Demonstration of Survivable vSD-EON Slicing with Automatic Data Plane Restoration to Support Reliable Video Streaming

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Abstract: We design and experimentally demonstrate a network slicing system which can not only construct vSD-EONs dynamically for upper-layer applications but also recover their data plane services automatically and timely during substrate link failures.

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1. Introduction

It is known that software-defined elastic optical networks (SD-EONs) provide operators more flexibility to customize their optical infrastructure dynamically and adaptively [1]. Meanwhile, network virtualization, *i.e.*, infrastructure-as-a-service (IaaS), can further enhance the adaptivity of SD-EONs, since the network slicing with IaaS enables multiple tenants to share optical infrastructure efficiently and shortens the time needed for introducing new services [2, 3]. Nevertheless, as network slicing makes multiple virtual SD-EONs (vSD-EONs) share the same substrate elements (*i.e.*, optical switches and fiber links), the network failure on a single substrate element might disrupt the services of multiple vSD-EONs simultaneously. Hence, it is desirable to develop survivable network slicing schemes that can ensure the intactness of vSD-EONs during network failures. Although a few previous studies have already considered survivable optical network slicing, they either only designed the algorithms [4] or just validated their proposals in a software-emulated system [5]. While the "full stack" implementation and demonstration that incorporates data plane (DP) operations to carry real application traffic needs to be considered in a timely manner, for evaluating how the DP restoration in survivable vSD-EON slicing would affect the quality-of-service (QoS) of upper-layer applications.

In this work, we first design and implement a survivable vSD-EON slicing system that uses an OpenVirteX [6] based network hypervisor (NHV) to realize automatic DP restoration. Specifically, the NHV leverages virtual link (VL) remapping to restore the DP services of vSD-EONs when substrate link (SL) failures happen. Therefore, DP restoration is automatic and transparent to the controllers of vSD-EONs, which can lead to simplified vSD-EON management and fast recovery. Then, we build a semi-practical network testbed that consists of optical transmission chassis (OTC), bandwidth-variable wavelength-selective switches (BV-WSS'), high-performance severs, and commercial video streaming equipment (VSE). The testbed is used to experimentally demonstrate the creation of a vSD-EON, the activation of a virtual lightpath in the vSD-EON to support high-throughput video streaming, and the automatic DP restoration during an SL failure. Experimental results indicate that our network slicing system can not only build vSD-EONs dynamically for upper-layer applications but also recover their DP services timely during SL failures.

