An Integrated Control of IP and Optical Network for Multi-grade Virtualized Networks

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***Abstract*—In the 5G era, it is expected that various services will be provided on network slices, which are virtualized network resources. A network slice has to support isolation capabilities and multi-grade performance capabilities such as ultra-low-latency and ultra-reliability due to the 5G requirements. IP and optical networks are also required to provide multi-grade property as a part of a network slice. Multi-layer SDN control is beneficial technology to realize the multi-grade network because an integrated control of IP and optical layers enables to combine network technologies across layers. It brings flexibility of service levels in terms of network performance and reliability. In this paper, we propose and demonstrate a multi-grade network which provides various types of virtualized network according to user requirements. Our platform is composed of IP and optical layers and ONOS-based SDN controller. We show on-demand provisioning of a virtualized network with a provisioning tracker that presents current status of provisioning in real-time.**

***Index Terms*—5G, network slice, SDN, multi-layer control.**

I. Introduction

Network slicing is expected as a key technology in the 5G network in order to support various types of services like broadband service, IoT service, and mobile edge computing. IP and optical networks composed of 5G access and core have to support functionality of the network slicing. They are required to provide a virtualized network as a part of network slice with isolation capability and multi-grade performance capability such as ultra-low-latency and ultra-reliability due to the 5G requirements [1]. In addition, on-demand provisioning of the virtualized network is also an important feature because service lifecycle will be more short-term and the virtualized network may be required in an automatic manner by a service orchestrator (i.e. not human operators) in the 5G era.

In order to realize the multi-grade network and on-demand provisioning in IP and optical layers, multi-layer SDN control is beneficial technology. Figure 1 shows the basic concept of multi-layer SDN control that virtualized networks can be provided by controlling IP and optical networks by a unified SDN controller according to user demands. The integrated control of IP and optical layers enables to provide different types of virtualized networks such as dedicated line and L2/L3 virtual private network on a common physical network. Some SDN controllers such as ONOS (Open Network Operating System) [2] have functionality of the integrated control. It can manage network resources both IP and optical layers and control network equipments through open API (NETCONF/YANG, REST, etc.).

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In this paper, we propose a multi-grade network for network slicing that provides various types of virtualized networks by leveraging mechanisms of IP and optical layers. We also developed management functions for the multi-grade network in ONOS. We will demonstrate on-demand provisioning of a virtualized network with appropriate network grade according to user requirements.

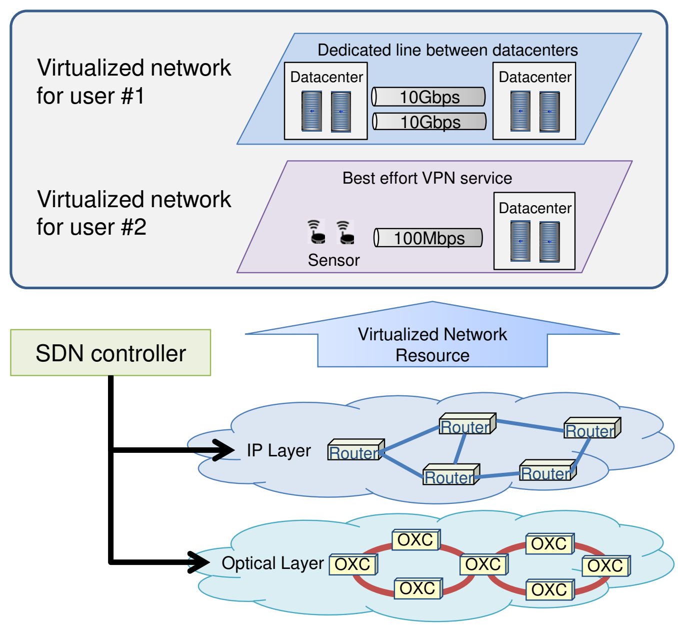

Fig. 1. Overview of multi-layer SDN control.

II. Multi-layer SDN Control

A. Multi-grade network for network slicing

For various types of services in the 5G era, a network slice has to provide multi-grade property which has multi-level of network performance in terms of bandwidth, latency, and reliability as stated in the 5G requirements [1]. IP and optical networks are also required to provide the multi-grade property as a part of a network slice. We take following mechanisms to realize multi-grade performance and reliability capabilities:

1) Network path type: We provide two network path types, shared path and dedicated path. The shared path can be

realized by L2/L3 VPN based on IP/MPLS technology. A user can specify its bandwidth which is guaranteed by QoS control of edge and core routers. In the dedicated path, a fixed bandwidth can be allocated at the OTN (optical transport network) layer like E-line service. This means that it is not affected by other user traffic.

