Enabling Multiband Transmission and Programmability in Disaggregated Optical Metro Networks

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Abstract: A multi band (MB) sliceable bandwidth/bit rate variable (S-BVT) architecture is experimentally assessed over a disaggregated optical metro network. The programmability of the MB S-BVT is demonstrated by the implementation of an OpenConfig SDN agent.

1. Introduction

The increasing traffic and number of connected devices, as well as the emergence of new 6G immersive applications pose stringent network requirements in terms of bandwidth/capacity, latency and efficiency. The global data traffic has been doubling every 2-3 years over the past 15 years and will continue increasing in the future. To cope with this prediction, line and node capacities of 600 Tb/s and 3.6 Pb/s, respectively are expected within the metro/core segment by 2028 [1]. Hence, innovative technologies and disruptive transceiver architectures which enable new features and capabilities, should be investigated and implemented to drive the upcoming 6G era. To this extend, the adoption of multi band (MB) technology based on the exploitation of new spectrum bands, such as E-, O-, L- and S-bands, becomes a potential solution to target the required network capacity scaling. This poses new technology challenges as the adoption of new optical devices and configurations, at the network node and transceiver architecture level, capable to operate beyond the C-band. Additionally, the adoption of reconfigurable, disaggregated and open network solutions/architectures will enable new and highly flexible networking capabilities towards fulfill the requirements of future 6G networks. Software defined networking (SDN) paradigm arises as a solution to fully exploit network programmability and reconfigurability further enhancing network flexibility and agility. SDN will facilitate to manage the network resources and new available bands in an efficent way.

In this paper, we propose and experimentally assess a cost-effective SDN-enabled MB sliceable bandwidth/bit rate variable transceiver (S-BVT) architecture, which enables point-to-point and point-to multipoint operation within a metro network, enhancing flexibility, scalability and reconfigurability. We experimentally validate MB transmission, within C- and S-bands, by sending 2 double side band multicarrier-modulated slices of 20 GHz bandwidth over a disaggregated optical metro network. Furthermore, the programmability to configure the proposed MB S-BVT is also assessed by the implementation of SDN agents based on the OpenConfig data model.

2. SDN-enabled MB S-BVT architecture

The proposed modular S-BVT architecture is composed of multiple bandwidth/bit rate variable transceivers (BVTs) that can work within multiple bands, including the C- and S-bands, and can be enabled and disabled according to the traffic demand and network requirements, as seen in Fig. 1. In particular, the adopted approach includes, at each bandwidth/bit rate variable transmitter (BVTx), a tuneable laser source (TLS), a Mach-Zehnder modulator (MZM) and a digital-to-analog converter (DAC). The multiple slices are aggregated and distributed by means of a mulit-band multi-flow aggregator/distributor that can be based on different technology options. Programmable wavelength selective switches (WSSes) are attractive solutions to implement this device. However, current commercial WSSes operation is limited to the C- and L-bands. Hence, alternative options should be analyzed including band pass filters or other passive components. At the receiver side, each bandwidth/bit rate variable receiver (BVRx) is based on direct detection implementation comprising a simple photo-detector (PIN), a transimpedance amplifier (TIA) and an analog-to-digital converter (ADC) [2]. The digital signal processing (DSP) is based on multicarrier modulation (MCM) further enhancing system flexibility. Bit and power loading algorithms are implemented in order to assign at each subcarrier different modulation formats and power values according to the channel profile [2]. A MB node based on a 16x16 polymer spatial switch has been included in the setup of Fig. 1 as an evolutionary path towards possible joint exploitation of MB and spatial division multiplexing (SDM) technologies to enable the future capacity targets. On the other hand, enhancing the overall system's flexibility/programmability is fundamental to meet the identified key requirements and characteristics of 6G. The implementation of SDN agents enable the reconfiguration of different MB S-BVT programmable elements adapting the transmission to the network demand. Open data models such as OpenConfig, are envisioned within a disaggregated network scenario enabling to implement vendor-agnostic agents [3]. Two main operations are implemented within the different S-BVT agents including i) optical channel configuration and ii) logical channel

