Pre-Emptive Detection and Localization of Failures Towards Marginless Operations of Optical Networks

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ABSTRACT
Operating optical networks much closer to their physical capacity is very tempting but necessarily requires much improvement on the way failures are handled. In this paper, we experimentally demonstrate the ability of the ORCHESTRA solution for early detection and localization of failures, to proactively mitigate their impact and thus guarantee smooth operation without traffic interruption.
Keywords: optical networks, cross-layer optimization, marginless operations, soft-failures, failure localization.

1. INTRODUCTION

A typical optical network is designed with high margins [1] to achieve resiliency to any form of uncertainty related to its deployment and operation. Uncertainty sources are typically from initial network equipment performance, ageing, fluctuations from polarizations effects, increasing network load, fibre repairs, etc. ... High margins generally allow low maintenance strategies: network operation is only troubled by occasional failures, e.g. from accidental or voluntary fibre cuts [2], or critical network equipment breakdowns. Such events leading to traffic interruptions are usually called *hard failures*. To re-establish traffic after hard failures, various recovery strategies exist, entailing network capacity overprovisioning from 25% to 100% [3] depending on the class of service. Thus, between performance margins and restoration strategies, current optical network operation allows a lot of capacity to generally remain unused.

Simultaneously, the industry must face steep traffic increase with constant revenue [4]. *Marginless operation* appears as a potent solution to overcome this challenge. It consists in meeting increasing traffic demands by optimizing the use of available resources rather than deploying new ones [5]. Modern flexible network elements already enable marginless operation. With current practices in network maintenance however, operating closer to critical performance levels would increase the probability of hard failures. Operations would thus require more overprovisioning for restoration and thus defeat the purpose. Reliable marginless operation requires new network maintenance strategies where multi-parameter monitoring, data analytics and artificial intelligence techniques must be leveraged to detect and diagnose network health issues, i.e. *soft failures*, before they turn into hard failures. Furthermore, these techniques can lower hard failure probability by preventively acting at the cause, or by diverting traffic before performance reach critical levels [6]. Finally, failure classification and localization can ease maintenance and reduce the mean-time-to-repair, significantly lowering related operational expenditures.

In this paper, we experimentally demonstrate the ability of the ORCHESTRA solution [7] for early detection and localization of soft failures before they can lead to hard failures.

2. CONTROL PLANE ARCHITECTURE

We use ORCHESTRA's hierarchical and programmable management infrastructure [8] illustrated in Fig. 1. The two key building blocks are the Operations, Administration and Maintenance (OAM) Handler, and the Application-Based Network Operations (ABNO) Controller. The ABNO controller implements workflows for several ORCHESTRA use cases and uses the DEPLOY [7] software module as a Path Computing Element (PCE) extended with Quality of Transmission (QoT) estimation ability. DEPLOY performs monitoring-based

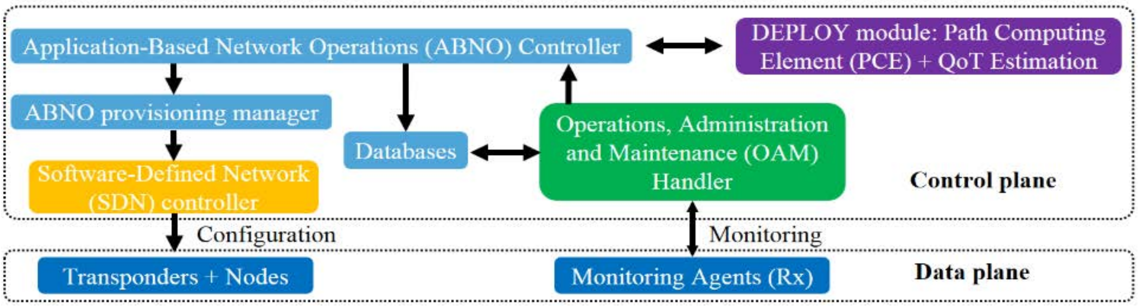

Figure 1. Overview of H2020 ORCHESTRA hierarchical control layer.

