Leveraging Multilayer Telemetry to Realize AI-assisted Service Provisioning in IP over Elastic Optical Networks
(*Invited Paper*)

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Abstract: We discuss how to design automatic and effective network control and management (NC&M) for IP over elastic optical networks (IPoEONs). We first develop a flexible multilayer in-band network telemetry (ML-INT) system and then propose the artificial intelligence (AI) assisted NC&M framework to leverage the ML-INT data for application-aware service provisioning.

Keywords: Artificial intelligence (AI), Multilayer in-band network telemetry (ML-INT), Elastic optical networks (EONs).

1. Introduction

Nowadays, due to the raising of datacenters (DCs) and related emerging network services [1–3], both the traffic and infrastructure of optical core networks are experiencing dramatic and unforeseeable changes [4]. Hence, network operators would expect an agile network architecture that can establish dynamic lightpaths with just-enough bandwidth capacities in the optical layer to carry time-variant IP traffic flows, and moreover, they would need an automatic and effective network control and management (NC&M) scheme whose decisions would be intelligent and timely for grooming and routing IP flows over the lightpaths to not only achieve high bandwidth utilization but also guarantee high quality-of-service (QoS). The architectural demand could be potentially addressed by leveraging the advances on flexible-grid elastic optical networks (EONs) [5–7] and building IP-over-EONs (IPoEON) [8, 9] to seamlessly combine the advantages of IP and EON technologies. Nevertheless, the requirement of automatic and effective NC&M is still an open question to answer and needs continuous efforts from both the academia and industry. Although more programmable and adaptive NC&M schemes can be architected by leveraging software-defined networking (SDN) [10, 11], how to effectively orchestrate the resources in IP and EON layers and respond quickly to network status changes for satisfying stringent QoS requirements from applications, still needs further investigation. More specifically, there are two challenging problems to solve: 1) how to visualize a complex network system like an IPoEON in realtime for fine-grained performance monitoring and troubleshooting, and 2) how to utilize the monitoring results proactively for making timely and wise NC&M decisions to address the specific need of each application.

In this paper, we explain our attempts to solve the problems mentioned above. We first develop a flexible multilayer in-band network telemetry (ML-INT) system [12] to visualize an IPoEON in realtime, and then design an NC&M framework [13] that can utilize the telemetry data for realizing artificial intelligence (AI) assisted service provisioning [14]. Our ML-INT system leverages the idea of in-band network telemetry (INT) [15], and is designed over a programming protocol-independent packet processor (P4) based programmable data-plane (PDP) [16] to facilitate realtime, distributed, programmable and end-to-end flow monitoring in an IPoEON. Our NC&M framework tries to avoid flooding the network controller with tremendous telemetry data and enable each application to define its unique way of determining exceptions and requesting network adjustments. Specifically, the NC&M system utilizes the joint effort of both the network controller and the applications, *i.e.*, the applications leverage the ML-INT system to realize distributed but fine-grained monitoring and only flag alarms to the controller when exceptions happen, while the controller is equipped with an AI module to analyze the digested telemetry data (*i.e.*, the alarms) together with its own lightpath-level (λ-level) monitoring results for reaching timely and wise NC&M decisions. In the following, we will first elaborate on the design of the P4-based ML-INT system, then describe the architecture of the AI-assisted NC&M framework and related experimental results, and finally discuss the open questions in this research direction.

2. Flexible ML-INT System

Fig. 1(a) shows the overall architecture of our flexible ML-INT system. In the IP layer, we have P4-based PDP switches and application hosts. The PDP switches use the lightpaths established in the EON layer to transmit IP flows, and they are programmed with the packet processing pipelines to realize flexible ML-INT, as illustrated in Fig. 1(b). Then, if an IP flow between two hosts needs application-level (App-level) monitoring, the ingress and subsequent PDP switches on its routing path will collect the required telemetry data in realtime, but only select a portion of the flow's packets to insert the collected data as INT fields, for reducing the INT overhead [12]. Here, each INT field contains a statistic regarding an electrical or optical network element (NE) on the flow's routing path, *e.g.*, the packet processing latency in a PDP switch or the optical signal-to-noise-ratio (OSNR) of a lightpath. Our design of the ML-INT system ensures

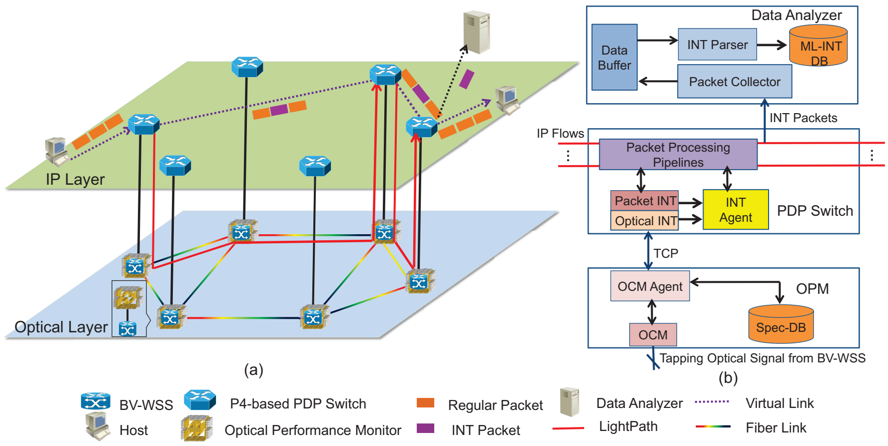

Fig. 1. System architecture of our flexible ML-INT system, ML-INT DB: multilayer INT database, Spec-DB: optical spectrum database (adapted from [12]).

