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Strategy and innovation for clock services over optical-fibre networks

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Overall vision for time and frequency service delivery

Final

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Disclaimer

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LIST OF ACRONYMS AND ABBREVIATIONS

CE	Commercial Entity
CLONETS	CLOck NETwork Services: Strategy and innovation for clock services over optical-fibre networks project
GNSS	Global Navigation Satellite System
H2020	Horizon 2020
NMI	National Measurement Institute
NTP	Network Time Protocol
POS	Point of Service
PPS	Pulse Per Second
RF	Radio Frequency
RI	Research Institution
SOS	Source of Service
SP	Service Provider
SU	Service User
T&F	Time and Frequency
TL	Time Laboratory
TM	Transmission Medium
UTC	Universal Time Coordinated

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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# third party to INRIM
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1. Ł. Śliwczyński, P. Whibberley, D. Calonico, J. Kronjäger, P.-E. Pottie, A. Amy-Klein, A. Tampellini, E. Bookjans, H. Schnatz, P. Krehlik, E. Leyer-English, P. Tuckey, T. Garcia, V. Smotlacha and J. Vojtech, "D1.5 – Fibre-based time and frequency transfer techniques," CLONETS project, 2018.

EXECUTIVE SUMMARY

This deliverable proposes a vision for an advanced time and frequency service for Europe based on deployed optical fibre infrastructure. This vision is based on an analysis of the results of the surveys carried out in WP1 and WP3, which were performed to identify future needs of research infrastructures (RIs) and commercial entities (CE) in Europe.

This document does not describe technical issues in detail, but focuses on the logical aspect of the time and frequency (T&F) service. It shows a logical overall vision of the T&F distribution network and gives a preliminary indication of the geographical distribution of potential users of the service provided by this network.

1 INTRODUCTION

Each service consists of three basic components:

- a service provider (SP) – which is responsible for providing service to users,
- a service user (SU) – which needs access to the service in order to use it for its own purposes (research, business, etc.)
- a transmission medium (TM) – which has to connect service provider with service user.

The transmission medium in the CLONETS project is obvious – deployed optical-fibre, service providers are well-established institutions such as National Measurement Institutes (NMIs) and Time Laboratories (TLs), which maintain their own time scales. Service users may be any entities that need precise T&F signals for any R&D or business activities.

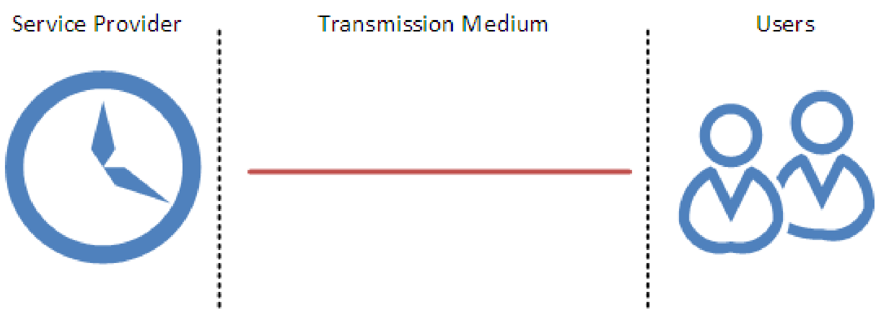

Figure 1. Idea of access to a service

Service users have different requirements regarding the type of signals (1 PPS, 10 MHz, optical carrier, etc.), their accuracy, stability metrics and access to specific time scales. For some user applications other characteristic of T&F signals such as availability, continuity of delivery, redundancy, or security can be of great importance, even with reduced accuracy and stability parameters. Moreover the coverage and scalability must be taken into account. The service must be ready to be expanded to new users.

Service users can be categorised into three main groups, those that

- can provide T&F signals to their internal system (RI),
- need access to external precise T&F signals (RI),
- or are commercial entities (CE).

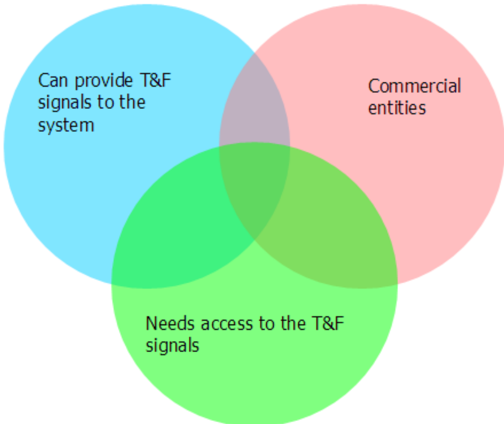

Figure 2. User group categorisation

The main inputs into the design of the overall vision are the surveys provided by WP1 and WP3, and the knowledge and experience of the project partners.

