Seamless Optical Path Restoration with Just-in-Time Resource Allocation Leveraging Machine Learning

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Abstract *We present an experimental proof-of-concept on just-in-time resource allocation in elastic optical networks to provide seamless path restoration. Our method relies on state of polarization monitoring via standard coherent receiver paired with machine learning for proactive fiber cut detection.*

Introduction

While Internet traffic continues its growth, 5G requirements bring new opportunities to increase dynamicity, especially in meshed optical metro networks, where in recent years evolutions occur faster[1]. One of the biggest challenges for dynamic networks is to provision hardware resources during the design phase to ensure resilience. Alternatives to higher layer mechanisms such as OTN switching (Layer 1) and IP routing (Layer 3) are dedicated 1+1 optical protection and optical restoration. Dedicated 1+1 optical protection enables switching in less than 50 ms. This high-level guarantee, idling 50 % of the network capacity, is limited to mission-critical services and can be expensive with a dynamic network design. Concerning optical restoration, switching time (between 10 and 30 s[2,3]) is too slow to avoid outage, hence research to predict network failure and traffic re-routing at the higher layer is a very active field[4]. In this context, new solutions were proposed at the physical layer level. For instance in [5], the authors introduced a new Quality of Service-aware protection mechanism for flexgrid optical networks. They demonstrated that the use of two-wavelength fast variable Baudrate elastic transponders, enables spectral usage to be boosted by 80%, when premium traffic accounts for 25% of total traffic. Despite this huge gain, the protection channel is always enabled and need to be allocated in advance.

In this demo, we present an experimental proof-of-concept going even further in saving resources, while increasing the network resilience with just-in-time resource allocation for optical restoration. The demonstration follows our previous works[6,7] in which we developed an algorithm extension embedded in a coherent receiver coupled with machine learning to monitor mechanical stress on an optical fiber and recognize potential fiber breaks before they occur. We demonstrated event classification with 95% accuracy over a real-time DP-QPSK testbed. Here, we use our real-time testbed to establish a restoration path using an elastic transponder. The use of this elastic transponder with two lasers is a key enabler for seamless restoration by (i) enabling a second route to be established dynamically in parallel of the working one, (ii) easing the channel allocation with potentially two different wavelengths for working and restoration paths. This way, without leaving 50% of network capacity idle as in 1+1 protection and without waiting for a fiber cut as for usual optical restoration, the restoration path is activated proactively only when needed and available in a very short time (<50ms) to avoid outage.

Method description

This demo presents a real-time establishment of the new restoration path following the recognition and identification of a dangerous event. We define a dangerous event as any event that would lead to the fiber cut and traffic disruption, according to the probability rules established via machine learning process. A new restoration path is preemptively allocated, before a fiber cut, thus avoiding potential traffic loss.

State of Polarization (SOP) proved to be a good indicator for introduced mechanical stress on the fiber[8,9]. In this demo, for monitoring the SOP fluctuations we rely on the standard digital signal processing building blocks of a real time FPGA-based coherent receiver and especially on the Constant Modulus Algorithm filter responsible for polarization demultiplexing. Consequently, it enables the extraction of the SOP values, without any additional hardware cost, which allows detection of the signature of the event before any outage occurs, e.g. an excavator digging close to the fiber. The SOP monitoring is coupled with the machine learning software Khiops[10]. During the learning phase, Khiops automatically builds naïve Bayesian classifier with a very low final complexity. This classifier recognizes and

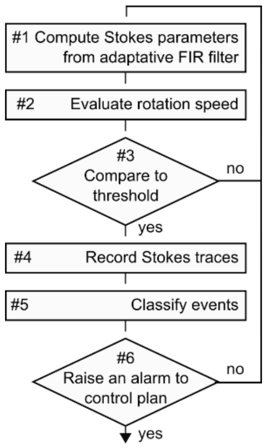

Fig. 1: Proactive fiber detection algorithlm

identifies the type of the event. The principle of the embedded detection algorithm is presented in Fig. 1 while details can be found in [7].

