Experimental Demonstration of Tunable Optical Channel Slicing and Stitching to Enable Dynamic Bandwidth Allocation

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Abstract: A tunable optical channel slicing and stitching scheme is experimentally demonstrated in QPSK/16QAM systems. Its application to dynamic bandwidth allocation in WDM channels brings >6dB OSNR improvement at 1e-3 BER comparing to direct channel insertion.

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1. Introduction

Flexible and heterogeneous optical networks that utilize dynamic bandwidth allocation are of great interest due to their potential for highly efficient operation with limited spectrum [1–4]. One key function is the ability to groom a given data channel so that it “fits” within any available wavelength slot in the flexible spectrum [5]. For example, if a transmitting optical networking unit requires 200 GHz of bandwidth, but only two spectral regions of 50 and 150 GHz are available, then a straightforward approach would be to electrically generate two different data signals that occupy these free spectral slots and transmit them on two lasers.

However, it might be valuable in a transparent flexible optical network to perform this function optically and tunably to avoid inefficient optical-electrical-optical (O-E-O) conversion at intermediate nodes. In this case: (i) an incoming data channel is optically “sliced” in frequency; (ii) its smaller frequency sections are placed into the free parts of the existing spectrum; and (iii) the component slices are finally “stitched” together optically at the node where the combined entire data channel is destined.

In this paper, we propose a tunable optical channel slicing and stitching approach to enable dynamic bandwidth allocation for an incoming channel based on optical frequency combs and nonlinear wave mixing. The proposed scheme is first experimentally demonstrated both by 20/28-Gbaud QPSK and 20-Gbaud 16QAM single channel systems. Then, the application to dynamic bandwidth allocation in WDM systems is experimentally verified and compared to direct channel insertion, demonstrating more than 6dB OSNR improvement at a BER of 1e-3.

2. Concept

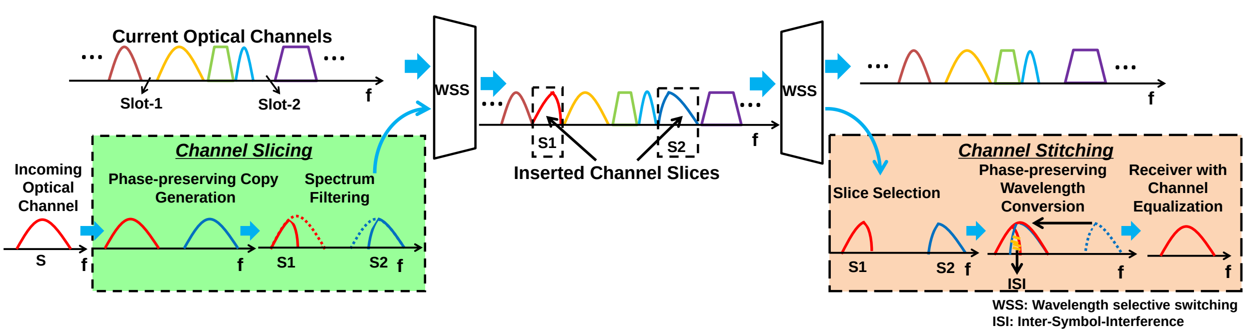

Fig. 1. Concept of the proposed optical channel slicing and stitching to enable dynamic bandwidth allocation.

Figure 1 shows the concept of the proposed dynamic bandwidth allocation based on optical channel slicing and stitching. In this example, the current optical spectrum includes heterogeneous data channels and only two small available slots (Slot-1 and Slot-2), where neither slots can accommodate the entire incoming high-bandwidth optical channel (S) without introducing critical inter-channel-interference (ICI). To solve the problem, a channel copy is first generated on another wavelength via phase-preserving wavelength conversion using optical frequency combs and nonlinear wave mixing [6]. Then, partial spectra of the channel and channel copy are sliced into two smaller channels by optical filtering. Now, the two resulting channel slices (S1 and S2) preserve all the information of the original channel (S) and S1/S2 are each narrow enough to be separately added onto the available Slot-1/Slot-2 for transmission as shown in Fig. 1. The bandwidths of S1 and S2 are determined by the available space of Slot-1 and Slot-2, which do not have to be the same.

In the receiver, the two slices S1 and S2 are first selected from the current WDM spectrum. Then, again using phase-preserving wavelength conversion, S1 and S2 are recombined to recover the original data channel (S). Because the filtering in stages of spectrum slicing and slice selection is non-ideal, partial spectrum overlap is unavoidable as shown in Fig. 1. However, the resultant inter-symbol-interference (ISI) can be readily compensated by a static linear channel equalizer after receiving the stitched channel.

