Versatile Optical Path Calculation and Monitoring Using Common YANG Model

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Abstract—**The recent evolution in technologies such as software-defined networking (SDN) and network function virtualization (NFV) allows telecom operators to transform network management and operation driving the automation of each management process such as configuration and monitoring. In the 5th generation (5G) era, end-to-end (E2E) life cycle automation is expected to enhance flexibility, robustness and optimization of networks and services. E2E automation involves the management of multiple networking domains including optical networks where disaggregation is in progress. In this paper, we describe how we designed and implemented a novel optical path calculation and monitoring system for the management of optical networks toward E2E automation. Our proposed system consists of an SDN controller to calculate and provision optical paths and a telemetry analysis framework to monitor and analyze the paths, both of which are able to manage multi-vendor equipment using the common Yet Another Next Generation (YANG) data model. Furthermore, the common model enables setting up monitoring parameters automatically in deploying the paths. We demonstrated the provisioning and monitoring of the new wavelength path set in a heterogeneous environment including auto-configuration of monitoring, which showed that the proposed architecture provides the assurance functionality that predicts and monitors the optical transmission quality to guarantee the interoperability of the disaggregated elements.**

Keywords—SDN, telemetry, YANG, disaggregation.

I. INTRODUCTION

A major concern of network operators toward the 5th generation (5G) era is how to accelerate time-to-market of services and how to enable cost savings. With the recent advances in software-defined and virtualization features, which are called software-defined networking (SDN) and network function virtualization (NFV), telecom operators have a strong expectation that there will be a dramatic transformation in network management and operation using a new management functionality such as automation by an orchestrator. This function will enable to coordinate resources and networks according to the quality and service level agreement (SLA), and automate lifecycle management of networks and services.

Moreover, end-to-end (E2E) lifecycle automation is playing a significant role to rapidly offer a wide variety of network services including network slicing toward the 5G/internet of things (IoT) era. E2E automation needs to support not only the lifecycle of network functions, but also network configuration and monitoring for several networking domains such as IP core, mobile core and optical networks. In order to realize an automated network management process, many operators favor leveraging an SDN controller in IP and mobile network domains, which can detect network conditions, calculate optimal paths and configure them.

On the other hand, one of the recent trends in optical networks is disaggregating the optical network elements that decouples the components (e.g., transponder) of an integrated system from each other. The benefits from this include the capability of providing agility, flexibility to meet service requirements and reducing costs compared to legacy all-in-one architecture. Following other domains such as IP networks, an SDN controller is expected to achieve the automation of the management process in disaggregated optical networks in place of the conventional element management system (EMS) that is able to manage proprietary networks only. Progress has already been achieved in developing SDN control functionalities for optical networks [1]. However, challenges still remain in how to apply the SDN controller to the management of disaggregated networks and also have fault and performance management functionalities. The disaggregation allows operators to accommodate optical devices provided by different vendors, thus the controller is required to have two capabilities; one is managing multi-vendor networks whereas EMS only guarantees fine tuning of the quality of single-vendor networks, and the second one is achievement of simple operation without a complicated setup in terms of planning, configuration and monitoring processes toward full lifecycle automation.

In this paper, we propose a versatile optical path calculation and monitoring system with a model-based auto-configuration mechanism composed of an SDN controller and telemetry-based monitoring to address this challenge. Our proposed system is equipped with a common database using the common Yet Another Next Generation (YANG) data model to manage the optical devices from multiple vendors in an unified format. Then, we developed path calculation and monitoring functionalities that leverage the data stored in this database to maintain the quality of the optical path. The common YANG model contains several optical parameters such as amplifier gain and modulation-format, hence our implemented system is able not only to control and configure devices but also to calculate and monitor the transmission performance of the optical path. In provisioning a new wavelength path, the path quality calculation predicts the optical quality to plan the optimal route taking optical transmission information into consideration. Then, the path quality monitoring function monitors the deployed path using the predicted quality as a threshold. Here, to initiate path monitoring in multi-vendor networks, it is necessary to configure various parameters such as target interface and monitoring item in a different way with the result that a huge workload is imposed on operators. Our path calculation and monitoring functions

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work in cooperation employing the common model to set up parameters without human intervention to reduce the workload and also to start monitoring in real time after provisioning.

