Procurement Requirements Analysis

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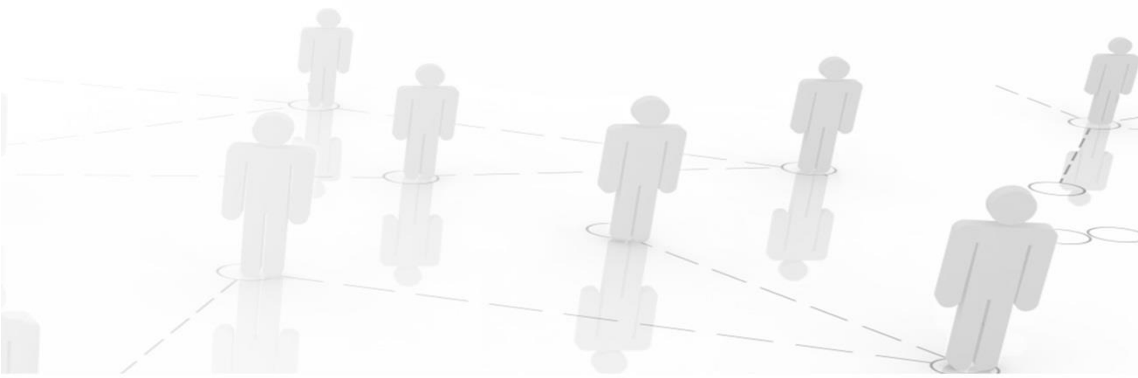

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1 Executive Summary

This deliverable broadly overviews NREN user communities' needs and requirements on the services provided. In many cases this represents key factor for the innovation process, because many of the requirements do not match any technologies and/or services in the area of advanced optical networks available nowadays. The first part of this Deliverable is devoted to user communities, their needs and requirement analysis of target groups. It continues on to the specification PCP and its importance for the innovation process. The following chapters characterize essential end user communities, which influence (or would influence in near future) quality and state of the art NREN services provided. The next part briefly describes lessons learned from public procurement and gives some of general PCP recommendation specific for the optical networking. Based on such information, a new technological approach can be defined. This approach is based on users' needs to fulfil their requirements on the more efficient used of the spectrum available in the optical fibre (in other words to pay less for more, or at least for the same bandwidth available). The last part of this document concludes with the findings and gives predictions about technological challenges in the academic and research networks for the next three years.

2 Introduction

A procurement requirements analysis represents the essential part of every procurement activity. A key element of this Deliverable are needs of target user groups, which represents the potential critical mass of buyers. Their needs and requirements will be explained in greater detail in the first part of Chapter 4. This Deliverable aims to precisely map the needs, requirements and technological approaches related to the area of optical networking. In case of new technological approaches, services built on top of the network are driven by the needs of the NREN community, which usually influences strategic NREN decisions (e.g., selected academic representatives are members of most NRENs' Board of Directors). As such, some of them were asked to provide feedback as to the direction they want to go in the upcoming three years' time-frame, and if such a plan fits in with their needs. The results of this action will be briefly summarized in the last section of this Deliverable.

This deliverable presents the result of preliminary analysis of users' needs gathered by project partners during the first months of project execution. The needs and requirements collected in this deliverable will be used for further analysis and definition of potential areas for cooperation in the PCP domain. The key element of the whole PCP procedure is to gain the critical mass of users and their needs to stimulate next phases of PCP. We strongly believe that the findings reported in this deliverable will enable future collaboration among NRENs and other public operators towards a joint cross-border PCP project.

At the early stage of the project we have identified the following procedure for execution of PCP in the network operators' community, as depicted on Figure 2.1. The figure shows a PCP process which is crucial for this Deliverable. Analysis of users' requirements and the subsequent viability evaluations are the key elements of success in the optical networking domain.

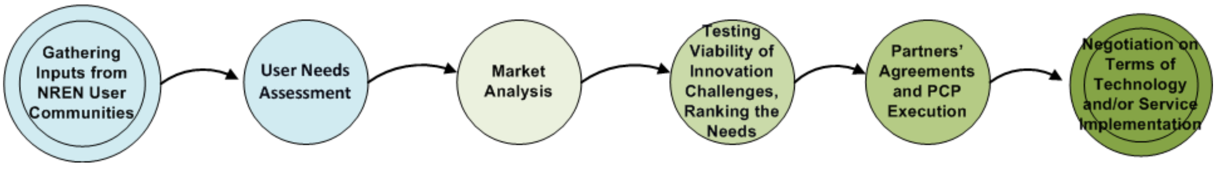

Figure 2.1 COMPLETE PCP Process

This deliverable covers the first two stages of the abovementioned procedure. We report the interaction with users of public networks and initial findings on technology requirements and definition of potential themes for future PCP projects. The deliverable will be used as an input for further work, with a primary goal to measure the innovation gap between user requirements and needs and the acual state of the art technology already available and their possible linkage. This should be part of market analysis, but it is not deeply inventend in this project.

At the early stage of the project we have identified the following procedure for execution of PCP in the network operators' community, as depicted on Figure 2.1. The figure shows a PCP process which is crucial for this Deliverable. Analysis of users' requirements and the subsequent validation of innovation challenges and procurement path are the key elements of success in the optical networking domain.

3 Users communities – Potential Stakeholders of Future PCP Activities

As presented and discussed in the previous chapter, NREN user communities are those which take control and provide the direction that NRENs should follow. With respect to the increasing demands of the users of NREN networks, we have identified key technological challenges the users of NRENs are nowadays facing, followed by the proposal of a new fibre spectrum allocation and analysis of user scenarios.

The most active groups of users, who have direct or indirect requirements imposed on network resources, are outlined below:

1. Bioinformatics
    a. This, mainly research oriented multidisciplinary group of users, combines raw biological outputs (mostly in the form of unstructured data, e.g. as an output from NGS – Next Generation Sequencing) together with an application of modern methods in informatics. Such data, usually from tens of GBs to tens of TBs in size, needs to be transferred from various sources (e.g. gene databanks) over long distances and then processed locally. Therefore, the transfer speed is a crucial element, which also influences the speed of the research itself, such as the development of new drugs.
2. Media related
    a. Academic and experimental users, who conduct applied research activities in audio and video, including remote collaborative tools. These services act as important supportive utilities for other users. These include media users, including (among others) doctors and medical assistants, who often require the video transmission of surgeries and remote guidance and assistance. Such media related activities require not only dedicated high bandwidth lines (at the time of the writing of this document, image processing high-resolution cameras are 4K minimum) but also low and fixed latency (stable jitter).
3. Physicists and Natural Science researchers
    a. The most demanding user group of scientists, so far. This covers large scale trials for theoretical physics (simulations, molecule dynamics, high energy, etc.), that require dedicated circuits to CERN. To this user group we can also include geophysics, astronomy, meteorology, biology, material sciences or nuclear research. Remote instrument control, which means fixed latency together with extreme data transfers, makes Physicists one of the most challenging user groups.

On the other hand, technology requirements, which could arise from the presented user groups, should be compatible with already existing services provided by particular NREN. However, compatibility must NOT be a barrier for innovation. If so, user voices calling for innovation and on top state of the art technology cannot be heard and procurers will probably fail in their effort.

3.1 NRENs and Their Users

NREN is the acronym for National Research and Educational Network. As the name suggests, NRENs can be described as Internet Service Providers (ISP) focussed on the special and advanced needs of research and educational community. NRENs are established in many countries on all continents (except of Antarctica) and some of them were founded already in 80’s (examples are the German NREN DFN in 1984 and the Dutch NREN SURFnet in 1986), usually they are not-for-profit organizations. In recent years NRENs are connected by high speed multi gigabit optical links between continents, for example 100G connection between Europe and North America and multiple 10G connection between North and South Americas. NRENs usually test and pre-deploy new technologies like Internet Protocol version 6 (IPv6) or IP multicast. Another example can be new architectures on so called low layers, like is flexible optics and photonics with help of reconfigurable optical add drop multiplexers (ROADM). There are other services like National Identity federations or eduroam.

NRENs can usually be distinguished by strong support for high-speed network connections not only in the backbone networks but also in the so called last miles. This feature is essential because NREN **users may generate huge amount of data due to their unique character** – these ‘users’ can be institutions like CERN or an array of radio telescopes like the Atacama Large Millimetre/sub-millimetre Array (ALMA). These ‘users’ have very specific requirements which cannot be fulfilled by typical Internet Service Providers, for example dedicated high speed data channels, usually optical fibres, are necessary. Of course NRENs user base may differ in every country but usually they are universities, academies of sciences and any institutions with research or scientific projects.

3.2 Public Operators

There are many other public operators – ISPs – some of them built in cooperation with academic and commercial partners. They can be co-funded by states and regional funds and in Europe also by EU funds. They provide services to regional and local governments, hospitals, elementary and secondary schools, state authorities or rescue systems. Another important goal is to develop and provide services in rural regions where infrastructure and services are not developed that much. Competition among different public operators is beneficial for end customers – may it be real people in small villages or institutions.

Many users of public operators do not require multi gigabit speeds so wireless services are frequently deployed in addition to optical backbone networks. That said, many public operators use quite advanced equipment not only on IP level but also on optical level and multi-gigabit speeds are rather common in backbone networks.

There are interesting examples of cooperation between NREN and public operators. In Poland it is Wielkopolskie Sieci Szerokopasmowe (WSS) together with the Polish NREN PSNC, ROWANET together with the Czech NREN CESNET and SYZEFXIS together with the Greek NREN GRNET. Because of this close cooperation, the results of COMPLETE project may be presented to the public operators and make them aware of PCP possibilities.