2 CHALLENGES & REQUIREMENTS

This chapters describes end user requirements and main challenges which must be met by the proposed T&F service.

2.1 User requirements based on surveys

The CLONETS project has carried out surveys in WP1 and WP3, which have collected user responses regarding requirements. 37 Research Institutions (RIs) from 12 countries responded to the survey (11 were UTC(k) labs, 26 were classified as non-UTC(k) labs), which was sufficient to obtain an overview of RI user needs.

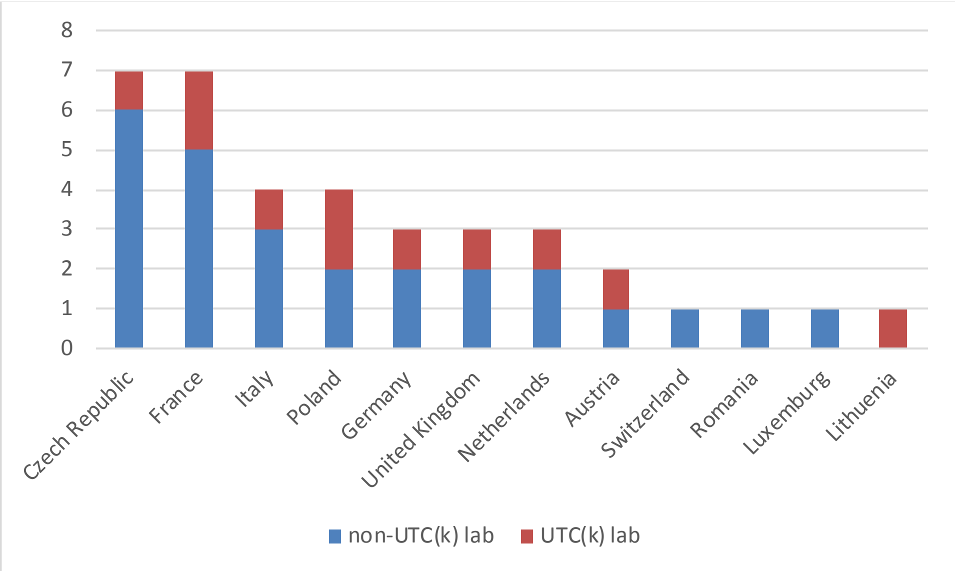

Figure 3. Responses according to country with non-UTC and UTC labs

The questionnaire of the survey was divided into four sections:

- general information on the RI,
- status-quo of the T&F systems employed,
- T&F reference performance requirements,
- future needs of high precision T&F signals.

The survey results are summarized in D1.1 “High precision T&F needs of research infrastructures”. Moreover, the results of the survey were deeply analysed and discussed at an internal workshop of the CLONETS project in Prague.

2.1.1 T&F signal senders & receivers

As mentioned in the Introduction one of the most important roles is that of the Service Provider. SP have to provide to the transmission medium T&F signals with a very high level of accuracy, reliability, etc.

