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Fibre Sensing Focus Group: Conclusions and Future Work

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Authors:	Bartosz Belter (PSNC); Chris Atherton (GÉANT); Gloria Vuagnin (GARR); Jan Radil (CESNET); Kurosh Bozorgebrahimi (Sikt); Ivana Golub (PSNC); Ramaz Kvatadze (GRENA); Magnus Bergroth (SUNET); Martin Čížek (CESNET); Krzysztof Martyn (PSNC); Kostas Koumantaros (GRNET); Josef Vojtech (CESNET); Guido Aben (SUNET)

Abstract

In January 2024 a new Network Development incubator focus group was formed with a goal to explore the need for and interest in fibre sensing technologies among National Research and Education Networks involved in the GN5-1 project and their applicability, usage and usefulness for research and education networks. This document summarises the findings of the focus group and outlines possible future work.

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Executive Summary

Although using optical cables as a sensing instrument is not a new approach, several European National Research and Education Networks (NRENs) are now considering using their existing optical fibre infrastructure as a sensing instrument. This allows NRENs to both learn more about their networks and capture more information that might be of interest to other groups such as seismologists, ocean zoologists, oceanographers and other researchers.

Inspired by interest in fibre sensing and its use in NREN environments, a Network Development (NETDEV) incubator project was proposed to explore the technology and how it might be aligned with NREN use cases.

This document summarises the work performed by the incubator focus group during the first three months of 2024. It explains the rationale for using fibre sensing technologies in the GÉANT environment, presents an overview of the technology and related projects, and proposes a possible roadmap of the future work within the community, including (but not limited to) the GÉANT project.

1 Introduction

Optical fibres can be used not only to transport huge amounts of data across the globe but also as sensors, a technique often referred to as fibre sensing. They can be used as local sensors (recording, for example, temperature in one location) but it is their capabilities as distributed sensors that attract much more attention. Such distributed systems can be used for monitoring temperature, strain and acoustic fields (in effect, serving as a distributed microphone). Using fibre sensing techniques on deployed fibre optic communication cable increases the range of use of the cables and provides new tools to monitor a range of different parameters.

Fibre sensing (FS) has recently been considered of interest by the GÉANT National Research and Education Network (NREN) community because of the large amount of data that could be gathered and information it can provide about the NREN operational infrastructure and underlying and encompassing environment, as well as the fact that many NRENs are in possession of either their own or long-term leased optical infrastructure which can be used for such a purpose. At the time of writing, at least thirteen GÉANT project partners have an interest in fibre sensing and participate in either EU-funded or internal projects or initiatives that deal with exploring fibre sensing technologies and their possible use for other stakeholders (e.g. members of the research and education (R&E) community, governmental bodies, etc.).

Through the NETDEV incubator process in the Network Development Work Package (WP6) of the GN5-1 project, a group of eight project partners – CESNET (Czechia), GARR (Italy), GÉANT (pan-European), GRENA (Georgia), GRNET (Greece), PSNC (Poland), Sikt (Norway), SUNET (Sweden) – proposed a focus group (also referred to as the FS incubator team or the FS team) to determine how European NRENs and the R&E community can benefit from fibre sensing infrastructure and capabilities and whether a useful service could be designed using data gathered in this way.

This document presents a summary of the focus group's discussions and outlines short-, mid- and long-term plans for fibre sensing activities in the GÉANT community.

Section 2 explains why fibre sensing is relevant and should be considered by NRENs, Section 3 gives an overview of fibre sensing technology and related projects, Section 4 presents a roadmap for fibre sensing activities in the community, with conclusions offered in Section 5.

2 Rationale for Including Fibre Sensing in GÉANT

The FS incubator team has identified two aspects where fibre sensing is of interest to the GÉANT community. The first is as individual NRENs; the second is as a community.

From an individual NREN perspective, fibre sensing has synergies with existing technologies that NRENs already have installed and provide as services in their networks. With fibre sensing, NRENs can detect physical changes in their networks. This is important for both time and frequency distribution and quantum networking, as well as for security and operational requirements. Detected disturbances – discovered through fibre sensing – can be used to correct the optical signals that are sent. Fibre sensing also helps to pinpoint disturbances or intrusions on the cables that the operational teams rely upon for connectivity.

