Design and Deployment of an SDN Programmable Optical Metro Network with VCSEL-Based S-BVTs

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ABSTRACT
Upcoming metro networks are required to transport huge and highly dynamic data traffic whilst resulting cost and power efficiency. In this context, the EU-H2020 PASSION project targets such a network design exploiting a solution based on both: i) programmable, modular, cost-efficient and low-power sliceable bandwidth/bitrate variable transceivers (S-BVTs) formed by a pool of vertical cavity surface emitting lasers (VCSEL) and Coherent Receivers (CO-Rx); ii) hierarchical switching nodes in an optical flexi-grid network to provide all-optical transport and aggregation capabilities. In this context, an SDN controller is designed and deployed to attain the automatic programmability of the underlying transport network. Thereby, this work focuses on detailing the specific functions, workflows and control interfaces handled by the SDN controller which are tailored to the imposed requirements and capabilities of the targeted PASSION optical network solution. The goal is to attain the complete data plane configuration (involving several network elements and devices such as S-BVT and optical switches) to dynamically accommodate end-to-end heterogenous data rate optical connections.

Keywords: SDN, Flexi-grid Optical Metro Networks, VCSEL, S-BVT.

1. INTRODUCTION
Metro networks are crucial to cope with the huge transport and highly dynamic traffic of 5G (and beyond) network services. Such networks need to be designed with enhanced flexibility and higher capacity while attaining reduced cost, energy, and footprint [1]. The EU-H2020 PASSION project [2] targets those metro network challenges exploiting the advantages of photonic technologies over flexi-grid networks. Specifically, dense photonic integration and cost-effective photonic devices are adopted to deploy programmable and flexible network elements such as optical transceivers. Network programmability is attained by a centralized SDN controller. To this end, the controller uses defined interfaces (APIs) to directly configure the underlying pool of network elements [3].

In the PASSION project, the emerging photonic technology of VCSEL at long-wavelength is considered to deploy novel, low cost, power, and footprint SDN-controlled transceivers. VCSEL technology and photonic integrated circuits (PICs) are combined to attain a modular and scalable sliceable bandwidth/bitrate variable transceiver (S-BVT) reaching Tb/s capacity within the metro networks. The modular SBVT is based on a hierarchical architecture formed by the tuple Module/subModule/VCSELS (as shown in Fig.1 (left)). A Module is bound to a silicon-on-insulator (SOI) chip. Such a Module integrates 4 subModules having 10 VCSELS each. Thus, a S-BVT with a single Module where all the possible VCSELS are licensed achieves a compact transmitter (Tx) with 2 Tb/s maximum capacity. Each VCSEL provides up to 50 Gb/s operating at a C-band wavelength: 191.900 - 195.875 THz. The modular S-BVT can achieve a transport capacity of 2 Tb/s by adding (up to 4) Modules. This results on a fully equipped S-BVT providing a maximum transmission of 8 Tb/s via 160 VCSELS. At the S-BVT Receiver (Rx), a set of integrated Coherent Receivers (CO-Rxs) with tunable local oscillators (LO) are used.

The considered metro optical network is formed by heterogenous optical switches bound to the so-called Hierarchical Level (HL): HL4, HL3 and HL2/1. Specifically, HL4 nodes border the access network segment (e.g., mobile infrastructure) equipped with S-BVTs configuring a limited number of VCSELS and CO-Rxs devices for capacities up to e.g., 1 Tb/s. HL4 nodes are built using Array Wavelength Grating (AWG) of 50GHz. HL3 nodes are used as transit optical switches for all-optically interconnecting HL4 and HL2/1 nodes. Such HL3 nodes are not equipped with S-BVTs and are based on Wavelength Selective Switch (WSS) with filters of25GHz. Finally, HL2/1 nodes connect to the core network, and are attached to fully equipped S-BVTs (i.e., up to 8 Tb/s). The HL2/1 nodes are also based on 25GHz WSS filters. Figure 1(right) provides a representation of the involved HL nodes for an optical flow from the access-metro border towards the metro-core reference point. A candidate and illustrative optical metro infrastructure considering both the HL optical switches within a specific network topology as well as the use of the modularity feature of the S-BVT can be found in [4].

This work focuses on the programming APIs and functions supported by an SDN controller to automatically accommodate optical connections within the designed PASSION metro transport network. To this end, the specific features derived from the supported solutions and technologies in the metro network are considered.
Each optical connection is established over its own S-BVT VCSEL and CO-Rx devices (at the endpoints) as well as the spectral resources (i.e., frequency slot, FS) on each link along the path.

2. SDN CONTROLLER AND NETWORK ELEMENTS AGENT ARCHITECTURES

Figure 2 depicts the architecture (i.e., building blocks and functions) forming i) the deployed SDN controller to handle the programmability of the S-BVT and optical switches when managing the lifecycle of the connections (i.e., creation, update and removal); ii) the required elements and functions constituting a generic agent bound to such network elements and devices. Additionally, it is also illustrated the control interfaces from the SDN controller perspective to communicate with: i) an external application to request/update/remove optical connections via the so-called NorthBound Interface (NBI); ii) the agents to actually conduct the configuration of the underlying optical infrastructure (i.e., S-BVT and optical switches) via the SouthBound Interface (SBI).