3.3 Brief Overview of Technological Challenges

Feedback from the NREN users leads to technological challenges, the solutions to which are imposed on the networks of the R&E operator. In conjunction with future Deliverables (D2.1 and D2.5) a synthetic analysis of the state of art and the definition of the innovation should be briefly mentioned here. In this case, here we present only brief overview of the challenges we are facing today. This content is connected and integrated explicitly to the analysis of innovation requirements presented in this Deliverable.

In the optical networks domain, such challenges are summarized in the following table:

Technology Challenge	Description
400 Gbps transmission	Technology to speed-up backbones of NRENs with relatively low cost for the technological change (400G is 4x 100G).
Flexi-Grid	The flexible assignment of the optical spectrum to channels. Maximizing flexibility in the channel spacing of DWDM networks which improves spectrum utilization. The possibility to dynamically adapt the wavelength grid to the NREN needs.
1 Tbps transmission	Actual needs of user communities points towards the next generation of networks enabling high volume of data transfers in a short period of time
Flexi-Rate	The ability to dynamically switch between modulation formats, depending on the physical infrastructure, and thereby transmit higher bit rates, including superchannel bit rates. This allows network operators to achieve an optimal balance between data throughput, transmission reach, and maximum spectral efficiency.
Software Defined Networking	SDN simplifies networks by implementing a centralized control layer with open application interfaces (APIs). Using open APIs, SDN architectures decouple the network control and forwarding functions, enabling network control to be directly programmable and the underlying infrastructure to be abstracted for applications and network services.

Table 3.1 COMPLETE Optical Technology Challenges

The table presents the overall themes, which are the result of analysis of users' needs collected during the first months of execution of the project. The detailed description of data collected from the users is provided in the following chapters.

4 New Technological Approach - Cost Effective Full Fibre Spectrum Availability for End Users

Overview of the technologies written out in the previous chapter do have a common denominator. This denominator is a more efficient way to use the spectrum available in the optical fibre to the end user. All the technologies tries either to increase the bandwith, or use elastic approach to the grid or rate. But all of those are working in a space allocated for such approach.

Based on the facts state above this chapter describes the (alien) Spectrum as a Service (aSaaS) technological approach. The aSaaS is the result of user needs investigation among European NRENs in the domain of cost effective spectrum sharing. As can be observed in the following chapters, this approach is based on Alien Wavelength (AW) and is mainly desired by those user groups who use AW in their optical networks.

4.1 Motivation

End users in Research and Innovation fields often require access to a cost effective, full fibre spectrum network. These networks are built on Photonic transmission technology which enables new applications, for example the remote control of scientific equipment, ultra-stable frequency transfers, or an increase in reproducibility of the conducted experiments. Networks with full fibre spectrum access have industrial applications, too – for example they contribute to improvements in the reliability of power plants. Such applications are different from common digital services and cannot be implemented on top of “just” faster networks.

This Deliverable 2.6 presents an overview of the requirements, recommendations for specifications, procurement and development of networks. A notable focus of this document is infrastructures which are funded fully or partially from public resources and are therefore a subject of public scrutiny. The end users expect to get their advanced requirements fulfilled, and achieving cost effectiveness is imperative. Designing and building these networks, based on a formal specification of the desired features, can **often lead to cost savings compared to the case when the networks are built with components offered by just a single vendor**. Research, development and innovation are usually partially or fully supported by public funds, and end users are connected to the public network by a dark fibre. This means that the cost effectiveness is under public scrutiny**.** As a result of these circumstances, the users expect to get their advanced requirements fulfilled.

The usefulness of the photonic transfer is not limited to a particular field of science, which means that a common service can be shared by all disciplines and all users can be effectively served by a unified network infrastructure. Indeed, requests for services based on an Alien Spectrum as a Service (ASaaS) in fibre lines are coming from several fields.

Our suggestion is to keep this trend in mind and to follow key EU policies, such as the Digital Single Market. Fostering photonic services and preparing for their deployment is within the scope of the COMPLETE project.

The implementation of ASaaS is a development task with the strong cost-effectiveness motivation of fibre sharing, because the fibre lease costs are responsible for roughly 65% of the overall network cost.

4.2 End users update

The main reason for the creation of D2.6 (Procurement Requirements Analysis) is the user base. Their requirement for research and development teams from universities, academies and industry for using Alien Spectrum as a Service (ASaaS) in fibre lines.

Research, development and innovation are usually partially or fully supported by public funds, and end users are connected to the public network by a dark fibre. This means that the cost effectiveness is under public scrutiny. As a result of these circumstances, the users expect to get their advanced requirements fulfilled. ASaaS approach, like other PCP resulting nowelty, are not (yet) commercially available on the market at the time of writing. Because ASaaS is a brand new approach to what is called Alien Waves, we have decided to update Deliverable 2.6 with the description of this technology. Another reason that we have decided to do so is because the vast majority of the technologies mentioned rely on the spectrum available in the fibre, and its smart use is the key approach to success. Moreover this approach also should lead to research and development of a new generation cost effective solutions, actually not economically affordable.

The demand for satisfying these requirements is already increasing despite the fact that an active outreach to end users has been rather limited.

In principle, transmission between end users (U2U) is a multi-domain problem. Each transmission service or equipment vendor should expect to deliver their service in just one domain, not in all. Moreover, it should be used only a part of the fibre frequency spectrum, and keep other parts free for the ASaaS. In this concept, in general, the transmitted signals are sent and received by the end users' equipment. The end users can use digital and non-digital transmissions in parallel, as they see fit, without causing any interference.

Such a scenario effectively prevents a monopoly by any single vendor. In general, ASaaS focuses on end users' requirements, including requirements expected in the future. This future planning is based on experience with early adopters and their projects.

Fundamental research in this area was done previously, see, for example, Harald Schnatz , PTB[1].

4.2.1 Collaboration on Analysis with End Users

The Alien Spectrum as a Service technology enables new and advanced network opportunities beyond traditional Internet (aka IP) services by allocating the unused frequency spectrum in optical fibre.

Without going into technical detail, such services could be beneficial for various end users in many fields of research and expertise, such as the following examples:

- Earth sciences
  - Meteorology
  - Earth and space observation
  - Early warning systems (e.g., seismology)
- Life sciences
  - Medicine
  - Biology (especially next generation sequencing, genomics, proteomics)
  - Art (e.g., distant (long-range) musicians´ performances)
- Physics
  - Nuclear physics
  - Spallation and Accelerators

Among the early adopters which are ready to use services based on the dedicated optical fibres spectrum are:

- The Institute of Photonics and Electronics (Prague).
- The Astronomical Institute (located in Ondrejov).
- The Geodetic Institute (Observatory located in in Pecny).
- The Temelin Nuclear power plant (located in Temelin, the precise frequency transfer is being used for containment stability exact measurements).
- The Nuclear Physics Institute (located in Rez).
- Extreme Light Infrastructure (the most intense laser in the world is to be located in Dolní Břežany – currently under construction).

The involvement of the research institutions listed above is described in greater detail in the following chapters.

1 http://archiv.ces.net/events/2012/cef/p/Comparison%20of%20clocks%20using%20optical%20fiber%20links%20in%20recent%20results%20and%20future%20projects.pdf

Predehl, Katharina; Grosche, Gesine; Raupach, Sebastian M. F.; Droste, S.; Terra, Osama; Alnis, J.; Legero, Thomas; Hänsch, Theodor W.; Udem, Thomas; Holzwarth, Ronald; Schnatz, Harald: A 920-kilometer optical fiber link for frequency metrology at the 19th decimal place. Science 336, 441 (2012).

ASaaS has not only a regional impact, but it is designed to be a multi-domain service, if proper in-line optical network devices are installed. This means that such a service can be run out of the standard NREN's service territory. Thanks to this capability, ASaaS can provide, for example, remote control of experiments in a distant location (e.g. research station) while the person managing these activities can be based in a research institute in the home country. Moreover, thanks to the existence of CBF, these services can be run in the neighbouring country as well.

Due to the fact that some giant projects are extremely interesting from a worldwide point of view, the ASaaS approach could enlarge the possibilities of remote access to such projects for the scientific community. Fine examples of this are the CERN Large Hadron Collider located on the French-Swiss border, or the European Spallation Source (ESS), which is based in Lund, Sweden and CESNET, is negotiating for connection to the project where ASaaS is preferred. There are other "minor" examples of international collaboration - the precise time comparisons of national accurate time centres: Bundesamt für Eich- und Vermessungswesen (BEV) located in Vienna, Austria and CMI, Prague, CR.

Regardless of physical location, all devices which could use an ultra-stable and precise remote control via fibre optics (e.g. telescopes) benefit from the ASaaS model.

On top of that, ASaaS can be used in cases where the unused capacity of the fibre can be better utilized for standard digital transfers, but via using more advanced technology in order to archive higher transmission speeds (using modern DWDM technologies like flexi-grid, tighter channel spacing, different symbolic speed or modulation, etc.).

4.2.2 End Users in Academic and Public Fibre Networks

As the NRENs are generally focused on advanced backbone fibre infrastructures with very big capacities, sometimes in such an environment there might seem to be a lack of the variety and/or amount of possible end users. Constant efforts in searching for the end users who fulfil the exacting NREN´s criteria (public funding) are hallmarks of NRENS' many years of experience.

A large number of such end users can benefit from the NREN´s infrastructure over publicly funded fibre networks, e.g. university fibre networks. For instance, in Czech Republic, such networks have been developed independently, and their advanced demands on connection capacities represent the very suitable field for a win-win collaboration with the NREN. All the end users depending on such public funded networks generally belong to the mentioned NREN´s criteria, and the amount of such users can be very significant.

Furthermore, fibre networks connected to fibre NREN´s infrastructure present unique possibilities within the whole country (the connection with further Uni´s locations) or even Europe (ASaaS).

