONETS project and potential benefits for commercial companies working in networking/informatics /fibre optics/measurements.	
21 Jun 2018	Presentation for PROfiber Networking			Brno	Czech Republic	Jan Radil	**CESNET**	Providing information about new photonic applications, CLONETS project and potential benefits for commercial companies working in	

							networking/informatics /fibre optics/measurements.		
9 Aug 2018	National seminar on information technology	Internet in Telc, Cz („Internet v Telči 2018")	Telc	Czech Republic	Jiri Stefel	**OPTOKON**	Lecture and poster presentation at "Internet in Telc 2018", an annual seminar on the developments of the internet and related services for IT experts in public administration and IT technology suppliers.	Secure time in optical networks	09 August 11:25-11:40
5-8 Nov 2018	**ITSF 2018**	International Timing and Sync Forum	Bucharest	Romania	Elizabeth Laier English	**NPL**	Presentation on UTC as a time reference for industry,	UTC as a Time Reference for Industry	08 November 2018, 11:50 - 12:10
13-15 Nov 2018	**AfricaCom 2018**	Africa Com	Cape Town	South Africa	Jiri Stefl	**OPTOKON**	Poster at booth		
3-7 Mar 2019	**OFC 2019**	The Optical Networking and Communication Conference & Exhibition	San Diego, CA	USA	Jiri Stefl, Josef Vojtech, Radek Velc, Rudolf Vohnout, Vladimir Smotlacha, Jan Radil	**OPTOKON / CESNET**	Poster at booth		Booth no 4549

19-21 Mar 2019	Trade fair	AMPERE 2019	Brno	Czech Republic	Ondrej Cip	**ISI**	Review lecture - Lecture about research and development in the field of frequency and time transmission is the domain of Europe where a dense network of photonic fibers are available across the continent. The lecture provided a overview of techniques for transmitting the most accurate signals from both atomic and optical clocks currently in operation in Europe (fair trade AMPER)	European network for precise frequency and time transfer from atomic and optical clocks	21 March 12:30-13:00 in the Forum Optics
19-21 Mar 2019	Trade fair	AMPERE 2019	Brno	Czech Republic	Lenka Pravdova	**ISI**	Review lecture - Lecture about the current state of photonic networks in the Czech Republic useful for transmiting signals from highly stable optical oscillators to industrial applications (fair trade AMPER)	Transmission of optical frequencies via optical fibres in the Czech Republic	21 March 13:00-13:30 in the Forum Optics
25-28 Mar 2019	**WSTS 2019**	Workshop on Synchronization and Timing Systems	San Jose, CA	USA	Elizabeth Laier English	**NPL**	Presentation on the CLONETS (Clock Network Services) project, including a	CLONETS – Clock Network Services	27 March 2019, 16:20-16:40

							brief overview of fibre-based time and frequency activities in Europe		
1-3 Jul 2019	**TSP 2019**	International Conference on Telecommunications and Signal Processing	Budapest	Hungary	Josef Vojtech, Radek Velc, Rudolf Vohnout, Vladimir Smotlacha	**CESNET**	Roll-up Poster and Flyers		
8 Aug 2019	Local Czech event	"Internet in Telc"	Telc	Czech Republic	Jiri Stefl	**OPTOKON**	Lecture and Poster presentation	Data Center Vysocina and the ability to use accurate time measurement	
3-4 Sep 2019	Organization of a Workshop	10th Customer Empowered Fibre Networks Workshop	Prague	Czech Republic	Josef Vojtech, Radek Velc, Rudolf Vohnout, Vladimir Smotlacha, Jan Radil	**CESNET**	Roll-up Poster and Flyers		

Table 2: Dissemination Events

Reporting to stakeholder committees and bodies						
Date	**Stakeholder Committees and Bodies**	**Presenter**	**Affiliation**	**Location**	**City**	**Country**
7 Mar 2017	**EURAMET Time and Frequency Technical Comitte (TCTF)**	Philip Tuckey and Paul-Eric Pottie	**OBSPARIS**	IPQ (Portugues Institute for Quality)	Caparica	Portugal
15-16 May 2017	**IAG Joint Working Group 2.1**	Paul Eric Pottie	**OBSPARIS**	LUH	Hannover	Germany
7 June 2017	**Study Group on Optical fiber Links of UTC under the CCTF WG ATFT**	Davide Calonico	**INRIM**		Sevres	France
7 June 2017	**REFIMIEVE+** General Assembly	Philip Tuckey and Paul-Eric Pottie	**OBSPARIS**	LP2N	Bordeaux	France
18-Jan-18	**RENATER-GEANT** Executive meeting	Philip Tuckey and Paul-Eric Pottie	**OBSPARIS**	RENATER	Paris	France
10-11 Oct 2018	**IAG Joint Working Group 2.1**	Paul Eric Pottie	**OBSPARIS**	BIPM	Sevres	France
15 Feb 2019	**ESFRI meeting with Executive Chair**	Ondrej Cip and Josef Lazar	**ISI**	ESFRI office	Prague	Czech Republic
7-8 Mar 2019	**EURAMET Time and Frequency Technical Comitte (TC-TF)**	Jochen Kronjaeger	**NPL**	NPL	Teddingtion	UK
11-Jun-19	**OTFN - Time and Frequency Workshop** - RENATER did a presentation about the collaboration with the REFIMEVE project and the return over experience.	Nicolas Quentin	**RENATER**	RENATER	Paris	France
TBD	**Contact with UK ESFRI delegate** - scheduling of a meeting is being discusssed	Riley Ilieva and Jochen Kronjaeger	**NPL**	TBD	TBD	TBD