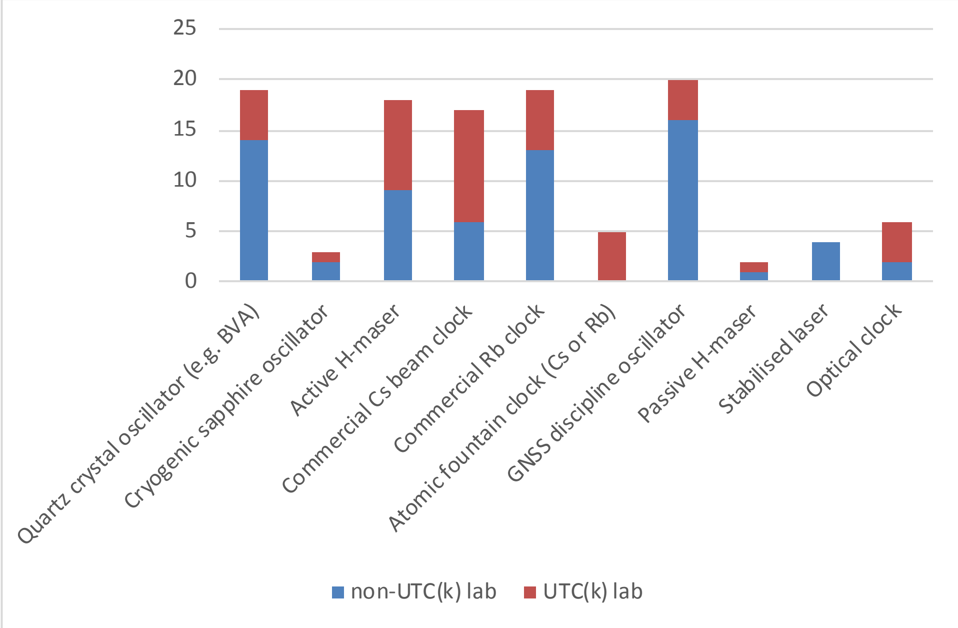

Figure 4. Frequency standards and clocks operated at UTC-labs and non-UTC labs (data from survey)

All of the surveyed RIs are equipped with frequency standards and/or clocks. The most popular overall solutions are:

- GNSS disciplined oscillator (20 installations),
- Commercial Rb clock (19 installations),
- Quartz crystal oscillator (19 installations),
- Active H-maser (18 installations),
- Commercial Cs beam clock (17 installations).

Most of the in-house frequency standards operated in RIs are based on radio-frequency (RF) sources. The next conclusion of the study is that the majority of RIs use more than one frequency standard with GNSS referenced devices. It should be noted that some RIs use frequency standards and clocks only for their internal applications and do not plan to share T&F signals externally.

The suitable infrastructure for continuously generating T&F signals is already in place UTC-laboratories, in particularly NMIs. These institutions can play a dual role – first as T&F signal senders in a T&F service delivery, in other words as SPs – second as a signal receivers from other NMIs, in other words as users.

Some of CE are equipped with commercial clocks, like Cs beam clocks, Rb clocks, H-masers or quartz crystal oscillators. Some others do not have a separate clock and use GNSS signals or NTP. CE are considered as T&F service users.

2.1.2 Continuous vs occasional access to the T&F service

The survey shows that most RIs have their own T&F installations, which can provide signals for their internal needs. Some of them are based on oscillators disciplined by GNSS. In such cases T&F services delivered by fibre will become a primary (more accurate) source in relation to GNSS, which can be a secondary/backup source. Moreover, RIs own T&F installations allow to reduce the requirement for continuous access to T&F signals.

However, it cannot be excluded that some RIs or commercial entities will need continuous access to signals, at least in the short or medium term.

2.1.3 Importance of accuracy and stability of T&F service

According to the survey, a key parameter for RI users is frequency instability. Short-term instability (1 s of integration time) at the level of around 10^{-12} to 10^{-15} is sufficient for RI users. No RI users have indicated the need for short-term stability better that 10^{-15}. Long-term stability (1 day of integration time) better than 10^{-14} is required by 75% of RI users, and 27% need instability better than 10^{-15}.

The survey indicates two peaks for frequency accuracy. The first one is on the level of 10^{-12}, the second one is on the level of 10^{-16}. The first peak can be reached by conventional methods, but the second peak can only be reached by primary fountain clocks with frequency dissemination by optical fibre (except for very long measurement durations).

Regarding timing requirements, RI users can be split into three main groups: stability and accuracy up to 10 µs, up to 10 ns, and a larger group which needs performance better than 1 ns or even 100 ps.

The RI users were also asked in the survey to rate the importance of T&F parameters from critical to irrelevant. The most important answers can be summarised in four sentences:

- Traceability tends to be either critical or irrelevant.
- Security is the least important (lowest critical rating and highest irrelevant rating). It does not seem to be a concern for most of the applications
- Resilience is desired, but not rated as critical.
- Availability is of highest importance, with no respondants considering it as irrelevant.

2.1.4 Commercial and research institution needs

The infrastructure for T&F service delivery should meet the needs of both Research Institutions (RIs) and Commercial Entities (CEs). The surveys show that the requirements of RIs do not coincide with those of CEs. Most RIs have their in-house frequency standards and their needs focus mostly on precise frequency signals. CEs are not equipped with precise T&F devices, and they need access to precise time signals.

The overall vision of T&F service delivery must take into account all requirements. Moreover the system must be open to new T&F dissemination technology over fibre.