As an example of such collaboration, CESNET has been operating as a connection provider for the Prague Academic and Scientific NETwork (PASNET). The topology (Figure 5.1) shows their large metropolitan fibre network serves local LAN networks of the Universities and the Academy of

Sciences localities. The network consists of leased and their own fibres (hundreds of kilometres) with CWDM technology, plus Ethernet.

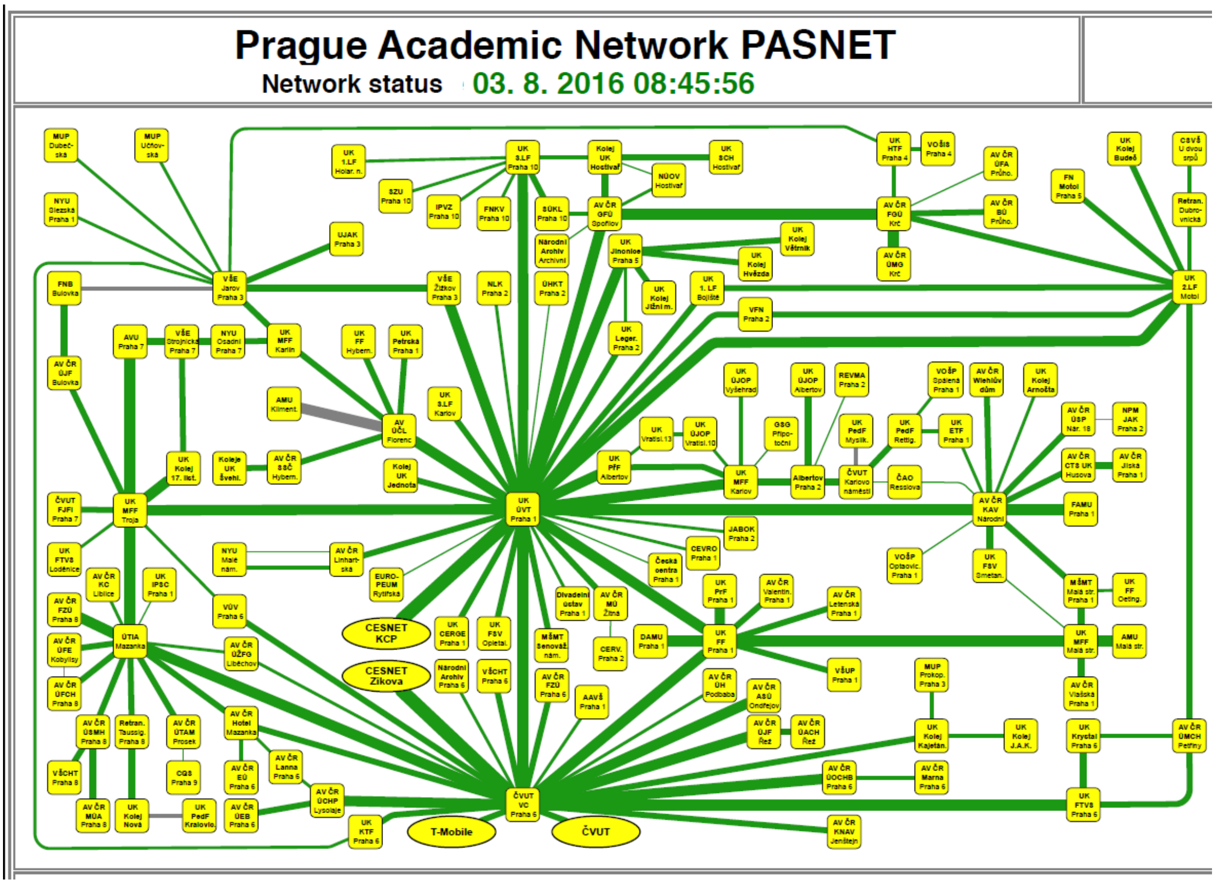

Figure 5.1: PASNET Virtual Topology

Another example would be the Brno Metropolitan Academic Network (BAPS), which has been in existence since 1993, and, for current extensions, new lines with 96 pairs of fibres are being used. Again, the number of various end users (e.g. Picture Archiving and Communication System, Medical Instruments outputs and archives, etc.) is connected to the backbone infrastructure via the university metropolitan fibre network.

Czech Light equipment is also deployed outside the network in the Central Bohemia Region of the Czech Republic, on single-optic route between Prague and Kladno. Furthermore, in the Slovak Republic (Bánovce nad Bebravou) for access network FTTx, where optical amplifiers for CATV have been developed. Another network lighted by Czech Light is in Plzen named PilsFree. The most significant example of the NREN – Regional Public operator is ROWANET. This cooperation is that much intensive we have decided to dedicate it a standalone chapter in the future Deliverable, D2.1. – Partner Agreements.

Outside the borders of the Czech Republic, Czech Light transmission system has been successfully utilized in the UK, Denmark, Egypt, Jordan, Slovak Republic, Serbia and Ukraine.

4.3 Requirement Analysis

Previous sub-chpaters represent a good critical mass base of users, from which requirements for the PCP can be extracted. The purpose is to prepare a detailed explanation, that Alien Spectrum in fibre lines will probably be requested by many NRENs and publicly funded networks in the future.

Up to now, it has been in general totally unaware of such a requirement, especially in multi-vendor transfers. Results in technology developments enable the cost effective allocation of Alien spectrum in fibre lines. Alien Waves, Photonic Services and other non-digital services implemented without OEO conversion are running in fibre lines without compromising digital transfer.

New generation services should enable:

- **Reproducibility (especially reproducibility of remotely controlled experiments in science and research).**
- **Remote process control (hard real-time) in industry (for example power-plants) and research (for example, remote control of a telescope or ESS or Air Traffic Control and radar facilities).**
- **Accurate time transfer, ultra-stable frequency transfer (also allows the transfer of etalons for measurement).**
- **Remote sensing of natural resources with 100-1000 times higher accuracy than GPS (e.g., Groundwater Storage** http://www.hydrology.nl/images/docs/dutch/2009.04.27_Shaakeel_Hasan.pdf
- **Flexibility (In terms of spectrum expansion and shrinking).**
- **Dynamic adoption to the actual utilization.**
- **Scalability (in terms of use of the spectrum assigned).**
- **Multi-Domain feature (must enable adoption in the multi-domain environment – via multiple NREN domains).**

As presented and discussed in the previous chapters, NREN user communities are those who take control and provide the direction that NRENs should follow.

4.4 The Purpose of ASaaS

Some of the end users are not sufficiently aware of the fundamentally new applications which enabled by Alien Spectrum as a Service (ASaaS) in fibre lines. The ASaaS should be a also multi-domain service enabling end user to end user connection by non-digital signals.

An important benefit of the ASaaS is that the end users do not have to be aware of the underlying connection details of last miles, metropolitan fibre lines, regional fibre lines, NREN fibre lines, Cross Border Fibres (CBF) and GÉANT backbone fibre lines.

Alien Waves, Photonic Services and other non-digital services are implemented without OEO conversion, and are running in fibre lines without compromising the digital transfer.

Alien spectrum allows for a fundamentally new utilization of fibre networks; it attracts new customers and early adopters for implementing technologies that give them market advantages.

Within the COMPLETE project, the long-term and very important work has already been initiated, mostly on high-tech R&D equipment procuring for public bodies, such as, for example, Research and Education Networks. Now we are radically improving this view by gathering the requirements of end users, as recognized in our work with possible early adopters of ASaaS.

The early adopters of the actual ASaaS approach are usually located in regional, metropolitan and city networks, sometimes using dedicated last mile fibres. Lighting procurement can be subject to public overseeing, if public funding is partially or fully used. An important criterion, when allocating funds, is to build an infrastructure which is useful on a long-term basis. This means that future-proof functionality is necessary. In general, it is reasonable to assume that any end user might ask their service provider for an ASaaS during the next 10 years.

These expectations do not apply just to the research/education/academic fields. With the increased frequency of collaboration with industry, the non-academic partners from the private sector can ask for the ASaaS for innovation purposes. As an example, consult the collaboration of JISC and Rolls-Royce at https://www.jisc.ac.uk/news/rolls-royce-first-company-to-join-supercomputing-initiative-07-jul-2015 .

The ultimate goal of the project is to optimize the usage of public funds for building beyond state-of-the-art public networks. The ASaaS is a very visible example of beyond state-of-the-art public networks. We should emphasize that the ASaaS has been used for many years, see the description of services in the next chapter. Now it is time to use the advantages of this technology, and to support the outreach activities.

A key element of every procurement activity is the procurement requirements analysis. It aims to precisely define the needs and services related to the optical networking equipment. The services built on top of the network are driven by the needs of the end users and the NREN community, both of which usually influence strategic NREN decisions.

4.5 PCP in Cost Effective Spectrum Sharing

Because successful deployments of networks which support full-spectrum access typically require specific choices when ordering hardware components (please refer to the Deliverable D2.5 for details), it is beneficial to ensure access to the vendor’s most up-to-date offerings. In addition, aligning to the PCP principles is a requirement for access to additional EU funding as per https://ec.europa.eu/digital-agenda/news/calls-eu-funding-opportunities-pre-commercial-procurement-and-public-procurement-innovative

5 End User Use Cases

In this very important chapter it will be expressed what are the most probably condidates for early adoption of the new services based on the requirements gathered (Chapter 4.3). The following candidates are coming from carefully selected end-users base, which is the most promising in terms of possible adoption. What this chapter is going to focus on are fragments missing to reach the innovation, performance and quality target set in previous chapters.

