TRANSFORMING DEPLOYED SUBMARINE FIBRE CABLES INTO SENSORS: ENHANCING SECURITY AND ENVIRONMENTAL MONITORING - A TELECOM OPERATORS PERSPECTIVE

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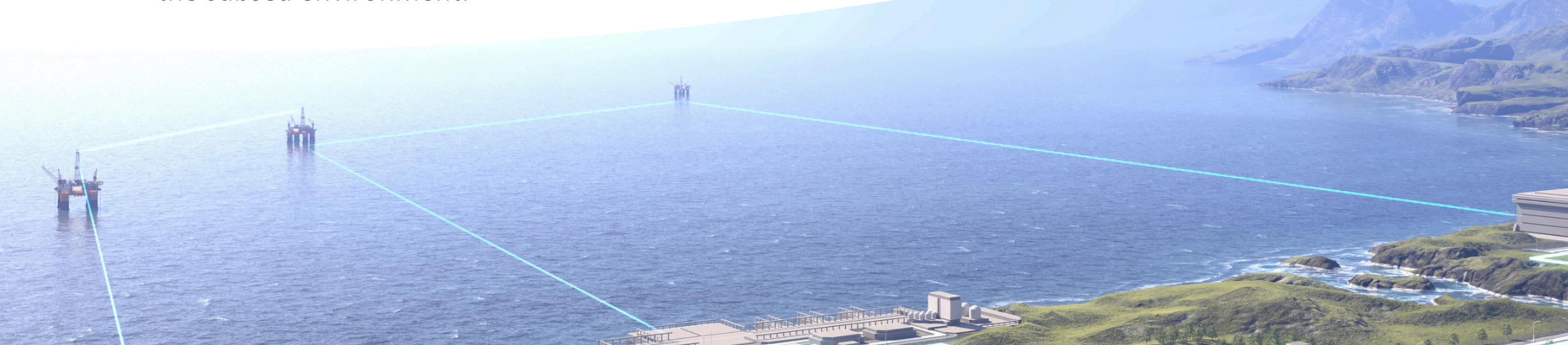
Submarine fibre cables, essential for global telecommunications, face vulnerabilities from physical disruptions such as anchor drags, fishing activities, and natural disasters. Furthermore, traditional subsea environmental monitoring requires costly deployments of standalone sensors, making the process time-intensive and non-real-time. Using fibre-sensing technologies like Distributed Acoustic Sensing (DAS) and State of Polarization (SoP), submarine cables transform into multi-functional sensors.

DAS operates by detecting changes in fibre strain, offering high sensitivity and spatial resolution. This enables real-time detection of physical threats, such as approaching trawlers and anchor drags. Additionally, whale vocalizations and geophysical phenomena like earthquakes can be monitored. However, DAS requires a dark fibre or L-band operation to avoid interference with data signals, and its functionality is constrained to the fibre span before the first optical amplifier, limiting its applicability in long-haul systems. SoP sensing, in contrast, provides cost-effective integration into existing networks, leveraging a dark fibre, separate wavelength, or coherent receiver data. While less sensitive and lacking full spatial resolution, SoP can detect strong and weak fibre movements, permanent shifts in cable positions, and environmental factors like storms.

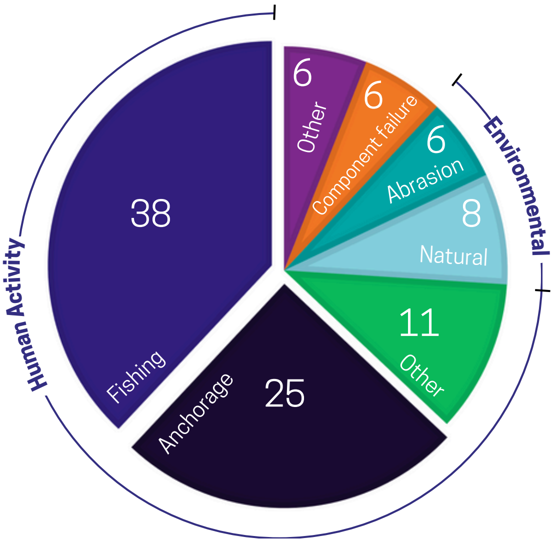
By integrating data from multiple sources, including DAS, SoP, OTDR, AIS, weather, and other geophysical sensors, fibre-sensing systems enhance decision-making within Network Operations Centers (NOCs). Operators can proactively address threats, such as anchor drags, by alerting authorities or switching traffic to alternate paths. Furthermore, the ability to extract valuable environmental data benefits external stakeholders, such as oil and gas companies or oceanographers. Fibre-sensing systems also enable proactive mitigation of potential damage through discovery of risk zones along the cable, where it may not be properly buried. Exposed parts of the cable may then be covered with rock-dumping.

