Dynamic Upgrade/Downgrade of WDM Link Capacity in SDN-enabled WDM VNTs over SDM Networks

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Abstract *We present a WDM over SDM control system that detects overloaded/underloaded WDM links between ROADMs and provisions/removes virtual WDM links in response to dynamic traffic changes in SDN-enabled WDM VNTs over SDM Networks. We have experimentally validated the architecture in a WDM over SDM testbed.*

Introduction

The traffic in the transport optical networks is continuously growing in terms of volume and variance over decades. In the last 15 years, the global data traffic has doubled every 2-3 years, and this trend can be extrapolated in the upcoming years[1].This situation will exhaust the available spectrum in the wavelength division multiplexing (WDM) networks since advanced multi-level modulation formats combined with polarization multiplexing and WDM are approaching the Shannon limit.

A short-term solution to increase the spectrum is ultra wide band (UWB) WDM systems[2]. It aims at extending the exploited optical spectrum used by WDM to the entire set of available bands (L, C, S, O and E) in standard single-mode fibers (SSMFs). It allows to reuse the already deployed SSMFs, but it needs upgrades on the transceivers, optical amplifiers and ROADMs for the non-C-bands.

In the long-term scenario, the only way to guarantee a sustainable scaling of the optical transport system is combining WDM with space division multiplexing (SDM) transmission to exploit the spectral and the spatial dimensions. The simplest way to make use of the spatial dimension is to deploy (or use the deployed) bundles of SSMFs. It was first commercially deployed by Alcatel submarine networks in 2019[3]. However, the final goal is exploiting the spatial dimensions of the optical fiber (i.e., cores and/or modes), having parallel propagation in the same fiber.

We presented for the first time the concept of SDN-enabled WDM virtual network topologies (VNTs) over SDM networks in[4]. An SDN-enabled WDM VNT can be deployed as a set of physical WDM nodes (i.e., ROADMs) controlled by an SDN controller, and spatial channels providing connectivity between the ROADMs that are handled as virtual links in the WDM network, following a similar strategy as done for IP over WDM. This architecture supports multi-tenancy, since several WDM VNTs can be deployed on top of the shared physical SDM infrastructure. A WDM VNT is reconfigurable in response to network failures as presented in[5]. In this paper we propose the dynamic upgrade/downgrade of WDM link capacity between ROADMs in response to dynamic traffic changes for SDN-enabled WDM VNTs. This approach is much more beneficial than statically upgrading WDM links to exploit UWB WDM.

WDMoSDM network and control Architecture

We consider a WDM over SDM (WDMoSDM) physical network based on the concept of a spatial channel network (SCN) proposed in[6]. An SCN is composed of spatial cross connects (SXC) that enable to provision spatial channels that occupies the entire available spectrum of a SSMF or one core in a multi-core fiber (MCF). An SXC is responsible for the switching of cores/SSMFs from any input port to any output port (i.e., MCF or bundle of SSMFs). 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, as shown in Fig.1.a.

One (or several, one for each tenant) N-degree ROADM can be connected to the SXC, as shown in Fig.1.a. The N-degree ROADM is based on the route-and-select architecture implemented with N twin 1:N WSS, one for each degree. Each ROADM deploys a colourless, directionless and contentionless (CDC) add/drop stage implemented with two N:M WSS, where M is the number of transponders (TP).

