Shared Risk Link Group Fiber Identification with fiber sensing for Open APN PoC Reference

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Contents

List of Figures

List of Tables

No table of figures entries found.

1. Purpose, Objectives, and Scope

1.1. Preface

In advanced optical communication systems, coherent detection often utilizes the State of Polarization (SoP) as part of the high-capacity data transmission process—particularly in polarization-division multiplexing schemes. As a result, SoP information is inherently available as a byproduct of standard signal processing. This creates an opportunity to extract additional value from the same transmission system without requiring intrusive modifications or added hardware.

While Shared Risk Link Group (SRLG) identification is the primary and most operator-relevant motivation for deploying SoP-based sensing, the method's value is further reinforced by its ability to operate non-intrusively alongside coherent transmission systems. Since SoP data is already processed in many advanced optical links, its use for SRLG detection introduces minimal additional complexity. The approach offers a practical, low-impact means to enhance network situational awareness, particularly in identifying fibers that share physical infrastructure and may be vulnerable to common-mode failures. Although additional applications exist, the focus remains on using SoP sensing to strengthen reliability through accurate, real-time SRLG mapping.

The objective of this document is to provide the background rationale for conducting a Proof of Concept (PoC), establishing the technical foundation, relevance, and expected value of the proposed approach.

1.2. Introduction

When operators, such as communication service providers (CSPs), infrastructure owners, and other fiber network stakeholders, are unaware of whether fibers are in the same fiber duct, several issues can arise, potentially impacting network performance and operational efficiency. Network redundancy failures may ocur if operators mistakenly assume fibers are in separate ducts when they are actually in the same one. A physical issue in that duct could disrupt both primary and backup systems, causing total service outages with no failover options. Disaster recovery becomes riskier when fiber duct configurations are unclear. If a single duct fails due to a disaster, it could take down multiple critical connections, affecting both primary and backup systems and causing significant network disruption.

An insufficient understanding of duct occupancy can significantly impede network expansion efforts, leading to delays and inefficiencies. Operators often struggle with the reliable identification of entrenched fiber cables, and when operators lack this precise information about the allocation and utilization of fiber ducts, they may struggle to optimize available resources, resulting in underutilized space or the need for additional, costly infrastructure. This can lead to delays in project completion and inflated operational costs. Moreover, without accurate knowledge of duct configurations, strategic planning for future network growth becomes difficult, further compounding the challenges of scaling operations efficiently. Additionally, this lack of knowledge can severely complicate maintenance and repair operations. When fiber duct occupancy is unclear, identifying and isolating faulty fibers becomes more time-consuming, which extends repair times and leads to prolonged service outages. This not only increases downtime but also impacts service reliability, particularly in scenarios where swift recovery is critical, such as in high-traffic networks or essential services.

The proposed technology can be applied in several key use cases within optical network management. One primary use is **network redundancy verification**, where operators ensure that primary and backup fibers are not co-located in the same duct, reducing the risk of simultaneous failures. As it is still based on the State of Polar (SOP) fiber sensing mechanism, it is there for possible and useful for **fiber maintenance** by providing real-time confirmation of fiber locations, improving efficiency during repairs and upgrades. Additionally, the technology supports **proactive fault detection**, allowing operators to monitor for early signs of fiber degradation or damage. Finally, it enhances **network planning and expansion**, ensuring optimal use of duct space and infrastructure.

1.2.1. Shared Risk Link Groups

Shared Risk Link Groups (SRLG (Shared risk resource group) emphasize the importance of understanding duct configurations. SRLGs group network elements and the interconnecting physical connection (fibers) that share a common risk, meaning a failure in one could affect others in the same group. Without clear knowledge of fiber locations, operators risk placing both primary and backup fibers within the same SRLG, undermining redundancy and increasing vulnerability to outages. Effective SRLG management is crucial for ensuring network resilience and preventing widespread service disruptions.

SRLGs are critical for ensuring network reliability and performance. They help identify single points of failure by grouping links that share common risks. This allows network operators to diversify traffic, avoiding links with shared risks, thus improving fault tolerance. SRLGs also aid in implementing protection mechanisms, such as backup paths and load balancing, ensuring efficient rerouting during failures. Additionally, they optimize network design by assessing potential weaknesses.

