Observe-Decide-Act: Experimental Demonstration of a Self-Healing Network

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Abstract: We experimentally demonstrate a self-healing network, following the observe-decide-act paradigm: monitoring reveals degradation, decision is taken, network is reconfigured to restore service. We also demonstrate, for the first time, pre-programmed resilience in integrated data/control testbed.
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1. Introduction

The continuous growth of IP traffic, the emergence of new services and the future introduction of 5G [1], motivate the design of a new truly flexible and programmable network. Typically, metro/regional and core optical networks are designed and operated in a static manner. Elastic optical networks (EONs) provide finer granularity and flexibility that can be harvested to improve network efficiency. However, lightpaths are overprovisioned for both physical layer attributes and capacity, and remain unchanged for several years. To be more specific, the current practice in the physical layer is to estimate the lightpaths' Quality of Transmission (QoT) with high *margins* to achieve uninterrupted network operation until End-of-Life (EOL) [2].

Reducing the margins (set apart to account for, e.g., ageing and QoT estimation inaccuracy) can yield significant cost savings [3]. The network then operates more efficiently, closer to its limits, but as conditions change, it needs to dynamically re-adapt to QoT degradations (*soft-failures*) as they appear. To enable an agile optical network that operates efficiently, with reduced margins, throughout its lifetime and is able to resolve any occurring soft-failure, the feedback from the physical layer is crucial. ORCHESTRA (www.orchestraproject.eu/) uses feedback from the physical layer as part of an *observe-decide-act* control loop to enable a dynamic optical network of unprecedented efficiency. ORCHESTRA exploits coherent receivers as software defined optical performance monitors (soft-OPMs) and leverages a novel hierarchical monitoring infrastructure [4] to transfer and manipulate monitoring information from multiple soft-OPMs. This information is used to obtain a more accurate knowledge of the physical layer, enabling the reduction of margins and a fine cross-layer optimization. Moreover, the improved physical layer observability is used to efficiently localize and handle soft failures.

In this paper we experimentally demonstrate the dynamic operation of ORCHESTRA network and its ability to re-adapt to current physical layer conditions. In particular, we demonstrate the automatic recovery of lightpaths from typical soft-failures caused by equipment ageing (e.g., amplifier and filters). A centralized controller enhanced with soft failure workflows and re-optimization algorithms takes re-adaptation decisions depending to the lightpath's class of service. The decisions are communicated for execution back to the network to resolve the soft-failure, manifesting ORCHESTRA self-healing operation. We demonstrate both centralized and also, for the first time, pre-programmed resiliency scheme in an integrated data and control plane testbed.

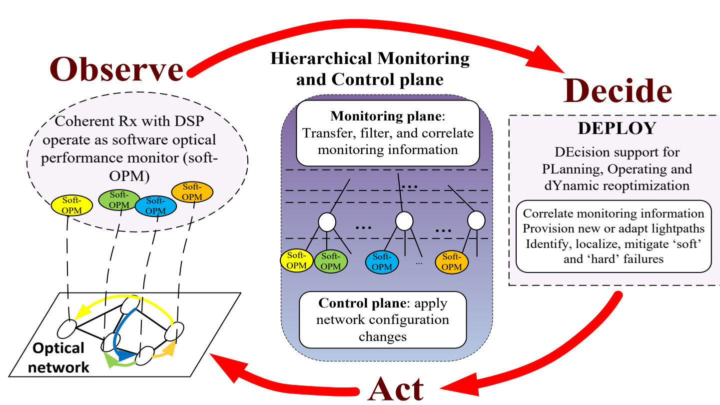

Fig. 1: Observe-decide-act paradigm, enabling high efficiency (reduction of margins) and dynamic/automatic restoration of QoT degradations.

2. Observe-Decide-Act

We consider an EON exploiting coherent detection and Digital Signal Processing (DSP)-based impairments mitigation, thus enabling end-to-end performance monitoring. Control and management of the EON are based on the *observe-decide-act* control loop envisioned by the ORCHESTRA project (Fig. 1). First, end-to-end parameters, such as pre-forward error correction-bit error rate (pre-FEC-BER), signal to noise ratio (SNR), optical SNR (OSNR), signal bandwidth and others can be monitored by DSP at each receiver, which operate as software defined optical performance monitors (soft-OPMs). Soft-OPMs combined with any available node and link power monitors, enable the *"observation"* of the physical layer. Monitoring information is transferred over the management plane, forming a hierarchical and programmable infrastructure [4]. For example, the management plane can be programmed to raise alarms when some monitored value exceeds a threshold. By correlating monitoring and alarm information, the type of the fault or degradation is recognized and the network elements involved are identified (i.e., failure localization). Filtering and multi-lightpath correlation functions are applied on the monitored information at management elements belonging to intermediate levels or to the root of the hierarchy implementing the OAM Handler of the ABNO controller [4]. The ABNO controller, extended to implement the related workflows, based on the interpretation of the feedback data, takes a *"decision"* using the DEPLOY tool (extension of [5]) as the PCE. Such decisions can impact the routing and spectrum assignment of new connections (e.g., producing accurate QoT estimates before their establishment), as well as the recovery of degraded connections (e.g., through re-routing, change of modulation format or baud/code rate). Finally, the ABNO controller uses the provisioning manager to "act", and (re-) configure the related equipment so as to execute the decisions. In particular, Opendaylight extended with appropriate YANG models, i.e., the transponder YANG model defined in [6], and using NETCONF was used as the provisioning manager.

