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ML-Aided Transponder-Native SOP Sensing for Proactive Restoration in Live Metro Data Center Xchange

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Abstract *We demonstrate transponder-native SOP sensing over a live metro DCX spectrum service. Coherent transponder telemetry feeds a Kafka-based ML pipeline that classifies fiber disturbances and triggers real ROADM restoration without external polarimeters. ©2026 The Author(s)*

Introduction

The rapid growth of artificial-intelligence (AI) workloads is changing the nature of data traffic in transport networks. AI training, distributed inference, data replication, and storage synchronization increasingly generate machine-to-machine traffic between computing sites, shifting part of the network demand from human-centric access services toward high-capacity data-center-to-data-center connectivity [1]. In this context, metro data-center exchange (DCX) [2] and optical spectrum-as-a-service scenarios are becoming increasingly relevant [3], as they allow data-center resources to be interconnected through transparent optical capacity over metropolitan infrastructures [4]. For these services, high availability and fast recovery are critical: a fiber disturbance affecting a metro optical path can directly impact machine-driven workloads that rely on continuous exchange of large volumes of data. This evolution increases the importance of physical-layer monitoring capable of detecting events on the fiber plant before they become service-affecting failures. The need is particularly acute in metropolitan deployments, where optical cables are commonly installed in dense underground utility corridors and are exposed to excavation and construction activities. Conventional optical telemetry, including received optical power, pre-forward-error-correction bit-error rate (pre-FEC BER), and optical signal-to-noise ratio (OSNR), remains essential for service assurance. However, these quantities are primarily designed to assess communication performance. Mechanical activity on the fiber plant, such as vibration, bending, cable movement, or civil-work-like perturbations, may produce only weak signatures in conventional telemetry before evolving into a service degradation. Optical fiber sensing provides a complementary view by exploiting the sensitivity of light propagation to environmental perturbations along the fiber [5]. Among the possible observables, state-of-polarization (SOP) dynamics are particularly relevant because fiber birefringence changes – induced by mechanical stress – can be observed at the receiver side [6]. SOP-based detection has been demonstrated in metro-like environments [7, 8] and has recently attracted interest in optical networking because coherent receivers already track polarization-related quantities as part of their DSP operation [9, 10]. However, many real-time SOP sensing demonstrations still rely on external polarimeters or dedicated sensing equipment [11]. Although effective for experimental validation, this additional instrumentation might complicate deployment in operational transport networks.

This work demonstrates a step toward operational SOP-based sensing by removing the external polarimeter and acquiring SOP telemetry directly from coherent transponders with per-subcarrier monitoring. The demonstration is performed in a lab-to-field optical scenario connecting the LINKS Foundation laboratories to a production metro network under the city of Turin of GARR. The data-center side is emulated in the laboratories, while the optical connection reaches a metro network point of presence and then transparently traverses the metropolitan infrastructure. This realizes a live metro DCX optical spectrum-as-a-service scenario, where sensing and restoration are demonstrated over a field-connected optical path rather than only inside an isolated laboratory testbed. The AI/ML module classifies the SOP evolution into nominal, warning, or critical states [11, 12]. Critical alarms are forwarded to the Python orchestrator, which activates the pre-provisioned protection path through RESTCONF commands compliant with OpenROADM data models. The demonstration therefore shows how transponder-native SOP telemetry can support ML-aided disturbance detection and proactive restoration in a live metro DCX spectrum-as-a-service environment.

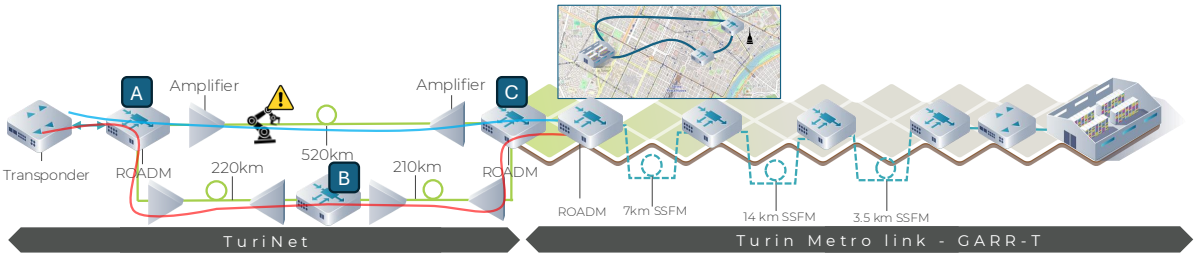

Fig. 1: Lab-to-field demo topology for live metro DCX spectrum-as-a-service. The data-center endpoint is emulated in the LINKS Foundation laboratories and optically connected to a production metro network point of presence. The optical service transparently traverses deployed metropolitan fiber infrastructure in Turin and returns to the laboratory testbed.