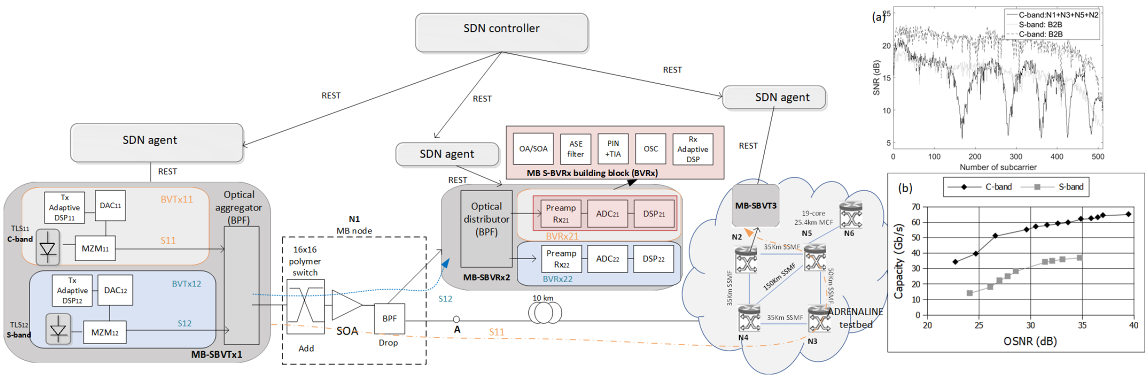

Fig. 1. MB S-BVT architecture and experimental set-up. (a) SNR profile for different bands and configurations. (b) B2B MB assessment.

assignment, as defined within OpenConfig. The first operation, configures an optical channel with the specified power, frequency and operational mode. This last parameter, is vendor-specific and can include transmission information such as forward error correction (FEC), modulation format, etc. The second operation assigns a client to a logical channel to establish a connection [3].

3. Performance assessment and programmability

The proposed MB S-BVT, depicted in Fig. 1, is experimentally validated targeting different network scenarios/configurations, as detailed in table 1. MB transmission, within C- and S-bands, is enabled by programming two slices of the S-BVT1 at 1550.12 nm (S11) and 1497.01nm (S12). The TLS power is set to 6.5 dBm and 4 dBm, respectively in order to limit power fluctuations due to laser stability. 20 GHz signals based on MCM are created by means of a DAC, working at 64 GSa/s, and MZM, working at the quadrature point. The two MB slices are aggregated using a band pass filter (BPF). The aggregated MB flow is injected to the network by means of a 16x16 polymer switch photonic integrated circuit (PIC) prototype [4], which is part of the H1 MB node, depicted in Fig. 1. The MB node also includes an SOA and a BPF, that emulates the drop operation. A 10 km fiber link connects the node to the ADRENALINE testbed [5]. The S-band slice is received at S-BVT2, after the H1 MB node, whereas the C-band signal also traverses different nodes of the ADRENALINE testbed considering up to 95 km of standard single mode fiber (SSMF). At the corresponding S-BVRx, the contributions are amplified with an erbium Fiber Amplifier (EDFA) for the C-band and a semiconductor Optical Amplifier (SOA) for the S-band. After the amplification stage, a spontaneous emission (ASE) noise filter is used based on WSS for the C-band slice and a BPF for the S-band one. A 100 GSa/s OSC is used to analog-to-digital convert the different slices. As a first step, a B2B configuration is experimentally assessed considering MB transmission within C- and S-bands. The achieved results are depicted in the inset (b) of Fig. 1, achieving maximum capacities of 65 Gb/s and 37 Gb/s, at 39.5 dB and 34.8 dB optical signal to noise ratio (OSNR) and considering a hard decision (HD)-FEC of $4.62 \cdot 10^{-3}$ threshold [6]. In the analysis of additional configurations/scenarios, summarized in table 1, a target capacity of 30 Gb/s per band and a bit error rate (BER) below the target FEC threshold are considered for fairness in the performance evaluation of both slices. Due to set up limitations the performance of the S-band signal is more degraded, as also identified in Fig. 1 (b), where the SNR profile of both slices is depicted in B2B. Specifically, from the results, included in table 1, it can be seen that 60 Gb/s MB transmission is ensured in back-to-back (B2B) and at N1 MB node. 30 Gb/s C-band transmission is guarantied after up to 3-hops path of 95 km at 31.2 dB OSNR, despite the appearance of attenuation peaks due to chromatic dispersion that degrades the system performance, as seen in Fig. 1(a). The modular MB S-BVT approach is a key enabler towards meeting the high-capacity network targets imposed by the 6G. By considering the full available spectra of the analyzed bands, 160 C-band channels and 350 S-band channels of 25 GHz can be enabled, envisioning up to 23.35 Tb/s transmission. By exploiting additional bands, SDM technology and improving the experimental setup with optimized elements per transmission band, this capacity can be further enhanced towards meeting the mid-term targets within the metro/core segment [1].