Upon detection and classification of the risk event, the Software Defined Network (SDN) controller is informed about the span location of the potential fiber cut. A new restoration route is then calculated and allocated. The time obtained thanks to the proactive fiber damage detection unit, allows a new restoration light path to be seamlessly settled and configured, without introducing disruption in the optical network, especially regarding inline amplifiers stability. It is only later when a metric, e.g. loss of light or loss of power, is detected that the active traffic switches to the newly established restoration path.

Demonstration setup

Fig. 2a shows a scheme of the optical network demo. The network is made of four physical nodes: A, B, C and D. Node A consists of a two-frequency DP-QPSK coherent elastic transmitter for data transmission and one emulated transmitter (a continuous wave laser). Both sources are enabled to generate two services, the red and blue one. For simplicity, the optical nodes consist of a simple optical element, e.g. one WSS has a role of a complete node. Nevertheless, in a real network environment, it may be colorless, directionless and contentionless Reconfigurable Add/Drop Multiplexer (ROADM) architecture to enable the advanced and multi-directional routing mechanisms[11]. Node B has an optical switching/routing role and consists of a WSS. Node C has a dual role: switching/routing role and is the drop port of the emulated channel. The emulated receiver is an ultrafast real-time polarimeter. Node D receives traffic from Node B and from Node C (not used at this stage of the scenario). The real-time SOP tracking relies on the coherent receiver. Finally, the SDN controller running on top of the network collects the

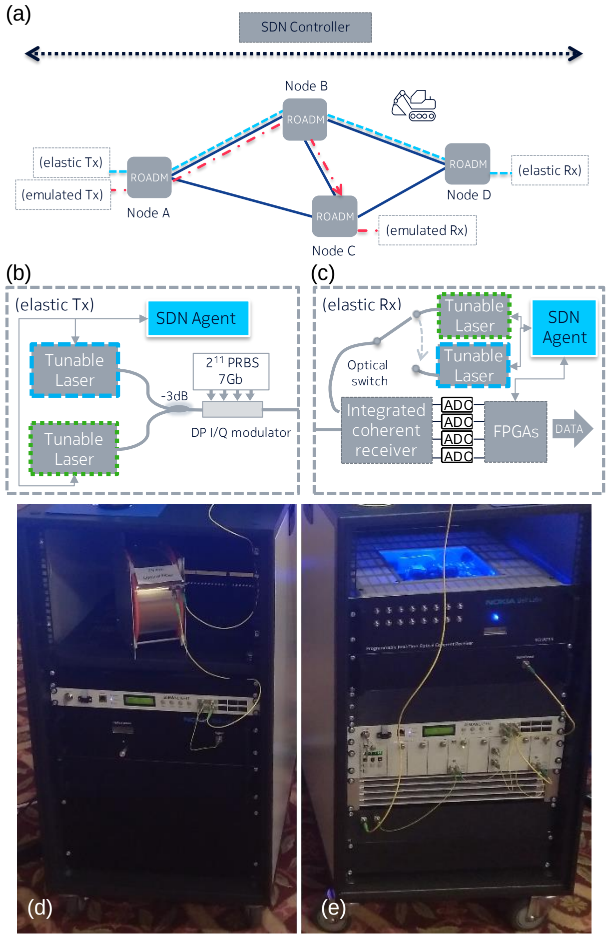

Fig. 2: (a) Schematic representation of the optical network. (b) Zoom on the two-frequency elastic transmitter. (c) Zoom on the two-frequency elastic coherent receiver. Photos of (d) transmitter and (e) receiver prototypes.