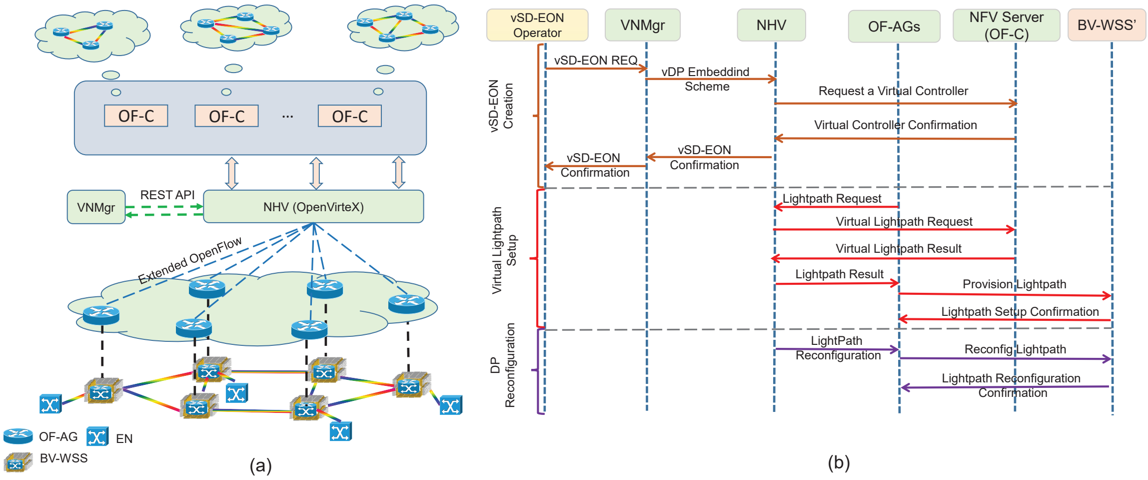


Fig. 1. (a) Architecture of our vSD-EON slicing system, EN: end-node; and (b) Operation procedure for 1) vSD-EON creation, 2) virtual lightpath setup, and 3) DP restoration with lightpath reconfiguration (*i.e.*, virtual link remapping).

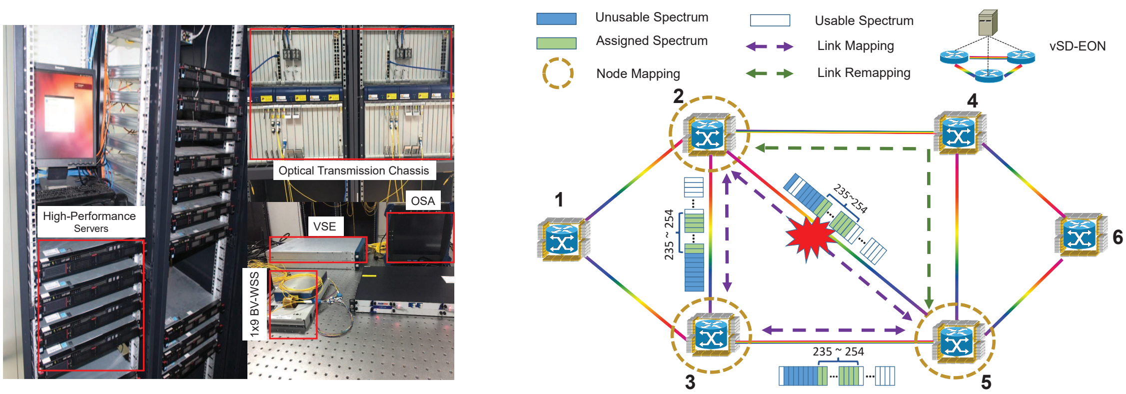
2. System Design and Implementation

Fig. 1(a) shows the architecture of our vSD-EON slicing system. The infrastructure provider utilizes the virtual network manager (VNMgr) and the network hypervisor (NHV) to realize the network slicing for each vSD-EON. We program VNMgr to calculate the virtual DP (vDP) embedding results (*i.e.*, node mapping and link mapping results) for each vSD-EON request, and VNMgr communicates with NHV using the RESTful API. NHV is implemented based on OpenVirteX, which realizes the control message interpretation between the virtual and substrate network elements and gives each vSD-EON operator the capability of transparent control. Meanwhile, NHV collects the status of substrate elements and will invoke VL remapping automatically to restore the vDPs of affected vSD-EONs in case of SL failures. Hence, DP restoration is made transparent to the vSD-EONs. We also implement the OpenFlow controller (OF-C) for vSD-EONs, which can be instantiated in high-performance servers on demand with network function virtualization (NFV), and extend the OpenFlow protocol to support the routing and spectrum assignment (RSA) on BV-WSS'. Moreover, OpenFlow agents (OF-AGs) are realized to configure BV-WSS' according to the flow-entries from an OF-C and implement the required RSA correctly.