If SRLGs are not properly identified, the risk of service disruptions increases, resource allocation becomes inefficient, troubleshooting becomes difficult, and network reliability is compromised. Therefore, accurate identification of SRLGs is essential for effective network planning, design, and maintenance.

Based on the figure, we can understand how Shared Risk Link Groups (SRLG) play a crucial role in ensuring network resilience.

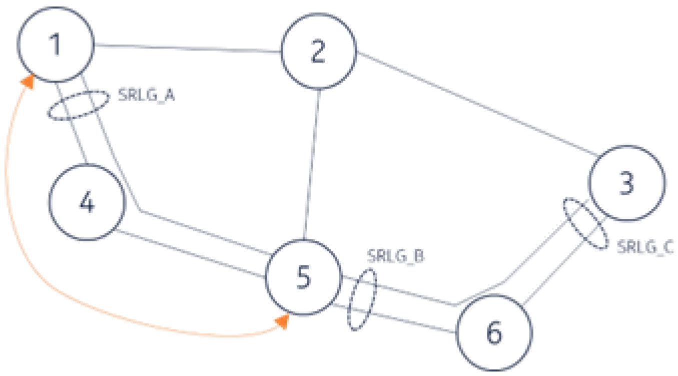

Figure 1: Example of SRLG-Aware Resilient Paths over a transport network

Based on the figure, routing a resilient path between **node 1** and **node 5** without knowing SRLGs could involve using the direct path between **node 1 and node 5** for one connection and the path through **node 4** for backup. However, if the shared fiber duct is severed, both paths would fail, affecting service. When SRLGs are known, these paths can't be used for both the primary and backup links as they share the same risk. Instead, the backup path should be routed via **node 2** to avoid the SRLG, ensuring the network remains operational in case of a failure.

1.3. Problem statement

The methods for determining whether fibers are in the same duct, such as Inventory and Asset Management Systems, rely heavily on accurate record-keeping during the initial fiber installation. However, these methods face significant challenges. Over time, documentation might be lost, inaccurate, or outdated due to network modifications or incomplete updates by field technicians. Changes such as fiber rerouting, repairs, or expansions might not be consistently recorded, leading to discrepancies between the physical network and the recorded data. Alternatively, switching transponders on and off for fibers suspected to share the same duct is not a reliable solution, as it is highly time-sensitive, disrupts normal operations, and is prone to human and procedural errors.

Note that it depends on the integrity of initial records to provide meaningful insights. If these records are flawed or incomplete, the tools' effectiveness in identifying shared ducts diminishes. This lack of accurate information increases the risk of misidentifying fibers in the same SRLG or duct, which can compromise network redundancy and lead to vulnerabilities, inefficiencies, and potential service outages.

1.4. Solution - SOP-Based Sensing via cAPN-Ts

With the advent of transponders capable of reading the state of polarization (SOP) via their digital signal processing (DSP), the ability to monitor and manage complex fiber networks has been revolutionized. Transponders can measure polarization (SOP) changes, which are highly sensitive to variations in birefringence, i.e., when the structure of the fiber changes, the polarization of the light also changes. This sensitivity allows SOP to be used for detecting fiber movements, which is particularly advantageous for identifying fibers in proximity, as they exhibit similar mechanical movement behaviors.

We term in the IOWN Global Forum context a transponders that can measure the SoP – a coherent All Photonic Network Transponder; cAPN-T.

This method of detecting proximity by SOP measurement is particularly valuable in scenarios where there is a high density of fibers within a confined space, such as within ducts or shared pathways. By correlating the SOP changes across multiple fibers, technicians can gain insights into the physical layout and proximity of fibers, which may not be easily observable through traditional visual inspection or basic testing methods.

Moreover, the process allows for real-time monitoring without the need for service interruptions. The polarization-based method, paired with advanced transponders, ensures that the network's operational health can be continuously monitored, and issues can be identified before they escalate into major problems.

This Proof of Concept (PoC) aims to validate the feasibility and effectiveness of this approach in real-world scenarios.

