Dynamic bypass of wavelength switching in SDN-enabled WDM VNTs over SDM Networks with high bit-rate optical channels

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Abstract: We experimentally demonstrate an SDN architecture for WDM VNTs to offload pass-through high bit-rate optical channels from overloaded ROADMs by provisioning spatial channels between the source and destination ROADM's add-drop stages, and rerouting the optical channels.

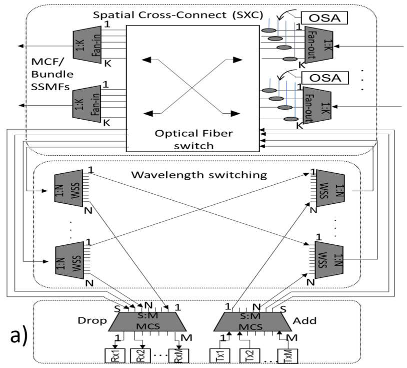
1. Introduction

Future traffic projections predict that 10 Tb/s optical line interfaces will be required by 2025 [1]. Since current spectral efficiency is approaching the Shannon limit, the only way to increase the data rate of the optical line interface is by increasing the bandwidth of the optical channel. The routing of these high bit-rate optical channels will exhaust the available spectrum in the whole c-band wavelength division multiplexing (WDM) links and will overload the pass-through reconfigurable optical add-drop multiplexers (ROADMs) (e.g., A 10 Tb/s optical channel with a spectral efficiency of 4 bits/s/Hz will require a channel bandwidth of 2.5 THz). A novel architecture proposed to increase the capacity of the optical networks leveraging on Spatial Division Multiplexing (SDM) is the spatial channel network (SCN) [2]. SCN allows to bypass the overloaded WDM networks by provisioning spatial paths between ROADMs. 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 uncoupled/weakly-coupled multi-core fiber (MCF).

We presented for the first time the concept of SDN-enabled WDM virtual network topologies (VNTs) over SDM networks in [3]. An SDN-enabled WDM VNT can be deployed as a set of physical ROADMs controlled by an WDN VNT SDN controller, interconnected with virtual WDM links dynamically deployed as spatial channels in the SDM network, controlled by an SDM SDN controller. A WDM over SDM (WDMoSDM) SDN orchestrator is responsible for provisioning, reconfiguration and removal of the SDN-enabled WDM VNTs, following a similar strategy as done for virtual topology mapping in IP over WDM. Previously, we have demonstrated the reconfiguration of the virtual WDM links of WDM VNTs in response to network failures [4] and dynamic traffic changes [5]. In this paper we extend the SDN-enabled WDMoSDM network architecture to enable the provisioning of spatial channels directly between the add-drop stages, bypassing the wavelength switching stages in the ROADMs. The proposed SDN architecture detects sets of high bit-rate optical channels overloading pass-through ROADMs with the same source and destination nodes, dynamically provisions spatial channels between the add-drop stages of the source and destination ROADMs as virtual SDM links, and reroute the high bit-rate optical channels trough them.

2. SDN-enabled WDMoSDM network architecture for wavelength switching bypass

Fig.1.a shows the proposed WDMoSDM node architecture. It is composed by an SXC responsible for the switching of cores/SMFs from any input port to any output port (i.e., MCF or bundle of SMFs). It can be implemented with 1:K fan-in/fan-out devices (where K is the number of cores) and/or one optical fiber switch that is configured by the SDM SDN controller. SXCs are equipped with optical spectrum analyzer (OSA) modules to measure the parameters of the optical channels (e.g., OSNR). We deploy an SXC telemetry agent to stream the measured data from the OSA modules to the WDMoSDM SDN orchestrator. Then, for each tenant, an N-degree ROADM is connected to the SXC and configured by the tenant's WDM VNT SDN controller. The N-degree ROADM is based on the route-and-select architecture implemented with N twin 1:N WSS, one for each degree, and a colourless, directionless and contentionless (CDC) add/drop stage. The main difference with regards to a traditional ROADM architecture is that the add/drop stage is also connected to the SXC with a number of express ports, E, that allows to bypass the wavelength switching stage. The add/drop stage is implemented with two twin S:M Multicast Switch (MCS), where M is the number of transponders (TP), and $S = N + E$. In this way, the signal from different transponders can be multiplexed/demultiplexed together and sent/received to/from either the spatial or the spectral switching stage.