Reconfiguration can be initiated by the ABNO centralized controller exploiting NETCONF protocol or it can be pre-programmed [6]. In the latter case, the transponder has been pre-instructed [6] by the controller and already knows the actions to perform when the DSP reveals a specific performance degradation. Thus, the transponder can promptly react without propagating the alarm over the monitoring hierarchy to the central controller, and waiting for the calculation of the decision and the control plane to transfer the action back.

3. Experimental demonstration of self-healing

The setup of Fig. 2a was used for the experimental demonstration: a lightpath and two (2) WSS (emulating optical nodes) were considered as the reference topology. Two service classes were assumed: *gold* and *bronze*. In case of a gold connection, the full bit rate has to be maintained in case of failures/degradations, while in the case of a bronze one, the full bit rate is not necessary maintained [4]. We performed three experiments demonstrating dynamic network reconfiguration and self-healing operation, according to connection's class of service.

Experiment 1 – Gold class, OSNR degradation and action by the ABNO controller: a 100 Gb/s 28Gbaud PM-QPSK gold connection is established. Fig. 2b shows the content of the NETCONF message sent to configure a filter along the path with ITU-T flex-grid parameters n=80 (193.6 THz) and m=3 (i.e., 37.5 GHz). Then a soft failure (representing e.g., amplifiers' ageing or fiber cuts reparation) is introduced with the VOA, resulting in OSNR decrease. Pre-FEC BER threshold of 4×10^{-3} is exceeded because of the soft failure. The net bit rate has to be *maintained* after the degradation (*gold class*). Note that the threshold is set before QoT is unacceptable, and thus net bit rate is not lost but we are given the time to re-adapt to maintain it. An alarm is forwarded to the management system, reaches ABNO, and the PCE (DEPLOY) decides the reconfiguration of the code rate (from 12% to 28%, assuring a higher FEC threshold of 2×10^{-2}) and the corresponding increase of the baud rate (from 28 to 32 Gbaud) to maintain the net bit rate. Fig. 2c shows the computation result of the DEPLOY tool, indicating "fec_adaptation". Fig. 2d shows the evolution of the BER and signal bandwidth before and after FEC adaptation: BER increases above the (initial) threshold because of the soft failure, but when FEC is adapted, the BER threshold changes and is no longer violated. Note that in this experiment, although the transmission bandwidth increases from 28 to 32 GHz the filters remained at 37.5 GHz. In a follow-up experiment (not detailed here due to space) the soft failure had two causes, including, in addition to increased VOA attenuation, a high filtering penalty. In that case the BER was still not rendered acceptable after the code adaptation and the filters were opened to 50 GHz in a subsequent action (in a second observe-decide-act instantiation) to maintain the gold service.

Experiment 2 – OSNR degradation and pre-programmed action by the ABNO controller: a 150 Gb/s 32 Gbaud PM-8-QAM bronze connection is established. Thus, the net bit rate can be reduced in case of degradations (*bronze class* [4]). Resiliency scheme is pre-programmed [6] in the transponder controller: in case the BER exceeds the (configured) threshold, the transponder self-reconfigures the modulation format from PM-8-QAM to PM-QPSK, thus reducing the bit rate to 100 Gb/s. In this case, when the soft failure occurs, the transponder controller already knows the action and does not wait for ABNO controller computations. Fig. 2e shows the pre-programmed action computed by the DEPLOY tool. Fig. 2f shows the installation message of the pre-programmed action to the transponder controller: while the connection is in “steady” state (i.e., normal operation) and an event occurs (exceed of BER threshold), a reaction consisting of adaptation to PM-QPSK is applied. Fig. 2g shows the BER before and after the modulation format adaptation: the soft failure causes the BER to increase above the threshold, and upon the application of the pre-programmed action and the adaptation of the format, the BER returns below the threshold.