1.5. Purpose of the Proof of Concept

The purpose of this project is to enhance service availability and operational efficiency within All-Photonic Networks (APNs) by enabling operators to accurately and proactively determine whether fibers are co-located in the same duct. When operators lack this visibility, it can lead to increased risk of simultaneous failures, reduced redundancy, and inefficient maintenance planning. This Proof of Concept (PoC) aims to validate the feasibility and effectiveness of SOP-based fiber sensing as a non-intrusive method for identifying such co-location, ultimately improving network resilience, minimizing operational risk, and supporting more informed infrastructure management decisions.

This method significantly enhances fiber management by accurately identifying co-located fibers within the same duct. By precisely identifying which fibers are co-located within the same duct, operators can make informed decisions about network planning and redundancy. This prevents primary and backup fibers from being placed in the same duct, reducing the risk of simultaneous failures and enhancing overall network reliability.

Additionally, this approach helps improve the efficiency of maintenance and repair operations. Instead of relying on outdated or incomplete records, operators can quickly confirm the physical proximity of fibers in real time, minimizing downtime during repairs and upgrades.

The use of coherent All-Photonic Network Transceivers (cAPN-T) and monitoring of SOP also provides a non-invasive, continuous monitoring method. This enhances network visibility, allowing operators to detect potential issues early and proactively address them before they lead to significant service disruptions, ultimately reducing operational costs and improving service quality.

1.6. Key Benefits for fiber network owners and fiber network Operators

This SoP-based sensing approach offers tangible benefits across several operational dimensions.

- **Enhanced Network Resiliency:** Accurate fiber identification reduces downtime and improves availability of connectivity services
- **Operational Efficiency:** Automating fiber identification simplifies inventory management and minimizes manual errors.
- **Proactive SLA Management:** Real-time monitoring helps prevent network disruptions.
- **Cost Efficiency:** Faster fiber identification reduces operational expenses.
- **Accurate Fiber Identification:** Improves Shared Risk Link Group (SRLG) management and disaster recovery.
- **Scalability:** this approach does not require additional equipment as with every installed transponder there is a sensing opportunity.

By implementing this technology, operators gain better control over their infrastructure, ensuring more reliable, cost-effective, and scalable fiber network management.

1.7. Objectives:

- Demonstrate the capability of SOP-based fiber sensing to accurately identify co-located fibers. Ensure effective Shared Risk Link Group (SRLG) management to prevent service outages.
- Validate the use of coherent All-Photonic Network Transceivers (cAPN-T) for real-time fiber monitoring.
- Provide network operators with data-driven insights for improved fiber network planning and maintenance.

1.8. Scope:

This PoC will focus on evaluating the effectiveness of SOP-based fiber sensing technology in detecting fiber co-location. The scope includes real-time fiber monitoring, correlation of SOP variations, and evaluating test cases to measure accuracy, detection sensitivity, and operational efficiency

2. Reference Cases

The Proof of Concept will be conducted across two distinct environmental scenarios—**Lab Environment** and **Live Environment**—each corresponding to specific use cases and validation objectives.

Lab Environment: The lab setting offers a tightly controlled environment that minimizes external and unpredictable variables. It is ideally suited for the calibration of sensing equipment and the validation of detection principles under stable and reproducible conditions. The setup consists of interconnected fiber coils that emulate a multi-hop optical network. The interconnection points simulate manholes or access points typically found in deployed networks, providing a realistic structural testbed. This phase will support Test Cases 1 and 2.

Live Environment: The live environment involves deployments on real terrestrial fiber infrastructure and reflects actual field conditions, including shared ducts, environmental variability, and the presence of co-located services. The objective is to validate system performance in operational scenarios and confirm the feasibility of SoP-based sensing in realistic conditions. This environment will support Test Case 3.

To structure these efforts, the PoC will follow a phased approach:

Phase 1: Conducted in the lab, this phase will focus on verifying the system's technical feasibility, calibration accuracy, and responsiveness to controlled stimuli. It will be essential to establish baseline performance and refine measurement techniques. The Test Use Case 1 and 2 will be done in this phase.

Phase 2: This field-based phase, and will be covered by Test Use Case 3, will be split into two sub-phases:

- **Phase 2.1:** Testing on deployed fibers that do not carry live traffic, allowing further evaluation in an operational environment without impacting services.
- **Phase 2.2:** Testing in a fully operational network with live traffic to confirm non-intrusiveness and performance stability under real-time traffic conditions.