The detailed operation procedure of the vSD-EON slicing system is illustrated in Fig. 1(b). When a vSD-EON request comes in, VNMgr calculates the vDP embedding scheme based on the information in it, *i.e.*, the virtual topology, bandwidth requirement, and end-node locations. Then, VNMgr sends the vDP embedding scheme to NHV. Next, NHV embeds the virtual nodes (VNs) and VLs to substrate nodes (SNs) and paths accordingly. Meanwhile, NHV assigns the spectral to the corresponding substrate paths of the vSD-EON, and also requests a virtual controller (*i.e.*, an OF-C) for the vSD-EON from the NFV server. At this moment, the vSD-EON is created and it is then handed over to its operator, which will deal with the lightpath requests from the end-nodes. When an end-node needs to support an application, it can formulate a lightpath request, which will be collected by the OF-AG on the BV-WSS that connects to the end-node and forwarded to NHV. NHV finds the vSD-EON that the request belongs to, and forwards it to the corresponding OF-C in the NFV server. The OF-C then calculates the provisioning scheme for the lightpath in the vSD-EON, and returns the result to NHV. NHV translates the provisioning scheme into what it should be in the substrate network and sends the result to the related OF-AGs. Upon receiving the lightpath provisioning result from NHV, the OF-AGs configure their BV-WSS' to establish the lightpath in the DP. Then, the lightpath is set up in the vSD-EON to carry application traffic. Then, during the operation of the vSD-EON, if an SL failure impacts its vDP, NHV will restore the vDP automatically with VL remapping. Specifically, upon detecting the failure, NHV updates the substrate topology and determines the remapping schemes for affected VLs. Then, NHV sends lightpath reconfiguration instructions to the related OF-AGs, which will in turn reconfigure their BV-WSS' to recover the vDP.

3. Experimental Demonstration

The experimental testbed is shown in Fig. 2(a). We implement the control plane of the vSD-EON slicing system, *i.e.*, VNMgr, NHV, OF-Cs and OF-AGs, in high-performance Linux servers. The substrate network consists of two OTC (Huawei Optix OSN3500) and several Finisar 1×9 BV-WSS'. On one side, the OTC can aggregate the Ethernet inputs from end-nodes (at 100 Mb/s and/or 1 Gb/s) into an STM-64 optical signal (*i.e.*, at 9.95 Gb/s) and transmit it out with a center wavelength of 1543.27 nm. On the other side, the chassis can receive the STM-64 signal and de-aggregate the Ethernet signals for end-nodes. The operation range of the BV-WSS' is 1528.43 to 1566.88 nm in the C-band, and its minimum frequency slot (FS) width is 12.5 GHz. For the end-nodes, we use a pair of VSEs for high-



(a) (b)

Fig. 2. (a) Experimental testbed, VSE: video streaming equipment, OSA: optical spectrum analyzer; and (b) Substrate topology and the vSD-EON to be embedded.

