Role of monitoring and analytics in next generation optical networks (Invited)

Ll. Gifre(1,2, *), F. Boitier(1)

(1) Nokia Bell Labs, France, lluis.gifre_renom@nokia-bell-labs.com, fabien.boitier@nokia-bell-labs.com

(2) Centre Tecnològic de Telecomunicacions de Catalunya (CTTC/CERCA), Spain, lluis.gifre@cttc.es

(*) Nokia Bell Labs affiliation applicable until 22/June/2021; CTTC affiliation applicable since 1/July/2021.

Abstract *We study the requirements that Control, Orchestration, and Management (COM) systems for optical networks should fulfil, present a minimal set of components they should implement, and propose our research point of view regarding the future needs for COM systems for optical networks.*

Introduction

Network monitoring has always been very popular for higher layer networks, such as the packet networks. The operators got basic insight of their networks by monitoring their state. The data retrieved was, essentially, time-varying counters, like the absolute and delta values of packets and bytes transmitted, received, lost, and dropped. Historically, network supervision was based on comparing the counter values against some configured thresholds that raised alarms with different levels of severity when thresholds were crossed; for instance, an excess in packets dropped on a switch port. These alarms and the counters were conveyed to centralized systems for their visualization and manual analysis.

Optical networks are the *de-facto* technology for back/metro haul networks given their higher bandwidth capacity at a reasonable Total Cost of Ownership (TCO). Former optical networks were static and had relatively few changes upon deployed. However, new generation services and applications demand higher capacity, flexibility, and dynamicity, and ensure them by means of stringent Service Level Agreements (SLA).

Nowadays, deeply monitoring the optical network gained notorious interest to enable the dynamic operation of the networks. For instance, enabling the dynamic tuning of the configurations might reduce network operational margins incurring in a reduction in CAPEX [1]. By predicting degradations in the service, the network can reduce the impact on end users and accelerate the localization of failures and their repair [2],[3]. The complexity of monitoring optical networks increased with the emergence of Flexgrid that brings an unprecedented flexibility in sizing and placing the optical channels over the spectrum. Combined with the increasing size of the networks, the heterogeneity of equipment, and the large number of connections conveyed, it results in huge amounts of data to be treated.

In this paper, we first introduce a monitoring context for the paper, then we present the essential components a Control, Orchestration, and Management (COM) system should have to illustrate how monitored data can be exploited. Finally, we present our research view on how COM systems should deal with automation on future optical networks.

Monitoring of Optical Networks

Fig. 1 illustrates a simple optical network with two packet switches (top), two transponders (middle), and 4 Reconfigurable Optical Add/Drop Multiplexers (ROADM) (bottom). To bring a context, below we enumerate the minimal data typically monitored in optical networks. However, manufacturers of optical equipment might decide to provide deeper insight on their equipment and on the light properties passing through.

For transponders, collected data includes, the launch power at the transmitter side and, at the receiver side, the received power, pre/post-Forward Error Correction (FEC) Bit Error Ratio (BER), and other impairments evaluated by the Digital Signal Processing (DSP) in coherent transponders, e.g., the chromatic dispersion or the polarisation mode dispersion.

For ROADMs, it is common to monitor: *i*) the Pre-Amplifier and Booster optical amplifiers' input and output power, the measured gain and tilt; *ii*) the relative per-channel attenuations applied by the Wavelength Selective Switches (WSS) to equalize the power of the channels; *iii*) the attenuation applied by the Variable Optical Attenuation (VOA) at the output of the Booster; and *iv*) the per-channel power monitored by the

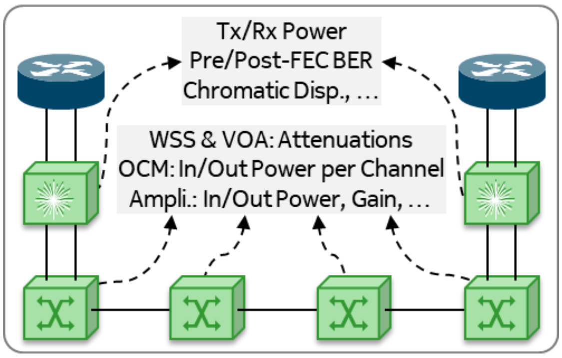

Fig. 1: Typical parameters monitored in optical networks

Optical Channel Monitor (OCM) at the output of the Booster to feed the equalization algorithm.