2.1. Test Case 1: Controlled Fiber Excitation in lab environment

Objective

Demonstrate and validate the effectiveness of SOP-based hardware tagging to detect and differentiate individual fibers within a controlled lab environment. The goal is to confirm that intentional excitations applied to a single fiber result in measurable and distinguishable SOP changes, enabling accurate fiber identification and correlation. This serves as a foundational step in proving the feasibility of non-intrusive SRLG identification using coherent optical transmission systems.

Setup Highlights

- Single fiber run with multiple fiber segments configured to represent distinct single fiber.
- Controlled excitation mechanisms applied with varying amplitudes and different distances from the fiber to simulate real-world disturbances.
- Verification that SOP variations correspond with known physical characteristics of the setup.
- Tests will be conducted under two conditions:
    a. With actual data transmission on the fiber to assess simultaneous sensing and communication.
    b. Without data transmission to isolate the sensing performance.

Method:

- Introduce controlled mechanical vibrations or perturbations on a known set of fibers.
- Monitor SOP variations on all fibers in real time.
- Correlate SOP changes with known fiber placement records within a defined time window.

Measured Parameters:

- **SOP Change Magnitude:** Quantifies the extent of polarization shift due to induced disturbances.
- **Detection Sensitivity:** Determines the minimum excitation level required for reliable SOP detection.
- **Error Rate in Fiber Grouping:** Compares the detected correlations against the known physical layout to assess accuracy in identifying co-located fibers.
- **False Positive Rate** – Tracks erroneous groupings or detections caused by unrelated environmental noise or transient changes

2.2. Test Case 2: SRLG Identification in Multi-Fiber Cables

Objective

Evaluate the capability of the SOP-based sensing system to accurately identify Shared Risk Link Groups (SRLGs) using real fiber trunks (multi-fiber optical cables) in a controlled lab environment. The aim is to demonstrate that the system can distinguish fibers sharing the same physical path by analyzing correlated SOP responses across bundled fibers.

Setup Highlights

- Use of actual multi-fiber cables with pre-defined SRLG assignments.

- Excitation applied to one or more fibers within the bundle to simulate shared environmental impact.
- All fibers monitored simultaneously for correlated SOP variations.

Method

- Introduce controlled disturbances to selected fibers within a known SRLG group.
- Continuously monitor SOP responses across the entire bundle.
- Apply correlation analysis to determine fiber groupings and compare against known SRLG mappings.
- Experiments will be performed in two phases:
    a. With **live data transmission** over selected fibers to validate sensing during active service.
    b. With no data transmission, ensuring a clean baseline for detection accuracy.

Measured Parameters

- **Accuracy in Fiber Grouping:** Validates the ability to correctly assign fibers to the same SRLG.
- **Error Rate in SRLG Detection:** Measures the difference between algorithmic output and the known SRLG assignments.
- **SRLG Identification Time:** Measures the efficiency of the detection process.

2.3. Test Case 3: Real-Time Monitoring Under Network Operations

Objective

Validate the reliability of the SOP-based sensing system in a real-life fiber network deployment. This test aims to assess system performance under realistic conditions, while taking into account that the network may carry live traffic. As such, all operations must be non-intrusive and must not interfere with service continuity.

Setup Highlights

- Deployment on a real-world terrestrial fiber route, with known topology and access points (manholes).
- Test fibers may be active or passive; in cases where traffic is present, strict non-disruption protocols are enforced.
- Environmental conditions (e.g., temperature, vibration, routing proximity) reflect actual field variability.

Method

- Deploy the sensing system on selected fibers in the field.
- Continuously monitor SOP variations during standard network operations.
- Perform correlation analysis to detect and classify fiber relationships and changes over time.

Measured Parameters

The KPIs of interest to measure the effectiviness relate to how well the SOP-based sensing system accurately and consistently identifies co-located fibers perform in a live network environment without disrupting normal operations. More specifically, effectiveness can be assessed through:

- **Accuracy of detection:** How reliably the system correlates SOP changes with physical proximity.
- **Coverage:** The extent to which the system can monitor fibers across diverse network segments.
- **Detection resolution:** The system's ability to discern between adjacent and non-adjacent fibers.
- **Time to Identify Fiber Changes** – Measures the system's responsiveness to detectable SOP shifts.
- **Confidence Levels Over Time** – Evaluates the stability and reliability of SRLG identification in a dynamic environment.

