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Demonstration of Bandwidth Maximization between Flexi/Fixed Grid Optical Networks with Real-Time BVTs

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Abstract *Real-Time SDN-based BVT enables baud-rate tunability to combat the filtering effect of the legacy filters for interoperability between fixed-grid/flexigrid. Based on the passed filters and link-distance, SDN controller configures BVTs to maximize the link capacity.*

Introduction

Elastic optical networks, routing signals with variable spectral widths and center frequencies, provide a promising solution for future large capacity and dynamic optical transport networks. However, the cost of the key enabling technologies, such as spectrum selective switches (SSS) and flexible transceivers, prohibits the update of currently installed fixed grid DWDM network infrastructure. Thus, both fixed grid and flexigrid optical networks will have to coexist in the future[1]. This coexistence raises many challenges for the interoperability between fixed grid and flexigrid optical network domains.

Several studies about the gradual migration from fixed to flexigrid networks have been demonstrated[2,3]. Since the flexigrid network is backward compatible with fixed grid one, main challenges rise from the inverse compatibility, i.e., from flexigrid to fixed grid. The signals from flexigrid will undergo severe degradations in the fixed grid, mainly due to the filtering effect of the multiple optical filters such as wavelength selective switches (WSS) or array waveguide gratings (AWG) that each signal has to pass through at each fixed-grid node. The spectrum-compact optical signals in flexigrid are more sensitive to the filtering effect. Thus, the filtering effect dominates the transmission performance of channels close to the filter edge. Therefore, new techniques need to be proposed to accommodate the signal capacity and spectra of the originated channels into the fixed grid nodes and links with strong filtering effects.

In this paper, we present the use of a software-defined Optical Transport Network (OTN) bandwidth variable transmitter (SD-BVT) for mitigation of the filtering effect in the fixed grid network. By slightly reducing the signal baud-rate, more filtering effect can be tolerated. The Software-defined networking (SDN)-based network planning algorithm decides the baud-rate according to the link conditions, such as number of nodes & transmission distance. Thus, the link capacity can be maximized for interoperability between fixed and flexigrid optical networks. We experimentally demonstrate three signals with 37.5GHz channel width originated from the flexigrid domain and packed within a 100GHz fixed grid channel. The channels, which are close to the edge of the equivalent filter of the fixed grid network, adjust their baud-rate to tackle the filtering effects for different link configurations by using a baud-rate variable SD-BVT[4]. A total capacity of 304Gbit/s is transferred through the 100 GHz optical channel with PM-QPSK modulation format for a 250-km link. To the best of our knowledge, it is the first time to explore the physical limitations for fixed grid and flexigrid optical network interoperability with SDN-enabled real-time BVTs.

SDN planning

The filtering effect in fixed grid networks can be addressed by using intelligent network planning algorithms combined with an SDN controller for the network configuration. The SD-BVTs can vary the occupied optical bandwidth by adjusting the baud-rate, which will improve the transmission quality of channels suffering from filtering effects. In this paper, the proposed network-planning algorithm (Fig. 1a) receives the lightpath requests and computes the bandwidth and modulation scheme required for the lightpath. The algorithm then computes the shortest path that can fit the required bandwidth on the fixed-grid spectrum map or the path with the least number of fixed-grid filters. Depending on the number of fixed grid filters on the path, the algorithm computes the optimal baud-rate for the SD-BVTs.

Experimental demonstration

Fig.1(b) presents the testbed for flexi/fixed grid optical networks. The flexigrid optical network consists of three nodes with SSS-based ROADMs. In node A, several transmitters are deployed, including a 28 Gbaud PM-QPSK transmitter and two SD-BVTs. The SD-BVTs aggregate the incoming OTN tributaries onto a
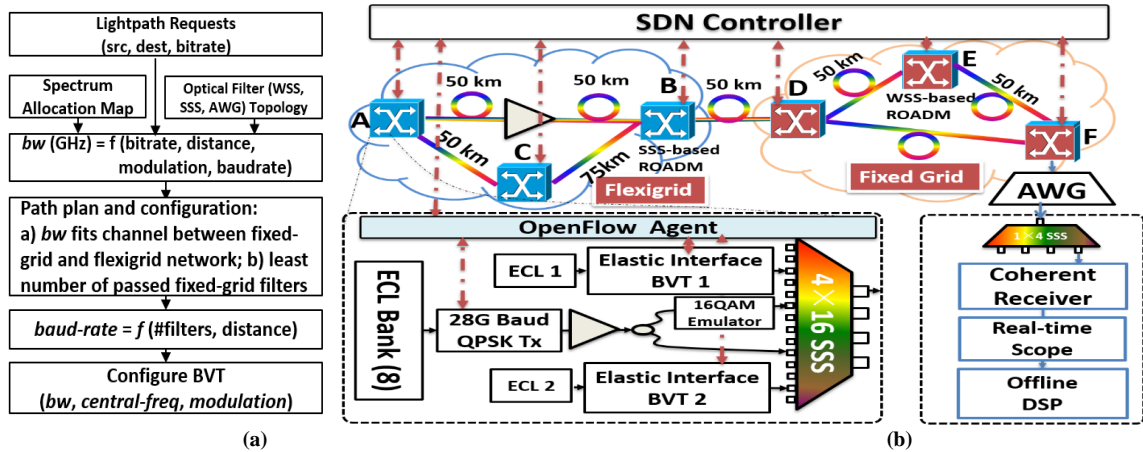
Fig. 1: (a) Workflow for SDN-based network planner; (b) Experimental testbed with fixed and flexigrid optical networks

