Dynamic Reconfiguration of WDM Virtual Network Topology over SDM Networks for Spatial Channel Failure Recovery with gRPC Telemetry

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Abstract: We experimentally demonstrate the dynamic reconfiguration of WDM VNTs in response to SDM spatial channel failures. We present an SDN control architecture with gRPC-telemetry and analytics to detect failures and restore failed virtual WDM links ©2022 The Authors.

1. Introduction

The data traffic in the transport networks is continuously growing in terms of volume and variance over decades. The current research goal is to deploy 1 Pb/s optical transport systems with 10 Tb/s optical line interfaces to meet the future traffic demands. A novel architecture that has been recently proposed to increase the capacity of the optical transport systems is spatial channel network (SCN) [1]. SCN allows to bypass the overloaded wavelength division multiplexing (WDM) networks by provisioning spatial paths between WDM nodes. It is composed of spatial cross connects (SXC) that enable the provisioning of spatial channels that occupy the entire available spectrum of a single-mode fiber (SMF) or one core in a multi-core fiber (MCF). MCFs can be carefully designed to suppress the crosstalk between cores below the level permitted by the transmission system, allowing spatial cores to be individually switched.

We presented for the first time the concept of SDN-enabled WDM virtual network topologies (VNTs) over SDM networks in [2]. An SDN-enabled WDM VNT can be deployed as a set of physical WDM nodes (i.e., ROADMs/OXCs) controlled by an SDN controller, and spatial channels providing connectivity between the ROADMs/OXCs, that are handled as virtual links in the WDM layer network, following a similar strategy as done for IP over WDM. A VNT is reconfigurable in response to traffic-demand changes or network failures for achieving better network performance. This architecture supports multi-tenancy, since several VNTs can be deployed on top of the shared physical SDM infrastructure. We have proposed a cloud-native WDM over SDM (WDMoSDM) SDN orchestrator responsible for the lifecycle management of the SDN-enabled WDM VNTs. In [2], we experimentally validated the provisioning and removal of SDN-enabled WDM VNTs by deploying virtual links between ROADM/OXC nodes using spatial channels. In this paper, we propose and experimentally validate the reconfiguration of SDN-enabled WDM VNTs in response to spatial channels failures. It enables to restore failed virtual WDM links instead of restoring the optical channels at the WDM layer. We have extended the proposed WDMoSDM SDN orchestrator with gRPC streaming telemetry and analytics to detect spatial channel failures and restore the failed virtual WDM links.

2. Target scenario and proposed SDN control architecture

We consider a WDM over SDM physical network consisting of ROADMs/OXCs and SXCs, as shown in Fig.1.a. SXCs are with Optical Performance Monitors (OPMs) such as Optical Spectrum Analyzer (OSA) to measure the parameters of the optical channels (e.g., OSNR). To this end, passive optical taps can be located at the input ports of the SXCs to extract a small percentage of the power of each SSMF or spatial core, that is sequentially monitored by the OSA module. Another approach is to deploy in-line Optical Power Tap Monitors to measure the overall power of the SSMFs or spatial cores. We deploy an SXC telemetry agent for each OPM to stream the measured data to the cloud-native WDMoSDM SDN Orchestrator via gRPC interface. The cloud-native WDMoSDM SDN Orchestrator is based on the μABNO [3], an SDN controller built using a microservices architecture. Given the modularity that microservices provide, it is easier to develop new functionalities, deploy it on cloud computing servers and scale the different modules depending on the load. To support the creation of WDM VNTs, we already proposed a WDM VNTM (VNT Manager) microservice responsible for the provisioning and removal of WDM VNTs. In this work we extend the WDMoSDM SDN orchestrator with two additional microservices as shown in Fig.1.a, an SXC Telemetry collector for collecting thes treaming telemetry data using gRPC, and an SXC Degradation Analyzer for SSMF/core link failures.