3. Desired Features

Parameters to Measure

To validate the effectiveness of the PoC, the following parameters will be monitored:

- **State of Polarization (SOP) Changes:** Measuring the impact on the polarization in response to fiber excitation.
- **Confidence Levels in Fiber Identification:** Ensuring that identified fibers match actual proximity data.
- **Detection Sensitivity:** Assessing how small movements affect detection accuracy.
- **Error Rate in Fiber Grouping:** Comparing detected fiber groups with known physical deployments.
- **Time to Identify SRLGs:** Measuring how quickly the system can map fiber groupings.

To ensure comprehensive validation, the PoC will be conducted in two phases as per paragraph...

3.1. PoC Methodology

The PoC will involve the deployment and testing of fiber sensing technology in controlled environments to evaluate its performance.

Approach

1. **Fiber Excitation and Detection:**
    - Use manual excitation techniques (vibration, movement) on specific fibers to generate a detectable response.
    - Monitor changes in the State of Polarization (SOP) using optical transponders.
2. **Data Correlation and Proximity Identification:**
    - Correlate SOP variations across multiple fibers to determine proximity and shared deployment.
    - Identify fibers that exhibit similar SOP changes as belonging to the same SRLG.
3. **Real-Time Monitoring:**
    - Use WaveSuite Fiber Sensing to track and log changes in fiber polarization.
    - Ensure confidence levels in fiber proximity detection are sufficient for practical deployment

There are two different measurement approaches for optical fiber sensing in a network with Shared Risk Link Groups (SRLGs). These approaches are visually indicated by numbered sections (1 and 2).

Measurement Approaches:

1. **Approach 1 - Manual Procedure with Multiple Excitations**
   - Involves exciting each fiber separately (Fiber 1, Fiber 2, and Fiber 3).
   - The sensing data is processed manually for each excitation.
   - SRLG_A is created and recorded in inventory.
2. **Approach 2 - Manual Procedure with Single Excitation**
   - Excitation is applied once.
   - The sensing data is processed in one step.
   - The result includes SRLG_A and an additional grouping (SRLG_B).

Advantages:

1. **Approach 1 (Multiple Excitations):**
   - Provides a more detailed step-by-step analysis of each fiber.
   - It is useful for troubleshooting specific fibers separately.
   - May offer higher accuracy when identifying individual fiber characteristics.
   - can be also used for general inventory
2. **Approach 2 (Single Excitation):**
   - More efficient and faster as it requires only one excitation step.
   - Reduces the complexity of the process.
   - Enables quicker inventory creation and classification of multiple SRLGs.

In summary, Approach 1 is more granular and precise, whereas Approach 2 is faster and more efficient for bulk processing.

