Experimental Validation of Transport SDN Restoration of Signal-Degraded Connections in Flexi-Grid Networks

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Abstract: We validate experimentally the integration of a PCE-based T-SDN controller with an OAM Handler to restore signal-degraded flexi-grid connections. A distributed monitoring system is adopted where a RSMA algorithm exploits benefits of elastic optical networks.
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1. Introduction

The increasingly demand of more dynamicity and flexibility of data traffic in metro/core networks is challenging operators and vendors to deploy cost-effective, spectrum-efficient and programmable data planes solutions [1]. Elastic optical networks cope with such requirements adopting a finer granularity of the optical grid (flexi-grid) to enhance optical spectrum utilization and using (sliceable) bandwidth-variable transponders (SBVTs) supporting multiple modulation formats. Thus, connections with heterogeneous bit rates are adaptively accommodated.

Data plane configuration is made by a centralized Transport SDN (T-SDN) controller. This dynamically computes the path and resources and configures the network elements (optical switches and SBVTs). We rely on an implemented T-SDN controller following the architecture of a PCE Connection Controller (PCECC) [2], where PCE protocol (PCEP) operates as the south-bound interface (SBI) for data plane configuration. T-SDN controller should provide additional and required management functions to ensure high reliability and correct service status (i.e., QoS, QoT, failure detection, etc.). These are addressed by the operation, administration and maintenance (OAM) Handler. Specifically, the OAM interacts with the data plane devices (e.g., monitoring system) to receive notifications about connection failures or degradations and triggers the required actions to preserve / recover the services. This requires tight collaboration and control communication between both OAM Handler and T-SDN controller.

Herein, a distributed monitored system is assumed where each network element is equipped with a high-resolution optical spectrum analyzer allowing in-band OSNR measurements. This measurement element is a commercial product called BOSA [3]. The goal is to provide OSNR measurements for each existing connection and report them to the OAM Handler. Next, the OAM can check whether a connection's OSNR level is acceptable. If not, the connection is declared as signal-degraded and the OAM triggers its restoration. This paper reports the implemented architecture and experimental validation of the integrated T-SDN controller and OAM Handler as well the performance obtained of a devised restoration RSMA algorithm.

2. Integrated T-SDN Controller and OAM Handler Architecture

Fig. 1. a. shows the integration of the T-SDN controller and the deployed OAM Handler. Upon receiving a connection request (endpoints and data rate in Gb/s), the T-SDN controller uses the topology and network resource information, updated via BGP-LS and stored in the TE Database (TED), to compute the spatial path (i.e., nodes and links) and select the SBVT sub-transponders, frequency slot and modulation format. The applied RSMA algorithm [4] to do that is an iterative distance-adaptive mechanism prioritizing the use of the most advance modulation formats as long as a feasible path (maximum permitted distance) is found. The computed path and resources are then allocated via a PCEP SBI [2]. Finally, all active connections are stored in the LSP Database (LSPDB).

The OAM Handler may or may not physically co-located with the T-SDN controller. Both elements interact via a PCEP interface providing: i) replication of LSPDB in the OAM Handler's LSPDB* to have connection details awareness; ii) degraded connection re-computation requests to T-SDN controller. The OAM Handler decision to restore a signal-degraded connection is triggered after processing the OSNR measurements sent by the distributed BOSA devices. As shown in Fig. 1.b., 5% of the optical signal on each node's outgoing link is processed by the BOSA attaining the aggregated in-band OSNR for each active flow. The measured OSNR is reported to the OAM Handler (e.g., REST interface) with the Node Id (IP address), Link Id and central frequency of the optical flow.

With the above BOSA notifications, the OAM Handler retrieves connection features from the LSPDB*. This allows OAM resolving whether the received OSNR is below the expected threshold for that flow. If this occurs, the connection is declared as signal-degraded and needs to be restored. The OSNR threshold for each optical flow depends on a set of connection attributes such as the bit rate, modulation format, path distance and number of hops.