just-enough optical transported data rate, acting as an elastic interface. The operation of baud-rate can change from 2.67 Gbaud to 26.7 Gbaud with a step of about 2.67 Gbaud, to deliver a variable bit rate from 10.7 Gbit/s to 107 Gbit/s on a PDM-QPSK optical format. The FPGA-based design of the SD-BVT is shown in Fig.2 (a). The back-to-back measured BER performance for different baud-rate is shown in Fig.2(b). We also tested the OSNR vs. BER curves of the 28 Gbaud PM-QPSK signals filtered with different filter bandwidth. All these results are fed to our network planning algorithm.

The testbed is shown in Fig.1 (b). In flexigrid optical networks, Node A and node B are connected by a 100-km fiber. Then a 50-km fiber connects the flexigrid and fixed grid optical networks together. The fixed grid optical network consists of three nodes, where commercial 100-GHz grid WSS-based ROADMs are deployed. Node D and F deployed one WSS at each node. In node E, a 4-degree ROADM is deployed. Thus, each channel would pass two WSSs in node E. At node F, an AWG-based demultiplexer is connected to the WSS for optical demultiplexing. The three nodes are interconnected with 50-km-long fibers and EDFAs.

In this demonstration, a link from node A to node F is setup through node B, D, and E. To enable compatibility between the two networks and maximize the link capacity, the channel slot

is set to 112.5 GHz (3×37.5 GHz) in the flexigrid network and 100GHz in fixed grid network with center wavelength at 1548.5 nm. Ten carriers with PM-QPSK signals are generated at node A. Fig. 3(a) shows the spectrum of the generated 10-carrier signals. Three signals are dropped at node B and sent to the fixed grid network. Each channel in the dropped signals occupied a 37.5 GHz bandwidth. The center channel adopts 28 Gbaud PM-QPSK signal, while the two side channel signals are generated by two SD-BVTs at full capacity with 26.7 Gbaud PM-QPSK signals. The three-channel signals are packed into a 100 GHz channel with center wavelength at 1548.5 nm.

Since the flexigrid optical network can adjust the channel bandwidth easily with current SSSs, we only consider the filtering effect inside of the fixed grid network. We tested the accumulated filter profiles of the channel with center wavelength at 1548.5 nm. Fig.3 (b) shows the obtained equivalent filter profiles at different nodes. The 3-dB filter bandwidth decreased from 0.649nm at node D to 0.457nm at Node F. The severe filtering effect in the fixed grid network will affect channels closed to the filter edge. In the fixed grid optical network, the dropped signals from flexigrid passed through nodes D, E, and F. At the node F, the three channel signals will be dropped by the WSS-based ROADM, and then the signals will be demultiplexed with an AWG-
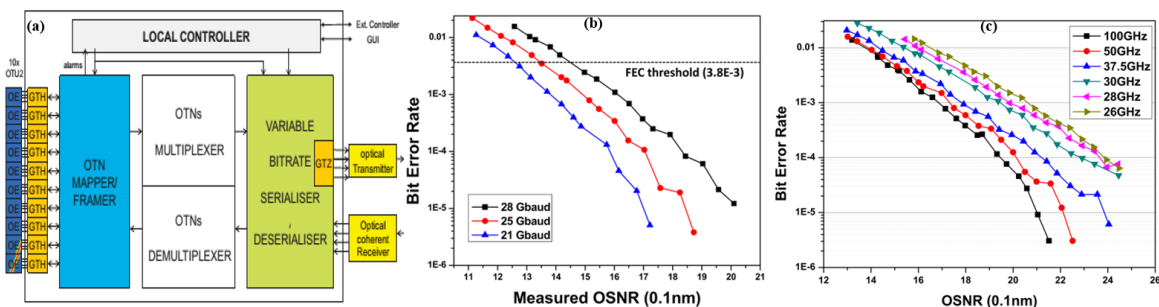