In conclusion, fibre-sensing transforms submarine cables into real-time tools for network resilience and environmental monitoring. By addressing challenges in cable security and environmental sensing, it offers cost-effective, integrated solutions that enhance both telecommunications and broader scientific understanding of the subsea environment.



Introduction and summary

Submarine fibre cables serve as the backbone of global telecommunications, carrying vast amounts of data across oceans. Unlike terrestrial cables, which are often subject to risks from digging activities, submarine cables face threats from anchor drags and fishing activities. These physical disruptions can cause damage, leading to network outages and costly repairs. For instance, incidents in the Baltic Sea during December 2024 resulted in multiple cable breaks, underscoring the limitations of conventional monitoring methods, which often rely on reactive measures that come too late to prevent significant disruptions. Figure 1 illustrates causes and frequency of cable failures. Numbers are from Telegeography, stating that 74 % of cable failures are caused by human activity.



In addition to these network availability and security related challenges, monitoring subsea environmental parameters, such as seismic activity, ocean currents, and earthquakes, has traditionally been a complex and non-real-time process. It typically involves deploying standalone sensing probes that must later be retrieved by vessels, making the process time-intensive and expensive.

Figure 1, Causes of faults for subsea fibre-cable failures, numbers from Telegeography (Source: https://blog.telegeography.com/what-happens-when-submarine-cables-break).

Fibre-sensing technology has emerged as a transformative solution to these challenges. By leveraging existing submarine telecommunication cables, fibre-sensing techniques like Distributed Acoustic Sensing (DAS) and State of Polarization (SoP) enable real-time detection of both physical disturbances and environmental phenomena. DAS provides high sensitivity and spatial resolution, allowing precise localization of events along the cable, while SoP offers cost-effective integration with optical transmission systems and the ability to detect movements and permanent shifts in the position of cables and patch-cords. These technologies enable targeted subsea infrastructure inspections because inspections may only be required if the monitoring shows that is has been an actual physical impact to the cable. Furthermore, it eliminates the need for costly standalone sensors and enable proactive monitoring, enhancing both network resilience and environmental observation capabilities.

DAS and SoP fibre-sensing technologies

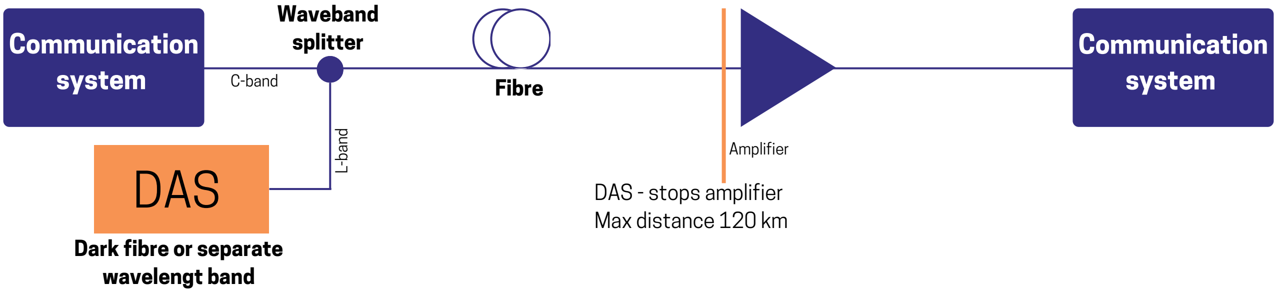


Figure 2, shows how DAS can be used on a deployed telecom cable, using a dark-fibre or a separate wavelength band (L-band) while still using the C-band for communication. DAS is connected at one end of the cable and based on phase measurements of the back-reflected signal. DAS does not work through the optical amplifiers currently deployed in optical networks.