This paper is structured as follows. Section 2 describes the background of our proposal including SDN and YANG. In Section 3, we present the architecture of our proposed system consisting of optical path calculation and monitoring to assure the quality of the optical path deployed on heterogeneous networks. Section 4 describes a demonstration of provisioning and monitoring of a new wavelength path including auto-configuration of monitoring. Finally, a brief conclusion is provided in Section 5.

II. BACKGROUND AND RELATED WORK

A. *E2E Management*

E2E lifecycle management is required to plan and deploy a network service rapidly, and operate and optimize the service dynamically and flexibly aligned with SLA interworking with the orchestrator and controller of related domains [2], [3]. Fig. 1 illustrates the architecture of E2E multi-domain management in a telecom network, where the E2E orchestrator manages and operates an E2E service such as IoT via the north-bound application programming interface (API) for the management of each domain such as access, optical, transport and core management. Here, a domain controller or orchestrator in a radio access network (RAN), IP and mobile core have been developed to operate and optimize each domain network, some of which have already been introduced into the commercial networks of telecom operators; however, the capabilities of that in the optical domain are still being developed. Therefore, our focus is to implement optical path management toward E2E automation.

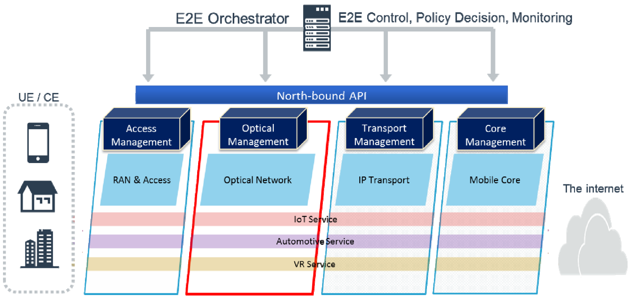


Fig. 1: E2E Management in Telecom Network

B. *SDN Controller*

An SDN controller is a key component of management in the optical domain. SDN has been developed on the basis of decoupling the control plane from the data plane to enable programmable and unified management of the network. For the controller in optical networks, V. López et al. [4] and O. F. Yilmaz et al. [5] presented the orchestration and control of multi-vendor optical networks exploiting SDN technology, but their integrated system mainly focused on provisioning and is lacking in terms of assurance functionality that is essential for the management of disaggregated networks.

Several SDN controllers have been designed and implemented in the last decade. The open network operating system (ONOS) [6] is one of the open source SDN controllers developed to control a carrier-grade network. It consists of a distributed core, northbound interface, southbound interface and application. Users are able to introduce additional functionalities necessary for their operation as a new application combining northbound interfaces exposing the management of the distributed core. In addition, the distributed core provides scalability for telecom networks. We implemented the path calculation component based on ONOS because it provides a couple of applications that support optical devices. We extended them to manage and assure the quality of the disaggregated optical networks.

C. *YANG Data Model*

YANG is an extensible data modeling language used to model the configuration and operational data of network devices. Numerous YANG data models are provided by standardization organizations, vendors and other communities. The network configuration protocol (NETCONF) is a protocol for control and management used with the YANG model to exchange data. Jung-Yeol Oh et al. presented the architecture to accommodate multi-vendor passive optical network (PON) using NETCONF/YANG [7], but its capability is limited to configuration, and does not include monitoring.

The Open reconfigurable optical add/drop multiplexer (ROADM) multi-source agreement (MSA), organizations specifying ROADM features for interoperability to drive the disaggregation of the optical networks, has defined the Open ROADM YANG model [8]. This model contains various optical parameters such as amplifier gain and span length. There is another data model named OpenConfig [9] specified by a working group of operators. This model has been developed mainly for IP devices, and currently is being extended to the optical layer. We adopted the Open ROADM model as the common optical data model in our implementation since it focuses on the optical area toward the open interfaces of disaggregated elements for an optical SDN controller to manage and control in a unified manner.