Algorithm 1 Detection of optical channels overloading ROADMs

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Identify optical channels, och, ∈ WDM VNT
Classify och according to path, P (i.e., virtual WDM links, vl )
for Each Group of och with the same path, GSP do
    Compute occupancy rate in all vl ∈ P
    if Occupancy rate for all vl ∈ P ≥ 70% then
        Recompute occupancy rate if removing all och ∈ GSP
        if new occupancy rate ≤ 30% then
            Identify source node, s, and destination node d of P
            Trigger new virtual SDM link between s and d
            Reroute och ∈ GSP
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c)

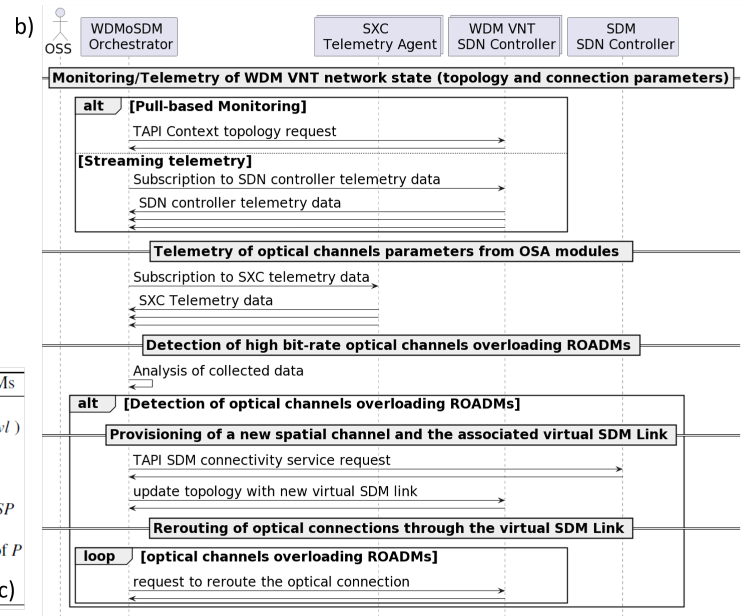

Fig. 1. a) Proposed WDMoSDM node architecture, b) Workflow for dynamic bypass of wavelegnth switching, c) Pseudo-code algorithm to detect optical channels overloading ROADMs

The WDMoSDM SDN orchestrator is based on the ETSI OSG TeraFlowSDN, an open-source cloud-native SDN controller built using a microservices architecture [6] . The cloud-native WDMoSDM SDN orchestrator interfaces with the SDM SDN controller and the tenant WDM VNT SDN controller. To support the creation and monitoring of WDM VNTs, we have developed several microservices such as the WDM VNTM (VNT Manager) responsible for the provisioning and removal of WDM VNTs, the SXC Telemetry collector for collecting the streaming telemetry data from OSA modules using gRPC, or the SXC Degradation Analyzer for analysing the data collected from the OSA. In this paper we have extended these modules to deploy the proposed wavelength switching bypass in WDM VNTs.

3. Dynamic wavelength switching bypass in WDM VNTs with high bit rate optical channels

Fig.1.b shows the proposed workflow. Once the WDM VNT is deployed, first the WDMoSDM SDN orchestrator collects the information of the state of the topology and the active optical channels on each WDM VNT SDN controller, following ONF Transport API (TAPI). It can be performed by streaming telemetry or by pull-based monitoring with periodic requests to the WDM VNT SDN controller. Similarly, the WDMoSDM SDN orchestrator also subscribes to the SXC telemetry agents to get the optical channels parameters (e.g., OSNR). The WDMoSDM SDN orchestrator is continuously analysing the collected data in order to detect optical channels overloading ROADMs using the pseudo-code algorithm shown in Fig. 1.c. In a nutshell, the proposed algorithm classifies the active optical channels of the WDM VNT according to the path (i.e., set of virtual WDM links, *vl*, from the source to the destination node), and computes the occupancy rate on each *vl* of the path, defined as $\frac{\sum_{c=1}^{C} occupied-spectrum_c}{supportable-spectrum_{vl}}$, where C is the set of active optical channels. If the occupancy rate in all *vl* is higher than 70%, then the algorithm recomputes the occupancy rate by removing the set of active optical channels with the same path. If the new occupancy rate in all *vl* is less than 30%, the algorithm triggers the provisioning of a new spatial channel between the add/drop stages of the source and destination ROADMs as a virtual SDM link, and the reconfiguration of the set of optical channels with the same path through the new virtual SDM link. A virtual SDM link can only be used to multiplex/demultiplex optical channels from the transponders connected to the edge add/drop stages. After that, the WDMoSDM SDN orchestrator requests the provisioning of a new spatial channel (i.e., SDM TAPI connectivity service) to the SDM SDN controller. Once provisioned, the WDMoSDM SDN orchestrator configures the new virtual SDM link by updating the new topology in the WDM VNT SDN controller. Finally, the WDMoSDM SDN orchestrator requests the reconfiguration of the set of optical channels to the WDM VNT SDN controller. In this reconfiguration request, the WDM VNT SDN controller removes the optical channels but not the digital channels (i.e., transponders). The WDM VNT SDN controller can use the virtual SDM link to provision new direct optical connections between the edge ROADM's transponders. Once the virtual SDM link is not used, the WDMoSDM SDN orchestrator can remove it.