Ideas need verification, development and experimental research. The approach to prove such a statement needs a lot of drive, which is especially true within the complex environment of a NREN. Nevertheless, COMPLETE consortia members have been focused this way for many years, and we are sure it is worth the effort. Anyway, end users are the very basis and source of requirements for any development and investments in infrastructure elements. As NRENs provide state-of-the-art networking services (e.g. photonic services), searching for appropriate end users is an essential part of their activities. A NREN's mission is to connect its own research activities in the field of advanced networking with current projects, where the unique connection possibilities should be utilized and evaluated. Such collaboration should result in a win-win relationship. Yet, the needs of the end users are actually unpredictable, therefore the only way to meet the expectations is via a realization of an experimental facility which is open to all possible end users´ wishes, i.e. a fully photonic facility.

5.1 Use Case 1: IPE and BEV

The comparison of time scales between Czech and Austrian national time and frequency laboratories in Prague and Vienna was established in August 2011. It uses a CESNET developed precise time transfer system, which implements a two-way time transfer method. Such a system is capable of operation over all-optical lambdas, both unidirectional or bidirectional. For this connection, the pair of unidirectional all-optical lambdas have been chosen, as it represents a reasonably economical solution, with limited requirements to necessary upgrade expenditures. The photonic path between institutes IPE (Institute of Photonics and Electronics) in Prague, and BEV (Bundesamt für Eich - und Vermessungswesen) in Vienna has a total length of 550 km (see Fig 6.1) and passes through dark fibres in local loops and two different DWDM systems: first Cisco ONS 15454 utilizing 50 GHz wavelength grid and fibre based Dispersion Compensating Modules (DCMs) and second Czech Light utilizing 100 GHz wavelength grid and Fibre Bragg Grating DCMs. The Czech Light system also overcomes two excessive fibre segments, both with attenuation of almost 30 dB. For details, see Fig. 6.2.

In principle, the time offset between an atomic clock with an uncertainty of about 10^{-10} s (i.e., 100 ps) is measured. During the months of measurement, a very good correlation between optical transfer and the standard GPS Common View method, i.e. a method when the signal from the same satellite is received in both sites, has been achieved. A good correlation with the published so-called Circular-T, the official documents evaluating time offset between UTC time scales and its national approximations, has been achieved. The time stability of all three methods, in terms of Time Deviation (TDEV) is visualized in Fig. 6.3. It confirms our observation that optical time transfer has a smaller noise than both GPS based methods[2]. We can identify the white phase modulation noise for optical transfer in averaging intervals 1–20 s and the white frequency modulation noise in averaging intervals 2·101–3·105 s. The lowest noise in terms of Time Deviation observed is 30 ps at a 20-s averaging interval[3].

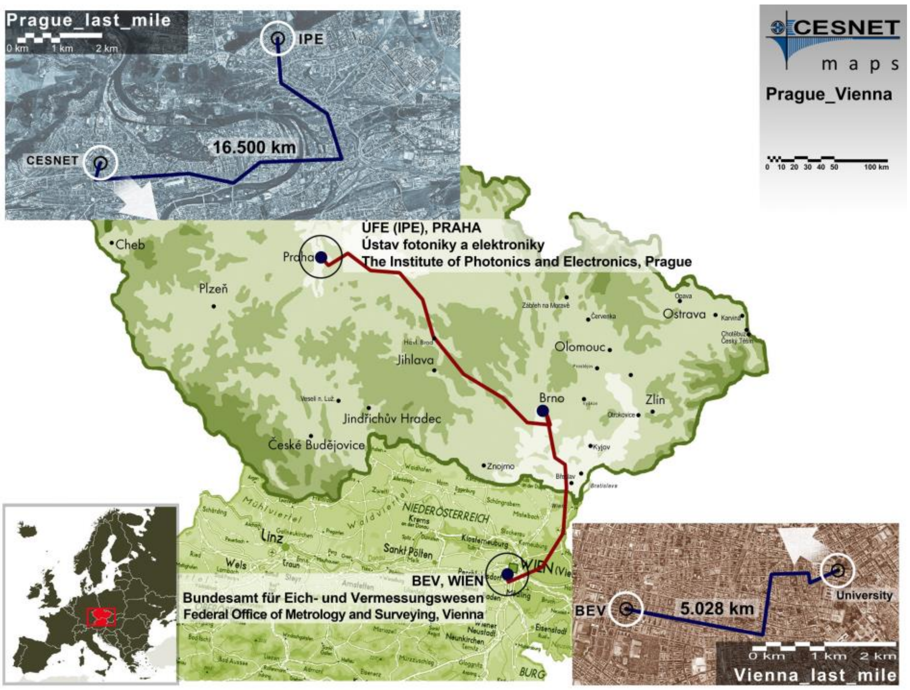

Figure 6.1: Photonic path between IPE and BEV

2 A new method of accurate time signal transfer demonstrates the capabilities of all-optical networks (online) in press release at http://www.ces.net/doc/press/2010/pr100401.html

3 V. Smotlacha, A. Kuna: Two-Way Optical Time and Frequency Transfer between IPE and BEV, EFTF 2012, Gothenburg, Sweden, 2012.

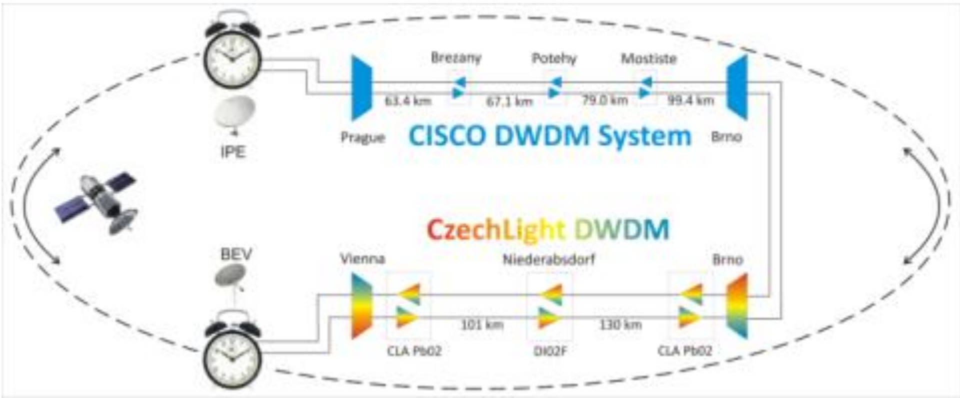

Figure 6.2: Transmission systems on a photonic path

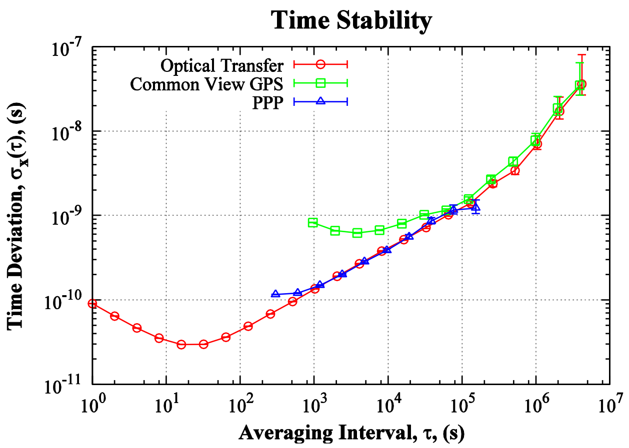

Figure 6.3: Time transfer stability

5.2 Use Case 2: Pecny

The next precise time transfer line was established as bidirectional over a single fibre to decrease transmission uncertainty. The fibre is shared by both the standard data service (n x 10Gbps) and time transfer to VUGTK (Geodetic Observatory in Pecný). The geographical distance between both sites (Prague and Pecny) is 35.2 km, however the link is represented by a 78 km long single fibre which has an attenuation of about 21.2 dB. The link setup reserves optical bandwidth of 400 GHz for time transfer and the rest is dedicated to data, actually the link supports up to 16 amplified DWDM wavelengths. The line outperforms the IPE-BEV line in terms of 3 times lower phase white noise and according to the analysis, uncertainty of any of these effects is up to just a few picoseconds, and the sum does not exceed 10 ps for this setup. The common contribution to time transfer uncertainty is half of propagation delay uncertainty, i.e. no more than 5 ps[4].

[4] V. Smotlacha, J. Vojtech and A. Kuna, "Optical infrastructure for time and frequency transfer", Proc. EFTF, Prague, pp. 481–484, 2013

In order to extend the transmission to national time and frequency laboratories IPE, a passive channel 1550nm within a 3rd party CWDM infrastructure was rented. The channel exhibits an attenuation of about 21 dB. As a solution of choice - a bidirectional EDFA from the CzechLight family has been chosen to partly compensate for the composite link attenuation. Figures 6.4 + 6.5 and 6.6 + 6.7 show the extended line and its setup. Fig. 6.8 further shows the achieved time stability, in terms of TDEV for the resulting composite link. The best value was achieved about 20 ps for an averaging interval of 16 s.