The potential benefits NRENs could receive from enhancing their networks with fibre sensing capability are numerous. They would have an additional source of information about their network that can help advance and better manage and control that network. It could then be used to support and improve other services, for example those based on time and frequency transmission or quantum technologies. It can also provide a means of situational awareness for the security of deployed fibres, as more data would be collected to monitor the infrastructure.

Fibre sensing also produces data. This data is not just useful for NRENs from an operational perspective but also for a wide range of national use cases. For example, data about possible earth instabilities might be of interest for seismologists, data from subsea fibre sensing for oceanographers, zoologists, etc. Making this data available to wider stakeholder groups allows NRENs to develop closer ties with existing research and education communities with which they work. It also allows NRENs to build new relationships with previously unapproached or infrequently contacted communities.

This user-focused data-product development methodology can bring additional benefits to NRENs. It can open up a new arena and potential for new services for their users. For example, users might request to use the infrastructure to test their specific scenarios and use cases; they might be interested to use the data gathered through the NREN fibre sensing infrastructure, or to work with NRENs to expand the fibre sensing infrastructure for some user-group-specific cases. In some cases, it might be a unique opportunity that could then generate new users for the NRENs.

New technologies such as fibre sensing allow NRENs to create new services for their existing user communities or for new user groups not currently served. These new services leverage existing investments in infrastructure, allowing further utilisation and efficiencies of use of already deployed network connections, especially for dark fibre.

Such instrumentation, once deployed, can also be used to independently verify the path of fibre cables which have been procured from commercial partners. Currently, acceptance tests typically focus on performance. However, the fibre path, essential in ensuring redundancy and geographic separation of services, can only be verified by the assertion of the commercial provider. Using a distributed acoustic sensor, for example, allows a true fibre path to be established and compared against the map file that a supplier provides.

In a similar fashion, fibre sensing techniques enable the detection and localisation of fibre cable faults. This is especially relevant for raising awareness of potential tampering and the overall situational security of the essential national infrastructure that NRENs run. Knowing where a fibre cut or degradation in optical signal is located can not only help to hold suppliers to account, this information has a financial value too. For instance, in the case of submarine cables, deploying repair ships is the most costly aspect of the repair operation as it takes time to localise the area of fibre needing repair. Technologies such as distributed acoustic sensing (DAS) and state of polarisation (SoP) have the ability to identify suspensions in underwater cables. Suspensions are a recognised potential failure point in a submarine cable system. Early identification of such a suspension can allow preventative maintenance to be performed in advance of a costly cable break.

Cable security, especially submarine cable security, is becoming a hot topic given the current geopolitical environment. Recently the EC published a document with recommendations for the EU to improve cable security. Fibre sensing is an effective and cost-effective means of improving the security of a cable, in a similar way that CCTV is an effective means of deterrent. Fibre sensing gives the group that deploys and operates the sensing infrastructure the ability to have situational awareness around the fibre cable. Such situational awareness can assist with securing the infrastructure and allowing a proactive response to threats to both submarine and terrestrial cables.

It is through providing access to cable infrastructure that further value can be generated for the research community. Currently, scientists must rent or borrow access to fibre cables to perform their experiments. This puts a burden on scientists to negotiate with cable operators and to find suppliers who are willing to collaborate with them. NRENs are in a natural position to collaborate with research groups who are exploring fibre sensing technologies in order to facilitate their work.

From a technical perspective, fibre sensing offers potential benefits to NRENs by enhancing their optical networks. There are already existing means of managing and monitoring optical quality across R&E networks. However, they require expensive proprietary equipment to be used or separate maintenance windows to be organised to run time-bound tests. With fibre sensing, NRENs could have an additional source of information about the optical stability of their network. This information could help advance fibre optic cable quality monitoring and allow better management and control of their network to ensure optical stability. It could then be used to support and improve other services which rely on fibre networks, for example time and frequency transmission or quantum technologies, both technologies being extremely sensitive to optical disruptions. As such, complementing optical spectrum analysers with fibre sensing techniques to improve optical stability over a fibre would allow performance tuning of optical DWDM systems.

Fibre sensing is a nascent technology. Currently there are not many thought leaders in this field, including from within academia. There is a well-developed community around cable protection [ICPC] and also around Science Monitoring and Reliable Telecommunications (SMART) cables [SMART]. Both communities have well-developed and strong thought-leadership capabilities. Although these are similar subject areas to fibre sensing, they are not the same. From a policy perspective, fibre sensing offers the possibility to articulate innovative, forward-thinking ideas, and strategies that address existing and emergent policy challenges, by using digital infrastructures and NRENs.