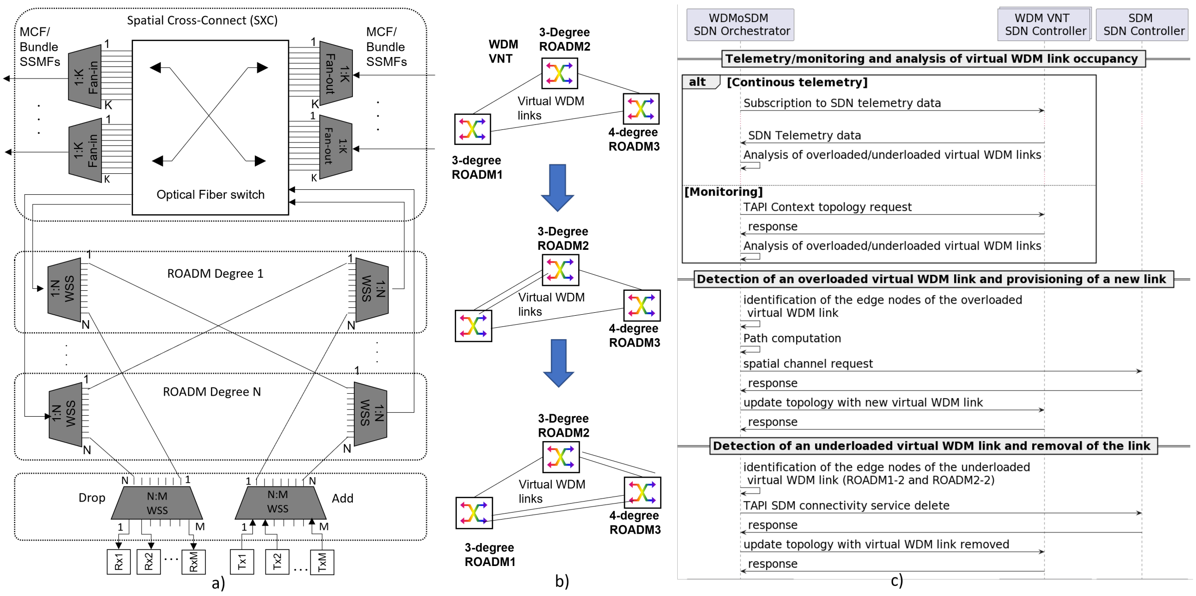

Fig. 1: a) WDMoSDM node architecture, b) Flexible WDM VNT topologies c) workflow for upgrade/downgrade a WDM VNT

Fig.1.b shows an example of the flexibility achieved by the proposed architecture to upgrade/downgrade the WDM link capacity. In the provided example, first a WDM VNT is deployed involving three ROADMs following a ring topology. The 3-degree ROADM1 and ROADM2 have one degree available between them. Therefore, a new virtual WDM link can be provisioned if the traffic demand justifies it. It is worth noting that despite the 4-degree ROADM3 has two available degrees, no additional virtual WDM links can be deployed with ROADM1 and ROADM2 because they do not have any available degree. Once the virtual WDM link between ROADM1 and ROADM2 is realised, two new virtual WDM links can be provisioned between ROADM1-ROADM3 and ROADM2-ROADM3, as shown in Fig.1.b.

At the control level, we deploy an SDM SDN controller for the management of the spatial channels (SCh) by configuring the SXCs, and several WDM VNT SDN controllers, one for each tenant, for the management of the optical channels (OCh) and digital channels (DCh) by configuring the ROADMs and TPs respectively. On top, we deploy the WDMoSDM SDN orchestrator that interfaces with the SDM SDN controller and the WDM VNT SDN controllers. The WDMoSDM SDN Orchestrator is based on the μABNO[7], a cloud-native SDN controller built using a microservices architecture. The detailed architecture of the WDMoSDM orchestrator is described in[4],[5].

Fig.1.c shows the workflow for the upgrade/downgrade of the WDM link capacity in deployed WDM VNTs. Once the WDM VNT is deployed, the WDMoSDM SDN orchestrator collects the information of the active optical channels of the WDM VNT SDN controllers. To this end, two mechanisms are considering, streaming telemetry or monitoring. In the former, the WDMoSDM SDN orchestrator subscribes to the WDM SDN controllers to get telemetry data of the topology and optical channels. In[8], 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 (TAPI)[9] implementation agreement. In the latter, the WDMoSDM orchestrator requests, with a given periodicity (i.e., polling), the TAPI topology and connections to the WDM SDN controllers.

Then the WDMoSDM SDN orchestrator executes the proposed pseudo-algorithm shown in Fig.2.a for detecting overloaded or underloaded WDM virtual links. If the WDMoSDM SDN orchestrator detects an overloaded virtual WDM link (i.e., with an occupancy rate $\geq$ 90%), it provisions a new parallel WDM link between the same pair of ROADMs as long as both ROADMs have a nodal degree available. Similarly, if the WDMoSDM SDN orchestrator detects an underloaded virtual WDM link (i.e., with an occupancy rate = 0%) and there is another parallel virtual link, it removes the virtual WDM link. It allows to upgrade/downgrade the WDM VNTs according to the traffic changes. The procedure and algorithms used by the WDMoSDM SDN orchestrator for provisioning and removing the virtual WDM links are the same as for the provisioning of the WDM VNT, as described in[4]. Once the virtual WDM links are provisioned/removed, the WDMoSDM SDN orchestrator notifies the corresponding WDM SDN controller to update the topology.