2.2 Challenges for time and frequency service delivery

2.2.1 Performance of T&F signals

End-Users of T&F service have different requirements regarding accuracy as mentioned in the previous chapter. A T&F dissemination network has to provide at least an order of magnitude better accuracy than most advanced user requirements. Moreover, it should be considered that user requirements will increase in the coming years. Thus, the T&F dissemination network must be ready to introduce new technologies to meet future requirements.

The performance of the T&F service is affected by two factors:

- the type of clock which provides the T&F signals,
- the optical fibre technique used to distribute the T&F signals.

Figure 5 shows the performance of different types of clocks. The highest performance is obtained by using optical clocks or fountains. In some cases also H-masers can be used. Commercial caesium clocks and H-masers can be used for medium performance. Lowest performance is achieved by rubidium clocks and local oscillators.

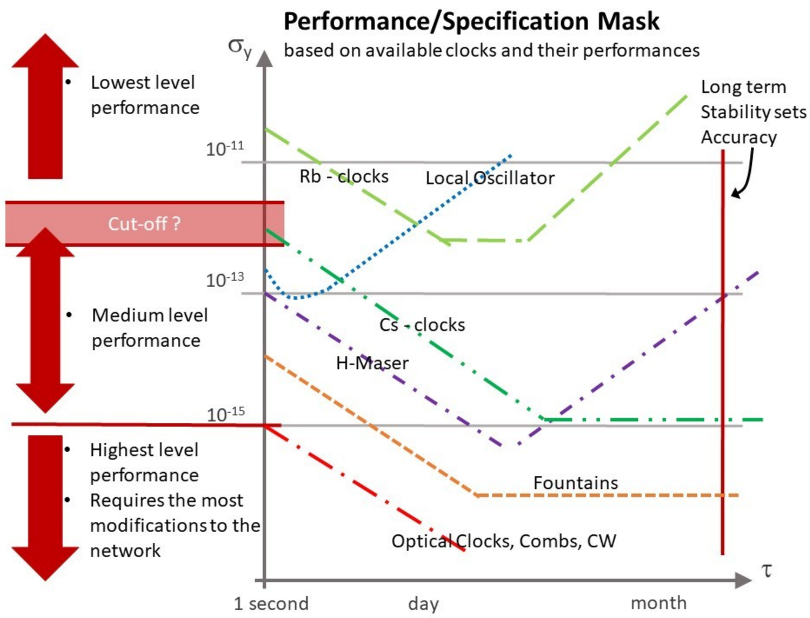

Figure 5. Clock Performance

Currently, optical fibre techniques provide the best short term instability and accuracy signals, being limited only by the performance (uncertainty) of the remote reference clock. More information can be found in Deliverable D1.5 "*Fibre-based time and frequency transfer techniques*" [1].

2.2.2 Coverage of the T&F service

There are several test-beds for T&F dissemination installed in Europe, some already crossing European boarders:

- Germany – France – UK,
- Netherlands,
- Czech Republic – Austria,
- Poland,
- Italy,
- Sweden – Finland.

Figure 6 shows their geographical locations. These installations are based on different technologies and have been built to solve certain specific problems. Therefore, they do not create a comprehensive, consistent infrastructure offering a uniform range of services to a wide range of users. However, the CLONETS project should not lose the potential of these installations. Individual solutions used there (explained in more detail in D1.5) or individual links can be used in the process of creating the target structure of the CLONETS network. The overall vision takes into account existing installations to create T&F service which will cover a whole Europe. However, it is impractical to provide the highest accuracy T&F service proposed by the CLONETS project, to general single end users in the near future. To overcome this the service will be implemented using a hierarchical connection structure and well-defined, functional division of tasks and functionalities. Details will be given in section 3.