There are many use cases for the fibre sensing data that is generated, not just from the perspective of an NREN. An aspect of the technology that will benefit an NREN is the opportunity to engage with new and emerging user groups. It might be difficult for an NREN to cater to the needs and wishes of individual research or scientific groups. Such an approach is not scalable. However, without data there is little a research group can do. Providing data from fibre sensing to an NREN's national community can help with engagement activities and developing stronger ties with user communities, both known and unknown. The FS focus group has seen that this technology can be used to monitor railway tracks, trains, and power draw from trains. It has received interest from national seismology communities and institutes to complement their existing seismic sensing station network. The technology has even been used to track whales during migrations through the Atlantic. The GÉANT NREN community is not in a position to dream up every use case for fibre sensing. What *is* known is that when this data has been provided to researchers they have found a wealth of uses and gained globally significant scientific insights.

2.1 Possible NREN Roles in Fibre Sensing

In all the opportunities described above, an NREN might have different roles related to fibre sensing, as presented in Figure 2.1. NRENs might enhance their already existing optical network infrastructure, or consider expanding with new functionalities. Some NRENs might decide to provision and introduce new fibre sensing instruments, targeting NRENs, but other user groups as well. Some NRENs might focus more on data acquisition and transportation, for their own purposes, or for their users, etc.

NRENs have a variety of different stakeholders and national contexts which need to be appreciated when suggesting possible roles to be fulfilled. As such the diagram below identifies different roles to which an NREN could potentially contribute, should they wish. However, it should be understood that all of the aspects would need to be fulfilled at a national level in order for fibre sensing to be possible. An NREN can play a crucial role in supporting the development of this type of infrastructure and is uniquely positioned to enable such an instrument to be created in their country.