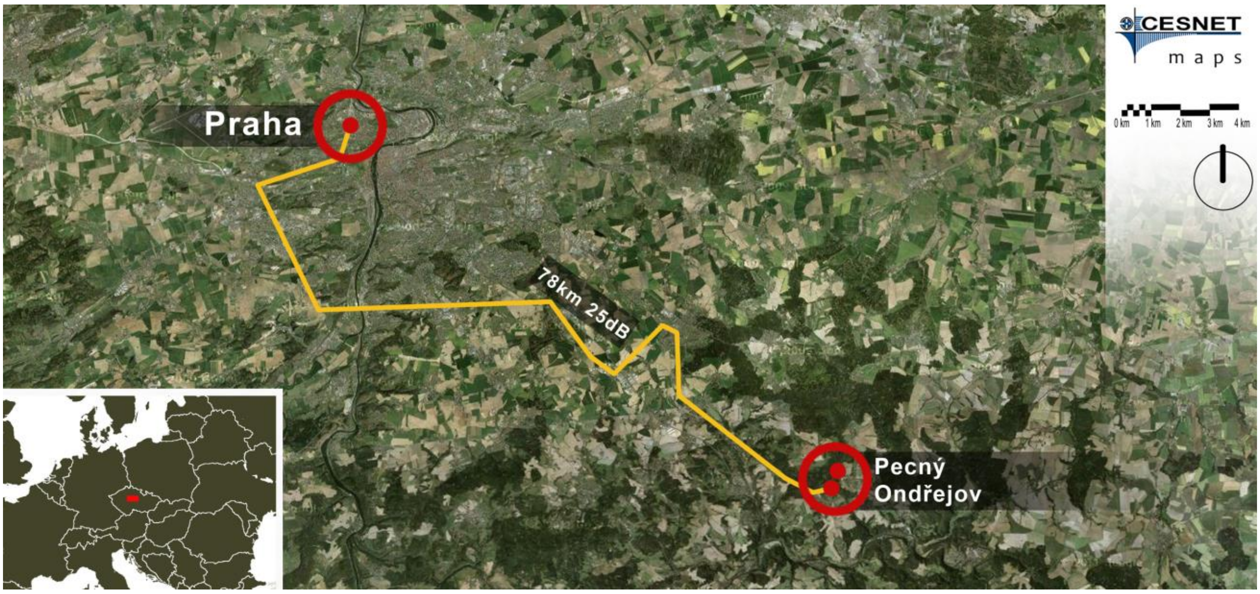

Figure 6.4: VUGKT line

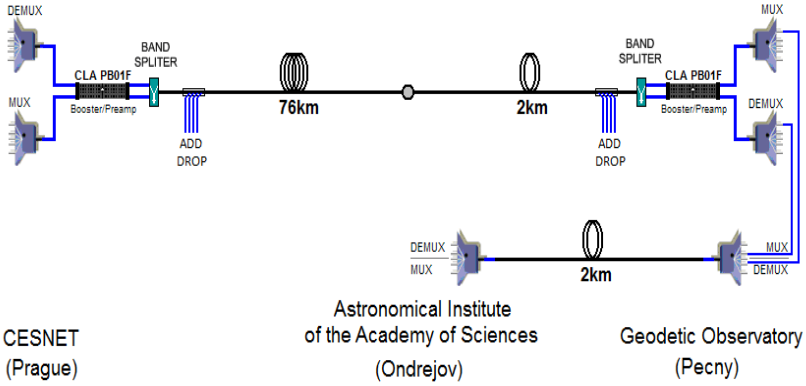

Figure 6.5: Schematics VUGKT line

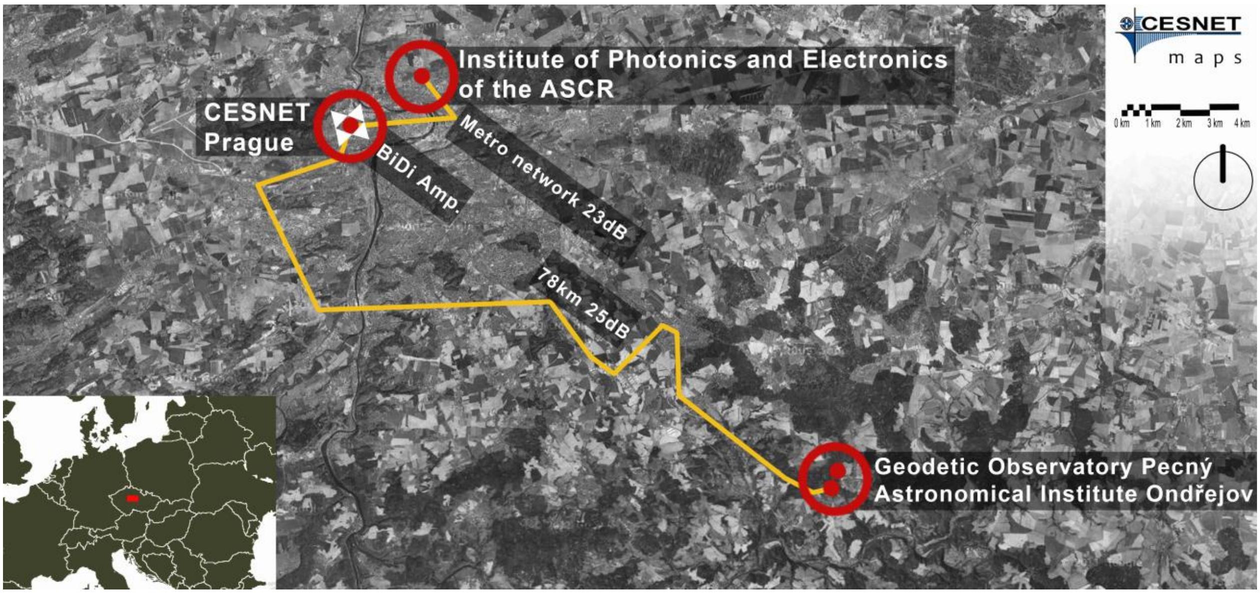

Figure 6.6: IPE - CESNET - VUGKT line

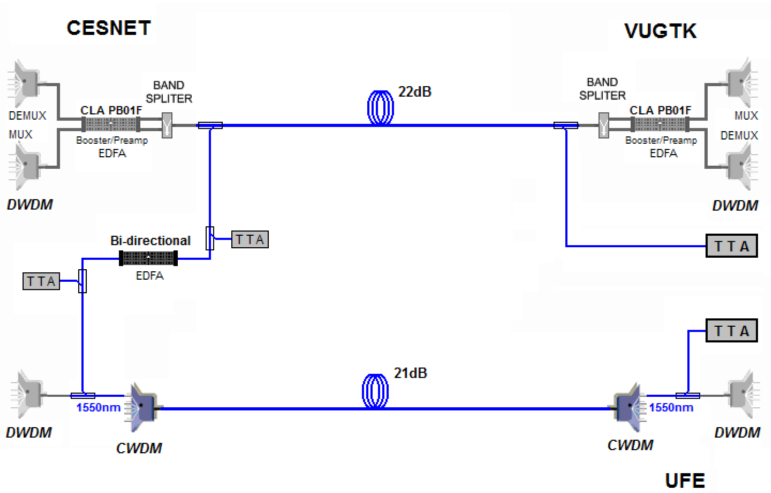

Figure 6.7: Schematics of IPE - CESNET - VUGKT line

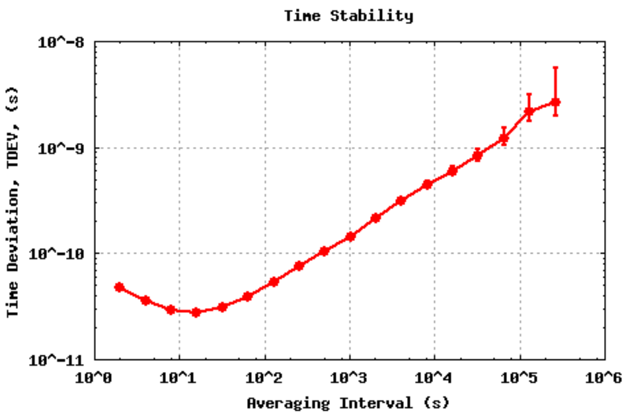

Figure 6.8: Time stability of IPE - VUGKT trensmission in terms of T_{DEV}

5.3 Use Case 3: Temelin, Rez, ISI

The effort described here in more detail is a part of the metrology infrastructure. The precise frequency from the Hydrogen maser located in the ISI, Brno, will be distributed into the Institute of nuclear Research, Řež and Temelín nuclear power plant. The initial phase begun with an upgrade of the experimental line Brno Prague by a parallel transmission of frequency and time. The transmission was established over 306 km of fibre, where about 270 km consists of fibres according to G.655 specification, the rest accords to G.652. The total attenuation is about 85 dB, the link originally contained two excessive spans of 28 dB and 26 dB. The geographical position of the line is shown in Fig. 6.9.