The volume of data from the transponders grows with the number of lightpaths established, while the data collected from the ROADMs increase with both the number of lightpaths and traversed ROADMs along their paths. Capturing the whole optical spectrum at different network locations using Optical Spectrum Analysers (OSA) along the network, or high-resolution OCMs within the ROADM devices, might be very useful to monitor and troubleshoot the network. However, since these devices are expensive and generate larger amounts of data, they are not very common in operator networks.

Components of a COM System

Collecting monitoring data from the optical networks can provide insight on the state of the network for troubleshooting and optimization tasks. However, without appropriate treatment of the data, it might turn infeasible to exploit it. Even more, with the increase in dynamicity and variety of services demanded, the COM system has to continuously monitor the network, extract knowledge from data, make decisions, and implement appropriate changes promptly. An extensive explanation on COM architectures and protocols can be found in [4]. However, in Fig. 2, and for illustrative purposes, we present a generic set of components that should easily be adapted and extended to any applicable use case. The components are described below:

i) The system operates around a **Timeseries Database (DB)** repository where the operational data lives, including monitoring data described in previous section. Common choices to implement the repository include Prometheus, InfluxDB, Cassandra, TimescaleDB, and Elasticsearch. Given the variety and volume of data to be stored, it is convenient to choose a repository able to cope with the Big Data paradigm and scale horizontally. Besides, the repository might be combined with a Message Broker to distribute collected data between the rest of components. In that regard, typical choices might include Kafka [5], RabbitMQ or ZeroMQ-based sockets.

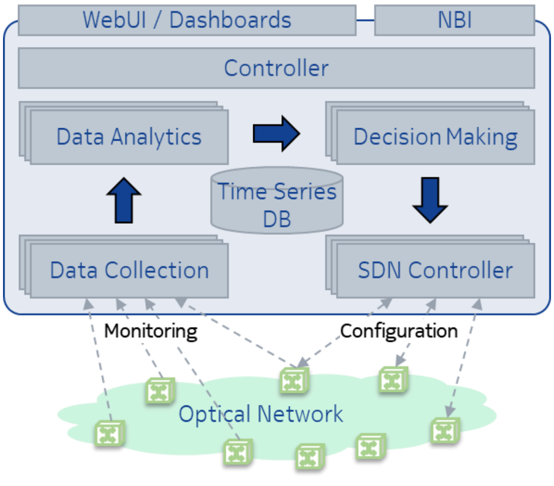

Fig. 2: Components of a COM system for optical networks

ii) The **Data Collection** component is in charge of running appropriate monitoring and telemetry streaming protocol speakers to ingest data from the different devices composing the network, transcoding the data into the data model used by the repository and storing it. Some common protocols used for monitoring nowadays include gRPC-based protocols —like gNMI [7]—, Netconf streams, IPFIX and Apache Thift.

iii) The **Data Analytics** component identifies new data stored in the repository and uses automated inference techniques, usually based on Machine Learning (ML) models to extract knowledge from data. These ML models, in general, are used to categorize and/or to predict trends in data. Knowledge extracted is then used to identify, in a proactive and/or reactive manner, anomalies on the network.

iv) The **Decision Making** component exploits knowledge extracted by the Data Analytics component and decides the actions to be taken; among others, these actions might include: *a*) reconfiguration of a set of network resources, like rerouting a lightpath; *b*) self-tuning the monitoring parameters to gain deeper insight on the network, like temporarily increasing the sampling rate of an equipment to collect finer-resolution data and improve localization of an anomaly [8], or activating an OSA/OCM in a ROADM to inspect the optical spectrum in a link [9]; and c) re-training some ML models used by the Data Analytics module when a network resource changes, like in the creation of a new lightpath in the network.

v) The **Software Defined Network (SDN) Controller** interacts with the network equipment and configures the rules resulting from the translation of the actions specified by the Decision Making component. Common choices in the research field are Open Networking Operating System (ONOS) and OpenDayLight.