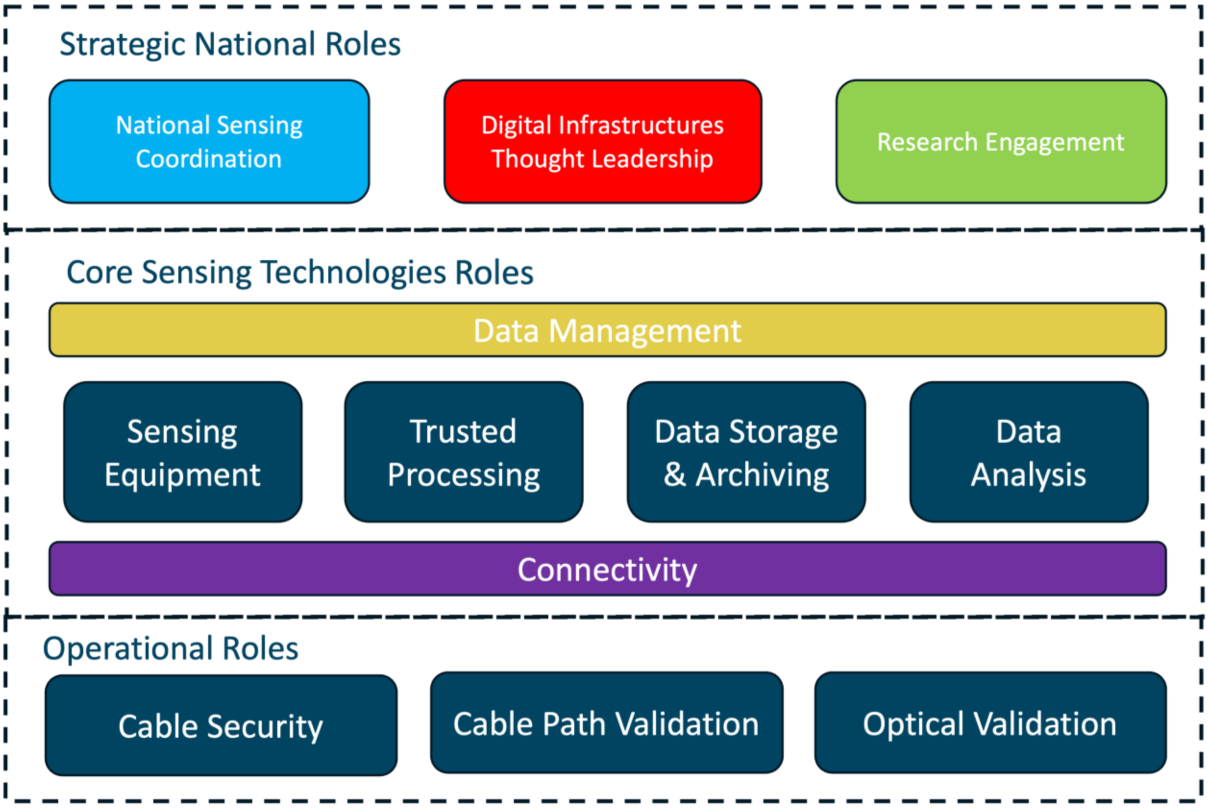

Figure 2.1: Possible NREN roles in a national context in the fibre sensing domain

An NREN may not be able to take on certain roles and some roles may be shared by several NRENs at a European level. However, as a community, there are several opportunities and roles at many stages where data is created and handled within the fibre sensing field. It is up to each NREN to determine which roles they may wish to get involved in. Nationally speaking, all roles need to be filled for fibre sensing to take place. This provides an opportunity to create a national consortium of partners to collectively provide the fibre sensing infrastructure. At a European level, there is a need to provide an inter-federation layer to provide wider access across all countries involved in fibre sensing.

Acknowledging and respecting differences among European NRENs, it can be expected that not all NRENs would have the same use cases, approaches, opportunities, interests – in building the fibre sensing infrastructure and capabilities, in sharing the infrastructure and/or data, in providing services. Nevertheless, it does not diminish the opportunities fibre sensing provides nor the possible value and benefits NRENs might gain of learning, exploring and getting experience and expertise in fibre sensing technology.

The purpose of this document is to shed light on different aspects and possibilities, and not to try to prescribe the actual tasks any NREN should take. The scope, use cases, responsibilities and all related activities remain NREN domain only.

3 Technology Overview and Related Projects Review

3.1 Technology Overview

Distributed optical sensing systems use optical time domain reflectometry (OTDR) principles, i.e. detection of light (a laser pulse) which is injected into the fibre and the light backscattered and measured at the receiver. There are a few scattering effects (interaction of light with the silica molecules) which can be used for sensing purposes. When the scattered light returns to the receiver, it carries information about the fibre's condition. By analysing the amplitude (how strong the light is), frequency (how often the light wave peaks pass a point), and phase (the position of the wave in its cycle) of this returned light, the system can deduce various physical properties of the fibre or its surroundings. Using advanced techniques similar to those in digital coherent receivers (a technology used in modern data transmission systems), it is possible to extract detailed information from these interactions. This allows a comprehensive understanding of the fibre's status or of the environment through which it runs.

The four scattering effects are important and are briefly described below:

- **Rayleigh scattering**, which is used for distributed acoustic sensing (DAS). As the name implies, DAS systems can be used to characterise acoustic properties of the environment where optical fibre is placed, including for seismic applications.
- **Brillouin scattering**, another nonlinear effect, can be used to obtain information about strain and temperature, using distributed strain and temperature sensors (DSTS). The double capabilities of DSTS are also the source of a potential problem (how to distinguish temperature and strain responses) and another nonlinear Raman effect is usually used for so-called distributed temperature sensing (DTS) to provide temperature values without strain interferences which are the property of the Brillouin effect.
- **State of polarisation (SoP)**. SoP-sensitive optical time domain reflectometry (SoP-OTDR) is another method which is used for fibre sensing. SoP-OTDR can monitor regular data signals (DWDM in most cases but it can be any optical signal) with dedicated polarimeters or with the advanced capabilities of digital coherent receivers. SoP-OTDR is a new technique (2022) described and published by Infinera and Google [SoP].
- **Optical interferometry** is another technique, where changes of the phase of an optical signal are detected. This technique is rather sensitive but requires expensive ultra-stable lasers. A modification to optical interferometry, using microwave ranges (order of GHz instead of optical frequencies), is also available. Ultra-stable lasers are not required but precise microwave sources are a must, and sensitivity is lowered compared with optical interferometers.

For the purposes of this project, detailed descriptions of different scattering processes (including terms such as *phonons*, *Stokes* and *anti-Stokes waves*) are not given. Interested readers can find them in many good online resources (for example, [Banwell], [Smith]).