Bit Error Ratio (BER) predictions and determines appropriate recovery actions. Finally, the ABNO controller (re)configures lightpaths – Transmitters (Tx), Receivers (Rx), and Reconfigurable Optical Add-Drop Multiplexers (ROADM) – through a provisioning manager and Software Defined Network (SDN) controllers. The control logic is applied via NETCONF following YANG model and REST. This versatile control plane architecture can notably be programmed to detect, identify, localize and react to various types of soft and hard failures. At lowest complexity level, monitoring agents placed in receivers (Rx) can check any monitored parameter against one or more thresholds, and generate parameter-specific alarms when corresponding thresholds are exceeded. For instance, a hard failure alarm is automatically generated when the monitored BER exceeds the hard failure threshold, set at the estimated Forward Error Correction (FEC) limit over which packet losses are expected. An alarm can be handled at all levels of the hierarchical architecture. Additionally, the way an alarm is handled by each monitoring agent is programmable: the agent can either apply correlation or suppression functions, try to solve the problem locally [8], or forward the alarm to a higher level.

3. SOFT FAILURE DETECTION AND LOCALIZATION

Setting safety thresholds close to the FEC limit is appropriate to handle moderate and slow variations of performance, e.g. as expected from equipment ageing. In contrast, a sudden and relatively large BER increase could be due to an expected event such as a network load increase, but could also be due to an unexpected event such as a fibre degradation or equipment malfunction. Such BER variations should thus be treated as threats and systematically investigated. The soft-failure detection method we implemented is designed accordingly. It is based on a dynamic threshold individually defined for each lightpath according to the current BER average <BER> and standard deviation σ, as: $Th_{SF} = \langle BER \rangle + k\sigma$ where <BER> and σ are periodically evaluated from monitored BER values, and k is a positive parameter. By simulation, we test the impact of k assuming Gaussian distributed BER variations outside soft-failures (Fig. 2a, 2b). As key performance indicators, we define the soft-failure *Detection Limit* as the smallest relative variation of BER leading to an alarm, and the *false alarm probability* as the probability that a random variation of BER is mistaken for a soft-failure. As expected, we observe in Fig. 2c, 2d that the parameter k trades-off soft-failure detectability with false alarm probability. Experimentally, we choose $k = 4$ to achieve a false alarm probability below 0.01%.

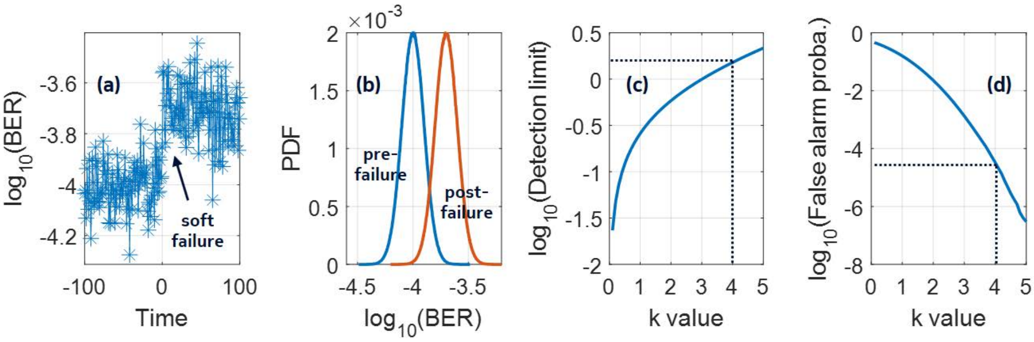

Figure 2:(a) Simulated evolution of BER over time with soft-failure; (b) Probability density function (PDF) of BER before and after the soft-failure; Soft-failure detection limit (c) and false alarm probability (d) versus k.

Once a soft-failure is detected, the monitoring agent (Fig. 1) generates an alarm that reaches the OAM handler. For localization purposes, the OAM handler introduces a *correlation delay* to capture similar alarms from other lightpaths. This delay is set according to the BER polling rate. Once the correlation delay is over, the OAM Handler forwards all received alarms to the ABNO controller which in turn forwards them to DEPLOY to execute the failure localization algorithm [9]. It relies on the *routing matrix* where rows correspond to lightpaths and columns to links. If the routing matrix has a full rank, the algorithm can theoretically localize any single soft-failure at the link level. In that case, DEPLOY returns the faulty link to ABNO, which can then inform the network operator and/or take automatic proactive actions e.g. further investigations, rerouting, or maintenance operation scheduling. When the number of active lightpaths is low, the routing matrix is typically rank deficient leading to a potential ambiguity in the localization. In such case, DEPLOY can suggest probe lightpaths to be established to remove the failure localization ambiguity.