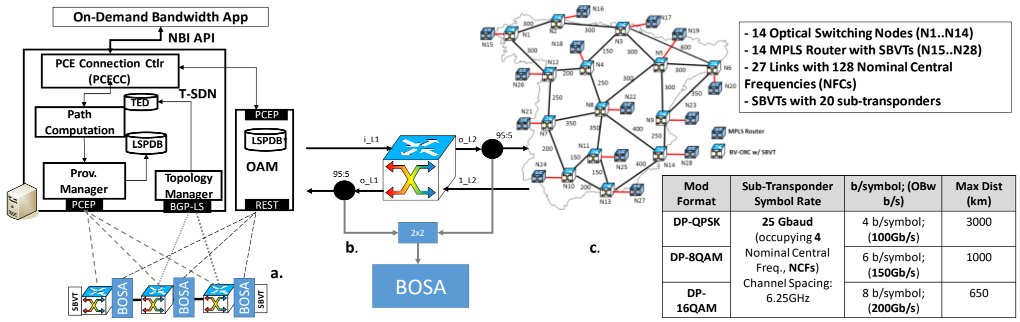

Fig. 1. a. Integrated Architecture T-SDN Controller – OAM Handler; b. Distributed Monitoring System; c. Topology and SBVT Capabilities

The PCEP interactions between the T-SDN controller and the OAM Handler are illustrated in a workflow (Fig.2.a.). This is divided into two parts. The first one (steps 1 – 6) regards to the setting up of a new flexi-grid connection. The T-SDN controller computes, instantiates and configures the connection using the procedures of the PCECC architecture (T-SDN Controller) [2]. The second part addresses the restoration of a signal-degraded connection (steps 7 – 13). As aforementioned, BOSA devices report to the OAM Handler a connection measured OSNR level. If the connection restoration needs to be triggered a break-before-make strategy is adopted. That is, the OAM Handler triggers the connection removal (via a PCEP PCInitiate message carrying the connection Id). Next, the T-SDN controller deallocates all the resources (aggregated in Step 8) and reports (using a PCRpt message) to the OAM Handler that such connection is to be removed from LSPDB* (step 9). After that, the OAM Handler requests a path computation (PCReq message) to the T-SDN controller for restoring the signal-degraded connection (Step 10). This message carries besides the endpoints and the requested bandwidth, information (into the so-called Record Route Object, RRO) about the route (i.e., spatial path, frequency slot and SBVT resources) of the degraded connection. Additionally, the eXclude Route Object (XRO) is also added into the PCReq message to indicate the used modulation format. Both RRO and XRO information are then used to constrain the restoration path computation. Specifically, they are used to find a feasible path which either uses the same spatial route but with a more robust modulation format or a completely disjointed (spatial) path. If a feasible route is found, this is sent back to the OAM Handler (Step 11) in the PCRep message with the new computed route and selected resources (formatted into the Explicit Route Object, ERO). The restored path is then instantiated by the OAM Handler sending a PCInitiate to the T-SDN controller with the new ERO (Step 12) which is set up as described in [2].

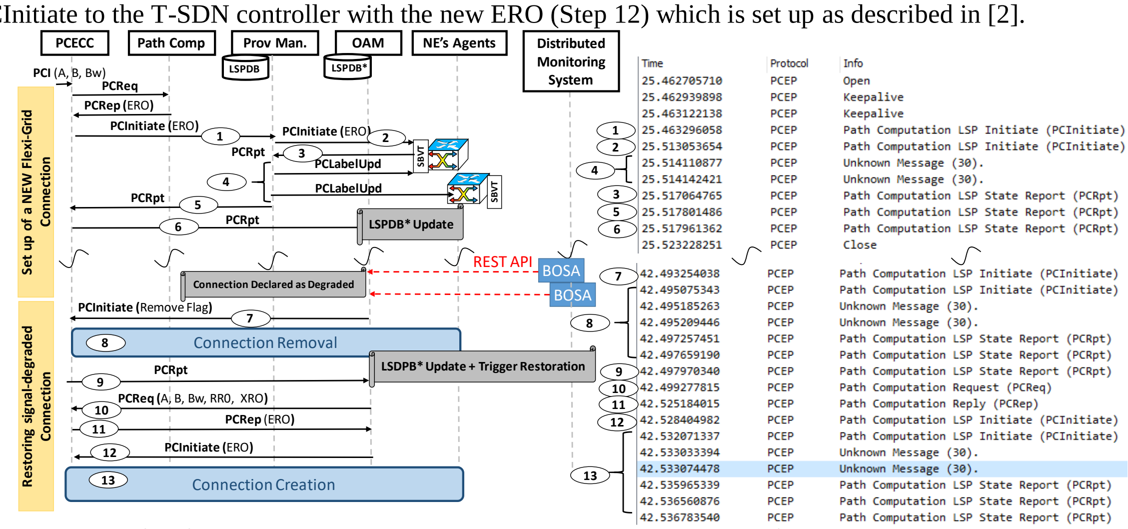

Fig. 2. a. Workflow for setting up and restore degraded connections; b. PCEP messages of T-SDN controller – OAM Handler interaction

3. Proposed On-Line Restoration RSMA Algorithm

The devised algorithm for restoring a degraded connection is implemented in a two-step approach. First, it tries to restore connections along the same spatial path (PCReq RRO) but selecting a more robust modulation format than the one carried into the XRO. This allows exploiting appealing elastic features of SBVTs and flexi-grid technologies where active connections can be dynamically re-configured over the same path but occupying different amount of resources (i.e., optical spectrum and SBVT' sub-transponders). This in turn fosters the adoption of hitless restoration techniques [5]. If this step fails, the algorithm computes a complete link-disjointed path. Thereby, all links and nodes contained into the PCReq's RRO are pruned from the topology graph where the RSMA algorithm [4] is triggered.