vi) The **WebUI (and Dashboards)** provides a graphical Web-based user interface where the operator can manage its network. Usually, the WebUI will contain a set of Dashboards to filter and plot the collected data and gain visual insight on the state of the network. The WebUI and Dashboard should be integrated to enable fast access from the plotted data to the configuration panels for the component that produced the data.

vii) The **NorthBound Interface (NBI)** enables external systems to interact with the COM system. A common trend is to expose a REST Application Programming Interface (API), and/or some YANG-based data models over Netconf/ RESTConf or Transport API (TAPI) [6].

ix) The **Controller** manages and orchestrates the rest of components. Usually, it deals with: *a*) the routing of the commands from the network operator or external systems to the appropriate component, e.g., forwarding a lightpath creation request to the SDN controller; and *b*) the orchestration of workflows when the actions involve multiple components.

Note that many protocols can be used to integrate COM systems with other external systems [6]. In general, it will be convenient to define the components as subsystems that could be extended to reduce the overall complexity of the COM system. For instance, the Data Collector might implement a set of speakers following a common API. Then, a new speaker can be integrated by implementing such API. Similarly, the SDN Controller should implement a driver API to easily extend its capacity to control new devices. The NBI is another case where an API might reduce the complexity of the system.

Challenges and future of COM systems

Last years, many new generation services and applications demanding high-quality and resilient network connectivity. To fulfil the demand at a reasonable TCO, COM systems should monitor the state of the optical network, identify undesired and/or non-optimal conditions, and provide automatic mechanisms to resolve them. The architecture presented in the previous section has been kept intentionally simple for illustrative purposes. However, a real COM system should cope with high volumes of heterogeneous data coming from diverse sources, e.g., a connection establishment might alter the metrics in many ROADMs at the optical layer, and the computed traffic models at the packet layer [15].

To overcome these challenges, COM systems are usually designed as cloud-based applications even following Big Data-based strategies to benefit from horizontal scalability. Even more, thanks to novel Edge-cloud computing solutions, hierarchical architectures, such as that proposed in [16], can be considered. These architectures implement some agents that can be deployed at network central offices where the optical equipment is. These agents become responsible for central office—wide monitoring and decision making. Many experiments have been done in that regard; here we cite some notable ones.

In [9], the authors deal with hierarchical monitoring of disaggregated optical networks. Then, a disaggregated optical network is monitored in [11] to identify soft-/hard-failures by means of data analytics, and apply automatic mechanisms to prevent interruptions in optical connections. The COM of optical whitebox-based networks is tackled in [12], and autonomic network slicing is treated in [13].

Moreover, network automation can also be implemented at the device level. Many research work has been done in that field; for instance, to reconfigure transponders in a hitless manner. To cite some of them, the authors in [14] propose an ultra-fast hitless bandwidth variable transmitter operating at 100 Gbit/s able to switch transmitter parameters with no packet loss. Even more, authors in [17] implemented methods in a Field Programmable Gate Array (FPGA) to provide fast monitoring, data analysis and reconfiguration capabilities when the quality of the line degrades.

Data analysis and decision-making blocks are usually implemented by means of ML-based models. Given the computational complexity of (re)training ML models, a good decision might be to keep the models as simple as possible, or even enable the system to choose simple enough models based on automatically evaluated fitting scores. However, automatic selection of models might be prohibitive in terms of computation complexity. For this reason, ML-based COM systems should exploit hardware acceleration, e.g. using TensorFlow Processing Units (TPUs), Graphical Processing Units (GPUs), and/or FPGAs, to (re)train models and make fast-enough inference over the data collected.

Finally, the Decision Making processes should interact with the network operators to gather knowledge. Upon the system identifies a network issue, it might try to use its previous knowledge to find possible solutions and automatically validate them in a simulated network environment to validate it does not violate any configured policy and SLA. Then, the system should ask the network operators to validate the solution. If the solution is rejected by the network operator, the COM system should learn that condition and extract a set of new policies and rules to be considered in future simulations. As a result, the COM system might perform some form of reinforcement learning from network operators.