D. *Monitoring*

The monitoring function plays a significant role in the automation of the management process. The existing EMS has served as a monitoring component in optical networks mainly using a simple network management protocol (SNMP) to gather performance management (PM) and fault management (FM) data from devices according to the standard and vendor-specific management information base (MIB). NETCONF is also able to collect PM and FM data in addition to configuration. Recently, a novel framework, google remote procedure call (gRPC), has emerged for receiving streamed PM data from devices, enabling high-performance data collection. Both NETCONF and gRPC gather monitoring data according to a YANG model. For monitoring optical networks using YANG, M. Dallaglio et al. demonstrated the monitoring of a transponder to derive PM and FM data [10], but the target was a single-vendor element, not heterogeneous ones. J. Kundrat et al. [11] and J. Akhtar et al. [12] described the use of the YANG model for configuration and monitoring of flexgrid ROADMs and elastic optical network (EON) respectively; however, both provided the separate capabilities of configuration and monitoring, and their collaboration for simple operation was outside the scope of their studies. While emerging monitoring methods are expected to enhance network analysis such as anomaly detection leveraging artificial intelligence (AI) in future, it could be troublesome for operators due to the increased workload involved in preparation for a lot of complicated parameters for monitoring such as which YANG tree to collect. Therefore, we implemented auto-configuration of monitoring on our optical path management system.

III. OPTICAL PATH CALCULATION AND MONITORING

A. *Architecture Overview*

In the conventional operation of optical networks, a traditional EMS manages specific devices of a single vendor and it guarantees the quality of networks, but this dedicated system cannot be used for the management of disaggregated elements from different vendors. Therefore, we propose a novel optical path management system supporting automated operation by an optical SDN controller based on ONOS and optical monitoring using the telemetry analysis framework [13], both of which are compatible with multi-vendor devices. The controller manages optical paths and configures devices for provisioning, and the telemetry framework collects PM data from devices and monitors the provisioned optical paths. Fig. 2 illustrates overview of our proposed system architecture.

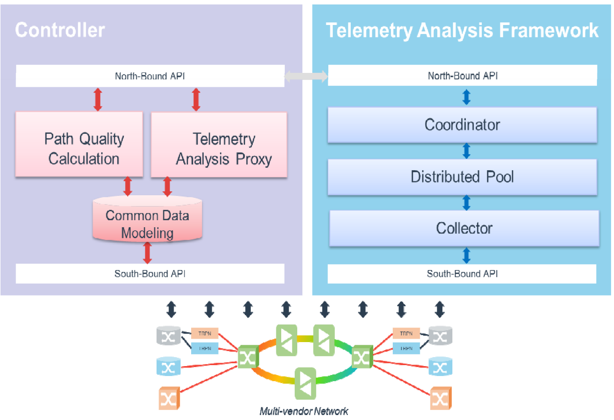


Fig. 2: Architecture of Optical Path Management

To assure the optical quality of the path on a multi-vendor network, our optical path management system is designed to have three capabilities; common data modeling, path quality calculation and path quality monitoring. Firstly, common data modeling on the controller provides the database of the configuration data in a unified format, the Open ROADM YANG model. Next, path quality calculation predicts the quality (Q) factor of the wavelength path using optical transmission parameters stored in the common data modeling. The calculation result is also put into the database for further use. Finally, path quality monitoring, composed of the telemetry analysis framework and the telemetry analysis proxy on the controller, runs in two steps. When a new wavelength path is deployed, the proxy sends the path information including the Q factor predicted by the path quality calculation to the coordinator on the telemetry framework to initiate monitoring. Then, the telemetry framework starts to monitor and analyze the new provisioned path leveraging the estimated Q factor as a threshold. We describe the three main functionalities in detail in the following.

B. *Common Data Modeling*

Many disaggregated optical devices support YANG for configuration and operation; however, the available models are vendor-specific only in most cases. Thus, a set of applications for the lifecycle management of a network, such as performance analysis, require the common data store containing the configuration and operational data in the same format. The common data modeling on the controller performs the role of storing the data of the heterogeneous network in the Open ROADM YANG data model and exposes the interface to access the data. We use version 2.2 of the model in our implementation. The Dynamic Config application in ONOS supports the importation of this YANG model into ONOS to make it to be accessible from other applications.