4. EXPERIMENTAL DEMONSTRATION

The experimental setup is depicted in Fig. 3a. We emulate a topology integrating three nodes connected by two links and carrying two lightpaths (cf. Fig. 3b). We use two pairs of custom flexible transmitters (Tx) and receivers (Rx) with different technologies and performances, thus emulating a multi-vendor environment [8]. Links are emulated through software-controlled variable optical attenuators (VOAs). With 32 GBd/s baud rate and QPSK modulation format, both lightpaths carry a net capacity of 100 Gb/s. The first lightpath LP1 goes through both $Link_{0\text{-}1}$ (VOA_1) and $Link_{1\text{-}2}$ (VOA_{2a}). Using a 2×2 (50% or 3 dB) coupler, the second lightpath only

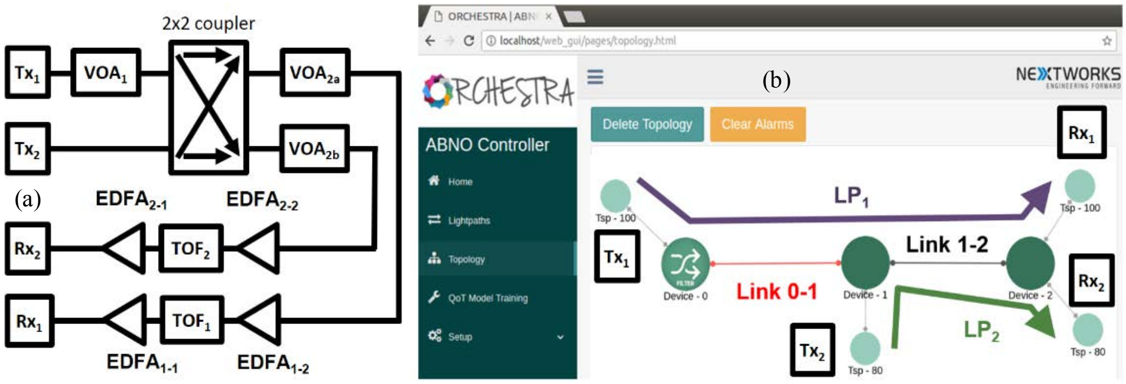

Figure 3. Data plane and control plane view (ABNO user interface) of the soft-failure detection experiments.

goes through $Link_{1\text{-}2}$. Note that to achieve this, VOA_2 is composed of VOA_{2a} and VOA_{2b} as two identically set ports of the same device. The two lightpaths are spectrally positioned 37.5 GHz apart. They are both amplified by two 2-stage-amplifiers (EDFAs) before reception. Two tunable optical filters (TOF) are placed between the stages of the EDFAs to filter out LP2 before Rx_1, and reciprocally to filter out LP1 before Rx_2. The signals are demodulated offline using digital signal processing (DSP), also achieving multi-parameter monitoring.

The soft-failures are created as sudden increases of optical attenuation, on $Link_{0\text{-}1}$ through VOA_1, and on $Link_{1\text{-}2}$ through VOA_2. Additionally, the attenuation sets of VOA_1 and VOA_2 are randomly modified for each new acquisition to emulate in lab the natural performance variations of deployed optical networks.

