Demonstration of an SDN-enabled VCSEL-based Photonic System for Spectral/Spatial Connectivity in Disaggregated Optical Metro Networks

M. Svaluto Moreolo\textsuperscript{1}, R. Martínez\textsuperscript{1}, J. M. Fabrega\textsuperscript{1}, R. Casellas\textsuperscript{1}, J. Vilchez\textsuperscript{1}, L. Nadal\textsuperscript{1}, R. Vilalta\textsuperscript{1}, R. Muñoz\textsuperscript{1}, C. Neumeyer\textsuperscript{2}, H. D. Jung\textsuperscript{3}, J. U. Shin\textsuperscript{3}, A. Gatto\textsuperscript{4}, P. Parolari\textsuperscript{4}, P. Boffi\textsuperscript{4}, D. Larrabeiti\textsuperscript{5}, J. P. Fernández-Palacios\textsuperscript{6}

\textsuperscript{1}Centre Tecnològic de Telecomunicacions de Catalunya (CTTC/CERCA), Castelldefels, Spain; \textsuperscript{2}Vertilas GmbH, Garching, Germany; \textsuperscript{3}Electronics and Telecommunications Research Institute (ETRI), Daejeon, Korea; \textsuperscript{4}Politecnico di Milano, Milan, Italy; \textsuperscript{5}Universidad Carlos III de Madrid, Spain; \textsuperscript{6}Telefonica Global CTO, Madrid, Spain

michela.svaluto@cttc.es

Abstract: This demo showcases an SDN control platform configuring VCSEL-based photonic transceiver and white-box nodes for end-to-end programmability in disaggregated optical metro networks also including the spatial dimension with a polymer switch and 25km 19-core MCF. © 2021 The Author(s)

1. Introduction

The evolutionary metro area network (MAN) scenario we are facing needs for dynamically adaptive high-capacity transport at low cost and power consumption. The synergy of software defined networking (SDN) and photonic technologies is key as well as enabling optical disaggregation and pay-as-you grow paradigms \cite{1}. Such requirements became crucial when considering novel services and 5G-supportive large MAN \cite{2}.

In previous works, we designed and assessed SDN-enabled S-BVTs as well as photonic systems tailored for disaggregated, agile and sustainable MANs offering up to multi-Tb/s connectivity \cite{1,2-4}. We proposed alternative solutions adopting integrated photonic circuits (PICs) and novel emerging photonic technologies, such as vertical cavity surface emitting lasers (VCSELs), for cost-effective designs with low power consumption and footprint \cite{2}.

In this demonstration, we implement a programmable photonic system adopting a VCSEL-based S-BVT, tailored for disaggregated optical networks. The S-BVT is based on directly modulated (DM) VCSEL technology at long wavelengths combined with a coherent receiver (CO-Rx) with integrated components and adopting tunable local oscillator (TLO). For a targeted lightpath to be set up, the SDN controller automatically configures/programs: i) the S-BVT elements according to the network condition/requirements, opportunely enabling/disabling the VCSEL at the transmitter (Tx) module; ii) the frequency of the TLO at the receiver (Rx) module; and iii) the white box ROADM/OXC nodes of a real network. In addition to the management of the spectral resource according to fixed/flexi-grid dense wavelength division multiplexing (DWDM), also the spatial dimension is considered including in the testbed a 16x16 polymer switch prototype \cite{5} and a 25 km 19-core multicore fiber (MCF).

2. Innovation

The innovation of this demo resides in enabling the end-to-end programmability of the metro network based on the concepts and features targeted in the EU H2020 PASSION project \cite{6} and the synergy of control and data planes adopting the proposed photonic technologies \cite{1}. This allows exploring the potentialities and advantages of the proposed emerging technologies, understanding their peculiarities to take full benefits of their usage in MANs, and solving/addressing the limitations and specificities of each adopted technology. In addition to the VCSEL technology, it is also worth mentioning the integration of a 16x16 polymer switch to exploit the spatial dimension \cite{5}. Among the multi-fold innovations showcased by this demo, we emphasize the control of disaggregated network elements including transceivers and nodes, which can be from different vendors and may rely on different technologies. Thus, thanks to the deployed SDN control platform, the programmability of disaggregated network elements is enabled. Disaggregation depends on the availability of open APIs and service and data models that can support the configuration of these elements. The proposed programmable system is envisioned as part of a full disaggregated network based on bare metal blades, where the network nodes can be assembled from diverse subsystem blades from different vendors. The S-BVT can be also seen as a white box transceiver, where both the Tx and the Rx modules (and their elements) can be from multiple vendors.

Another key innovation is the programmability of photonic technologies/devices: the SDN control platform allows VCSEL enabling/disabling at the S-BVT Tx and TLO frequency selection at the S-BVT CO-Rx. The node programmability/configuration enables resource (i.e., links and frequency slots, FSs) management/selection within...
the testbed network upon heterogenous node architectures. In particular, the selection of the central frequency for suitably aggregating the active S-BVT flows and enabling different node spectral granularities via the selection of the number of 12.5 GHz FSs at the wavelength selective switches (WSSs). Also, the target capacity considering the established connection characteristics is selected for ensuring a successful transmission supported by the underlying photonic technologies.

3. Overview

Figure 1 shows the proposed demo detailing the main involved transport and control elements for demonstrating the end-to-end programmability of the considered photonic system tailored for MAN connectivity.