The common model, Open ROADM YANG, has two YANG trees; a network tree and a service tree. The network tree can be divided into a node and link container. The node contains the parameters of each device, for example, the type of device such as ROADM, the vendor of the device, rate and modulation-format. The link container stores the information about the physical links including amplifier information as amplified-link as is shown in Fig. 3, for example, the source and destination of link, the type of amplifier and span length. On the other hand, the service tree contains the topology of the optical path, both wavelength-division multiplexing (WDM) path and wavelength path. As is shown in Fig. 3, the WDM path is the path between the optical multiplexing section (OMS) add/drop ports on the ROADM, and the wavelength path is the path between the optical channel (OCh) ports on the transponder, or the transponder inside switch or router. This tree stores all the passing devices and links in line. Here, for the cooperation of path quality calculation and monitoring, we added several leaf nodes in the service tree; estimated-q-value, q-lower-limit. The estimated-q-value is used to store the Q factor predicted by the path quality calculation, and the q-lower-limit is used to contain the lower limit of the Q factor in use depending on the model of the amplifier.

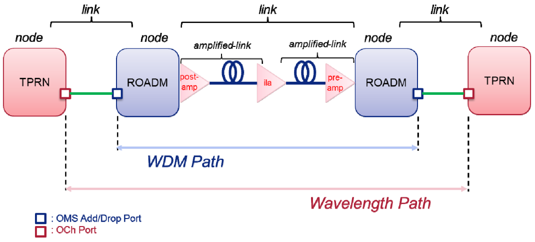


Fig. 3: Open ROADM YANG Elements

C. *Path Quality Calculation*

For disaggregated optical networks composed of multi-vendor devices, it is necessary to enhance the assurance function to verify interoperability compared to vertically integrated networks managed by EMS. The Path Service application in ONOS provides the capability of exploring the optimal route; however, this path exploring does not consider optical transmission performance such as the optical signal to noise ratio (OSNR). Therefore, the application of path quality calculation developed on the ONOS-based controller predicts the Q factor of the wavelength path before provisioning using the optical parameters stored in the common data modeling. Here, we use ONOS 1.12 called Magpie in our implementation.

This application performs WDM path calculation as the first step, followed by wavelength path calculation as the second step resulting in the predicted Q factor. In the WDM path calculation, firstly all the OMS add/drop ports of ROADMs in the network are extracted, and the route for each combination of ports is explored by the K shortest path algorithm provided by the Path Service. Next, nonlinearity-inclusive OSNR is calculated by the formula in [14] for all the WDM paths. Here, the calculation is performed for each rate and modulation-format such as R150G/dp-qam8. Then, the wavelength path calculation is performed with the source and destination of the OCh port. Once the input of OCh ports has been received from the user, the corresponding OMS add/drop ports to the OCh ports are derived from the topology information, and the Q factor of the wavelength path is calculated by (1) assigned with the nonlinearity-inclusive OSNR values obtained in the previous step, where C_0, C_1, C_2, C_3, and C_4 are provided depending on the vendor, rate and modulation-format. The obtained result shows candidate wavelength paths with the information of its route, available frequencies and calculated Q factor. Therefore, the application allows the user to select the best path from the list for provisioning based on the information.

$$Q = C_4 OSNR^4 + C_3 OSNR^3 + C_2 OSNR^2 + C_1 OSNR + C_0 \qquad (1)$$

D. Path Quality Monitoring

For monitoring function, it is necessary to maintain the optical transmission performance of the multi-vendor devices. For this purpose, the telemetry analysis framework serves as the path quality monitoring to collect and analyze the optical quality data to assure interoperability.