Algorithm 1 Overloaded/Underloaded virtual WDM link detection

for each virtual WDM links, vl, $\in$ WDM VNT **do**
    Identify the active WDM connections, C
    Compute occupancy rate, O, as $\frac{\sum_{c=1}^{C} occupied-spectrum_c}{supportable-spectrum_{vl}}$
    Identify two edge nodes of vl, $en1$ and $en2$
    if $O \geq 90\%$ **then**
        if $en1$ AND $en2$ have a degree available **then**
            vl is overloaded
        else
            error
        end if
    else if $O = 0\%$ **then**
        Compute the number of parallel virtual links to vl, PVL_{vl}
        if $PLV_{vl} \geq 2$ **then**
            vl is underloaded
        end if
    end if
end for

a)

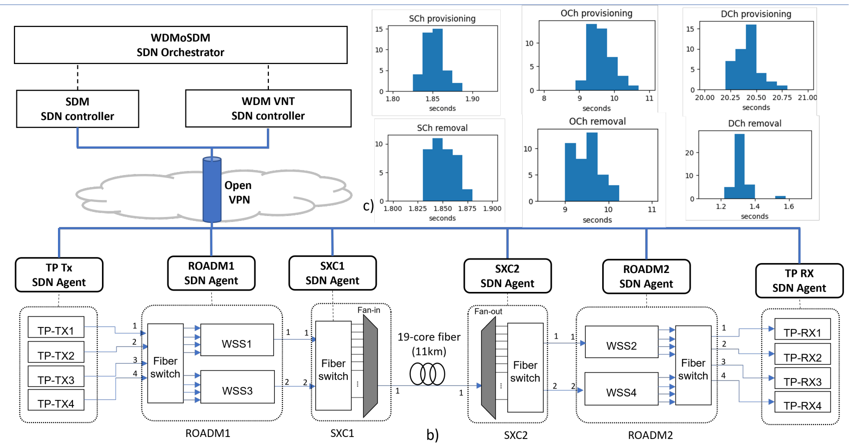

Fig. 2: a) proposed pseudo-code algorithm, b) experimental scenario, c) histograms for provisioning and removal time

Experimental scenario and validation

The experimental setup is shown in Fig. 2.b. It is based on a WDMoSDM control plane deployed at CTTC in Barcelona (Spain), and a WDMoSDM data plane with the SDN agents deployed at KDDI Research in Saitama (Japan). Both sites are connected using an OpenVPN tunnel on top of Internet. On the one hand, the WDMoSDM control plane is integrated by a WDMoSDM SDN orchestrator, an SDM SDN controller for the SDM domain, and a WDM VNT SDN controller. On the other hand, the WDMoSDM data plane deploys two 2-degreee ROADM (Lumentum) and four transponders (TPs) for the WDM VNT, as well as two SXCs. The transponders (ADVA FSP3000) employed at the transmitter and the receiver side, are equipped with a C-band tunable laser following the 100 GHz ITU grid, with two transmission rates, 100-Gb/s (DP-QPSK) and 200-GB/s(16QAM). Finally, the SXCs are implemented with 1:19 fan-in/out devices and an optical fiber switch from POLATIS, connected with an 11-km SDM transmission line (i.e. 19-core fiber[10]).

First, the WDMoSDM SDM orchestrator creates a WDM VNT composed of ROADM1 and ROADM2, and a virtual WDM link connecting both ROADMs through a spatial channel Then, the WDM SDN controller dynamically provisions digital channels at 200Gb/s, involving the configuration of the transponders and the associated optical channels. The WDMoSDM orchestrator is continuously monitoring the TAPI context to WDM VNT SDN controller that includes the topology and connectivity services (optical and digital channels). For testing purposes, when the WDMoSDM SDM orchestrator detects that the virtual WDM link has three active wavelengths, it provisions a second virtual WDM link between ROADM1 and ROADM2 and updates the topology of the the WDM SDN controller. Similarly, when the WDMoSDM SDN orchestrator detects that one of the two virtual WDM links between ROADM1 and ROADM2 has no active wavelengths, it removes the WDM virtual link. Fig.2.c shows histograms, after the execution of several tests, for the provisioning and removal of spatial channels (including only SXC configuration), optical channels (including only ROADMs configuration), and digital channels (including only the time to change the optical signal condition from "Out of service" to "In service" in the transponders, since the complete setting of the optical signal from no light condition in the transponders takes few minutes). The average provisioning time of the SCh is only 1.85s, that is much faster than provisioning an OCh (9.63s) or a DCh (20.40s). A DCh only includes the configuration of the TPs, therefore the overall average time to provision the service, including the configuraiton of the ROADMs is 30.03s. On the other hand, the average removal time of SCh is also very fast (1.85s), but a bit slower than that of the DCh (1.31s). For OCh, the average removal time is similar to the provisioning one (9.50s).

Conclusions

We have demonstrated the feasibility of dynamic upgrading/downgrading of the WDM link capacity in WDM VNTs over SDM networks. The spatial channels associated to the overloaded or underloaded virtual WDM links can be provisioned or removed in less than two seconds, while the overall provisioning time of a digital service, including ROADMs and TPs is arround 30s.

Acknowledgements

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