SDN/NFV Control and Orchestration for SDM Networks

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Abstract: *We present an SDM network and node architecture based on sliceable spatial-mode, spatial-core and spectral transceivers, and a centralized SDN controller with NETCONF and TAPI for the management of SDM super-channels by multiple NFV orchestrators*

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I. INTRODUCTION

The combination of space division multiplexing (SDM) with wavelength division multiplexing (WDM) transmission enables to jointly exploit both the spatial and spectral dimensions of the fiber (i.e. frequencies, cores and modes) to provide SDM super-channels [1]. An SDM super-channel is composed of multiple optical channels transmitted in parallel over different spectral frequencies, spatial cores and/or spatial nodes in the same fiber using multicore fibers (MCF), multimode fibers (MMF), or combining cores and modes in few-mode multicore fibers (FM-MCFs). The main limitation of the SDM transmission is the optical channel crosstalk due to the mixing among randomly-coupled SDM cores and/or modes. Efficient fiber designs can minimize the coupling among spatial cores to almost negligible values that maintain the orthogonality of cores. However, the coupling among modes raises in real fibers due to non-ideal fiber cross sections or longitudinal variations. To undo the channel crosstalk, multiple input multiple output (MIMO) digital signal processing (DSP) is required at the receivers to equalize the modes.

The adoption of an SDN control architecture with common and open APIs is key for the management (i.e., provisioning, monitoring, reconfiguration and deletion) of the SDM super-channels. On the one hand, it is required to define the southbound interface (SBI) to export the programmability along with unified and systematic information and data modelling of the SDM hardware. On the other hand, another challenge is the integration of cloud and edge computing with SDM networks in order to support 5G and IoT-oriented services [2]. To this end, the integration of the network function virtualization (NFV) orchestration framework defined by ETSI with SDN is key to provide an efficient resource orchestration (i.e., networking and computing). Therefore, it is required to define the SDN controller's northbound interface (NBI) with the NFV orchestrator (NFVO) to enable the integration of the SDM network in the NFV framework.

In this paper we present an SDM network architecture based on sliceable spatial-mode, spatial-core and spectral transceivers, and an SDN control architecture for the management of SDM super-channels by multiple NFV orchestrators.

II. PROPOSED SDM NETWORK ARCHITECTURE

We consider the following assumptions for the design of the target SDM network: i) all modes have to be jointly routed from the source to the destination nodes along the same path in order to perform joint MIMO DSP equalization; ii) no mode switching can be performed at the intermediate nodes, and the modes of one core can only be jointly added or dropped at the edge nodes; iv) spectrum can neither be switched at the intermediate nodes, and similarly to the modes, it can only be added and dropped at the edge nodes, and; v) spatial cores can be independently switched from any input port to any output port at any node of the network due to its orthogonality, enabling to provision core switched paths between the source and destination nodes.

Fig.1. shows the considered SDM node architecture. It is composed of a core, mode and spectrum add/drop (CMSAD) stage and a spatial core switching (SCS) stage. The CMSAD deploys three different types of transceivers; i) sliceable-spectral transceivers (S-STs); ii) sliceable-mode transceivers (S-MTs), and; iii) sliceable-core transceivers (S-CTs). The sliceable-spectral transceiver provides WDM super-channels composed of multiple flexi-grid DWDM channels with bandwidth adaptability (for variable bitrate/distance data flows) transmitted in parallel in a single mode fiber (SMF). The S-ST supports sliceability to generate multiple WDM super-channels that can be logically assigned to a slice as if they were generated by independent (virtual) transceivers. The S-STs can be implemented by an array of M bandwidth variable transponders (BVTs) modules. The BVTs are connected to programmable spectrum selective switches (SSSs).

On the other hand, the sliceable-mode transceiver transmits SDM super-channels composed of multiple optical channels that can be allocated in different frequency slots and on different modes. In particular, it is developed with an array of F S-STs connected to mode muxes/demuxes. Similarly, the sliceable-core transceiver also generates SDM super-channels but the optical channels are allocated on different cores. It is also deployed with an array of S-STs but connected to core muxes/demuxes (i.e., fan-in/fan-out). Both the mode and core transceivers support sliceability, enabling to deploy

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multiple slices on each transceiver. Tx and Rx DSP modules for each transceiver are deployed to support multiple modulation formats and BER processing. MIMO equalization is also performed in the joint Rx DSP modules of the sliceable-core transceivers.

As regards the SCS stage, it is responsible for the switching of the cores from any input node to any output node, as well as from/to the transceivers allocated in the CMSAD stage. The SCS stage is developed with MCF fiber fan-in/fan-out devices and one (or several concatenated) spatial fiber switch.