Another important concept to be aware of is Science Monitoring and Reliable Telecommunications (SMART) cables. This technology is different from fibre sensing in that it uses sensors deployed on the repeater units of submarine telecommunications systems to detect environmental changes. What the SMART cable concept does not do is to use the fibre as the sensing medium. However, it is a well-known and established concept, recognised through the establishment of a UN task force [SMART JTF]. As such it is mentioned here to clarify that the FS focus group is not concerned with deploying SMART cables.

3.2 Related Projects Review

Several fibre sensing projects exist in the GÉANT community and worldwide. To name just a few:

- The **Distributed Acoustic Sensing (DAS) Research Coordination Network (RCN)** [DAS RCN] aims to identify applications, train users, address required technical developments, and tackle challenges of DAS technology on fibre optic cables. It attributes the transformative potential of DAS to the fibre itself being the sensor and to its offering spatially continuous measurements over long distances. The RCN sees DAS applications in geosciences and engineering as being numerous and growing, including opportunities for deploying early-warning systems for earthquakes, volcanic eruptions, continental and marine landslides, and avalanches, and for monitoring reservoirs and civil infrastructure. The DAS RCN identified 4 main objectives:
    - Identify applications of DAS and develop a network of potential DAS users.
    - Train a community of DAS users in the acquisition, handling and processing of DAS data.
    - Identify needed technical development (engineering and scientific).
    - Identify major challenges and next steps for supporting DAS science beyond the RCN.

  This research coordination network is supported by funding from the US National Science Foundation.

- The **Center for Transformative Environmental Monitoring Programs (CTEMPS)** [CTEMPs] is an initiative of Oregon State University. It aims to support scientific observation of Earth by offering instruments, an environmental sensing lab, technical skills, technology, methods, training and culture by combining open-source development and cutting-edge technology. The Center's policy is that delivery of data is an obligation of the investigator, and archiving the data for potential community use after the proprietary period is the responsibility of the Center.

- **Geosphere INfrastructures for QUestions into Integrated REsearch (Geo-INQUIRE)** [Geo-INQUIRE], initiated on October 1, 2022, aims to advance access to data, products, and services for monitoring and modelling dynamic geosphere processes with enhanced spatial and temporal precision. Overcoming cross-domain barriers, particularly between land, sea, and atmosphere environments, the project will utilise innovative data management techniques, modelling and simulations methods, AI and big data, and extend existing data infrastructures to disseminate resources to the wider scientific community, including the European Open Science Cloud (EOSC).

  With a partnership of 51 major national research institutes, universities, and geological surveys, Geo-INQUIRE will enhance interoperability among partners and offer dedicated training programmes, ensuring that resources reach high scientific standards and follow FAIR principles, adopting open licences and aiming to cross-disciplinary interoperability.

- The **Polar Connect** project [Polar] is aiming to establish a direct and shortest possible connection between Europe and East Asia via an innovative Arctic route, employing proven subsea cable construction techniques and creative system design. This breakthrough offers users enhanced speed and security in connectivity, while also extending broadband access to Northern communities and paving the way for advancements in environmentally friendly data storage solutions. The Polar Connect system aims to integrate SMART cable technologies, giving advanced new tools to study various areas of Arctic research, such as climate change, marine biology, seismology and oceanography in the most rapidly changing ocean on Earth.

- Since 2021, **Colorado School of Mines** has been using a distributed acoustic sensing (DAS) interrogator on a fibre at the bottom of Lake Hattie in Wyoming to explore seismic velocity structure at the lake bottom and characterise vibration signals at the lake bottom induced by fish activity and water waves. [CSoMines].

- The **SUBMarine cablEs for ReSearch and Exploration (SUBMERSE)** project [SUBMERSE] seeks benefits from fibre sensing capabilities for three global research communities (Seismology, Oceanography and Marine Biology), and national civil protection groups (Greece, Portugal, Norway). It focuses on creating a proof-of-concept fibre sensing system in submarine cables, at the same time producing scientifically usable datasets for research use. It also focuses on creating a proof-of-concept technical architecture for submarine fibre sensing which incorporates three countries, starting from identification of potential submarine cable sensing locations.

