A SCALEABLE FIBRE SENSING ARCHITECTURE FOR TELECOM OPERATORS

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Abstract: This paper explores the use of Distributed Acoustic Sensing (DAS) and State of Polarization (SoP) fibre sensing technologies for subsea telecom cable monitoring and broader applications in environmental and geophysical research. We address the challenges of managing large data volumes and propose a scalable architecture for data processing and storage. The integration of these technologies in infrastructure protection combined with a variety of other applications is discussed. We find that tailoring the data processing for different use cases to be essential. Overall, the paper demonstrates how fibre sensing can enhance infrastructure security and enable innovative new applications based on reusing the existing fibre infrastructure.

1. INTRODUCTION

Fibre optic sensing, utilizing Distributed Acoustic Sensing (DAS) and State of Polarization (SoP) fibre-sensing technologies has emerged as a powerful tool for telecom operators in monitoring the integrity of subsea fibre cable infrastructure. It provides critical early warning of potential risks from fishing activities, anchoring or sabotage [1]. Beyond infrastructure protection, fibre sensing offers a unique opportunity to deliver real-time environmental and geophysical data from the ocean floor by leveraging the vast networks of subsea telecom cables that span significant areas of the world's oceans [2].

However, integrating fibre optic sensing across a large telecommunications network infrastructure presents challenges, particularly regarding data volumes. Each sensing unit generates vast amounts of data, which is costly to store and process. Different applications have varying data processing and presentation requirements [3]. For instance, detecting small earthquakes (microseism) near oil & gas or carbon capture wells may apply correlation and analysis across multiple cables, and may not be time-critical. On the other hand, real-time alerts for bottom trawling or anchor drags approaching a vulnerable section of the cable must provide immediate response.
This necessitates efficient, real-time categorization, filtering, and edge data processing tailored to specific use cases.
In this paper we propose an architecture for managing and presenting fibre sensing data from a large number of sensing units. We discuss the balance between centralized and decentralized data storage and processing approaches, exemplifying the diverse requirements of applications. Illustrations and practical examples from cable surveillance and environmental monitoring are provided, explaining architectural choices.

Achieving an extensive implementation of fibre sensing in operator networks enhances infrastructure protection but also opens new avenues for oceanographic research, seismic monitoring, and environmental management, paving the way for innovative applications in subsea sensing.

2. FIBRE SENSING APPLICATIONS, STORAGE AND PROCESSING NEEDS

Fibre sensing is known to produce large amounts of data. However, the data volume

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needed highly depends on the technology and the application. For DAS sensing, the sampling frequency, gauge-length and cable-length decides the amount of raw data. Telecom operators may typically interrogate cables from tens of km to hundreds of km in length. The raw data from a DAS interrogator may then typically be several tens of TeraBytes (TB) a week. Interrogating several cables multiplies the need for storage, but also puts requirements on the network because of the Gb/s speeds needed on the network links supporting the DAS units if real-time transfer of raw-data is desirable. The high data-rate poses a need for heavy signal-processing capabilities if real-time processing is required. A practical solution may e.g. be to dedicate a server to processing of data from each DAS unit.

For SoP, the amount of data from each unit is far less than for the DAS, because the sensing signal is integrated over the entire length of the link. Typically, the amount of data for a week is in the order of tens of Gigabyte and link speed needs for real-time transfer of raw data are in the range of Mb/s. This also simplifies real-time processing capacity needs so that e.g. a simple and low-cost processing unit will be sufficient for real-time processing of the signal from a SoP monitoring unit even at 10's of kHz sampling frequency.

The amount of data to be stored and processed does, however, also highly depend on the application. For e.g. earthquake observations, typically containing information in the range of Hz and perhaps 10s of Hz, sampling frequency can be lower, than when observing e.g. vocalization from whales.

In contrast, monitoring marine mammal vocalizations, like those of whales, necessitates higher sampling frequencies due to the broader frequency spectrum of these sounds. For example, fin whale calls have been recorded using DAS with a sampling frequency of 625 Hz, accommodating the detection of their vocalizations around 20 Hz. Additionally, a DAS study in the Arctic recorded baleen whale sounds using a sampling frequency of 645.16 Hz, providing a bandwidth sufficient to capture the low-frequency calls of these species. It's important to note that some marine mammal sounds, such as certain sperm whale clicks, can contain frequency components extending into the kilohertz range. Traditional hydrophone recordings of sperm whale vocalizations have employed sampling rates between 10 kHz and 166.6 kHz to capture these higher-frequency components [4,5,6]. Therefore, when using DAS to monitor such high-frequency sounds, higher sampling rates would be necessary to accurately capture the full range of these vocalizations. Since DAS is based on backscattered pulses, such high sampling frequencies imposes strong limitations on the maximum length of the interrogated cable.