2) Latency: We provide three latency options, ultra-low-latency, low-latency, and best effort. The ultra-low-latency option is based on the dedicated path. It is completely unaffected by other traffic and avoids the packet forwarding latency because traffic does not through routers in the dedicated path. The low-latency and best-effort options can be realized on the shared path. The differentiation of the latency can be provided by QoS control mechanisms at edge and core routers, i.e. priority packet scheduling.
3) Reliability: For the reliability of network slicing, we proposed the multi-level reliability architecture to provide different levels of reliability on a common IP and optical network [3]. We provide three types of reliability options, protection, restoration, and non-redundant, based on the proposal. The protection model can be realized by Segment Routing LFA (Loop-Free Alternate). The restoration model can be realized by rerouting optical wavelength with SDN control when link failure occurs.

Figure 2 shows a layer model and mechanisms in our proposed multi-grade network. These mechanisms for the multi-grade network are implemented across multiple layers, mainly layer 3 and layer 0/1. We can comprehensively control these mechanisms by an unified SDN controller. In this layer model, we assume that virtual machines or containers can be provided to users as IaaS (Infrastructure as a Service). They are connected to a switch which is a service end-point of the multi-grade network. The switch decides appropriate layer to handle the traffic according to the user requirement. When a user requests a shared path, the user traffic is forwarded to the layer 3 to connect to an appropriate VPN.

From a point of view of efficient resource usage, the multi-grade network supports traffic engineering so that the SDN controller can select an optimized route which has enough bandwidth in layer 3 and enough wavelength in layer 0. We use Segment Routing in layer 3 and wavelength selective switch (WSS) in layer 0 for the traffic engineering and implemented two types of WSS control mechanisms, broadcast-and-select and route-and-select [4], in the SDN controller.

B. Multi-layer SDN control

We impletemed management functions into ONOS to control the multi-grade network. Figure 3 shows the overview of the management functions. We use basic functions of ONOS such as southband interface and device & link management. On top of that, we developed new management functions which are virtual path management function, L3/L2 VPN configuration, IP/optical route configuration, and protection/restoration configuration. L3/L2 VPN configuration is a function to setup MPLS-VPN on MPLS routers via NETCONF protocol with using vendor specific YANG model. IP/optical route configuration calculates an optimized route and configures routers and WSSs via NETCONF and REST protocol. Protection configuration sets up LFA of Segment Routing function on routers to enable fast reroute for failure recovery on the IP layer. Restoration configuration changes a wavelength route to avoid failure route by controlling WSSs for failure recovery on the optical layer.

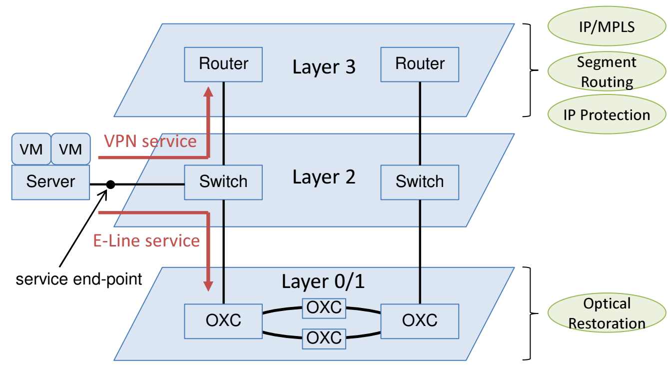

Fig. 2. Layer model for multi-grade network.

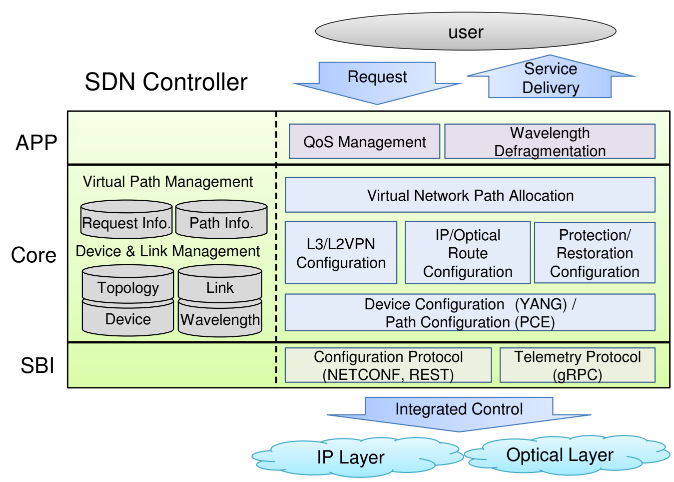

Fig. 3. Functions of SDN controller.

III. Experimental Network and Demonstration

We designed our experimental network which is composed of four sets of IP and optical equipments with two ROADM rings as shown in Figure 4. Each equipment is connected to the ONOS-based SDN controller through a management network. Figure 5 shows a picture of IP and optical equipments of the racks 1 and 2. The racks 1, 3 and 4 have a two degrees CD-ROADM, a 200G transponder, a SR-enabled router, and a L2 switch. The rack 2 has almost same equipments except for four degrees CD-ROADM.