The SDN controller takes over of selecting the resources and coordinating the establishment of the optical path over the ADRENALINE testbed network. This entails configuring the underlying data plane elements consisting of a VCSEL-based S-BVT Tx module, an S-BVT Rx module and multiple nodes connected by amplified links. The optical path can either traverse the nodes N1, N3 and N4 based on WSSs and photonic cross connects (PXCs), or also including a 25 km 19-core MCF and a 16x16 polymer switch module (PSM), as shown in Fig. 1. At node N5, before the CO-Rx, a WSS is required for dropping the optical flow.

As shown in Fig. 1, one of the main building blocks of the proposed demonstration is the SDN control platform. This includes the SDN controller as well as the agents handling the specific configuration of every individual network element, namely, S-BVT Tx/Rx agents and network nodes. The elements at the S-BVT Tx/Rx are: i) a front-end based on a short-cavity (SC) VCSEL operating at long wavelength with 10 GHz bandwidth and a laser current control system (LCCS); ii) an integrated CO-Rx front-end with TLO; iii) offline DSP at Tx/Rx implementing OFDM and adaptive bit and power loading (BL/PL) for supporting the target data rate over the established path; iv) a 64 GSa/s digital-to-analog converter (DAC) at the Tx; v) an analog-to-digital converter (ADC) implemented with an oscilloscope up to 100GSa/s at the Rx. For the end-to-end transport of the optical flows, it is used the photonic network of the ADRENALINE testbed with ROADM/OXC white-box nodes (based on WSS and PXC, providing different functionalities, see Fig. 1), two amplified standard single mode fiber (SSMF) links of 35 km (connecting nodes N3 to N1 and N1 to N4), 25 km 19-core MCF, and the 16x16 PSM.

In this demo, the S-BVT Tx is composed of a module with a single SC-VCSEL and a remotely controlled equipment for driving it with the suitable current bias. The SDN controller activates/de-activates the optical flow communicating with the dedicated S-BVT Tx agent, which eventually turns on/off the underlying VCSEL operating wavelength configuring the LCCS. After the flow aggregator, the VCSEL-based S-BVT slice at the target data rate (e.g., 25 Gb/s) is transmitted over the testbed metro network suitably configuring the traversed nodes. The flow is received at the end-node, after the WSS with the drop functionality, by the CO-Rx module. To this end, the TLO is configured by a specific S-BVT Rx agent at the appropriate frequency. In addition to the FS in terms of nominal central frequency (n, being 193.1+/-0.00625 THz), different granularities can be conveniently selected at the network nodes by defining the slot width as 2\(\cdot\)m=6.25 GHz. The central frequency considered in the demo is 194.200 THz (1543.73 nm), which corresponds to n=176, according to the VCSEL operating wavelength. The demo results show that a successful connectivity at the target capacity is attained (being the obtained capacities above this value). This is accomplished in the two scenarios: 1) the 70 km flex-grid path within the ADRENALINE testbed (at 25 Gb/s target capacity), 2) the entire 95 km 3-hop path (shown in Fig. 1) including also the PSM and MCF (at 20 Gb/s target capacity). In this case, the granularity (slot width) that has been selected at the nodes is 50 GHz (m=4). Selecting m=2, a successful connectivity at 20 Gb/s is demonstrated for both scenarios.
The SDN programmability validation of the S-BVT Tx, Rx and network nodes for setting up the targeted optical connection is shown in Fig.2. Specifically, Fig.2.a depicts the SDN controller GUI of a possible roll out of an optical MAN in the Barcelona area. The optical connection (referred to as lsp1) is set up using the FS featured by $n=176$ (194.200 GHz) and $m=4$ (50 GHz), as detailed in Fig.2.b. The optical spectrum occupancy (i.e., FS) on the traversed links by lsp1 is also shown by the used GUI, see Fig.2.c. Finally, Fig.2.d describes the exchanged REST API messages between the SDN controller and the set of agents handling the S-BVT Tx, Rx and network nodes for the automatic optical resource configurations. The used REST API has been reported by the authors in [7]. It can be observed that the elapsed time to set up lsp1 takes around 13.6 s. This time accounts for the sequential SDN-driven configurations of the S-BVT Tx, S-BVT Rx and traversed nodes. The breakdown of such total time is: i) 400 ms for the S-BVT Tx (VCSEL) programmability; ii) 380 ms for the S-BVT Rx (TLO) configuration; and iii) the cross-connection configuration of PXC and WSS elements of each involved node (the most consuming contribution) requiring 4 s per node.

4. Relevance
This demo shows the end-to-end programmability in a platform for integration and early evaluation of the proposed concepts and photonic technologies in a close-to-real optical laboratory network, enabling key advanced functionalities and novel feature sets. A network-wide proof-of-concept is presented, including the developed SDN control and interfaces, cost/power-efficient technologies and devices envisioned to target future MANs. The demo shows the integration and assessment of an SDN-enabled photonic system (VCSEL-based S-BVT and white-box nodes) adopting the proposed photonic devices and technologies to support future agile disaggregated metro networks, enabling multi-Tb/s capacities with spectral/spatial switching over increased transport distances according to the network operator requirements and roadmaps.

Acknowledgements: Work funded by the EU H2020 PASSION project (780326) and the Spanish AURORAS project (RTI2018-099178-B-I00).

5. References
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