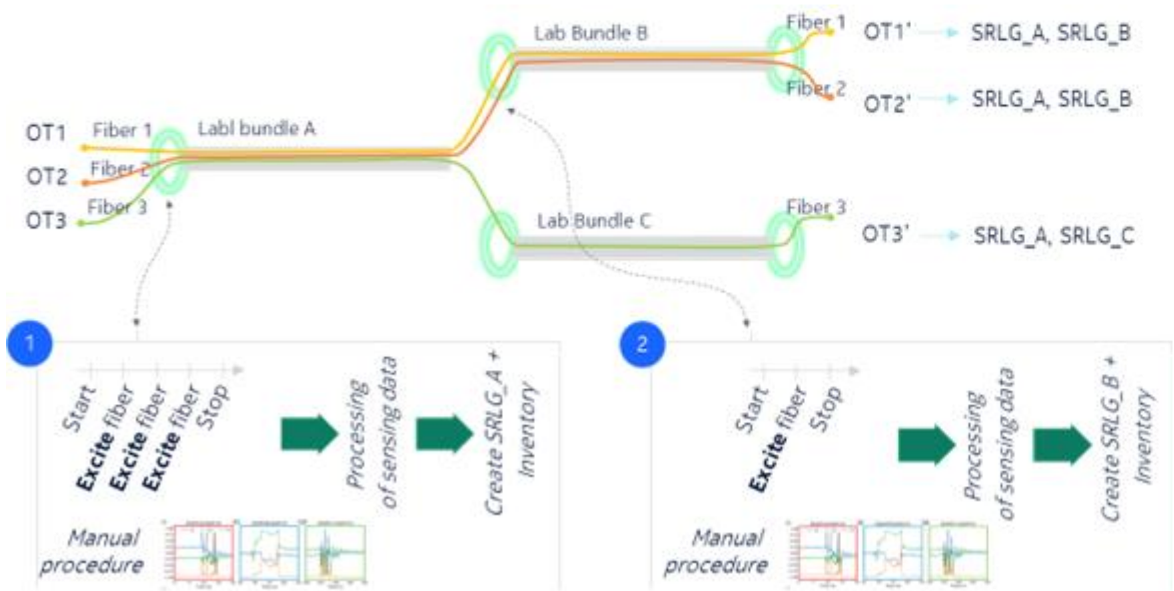

Figure 2: Shows the two methods for measurement

4. Applications of SRLG fiber identification

Once the SRLGs are identified, this information can then be used and made available for the following applications:

Application 1: SRLG-Aware Routing with GMPLS or PCE Integration
Once SRLGs are identified and configured into the network topology database or on their respective infrastructure links, they can be referenced by GMPLS or PCE-based systems for route computation. This allows service paths to be engineered with explicit risk awareness, ensuring that primary and backup connections do not traverse shared physical infrastructure, and thuenhancing fault tolerance and service continuity.

Application 2: SRLG Visibility for Risk Mitigation and Planning
By identifying SRLGs correlation and feeding this data into network operations systems, operators can proactively address potential vulnerabilities. Maintenance activities, route adjustments, and capacity expansions can be executed with a clear understanding of physical dependencies, reducing the risk of unintentional service disruption.

Application 3: Real-Time Fiber Monitoring for Operational Awareness
The SOP-based sensing process allows for continuous, non-intrusive monitoring of fiber conditions by analyzing subtle changes in polarization caused by physical influences such as vibration, bending, or mechanical stress. When correlated polarization shifts are observed across multiple fibers, it indicates a shared environmental impact, often pointing to a common physical pathway. These correlations can be mapped to pre-identified Shared Risk Link Groups (SRLGs), allowing operators to associate specific disturbances with affected fiber groups. This visibility enables proactive operational responses: operators can anticipate degradation trends, localize potential faults before service is impacted, and prioritize maintenance activities across all fibers within the same SRLG. This is particularly valuable in dense or hard-to-access duct environments where early warning and group-level awareness are critical to maintaining service continuity.

These applications collectively aim to enhance the availability and resilience of optical network infrastructure by enabling precise, non-intrusive monitoring and validation; supporting smarter planning, faster fault response, and more reliable service delivery across shared physical paths.

5. Key Benchmarks

Benchmarking methods that we expect implementors to follow

5.1. Benchmark 1 - Accuracy of Fiber Co-Location Identification Scope:

Assess how accurately SOP-based sensing determines fiber proximity. Metrics: Detection sensitivity, error rate in fiber grouping. Measuring Method: Comparing detected fiber placements with actual physical deployments.

5.2. Benchmark 2 - Time to Identify SRLGs Scope: Evaluating the speed of SRLG detection. Metric

Time taken to classify fiber groups into SRLGs. Measuring Method: Conducting multiple excitation tests to measure response times.

5.3. Benchmark 3 - Operational Efficiency Improvements Scope

Measuring the impact of SOP-based sensing on maintenance and planning. Metrics: Reduction in fiber troubleshooting time, improved SLA management. Measuring Method: Comparing pre- and post-PoC fiber maintenance operations.

6. Other Considerations

Timeliness and Future Considerations: To ensure long-term sustainability and adaptability, the following key factors must be considered:

- Ensuring seamless integration with existing network infrastructure to minimize disruptions and facilitate smooth deployment.
- Mitigating potential environmental influences on SOP readings to enhance measurement reliability.
- Leveraging advancements in automated fiber monitoring and SRLG management to optimize long-term network scalability and efficiency.
- Establishing a framework for continuous evaluation and improvement, ensuring that emerging technologies and methodologies can be incorporated seamlessly into future implementations.

History

Revision	Release Date	Summary of Changes
1.0	July 24, 2025	Initial version