Experimental demonstration of network automation based on QoT estimation and monitoring in both single- and multi-domains

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Abstract *We experimentally demonstrate the integration of 100-200Gb/s data plane with NETCONF agents, SDN-controllers, and management plane exploiting monitoring and QoT estimations. We report on successful experiments for provisioning and reliability in single- and multi-domains.*

Introduction

Networks are evolving towards more automation and flexibility at both data and control&management (C&M) planes. Moreover, network operators and vendors are evaluating the reduction of network margins in order to increase the optical reach, thus reducing the costs (e.g., of electronic interfaces)[1]. This is driving the needs of more effective management of monitoring information to verify the proper quality of service. At the C&M layer, the NETCONF protocol is emerging due to its support of configuration and management[2] in a vendor-independent way[3]. At the data plane, flexibility is required to make compatible systems and sub-systems from different vendors thus enabling multi-vendor interoperability[4].

In this paper, we experimentally integrate a data plane including 100Gb/s commercial cards and 200Gb/s custom-built tx/rx, all interfaced with NETCONF agents, managed through OAM Handler that exploits monitoring for failure localization and accurate Quality of Transmission (QoT) estimation, and controlled by SDN. We report on successful experiments demonstrating lightpath setup and reliability in both single- and multi-domains scenarios.

Data, control, and management planes

The reference network is shown in Fig. 1a including data plane, control (SDN controllers) and management (OAM Handlers and monitors) components. Two domains A and B – each one provided by a different vendor and controlled by the same operator – are connected by the bi-directional link connecting node n_3 in the domain A and n_4 in domain B. The link n_3-n_4 is drawn with two unidirectional links to illustrate the related domain responsibility: n_3-n_4 to domain A, while n_4-n_3 to domain B. Both single and multi-domain lightpaths can be generated. Control and management are performed in a hierarchical way, following and enhancing the ABNO approach proposed by IETF[5]. Regarding control, the ABNO Provisioning Manager coordinates lightpath provisioning, interacting with dedicated SDN-controllers performing provisioning of: i) single-domain lightpaths over the domain under its responsibility, and ii) single-domain segments of multi-domain lightpaths. The SDN-controller includes a Path Computation Element (PCE) for path computation, which relies on a Traffic Engineering Database (TED). PCE also relies on a QoT estimator tool integrated with the OAM Handler and on the Physical Layer database (PL-DB) including physical layer information (e.g., BER) that is periodically updated with dedicated monitoring information collection mechanisms. Once lightpaths are established, they are also monitored through the digital signal processing (DSP) module of coherent receivers. The management plane also follows a hierarchical approach. OAM Handler *Dom. A* is responsible for the single-domain lightpaths in A and multi-domain lightpaths involving A. Similarly, OAM Handler *Dom. B* is responsible for the single-domain lightpaths in B and multi-domain lightpaths involving B. The top-level OAM Handler is responsible for the whole network operation, administration, and maintenance: as an example, if OAM Handler *Dom. B* reveals a failure (either soft or hard) on multi-domain lightpaths but it is not able to localize the failure, the failure localization task can be solved by the top-level OAM Handler that correlates information coming from both OAM Handler *Dom. A* and OAM Handler *Dom. B*. NETCONF protocol including YANG model for flexible transponders[6] is exploited: between SDN-controllers and data plane for lightpath provisioning; between OAM Handlers and monitors for exchanging monitoring information.

The employed QoT tool is based on monitoring feedback and data analytics/correlation methods[7]. The estimation is performed on an Interference-aware (IA)-graph (as in Fig. 1b) so that physical layer monitoring information is correlated in space (paths) and spectrum (relative position of lightpaths in spectrum). The