that a complete and realtime view about all the NEs on the flow's path can be obtained after aggregating the INT fields in all the packets of a flow. The egress PDP switch removes all the INT fields in the packets to avoid affecting other features, while the extracted INT fields are sent to the data analyzer for data aggregation, analysis and storage.

In the EON layer, we implement an optical performance monitor (OPM) on each bandwidth-variable wavelength selective switch (BV-WSS) to collect statistics of the lightpaths passing through it, *e.g.*, OSNR, input power and central wavelength. The PDP switch that directly connects to a BV-WSS can poll its OPM in realtime and request for lightpath statistics. In the IP layer, each PDP switch can collect a flow's statistics, *e.g.*, its input/output ports and packet processing latency, in realtime too. Fig. 1(b) explains the detailed architectures inside the data analyzer, PDP switch, and OPM, and the interactions among them. Here, we develop the OPM based on a flex-grid high resolution optical channel monitor (OCM) to achieve high resolution optical spectrum analysis. Each PDP switch is programmed with the P4 language [16], *i.e.*, we define the packet processing pipelines for ML-INT in its forwarding hardware. The data analyzer is homemade and runs on a Linux server, and it can be utilized by an application to realize App-level monitoring. We optimize its design and implementation to guarantee high-throughput packet processing (*i.e.*, up to 2 million INT packets per second). For different applications, their data analyzers operate distributedly, and visualize the IPoEON in realtime to see how the packets of each flow are handled end-to-end.

3. AI-assisted NC&M Framework

The AI-assisted NC&M framework is illustrated in Fig. 2, where the data plane is an IPoEON and the control plane includes a centralized network controller and a few distributed App-level monitors [13]. As each application might have its own concerned telemetry data and QoS requirements, its App-level monitor leverages a data analyzer in the flexible ML-INT system to collect and analyze the concerned telemetry data for preliminary performance monitoring and troubleshooting. The App-level monitor will flag alarms to the controller when there are exceptions, and provide suggestions on how to address the issue based on its preliminary troubleshooting. Meanwhile, the controller also performs ML-INT on each lightpath to gather λ-level monitoring results such as packet loss rate, OSNR, *etc*, and combines them

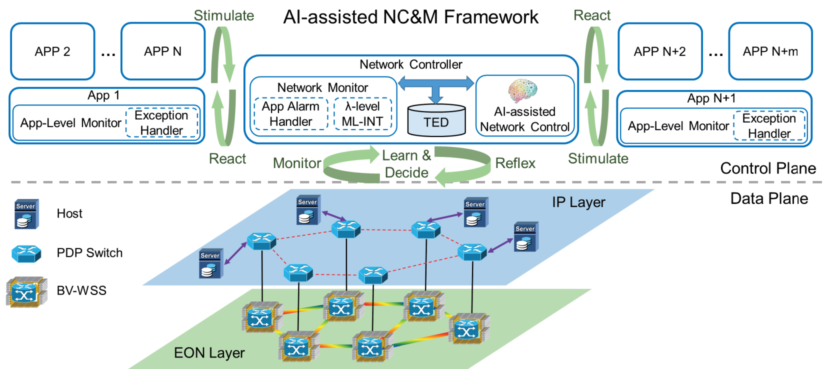

Fig. 2. Our AI-assisted NC&M framework, APP: application, TED: traffic engineering database (adapted from [13]).

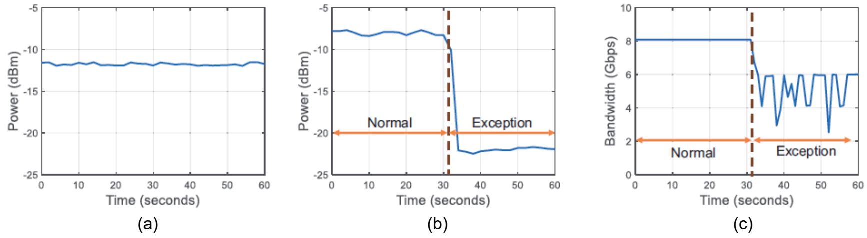

Fig. 3. Experimental results for ML-INT, (a) INT data on power of the flow's first lightpath, (b) INT data on power of the flow's second lightpath, and (c) INT data on the flow's end-to-end bandwidth.

with the alarms from the App-level monitors as the input to its AI-assisted network control module. The AI module has been trained to learn the correlation among applications' multilayer provisioning schemes, their App-level monitoring alarms, λ-level monitoring results, and hard/soft failure scenarios to identify the correct recovery schemes quickly. Here, we use the traffic engineering database (TED) in the controller to store the multilayer provisioning schemes of the applications' flows. Then, the controller invokes necessary network adjustments (*i.e.*, AI-assisted reflexes) to implement the selected recovery scheme and restore the service of the affected application accordingly.

