Enabling Programmable Multiband High-Capacity Optical Transceivers

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Abstract: *Multiband (MB) transmission is experimentally assessed up to 50.47 km of standard single mode fiber (SSMF), by the adoption of programmable MB (sliceable) bandwidth/bitrate variable transceivers, paving the basis to provide suitable network flexibility and capacity scaling.*
Keywords: *Optical fiber communication, communication systems*

I. INTRODUCTION

With the advent of 6G era new architectures, technologies and systems have to be adopted in order to deal with the stringent requirements and challenges in terms of bandwidth, capacity, flexibility and latency of future optical networks [1]. 6G networks will be able to support the big amount of data and digital information generated by the billions of things, humans, drones, robots and connected vehicles. The 6G architecture should be sufficiently flexible and efficient so as to enable easy integration of the different services. The need of higher data rates and bandwidth open the adoption of new technologies such as multiband (MB) transmission, based on the exploitation of new optical wavelength bands including L-, S-, E-, and O-band. Specifically, MB technology arises as a suitable solution that increases the optical fiber capacity by the transmission on different spectral bands beyond the C-band, while efficiently utilizing the available and deployed optical fiber infrastructure. However, it still presents several challenges and limitations to take into account, related to the development of key network/system components such as transceivers, optical amplifiers, optical filters and configurable optical switches [2].

On this regard, a MB transmission system is here presented and analyzed in order to be adopted in converged metro/aggregation and access networks towards promoting suitable network scaling in terms of higher capacity/bandwidth, increased programmability and enhanced reconfigurability. In particular, MB sliceable bandwidth/bitrate variable transceivers (S-BVTs) based on multicarrier modulation, such as orthogonal frequency division multiplexing (OFDM), and direct detection (DD) are proposed to be adopted at the metro/aggregation network nodes in order to deal with the stringent network targets. Whereas a simpler transceiver architecture based on MB BVT can be adopted at the access segment.

II. PROGRAMMABLE MULTI-BAND (SLICEABLE) TRANSCEIVER

A programmable MB (S)-BVT is presented as a solution to increase the spectrum usage/transmission capacity in 6G converged metro/aggregation and access networks, leveraging on 365 nm spectrum resources by enabling the exploitation of O, E, S, C, and L bands [3]. The S-BVT is composed of a set of BVTs that can be disabled or enabled to work at the different available bands, as seen in Fig. 1. Thanks to this modular approach, the MB S-BVT transceiver offers a wide range of possibilities that allow to suitably set a high capacity flow and target variable capacity/reach according to the required network targets. Regarding the S-BVT architecture, a simple optoelectronic front-end is considered enhancing transceiver cost-effectiveness. In particular, a digital-to-analog converter (DAC), an external Mach-Zehnder modulator (MZM) and a tuneable laser source (TLS) are included at each bandwidth/bit rate variable transmitter (BVTx). Whereas a simple photo-detector (PIN) followed by a transimpedance amplifier (TIA) and an analog-to-digital converter (ADC) is envisioned to perform DD at each bandwidth/bit rate variable receiver (BVRx) that composes the MB S-BVT. In order to aggregate/distribute the different slices a MB multi-flow aggregator/distributor should be included. The implementation of such element capable to work at different bands is key in order to achieve a bandwidth and capacity scaling towards the stringent requirements of 6G networks. However, currently this MB device can only be implemented by the adoption of individual commercially available wavelength selective switches (WSSes) working at C-, L- or S-bands or other programmable filters that are limited to a tuning range around a specific wavelength beyond C-band combined with band splitters and combiners [4, 5]. Research on the implementation of a unique WSS for MB transmission supporting continuous switching between 1300 nm and 1565 nm has been proposed and demonstrated in the literature [6].

Transceiver cost-effectiveness can be further exploited by the adoption of photonic integrated circuits promoting cost, power consumption and footprint reduction [7].

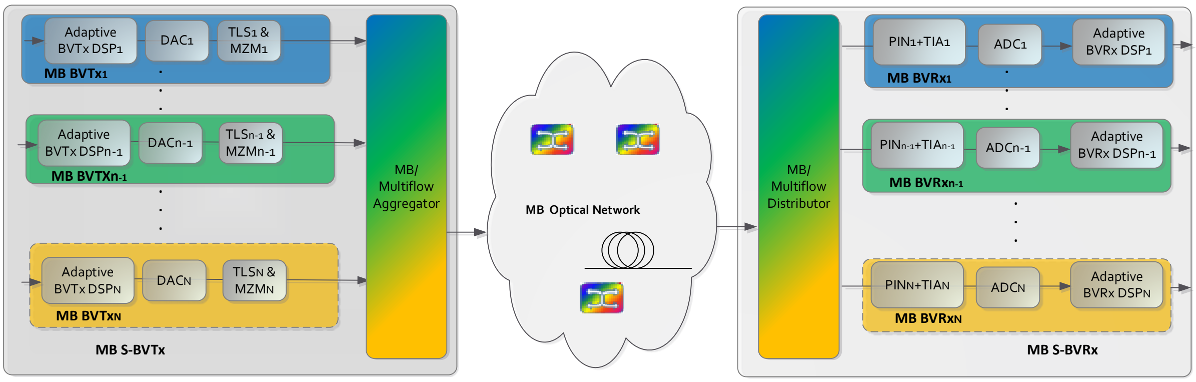

Fig. 1. MB S-BVT architecture. Tuneable laser source (TLS); Mach Zehnder modulator (MZM); Digital to analog converter (DAC); Photo-detector (PIN); Transimpedance amplifier (TIA); Analog-to-digital converter (ADC); Digital signal processing (DSP).

