

First Demonstration of Dynamic Deployment of SDN-enabled WDM Virtual Network Topologies (VNTs) over SDM networks

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Abstract We present the dynamic deployment of logical WDM VNTs by deploying virtual links between ROADM/OXC nodes using spatial channels provided by SDM networks. We propose a cloud-native WDM over SDM (WDMoSDM) SDN orchestrator that is responsible for the lifecycle management of the SDN-enabled WDM VNTs.

Introduction

It is predicted that 1-Pb/s optical transport systems will be required by 2024, based on a constant average traffic growth of 60% observed over the past years^[1]. Wavelength division multiplexing (WDM) networks will become overloaded, since multi-level modulation formats combined with polarization multiplexing and WDM are closely approaching the Shannon limit. Therefore, more spectrum will be required. A short-term solution to increase the capacity is band division multiplexing (BDM). It aims at extending the exploited optical spectrum used by WDM to the entire set of available low-loss bands in standard single-mode fibers (SSMFs)^[2]. However, the only way to guarantee a sustainable scaling of the optical transport system in the long-term is combining WDM with space division multiplexing (SDM) to exploit the spectral and the spatial dimensions.

SDM can be deployed by parallel SSMFs or multi-core fibers (MCFs) having parallel propagation in the same fiber. A novel WDM over SDM (WDMoSDM) network architecture recently proposed is spatial channel network (SCN)^[3]. It is composed of spatial cross connects (SXC) that enable to provision spatial channels that occupies the entire available spectrum of a conventional SMF or one core in an MCF. SCN allows to bypass the overloaded WDM networks by provisioning spatial paths between WDM nodes, following a similar strategy as done for IP over WDM (IPoWDM). In^[4], we presented the first SDN control architecture for WDMoSDM networks.

In this paper, we take advantage of the SCN to extend the concept of virtual network topologies

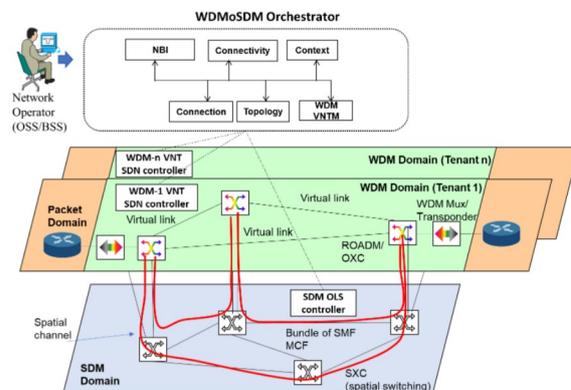


Fig. 1: WDMoSDM Orchestrator architecture and WDM VNT scenario

(VNTs) to the WDM layer as shown in Fig. 1). In a similar way as in IPoWDM networks, VNTs forming logical IP networks were created by connecting real IP routers through virtual links provided by lightpaths in the WDM layer^[5], here we propose for the first time WDM VNTs. It consists on providing logical WDM networks by deploying virtual links between real WDM nodes (ROADM/OXC) using spatial channels provided by the SDM layer. We propose a cloud-native WDMoSDM SDN orchestrator based on microservices that is responsible for the lifecycle management of the SDN-enabled WDM VNTs.

WDMoSDM Orchestrator

The cloud-native WDMoSDM SDN Orchestrator proposed in this paper is based on the μ ABNO^[6], an SDN controller with 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, a WDM VNTM (VNT Manager) microservice has been included