The SDN controller NBI is used to receive connection requests arriving from an external application (e.g., On-Demand Bandwidth Application). This interface, at least, must specify the connection endpoints and the required bandwidth. Other connection parameters can be also determined through the NBI such as maximum tolerated end-to-end delay, protection/restoration capabilities, imposed optical spectrum needs (e.g., to set up the optical flows in a specific optical frequency range), etc. In the PASSION project, the NBI is based on a RESTful interface as detailed in [4]. The basic elements forming the implementation of the SDN controller are:

- **Core Logic Control**: This function processes the incoming connection requests via the NBI and coordinates the different functionalities in the SDN controller to ensure the workflows when setting up, updating, or removing a connection.

- **Traffic Engineering Database (TED)**: it is a repository which is used to keep track of the (abstracted) resource information (e.g., S-BVT VCSELs and CO-Rxs availability, available optical spectrum on the links, nodes connectivity, etc.).
- **Connection Database**: it is repository that stores relevant information to the existing connections such as endpoints and allocated resources (e.g., allocated FS).

- **Path Computation Function**: This element takes over of computing and selecting the spatial path (i.e., nodes and links) and spectral resources (i.e., S-BVT VCSELs, CO-Rxs, and spectrum links) fulfilling the incoming connection requests. To this end, it relies on Routing and Spectrum Assignment (RSA) algorithms using as input the information in the TED along with the connection details (i.e., source/destination endpoints, bandwidth, etc.). An example of a devised RSA algorithm considering the PASSION project transport solutions is provided in [4].

- **Topology and Provisioning Management**: this function provides the means to communicate with the underlying network elements and devices (i.e., agents) using the SBI. In a nutshell, it retrieves updated status of each network element and device (then stored in the TED), and executes the management (programmability) of the end-to-end optical connections. The implementation of the SBI for communicating the SDN controller and the network element and devices agents has been done using RESTful interface (with JSON-encoded data) as detailed in [4].

As said before, the agent is a local controller which conducts the actual configuration of the hardware device according to the commands arriving from the SDN controller through the SBI. The key elements forming the agent regardless of the controlled hardware element / device are:

- **Core Logic Control**: This function processes and handles the commands (e.g., S-BVT VCSEL de-/allocation, optical switch cross-connection, etc.) arriving from the SDN controller. In other words, this enables the programmability of the agent-controlled hardware device.

- **Local Connection Database**: This is a repository mapping the specific connections which are indeed allocating resources (e.g., S-BVT VCSEL or CO-Rx) over the optical hardware element.

- **Resource Abstraction Database**: This repository stores the abstracted information (e.g., availability, status, configuration, capabilities, etc.) regarding the underlying network element/device which is sent to the SDN controller via the SBI.

- **Monitored Data**: This determines the monitored information related to the underlying optical hardware.

- **Equipment Controller**: This controller communicates with the hardware device to encompass the commands required by the SDN controller. As an example, this controller allows turning on/off a specific S-BVT VCSEL or configuring the Local Oscillator of the S-BVT CO-Rx, etc.

### 3. SDN CONTROL WORKFLOW VALIDATION

The interactions among the SDN controller and the agents governing each network element and device within the PASSION metro network are ruled by a sequence of operations and exchanged control messages (NBI and SBIs). The workflow detailing the messages and the involved SDN control functions and agents are depicted in Fig. 3.

An optical connection is requested by the On-Demand Bandwidth Application to the SDN controller using the NBI POST message. This includes the connection Id, the source and destination nodes and the requested bandwidth. It is important to recall that the source and destination nodes are bound to both S-BVT devices, i.e. transmitter (Tx) and receiver (Rx). The connection request (NBI) message is then received by the SDN controller. Internally within the controller, the Path Computation function is triggered. At this point, the Path computation updates its network resource view within the TED repository. This is done by the Topology Management function. Indeed, this process requests via the defined SBIs:

I. the resource availability of the S-BVT Tx devices (VCSELs) at the source node using the GET /.../sbvtTx message

II. the resource status of the S-BVT Rx elements (CO-Rxs) at the destination node using the GET /.../sbvtRx) message.

III. the status of the spectral resources on each optical switch port. It means to collect the information of all the optical switch agents within the network. This is supported via the GET /.../opticalSwitch message.

All HTTP responses are processed by the Topology Manager and the information of those messages stored into the TED. Once the TED is updated, the Path Computation Function triggers the routing algorithm (i.e., RSA). The routing algorithm uses as inputs the request’s attributes (Conn. Req) and the updated TED. The output of the routing algorithm provides:

I. the set of ordered network nodes to be traversed (detailing the input and output physical ports). This is referred to as spatial path.

II. the selected FS (i.e., optical spectrum) to accommodate the optical flow.

III. the configurable parameters of both S-BVT Tx and S-BVT Rx such as the selected set of VCSELs and the CO-Rxs and their central frequencies (i.e., LO).
Finally, Fig. 4 shows the captured RESTful control messages (via Wireshark) exchanged between the SDN controller and the set of agents governing the selected network elements and devices to be configured for accommodating an optical connection request. For the sake of completeness, further details of this experimental validation are available in [4].

4. CONCLUSIONS

This paper overviews the validation of the designed and deployed SDN control (i.e., workflow and APIs) for the automatic programming of optical connections within the EU-H2020 PASSION metro network infrastructure. This metro network is featured by two key innovations and technologies: i) programmable and modular S-BVT devices based on dense photonic integration and VCSEL; ii) hierarchical flexi-grid optical metro infrastructure.

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