On the other hand, at the digital signal processing (DSP) level, OFDM modulation is implemented to further increase the transceiver flexibility. Specifically, by the exploitation of bit and power loading algorithms (BL/PL) the transmission can be adapted to the target performance/capacity/reach [3, 8]. The DSP operations, at the BVTx block, include data parallelization and mapping, training symbol (TS) insertion, inverse fast Fourier transform implementation, cyclic prefix (CP) insertion, serialization and radio frequency (RF) up-conversion processes. At the receiver side, RF down-conversion, data parallelization, CP removal, fast Fourier transform implementation, equalization, symbol demapping and serialization processes are performed.

III. ENVISIONED NETWORK SCENARIO: ENABLING MB CAPABILITIES

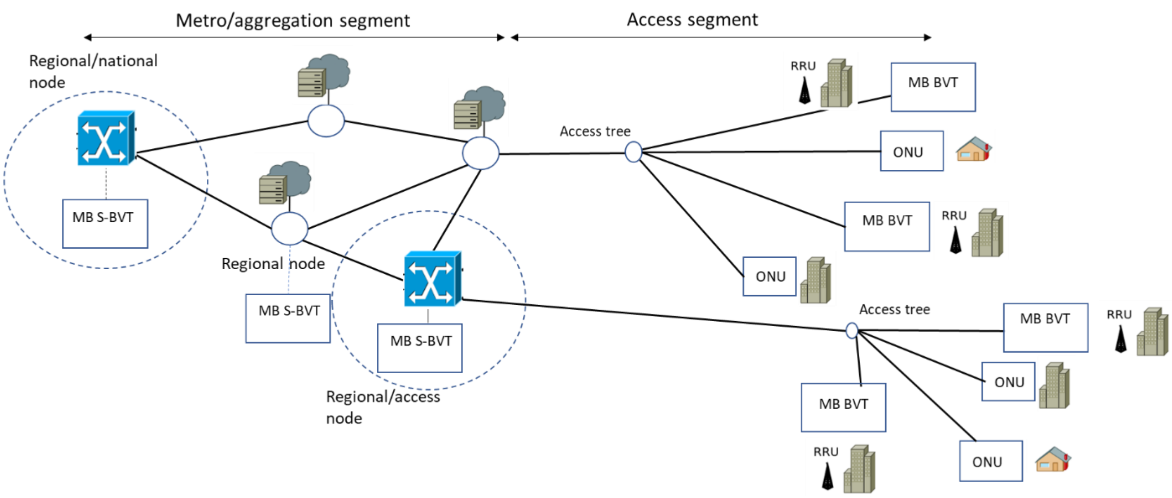

Fig. 2. Network scenario including MB S-BVTs and BVTs.

Here, possible placement of the MB (S)-BVT over the network are analyzed, as depicted in Fig. 2. In particular, a converged metro/aggregation and access network is considered as a target scenario. In order to deal with the high capacity/bandwidth requirements of the metro/aggregation segment MB technology becomes a suitable solution to be considered. On this regard, the presented MB transceivers with advanced capabilities are suitable options to provide an efficient and flexible delivery over the 6G metro/aggregation network. Furthermore, this allows adapting the transmission according to the evolving services and applications, which require variable ranges, capacities, and performance. Accordingly, the metro/aggregation nodes (regional/national, regional/access and regional nodes) are suitable locations to place the MB S-BVTs efficiently dealing with the high amount of network traffic and enabling suitable network scaling. These nodes have also to support MB switching capabilities to aggregate and distribute the MB flows [9]. At the access segment a simpler transceiver architecture is envisioned as a simple cost-effective MB BVT, that can also work at different wavelengths beyond C-band, promoting a transparent delivery over the two identified network segments [10].

Finally, by the implementation of a suitable control plane and the corresponding software defined networking (SDN) agents different network elements (e.g., nodes) and systems/subsystems (e.g., transceivers) can be reconfigured according to the network demand, promoting a flexible and efficient transmission. Regarding the transceiver, different programmable elements (i.e., TLS, WSS) and reconfigurable parameters (laser central wavelength and power, DSP, filter central wavelength and bandwidth) can be identified and varied [3, 11]. It is also worth mentioning that by the adoption of MB technology a sophisticated SDN platform capable to dynamically and efficiently manage the enormous available bandwidth is required [12]. SDN will also provide the MB network with the required programmability and flexibility capabilities, which are key features to be included in high-capacity future networks.