On the other hand, the programmability of the proposed MB S-BVT architecture, is also assessed by the implementation of SDN agents based on OpenConfig data model. The SDN controller will configure two BVTxs of the MB S-BVT1, centered within the C- and S-bands and corresponding to 2 different clients, with the OpenConfig operation ”optical channel” and assign them to two different optical channels with the operation ”logical channel assignment”, as depicted in the wireshark capture of Fig. 2. The first operation specifies different parameters including the channel frequency (193.4 THz, 200.26 THz), operational mode (111, 111), channel id (101, 102), channel power (6.5 dBm, 4 dBm), status (enable, enable), operation type (optical channel, optical channel) and direction (tx, tx), as depicted in Fig. 2 (a) and (b). The ”logical channel assignment” operation specifies client

Table 1. Experimental results at fixed capacity per slice of 30 Gb/s considering different scenarios

Configuration	B2B	N1	N1+N3	N1+N3+N5	N1+N3+N5+N2
Band	C+S	C+S	C	C	C
Slice	S11+S12	S11+S12	S11	S11	S11
Distance (km)	0	0	10	60	95
# of hops	0	0	1	2	3
BER	0(S11);4.2e-4(S12)	0(S11);4.6e-3(S12)	2.7e-5	2e-3	4.65e-3
OSNR(dB) in 0.1nm	40.4(S11);34.7(S12)	35.9(S11);27.8(S12)	33	33	31.2

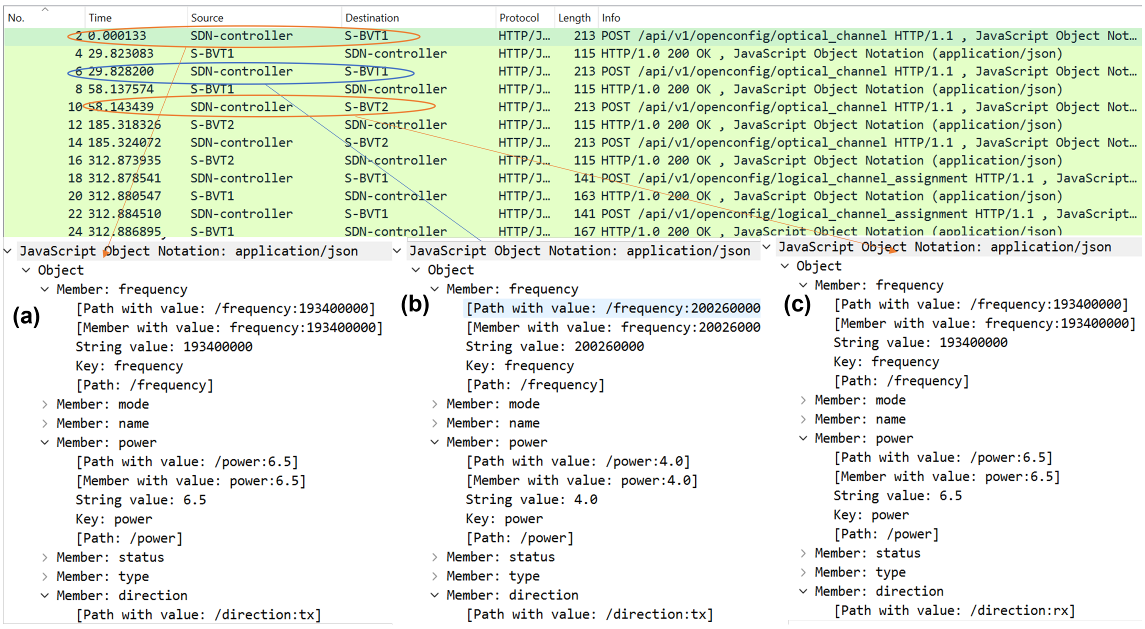

Fig. 2. Wireshark showing the configuration of the MB S-BVT1 and MB S-BVT2.

name (c1, c2), the channel id (101, 102), status (enable, enable) and type (client, client). The 2 configured slices will be received at MB S-BVT2, in a B2B scenario. The S-BVT2 is also configured by means of an OpenConfig SDN-agent with the operation ”optical channel”, as seen in Fig. 2 (c). A total setup time of 58.13 s is needed for the configuration of the 2 slices at MB S-BVT1, including the set up of each TLS and DAC. A higher set up time of 254.74 s is required for the configuration of the 2 BVRxs at MB S-BVT2, due to the OSC configuration operations which include the signal acquisition and SNR/BER calculation.

4. Conclusions

We have experimentally validated a MB S-BVT architecture suitable to face up the stringent network requirements imposed by the upcoming 6G era. 60 Gb/s aggregated MB transmission is demonstrated in B2B and after H1 MB-node, in a disaggregated metro network. Thanks to the proposed transceiver modular architecture these results can be scaled and improved towards multi Tb/s transmission. 30 Gb/s C-band capacity is achieved after up to 3-hops path of 95 km of SSMF. The programability of the MB S-BVT is also demonstrated by suitably implementing SDN agents based on OpenCofig data model to also foster transceiver flexibility and programmability.

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