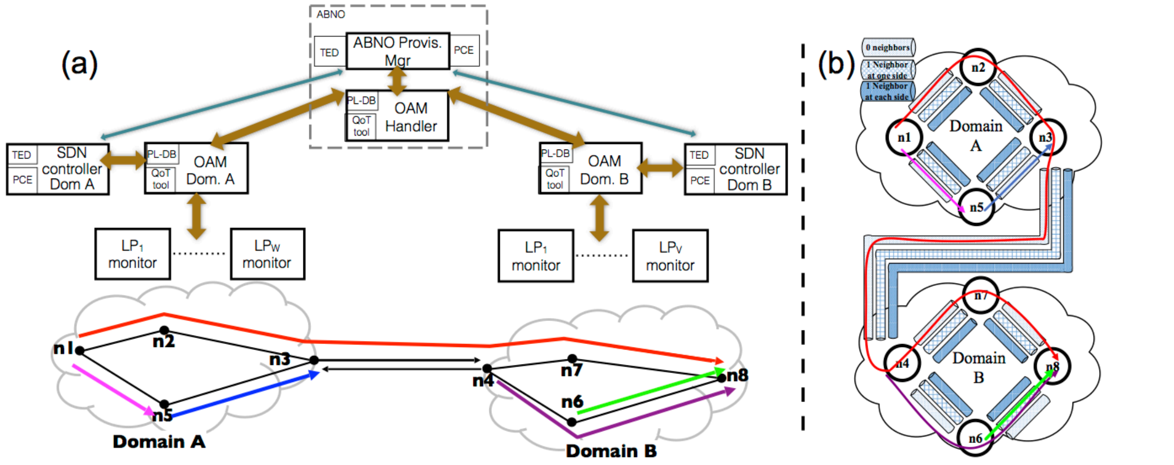

Fig. 1 (a) Integration of data plane, control (SDN controllers) and management (OAM Handlers and monitors) modules; (b) Interference aware (IA)-graph used by QoT estimation to correlate monitoring data in space and spectrum.

latter enables QoT estimations that account for interference effects. The tool improves its estimation accuracy the more lightpaths are established: first, interference is assumed in the worst-case scenario with the GN model[8], then it is corrected through the correlation (Network Kriging framework is adopted) of monitored lightpaths. Its high accuracy enables lightpath provisioning with low system (ageing and interference) and design margins[1].

Experimental demonstration

We present experiments to demonstrate: integration among all the modules, accurate QoT estimation and monitoring, lightpath provisioning and recovery upon soft-failure (i.e., BER degradation) in single- and multi-domains. Data plane of Fig. 1a is reproduced in the testbed of Fig. 2a. Up to three optical channels can be transmitted and detected: one through a commercial 100Gb/s (net rate) PM-QPSK card and the others through custom-built PM-16QAM at 200Gb/s (net rate) Tx/coherent-Rx. Fiber spans are G.652: one of 60km, the others of 80-km. At node n_7, channels are separated by means of a Finisar BV-WSS and then detected. SDN controllers are based on legacy Beryllium Opendaylight SR2 (v0.4.2), and are used for provisioning lightpaths in every domain translating requests from their northbound REST interface into NETCONF messages for transponders and data plane configurations[6]. The ABNO provisioning manager is an enhanced version of the open source netphony-abno tool[9], extended to integrate with OpenDaylight. The monitoring plane is implemented from scratch leveraging on netopeer libraries[10] as a combination of: a NETCONF client to interact with DSP monitors (e.g., Notifications); a NETCONF server to manage subscriptions to NETCONF Notifications (i.e., alarms) and to collect measurements from monitors; a correlation engine to elaborate failure alarms. Domain-scoped and root OAM Handlers embed specific functions to periodically collect, store and share (with QoT tools) measures from DSP monitors (BER and OSNR). Monitoring information of single-domain lightpaths is retrieved by the related domain OAM Handler, while information of multi-domain lightpaths is handled by the involved-domain OAM Handlers and the top-level OAM Handler. Finally, monitoring information is stored on the associated PL-DBs.

The following experiments will be shown: (1) BER at varying the impact of a soft-failure and the related QoT estimator training; (2) reliability upon soft-failure and after setup of new lightpaths accounting for interference; (3) segment restoration in a domain upon failure.

(1) Soft failures are emulated: the attenuation introduced by the VOA_1 (Variable Optical Attenuator) is varied to verify the robustness of the 100Gb/s commercial card (from n_1 to n_7) in the presence or not of the interfering 200Gb/s PM-16QAMs (added in n_2 up to n_7). Fig. 2b shows the BER of 100Gb/s vs. the output power at the first amplifier in the presence or not of PM-16QAMs. Indeed, VOA_1 variations cause a variation of the amplifier output power and, thus, of the OSNR. The less the power, the lower the OSNR, thus higher the BER. In case the PM-16QAMs are present (with a spacing among channels of 37.GHz as in Fig. 2c), the induced cross-phase modulation and cross-talk cause a BER increase on the 100Gb/s. Fig. 2e shows the learning process of the QoT tool. Monitoring at normal operation gives the required information and then the QoT tool can accurately estimate the effect of interference induced by PM-16QAMs at the different levels of soft failure (one value shown). Based on Fig. 2b the BER threshold (BER_{TH}) is set to 3×10^{-3}. When a monitor reveals a $BER>BER_{TH}$, a NETCONF Notification (alarm) is sent to the OAM Handler of the domain where the monitor is placed. If recovery (e.g., segment restoration)

