Experimental Assessment of a Programmable VCSEL-based Photonic System Architecture over a Multi-hop Path with 19-Core MCF for Future Agile Tb/s Metro Networks

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Abstract: An SDN-enabled photonic system adopting VCSEL technology is experimentally analyzed targeting dynamic 5G-supportive MAN. Direct and coherent detection modules are compared and programmability assessed over up to 6-hop 160km HL4-HL2/1 connection including 25km 19-core MCF. © 2020 The Author(s)

1. Introduction

The Metropolitan Area Network (MAN) is characterized by stringent requirements in terms of traffic volume [1], traffic variance, cost and power efficiency. In order to achieve a cost-effective ultra-broadband transport featuring dynamic capacity adaptation, novel architectures must be envisioned seeking for programmability and efficient photonic technologies [2]. This way the MAN will be able to deal with the challenges posed by the ever-increasing access rate offers, the support of 5G new radio backhaul/fronthaul traffic or the scalable provision of Gb/s mobile service in events gathering crowds of people. Finally, also CDN and corporate VPN traffic will continue to be large traffic flows traversing the MAN in the next years that need support [1].

In the framework of EU-H2020 PASSION project, we propose to approach the MAN challenges by adopting vertical cavity surface emitting laser (VCSEL) technology at long wavelengths with very high bandwidth (≥ 18 GHz) and dense photonic integration, to design programmable photonic sliceable bandwidth/bitrates variable transceivers (S-BVTs) with reduced cost, power consumption and footprint [2]. They can be modularly composed following a pay-as-you-grow scheme with license-based module activation, fully exploiting the available resources. Fine granularity is enabled by direct modulation (DM) of VCSEL with multicarrier technique. The programmability and automation of photonics is key to support hyperconnectivity [2]. Thus, we propose using a software defined networking (SDN) platform to enable a flexible, efficient and dynamic exploitation of the optical layer through smart traffic aggregation, statistical multiplexing and IP offloading at the MAN transit nodes.

In this paper, we analyze the performance of the proposed architecture up to 6 aggregation nodes and 160km (see Fig. 1), as a worst case path across multiple hierarchical levels (HL) in a 5G-supportive MAN based on real topologies [3, 4]. Different HL node functionalities are considered according to the specific architecture, as described in [3]. Lower level metro-aggregation nodes (HL4, aggregating traffic from edge nodes at HL5) are equipped with simple and cost-effective VCSEL-based transceiver (up to 2Tb/s) and switching technology exploiting spectral dimension. Higher level metro-core nodes (HL2/1) adopt fully-equipped (with modular approach) transceivers (up to 16Tb/s) and photonic switching nodes supporting multiple functionalities and granularities, handling both spectral and spatial dimensions. To experimentally assess the performance of the photonic system architecture, a single flow connection enabled by a specific VCSEL is considered over up to 6 hops and 160km, including a real testbed network (ADRENALINE) and 25km 19-core multicore fiber (MCF). We analyze both direct detection (DD) and coherent receiver (CO-Rx) options, showing that the latter achieves promising results for multi-hop MAN connections. Furthermore, the programmability via software defined networking (SDN) to configure S-BVTs and nodes is also verified.

2. SDN-enabled modular photonic system architecture and experimental set-up

Fig. 1 shows the SDN-enabled photonic modular system architecture based on the EU-H2020 PASSION approach [3]. The fundamental S-BVT module consists of 40 DM-VCSELs (4 submodules with 10 VCSELs each), integrated on a silicon-on-insulator (SOI) chip with 100GHz-spaced operating wavelengths within the C-band, supporting up to 2Tb/s (50Gb/s per each independent flow). To fully exploit the spectral resource, 4 modules generating 25GHz-spaced flows are required to obtain a fully-equipped (super module) S-BVT transmitter (Tx) supporting up to 8Tb/s (inset Fig. 1). This capacity can be doubled exploiting the polarization division multiplexing (PDM) and improve by a factor M , considering also space division multiplexing (SDM) with a MCF with M cores. Photonic integrated

(23.7Gb/s). After the characterization of the Rx modules, we analyze a HL4-HL3 connection (including N1 and N6) over 15km 2-hop path. In this case, the OSNR is 35.7dB and the capacity of DD (33.7Gb/s) and CO-Rx (26.4Gb/s) are similarly affected (slight decrease compared to B2B). Finally, we analyze the HL4-HL2/1 connection over the 160km 6-hop path, including the testbed network and the MCF (as in Fig. 1). The OSNR decreases to 26.4dB; the CO-Rx supports 22.6Gb/s, while the capacity with DD is lower than 10Gb/s (Fig. 2a). In fact, even if a simplified CO-Rx DSP is adopted due to intensity modulation at Tx [2], improved performance can be obtained after 160km thanks to a compensation module (CM) at CO-Rx DSP (Fig. 2b). Thus, the B2B capacity with CO-Rx decreases about 15% and 28% over HL4-HL3 and HL4-HL2/1 connections, respectively. Adopting higher bandwidth VCSEL and integrated CO-Rx, it is envisioned to improve the achievable capacity/reach to target up to 50Gb/s per flow [3].

The configuration of the different network elements (i.e., S-BVT Tx/Rx and nodes) is coordinated by an SDN controller. A defined REST API [6] enables the communication between the SDN controller and every network element agent. Fig. 2c depicts the set of REST API messages for: i) allocating the S-BVT Tx element (i.e., VCSEL) at 194.000THz ($n=144$) (see JSON encoding in Fig.2e); ii) configuring the S-BVT-Rx LO at 194.000THz ($n=144$); iii) programming the cross-connections at each traversed HL node with its frequency slot (FS) in terms of n and slot width as $2 \cdot m \cdot 6.25\text{GHz}$. Fig. 2d shows a protocol analyzer screenshot with the REST API messages validating the workflow. Since different HL nodes present different filtering capabilities (HL4 uses 100GHz whilst HL3 and HL2/1 use 50GHz), for each HL node cross-connection, in addition to specifying the input and output ports, the FS needs to be determined, according to the filtering switch features. For HL4 nodes, the FS has $m=8$ (i.e. slot width of 100GHz), whereas for both HL3 and HL2/1, $m=4$ resulting in a slot width of 50GHz (see Fig. 2f).

Fig. 2. (a) Capacity vs OSNR for different Rx modules and connections; (b) SNR vs subcarrier number. (c) Workflow for configuring S-BVT Tx/Rx at source/destination nodes along with FS over every traversed HL node; (d) validation of REST API messages enabling S-BVT and HL nodes programmability; (e) JSON with S-BVT Tx configuration ($n=144$); (f) JSON with HL2/1 N6 programmability ($n=144$, $m=8$).

4. Conclusions

We have assessed an SDN-enabled photonic system architecture, targeting 5G-supportive MAN, across multiple HL, enabling IP-offloading through up to 6 aggregation nodes and 160km, including a real testbed network and MCF. DD and CO-Rx are compared, showing that while DD is more affected by OSNR degradation and path length increase, with 10GHz VCSEL, CO-Rx allows supporting >30Gb/s in B2B and >20Gb/s capacity over the multi-hop path. Adopting programmable (SDN-enabled) photonic transceivers based on >18GHz VCSELs and integrated CO-Rx, exploiting spectral and spatial dimensions, the proposed solution is promising to target Tb/s MAN connections.

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5. References

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