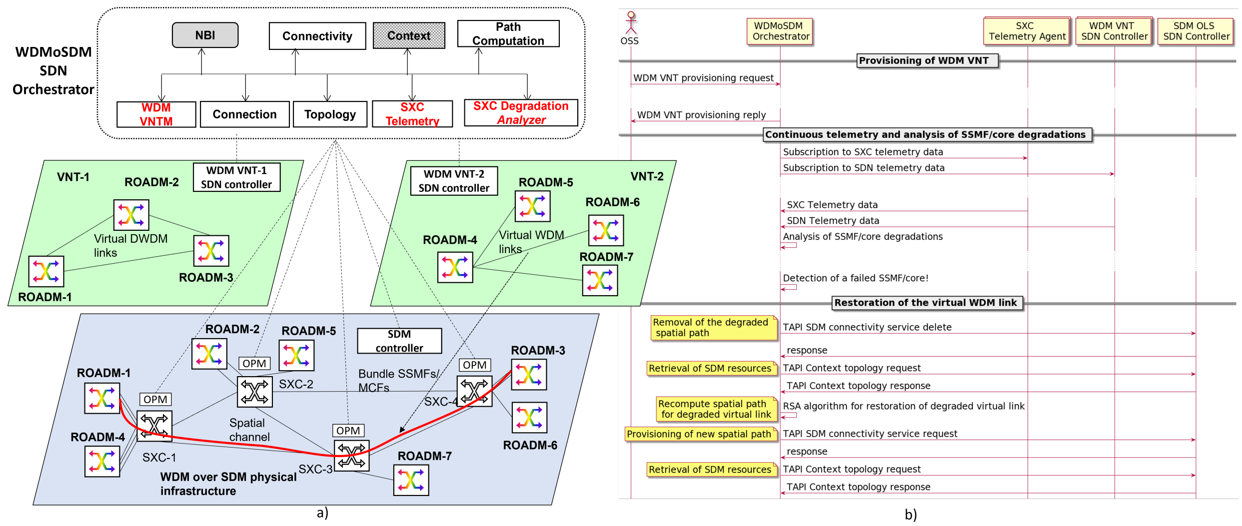


Fig. 1. a) SDN-enabled WDM VNTs scenario b) WDM VNT reconfiguration Workflow

3. Dynamic reconfiguration of WDM VNTs for spatial channel failure recovery

First, the network operator defines the logical WDM VNT (i.e., involved physical WDM nodes and virtual WDM links), and then, it requests the deployment from the WDMoSDM orchestrator, as shown in Fig.1b. For detailed information on the involved steps refer to [2]. Once the WDM VNT is deployed, the SXC Telemetry Collector subscribes to the SXC Telemetry Agents to get the telemetry data (e.g., OSNR) for the provisioned spatial channels used as virtual WDM links. The telemetry data is processed by the SXC Degradation Analyzer to detect failures in SSMFs or spatial cores in MCFs. To avoid false alarms, the SXC Degradation analyzer also needs to get in real-time the list of active connections in the WDM VNT SDN controller. In [4], we presented a streaming mechanism for optical networks based on the Kafka architecture and protocols. It enables an efficient distribution of the state and network updates following the ONF Transport API streaming implementation agreement. Once a SSMF/core failure is detected, the SXC Telemetry Degradation Analyzer notifies the WDM VNTM. It identifies the failed spatial channel and asks for its removal to the Connection microservice, that will send a request to remove the associated SDM TAPI connectivity service to the SDM SDN Controller. Then, the Topology microservice requests the context to the SDM SDN controller to update the available resources. After that, the WDM VNTM recomputes a new spatial path for the failed virtual WDM link. We propose the following routing and spatial assignment algorithm for restoration of failed virtual links:

1. Compute the available SSMFs/cores on each link of the same route of the degraded spectral channel. Remove the SSMF/cores used by the degraded spatial channel
2. Allocate a SSMF/core on each link of the route:
   - For SSMF, allocate the first SSMF available on each link. If a link has no available SSMF, go to step 3.
   - For MCF, compute the set of continuous cores that meet the spatial core continuity along the route (i.e. use the same core in all links of the route). For each continuous core, c, calculate the overall occupancy rate and select the core with the smallest overall occupancy rate aiming to avoid XT effect. The overall occupancy rate is calculated as:

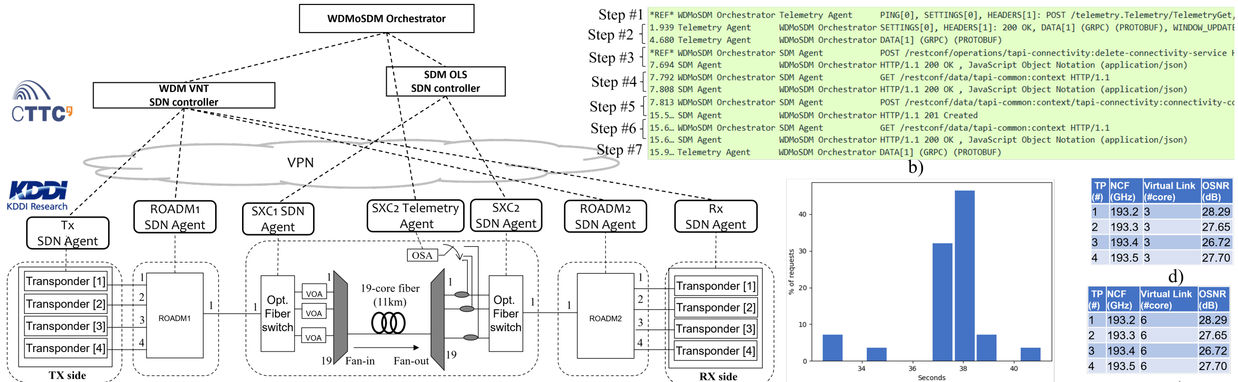
   $$\sum l \in L \sum n \in N \frac{occupiedSpectrum_{l,n}}{supportableSpectrum_{l,n}}$$

   Where L is the number of links along the computed route, and N is the number of neighbouring cores adjacent to c. If there is no continuous core, go to step 3.
3. Calculate a new set of routes in the SDM layer, R (i.e., SDM nodes and links) between the source WDM port (s) and the destination WDM port (d) of the degraded virtual link using a k-shortest path algorithm that minimizes the number of hops. Remove the route used by the degraded spatial channel. If the R is null, return error.
4. Take the first route in R and allocate the SSMFs/cores on each link as in step 2. If the SSMFs/cores cannot be allocated, repeat this step for the next route in R. If SSMFs/cores cannot be allocated in any route, return error.

