

Assessment of Flexgrid Technologies in the MAN for Centralized BRAS Architecture Using S-BVT

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Abstract *We numerically analyze a flexgrid metro network scenario identifying the requirements for BRAS centralization. A cost-effective S-BVT architecture based on MB-OFDM and DD with DSP-enabled software-defined flexible/adaptive capabilities is proposed and experimentally evaluated for supporting multiple 10Gb/s connections.*

Introduction

Flexgrid technologies¹ have been studied for core scenarios. However, due to the high bandwidth pressure in metro area networks (MAN), flexgrid technologies can also find application in that network segment to improve spectrum and network efficiency and reduce CapEx investment. Lately, main European network operators have been expanding their photonic mesh to the regional networks. A high capacity photonic regional network motivates the centralization of the Broadband Remote Access Servers (BRASes) that were distributed and placed at lower aggregation levels close to the users. Centralization in this scenario means the creation of a conveniently dimensioned pool of BRASes co-located in a transit router. For this metro scenario, using technologies for core networks is overkill, since the requirements are substantially different. Thus, a more cost-effective solution is required. A Sliceable Bandwidth Variable Transceiver (S-BVT) is able to concurrently serve multiple destinations through individual control of its carriers¹. This feature is well aligned with the requirements for the BRASes centralization. In a previous work², we proposed a cost-effective OFDM-based S-BVT solution using real-valued processing, double sideband modulation and direct detection (DD). For BRAS centralization in a regional network, the S-BVT must be both cost-effective and robust against transmission impairments, in order to support multiple low bit rate connections over regional optical paths of hundreds of km.

In this paper, we evaluate the applicability of flexgrid technologies in this evolutionary regional/MAN network scenario, proposing an improved S-BVT architecture based on multi-band OFDM (MB-OFDM) and direct detection (DD). We first analyze a representative network scenario considering a regional domain of the TID Spanish network, to obtain realistic requirements. Then we numerically assess the performance of the proposed S-BVT building

block according to those. Furthermore, we experimentally validate our solution within the 4-node ADRENALINE photonic mesh network².

Network scenario and S-BVT architecture

The network scenario consists of a flexgrid metro network, and in particular region-A of TID network, containing 30 optical nodes (Fig.1). The network has to support traffic generated by several Multi-Tenant Unit (MTU) switches that communicate with the centralized pool of BRASes. Actually, for protection purposes, there are 2 centralized BRAS pools and each MTU switch is connected to both of them via two different ingress nodes and node-disjoint lightpaths, as shown in Fig.1. It is assumed that the traffic demand per each MTU (aggregating traffic from lower level OLTs) is 10Gb/s and that traffic at the BRAS nodes is served by S-BVTs.

The cost-effective software-defined S-BVT is based on digitally processed MB-OFDM, also referred to as subcarrier multiplexing. It is able to serve $N \times M$ MTUs. The array of modulators generates N slices that can be directed towards different destinations nodes. The MB-OFDM BVT (S-BVT building block) serves M MTUs with a single optoelectronic front-end by using only one laser source and simple/cost-effective DD. The number (M) of MTUs per MB-OFDM slice (corresponding to a single optical carrier λ_n) is limited by the bandwidth of digital-to-analog converter (DAC) and optoelectronic components (we consider 10GHz for low-cost devices). Combining DD with single sideband (SSB) modulation, longer elastic optical paths can be supported, thanks to the enhanced robustness to chromatic dispersion (CD). This requires a guard band (B_G) and an optical filter at the transmitter (BVTx). The worst optical path to be covered is calculated for the regional topology and traffic at hand. As shown in Fig 1, the MTU channels can be formed by a variable number ($L \geq M$) of sub-bands (B_{Sk}) at variable rate, enabling distance-adaptive transmission.