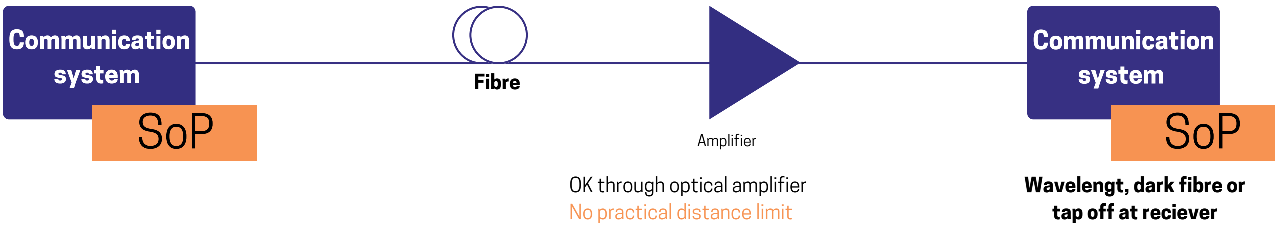


Figure 3, SoP sensing is fully integrated with the transmission system and based on sending at one end and receiving at the other end of the fibre, using the data signal itself, a separate wavelength or a dark fibre. SoP works through optical amplifiers and have no practical distance limit, but is preferably implemented span-by-span for spatial resolution.

DAS sensing

Distributed Acoustic Sensing (DAS) is a fibre-sensing technology that uses principles similar to Optical Time Domain Reflectometry (OTDR). In DAS, light pulses are sent down the optical fibre, and the backscattered light is analyzed. Unlike OTDR, which focuses on measuring distance to attenuations or reflections, DAS detects changes in the phase of the reflected light caused by variations in fibre strain. These strain changes can result from acoustic vibrations or physical interactions with the fibre cable, making DAS highly sensitive to a wide range of activities and environmental phenomena.

Thanks to its high sensitivity and spatial resolution, DAS is well-suited for proactive monitoring of submarine cables. It can detect objects approaching the cable, such as ships or fishing trawlers, allowing operators to address potential threats before damage occurs. Moreover, DAS is also applicable for geophysical sensing, including the detection of earthquakes and seismic events, as well as environmental monitoring, such as recording whale vocalizations and ocean currents.

However, DAS comes with certain limitations. It requires a dark fibre or operation in the L-band, which means that it cannot share the same fibre with active data traffic in the C-band. Additionally, its functionality is constrained by the span of the cable before the first optical amplifier or repeater, reducing its applicability in long-haul amplified systems. DAS systems also entail higher costs due to the need for specialized interrogator units and resources to process and analyze the large amounts of data generated.

SoP sensing

State of Polarization (SoP) sensing is another fibre-sensing technology that leverages the polarization properties of light traveling through optical fibres. Unlike DAS, SoP sensing can be fully integrated into existing optical transmission systems. It can operate using a dark fibre, a separate wavelength, or even by utilizing data from a coherent receiver in an active optical transmission system. This integration makes SoP a cost-efficient alternative to DAS, with lower equipment and deployment costs.

While SoP lacks the spatial resolution and sensitivity of DAS, it offers unique advantages. SoP can distinguish between weak and strong movements of the fibre, making it capable of detecting subtle shifts as well as significant impacts. It can also identify permanent shifts in the cable's position following a physical event, providing valuable information about the nature and aftermath of disturbances. Additionally, SoP sensing can detect weather-related effects, such as storms and temperature variations, further broadening its utility for environmental monitoring.
By leveraging these complementary strengths, combining DAS and SoP can create a robust fibre-sensing system optimized for diverse operational needs.

Monitoring, Data Integration and Network Operation

Effective fibre-sensing systems harness data from multiple sources to enhance situational awareness and enable informed decision-making. Figure 4 illustrates how fibre-sensing techniques, DAS and SoP can be supplemented with data from OTDR and telemetry from network equipment as well as AIS (Automatic Identification System) tracking and records of personnel activities. This integrated framework allows the Network Operations Center (NOC) to deliver precise, actionable insights.