This algorithm computes feasible paths satisfying both continuity and contiguity constraints and favors using the most advanced modulation formats when it is feasible. This leads to attain a more efficient use of SBVT and link optical spectrum resources. If both steps fail, the restoration cannot be completed, and the connection is blocked.

4. Protocol Validation and Experimental assessment

The validation of the T-SDN controller and OAM Handler architecture is shown in Fig.2.b capturing the PCEP messages to both set up a new flexi-grid connection (entailing OAM's LSPDB* synchronization) and OAM triggering degraded connection restoration. Observe that the restoration exclusively conducted at the control plane level of a degraded connection (step 7-13) takes around 40 ms. This time would increase as traffic load grows.

Table 1 gathers the obtained performance evaluation. These are the provisioning blocking probability (BP), the restorability, the average setup delay and the average maximum use of transponders for all nodes. The 14 node transport network topology and link features are depicted in Fig. 1.c. All nodes have a SBVT with 20 sub-transponders, where each one supports 3 modulation formats: DP-QPSK, DP-8QAM and DP-16QAM. SBVT capabilities in terms of supported bit rate and maximum distance are detailed in Fig. 1.c. 1000 connection requests are generated according to a Poisson process with a mean inter-arrival time (IAT_p) of 15s and holding time (HT), exponentially modelled, is varied for different traffic loads. The requested bandwidth is uniformly distributed as multiples of 100 Gb/s up to 500 Gb/s. To stress the devised restoration algorithm, an existing LSPDB* connection is randomly selected to be degraded (according to a Poisson process whose IAT_r is also varied).

Table 1. Experimental numerical results

	Provisioning						Restoration					
#Requests	IAT_p (s)	HT (s)	RSMA	Blocked	BP	Av. Setup Delay (ms)	IAT_r (s)	RSMA	#Degraded Connections	# No Restored Degraded Paths	Restorability	Max Used Sub-Transponders
1000	15	150	[4]	0	0	83,6	250	2 Steps: RRO + XRO based on [4]	56	0	1	12,2
1000	15	300		8	0,008	80,9	200		79	0	1	13,8
1000	15	450		11	0,011	78,6	150		105	3	0,97	17,9

With respect to the (new connection) provisioning, when HT is increased, traffic load grows, and thus, BP performance is worsened. Indeed, when traffic is increased more amount of resources (i.e., SBVT and optical spectrum) are occupied at the time of computing a new path. This complicates the RSMA algorithm [4] finding a route satisfying the demand requirements and network constraints. The higher use of resources can be perfectly seen in the max used sub-transponder metric which significantly grows as HT increases. Conversely, the setup delay is reduced when traffic load grows. This is due to the fact that large paths (in terms of hops and links) are more difficult to be set up (due to lack of available resources to meet the constraints). Thus, shorter routes are more likely to be established which this does lower the amount of network element / devices to be configured by the T-SDN controller and as a consequence the average setup delay. With respect to the restorability, we increased the degradation occurrences (i.e., IAT_r is reduced from 250 to 150 s) in parallel with increasing the provision HT. Analogously to the provisioning performance, the restorability is notably impacted when resources become more occupied. In this regard, we observed that when more traffic load is offered, restoring degraded connections along the original spatial route of the connection (but using a more robust modulation format) becomes more troublesome. Thus the restoration algorithm needs to rely on more link-disjointed computation paths (2nd step in the devised restoration algorithm) which in turn leads to increase the restoration time.

5. Conclusions

The integration of a PCE-based T-SDN controller and an OAM Handler is experimentally validated to automatically restore signal-degraded flexi-grid connections. A distributed monitoring system using high-resolution commercial BOSA devices is assumed to measure in-band OSNR at each outgoing link traversed by active optical flows. These measurements are reported to OAM Handler to decide whether connection restoration is needed. Besides the PCEP protocol exchange validation between the T-SDN controller and the OAM, some numerical results are gathered to illustrate the provisioning and restoration of a devised RSMA algorithm which aims at exploiting the elasticity advantages such as re-adapting the modulation format of degraded flexi-grid connections.

6. Acknowledgments

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7. References

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