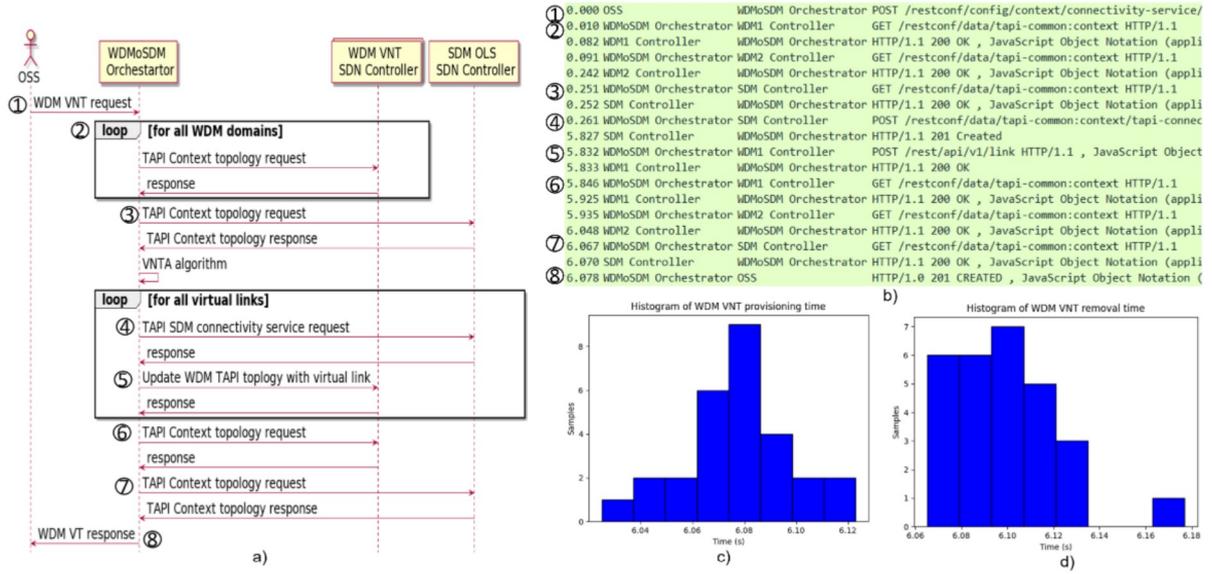


Fig. 2: a) WDM VNT provisioning Workflow b) WDM VNT provisioning Wireshark capture c) Histogram of WDM VNT provisioning time d) Histogram of WDM VNT removal time

into the architecture, responsible for the provisioning and removal of WDM VNTs.

The network operator is responsible for defining the logical WDM VNT (i.e., involved WDM nodes and required virtual links). Once defined, it requests the provisioning of the WDM VNT to the WDMoSDM orchestrator (1), as shown in Fig. 2a. First, the WDMoSDM Orchestrator gets the TAPI context of the WDM and SDM domains (2, 3). The TAPI context includes the topology and the active connectivity services (i.e., WDM and SDM connections). Then, the VNTM computes the spatial channel for each virtual link included in the requested WDM VNT. We propose the following VNT assignment (VNTA) algorithm:

1. Calculate a set of spatial routes, R (i.e. SDM nodes and links) in the SDM network between the source WDM port, s and the destination WDM port, d , of the virtual link using a k-shortest path algorithm that minimize the number of hops. Note that other constraints such as link disjointness could be considered to avoid multiple virtual links from the same VNT use the same MCF.
2. Compute the set of available cores, C , that meet the spatial core continuity along the computed route, r (i.e. use the same core in all links of the computed route). This continuity is imposed in order to simplify the procedure.
3. If one or more cores are found, for each core c , in C , calculate the overall occupancy rate:

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

Where L is the number of links along the computed route, and N is the number of neighbouring cores adjacent to c . The chosen core is the one with the smaller occupancy rate, aiming to avoid inter-core cross-talk effect.

4. Step 2 is repeated for the next r in R if no suitable core is found. If there are no more r and a suitable one was not found, return error.

After a suitable spatial channel is found for each virtual link, the WDMoSDM Orchestrator requests the provisioning of the SDM TAPI connectivity services to the SDM SDN Controller (4), specifying the computed spatial channel. After that, the WDMoSDM Orchestrator requests the WDM VNT SDN controller to update its topology with the newly created virtual links (5). This way, the WDM nodes are connected by virtual links deployed as spatial channels that are transparent to the WDM domain. Finally, the WDMoSDM Orchestrator gets the WDM (6) and SDM (7) domain TAPI contexts to check all operations are performed correctly before it replies (8).

Experimental demonstration

The experimental setup, shown in Fig. 3a, was based on a WDMoSDM Orchestrator and SDN controllers for WDM-1 VNT, WDM-2 VNT, and SDM domains deployed at CTTC in Barcelona (Spain), and the WDM and SDM hardware and SDN agents deployed at KDDI Research in Saitama (Japan). The controller and the agents were connected using OpenVPN tunnels across

