First Demonstration of MANTRA IPoWDM Convergent SDN Architecture using SONiC White Box and 400ZR/ZR+ Pluggables

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***Abstract*—In this work, the MANTRA "Single" IPoWDM architecture is implemented and experimentally demonstrated in a network testbed employing three SDN Controllers (IP, Optical and Hierarchical) and SONiC white box equipped with 400ZR and 400ZR+ coherent pluggable transceivers.**

***Index Terms*—400ZR, CMIS, pluggable, SDN, disaggregation.**

I. Introduction

The recent availability of cost-effective 400G coherent pluggable transceivers in QSFP-DD form factor (e.g., 400ZR) is driving the introduction of integrated IP over Wavelength Division Multiplexing (IPoWDM) solutions in the context of metro networks [1]–[7]. This is also facilitated by: (i) common implementation agreements for the management interface between the router and the coherent pluggable transceiver (OIF IA-CMIS and C-CMIS [8]); (ii) optical disaggregation enabled by Software Defined Networking (SDN) open and standard management interfaces for optical transport networks. IPoWDM eliminates the presence of traditional transponders/muxponder devices, thus potentially reducing CAPEX, equipment footprint, power consumption, and number of elements to be planned, installed, managed, and maintained. However, IPoWDM poses new challenges in defining and implementing novel convergent SDN architectures enabling coordinated control of IP and optical resources. Indeed, so far, IP and WDM configurations are typically provided by two different SDN controllers, one in charge of packet resources and the other in charge of optical transport.

The MANTRA (Metaverse ready Architectures for Open Transport) within the Telecom Infra Project (TIP) is one of the most relevant initiatives aiming at constructing an end-to-end reference network architecture for IPoWDM. They recently published a white paper where two different IPoWDM SDN architectures are identified [9], [10].

The first architecture is named Dual South Bound Interface (SBI) management of IPoWDM routers (here referred to as *Dual*). In Dual, the IP SDN Controller (IP-C) is the only entity configuring IPoWDM routers, including coherent pluggables. In addition, the Optical SDN Controller (Opt-C) is granted with read-only permissions (write permissions are not granted in order to avoid out-of-synch issues). The second IPoWDM SDN architecture is named Single SBI management of IPoWDM routers (here referred to as *Single*). In Single, the IP-C is the only entity directly interfaced with IPoWDM routers, including coherent pluggables. That is, the Opt-C has no access to routers. In both cases, coordination between IP-C and Opt-C (e.g., for impairment-aware provisioning) is guaranteed by a hierarchical SDN Controller (Hier-C). However, in Single, additional data need to be exchanged with respect to Dual, given the lack of visibility by Opt-C on pluggable capabilities and related monitored parameters.

The work in [11] and [12] presents valuable demonstrations of the Dual architecture. Specifically, [12] also shows an alternative architecture where the Opt-C is granted with both read and write permissions to routers, addressing out-of-synch issues through specific NETCONF functions defined by RFC 8341. So far, no scientific work reports on the implementation and validation of the Single IPoWDM SDN architecture as defined by the MANTRA initiative. Thus, in this work, we present the first demonstration of MANTRA Single IPoWDM Convergent SDN Architecture. The demonstration leverages on a 400G White Box equipped with 400ZR coherent pluggable transceivers and running the open-source network operating system SONiC [12], [13], extended with NETCONF and telemetry agents.

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II. MANTRA Single SBI Implementation

Fig. 1 shows the reference network scenario reproducing the Single SDI Architecture defined by MANTRA [9].

Router consists of a Edgecore 400Gb/s IPoWDM white box equipped with 400ZR and 400ZR+ coherent pluggable modules. The white box runs the open-source NOS SONiC_20220819 [14]. This version of SONiC includes the support to OIF CMIS version 5 and C-CMIS version 1.1 [8] implementing the interface between the NOS and the pluggables. In addition to the default SONiC applications (i.e., swss, soniccfggen, pmon, syncd, and redis database), our implementation includes, as containerized function, the NETCONF agent providing both configuration and monitoring of optical pluggable transceivers. The agent leverages on the OpenConfig model to describe hardware characteristics including packet-based interfaces and coherent pluggable modules.