After the allocation of the new spatial channel for the failed virtual WDM link, the WDMoSDM Orchestrator requests the provisioning of an SDM TAPI connectivity service to the SDM Controller, specifying the computed spatial channel.

4. Experimental scenario and results

The experimental setup, shown in Fig.2.a, was based on a WDMoSDM Orchestrator, a WDM VNT SDN controller, an SDM SDN controller deployed at CTTC in Barcelona (Spain), and the WDMoSDM physical infrastructure and SDN hardware agents deployed at KDDI Research in Saitama (Japan). The SDN controller and agents were connected using OpenVPN tunnels. The WDMoSDM infrastructure was composed of two ROADMs and four transponders (TPs)



TP (#)	NCF (GHz)	Virtual Link (#core)	OSNR (dB)
1	193.2	3	28.29
2	193.3	3	27.65
3	193.4	3	26.72
4	193.5	3	27.70

d)

TP (#)	NCF (GHz)	Virtual Link (#core)	OSNR (dB)
1	193.2	6	28.29
2	193.3	6	27.65
3	193.4	6	26.72
4	193.5	6	27.70

e)

Fig. 2. a) Experimental scenario b) Wireshark capture of WDM VNT reconfiguration c) Histogram of DSR provisioning time d) OSNR before failure e) OSNR after virtual link recovered

connected through an SDM network domain. It included an 11-km SDM transmission line (i.e., 19-core fiber [5]) with fan-in/out devices, and two fiber switches. The spatial cores are monitored by an OSA to measure the OSNR of the optical sub-channels. We also introduced a variable optical attenuator (VOA) to degrade all optical channels within an spatial channel. The transponders (ADVA FSP3000) were equipped with a tunable wavelength following the 100 GHz ITU grid, operating at 200 Gb/s with 16QAM controlled by NETCONF.

First, we created a WDM VNT composed of ROADM1 and ROADM2 connected through the spatial core #3, and the four transponders. Once the WDM VNT is provisioned, four digital signal rate (DSR) connectivity services at 200 Gb/s were created between the TX and RX of the four TPs. Fig.2.c shows the histogram of the provisioning time. On average, it takes around 38 s, consumed mainly by the hardware configuration (ROADMs and TPs). Fig.2.b shows the packet capture from the WDMoSDM orchestrator after the WDM VNT has been created. The step #1 corresponds to the subscription to the SXC telemetry agent by means of a gRPC stream, just after the creation of the WDM VNT. Step #2 shows the OSNR data sent by the Telemetry agent every three seconds (set by default). Fig.2d shows the initial OSNR data sent by the SXC telemetry agent for the four optical channels associated to the provisioned digital services at 200 Gb/s. After that, we generated a spatial channel failure by adjusting the VOA to introduce an attenuation of 30 dB to all optical channels. The detection of the OSNR degradation triggered the recovery of the failed virtual WDM link. First, the WDMoSDM orchestrator removed the SDM TAPI connectivity service (i.e., spatial channel) through core #3 (step #3), and requested the TAPI context (i.e., topology and resources) to the SDM SDN controller (step #4). After that, the WDMoSDM orchestrator computed a new spatial channel using core #6 and requested the provisioning of the SDM TAPI connectivity service (step #5) and the TAPI context (step #6) to the SDM controller . Once the virtual WDM is restored, the Telemetry agent started to send the new correct OSNR values using the new spatial channel (core #7), as shown in Fig.2.e. The overall time for recovering a virtual DWDM link is around 15 s.

5. Conclusions

We have demonstrated the feasibility of dynamic reconfiguration of a WDM VNT. The experimental validation has shown that a failed virtual WDM link can be recovered in just 15s, half of the time that would be required to restore the optical channels (in the order of 38s employed in the provisioning time, considering both TPs and ROADMs).

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References

1. M. Jinno, "Spatial channel network (scn): Opportunities and challenges of introducing spatial bypass toward the massive sdm era," Journal of Optical Communications and Networking **11**, 1–14 (2019).
2. C. Manso *et al.*, "First demonstration of dynamic deployment of sdn-enabledwdm virtual network topologies (vnts) over sdm networks," in "Proc. European Conference on Optical Communication (ECOC)," (2021).
3. R. Vilalta *et al.*, "uabno: A cloud-native architecture for optical sdn controllers," in "Proc. Optical Fiber Communication Conference (OFC)," (2020).
4. R. Vilalta *et al.*, "Optical network telemetry with streaming mechanisms using transport api and kafka," in "Proc. European Conference on Optical Communication (ECOC)," (2021).
5. D. Soma *et al.*, "10.16 peta-bit/s dense sdm/wdm transmission over low-dmd 6-mode 19-core fibre across c+ l band," in "Proc. European Conference on Optical Communication (ECOC)," (2017).