The choice of technology to use depends on the application. Suitability of the DAS and SoP technologies are summarized in table 1.

Sensing method / application	Microseism	Earthquake	Cable security and integrity	Environmental parameters
DAS	High sensitivity	High precision	High sensitivity Saturates	Gravity waves Tide waters, ...
SoP	No	Strong earthquakes	Low sensetitivy No saturation	Gravity waves, tide water, slow variations

Table 1, Fibre sensing methods and applications.

While DAS has a very high sensitivity and delivers spatial information, it comes with a high equipment cost and high cost of data processing and storage. SoP on the other hand comes without spatial information, low sensitivity, but at a moderate cost since data-volume is moderate and SoP data may be extracted from the coherent receivers in optical telecom transmission systems [7]. Because of this, a mass deployment of SoP sensing is viable, enabling scalability across the complete network of telecom operators, monitoring all available cable sections and correlating the sensor information.

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Furthermore, while DAS comes with a high sensitivity, it may saturate when movements of cables or patch-cords occur. This is caused by phase wrap-around occurring between the DAS pulses and limitations in the dynamic range of the DAS [8]. SoP on the other hand has a lower sensitivity, allowing the dynamic range to be available for detecting any movement of cables or patch-cords, avoiding saturation effects. Hence, SoP may be more suitable revealing actual hits to submarine cables, resulting in movements, than DAS. Because trawling across cables occurs frequently, detection of activity that is an actual threat to the cable, i.e. when the cable is moved and displaced, should be detected and separated from e.g. a trawl crossing the cable, not causing any impact. This is highly important for avoiding false alarms to Network Operation Centres (NOC) that perform the monitoring of the cables.

In the case of cable protection applications, if both DAS and SoP sensing is available on a cable, the combination allows detection of objects approaching the cable using the DAS, and physical movements of the cable using SoP. SoP may then be used to trigger alarms of potential cable damage while the DAS may give additional information about any object hitting the cable and the position of this object.

3. DISTRIBUTED STORAGE AND PROCESSING

For scaling the cost of a system with the deployment, distributing the processing and storage needs are preferrable. This enables the processing and storage to scale with the number of sensing units added to the infrastructure. The distributed storage may then be applied for short-term storage, storing raw-data, while a centralized storage may be added, for storing clips of raw-data or processed data from events for a longer time-period and analysis purposes. This is illustrated in figure 1.

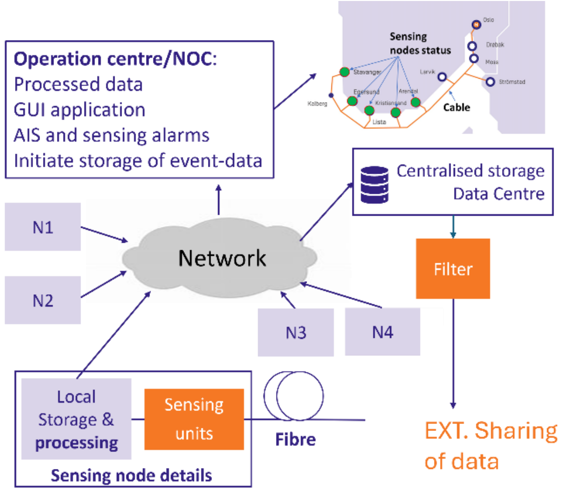

Figure 1, scalable sensing node infrastructure.

As an example of a specific use-case: When a fishing trawler makes contact with the cable, the DAS system registers the characteristic strain and vibration patterns before it happens, while the SoP sensing captures changes in polarization caused by the deformation of the fibre, while it happens.

Upon detecting an impact event matching the signature of a trawl hit, an automated alarm may be triggered to notify operators in real time. The local processing unit records and stores high-resolution data before and after the event, enabling detailed post-event analysis. However, due to storage and bandwidth constraints, only key event metadata and processed data are continuously transferred to a centralized storage system.

To optimize analysis, raw sensing data surrounding the time window of the impact event can be selectively uploaded to the central storage. This ensures that critical high-resolution information is available for forensic analysis, while minimizing overall data volume needs of the central storage. This workflow enhances both real-time monitoring capabilities and long-term event analysis, supporting preventive maintenance and response strategies.