In this demonstration, we have a web-based GUI system which shows network structure of IP and optical networks and has an interface to request new virtual network to the SDN controller with bandwidth, latency, and reliability options. We will demonstrate on-demand provisioning of a virtual network by using the GUI system. A user can choose any

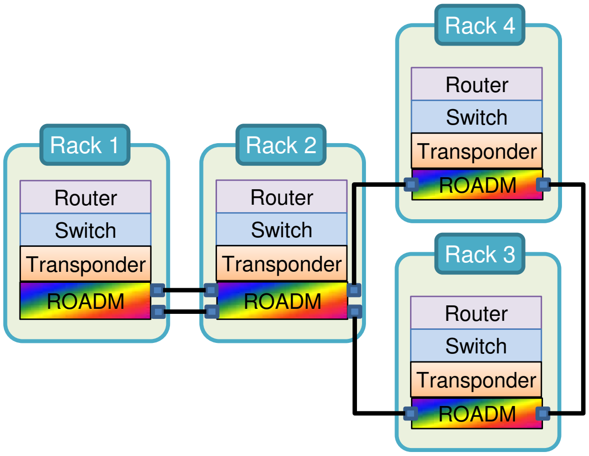

Fig. 4. Experimental network.

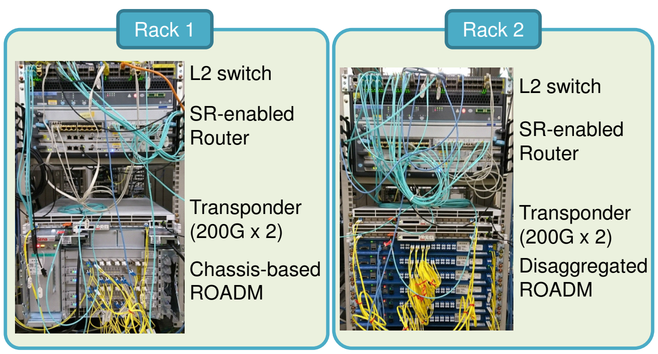

Fig. 5. IP and optical equipments.

types of virtual network, e.g. dedicated line, L3/L2 VPN, low-latency, high-reliability. We also developed a provisioning tracker which presents current status of provisioning in real-time. A network operator can see which equipment is already configured by the SDN controller as shown in Figure 7. For example, in case of provisioning of a dedicated line, the provisioning tracker shows configuration results as following steps: source transponder → destination transponder → ROADMs → source switch → destination switch. After provisioning of a virtual network, a multi-layer test tool that we developed can be automatically run and test power level of wavelength and IP reachability between end hosts.

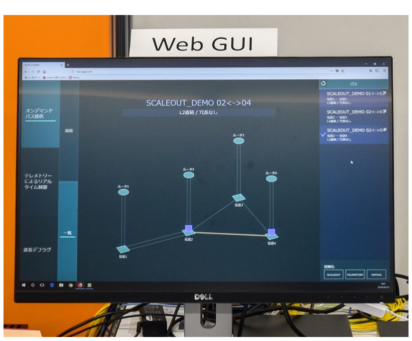

Fig. 6. Web-based GUI system.

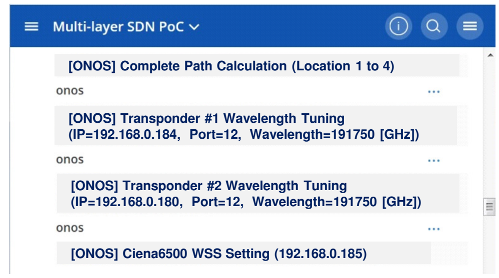

Fig. 7. Provisioning tracker.

IV. Evaluation

We evaluate configuration time of dedicated line and shared line in the experimental network. Table I shows the results of configuration time in creating and deleting operations for the dedicated line and the shared line. In the configuration of dedicated line, the configuration time of each equipment is between few seconds to ten seconds. Therefore, it takes around 40 seconds of total configuration time because the SDN controller configures about ten equipments of switches and ROADMs in this experimental network. On the other hand, it takes about ten seconds in the shared line because the optical layer and the MPLS backbone have been already configured. The SDN controller configures only routers in this case.

TABLE I
Create and delete time of virtual network.

Network type		Configuration time [sec]
Dedicated line (E-line)	Create	44.5
	Delete	41.0
Shared line (L3/L2VPN)	Create	9.7
	Delete	8.8

V. Conclusion

We proposed a multi-grade network with multi-layer SDN control in order to support network slice functionality in IP and optical networks. Our platform is based on a MPLS network using Segment Routing and a WSS-based optical network that are controlled by an ONOS-based SDN controller. We realize a multi-grade network by leveraging mechanisms of IP and optical layers. In our demonstration, on-demand provisioning of virtual networks is showcased with a web-based GUI in our experimental network. We also show our operation tools, provisioning tracker and multi-layer test tool, in order to check the current status of provisioning and the verification of provisioned networks.

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