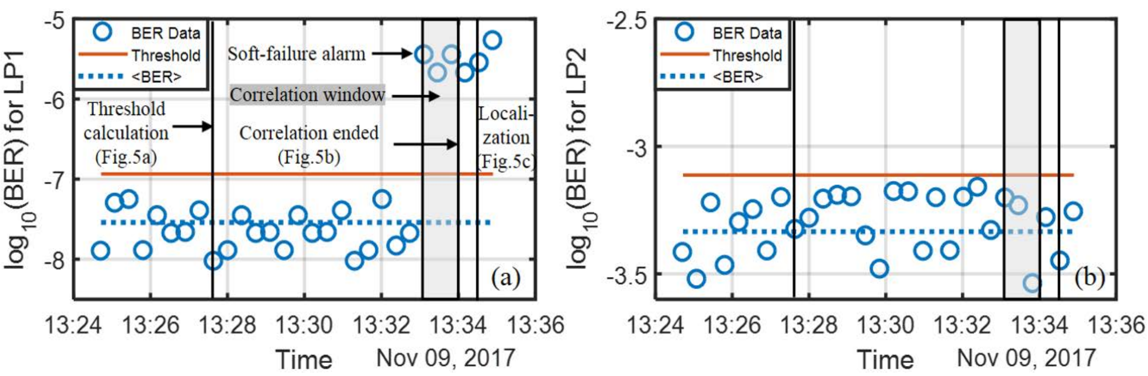

Figure 4. BER vs time for LP1 (a) and LP2 (b) for the emulated soft-failures on $Link_{0\text{-}1}$.

In a first experiment, we apply the soft-failure to $Link_{0\text{-}1}$. Typical evolutions of the BER for both lightpaths is illustrated in Fig. 4. The various actions taken by the control plane before and after the soft-failure are visible in the logs reported in Fig. 5. In Fig. 5a, ABNO sends a request to DEPLOY to calculate the soft-failure detection threshold for both LP1 and LP2 based on the nine-last recorded BER values. From the BER average <BER> and

```
[2017-11-09T13:27:33.035] => Threshold Calculation Request Parameters:
{"Established_Optical_Connections":[
{"lightpath_id":1,"golden":1,"tsp_id":100,"configuration_id":101,"grid"
:3,"n":8,"m":3,"trx_n_float":193.15,"src-dst":[0,1,2]},
{"lightpath_id":2,"golden":1,"tsp_id":80,"configuration_id":81,"grid":3
,"n":14,"m":3,"trx_n_float":193.187,"src-dst":[1,2]} ],
"Lightpath_ID":1, "Threshold_Type":111, "History_Monitoring_Details":[
{ "lightpath_id":1,"pre_fec_stats":[2.8843223E-8,1.7309853E-8,9.0]}
{ "lightpath_id":2,"pre_fec_stats":[4.6284284E-4,7.7271885E-5,7.0]}]}
[2017-11-09T13:27:33.461] => Threshold Calculation Results:
{"Threshold": 1.1582635e-07, "Calculation_Status": 1}
```
(a)

```
2017-11-09 13:33:59,164 DEBUG OamHandlerManager:78 - Received
notification message from queue
{"connections": [{"id": "1", "status": "DOWN", "failure-type":
"SOFT"}], "network-elements": [
    {"id": "0", "type": "LINK", "domain-id": "1"},
    {"id": "1", "type": "LINK", "domain-id": "1"}]}
2017-11-09 13:33:59,169 DEBUG AbnoController:502 - Received message
from queue
{"msgType" : "NOTIFICATION","failures" : [ {"id" : "1","status" :
"DOWN","failure-type" : "SOFT"}],
  "sender" : "OAM_HANDLER","msgType" : "NOTIFICATION"}
```
(b)

```
[2017-11-09T13:34:33.043] => Soft-Failure
Localization Request Parameters:
{"Affected_Lightpaths":[1],"Established_Opti
cal_Connections":[
{"lightpath_id":1,"golden":1,"tsp_id":100,"c
onfiguration_id":101,"grid":3,"n":8,"m":3,"t
rx_n_float":193.15,"src-dst":[0,1,2]},
{"lightpath_id":2,"golden":1,"tsp_id":80,"co
nfiguration_id":81,"grid":3,"n":14,"m":3,"tr
x_n_float":193.187,"src-dst":[1,2]}],
  "Current_Monitoring_Details":[
{"lightpath_id":2,"pre_fec":0.000633},{"ligh
tpath_id":1,"pre_fec":0.000004}],
  "History_Monitoring_Details":[
{"lightpath_id":2,"pre_fec_stats":[5.9945293
E-4,8.332191E-5,17.0]},
{"lightpath_id":1,"pre_fec_stats":[1.9369707
E-5,7.7529614E-5,18.0]}]}
[2017-11-09T13:34:33.228] => Soft Failure
Localization Results:
{"Localization_Actions": [{"failed_link":
[0, 1]}], "Localization_Status": 1}
```
(c)