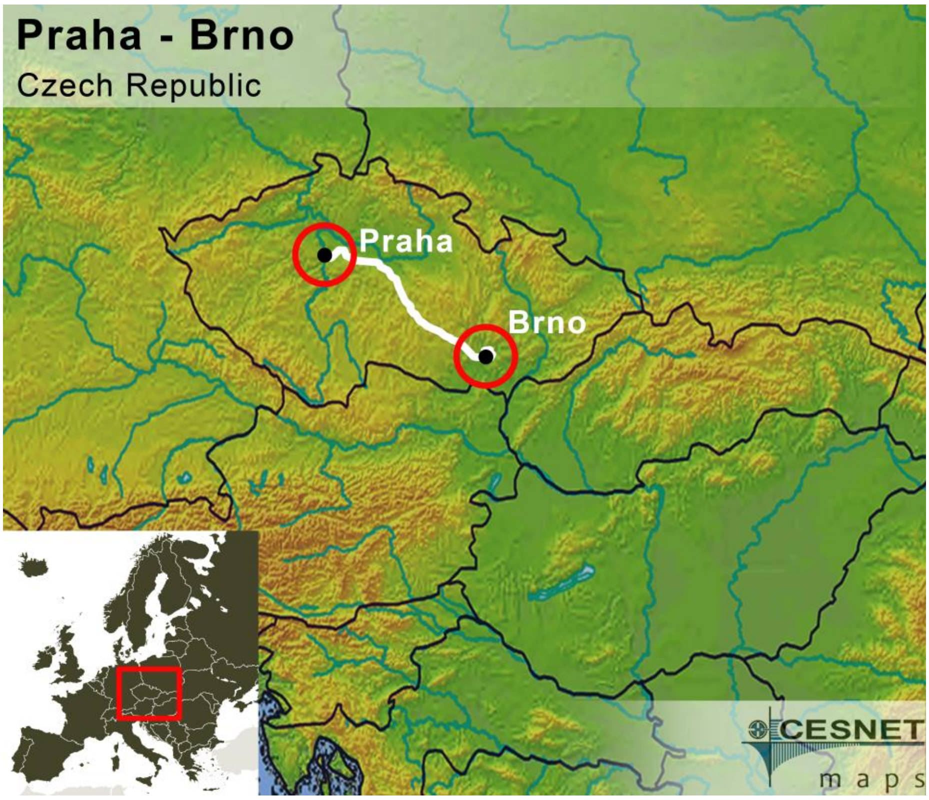

Figure 6.9: Geographical position of the shared line

The link was originally deployed by C and L band transmission systems. In the C band system, a channel with an optical bandwidth of 800 GHz was created. See the spectrum allocation in Fig 6.10. The losses in this channel were compensated for by four additional bidirectional Erbium Doped Fibre Amplifiers (EDFAs) with a single signal path for both directions. The main obstacle of bidirectional amplification with a single path is represented by the fact that reflections and backscattering (which is unavoidable in traditional fibre) create feedback. When such feedback is present, the maximum achievable discrete gain is limited, otherwise unwanted self-oscillations will appear. The max achievable gain is mentioned to be about 22 dB. From this point of view, the span of 28 dB can't be fully compensated, so the line was redesigned and the extensive segment split into roughly equal parts. Finally, the line is amplified by 5 bidirectional EDFAs, see Fig. 6.11.

The extension Prague-Řež, and the especially demanding arm Brno –Temelín, with a total length over 316 km, will be deployed in the future.

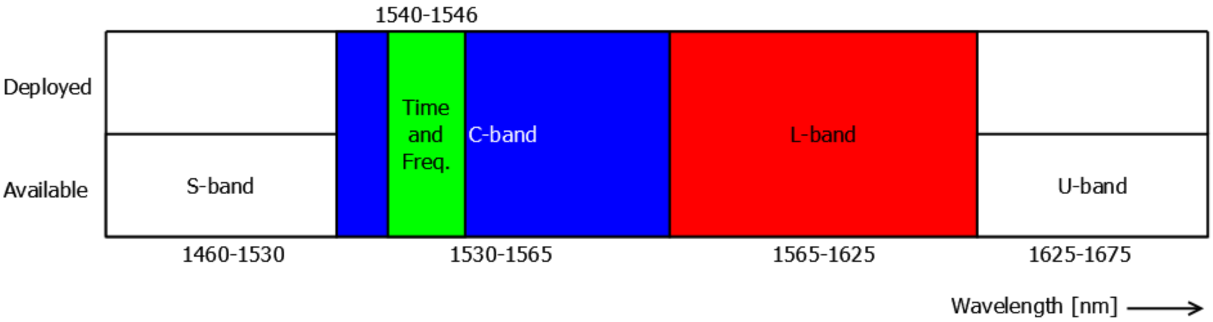

Figure 6.10: Scheme of spectrum allocation

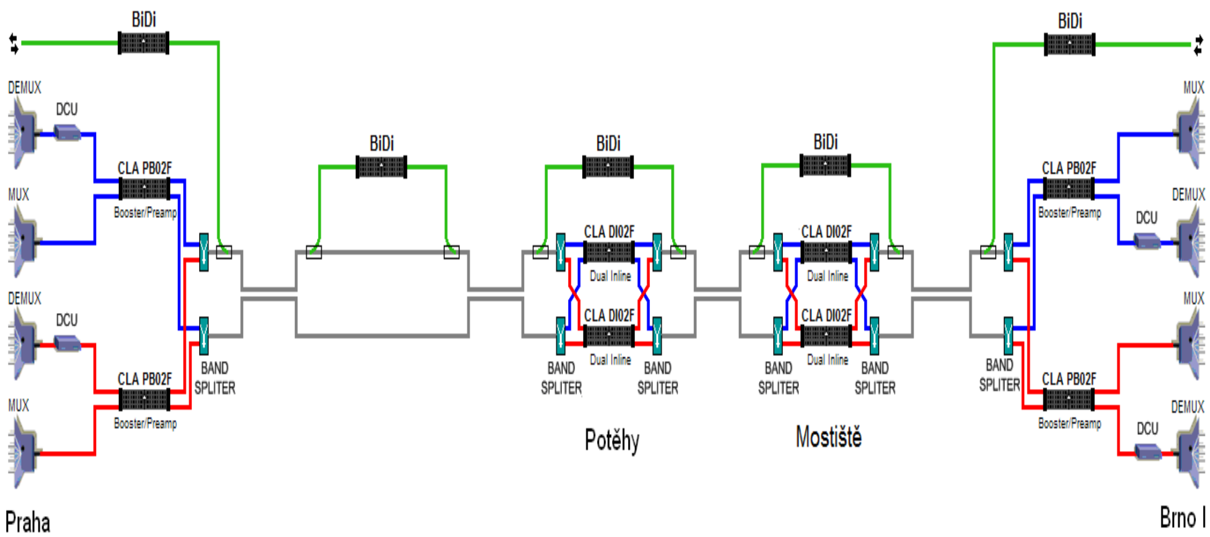

Figure 6.11: Schematics of the Prague – Brno line

5.4 Use Case 4: Redundant topologies for ELI and BIOCEV

The Extreme Light Infrastructure (ELI) project aims at advancing the state of art in the area of high-performance lasers. It is a part of a European plan to build a new generation of large research facilities selected by the European Strategy Forum for Research Infrastructures (ESFRI). The ELI project is a distributed facility, spanning three countries (the Czech Republic, Hungary and Romania). Czech NREN provides network services for its Czech site, which is located near Dolní Břežany. This geographical distribution presents opportunities for international transmission of alien waves among the three laboratories.

The BIOCEV project is a joint biotechnology/bioscience centre operated by the Czech Academy of Sciences and the Charles University in Prague. The BIOCEV is located at Vestec, and, similar to ELI, CESNET delivers advanced network services to this facility as well.

When preparing a connection for these two sites, it has been decided to build a robust solution based on a ring topology. That way, this redundant service remains available, even in the presence of a fibre cut. As of 2015, many of the end users are under upgrade, often located in places which are not so easily reachable, to a redundant connection with the smallest possible parallel fibre routing. Examples of this strategy include the two universities in Brno, the ICRC FNUSA at the VUT, and the Masaryk University.

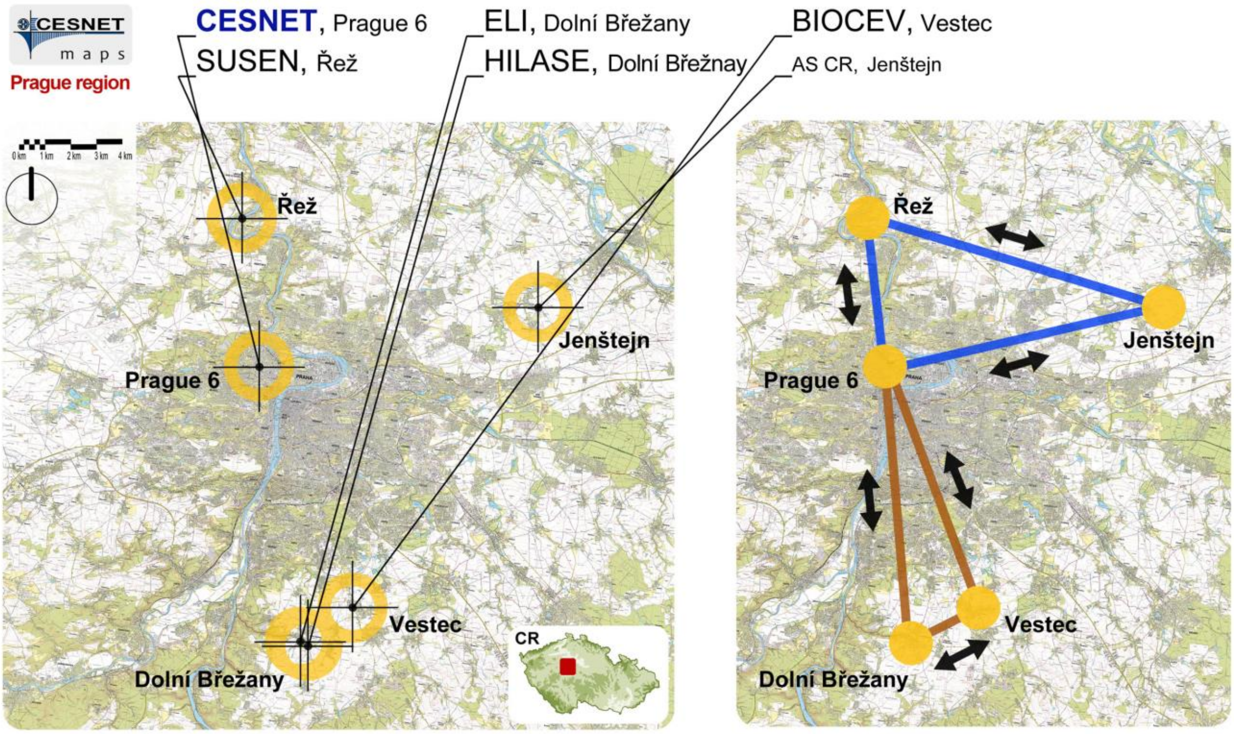

Figure 6.12: ELI and BIOCEV and other projects in Prague region

5.5 Area of Interest: Metrology network

In almost every country exists a time and frequency laboratory that operates a set of atomic clocks with the goal to provide a national approximation of the UTC time scale. Generally, a larger number of these interconnected clocks (Caesium primary standards and Hydrogen masers) might improve the accuracy and stability of the time scale. The term “interconnection” in this context means that time is transferred between them despite their location at geographically distant places. The common method of interconnection is a dedicated two-way satellite link, or a global navigation satellite based system (e.g. GPS, Galileo), however utilization of fibre links achieves higher transfer stability and constantly increases.