Most of the listed projects are either outside Europe or target specific user groups that are not European NRENs, which are the primary focus of the GÉANT project. One project that involves NRENs and can thus be considered more relevant to the GÉANT project than the others is the SUBMERSE project. However, there are several differences between SUBMERSE and the fibre sensing incubator project in the Network Development Work Package of the GN5-1 project:

- SUBMERSE looks at specific research communities, while the WP6 fibre sensing incubator group looks primarily at NREN interests in fibre sensing – either to support and enhance NREN network operations or as a set of activities an NREN should perform to support users interested in fibre sensing.
- SUBMERSE primarily focuses on submarine cables, while the scope for the fibre sensing incubator group is not limited to submarine cables only, but can include terrestrial (and other) cables as well, i.e. it is interested in exploring the deployment of the technology in a wider context.
- SUBMERSE includes eight European NRENs, while the WP6 fibre sensing incubator group includes eight organisations with a different composition. There has been an expression of interest from at least two more NRENs to join the WP6 fibre sensing incubator.

It can therefore be concluded that the interest of the WP6 fibre sensing incubator group in fibre sensing technology and its deployment is not the same as any other EU-funded project. The WP6 team will, however, consider the results of those other projects from the perspective of their relevance and possible use for the WP6 project objectives. The WP6 fibre sensing incubator might also look at the possibilities of developing the interconnection of national sensing sites into a wider European architecture utilising NREN infrastructure as proposed in the SUBMERSE project, or identify how fibre sensing infrastructure and capabilities might affect other infrastructures and services such as quantum, time and frequency, network footprint expansion, etc., and can propose ways to allow cooperative use of the network resources.

4 Roadmap for Fibre Sensing Development in the GÉANT Community

Possible future work on the fibre sensing activities relevant for the NREN/GÉANT community that could be run as a part of the GÉANT project is discussed below in different timeframes of implementation. Short-term activities are considered as part of the current GN5-1 project, with the aim to finalise the tasks by the end of 2024. The mid-term activities are looking at the three-year period from 2025 till 2027, with long-term activities aiming after that period.

4.1 Short-Term Activities (2024)

The short-term plan would include understanding the technology, what it means for the NRENs involved and which are the targeted users in their environments. This work could be run in two tracks. The first would explore technical aspects of fibre sensing and the activities that need to be performed by an organisation to build a fibre sensing capability, starting from building the physical infrastructure through to data acquisition and visualisation. The findings would be summarised in a document. Given that fibre sensing can be of use to many other user groups, not just the NREN operational teams, this short-term work would also include engaging with potential user groups in NREN communities to better understand which groups within the R&E community would be interested in using and/or contributing to fibre sensing infrastructure and possible services. This second track of work would finish with a document summarising possible users groups as recognised by the NRENs participating in the WP6 incubator project, an overlap/gap analysis between NRENs and different user groups, and a proposal on prioritisation of one or more user groups that will be the focus of collaboration in the mid-term plans.

The results of these short-term activities should include at least:

1. A technical document about the fibre sensing technology and instrumentation, looking at, but not limited to, existing techniques, equipment solutions (with a possible comparison of differences / advantages / disadvantages / test results, etc.), installation and usage best practices considering and respecting installation differences (e.g. terrestrial vs submarine, etc.).
2. A document summarising recognised user groups, starting with the NRENs involved in the WP6 fibre sensing incubator project, including the overlap/gap analysis between NRENs. If the same user groups are of interest to more than one NREN, collaboration and user engagement can be initiated for further discussions on possible joint work and collaboration on using the fibre sensing capabilities in the NREN networks.
3. A project plan proposal for the two-year period 2025–2027.

Depending on the available information and resources, the team may also look into the following areas:

- Data acquisition and visualisation – processes, procedures, requirements needed to collect the data from fibre sensing instruments, perform any cleansing or other preprocessing, approaches to designing and providing data storage, enabling access to data, processing of data and visualisation of analysed data, within the NREN as well as for any possible users external to the NREN.
- Identification and analysis of the resources needed to build a sensing infrastructure in a single- and/or multi-domain R&E environment, including understanding sustainability of it as a service.

All activities and their results should be actively promoted and disseminated using different methods of communication, such as Project Office weekly newsletter, *CONNECT* articles, infoshares, workshops, conferences, etc.

4.2 Mid-Term Activities (2025–2027)

It is assumed that successful execution of the short-term activities has already established a technical background on how fibre sensing technologies can be deployed in NREN networks and what their benefits are for NRENs and the R&E community. With NRENs being the primary users of the fibre sensing capabilities on their infrastructure, it is also assumed that at this stage NRENs will select, and get in touch with, the user groups from the R&E community that would constitute the secondary group of users.