IV. EXPERIMENTAL ASSESSMENT

This section provides a proof of concept of the MB (S)-BVT (see Fig.1) over the envisioned network scenario depicted in Fig. 2. Specifically, for the experimental assessment is considered the transmission of a single slice over different bands (C-, L- and S-band), without amplification and filtering stages for a fair comparison, and fiber lengths up to 50.47 km. Specifically, the tuneable laser source (TLS) is set to 1550.12 nm (C-band), 1592.5 nm (L-band) or 1525 nm (S-band), respectively. The MZM is set to work at the quadrature point. A high-speed DAC working at 64 GSa/s and a 100 GSa/s oscilloscope (OSC), as ADC, are considered to generate/capture double side band (DSB) 20 GHz OFDM signals. Additionally, at the DSP level, 512 subcarriers are taken into account and the Levin-Campello rate adaptive BL/PL algorithm is implemented considering different modulation formats (BPSK and optimized m-QAM constellations) for adaptive mapping. At the receiver side, a simple photo-detector (PIN) followed by a transimpedance amplifier (TIA) is adopted to perform DD. Finally, a target BER of $4.62 \cdot 10^{-3}$ with standard hard decision forward error correction (HD-FEC), is fixed [13]. The considered overheads due to TS, CP and FEC are 4%, 1.9% and 7%, respectively.

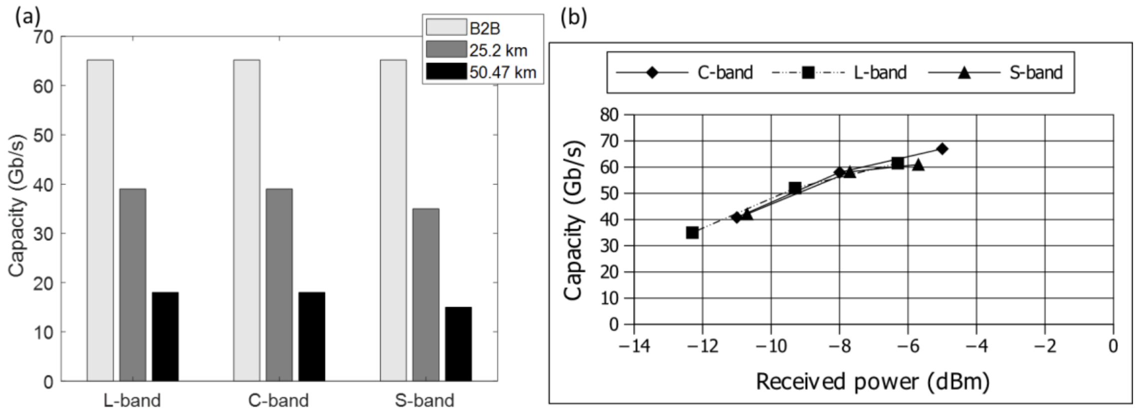

FIG. 3. (A) CAPACITY PER BAND IN B2B, 25.2 AND 50.47 KM OF SSMF. (B) CAPACITY VS RECEIVED POWER AFTER 5 KM OF SSMF.

A B2B configuration and different fiber lengths are considered to emulate the transmission over the two identified network segments. In particular, MB transmission over 25.2 km and 50.47 km of standard single mode fiber (SSMF) is evaluated to emulate possible metro/aggregation links, whereas a shorter path of 5 km is assessed envisioning the access segment. Fig. 3 summarizes the main experimental results in terms of achieved capacity per band. From Fig. 3 (a), it can be seen that the three analyzed wavelengths/bands achieve 65.2 Gb/s capacity in B2B and at the target BER for fixed receiver power of -5 dBm. After 25.2 km and 50.47 km of SSMF, the S-band capacity contribution decreases 4% in relation to the other two analyzed bands, which enable 39 Gb/s and 18 Gb/s capacities, respectively. This is mainly due to the fiber dispersion and attenuation differences at these wavelengths/bands. On the other hand, considering a shorter transmission length of 5 km of SSMF, emulating possible access links, the three bands present similar performance for different receiver power values, as depicted in Fig. 3 (b). The achieved capacities can be scaled by the adoption of a MB S-BVT by enabling multiple slices working at different bands towards the support of high-capacity network targets.

V. CONCLUSIONS

MB transmission is experimentally assessed over different fiber lengths by the adoption of MB (S)-BVT as a way to extend system/network capacity towards meeting the stringent requirements in terms of bandwidth and capacity of future 6G networks. From the experiments, it has been demonstrated that, even we are not including any amplification and filtering stages, MB transmission can be supported up to 50.47 km of SSMF ensuring the target BER. Hence, the adoption of a sliceable and modular transceiver architecture, working at multiple bands beyond the C-band, becomes an attractive and viable solution to promote network flexibility and capacity scaling towards the implementation of converged high-capacity metro/aggregation and access networks.

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