The presented metrology network is developed in order to achieve these goals:

- Transfer time from existing Caesium primary standards and Hydrogen Maser to Czech national time and frequency laboratory in UFE - Institute of Photonic and Electronics
- Distribute accurate time and stable frequency to users.
- Compare the national approximation of UTC with that from neighbouring countries.

The following organizations in the metrology network operate Caesium clocks:

- UFE – National time and frequency laboratory, Prague; CESNET, Prague; VUGTK – Geodetic observatory, Pecny.
- The precise time will be distributed to: CMI – Czech Metrology Institute, Prague; FEL – Faculty of Electrical Engineering, Czech Technical University
- The ISI – Institute of Scientific Instruments, Brno, operates Hydrogen maser, a source of stable frequency.
- It will be distributed into Institute of nuclear Research, Rez and Temelin nuclear power plant.

The present networks are designed for the simultaneous transmission of data streams. Data is typically packetized and processed in electronic devices, e.g. routers and switches. Unfortunately, statistical multiplexing of packets, digital signal processing and repeated OEO results in the fact that precise timing of data in packet networks is not guaranteed at the link layer. Time and frequency transfer shall be implemented at the physical layer that provides the dedicated optical channels preserving the precise timing.

The metrology infrastructure is quite heterogeneous, the design goal was to share the fibre footprint with data services as much as possible. The wavelength division based sharing is used in the first three cases:

- Pair of channels (with the same wavelength in both directions) in an operational DWDM optical network.
- Pair of DWDM channels with different wavelengths in a single fibre bidirectional transmission system.
- Pair of DWDM channels (both uni- and bi-directional) in experimental links, e.g. testbeds.
- Dark fibre – usually the last mile in the urban area.

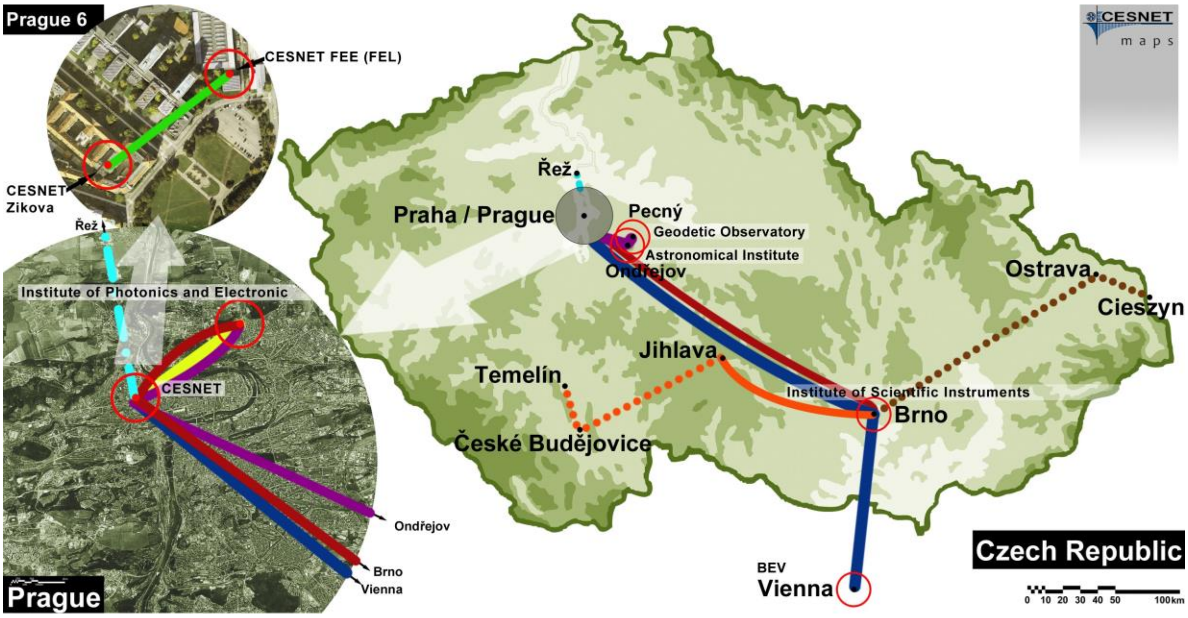

Figure 6.13: Metrology network in the Czech Republic

5.6 Collaboration with RENATER and NPL

Another example of end to end fibre connection for ultra-precise metrology transmission might be link between NPL (London) and SYRTE (Paris), via LPL (Paris). It is used for the comparison of optical clocks: the NPL Yb+ optical clock and the SYRTE Sr optical lattice clock.

Achieved stability of this comparison was achieved in the order of $1E^{-16}$ at 1 day integration time, with relative uncertainty dominated by the contribution of clocks themselves.

In the beginning there were suggestions for a Photonic Services implementation and further utilization of the REFIMEVE+ project. The collaboration with RENATER resulted in a GN3 document providing a vision for usage of the GEANT fibre link between London and Paris, after migration of the GEANT infrastructure. Such a possibility was examined with the essential last miles solutions, their conditions and possibilities for connection of NPL and SYRTE.

The precise time transfer over the distance of 812 km is another example which proves-out the advanced technology enabling international comparisons of atomic clocks. In this case, further enlargement is planned from SYRTE to the German metrology institution: Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig. Tests of fundamental physics, relativistic geodesy and a base line for the international Atomic Clock Ensemble in Space are just a few basic reasons for such research [5]. It is also a step toward the dissemination of traceable time and ultra-stable frequencies to universities, research laboratories and industry.

5 L. Altmannová, M. Altmann, M. Hažlinský, M. Hůla, O. Havliš, G. Korcsmáros, J. Kundrát, M. Míchal, J. Nejman, J. Radil, K. Slavíček, V. Smotlacha, S. Šíma, M. Šimek, P. Škoda, M. Šlapák, R. Velc, R. Vohnout, J. Vojtěch (CESNET); E. Camisard (RENATER): Photonic Services: Challenge for Users and for Networkers, GN3-13-110, 2013

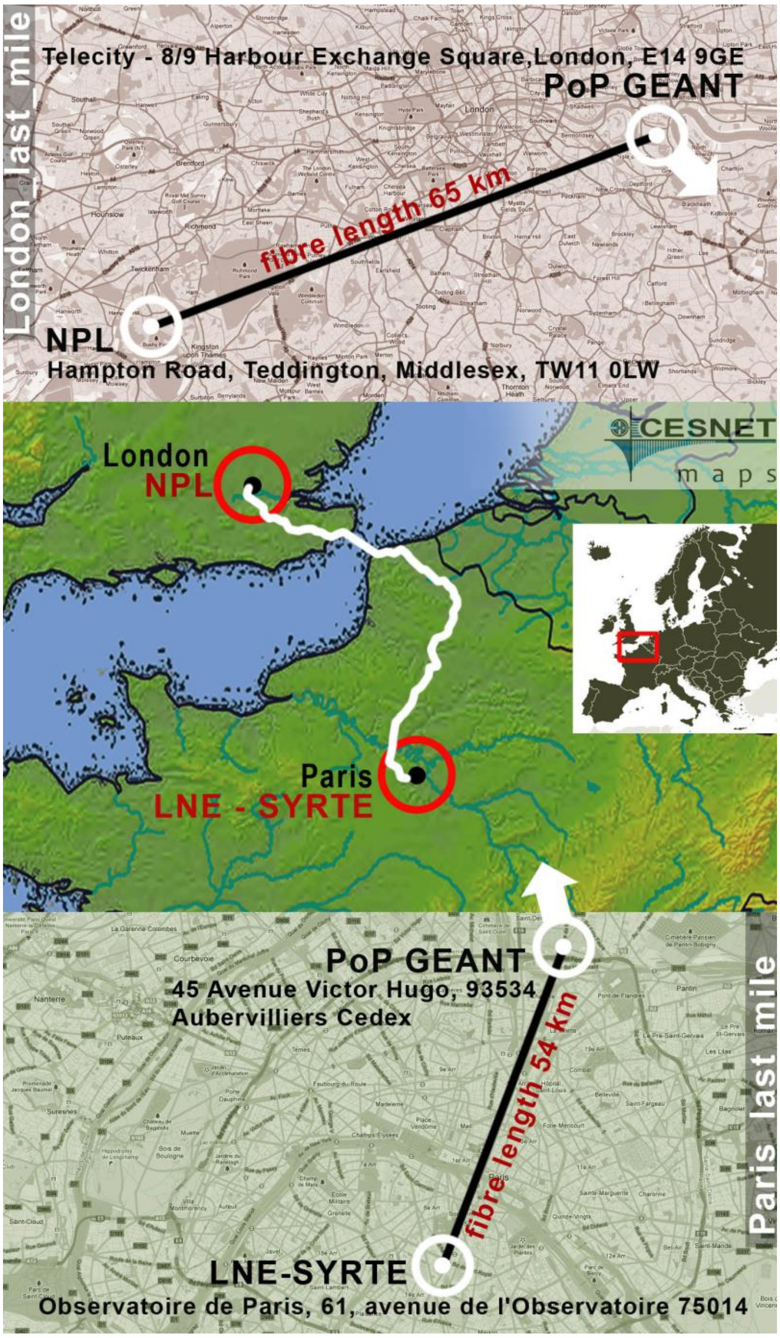

Figure 6.14: Metrology network in Europe

5.7 Outreach for New Technology

Apparently, definition of new technology and identification of (potential) users could not be enough for early adoption. Thus outreach is necessary to make sure the technology and/or services coming out from the PCP will be spread out to other user groups than those who were part of the initial PCP process.