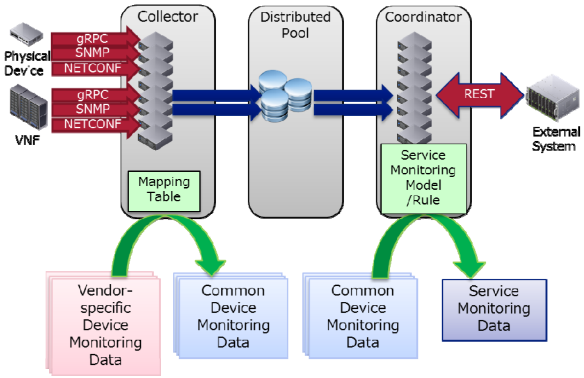


Fig. 4: Architecture of Telemetry Analysis Framework

The telemetry analysis framework provides service-centric monitoring to collect PM data from devices and analyze the data to show whether the state of the service is normal. As is depicted in Fig. 4, the telemetry framework processes PM data using three components; collector, distributed pool and coordinator. Firstly, the collector receives PM data from devices via gRPC, SNMP or NETCONF. Here, the collected data are provided in their own vendor-specific device monitoring model in most cases, hence the collector is capable of converting the data into the common device monitoring model referring to the mapping table defined by the user. Next, the data in the common monitoring model are forwarded to the distributed pool providing real-time data pipelines for scalability. Then, the coordinator selects appropriate data from the pool store according to the service monitoring model which is created by the user aligned with their operational policy. Finally, the coordinator determines the state of the service using the rule included in the service monitoring model, which can be derived using representational state transfer (REST) API from external systems. This framework enables the receiving and processing of big data obtained from multi-vendor devices for service-centric monitoring.

The telemetry analysis proxy on the controller takes a bridge role to realize cooperation between the controller and the telemetry framework. When a new wavelength path is deployed by the controller, the proxy posts the path service model stored in the common data modeling to the telemetry framework. Then, a new service monitoring model including the information regarding device, port and estimated Q factor is registered on the telemetry framework, and path monitoring is immediately started without the need for any manual configuration. This auto-configuration of monitoring reduces the large workload normally associated with setting up parameters whenever a service is deployed or updated.

In the monitoring phase, the state is determined according to the service monitoring model that indicates the target devices and the monitoring items and defines the state with the given threshold in the monitoring rule. Here, the calculation coded in the rule can be performed in this process. In our implemented system, the service model for the wavelength path consists of both end devices, a-end and z-end. Each device node contains several PM data sent from the collector involving pre-frame error correction (FEC) bit error rate (BER). To ensure optical transmission quality, the pre-FEC BER is converted into a Q factor using the given formula in the rule to be stored in the service tree. The monitoring rule specifies the service state as “*Normal*,” “*Major Alert*” or “*Minor Alert*.” Following the rule, when the Q factor of either node is lower than the estimated-q-value predicted by the path quality calculation, the state of the path becomes “*Minor Alert*.” If the Q factor of either node is under the q-lower-limit, the state becomes “*Major Alert*.”

This model-based architecture provides three benefits in terms of monitoring. Firstly, the collector converts vendor-specific PM data into the common PM data, which enables vendor-neutral data processing. Second, both the controller and the telemetry framework manage the configuration and operational data in the YANG model, hence they can cooperate easily exchanging the data via API. Finally, the operator is able to monitor and analyze the quality of the service (wavelength path in this paper) using the editable service monitoring model created based on the operational policy. Our proposal can be applied not only to the management of optical networks but also to that of IP and mobile core networks to realize simple operation toward fully automated management.

IV. EXPERIMENTAL DEMONSTRATION

We describe a use case and show how our implemented optical path quality calculation and monitoring system works in provisioning and monitoring a new wavelength path. Fig. 5 illustrates the network topology and scenario of the demonstration. The network is composed of disaggregated devices provided by two vendors. Vendor A provides

ROADMs and switches with a transponder module inside. Vendor B provides routers also with a transponder module inside. We explain the following steps after connecting two vendor B routers; device/link registration, path quality calculation, path reservation/registration and path quality monitoring.

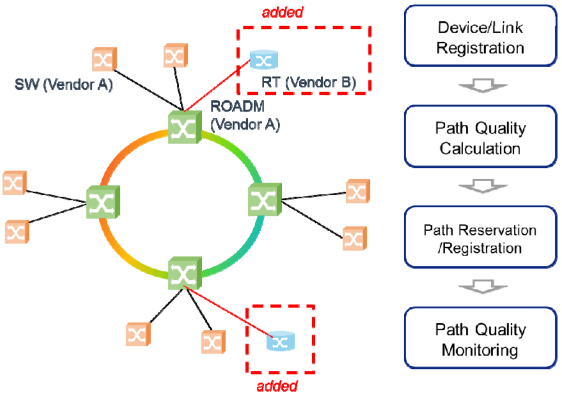
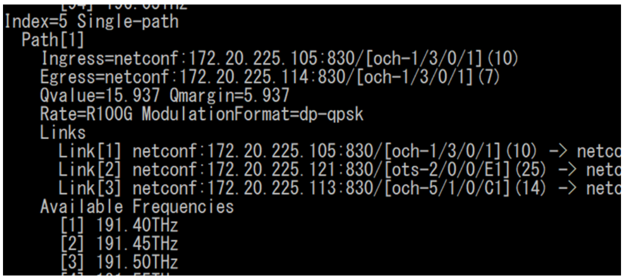