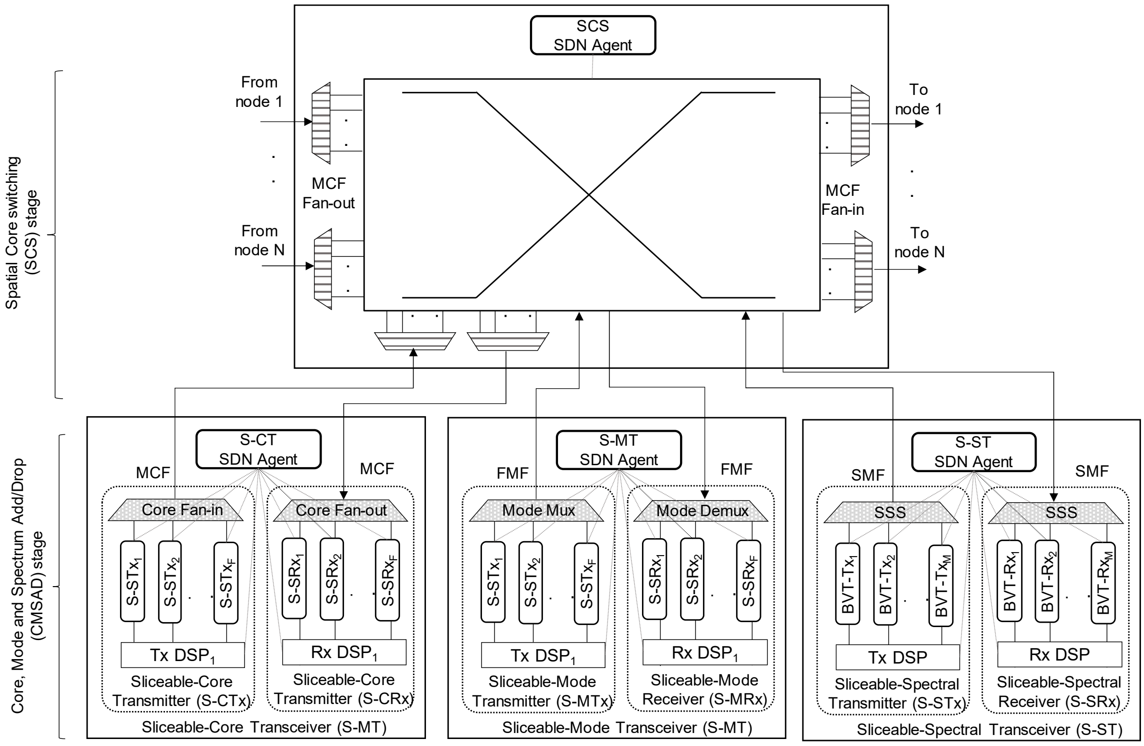

Fig. 1. Proposed SDM node architecture

III. SDN CONTROLLER FOR SDM NETWORKS

The considered SDN control architecture relies on a disaggregated approach with a centralized SDN controller and multiple SDN agents, one for each transceiver (i.e., S-ST, S-MT and S-CT), as well as for the SCS stages, as depicted in Fig.2 (right). The SDN agent's purpose is to abstract the low-level, hardware-dependent operations of the hardware into high-level operations, mapping the proprietary protocols of the hardware to a common protocol used by the SDN controller. By means of the SDN agents, the SDN controller can configure the slices with the SDM and WDM channels, and monitor the BER of the associated optical channels. The SBI of the SDN controller towards the SDN agents is based on YANG/NETCONF. YANG data modelling language is used to define the configurable and monitoring parameters, and NETCONF protocol provides mechanisms to install, manipulate and delete the configuration of network devices.

We have developed a YANG data model for the capability functionalities (*sliceable-transceiver-sdm-capabilities.yang)* and another for the connectivity functionalities *(sliceable-transceiver-sdm-connectivity.yang)* of the transceivers in [3]. The capability YANG module encompasses a list of available cores and a list of available BVTs for each S-ST. Each core is composed of a core ID and a list of available modes. Each mode encompasses a mode ID, a list of available frequency slots, and another list with the occupied frequency slots. The list of available/occupied frequency slots is composed of the slot ID, the nominal central frequency, and the slot width number. As regards the list of available BVTs, the state data defined are a list of the supported modulation format identified by modulation ID and type, the range of supported nominal central frequencies, the maximum and minimum supported bandwidth, as well as the supported FEC, equalization and monitoring parameters. This YANG module can be applied to all defined transceivers by making the following assumptions; for S-CT, just one mode (fundamental) is used; for S-MT, just one core (main) is used; for S-ST, just one core (main) and mode (fundamental) is used. As regards the connectivity YANG module, it encompasses a list of slices (each transceiver can support multiple slices). Each slice is composed of a slice ID, a list of optical channel parameters (i.e., frequency slot, mode-id, core-id) and the associated signal parameters (modulation, bandwidth, equalization, and monitoring) to each optical channel.

The SDN controller's NBI is based on Transport API (TAPI). We propose to use the TAPI as the interface between the SDN controller and the NFV orchestrator. The TAPI is defined by the ONF as a common API that abstracts a set of common SDN control plane functions (e.g., topology and connectivity services) and defines a common data model and protocol based on YANG/RESTconf. We have extended the TAPI for SDM networks in [4]. The SDN controller supports multiple NFV orchestrators by assigning different slices to the requested connectivity services.