Next, we conduct a simple experiment to demonstrate the effectiveness of our proposal. Here, we assume that the IP flow of an application gets routed over two lightpaths in the IPoEON. Then, the experiment ensures that all the IP layer NEs over the flow's routing path stay intact, but emulates a sudden optical power drop on the second lightpath in its path. Fig. 3 shows the ML-INT results collected by the flow's App-level monitor. The results regarding the optical power of the two lightpaths, in Figs. 3(a) and 3(b), respectively, clearly indicate that the exception is caused by the sudden power drop on the second lightpath. Meanwhile, the power drop coincides with the end-to-end bandwidth drop in Fig. 3(c) in the time domain, which will let the App-level monitor identify the root cause of the exception and provide right suggestion to the controller. Next, after the receiving the alarm from the App-level monitor, the controller uses its AI-assisted network control module to select the best recovery scheme to address the power issue on the second lightpath, and implements the scheme immediately for timely service restoration.

4. Discussion and Future Work

We explained our efforts on developing automatic and effective NC&M for IPoEONs. A flexible ML-INT system was first designed to visualize an IPoEON in realtime, and then we discussed the AI-assisted NC&M framework that could utilize the ML-INT data for realizing application-aware service provisioning.

Note that, in the AI-assisted NC&M framework, the AI-assisted network control module still needs further exploration. More specifically, it should be trained with much more data collected in practical IPoEON environments to make sure that correct NC&M decisions can be made for larger-scale and more complex IPoEONs.

Acknowledgments

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References

[1] P. Lu *et al.*, "Highly-efficient data migration and backup for Big Data applications in elastic optical inter-datacenter networks," *IEEE Netw.*, vol. 29, pp. 36-42, Sept./Oct. 2015.

[2] J. Yao *et al.*, "On fast and coordinated data backup in geo-distributed optical inter-datacenter networks," *J. Lightw. Technol.*, vol. 33, pp. 3005-3015, Jul. 2015.

[3] L. Gong *et al.*, "Virtual optical network embedding (VONE) over elastic optical networks," *J. Lightw. Technol.*, vol. 32, pp. 450-460, Feb. 2014.

[4] "Cisco Visual Networking Index: Forecast and Methodology, 2017-2022," Cisco [Online]. Available: https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-741490.html

[5] O. Gerstel *et al.*, "Elastic optical networking: A new dawn for the optical layer?" *IEEE Commu. Mag.*, vol. 50, pp. s12-s20, Feb. 2012.

[6] Z. Zhu *et al.*, "Dynamic service provisioning in elastic optical networks with hybrid single-/multi-path routing," *J. Lightw. Technol.*, vol. 31, pp. 15-22, Jan. 2013.

[7] L. Gong *et al.*, "Efficient resource allocation for all-optical multicasting over spectrum-sliced elastic optical networks," *J. Opt. Commun. Netw.*, vol. 5, pp. 836-847, Aug. 2013.

[8] W. Lu *et al.*, "On cost-efficient integrated multilayer protection planning in IP-over-EONs," *J. Lightw. Technol.*, vol. 35, pp. 5335-5346, Dec. 2017.

[9] S. Liu *et al.*, "On the cross-layer orchestration to address IP router outages with cost-efficient multilayer restoration in IP-over-EONs," *J. Opt. Commun. Netw.*, vol. 10, pp. A122CA132, Jan. 2018.

[10] N. McKeown *et al.*, "OpenFlow: Enabling innovation in campus networks," *ACM SIGCOMM Comput. Commun. Rev.*, vol. 38, pp. 69-74, Feb. 2008.

[11] S. Li *et al.*, "Protocol oblivious forwarding (POF): Software-defined networking with enhanced programmability," *IEEE Netw.*, vol. 31, pp. 12-20, Mar./Apr. 2017.

[12] B. Niu *et al.*, "Visualize your IP-over-Optical network in realtime: a P4-based flexible multilayer in-band network telemetry (ML-INT) system," *J. Lightw. Technol., submitted*, pp. 1-9, Jan. 2019.

[13] H. Fang *et al.*, "Building network nervous system with multilayer telemetry to realize AI-assisted reflexes in software-defined IP-over-EONs for application-aware service provisioning," *in Proc. of OFC 2019*, paper M2A.5, Mar. 2019.

[14] B. Li *et al.*, "Deep-learning-assisted network orchestration for on-demand and cost-effective vNF service chaining in inter-DC elastic optical networks," *J. Opt. Commun. Netw.*, vol. 10, pp. D29-D41, Oct. 2018.

[15] C. Kim *et al.* In-band network telemetry (INT). [Online]. Available: https://p4.org/assets/INT-current-spec.pdf

[16] P. Bosshart *et al.*, "P4: Programming protocol-independent packet processors," *ACM SIGCOMM Comput. Commun. Rev.*, vol. 44, pp. 87-95, Jul. 2014.