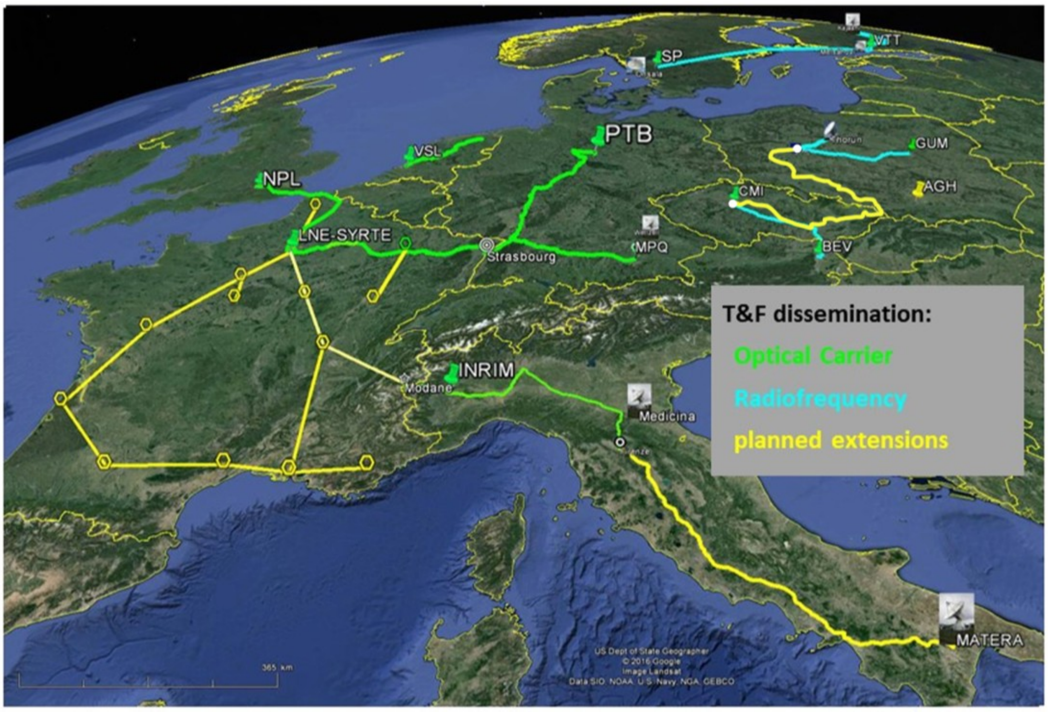

Figure 6. Existing T&F dissemination installations in Europe

2.2.3 Scalability of the T&F service

Any T&F service must meet the needs of the end users. Not all users need signals of equal quality / accuracy. For the same reason, depending on the end users requirements, signals can be transmitted to them using various systems/technologies, to optimize the costs of such a solution.

The most demanding users should be connected directly to the T&F network backbone via a Point of Service (PoS). A Point of Service will allow the network to maintain control over the highest quality of providing signals. It will be monitored and managed by the dedicated network operator.

The less demanding users can be connected via distributors or Regional Networks, which may be commercial entities. Distributors and Regional Networks will be also fed from PoSs, and will have access to the best T&F signals. Distributors and Regional Networks will distribute these signals to other users in the form and at the performance level they choose, and they will be responsible for maintaining the T&F service in their networks. An access to T&F service outside of the PoS is not under consideration.

2.2.4 Resilience of the T&F service

Resilience is defined as the ability to provide and maintain an acceptable level of service in the face of faults and challenges to normal operation . Resilience is one of the most important service characteristics, especially for critical services. The CLONETS project partners assume that the T&F service will become a critical service for many RI and CE users in next few years. The two most important issues in the resilience of T&F service are related to failures and the recovery from failures.

The T&F network should be resistant to failures of individual T&F signal sources and also to transmission line outages. The T&F network will use multiple highly stable reference sources of T&F signals to ensure the functioning of the network, in case of a failure of a single signal source. Continuous comparison of reference clocks will also enable the detection of signal source failures that may manifest themselves as a slow deterioration of the phase change.

Fibre optic links are typically characterized by a low failure rate (several per year), however these failures are usually long-lasting (several hours). The resistance to damage of individual fibre-optic links can be obtained through redundancy of connections and creating networks in the form of rings. It is assumed that most PoSs will ultimately receive a signal from at least two T&F sources, which are using two independent fibre-optic links. Further work requires the technical development of an automated signal switching method and taking this fact into account in the calibration corrections.

2.2.5 Security of the T&F service

Each service which can be critical for any institution must be protected by external intervention. Service users must be sure that the service provides information from a trusted source. In case of service problems end users must be notified, otherwise they cannot be sure that the service is not compromised.

One of the conclusions of the RI survey is that security is the least important (lowest critical rating and highest irrelevant rating), it does not seem to be a concern for most of the applications. However, the specificity of the RI work does not require very high security of the T&F service. Notification of maintenance work in most cases should be sufficient.