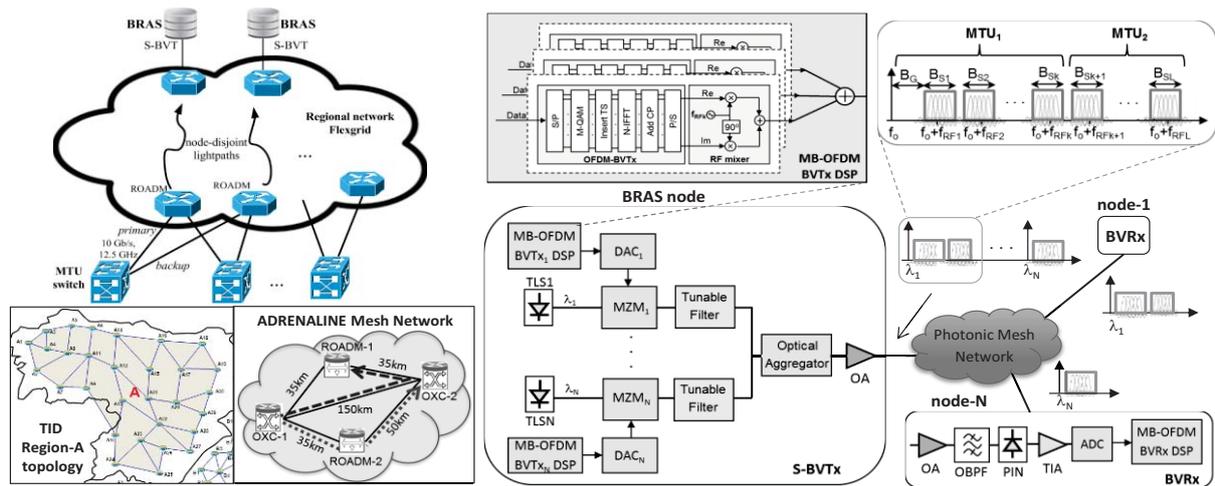


Fig. 1: Network scenario (top left); TID region-A topology and ADRENALINE photonic mesh network (bottom left), dotted and dashed lines indicate 2-hop paths of 85km (path1) and 185km (path2); S-BVT architecture based on MB-OFDM (on the right).

The transceiver digital signal processing (DSP) supports multiple m-QAM formats. By considering narrow sub-bands, the flexibility and spectral efficiency can be enhanced (reducing B_G), and the DSP requirements relaxed. Furthermore, the mixing between optical carrier and OFDM signal can also be reduced by properly adjusting the MZM biasing point². For a software-defined OFDM band tuning over the spectrum, the radio frequency (RF) mixing is performed in the digital domain, resulting in a cost-effective solution (no need for additional hardware).

Numerical analysis

Assuming a given topology and the placement of the BRAS pools we developed optimization algorithms to minimize the maximum length of the established lightpaths. The resulting maximum length lightpath is fed as the worst case requirement to the S-BVT design. Taking into account protection issues, we transformed the problem of establishing a connection between a single MTU switch and the BRAS nodes into a node-disjoint routing problem, and then considered the joint-optimization of all connections in a combinatorial manner. An exact algorithm based on an ILP formulation was developed, that was able to solve the problem at hand and obtain the optimal solution. However, we also developed a heuristic algorithm that can be used to find solutions in bigger problem instances and also in variations of this basic problem. For example, the dual of this problem, given the reach capability of the S-BVT minimizing the number and choosing the placement of the BRAS pools, is particularly interesting for applying the proposed solution to different regional networks. Assuming the placement of the BRAS pools at nodes 21 and 22 of the region-A TID topology the maximum

path length (among all primary and backup paths) was found to be 545km, with the longest path traversing the nodes: 1, 2, 7, 9, 10, 13, 22. In this case each MTU switch uses as backup entry node the one closest to its primary one.

To numerically assess the performance of the S-BVT building block, we consider the longest worst path (545km, 6 hops), from node A22 (BRAS location) to node A1, assuming that each MB-OFDM slice has maximum bandwidth occupancy $B_o=12.5\text{GHz}$. We analyze the SSB transmission, using linear field modulation, of one MTU channel composed of a single sub-band ($M=L=1$ and $B_G=B_{S1}$). B_{S1} is 6.11GHz ($B_o=12.22\text{GHz}$) to obtain a net bit rate of 10Gb/s with 4QAM, considering a target BER of $2 \cdot 10^{-2}$. The overhead is mainly due to the 20% soft-decision FEC (for shorter paths, 7% FEC can be either selected reducing the overhead); the cyclic prefix (CP) is set to 2% and only 3 training symbols (TS) every 512 frames are used for equalization. The DSP uses 512-points FFT for OFDM sidelobes minimization³. The signal, optimally clipped for high peak power mitigation, is modulated by the MZM, SSB filtered and transmitted over the path. The split-step Fourier method is used to model the propagation through the standard single mode fiber (SSMF). EDFAs are modeled as standard amplifiers with constant output power and noise figure of 4.7dB; filters are assumed to be LCoS tunable filters. At the receiver (BVRx), the PIN diode has responsivity of 0.7A/W, dark current of 10nA and thermal noise of 16pA/sqrt(Hz). The receiver DSP includes RF down-conversion, OFDM demodulation, equalization and demapping. The bit error rate (BER) is measured as the statistical counting of received bits. The OFDM signal is successfully transmitted over the considered worst path, with required optical

signal to noise ratio (OSNR) of 13.9dB at the target BER. Using 16QAM, B_G and B_{S1} decrease and $B_o=6\text{GHz}$, allowing the establishment of two connections at 10Gb/s (12Gb/s gross bit rate) within 12.5GHz. Further bandwidth occupancy reduction is achieved by using narrower sub-bands to form the MTU signal, as in the inset of Fig.1. For example, with $L=5$ sub-bands of $B_{Sk}=B_G=0.6\text{GHz}$, equally spaced by 0.7GHz, B_o is reduced to 4 GHz. Thus, this approach is used for the S-BVT experimental validation.