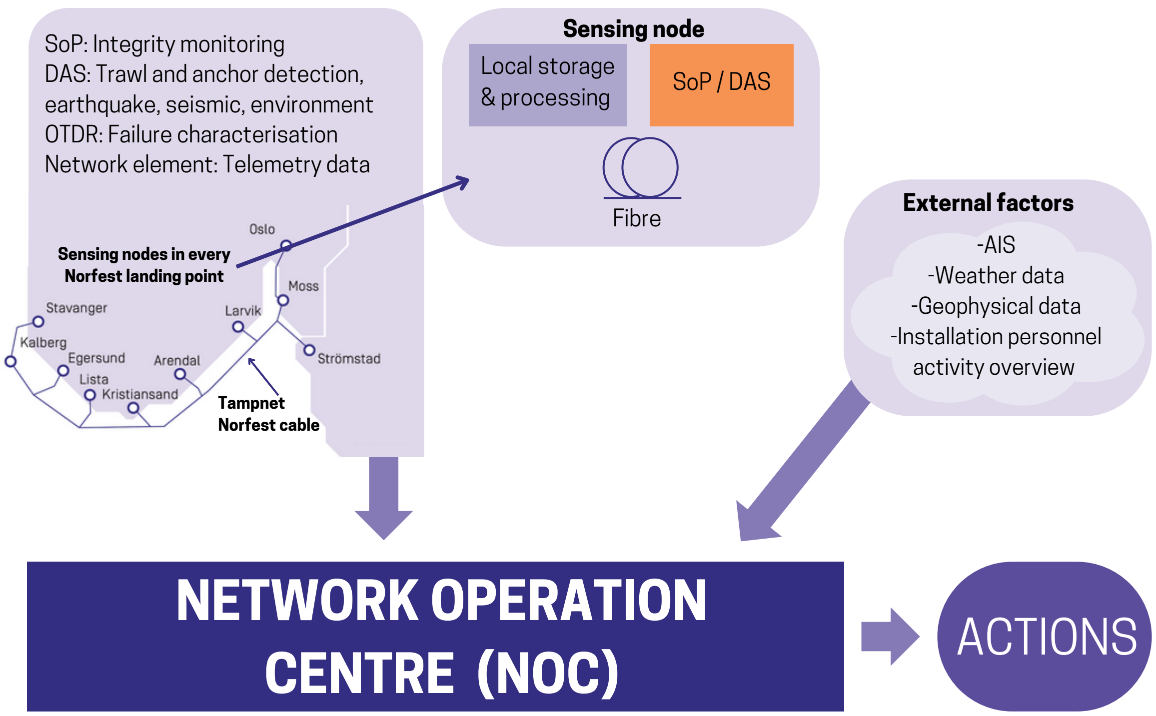


Figure 4, Combining fibre-sensing techniques with several other data-sources enables precise event characterisation and actions in the Network Operation Centres (NOC).

Raising the Standard

For instance, in the case of anchor drags near a submarine cable, fibre-sensing data can immediately trigger alarms, prompting the NOC to alert the coast guard and avert potential damage. If a physical impact or minor fibre movement is detected—such as a trawler passing over the cable—the system can flag the affected location for proactive measures. Operators may then decide to secure the exposed cable section, such as by rock dumping, to prevent future incidents. This approach ensures the cable remains protected while minimizing repair and downtime costs. Fibre-sensing also supports decisions related to telecom network management. For example, in situations where failures or potential threats to a subsea fibre path are detected, the NOC can initiate protection switching, rerouting traffic to alternative fibre paths to ensure uninterrupted connectivity. This proactive capability is particularly valuable in critical infrastructure, where service continuity is paramount.