Conclusions

We presented some relevant COM solutions for optical networks, studied the requirements these systems should fulfil and presented our research view on how COM systems should be designed to cope with the future optical networks.

Acknowledgements

Work partially supported by the EC H2020 TeraFlow (101015857) and Spanish AURORAS (RTI2018-099178-I00) projects.

References

[1] S. Oda, *et al*., "A Learning Living Network With Open ROADMs," in J. Lightwave Technology, vol. 35, no. 8, pp. 1350-1356, 15 April15, 2017. DOI: 10.1109/JLT.2017.2660540.

[2] S. Shahkarami, *et al*., "Machine-Learning-Based Soft-Failure Detection and Identification in Optical Networks," in Proc. Optical Fiber Communications Conference (OFC), 2018.

[3] A. P. Vela, *et al*., "BER Degradation Detection and Failure Identification in Elastic Optical Networks," in J. Lightwave Technology (JLT), vol. 35, pp. 4595-4604, 2017.

[4] R. Casellas, *et al*., "Control, Management, and Orchestration of Optical Networks: Evolution, Trends, and Challenges," in J. Lightwave Technology, vol. 36, no. 7, pp. 1390-1402, 1 April1, 2018, DOI: 10.1109/JLT.2018.2793464.

[5] A. Sgambelluri, *et al*., "Reliable and scalable Kafka-based framework for optical network telemetry," in J. Optical Communications and Networking, Vol. 13, E42-E52, 2021. DOI: 10.1364/JOCN.424639

[6] R. Vilalta, *et al*., "Experimental evaluation of control and monitoring protocols for optical SDN networks and equipment [Invited Tutorial]," in J. Optical Communications and Networking. Vol. 13, D1-D12, 2021. DOI: 10.1364/JOCN.424631

[7] R. Vilalta, *et al*., "Telemetry-enabled Cloud-native Transport SDN Controller for Real-time Monitoring of Optical Transponders Using gNMI," in Proc. European Conference on Optical Communication (ECOC), 2020.

[8] M. Dallaglio *et al*., "Demonstration of a SDN-based spectrum monitoring of elastic optical networks," in Proc. Optical Fiber Communications Conference (OFC), 2017.

[9] Ll. Gifre, *et al*., "Autonomic Disaggregated Multilayer Networking," in J. Optical Communications and Networking (JOCN), vol. 10, pp. 482-492, 2018.

[10] D. Rafique and L. Velasco, "Machine Learning for Optical Network Automation: Overview, Architecture and Applications," (Invited Tutorial) in J. Optical Communications and Networking (JOCN), vol. 10, pp. D126-D143, 2018.

[11] Ll. Gifre, *et al*., "Demonstration of Monitoring and Data Analytics-triggered reconfiguration in partially disaggregated optical networks," in Proc. Optical Fiber Communications Conference (OFC), 2020.

[12] L. Velasco, *et al*., "Building Autonomic Optical Whitebox-based Networks," in J. Lightwave Technology (JLT), vol. 36, pp. 3097-3104, 2018.

[13] L. Velasco, *et al*., "An Architecture to Support Autonomic Slice Networking [Invited]," in J. Lightwave Technology (JLT), vol. 36, pp. 135-141, 2018.

[14] A. Dupas, *et al*., "Ultra-fast Hitless 100Gbit/s Real-Time Bandwidth Variable Transmitter with SDN optical control," in Proc. Optical Fiber Communications Conference (OFC), 2018.

[15] F. Morales, *et al*. "Dynamic Core VNT Adaptability based on Predictive Metro-Flow Traffic Models," in J. Optical Communications and Networking (JOCN), vol. 9, pp. 1202-1211, 2017.

[16] L. Velasco, *et al*., "Monitoring and Data Analytics for Optical Networking: Benefits, Architectures, and Use Cases," in IEEE Network Magazine, vol. 33, pp. 100-108, 2019.

[17] A. Gouin, *et al*., "Dynamic auto-negotiation with real-time transponders in software defined optical networks," in Proc. Optical Fiber Communications Conference (OFC), 2021.