Experiment 3 – Bronze class, OSNR degradation and action by the ABNO controller: a 150 Gb/s 32Gbaud PM-8QAM bronze connection is established, then a soft failure is introduced with the VOA resulting in OSNR decrease. BER threshold is exceeded and recovered with modulation format adaptation (from PM-8-QAM to PM-QPSK), along with a reduction of the bit rate to 100 Gb/s, similarly to experiment 2. However, in this experiment the restoration is acted centrally by the ABNO controller. For space reasons, measurements and computations are not reported. We measured the restoration time (from alarm creation to Tx reconfiguration) to be in the order of sec in the centralized approach (includes alarm propagation over the monitoring plane to OAM Handler, notification to ABNO, DEPLOY’s computation, and re-configuration of Tx), and in order of hundreds of msec for pre-programming (experiment 2).

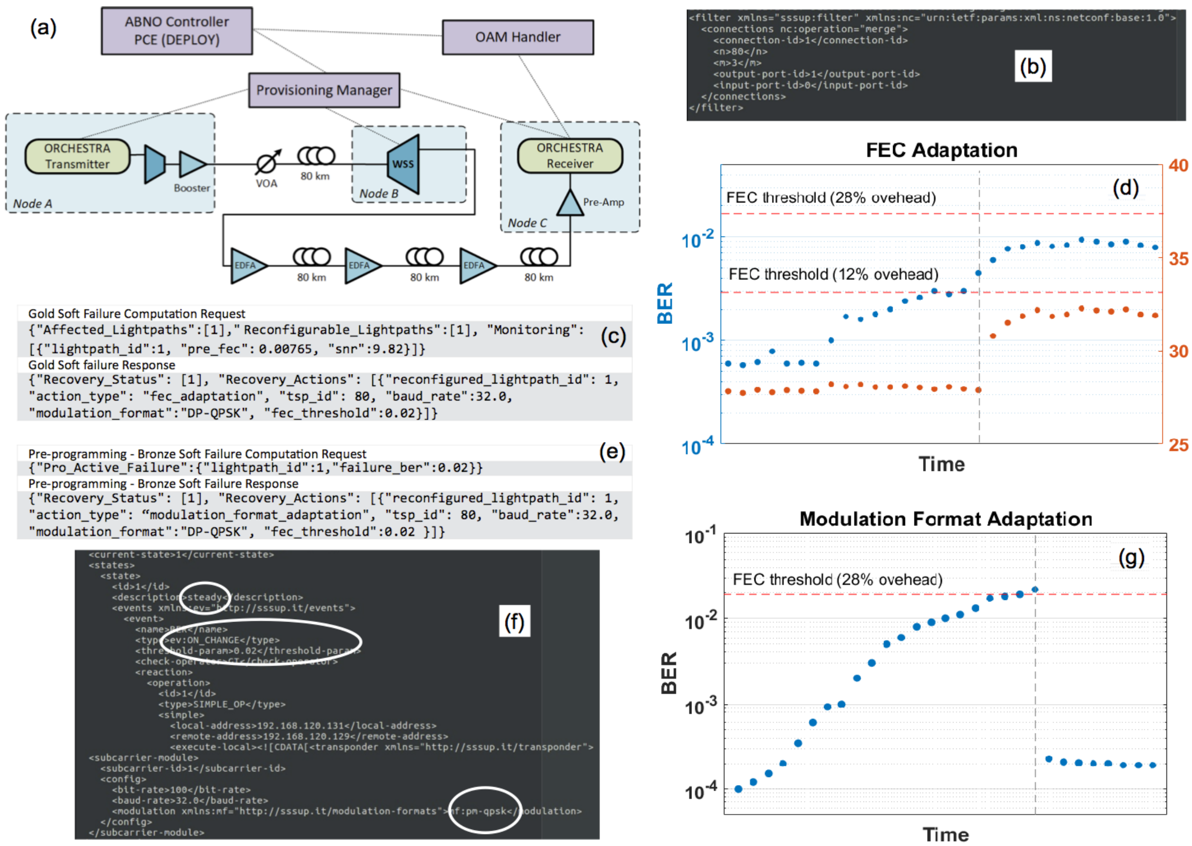

Fig. 2: (a) experimental testbed; (b) NETCONF <edit-config> message; (c) experiment 1 PCE computation: FEC adaptation; (d) BER evolution in experiment 1; (e) experiment 2 PCE computation: pre-programmed instructions to adapt the modulation format; (f) installation message of pre-programmed resiliency scheme; (g) BER evolution in experiment 2.

4. Conclusions

We successfully demonstrated a self-healing elastic optical network employing flexible transponder, management plane for disseminating monitored, an ABNO-controller, the DEPLOY tool acting as Path Computation Element, and NETCONF protocol for both monitoring and control operations. Self-healing is achieved following the observe-decide-act paradigm: monitoring/observation reveals physical layer degradation, a decision is taken (format and code rate adaptation), and then the data plane is reconfigured to restore the service.

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5. References

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