Table 3: Reporting to stakeholder committees and bodies

Training Activity or Event									
Date(s)	Type	Title	Details / Description	Audience	Location / Setting	City	Country	Unity	Name(s)
26-30 Jun 2017	Contribution to a week long seminar	Sync over Fibers / FS Combs	Course on Optical fiber links	students and young researchers	EFTS 2017	Besancon	France	**LPL-UP13**	Anne Amy-Klein
8-11 Aug 2017	Contribution to a summer school	Frequency and Time Metrology Activities at PTB - Do we need clocks at 10-18?	Lecture on frequency and time metrology	students and young researchers	B-IGSM Summer School 2017	Kloster Druebeck	Germany	**PTB**	Harald Schnatz
20 Feb 2018	Organization of a 1-day training event	Time and Frequency metrology via optical fibre links	Review lecture plus practical training. The review lectures included history, recent development and future of metrology of time & frequency, the description of the utilization of optical fibre links in time and frequency metrology andthe main ideas and activities of the CLONETS project. The lectures were followed by a practical training and was done at laboratories of Department of Coherence optics of the ISI CAS CR	researchers, students and technicians	Department of Coherence Optics at ISI	Brno	Czech Republic	**ISI**	Ondrej Cip, Josef Lazar, Simon Rerucha, Lenka Pravdova
9 April 2018	Contribution to pre-conference	Optical fiber link for ultrastable time and	Tutorial on optical fiber liks	students and young researchers	EFTF 2018	Turin	Italy	**LPL-UP13**	Anne Amy-Klein

	professional training	frequency dissemination							
24 May 2018	Organization of a 1-day training event	Secure delivery of accurate time	A workshop/seminar composed of three blocks: 1. The fundamental information about time and frequency (time, time scale and clocks, time synchronization, possibilities how to secure time delivery) 2. Optical links, their perspectives and networks architectures for secure and sharp time and frequency delivery, 3. Discussion, completing a questionnaire, conclusion.	members of the ICT community, industry, policy makers	At CESNET	Prague	Czech Republic	**OPTOKON, CESNET**	Tomas Muller, Jiri Stefl
25-29 June 2018	Contribution to a week long seminar	Sync over Fibers / FS Combs	Course on Optical fiber links	students and young researchers	EFTS 2018	Besancon	France	**NPL**	Jochen Kronjaeger
19 Feb 2019	Organization of a 1-day training event	Optical frequency standards and signal distribution via optical fibre links	Review lecture plus practical training. The review lectures was dedicated for all with interest in the field of basic time and frequency metrology in which atomic clock and photonic fibre networks start to play significant role in dissemination of the precise time and frequency for long distances. The lecture was devided into two lecture blocks: Optical frequency standards, Photonic networks	researchers, students and technicians	Department of Coherence Optics at ISI	Brno	Czech Republic	**ISI**	Ondrej Cip, Josef Lazar, Simon Rerucha, Lenka Pravdova

			for superstable frequency and time signals. The main ideas and activities of the CLONETS project were part of the lecture too. The lectures were followed by a practical training and was done at laboratories of Department of Coherence optics of the ISI CAS CR.						
26 Feb 2019	Organization of a 1-day training event	Introduction to time and frequency transfer over fibre networks	This event is a one-day entry level workshop on the current state-of-the-art time and frequency transfer techniques relevant to a European-wide optical fibre network infrastructure. There will be presentations from international experts and poster sessions from industry, and the opportunity for a tour of the Time Scale lab where the UK's national time scale UTC(NPL) is generated.	Network engineers, students, industry, policy makers	At NPL	Teddington	London	**NPL**	Elizabeth English
22-26 April 2019	Organization of a week-long physics school	High Precision Physics Using an Optical Fiber Link and Optical Frequency Comb	The goal of this school is to broadcast among a wide community of physicist the possibilities of high precision measurement thanks to the optical fiber transfer of an optical frequency reference, coupled to an optical frequency comb. The considered applications concern tests for	students, researchers, engineers	Les Houches School of Physics	Les Houches	France	**LPL-UP13 / MUQUANS**	Anne Amy-Klein

			fundamental physics, geodesy and astrophysical observations, as well as new protocols for atomic and molecular spectroscopy, made possible by these tools.						
9 May 2019	Organization of a 1-day training event	Time and Frequency over optical fiber networks	The Training Day focused on topics related to the transfer of ultra-stable time and frequency signals in optical networks based on CLONETS project. These networks have become very popular in recent years due to their accuracy and high level of security (compared to alternative satellite methods).	students	At PSNC	Poznan	Poland	**PSNC**	Wojbor Bogacki, Krzysztof Turza

Table 4: Training events