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 technologies[1] 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 carriers[1]. This feature is well aligned with the requirements for the BRASes centralization. In a previous work[2], 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 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 network[2].

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 *NxM* MTUs. The array of modulators generates *N* slices that can be directed towards different destinations nodes. Each 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 bandwidth 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.

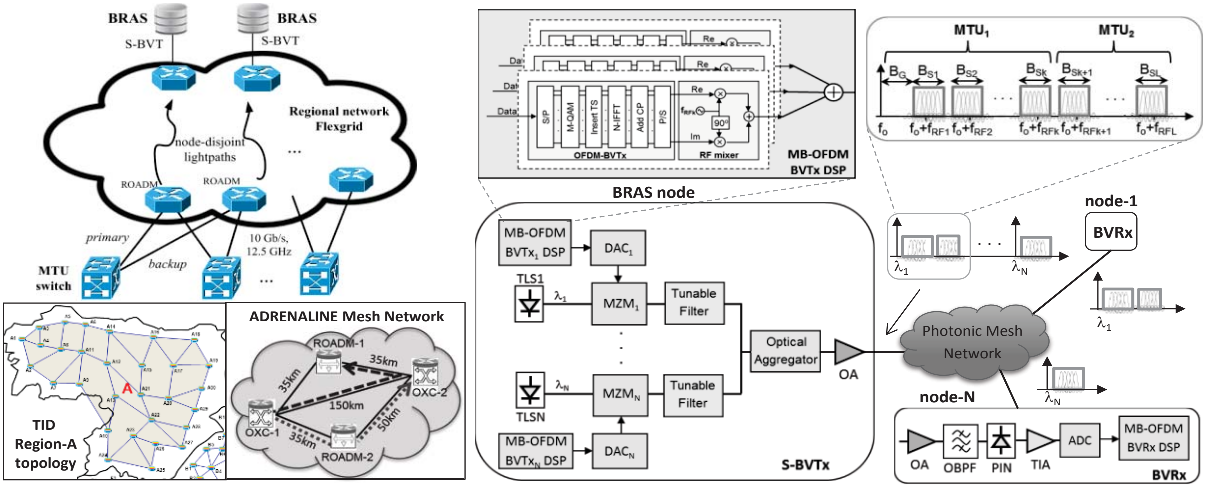

Fig. 1: Network scenario (top left); TID region-A topology and ADRENALINE photonic mesh network (bottom left), dotted and dashed lines indicate 2-hop paths of 85km (path1) and 185km (path2); S-BVT architecture based on MB-OFDM (on the right).

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 point[2]. 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 additional hardware).

Numerical analysis

Assuming a given topology and the placement of the BRAS pools, we develop 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 transform the problem of establishing a connection between a single MTU switch and the BRAS nodes into a node-disjoint routing problem, and then consider the joint-optimization of all connections in a combinatorial manner. An exact algorithm based on an ILP formulation is developed, that is able to solve the problem at hand and obtain the optimal solution. However, we also develop 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) is found to be 545km, 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 obtained 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=12.5GHz. 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=12.22GHz) 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 minimization[3]. 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 and the main figure of merit is the optical signal to noise ratio (OSNR) within 0.1nm. The OFDM signal is successfully transmitted over the considered worst path, with required OSNR of 13.9dB at the target BER. Using 16QAM, B_G and B_{S1} decrease and B_o=6GHz, 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 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 λ_1=1550.12nm. 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 BER of 10^{-3}, a 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 (M=2, N=1) at 10Gb/s (12Gb/s gross bit rate), the number of sub-bands is extended to L=14. In fact, to take into account the SNR profile of the AWG, 2 sub-bands support 8QAM and the last 7 are loaded with 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 the back-to-back (B2B) case and for a 2-hop path of 85km along the amplified SSMF (G.652) links (50km+35km) of the ADRENALINE network (Fig.1). As shown in Fig.2, the OSNR (within 0.1nm) at 10^{-3} BER ranges between 24dB and 27.1dB for both the curves. The performance is limited by the AWG SNR profile: more robust modulation formats are required at higher frequencies, which are also more affected by the transmission along the path. The last sub-bands are more degraded by the limited AWG bandwidth (9.6GHz).

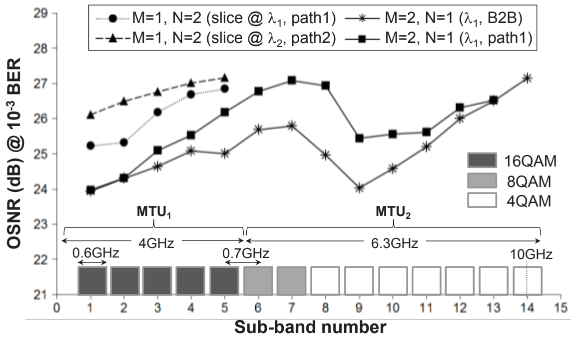

Fig. 2: Sub-band OSNR performance at 10^{-3} target BER.

Finally, we perform a proof of the sliceability concept, considering N=2 slices with M=1 and L=5. Two identical MB-OFDM signals are generated loading each sub-band with 16QAM and using the same MZM driven by TLS_1 at λ_1=1550.12nm and TLS_2 at λ_2=1550.92nm. 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 network, 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 for path1 and 2.2dB for the longest path2, with respect to the results for N=1 along path1. 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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