Review of the Research Topic and Demonstrated Technologies

The research topic addressed by the demo is the integration of fiber sensing into operational optical telemetry and restoration workflows. Transponder SOP-based sensing is attractive because it can exploit polarization dynamics observed at the coherent receiver side, without requiring a separate optical interrogator. Mechanical stress, vibration, bending, and cable movement alter the fiber birefringence and induce changes in the SOP. Coherent receivers already track polarization-related quantities as part of equalization and demodulation, and recent work has shown that SOP information can be used to monitor network health, detect link perturbations, and identify possible failure precursors [13]. This makes SOP telemetry a suitable candidate for self-monitoring and self-healing optical networks, especially when it is exposed directly by communication transponders.

The lab-to-field configuration is summarized in Fig. 1; here we focus on the telemetry and control technologies that turn this field-connected optical path into a sensing-to-restoration workflow. The demonstrated telemetry technology follows a streaming architecture. The transponder-side API-fast telemetry, to export the SOP, is provided by Nokia, while the open telemetry pipeline starts at the gNMI collector [14]. The transponder deployed in the experiment is described in [15] and uses Nyquist digital subcarriers. `gNMIc` receives one update per second from the coherent transponders; each update contains 100 SOP and Jones matrix samples per subcarrier acquired at 100 Hz with device-generated nanosecond timestamps. The samples are encoded as JSON records and forwarded to Kafka. Kafka decouples the telemetry source from multiple consumers and provides a common stream for storage, visualization, and real-time inference. Telegraf writes the same records to InfluxDB, while Grafana displays synchronized SOP traces, transmission monitoring, alarm state, and restoration logs.

The AI/ML module consumes the Kafka stream directly and classifies SOP telemetry into three alarm levels: nominal, warning, and critical.

Novelty

The main novelty is the replacement of the external polarimeter by SOP telemetry obtained directly from coherent transponders. Previous SOP-based sensing demonstrations commonly relied on polarimetric instrumentation to acquire the Stokes/-SOP traces [13, 16]. In this demo, the monitored SOP data are generated by the coherent transponders used for data transmission and are exported by vendor software for network telemetry ingestion. The second novelty is the treatment of SOP as network telemetry rather than as an offline or laboratory-only measurement. The 100 Hz SOP stream is collected through gNMI, serialized as JSON, queued in Kafka, stored in InfluxDB, visualized in Grafana, and consumed by an AI/ML inference service. SOP samples are indexed by device, direction, subcarrier, and device timestamp. The monitored optical wavelength is observed bidirectionally, and SOP telemetry is available per subcarrier for the connection under test. The third novelty is the closed-loop restoration action. The AI/ML alarm is not only displayed to an operator; it triggers real ROADM restoration through RESTCONF/OpenROADM commands [17, 18].

The proposed architecture [11] is vendor-agnostic downstream of the SOP telemetry interface. It does not require the Kafka, AI/ML, database, visualization, or restoration components to be tied to a specific transponder vendor. At the same time, the paper explicitly distinguishes this open-source telemetry and orchestration plane from the proprietary vendor software used to expose the SOP measurements.

Demo Implementation

Figure 2 illustrates the live evidence shown during the demonstration: the SOP telemetry evolution in InfluxDB, the robotic arm used to perturb the fiber, and the AI/ML logs reporting event detection and rerouting activation.

The objective is to demonstrate proactive optical restoration driven exclusively by SOP telemetry from coherent transponders. The testbed is a three-node ROADM topology, denoted A–B–C, hosted at the LINKS Foundation laboratories in