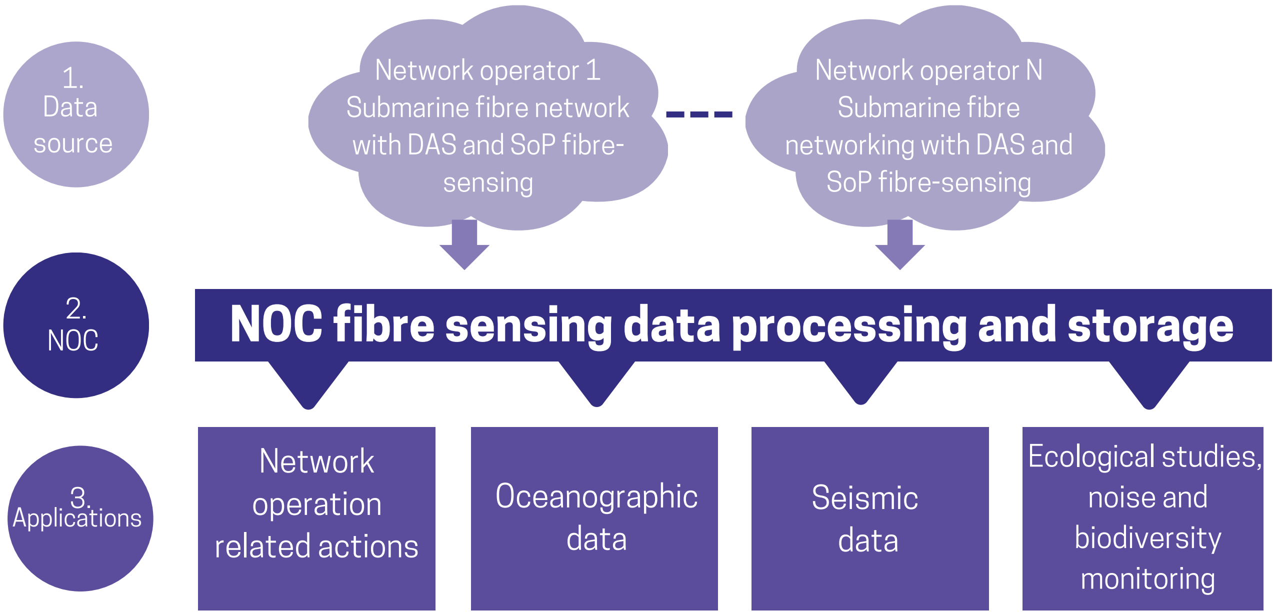
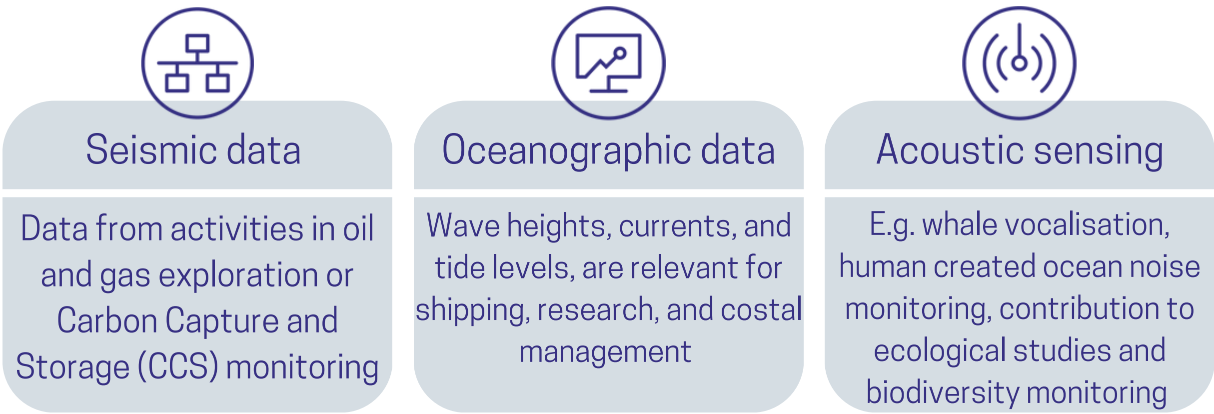


Figure 5, Processed raw data from fibre-sensing systems spanning multiple operator cable networks can be integrated and analyzed. This enables a wide range of applications, from enhancing network security and availability to monitoring environmental factors such as human-induced underwater noise that could impact marine ecosystems.

Beyond telecom applications, fibre-sensing generates environmental data valuable to external stakeholders. For example:



The real-time capabilities of fibre-sensing eliminate the delays associated with traditional sensing methods, where probes must be deployed and retrieved. DAS and SoP combine to deliver continuous, high-fidelity monitoring, enabling rapid responses to environmental and infrastructure-related events.

The NOC's ability to process and correlate fibre-sensing data with these diverse sources offers unparalleled situational awareness. This integration enables actions ranging from preventative maintenance to emergency response and long-term environmental planning. By extending the utility of existing submarine fibre cables beyond telecommunications, fibre-sensing delivers a transformative impact across industries, enhancing both infrastructure resilience and environmental stewardship.

Conclusion

Fibre-sensing technologies represent a transformative advancement for the proactive monitoring and management of submarine fibre cables. By leveraging existing infrastructure, these techniques enable real-time detection of both physical threats and environmental phenomena. Distributed Acoustic Sensing (DAS) and State of Polarization (SoP) sensing each bring unique strengths to the table: DAS offers unparalleled sensitivity and spatial resolution, while SoP provides cost-effective integration with active telecommunication systems and the ability to capture lasting fibre shifts in position after physical impacts.

The integration of fibre-sensing data with diverse sources—such as weather information, geophysical data, and network telemetry—within the Network Operations Center (NOC) greatly enhances situational awareness and operational decision-making. This approach allows operators to address risks preemptively, from preventing anchor drags to coordinating cable inspections or rerouting traffic in response to potential failures. Moreover, the ability to extract environmental data provides additional value for external applications, including seismic monitoring, oceanographic research, and resource exploration.

Deploying and maintaining fibre-sensing systems requires expertise in technology integration, data analysis, and operational response planning. As such, collaboration across telecommunications operators, technology providers, and environmental stakeholders is vital to unlocking the full potential of this innovative approach. By turning submarine fibre cables into versatile sensing platforms, the industry can simultaneously strengthen the resilience of global communications networks and contribute to a deeper understanding of our planet’s dynamic environments.