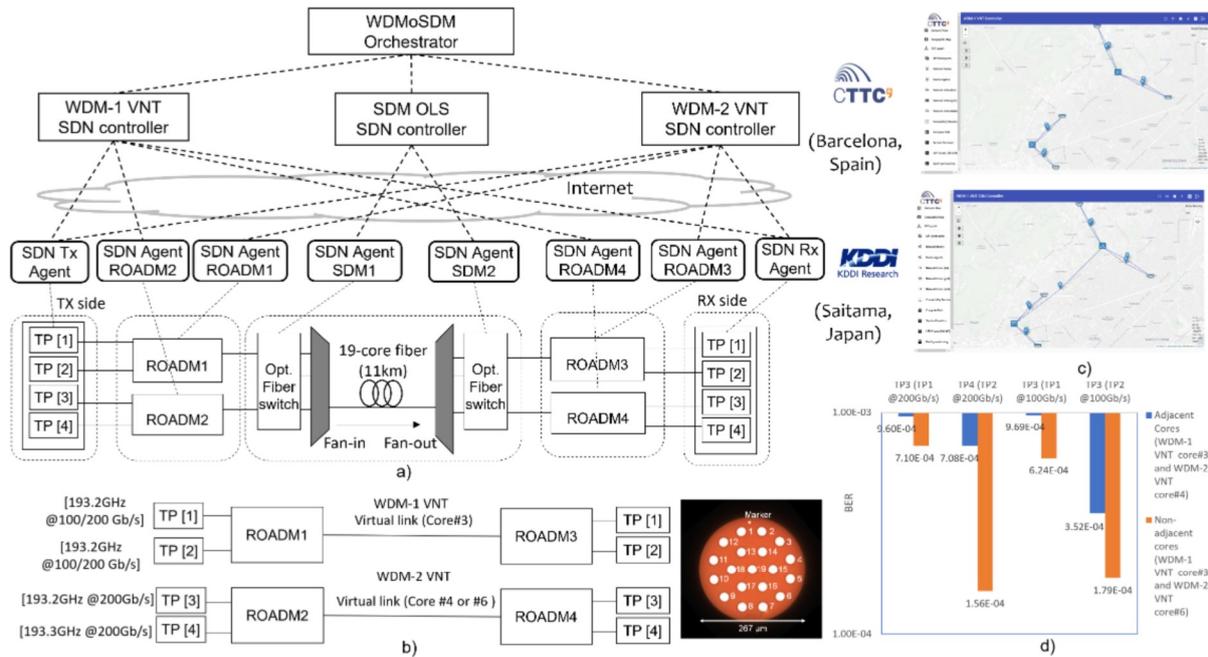


Fig. 3: a) Experimental scenario b) deployed WDM VNTs c) GUI of WDM-1 SDN Controller d) BER measurements

Internet. Each WDM VNT domain comprised two ROADMs and two transponders (TPs), whereas the SDM network domain included an 11-km SDM transmission line (i.e. 19-core fiber^[7]) with fan-in/out devices, and two optical switches. The transponders (ADVA FSP3000) employed at the transmitter and the receiver side, were equipped with a C-band tunable wavelength and they operated at a frequency range from 193.2 THz to 193.3 THz following the 100 GHz ITU grid. The transponders were also capable of two transmission rates, 100-Gb/s with DP-QPSK and 200-Gb/s with 16QAM controlled with NETCONF.

To validate the feasibility of the WDMoSDM orchestrator, we deployed WDM-1 VNT composed of ROADM1, ROADM3, and TP1 and TP2. Fig. 2b shows the whreshark capture of the exchange of messages between the WDMoSDM orchestrator and the WDM and SDM SDN controllers in order to provision the WDM-1 VNT. In this case, it was required to provide a spatial channel using the 19-core fibre between ROADM1 and ROADM3. The spatial channel is selected according the proposed VNTA algorithm, and the configuration of the spatial channel lasts 5.8 seconds. The top of Fig. 3c shows the GUI of the WDM-1 VNT SDN controller at the initial stage, where the two ROADMs are seen but are not connected to each other, and the bottom of Fig. 3c shows the GUI once the virtual link is deployed. Fig. 2c shows an histogram of the time to provision WDM VNTs, which was always able to finish between 6.09 and 6.12s, where Fig. 2d

shows an histogram of the time to delete it, between 6.068 and 6.177s.

In order to evaluate the impact of the core selection by the VNTA algorithm to reduce the inter-core crosstalk between WDM VNTs, we deployed a second WDM VNT between ROADM2 and ROADM4 with TP3 and TP4, and measured the BER. TP1 from WDM-1 VNT and TP3 from WDM-2 VNT were both configured at 193.2 GHz, and similarly, TP2 and TP4 at 193.3 GHz. TP1 and TP2 were configured at 100 Gbps or 200 Gbps and TP3 and TP4 were configured at 200 Gbps. The virtual link of WDM-1 VNT was always configured to use SDM core #3, and for WDM-2 VNT, it was manually assigned to an adjacent core (#4) and a non-adjacent core (#6). Fig. 3d shows the pre-FEC BER measured for TP3 and TP4. It is demonstrated that BER slightly deteriorates when WDM-2 VNT uses an adjacent core to WDM-1 VNT. Therefore it validates the proposed VNTA that avoids spatial channels with high occupancy rate for WDM VNTs.

Conclusions

We have presented the first demonstration of dynamic deployment of WDM VNTs over SDM networks and evaluated the architecture and its benefits.

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