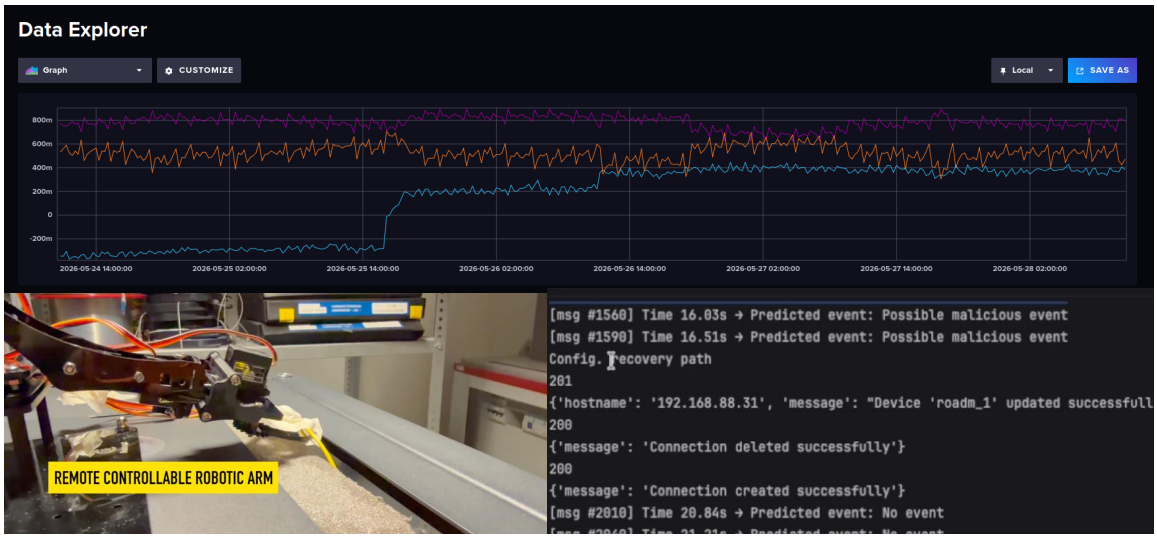

Fig. 2: Live sensing and restoration evidence shown during the demo. Top: InfluxDB Data Explorer displaying the time evolution of transponder-native SOP telemetry collected from the transponder. Bottom left: remotely controlled robotic arm mechanically perturbing the fiber. Bottom right: AI/ML inference logs showing event recognition, alarm generation, and triggering of the service restoration procedure.

Turin, Italy as illustrated in Fig. 1. It includes three bidirectional optical lines with span lengths of 520 km, 220 km, and 210 km. The setup uses Adtran ROADMs, Juniper and Cisco optical amplifiers, and a Nokia coherent transponder. The service configuration uses a primary and a protection path. In nominal operation, an 800 Gb/s optical service is established on the A–C path. A reduced-capacity 400 Gb/s protection connection is pre-provisioned on A–B–C, providing service continuity after a critical SOP alarm. The protection path is available before the event, allowing the orchestrator to execute restoration immediately after the critical SOP alarm. The path change is performed on the ROADMs through RESTCONF commands compliant with the OpenROADM data models.

The demo is executed remotely but live: the optical equipment remains in Turin and is remotely controlled during the session. A remotely activated Arduino-based robotic arm (live shown through a webcam) mechanically perturbs the fiber to emulate vibration and civil-work-like activity near the cable route.

The restoration logic is implemented in a Python orchestrator. When a critical alarm is received, the orchestrator sends commands directly to the ROADMs and switches the service from the 800 Gb/s A–C primary path to the reduced-capacity 400 Gb/s A–B–C protection path. When the alarm clears and the hold-off condition is satisfied, the orchestrator restores the 800 Gb/s service on the primary A–C path.

The live demonstration starts in nominal operation. Attendees observe the active 800 Gb/s service, SOP telemetry from the coherent transponders, AI/ML alarm state, and restoration status on Grafana. Kafka UI and InfluxDB views are also shown to verify that the SOP stream is being collected, buffered, stored, and consumed in real time.

The presenter then remotely activates the robotic arm. As vibration is applied, so that attendees will observe the SOP trajectory changing and the AI/ML state moving from nominal to warning or critical. When the critical alarm is reached, the orchestrator performs real ROADM restoration. Attendees see the control logs confirming the switch from the A–C primary path to the A–B–C protection path. After the perturbation stops, the system clears the alarm and automatically reverts to the primary path. Attendees will also interact with the demo through the presenter-guided workflow. They can request the perturbation event, inspect the live Grafana dashboard, observe Kafka and InfluxDB data views, and follow the restoration logs. The interaction exposes the complete sensing-to-control loop: transponder-native SOP generation, gNMI collection, Kafka streaming, AI/ML classification, and real optical restoration.

Conclusion & ECOC Relevance

This demo is relevant to ECOC because it connects coherent transponders, DSP-derived SOP telemetry, fiber sensing, AI/ML analytics, and software-controlled optical restoration in a live metro DCX scenario. It shows that coherent transponders can act not only as data interfaces, but also as in-service sensing probes for proactive network resilience. By removing the external polarimeter and triggering real ROADM restoration, the demonstration addresses a practical deployment barrier for sensing-assisted optical networking.

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