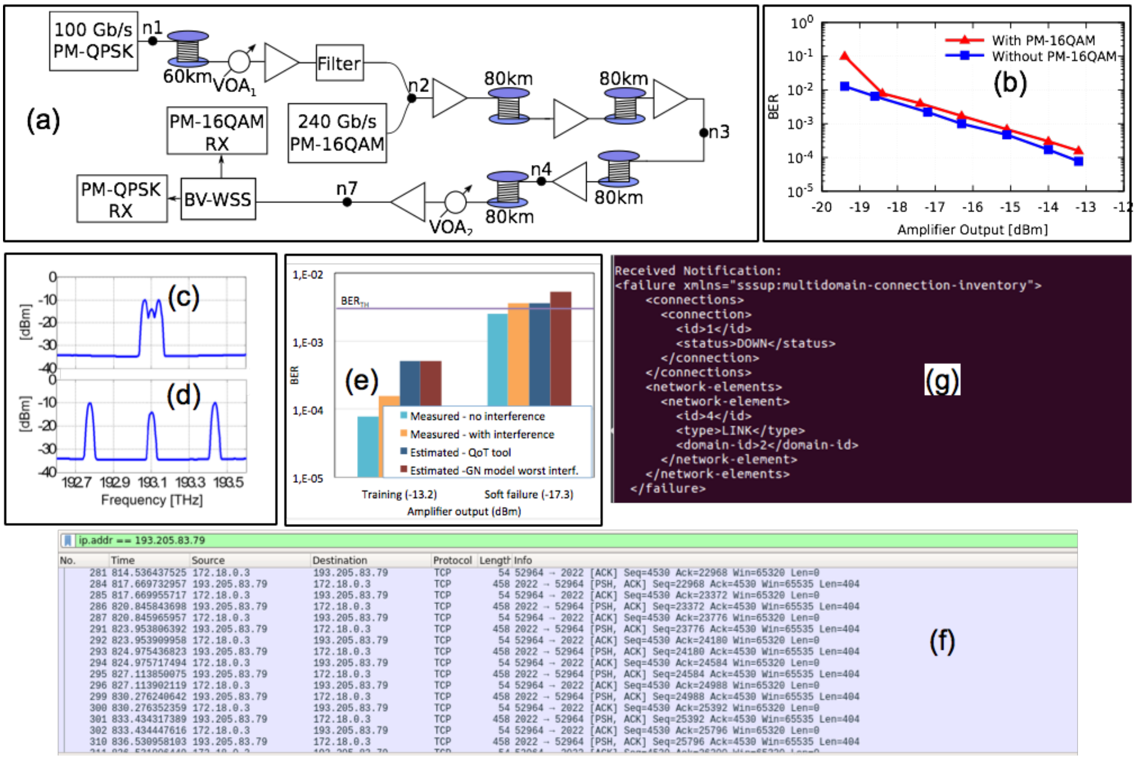

Fig. 2 (a) Data plane testbed; (b) BER at varying the relevance of soft failure; (c) and (d) channel spectra; (e) QoT tool training and estimation for soft failures; (f) packet capture; (g) NETCONF Notification.

can be taken involving only this domain, the top-level OAM Handler is only notified, otherwise the top-level OAM Handler takes the action. Fig. 2f shows the capture of NETCONF messages.

(2) Then, a network state including a 100Gb/s multi-domain lightpath between n_1 and n_7 has been tested. A soft-failure, induced with the VOA_1 on the 100Gb/s lightpath, is revealed by the management system through collection with NETCONF Get message. The resulting BER of 100Gb/s is 2.2×10^{-3}, below BER_{TH}. Then, two new multi-domain PM-16QAM requests arrive between n_2 and n_7. Considering Fig. 2b, such lightpaths cannot be placed in the spectrum close to the 100Gb/s because the interference would cause BER_{TH} exceed. Indeed, the QoT tool estimates a BER of 3.6×10^{-3} (measured in the testbed to have accuracy error 10^{-4}). Thus, guard bands between PM-16QAMs and 100Gb/s (300GHz as in Fig. 2d) are set and the 100Gb/s is successfully maintained despite the soft failure and the setup of new PM-16QAMs.

(3) Another soft failure is generated (with VOA_2 on n_4-n_7) showing a case where the OAM Handler of a domain reacts to the failure without involving the top-level OAM Handler. Two lightpaths are active: a multi-domain 100Gb/s between n_1 and n_7 and a single-domain PM-16QAM between n_4 and n_7. NETCONF Notifications (one related to the 100Gb/s with id 1 is shown in Fig. 2g) for both lightpaths are sent to the OAM Handler of *Dom. B* that, performing failure localization, identifies link n_4-n_7 as failed. The *Dom. B* SDN-controller triggers a segment restoration: link n_4-n_7 is bypassed with the new segment n_4-n_6-n_8-n_7. Thus, the OAM Handler of *Dom. A* is not involved.

Conclusions

We experimentally demonstrated an automatic network based on i) NETCONF, ii) SDN-controllers for setup, iii) management plane exploiting monitoring and QoT estimations. Provisioning and recovery are demonstrated in single- and multi-domains. First, the integration among all the modules is demonstrated. Then, soft failures are evaluated considering monitoring and interference. Reliability is guaranteed with: i) guard bands among interfering lightpaths; ii) segment restoration in a domain keeping unaware the other domain.

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