Figure 5. Control plane logs for the soft-failure on $Link_{0\text{-}1}$: (a) ABNO to DEPLOY to calculate the soft-failure threshold for LP1, (b) OAM handler alarms notification log, and (c) ABNO to DEPLOY localization call.

standard deviation σ provided by ABNO, DEPLOY calculates and answers with the corresponding threshold equal to <BER> + 4σ. Note that this process is periodically repeated. When the soft-failure is applied to $Link_{0\text{-}1}$, the BER for LP1 suddenly increases above calculated threshold while the BER for LP2 stays stable, as shown in Fig. 4a, 4b. Consequently, the monitoring agent for Rx_1 raises a soft-failure alarm which is received by the OAM handler and the OAM handler then forwards information describing the alarm to the ABNO controller (Fig. 5b). Finally, the ABNO controller sends a request to DEPLOY to localize the failed link, and DEPLOY answers that the failure occurred on $Link_{0\text{-}1}$ (Fig. 2c).

In a second experiment where the soft-failure is applied to link1-2, the system, from the monitored BER values for LP1 and LP2 presented in Fig. 6a and 6b, is also able to correctly localize the soft-failure.

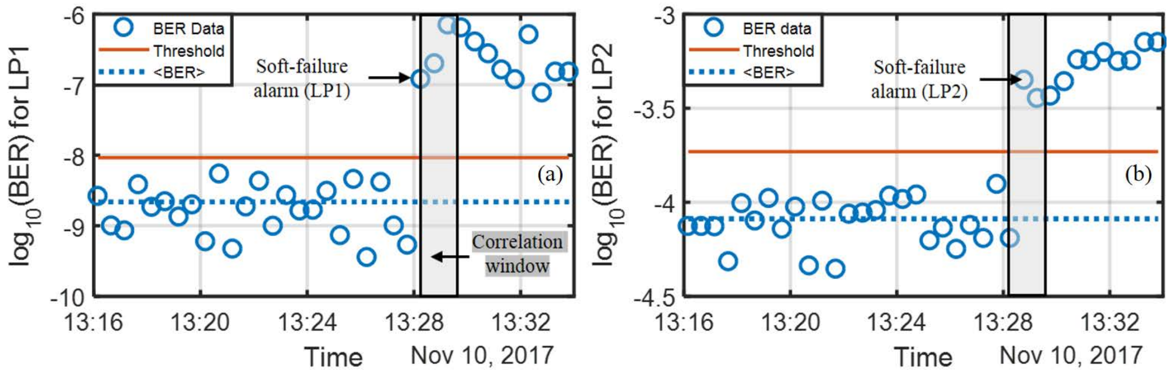

Figure 6. BER vs time for LP1 (a) and LP2 (b) for the emulated soft-failures on $Link_{1\text{-}2}$.

We can remark that detecting soft failures on both active lightpaths could also mean – in a field configuration – that soft-failures occurred on both links within the refresh period of the BER monitoring. This potentially ambiguous localization is not due to the rank of the routing matrix, but to a necessarily non-zero correlation delay applied to correlate the alarms. Since the probability of facing this issue grows with longer refresh periods, better localization reliability will be achieved with faster BER refresh rate. This result can be generalized from our experimental setup to full-scale optical networks.

5. CONCLUSIONS

In this paper, we presented the application of ORCHESTRA's hierarchical and programmable management infrastructure to the detection and localization of soft-failures, as a key enabler for marginless operations of optical networks. After discussing the performance of the system in terms of soft-failure detectability and false alarm probability, we demonstrated its smooth operation in laboratory experiments where natural performance fluctuations of deployed networks are emulated. Finally, we underline the impact of the BER monitoring refresh rate on the system's ability to localize soft-failure without ambiguity.

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