4. FIBRE SENSING DATA SHARED TO DIFFERENT USER-GROUPS

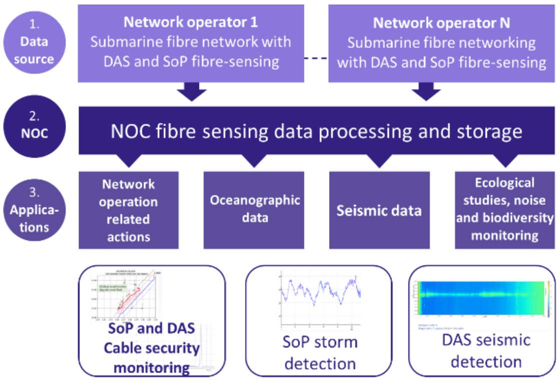

Figure 2, applications of fibre sensing needs different parts of the data, e.g. different frequency ranges. The data may be separated and shaped for the individual applications and user-groups.

Distributed Acoustic Sensing (DAS) and State-of-Polarization (SoP) fibre sensing technologies offer highly versatile data streams that can be tailored to the needs of different user groups. By applying filtering techniques, manual oversight in Network Operations Centres (NOCs), and machine learning (ML) algorithms, the data can be processed, refined, and shared across various stakeholders with distinct objectives. This is illustrated in figure 2. As part of data processing tailoring the data for specific applications, the amount of data is also reduced, improving scalability. Furthermore, by aggregating data from multiple cables, preferably also across different cable owners/telecom operators, large sets of data become available and the gain from correlating data increases. E.g. a vessel dragging an anchor may be detected and stopped before damaging other cables.

4.1. Network Operations Centre (NOC) – Monitoring for Cable Threats

One of the primary user groups for DAS and SoP fibre sensing data is the NOC, responsible for monitoring the integrity and performance of subsea cables, monitoring for mechanical impacts from trawl and anchor drags as well as potential sabotage. By applying filtering methods to the raw data, operators can isolate specific event signatures indicative of these potential threats. Machine learning algorithms may be employed to automatically detect and classify anomalies in the sensor data, providing real-time alerts to the NOC. If necessary, manual intervention can be applied by NOC operators to verify and analyse events in more detail, especially in cases of potential threats or marginal events. By continuous monitoring and analysis of events, the NOC ensures that proactive measures can be taken to protect the subsea infrastructure and prevent damage.

4.2. Oceanographic Data Users – Storm and Gravity Wave Detection

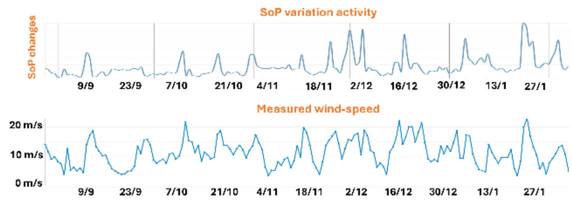

Figure 3, Ground wind-speed observation data (lower) and averaged SoP change activity (upper). A correlation can be seen, which can be improved by proper filtering and signal processing of the SoP data.

Another key group that benefits from DAS and SoP fibre sensing are oceanographic researchers. An example on how SoP monitoring data may correlate with wind-speed is illustrated in figure 3. The data from fibre sensing can be filtered to focus on detecting large-scale oceanic phenomena such as storms, gravity waves, and other ocean currents. This will typically involve a low-pass filtering of data with a cut-off at approximately 0.5 Hz, which is above the frequency of these effects. By applying signal processing techniques and machine learning, oceanographers can analyse real-time and historical data for studying the effects of extreme weather events and ocean conditions. This information may be applicable for forecasting, understanding environmental changes, and supporting maritime operations.

4.3. Seismic Detection, Earthquakes and Tsunamis

Seismic detection is another important application for DAS and SoP fibre sensing. For these applications frequencies below 10 Hz may typically be of main interest. The data can be used to detect earthquakes, tsunamis, and other seismic activities that might otherwise go unnoticed by terrestrial monitoring systems. The system's sensitivity to ground motion allows it to capture low-frequency seismic signals, making it an effective tool for early-warning systems. This is especially valuable for regions that are prone to seismic events, as early detection can provide precious minutes for evacuation and preparedness.

In the context of oil, gas, and carbon capture storage (CCS), seismic data is also used extensively to monitor subsurface activities. For example, in the oil and gas industry, fibre optic cables in the area around oil wells can be used to detect weak seismic waves that could indicate potential geophysical instabilities. In CCS projects, seismic data gathered from DAS helps ensure the safe and secure storage of CO2. When CO2 is injected in a well, pressure changes may cause a risk of sub-surface instabilities. Hence, the monitoring may provide early warnings of potential leakage and can support regulatory compliance.