4. Experimental scenario and results

The experimental setup (Fig.2.a), was based on a WDMoSDM SDN orchestrator, a WDM VNT SDN controller, and an SDM SDN controller deployed at CTTC (Spain), and a WDMoSDM data plane deployed at KDDI Research (Japan), connected using OpenVPN tunnels. The WDMoSDM infrastructure deployed a WDM VNT composed of

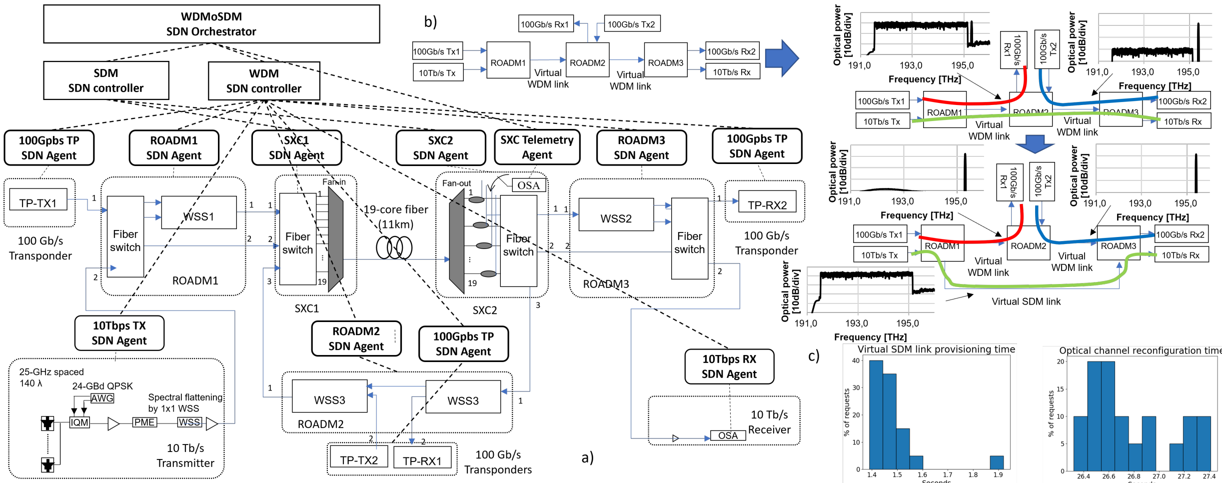

Fig. 2. a) Experimental scenario, b) Deployed WDM VNT topologies, c) Time histograms

three ROADMs with three transponders (TPs) connected through an SDM network domain. The SDM network included an 11-km SDM transmission line (i.e., 19-core fiber [7]) with fan-in/out devices and fiber switches. An OSA monitors the OSNR of the optical channels for each spatial core. Two different transponders were used, 100 Gb/s (tunable wavelength, 100 GHz ITU grid, DP-QPSK) and 10 Tb/s (140 wavelengths, 25 GHz spaced, 24 Gbaud QPSK).

First, the WDMoSDM SDM orchestrator creates a WDM VNT by deploying two spatial channels as virtual WDM links, one between ROADM1-ROADM2 and another between ROADM2-ROADM3 (Fig.2.b). Then, the WDM SDN controller dynamically provisions two 100 Gb/s connection between ROADM1 and ROADM2, and between ROADM2 and ROADM3, and a 10 Tb/s connection between ROADM1 and ROADM3. The WDMoSDM orchestrator is continuously monitoring the TAPI context (topology and connections) and the OSNR data from the optical channels. Fig.2.b shows the optical spectra measured in the spatial channels by the WDMoSDM orchestrator. After analysing the collected data, the WDMoSDM SDM orchestrator detects that the virtual WDM links between ROADM1-ROADM2 and ROADM2-ROAM3 are overloaded (occupancy rate >70%) and decides to setup a new spatial channel between ROADM1 and ROADM3 as a virtual SDM link. Once provisioned, the WDMoSDM SDM orchestrator notifies the WDM VNT SDN controller and it reconfigures the 10 Tb/s optical channel between ROADM1 and ROADM3 to use the new virtual SDM link, bypassing ROADM2. There is no reconfiguration of the 10 Tb/s transponder in order to speed up the reconfiguration time. Fig.2.c shows the measured histograms, after the execution of several tests. The average provisioning time of a virtual SDM link is 1.49s, and the reconfiguration time of the optical channels is 26.76s.

5. Conclusions

We have demonstrated the feasibility of dynamic wavelength switching bypass in SDN-enabled WDM VNTs over SDM networks. The experimental validation has shown that a virtual SDM link to offload ROADMs can be provisioned and the optical connections can be rerouted to the new virtual SDM link in les than 30s.

Acknowledgments

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