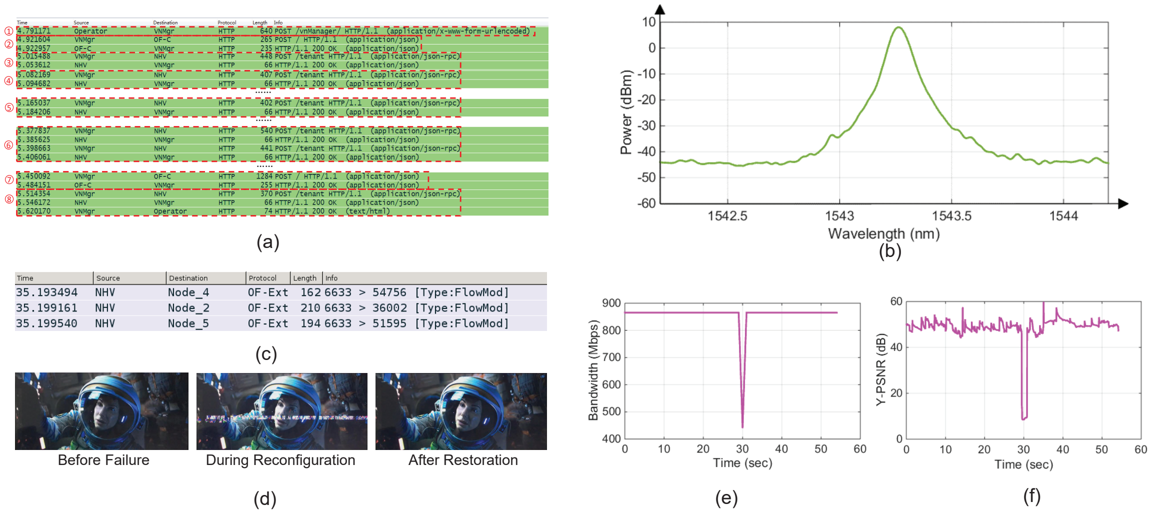


Fig. 3. (a) Messages used for vSD-EON creation, (b) Optical spectrum of the virtual lightpath, (c) Messages used for VL remapping, (d) Screen-shots of video playback, (e) Throughput of video streaming, and (f) PSNR of video playback.

definition video streaming, which can multiplex/demultiplex 20 streams of videos (with the resolution of 1920×1080) and send/receive them using Gigabit Ethernet (1GbE) ports (with a total data-rate of $\sim$865 Mb/s). Fig. 2(b) illustrates the substrate topology and the vSD-EON to be embedded in the experiment. The DP of the vSD-EON is in a triangular topology, and each of its VLs requires 250 GHz bandwidth (*i.e.*, 20 FS').

Fig. 3 shows the experimental results. The detailed procedure of vSD-EON creation is presented in Fig. 3(a). In **Step 1**, VNMgr receives the vSD-EON request from its operator and then it requests an OF-C for the vSD-EON in **Step 2**. Meanwhile, VNMgr calculates the vDP embedding result for the vSD-EON and decides to map the VNs to SNs 2, 3 and 5 and to map the VLs to substrate paths 2-3, 3-5 and 2-5 with the FS-block $[235, 254]$ on them (as shown in Fig. 2(b)). Note that, we number the FS' according to the way defined in the BV-WSS manual, and specifically, the FS-block $[235, 254]$ covers the FS' whose center wavelengths range from 1541.40 nm to 1543.28 nm. Then, in **Steps 3-6**, VNMgr communications with NHV to create the vDP of the vSD-EON. Next, VNMgr tells the vSD-EON's OF-C about the establishment of the vDP in **Step 7**, and in **Step 8**, VNMgr hands over the vSD-EON to its operator. It takes our system 829 msec to create the vSD-EON. Then, the OF-C activates a virtual lightpath with one FS (*i.e.*, 12.5 GHz) on substrate path 2-5 to carry the STM-64 signal from the OTC. Note that, we connect the VSEs to/from the 1GbE ports on the OTC, and hence the 865 Mb/s video streaming traffic is included in the STM-64 signal. Fig. 3(b) shows the virtual lightpath's spectrum, which indicates that the OF-C activates it with a center wavelength of 1543.28 nm (*i.e.*, using the first-fit scheme to allocate FS 235). Next, we emulate a failure on SL 2-5. Since the SL failure impacts the virtual lightpath for video streaming, NHV uses VL remapping to restore it automatically. Specifically, NHV decides to reconfigure the VL that carries the virtual lightpath to use substrate path 2-4-5, and implements the reconfiguration by sending *FlowMod* messages to the OF-AGs on SNs 2, 4 and 5, as shown in Fig. 3(c). We monitor the video playback quality before the SL failure, during the VL remapping, and after the restoration, and the corresponding screen-shots of a randomly selected video are shown in Fig. 3(d). It can be seen that even though the SL failure and VL remapping can cause playback quality degradation due to packet losses, the video's quality is recovered after the restoration. The video streaming's throughput is plotted in Fig. 3(e), which indicates that the video streaming is recovered within 2 seconds. Finally, Fig. 3(f) shows the results on luminance components peak signal-to-noise-ratio (Y-PSNR) for a randomly selected video, which also verify that the video's playback quality is restored within 2 seconds.

4. Conclusion

We designed and implemented a survivable vSD-EON slicing system that could realize automatic DP restoration, and demonstrated it experimentally to support reliable high-definition video streaming.

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