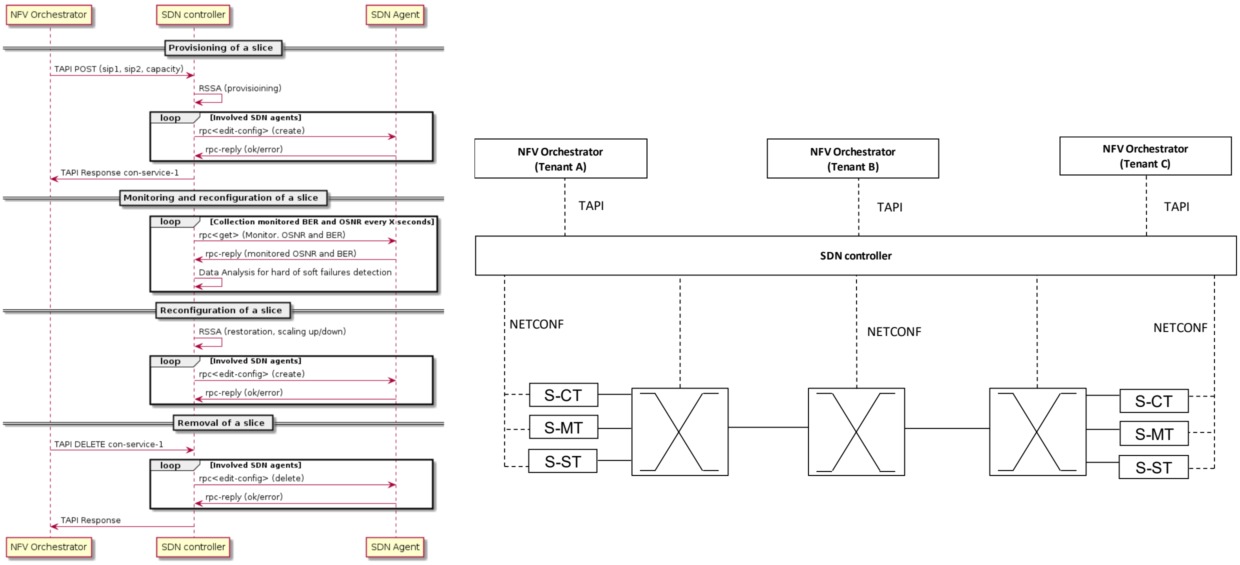

Fig.2. Left: Workflow for provisioning, monitoring, reconfiguration and removal of slices with SDM super-channels. Right: Example of SDN-controlled SDM network with multiple NFV orchestrators (NFVO) as tenants.

Fig.2 (left) shows the sequence of NETCONF and TAPI messages employed for provisioning, monitoring, reconfiguration and removal of a slice. First, there is an exchange of <hello> messages between the SDN controller and the SDN agents in order to discover the peer's supported capabilities (e.g. the supported capabilities in the transceivers). Once the session is open with all SDN agents, the NFV orchestrator can request the provisioning of a connectivity service specifying the end-points (i.e., source and destination transceivers) and the required capacity. When the SDN controller receives the TAPI connectivity service request, it executes a Routing Spatial and Spectrum Assignment (RSSA) heuristic to compute the core switched path/s between the source and destination transceivers and the SDM super-channel (i.e., list of optical channels parameters and associated signal parameters) to meet the required capacity. An example of a RSSA heuristic for scaling up/down of SDM super-channels is presented in [5]. Then, the SDN controller first configures the core switched path/s (if not already provisioned) and second the slice in the transceivers (both source and destination). It is performed by sending rpc<edit-config> (create) messages specifying the configurable parameters to the SDN agents. They reply with a rpc-reply<ok/error> message to the SDN controller.

After the provisioning of a slice, the SDN controller can request the BER or OSNR (of all or some of the optical channels of the provisioned slice) monitored at the receiver. It is performed by sending a <get> message to the SDN Rx agent. The SDN controller collects and processes the monitoring data from SDN agents to assess the performance of the provisioned SDM super-channels by detecting hard or soft failures and triggering the restoration mechanisms, as presented in [6]. To this end, the SDN controller sends a <edit-config> (merge/replace) message to the involved SDN agents to reconfigure the parameters of the optical channels, add or remove optical channels to/from the SDM super-channel. Finally, the NFV orchestrator can request to the SDN controller the removal of the created connection using TAPI. The SDN controller removes the associated slice by sending to the SDN agents a <edit-config> (delete) message.

IV. CONCLUSIONS

The control of SDM super-channels in disaggregated SDM networks and its integration to the NFV framework for joint orchestration of cloud and network resources is feasible using the proposed SDN control plane with open APIs such as YANG/NETCONF for the SBI with the SDM hardware and TAPI for the NBI with the NFV orchestrator.

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