The second huge group of users are Commercial Entities. CE are much more sensitive to security issues, especially in the fields of finance, telecommunication and energy. The origin of T&F signals is very important for these users. An optical fibre network which is the basis of the T&F service considered here is difficult to manipulate and attack. By monitoring the hardware, any break or disturbance of a link will immediately be noticed. Any manipulation of the link is therefore easily detectable guaranteeing the security of the signal.

3 OVERALL SERVICE ARCHITECTURE

3.1 Types of signals

The main purpose of the T&F network is providing T&F signals to end users. Different type of users need different types of signals. Regarding the surveys and experience of the project participants 3 types of signals were chosen:

- 1 PPS – a common output signal of clock devices. Its sharp, leading edge is synchronized with the local realization of UTC (i.e. the delay between the 1 PPS and UTC is known). A general rule is that the sharper the edge of the 1PPS signal, the lower the uncertainty of the time instant defined by 1PPS [1].
- 10 MHz – a common output signal by frequency devices, typically a sinusoidal signal.
- Optical carrier – a high-end technology, interesting mostly for science and metrology, but also of potential interest to innovative industry or spectroscopy laboratories. This technology allows for the creation of an international network of optical clocks and could form the basis for an extended network providing a highest-level reference for time and frequency metrology applications [1].

These signals can be easily transmitted over an optical network (1 PPS and 10 MHz must be converted from electrical to optical signals) and adapted to the requirements of the end users.

3.2 Topology

At the top level the service provides signals to some RIs or CEs (communication companies, banks, energy utilities, etc.) from regional/national points of service (PoS). Such a PoS will provide next level T&F services for regional redistribution by dedicated operators to their own users with the required quality. Each lower level T&F service will be monitored and under the control of the higher level project partners assuring traceability from one layer to the next.

3.2.1 Logical topology

Figure 7 represents the logical topology, showing the main groups of units which are involved in providing and using the T&F network and the main relations between them.