The focus of the mid-term activities would be threefold:

1. **Technical** – to deepen the understanding and support the deployment and management of fibre sensing technologies in NREN networks, which might include further investigation of chosen technological areas, technology evaluation, testing, prototyping, field trials, etc.
2. **User- and service-oriented** – to explore the interest in and possibilities for building user-oriented services based on fibre sensing, which might include, but not be limited to, creating a service definition followed by the definition of the necessary service management structure, specification of resources, processes, policies, etc., taking into consideration multi-domain aspects of such a distributed infrastructure and resources, as well as numerous differences between and specifics of European NRENs. Another aspect of this work would be to expand upon the overlap/gap analysis work performed in the short term. Renewed focus would be placed on incorporating NRENs not already involved in the incubator.
3. In this period special attention will be given to **data managemen**t. Since one of the aspects of the deployment of sensing instruments is the enormous volume of data that can be collected, it raises the question of the amount of storage which is then required. There should be an assessment of how much data management functionality can be implemented in the GÉANT/NREN community and whether the community can afford to deploy and maintain such data management infrastructure (DMI). Additional aspects, which are at a similar level of importance, may include the privacy and security of data collected, or policies for accessing data by end users. All these discussions lead to the definition of requirements for data management infrastructure for fibre sensing in GÉANT. As a follow-up activity, the first proof of concept of the DMI should be implemented for the community. Last but not least, this activity should define a plan for liaison with EOSC, with regard to data, interfaces and workflows.

All three activity threads are presented in Figure 4.1.

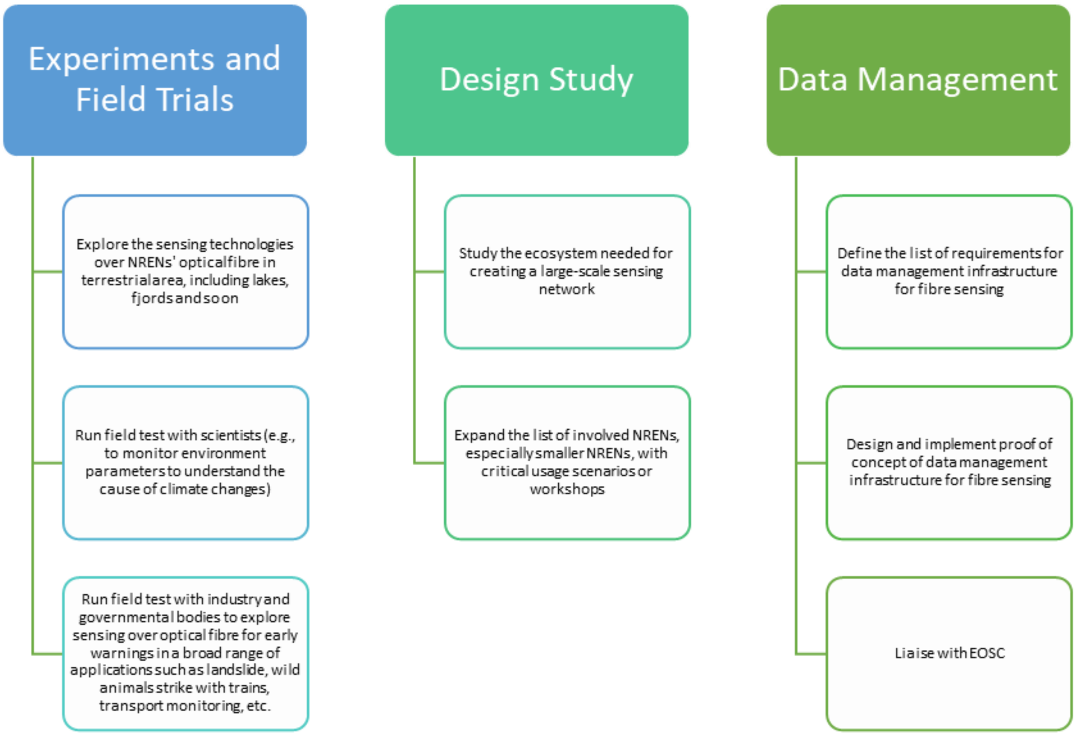

Figure 4.1: Mid-term activities of the fibre sensing project

Dissemination and knowledge sharing should take place in each of these areas and in different forms (which might include, but not be limited to, contributing to Network eAcademy training material, infoshares, presentations at events, online and on-site training, etc.) in order to raise awareness and increase knowledge in the community about the technology, its benefits, possible use cases, and to build and support a community of user groups willing to share, contribute to or use the data.