Fig. 5: Topology and Scenario of Demonstration

Firstly, the new devices and links are registered with a pre-defined JaveScript Object Notation (JSON) file on the controller to establish the initial connection with the management interface of the new devices. After that, the controller exchanges messages with the devices via NETCONF to gather complementary data such as port name and frequency and put them into the node container of the common data modeling. On the other hand, as the link data cannot be derived directly, all the physical connections need to be provided by the given file in the link registration.

Next, the path quality calculation is performed. In this case, the operator needs to run only the wavelength path calculation without WDM path calculation since the topology of ROADMs is not changed after connecting the additional devices. The calculation result is shown in Fig. 6. The result presents the calculated Q factor as Qvalue, rate/modulation-format, route as links with the information of passing links and all the available frequencies.



```
Index=5 Single-path
  Path[1]
    Ingress=netconf:172.20.225.105:830/[och-1/3/0/1](10)
    Egress=netconf:172.20.225.114:830/[och-1/3/0/1](7)
    Qvalue=15.937 Qmargin=5.937
    Rate=R100G ModulationFormat=dp-qpsk
    Links
      Link[1] netconf:172.20.225.105:830/[och-1/3/0/1](10) -> netco
      Link[2] netconf:172.20.225.121:830/[ots-2/0/0/E1](25) -> netc
      Link[3] netconf:172.20.225.113:830/[och-5/1/0/C1](14) -> netc
    Available Frequencies
      [1] 191.40THz
      [2] 191.45THz
      [3] 191.50THz
```

Fig. 6: Result of Path Quality Calculation

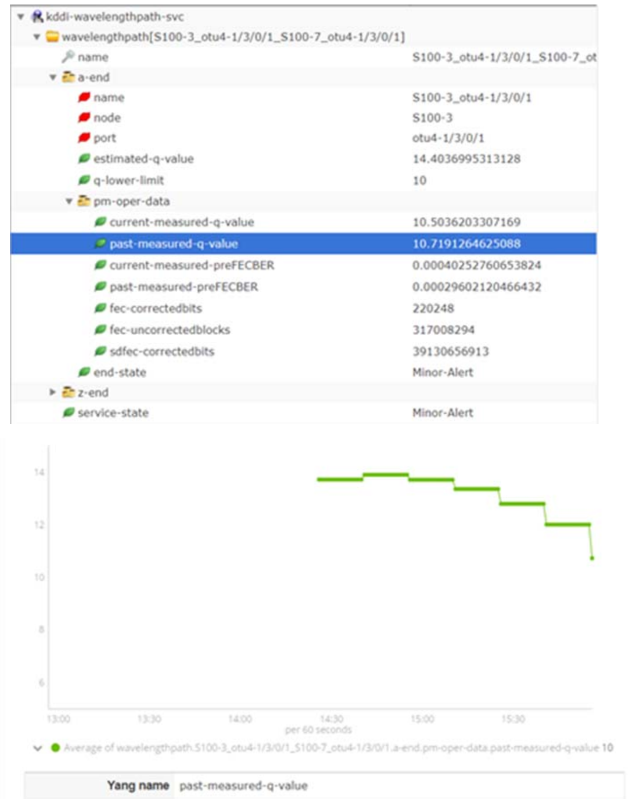
The operator selects which of the presented paths to be provisioned based on the obtained information, and reserved it with the preferred frequency. The reserved wavelength path is shown on the table view of the controller GUI, and also can be highlighted on the topology view to verify the visualized route. Here, all the passing devices and links of the reserved wavelength path are extracted to store in the service tree of the common data modeling as is shown in Fig. 7. In this model, the service-layer means whether the service is WDM path or wavelength path, lifecycle-state indicates whether the path is planned or deployed, and the container of wavelength-path-info added for auto-configuration of monitoring involves q-value and q-lower-limit. When the operator registers the reserved path, it is activated to configure all the devices with appropriate parameters such as wavelength and modulation-format, while the proxy on the controller sends the path service model to the telemetry framework to set up parameters for path quality monitoring automatically.

```
{
   "org-openroadm-service:services": [
      {
         "service-name": "wavelength-6",
         "connection-type": "wavelength-path",
         "lifecycle-state": "planned",
         "service-layer": "wavelength",
         "wavelength-path-info": {
            "q-value": "14.881914012761884",
            "q-lower-limit": "10.0",
            "name": "SWoch-2",
            "coupled-services": [
               "wavelength-5"
            ]
         },
         "topology": {
            "aToZ": [
               {
                  "id": "netconf:172.20.225.70:830/6-
netconf:172.20.225.66:830/20",
                  "hop-type": "node-external",
                  "resource": {
                     "physical-link-name": "SW-4|och-1/3/0/1=>ROADM-
1|och-4/1/0/C1"
                  },
                  "resourceType": {
                     "type": "physical-link"
                  }
               }, …
```