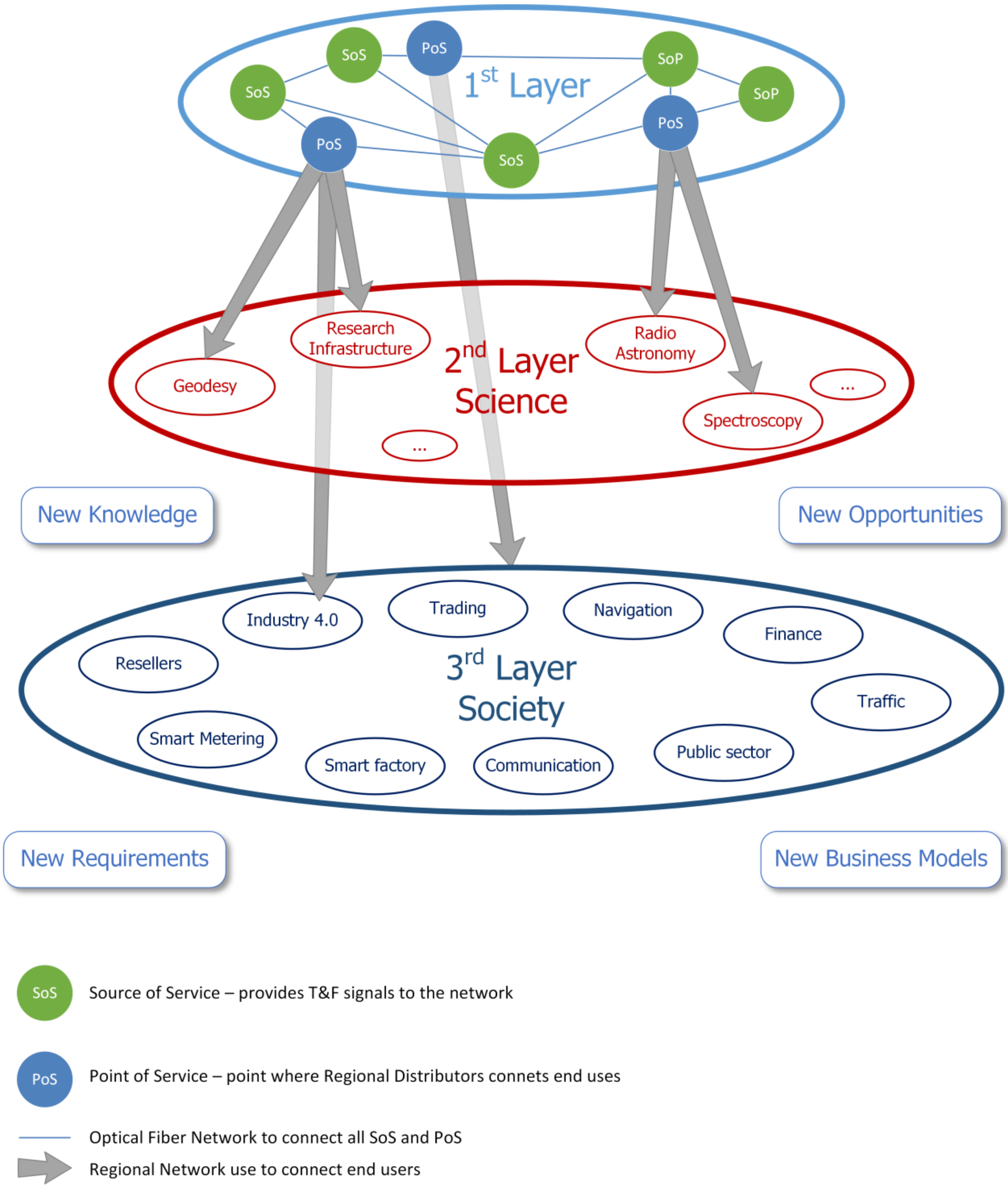

Figure 7. Logical vision of the T&F service delivery

The T&F Service network will be composed of 3 layers:

- 1st Layer – the top level fibre optic network responsible for providing reliable and highest accuracy signals (of all types describe in section 3.1) across Europe. This part of the network must be built using solutions based on bidirectional transmission (dark fiber or dedicated DWDM channels (dark channels)). The signals will be provided by Sources of Signals (SoS). Access to the signals distributed in the international T&F network will be provided by Points of Service (PoS). Ultimately, at least one PoS should be in every European country. Each PoS should receive T&F signals from at least two independent SoS, but some POS could be connected with only one SoS for network simplification. SoSs will be institutions which are be able to provide the highest performance T&F signals to the international T&F network. The NMIs have the best competence to act as SOSs. However, it is not excluded that other technologically advanced institutions will be able to join this group. From the logical point of view the PoS and SoS are different entities but in reality a single institution can cover both roles. The main role, in distributing signals from PoS to end users, will be playing Regional Distributors. In this area the NREN networks can play the main role, but some other institutions can also act in it. The choice of technology, topology and types of distributed signals will depend on the specific requirements of each end user. Institutions responsible for regional distribution will also be responsible for guaranteeing the quality and security of the transmitted signals. They will also be responsible for the calibration of the connection in the case of timing distribution (from PoS to the end user) and for the correct transfer of future services using the created infrastructure (at the regional level). In special cases, end users can be directly connected to a PoS,

- 2nd Layer – gathers scientific entities, e.g. (Geodesy, RI, Radio Astronomy, Spectroscopy, etc.). T&F signals will be received from PoS. Broader access to precise time signals should result in "new knowledge" and "new opportunities" for 2nd Layer.
- 3rd Layer – gathers commercial and other entities e.g. Industry 4.0, Smart factory, Communication, Public sector, Finance, etc. T&F signals will be received from PoS. The 3rd Layer users can also redistribute T&F signals. Access to T&F should result in "new business models".
- Regional Networks – provides access from PoS to 2nd Layer and 3rd Layer.

The CLONETS network should enable the creation of international services (e.g. the comparison of T&F sources or the synchronization of clocks in two different countries) without any additional activities, such as the calibration of individual links. The services provided by the T&F network must also include the access to the necessary data (such as a calibration chain or a current comparison of the 1st Layer T&F sources) to end users for its proper functioning.

3.2.2 Geographical topology

The 1st layer network will connect NMIs and high-performance T&F labs. The location of these institutions is well known, and the geographical topology must base on these locations. Some on these institutions are already connected by fiber links (chapter 2.2.2) and the geographical topology of T&F network will be based on these existing connections between NMIs and T&F labs. Some of advanced RI and high end commercial users will also be connected directly to the 1st Layer (via PoS). The rest of the users will receive access to the T&F service by Regional Networks. Each country will have at least 1 Regional Network on his territory. Figure 8 provides a first indication of the geographical repartition of users and the possible physical topology of the T&F network.