All the deployed SDN controllers (i.e., IP-C, Opt-C and Hier-C) are based on ONOS. They rely on specifically designed applications enabling the communication between IP-C and Opt-C, through the Hier-C.

The Hier-C exploits a specifically designed Hierarchical App (H-App) derived from [12]. It stores the network status and it communicates with both IP-C and Opt-C via REST APIs. In particular, the H-App encompasses a module to discover and manage child controllers and to locally store network element information on link and devices, including details about the coherent optical modules installed in the router that represent the demarcation point between the packet and the optical domain. Furthermore, when a new connection request arrives, the H-App performs end-to-end path computation across both the IP and WDM layers. Finally, the H-App stores the result of the connections installed in the network.

The IP-C also exploits a specifically designed IP-C App which (i) manages the communication with the Hier-C and (ii) provides NETCONF connectivity to retrieve and configure the configurable optical parameters of the pluggable modules, including their type, location, and status. For example, dedicated software modules are responsible to notify the Hier-C in case of intent enforcement or changes to link status upon discovery or failure.

III. Experimental demonstration

The experimental validation of the MANTRA IPoWDM Convergent SDN Architecture has been assessed considering both control and data plane perfomance.

From a control plane perspective, the Single solution has been validated analyzing the interactions among the three controllers. Controller communicate using REST APIs to: (i) discover the network topologies; (ii) discover detailed parameters of pluggable modules and their interconnection points to the optical layer; (iii) setup an optical connectivity; (iv) configure the pluggable modules; and (v) set up the packet connectivity. The whole experimental procedure to setup an end-to-end connectivity service involving the activation of a new lightpath and traversing two distinct packet islands has been repeated ten times taking an average time of about 4

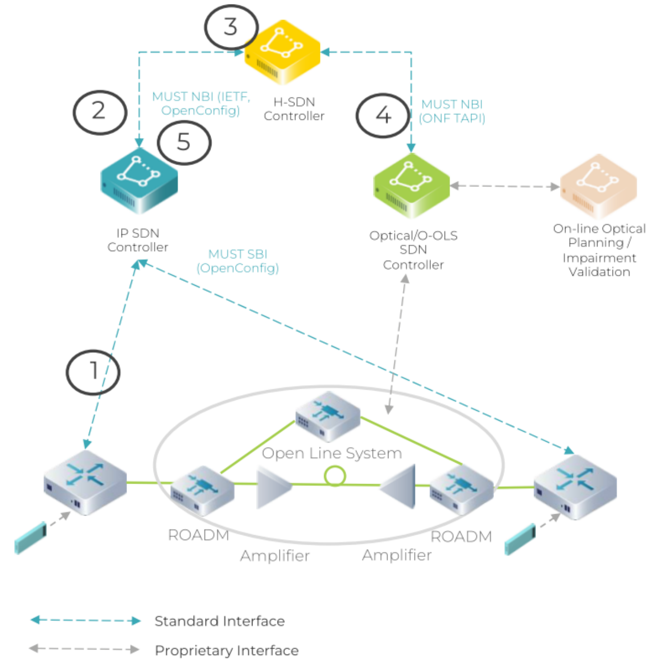

Fig. 1. MANTRA Single SBI management of IPoWDM routers [9], [10]

seconds. This time includes the time required to exchange all the control messages but does not include the time needed to physically activate the laser in the pluggable modules.

From a data plane perspective, focus has been devoted to the the performance of 400ZR/ZR+ transceivers in terms of configuration time. During the experimental evaluation, the setup of an end-to-end connectivity has been repeated several times, performing the variation of the central frequency adopted for the optical connection. More specifically, the optical carrier has been moved, performing the (re)-configuration using the library provided by SONiC.

The frequency shifts have been performed considering both nearby frequencies and distant frequencies in order to check whether the reconfiguration time depends from the frequency gap to be covered. The optical configurations have been performed considering the two types of pluggable transceivers (i.e., two ZR and two ZR+ modules). For each run, two time interval values have been collected: the first (named *prompt* in the table) is the time interval taken by SONiC to receive the command and return the prompt after a frequency change command; the second (named *laser* in the table) is the time interval passed form the command issue and the signal detection at the RX. In addition, an Optical Spectrum Analyzer (OSA) has been adopted on the optical link to monitor the spectrum occupancy.