4.3 Long-Term Activities (2028 onwards)

Long-term activities concentrate on **setting up a large-scale sensing network over the GÉANT and NREN infrastructure**. This will leverage the work already done by the community and expose the fully fledged sensing instrument, serving both the GÉANT/NREN community and the scientific communities attached to particular NRENs. Data collected, pre-filtered and optimised for better storage capacity will be available through the data management infrastructure with published policies for data access, data preservation and data processing.

These threads of work are illustrated in Figure 4.2.

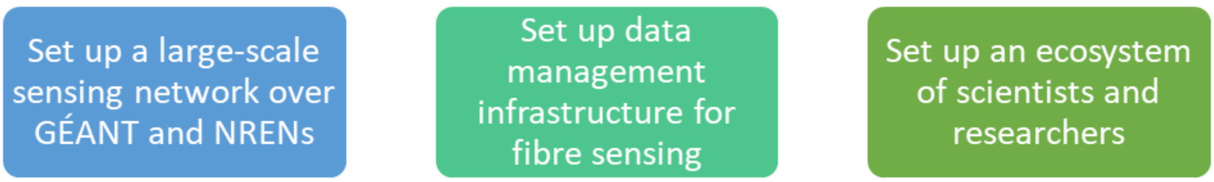

Figure 4.2: Long-term NREN fibre sensing activities

Such an ecosystem of NRENs with fibre sensing capabilities and scientists and researchers working closely with NRENs on providing and using the infrastructure would provide new possibilities for engagement and collaboration with the R&E community.

5 Conclusions

NRENs involved in the GN5-1 WP6 incubator project find fibre sensing technologies very useful and relevant given the length of fibre already in place in their networks as well as the current fibre sensing solutions and services existing in the community.

The FS incubator team finds it important to further explore technologies and solutions around fibre sensing and how it can be best used in NRENs, both for their network management and as a source of data for researchers, with the possibility of building a user community around it.

This document has outlined numerous advantages NRENs could gain by investing in infrastructure to provide fibre sensing capabilities. It has also provided a brief technical overview and a summary of similar projects, comparing them with the work aimed to be undertaken as part of the GN5-1 WP6 incubator project and beyond, as proposed in short-, mid- and long-term plans, starting from April 2024.

By the end of the GN5-1 project, the FS incubator team aims to deliver one technical document describing the fibre sensing technology, existing technical solutions and best practices. It also aims to deliver an overview of possible user groups within the team's NRENs, looking also for possible joint work opportunities between NRENs to collaborate with selected user groups. Finally, before the end of the project, the FS incubator team will provide a work plan for the next two-year period.

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Glossary

AI	Artificial Intelligence
CCTV	Closed-Circuit Television
CTEMPs	Center for Transformative Environmental Monitoring Programs
DAS	Distributed Acoustic Sensing or Distributed Acoustic Sensors
DMI	Data Management Infrastructure
DSTS	Distributed Strain and Temperature Sensing or Distributed Strain and Temperature Sensors
DTS	Distributed Temperature Sensing or Distributed Temperature Sensors
DWDM	Dense Wavelength-Division Multiplexing
EC	European Commission
EOSC	European Open Science Cloud
EU	European Union
FAIR	Findability, Accessibility, Interoperability and Reusability
FS	Fibre Sensing
GEO-INQUIRE	Geosphere INfrastructures for QUestions into Integrated REsearch
GN5-1	GÉANT Network 5, Phase 1, a project funded by the European Union's Horizon Europe research and innovation programme under Grant Agreement No. 101100680 and one of the projects implementing the actions defined in the GN5 Framework Partnership Agreement
ICPC	International Cable Protection Committee
NETDEV	Network Development
NREN	National Research and Education Network
OTDR	Optical Time Domain Reflectometry
R&E	Research and Education
RCN	Research Coordination Network
SMART	Science Monitoring and Reliable Telecommunications
SoP	State of Polarisation
SoP-OTDR	SoP-Sensitive Optical Time Domain Reflectometry
SUBMERSE	SUBMarine cablEs for ReSearch and Exploration
WP	Work Package
WP6	Work Package 6 Network Development