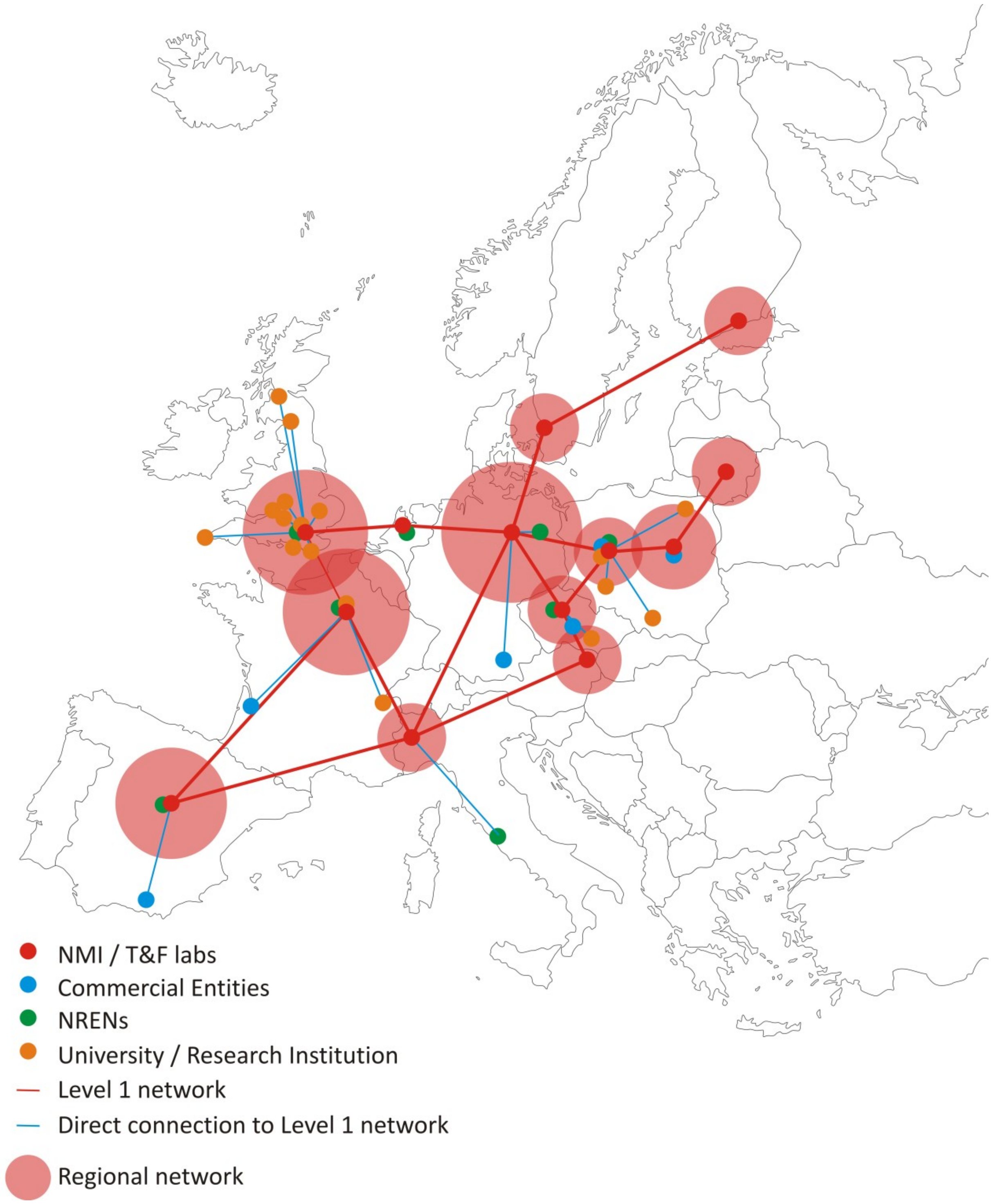

Figure 8. T&F network topology proposition with a first indication of the locations of potential users

4 CONCLUSION

The overall vision for time and frequency service delivery consists of 3 main layers. Each layer is well defined, the highest containing Sources of Signals and Points of Service, the second containing users with the highest performance needs, typically for science, and the third containing other users, typically for industrial and societal users. Commercial users commonly require access to secure, precise time signals. Many scientific users prefer access to precise frequency signals.

The proposed T&F service logical topology is simple and elegant. This topology allows the T&F service to be extended by adding new users and new service providers.