Fig. 7: Path Service Model

Finally, the monitoring of the provisioned wavelength path is started. The YANG tree of the service monitoring model of the wavelength path is shown in Fig. 8. Both nodes of a-end and z-end contain a node, port, estimated-q-value and q-lower-limit provided by the proxy on the controller. They also contain pm-oper-data defined as the common device monitoring model including pre-FEC BER and Q factor and so forth, where the data collected on the collector are stored. Each end-state is determined comparing the estimated-q-value, q-lower-limit and measured-q-value, and the service state is determined with the states of both ends. To verify the monitoring functionality, the power level of the transmission signal on the a-end port is gradually reduced using a variable optical attenuator, then the measured-q-value decreases accordingly as is depicted in Fig. 8. The state of the service becomes "*Minor Alert*" when the values are lower than the estimated-q-value, and it subsequently becomes "*Major Alert*" when the measured values are under the q-lower-limit.

This demonstration shows that the common YANG model enables the automated provisioning and monitoring of a wavelength path taking the optical transmission quality into consideration in multi-vendor disaggregated networks. The common model abstracts the configuration and monitoring data of different vendors to use in each management process. Furthermore, it is also shown that the auto-configuration of monitoring parameters by the cooperation of the controller and the telemetry framework enables the reduction of the workload and starting monitoring soon after provisioning compared with the case of manual setup.



kddi-wavelengthpath-svc	
wavelengthpath[S100-3_otu4-1/3/0/1_S100-7_otu4-1/3/0/1]	
name	S100-3_otu4-1/3/0/1_S100-7_ot
a-end	
name	S100-3_otu4-1/3/0/1
node	S100-3
port	otu4-1/3/0/1
estimated-q-value	14.4036995313128
q-lower-limit	10
pm-oper-data	
current-measured-q-value	10.5036203307169
past-measured-q-value	10.7191264625088
current-measured-preFECBER	0.00040252760653824
past-measured-preFECBER	0.00029602120466432
fec-correctedbits	220248
fec-uncorrectedblocks	317008294
sdfec-correctedbits	39130656913
end-state	Minor-Alert
z-end	
service-state	Minor-Alert

● Average of wavelengthpath.S100-3_otu4-1/3/0/1_S100-7_otu4-1/3/0/1.a-end.pm-oper-data.past-measured-q-value 10

Yang name past-measured-q-value

Fig. 8: Result of Path Quality Monitoring

V. CONCLUSION AND FUTURE WORK

To enhance the management of optical networks toward E2E lifecycle automation, the optical SDN controller is expected to manage and control heterogeneous devices involving optical transmission quality. In this paper, we implemented a novel optical path quality calculation and monitoring system, and presented a demonstration of provisioning and monitoring a new wavelength path in a multi-vendor network. The path quality calculation predicted the Q factor using the optical parameters stored in the common data modeling, and in provisioning the new path, the telemetry analysis proxy posts the path service model stored in the common database to the telemetry framework to configure the monitoring parameters, which initiates path monitoring automatically. This model-based auto-configuration mechanism can be applied to other networking domains such as IP and mobile core. To achieve full automation in optical networks, several open challenges still remain. The monitoring functionality requires high-performance and scalability for use in commercial networks, hence the experimental evaluation of our telemetry framework is a subject to be addressed in future work. In addition, the functionality of restoration essential for recovery after failure detection is one of the issues for future research.

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