information about each “pro-active fiber damage unit” from its communication with SDN agents implemented in each node. Using correlation of alarms from the different proactive units and light path (only two for simplicity), it identifies the fiber span where the dangerous event occurs. The controller is also in charge of calculating a new restoration route using path computational element and configuring it. A programmable robot arm emulates imminent fiber damage, by creating a multiplicity of mechanical stress events on the fiber located between node B and node D and the real fiber cut is emulated by an optical switch (not shown). Details of the elastic transmitter and receiver are shown in Fig. 2b and 2c, respectively. In the transmitter, signal coming from two tunable lasers are sent through a 3dB optical coupler to the same I/Q modulator. Both lasers can be configured independently and can emit at the same time. This feature allows to configure the restoration light path while reliable traffic is still in place on the working light path. In the elastic receiver, there are also two tunable lasers following the frequencies of the transmitter. The switch from the working frequency to the restoration frequency only requires an optical switch thus ensuring seamless restoration.

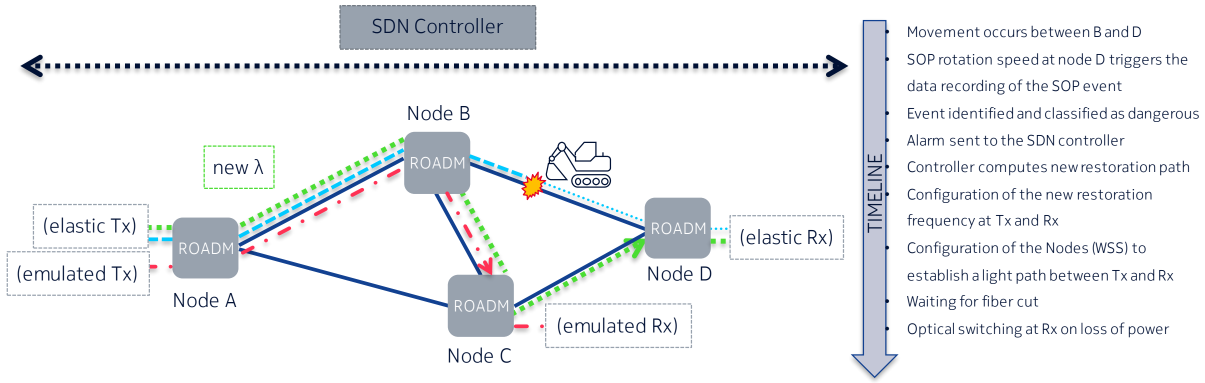

Fig. 3: Storyboard of overall scenario with the final state of the setup

Storyboard

In this section, we show how demonstration is scheduled and presented to the audience:

1. Introduction of the main causes of the link failures in the optical networks.
2. Presentation of available conventional solutions for the network resiliency, optical dedicated protection and optical restoration.
3. Description of the demonstration setup.
4. Presentation of the two already established light paths. The first one between node A and node D, passing transparently through node B and the second one between node A and node C, passing transparently through node B.
5. Presentation of the advanced SOP monitoring technique embedded in the real-time elastic receiver (node D) and with emulated receiver (ultra-fast polarimeter) (node C).
6. Introducing a mechanical stress on the fiber between node B and D using a robotic arm.
7. Detection of the increased SOP variation using a coherent receiver at node D. The ultra-fast polarimeter situated in node C does not record any unusual behavior of the SOP variation.
8. Presentation of the successful classification of the event in the node D, using machine learning software Khiops. The agent sends an alarm to the controller.
9. Establishment of a new restoration light path by the SDN controller using another wavelength from node A to node D passing transparently through nodes B and C. Presentation of the WSSs reconfiguration in nodes B and C.
10. Later, a fiber cut occurs on the link that was exposed to the mechanical stress between nodes B and D. The elastic coherent receiver detects the loss of power and switches to the restoration path.
11. Presentation of the new working light path connecting node A and node D allowing seamless traffic flow.

The overall scenario with the final state of the setup is represented in Fig. 3.

Conclusions

We successfully show how advanced monitoring available at low cost using coherent receivers can enable a new restoration mechanism. With just-in-time resource allocation leveraging machine learning, the new restoration improves the resilience of a dynamic optical network.

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