4.4. Ecological Studies – Noise and Biodiversity Monitoring

DAS and SoP fibre sensing can also be applied for ecological studies, particularly for monitoring marine life. Frequencies from acoustic signals of marine organisms, such as whale calls and fish movements vary depending on the type of whale, but may range up to several hundreds of Hz. Fostering the health of biodiversity, the technology can be used to monitor anthropogenic noise pollution, such as ship traffic or offshore industrial activities, which can have a significant impact on marine species. These data are important for conservation efforts, environmental impact assessments, and ensuring compliance with marine protection regulations.

5. CONCLUSION AND SUMMARY

This paper has explored the applications, technologies, and data processing requirements of Distributed Acoustic Sensing (DAS) and State of Polarization (SoP) fibre sensing in monitoring subsea telecom cable infrastructure and its broader potential in environmental and geophysical monitoring. We highlighted the challenges posed by the vast amounts of data generated by these sensing technologies, particularly for large-scale implementations, and proposed a scalable architecture for managing and presenting this data. The architecture balances centralized and decentralized data storage and processing, accommodating the different needs of various applications, such as cable protection, environmental monitoring, and seismic detection.

For infrastructure protection, we emphasized the value of DAS and SoP technologies in detecting threats like trawl hits, anchor drags, and sabotage, enabling early warning and preventive measures. Beyond cable protection, these technologies also offer a unique opportunity for real-time environmental data collection, enabling oceanographic research, seismic monitoring, and biodiversity assessments. The paper also discussed the importance of filtering, categorizing, and processing data based on specific use cases, allowing tailored solutions for diverse user groups, including Network Operations Centres (NOCs), seismic researchers, oceanographers, and ecologists.

In conclusion, the integration of DAS and SoP fibre sensing into operator networks not only enhances infrastructure protection but also provides a powerful tool for scientific research and environmental management.

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With efficient data processing and strategic data sharing, these technologies pave the way for innovative applications in subsea sensing, supporting sustainability efforts and enabling real-time decision-making across multiple industries.

6. REFERENCES

[1] E. Rønnekleiv, J. K. Brenne, O. H. Waagaard, and B. Moussakhani, "Distributed Acoustic Sensing for Submarine Cable Protection," in SubOptic Conference, New Orleans, Louisiana, USA, 2019.

[2] M. Landrø, L. Bouffaut, H. J. Kriesell, J. R. Potter, R. A. Rørstadbotnen, K. Taweesintananon, S. E. Johansen, J. K. Brenne, A. Haukanes, O. Schjelderup et al., "Sensing Whales, Storms, Ships and Earthquakes using an Arctic Fibre Optic Cable," Scientific Reports, vol. 12, no. 1, p. 19226, 2022.

[3] M. Alkhalaf, "Fiber-Optics Data Analysis on Cloud: Unlocking the Power of AI-Driven Cloud Computing for Well-Sensing Applications," The Way Ahead, August 8, 2023. [Online]. Available: https://jpt.spe.org/twa/fiber-optics-data-analysis-on-cloud-unlocking-the-power-of-ai-driven-cloud-computing-for-well-sensing-applications

[4] W. S. D. Wilcock, S. Abadi, and B. P. Lipovsky, "Distributed acoustic sensing recordings of low-frequency whale calls and ship noise offshore Central Oregon," JASA Express Letters, vol. 3, no. 2, p. 026002, 2023. [Online]. Available: https://pubs.aip.org/asa/jel/article/3/2/026002/2874322/Distributed-acoustic-sensing-recordings-of-low?utm_source=chatgpt.com [Accessed: 24-Mar-2025].

[6] L. Robey, "Spectral analysis of sperm whale vocalizations," Bachelor's Thesis in Mathematical Sciences, Lund University, 2024. [Online]. Available: https://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=9159350&fileOId=9159351

[7] Z. Zhan, M. Cantono, V. Kamalov, A. Mecozzi, R. Muller, S. Yin, and ¨ J. C. Castellanos, "Optical Polarization-Based Seismic and Water Wave Sensing on Transoceanic Cables," Science, vol. 371, no. 6532, pp. 931– 936, 2021.

[8] C.-R. Lin, S. von Specht, K.-F. Ma, M. Ohrnberger, and F. Cotton, "Analysis of Saturation Effects of Distributed Acoustic Sensing and Detection on Signal Clipping for Strong Motions," Geophysical Journal International, vol. 232, no. 2, pp. 1234–1248, 2025.

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