Experimental assessment

In the experimental set-up, the DSP at the transmitter/receiver is performed off-line. The stream of randomly generated data is mapped into 4QAM, 8QAM or 16QAM format (depending on the sub-band number) for adaptive loading according to the DAC SNR profile. After OFDM modulation and RF up-conversion, the digital to analog conversion is performed using an arbitrary waveform generator (AWG) at 24GS/s. The analog OFDM signal modulates an external MZM (biased at the quadrature point), driven by a tunable laser source (TLS) at $\lambda_1=1550.12\text{nm}$. An LCoS tunable filter is used for SSB modulation. At the receiver side, the transmitted signal is detected by a pre-amplified PIN with TIA. The data is captured by a real-time oscilloscope (ADC) at a sampling rate of 50GS/s and then off-line down-converted, demodulated, equalized and demapped. 2% CP and 3 TS every 40 frames (7%) are considered for equalization and synchronization. In order to assume a target bit error rate (BER) of 10^{-3} , a forward error correction (FEC) with 7% overhead is taken into account. Thus, the resulting total overhead is 17%. We first analyze the transmission of $L=5$ sub-bands of 0.6GHz, equally spaced by 0.7GHz. For setting a second connection at 10Gb/s (12Gb/s gross bit rate), the number of sub-bands is extended to $L=14$ to take into account the SNR profile of the AWG: 2 sub-bands support 8QAM and the last 7, 4QAM (see Fig.2). B_o is 10.3GHz, which fits within a 12.5GHz flexgrid channel. The performance results are evaluated per each sub-band (considering the adjacent ones) for a 2-hop path of 85km along the amplified SSMF (G.652) links (50km+35km) of the ADRENALINE testbed, as indicated in Fig.1. As shown in Fig.2, the OSNR at 10^{-3} BER ranges between 24dB and 27dB and the performance is limited by the AWG SNR profile. According to it, more robust modulation formats are required at higher frequencies and the last sub-band is highly degraded by the limited AWG bandwidth (9.6GHz).

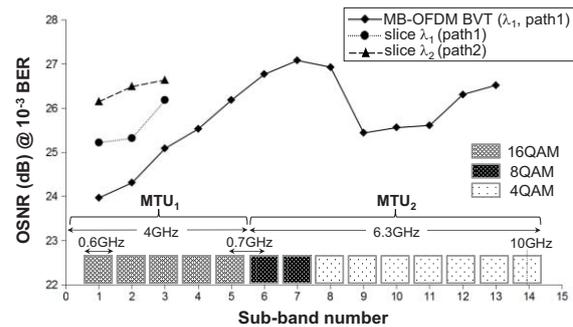


Fig. 2: Sub-band OSNR performance at 10^{-3} dB target BER.

Finally, we perform a proof of the sliceability concept. Two identical MB-OFDM signals with 3 sub-bands at 16QAM are generated using the same MZM driven by TLS_1 at $\lambda_1=1550.12\text{nm}$ and TLS_2 at $\lambda_2=1550.92\text{nm}$. They are selectively filtered, combined and amplified at the S-BVT. The two slices of the aggregated signal are sent to two different destination nodes, through 2-hop paths of 85km (path1) and 185km (path2) of the ADRENALINE testbed, as indicated in Fig.1. The OSNR performance of the sub-bands per each slice is evaluated at the destination nodes (considering the adjacent ones) and reported in Fig. 2. Successful transmission is evidenced with a maximum penalty of 1.2dB after 85km and 2.2dB for the longest path, with respect to the previously obtained results. If the bandwidth of DAC and optoelectronic devices is doubled, up to 5 or 6 MTUs can be served by a single MB-OFDM BVT, requiring an S-BVT with 17 or 20 blocks (total capacity of 1Tb/s) for 100 MTUs.

Conclusions

Flexgrid technologies have been assessed for a MAN scenario with centralized BRASes. The proposed S-BVT architecture with adaptive software-defined capabilities is an attractive cost-effective candidate for serving the multiple endpoints (MTU switches) according to the topology requirements.

Acknowledgements

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