Fig. 2: (a) Design blocks of the software-defined bandwidth variable transmitter (SD-BVT); (b) Back to back performance of the transmitters; (c) OSNR vs. BER curves of 28Gbaud PM-QPSK signals filtered by optical filters with different bandwidth
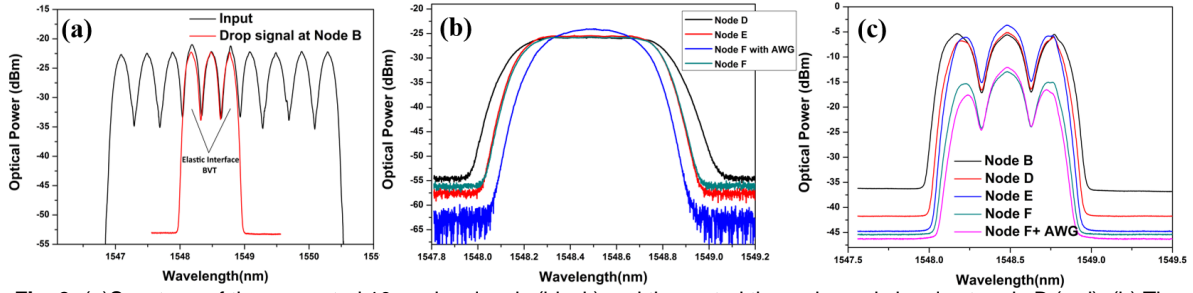
Fig. 3: (a)Spectrum of the generated 10 carrier signals (black) and the routed three channel signals at node B (red); (b) The cumulated filter profiles after each node of the fixed grid optical networks;(c) spectra of the three channel signals testing at

based demultiplexer. The three channel signals will be further separated by a 1x4 SSS and then received by a coherent receiver with offline DSP. As shown in Fig.3(c), the WSSs inside of the fixed grid network will filter the two side band severely. Thus, in metro-like short-range networks, the filtering effect inside of the fixed grid networks dominate the transmission performance of the side channels.

In the initial setup, the two side signals are operated at a full capacity of 26.7Gbaud. Due to the accumulated filtering effect inside the fixed grid network, the tested bit error rates (BERs) of the two side channel signals increased quickly. At node F, the BER value increases to about 1E-3, which is close to the FEC threshold and hence the signal cannot be transmitted through the AWG, which is used for the demultiplex operation. Thanks to the baud-rate variable feature of the BVT, the two side channels can adjust their baud-rate and therefore reduce their occupied bandwidth, to improve the filter tolerance. In addition, the center wavelength of the side channels is adjusted based on the baud-rate to avoid the filter effects, when a low baud-rate is used. Fig. 4 shows the BER performance of the left channel signals at different nodes with different baud-rates. Compared to the center channel, the filtering effect caused a large penalty. In the following testing, we adjusted the baud-rate of the BVT to about 25 Gbaud, which resulted in the BER performance to a similar range of the referred center channel signals. The total link capacity of the three channels is 304 Gbit/s after 250 km transmission. Then we
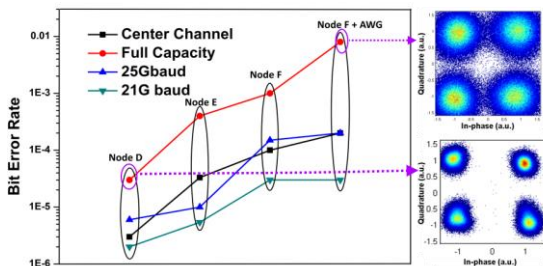
decreased the baud-rate further to about 21 Gbaud. The BER testing indicated the side channel signals get improved performance compared to the central channel signal. With the network planning, the filtering effect can be managed to obtain maximum capacity. Tab.1 shows several example of configurations based on the distance and link condition.

Tab.1: Results of the SDN planning module

Quan. of Filters	Ch. BW	Dist.	Solution
2(Node E)	0.606nm	200km	Full Capacity
3(Node F)	0.574nm	250km	9/10 Capacity
4(Node F+ AWG)	0.457nm	250km	9/10 Capacity

Conclusion

In this paper, the fine baud-rate tunability of the real-time BVT is used to combat the filtering effect in fixed grid optical networks. The network-planning algorithm computes the baud-rate of BVTs based on the transmission links, WSSs, and AWGs to mitigate the filtering effect and maximize the link capacity for interoperability between fixed grid and flexigrid optical networks. As a result, the software-defined BVT preserves an error-free transmission of the two side channels while maximizing the capacity sent from flexigrid to fixed-grid networks thanks to its granularity of 2.67 GBaud.

Acknowledgement

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Fig. 4: BER performance of one side channel with different baud-rates (Circle: Full capacity; Up triangle: 25 Gbaud; Down triangle: 21 Gbaud;). The center channel with 28 Gbaud PM-QPSK is shown with square for reference