5.7.1 Outreach Example: Remote Control of Spectroscope

There are unique experiments and technologies being prepared in the field of research infrastructures with an essential element: connectivity.

COMPLETE consortia members are working continuously on the initiation of collaboration with more adopters of the advanced networking possibilities (i.e. end users) and the results are very noticeable.

One example would be the Science and Technology Park of Palacky University in Olomouc. http://www.vtpup.cz/en.html
Outreach discussion indicates a potential interest of the research and innovation team of STP in remote control of a spectroscope. Such control requires all-optical connectivity, because a fixed delay is necessary. Both experiments and expected service should be developed as hard real-time control (acquirement of sensor values in time of availability and sending control signals in time). Connectivity between University fibres and NRENS' fibres should be part of the last mile solution (see map).

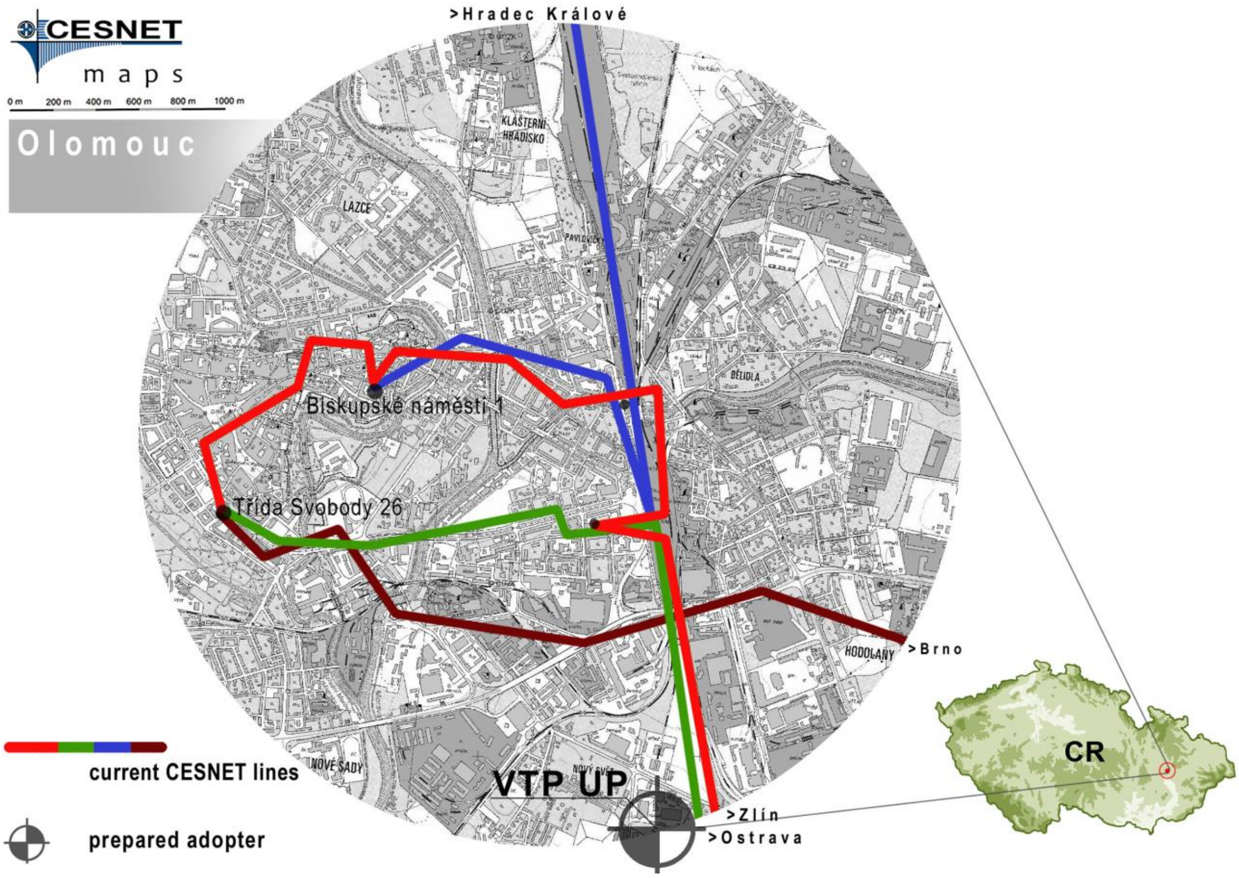

Figure 6.15: Current situation in Olomouc before last mile solution is solved

5.7.2 Collaboration with GÉANT on outreach

New emerging applications, like accurate time transfer, ultra-stable frequency transfer, Quantum Key Distribution or remote control of unique scientific equipment (e.g. Square Kilometre Array telescope), have extreme requirements that are difficult to fulfil with conventional networks. These are currently the major examples of advanced, and often non-digital, services. Support of such services gives NRENs a desired technology advantage and added value.

It is beneficial to focus on outreach to new users and early adopters of advanced applications and services. The dissemination of the network's potential to interdisciplinary network users worldwide is also desirable.

One example from the Czech Republic: a few years ago it was difficult to find medical applications on the CESNET network, because medical doctors were not aware of the possibilities provided by R&E connectivity. Today, now that doctors have received much more exposure to medical applications, they are demonstrated quite commonly.

Within GÉANT, COMPLETE consortia members worked on the "Photonic Services Enables Advances in Research" (PSEAR) task and, as a result, received some positive feedback. Discussions with networks both in Europe and on other continents was initiated, for example with Latin America R&E organizations Argentina (Innova|Red), Brazil (RPN) and Chile (REUNA), Japan (JGN-X), Australia (AARNet) and of course many European networks.

The results of PSEAR were disseminated at many international conferences, for example COIN 2012 Yokohama, Japan, SPIE Optics + Photonics 2012, San Diego, CA, USA, the International Conference on Advanced Computer Science Applications and Technologies, Kuala Lumpur, Malaysia, TIP2013 Honolulu, HI, USA and the ICMII International conference on mechatronics and industrial informatics Guangzhou, China.

Alien Spectrum as a Service (ASaaS) should be promoted in a similar way, more systematically and more focused, with real examples clearly defined.

6 Conclusions and Next Steps

Members of the COMPLETE consortium are now under heavy investigation of significant advancement in delivering all-optical Spectrum allocation service to end users. This is an effective solution providing principal advantages to the end users. The approach chosen has been mapped to a significant use cases (early possible pre-adopters of the technology), and we should take the steps necessary for supporting such innovation at higher management levels.

A more systematic outreach is needed to find a approapriate early adopter for ASaS. Positive experience shows that, after explanations and discussions, potential end users are usually very interested in proposed service. It is expected that the adoption rate of these recommendations will not be homogenous among different NRENs, depending on the level of financial possibilities and long-term strategic alignments of each NREN, as well as their interpretation of the concept of these Photonic Services. A significant example of a real-world application of the proposed approach in a large-scale procurement is a tender currently in progress at the SURFnet[6]. The crucial importance of COMPLETE in this process is due to its potential buying power.

The deployment of Photonic Services on legacy DWDM transmission systems could be a difficult task, depending on the DWDM system vendor approach and guaranty agreements, etc. (see the successful solution in RENATER backbone). A legacy fibre footprint is usually acceptable, with some exceptions (strong vibrations, for example air cables or ground cables along railways or roads). Nevertheless, suitable methods exist (see the Paris-London transmission under the Channel).

In summary, there are new requirements for lighting services, equipment procurement and dark fibre procurement (including last mile to end user premises or costal fibres), so as to avoid future difficulty in deployment or even long term blocking of Photonic services that are important for advanced science and engineering. These new requirements have been collected and reported in this deliverable. Future steps in the project will include further analysis of requirements, definition of new innovations resulting from this analysis and clear definition of the PCP process in the COMPLETE project for public network operators and their users.

User requirements are naturally crucial for targeting effort in this project. Obviously consortium will continue to analyse new and further user requirements. In order to extend user requirement analysis, the relations to non-project involved NRENs will be used in order to establish closer dialog and

[6] SURFNet is currently procuring a fully programeable, open network infrastcture. More info on this: https://www.surf.nl/en/innovationprojects/the-open-programmable-network/project-surfnet8.html

collaboration with these NRENs. The result of analysis will be part of the first partners' agreements on ranking of innovation needs to be potentially subjects of future PCP projects to be reported in Deliverable D2.1.

PARTNERS

CESNET develops and operates a national e-infrastructure in the Czech Republic, including a national research and education network, several HPC facilities, and infrastructures for efficient collaboration. The E-Infrastructure provides its services to universities, research organizations, laboratories and computing centers. The activities of CESNET's research teams are often related to advanced network technologies and applications from hybrid networking, programmable hardware, cloud and grid computing, high-quality video transmissions and development of various middleware components.

GRNET S.A. provides Internet connectivity, high-quality e-Infrastructures and advanced services to the Greek Educational, Academic and Research community. The GRNET backbone interconnects all universities and technological institutions, and many research institutes, as well as the public Greek School Network. The GRNET network is present in global networking for research and education, representing Greece in the Pan-European GÉANT network. GRNET's vision is the development of Education and Research in Greece along with the equal involvement of the R&E communities in the Pan European society of Knowledge, with the provision of modern, advanced and reliable Internet services to all Educational and Research Institutions.

PSNC is the operator of the National Research and Education Network in Poland. The Polish NREN, PIONIER, a nationwide broadband optical network for e-science, represents a base for research and development in the area of information technology and telecommunications, computing sciences, applications and services for the Information Society. It connects 21 Academic Network Centres of Metropolitan Area Networks (MANs) and 5 of the HPC (High Performance Computing) Centres using their own fibre connections in all regions in Poland.