Considering the two ZR modules, performing a frequency reconfiguration with 2 THz gap (passing from 193.0 THz to 195.0 THz) has taken around 10 seconds (10.39 and 9.6 seconds, respectively) at the prompt level, while a longer time interval (around 67.6 seconds) has been experienced to have the optical signal successfully transmitted to the other module.

		ZR sample 1		ZR sample 2		ZR+ sample 1		ZR+ sample 2	
Start F	Stop F	prompt	laser	prompt	laser	prompt	laser	prompt	laser
THz	*THz*	*s*	*s*	*s*	*s*	*s*	*s*	*s*	*s*
193.0	195.0	10.39	67.65	9.60	67.63	9.78	16.15	9.45	15.69
195.0	193.0	9.67	67.87	9.46	70.58	9.38	15.31	9.46	13.20
193.0	193.1	9.50	69.43	9.39	69.54	9.45	15.26	9.52	15.70
193.1	196.0	9.78	68.04	9.47	69.54	9.64	15.66	9.51	19.10
196.0	192.0	9.47	71.06	9.79	67.34	9.51	15.90	9.52	15.21

Fig. 2. Control Performance of coherent pluggable modules in IPoWDM white box

The reverse operation, passing from 195.0 THz to 193.0 THz, has presented similar time for the reconfiguration, with a command issuing time of about 9.5 seconds (respectively 9.67 and 9.46 seconds) and a laser activation time slightly greater that 67 seconds (respectively, 67.87 and 70.58 seconds). Even considering smaller frequency gap (from 193.0 Thz to 193.1 THz with 0.1 THz of gap) or bigger frequency gap (from 196.0 THz to 192.0 THz, with 4 Thz of gap) has not differently impacted the reconfiguration time, with values collected in the same order of magnitude (prompt issuing time around 10 seconds and laser activation time around 70 seconds).

Considering instead the two ZR+ modules, the frequency reconfiguration with 2 THz gap (passing from 193.0 THz to 195.0 THz) has achieved similar performance in terms of prompt results (repectively 9.78 and 9.45 seconds). However, significantly faster performance have been experienced considering the optical transmitted signal achieving configuration time around 15 seconds (i.e., 16.15 and 15.69 seconds, respectively). As collected for the ZR modules, the reverse operation, passing from 195.0 THz to 193.0 THz, has presented similar time for the reconfiguration, with the prompt issuing time in the order of 10 seconds (respectively, 9.38 and 9.46 seconds, respectively) and a shorter laser activation time (respectively, 15.31 and 13.20 seconds). Even considering small frequency gap (from 193.0 THz to 193.1 THz with 0.1 THz of gap) or bigger gap (from 196.0 THz to 192.0 THz, with 4 THz of gap) has not differently impacted the reconfiguration time, with similar values collected: prompt issuing time around 9.5 seconds and laser activation time around 15.5 seconds).

Further analyzing the results collected using the two classes of pluggable transponders (e.g., the ZR and ZR+ modules), it is clear that the modules present considerable differences. Specifically, ZR+ modules guarantee a faster laser activation time. Moreover, the table shows that the (re)-configuration time interval does not depend on the gap between the starting and stop frequencies. In addition, the collected results show that modules of the same type present similar behavior, showing a stable and uniform configuration time.

During the experiments, the modules presented some issues on configuring the frequency values at the extremes of the tuning bands, with respect to the nominal values configured and stored in the transceivers. This produced some critical states: in some cases the modules became unavailable and a manual intervention was needed in order to remove and reinsert the modules in the box to make them again available.

IV. Conclusions

The MANTRA "Single" IPoWDM architecture is implemented and experimentally assessed, specifically focusing on control and data plane configuration time. Results show that around 4 seconds are needed at the control plane level to provision IPoWDM connectivity while around 70 and 16 seconds are needed at the data plane level using respectively 400ZR and 400ZR+ coherent pluggable transceivers.

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