3. Experimental Setup

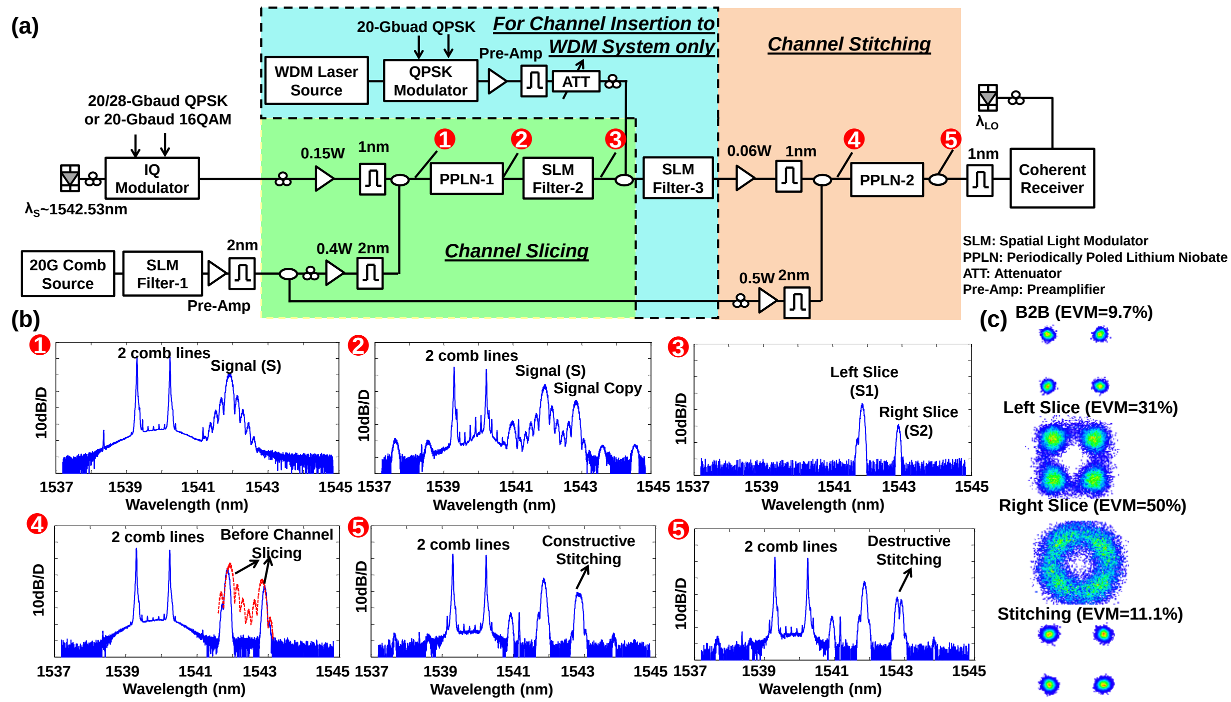

Fig. 2. (a) Experimental setup for optical channel slicing and stitching. The optical frequency comb is employed to achieve phase-preserving channel copy generation and slices recombination (stitching). The WDM channel emulator in the dotted area is only used for the results in Fig. 5; (b) measured spectra at the corresponding nodes; (c) measured EVMs of a 20-Gbaud QPSK channel under different scenarios.

Figure 2(a) illustrates the experimental setup to demonstrate the proposed scheme. In the transmitter, the data is encoded at the wavelength of 1542.53nm with an optical I/Q modulator. A comb source with a 20 GHz repetition rate generated by a mode-locked laser is employed and a spatial light modulator (SLM-1) filter selects two comb lines at the wavelength of 1538.90nm and 1539.86nm. Their wavelength difference determines the relative location of the channel copy in the next stage and can be tuned to accommodate the slots in the current WDM configuration.

In the stage of channel slicing, the optical channel (S) is amplified to be 0.15W and coupled with the selected two comb lines in a periodically poled lithium niobate (PPLN) waveguide (PPLN-1), whose quasi phase matching (QPM) wavelength is ~1541nm. The spectra of the input and output of PPLN-1 are shown in Fig. 2(b1, b2), in which a phase-preserving channel copy is generated. Then, SLM-2 filters a left slice of original channel (S1) and a right slice of the copy channel (S2) as shown in Fig. 2(b3). After that, the two slices are either sent directly to the stage of channel stitching or mixed with six 20-Gbaud QPSK WDM channels as shown in Fig. 2(a). The attenuator and polarization controller in the WDM emulator is used to align the power and polarization with optical channel S.

In the stage of channel stitching, the two slices S1 and S2 are amplified to be 0.06W and coupled with 2 comb lines with the same wavelength difference in PPLN-2, whose QPM wavelength is also ~1541nm. The spectrum prior to PPLN-2 is shown in Fig. 2(b4), where both slices are much narrower than the original channel. Since S1 and S2 have a partially-overlapped spectrum, tuning the phase offset ($\Delta\varphi$) between S1 and S2 in SLM-2 can stitch them in a constructive ($\Delta\varphi$=0) or a destructive ($\Delta\varphi$=180^o) manner, which are shown in Fig. 2(b5). Finally, the stitched channel is filtered and sent to the coherent box with 11-tap static channel equalization. Fig. 2(c) shows that the signal is successfully recovered with only 1.4% EVM deterioration.

4. Results and Discussions

Figure 3 shows that the channel stitching performance is influenced by different phase offsets (Δφ) between the two slices. With static channel equalization, the constellation is still visible even Δφ is 150^o as shown in Fig. 3(a). Without equalization, not only is the signal quality deceased, but also the tolerance to Δφ is limited below 90^o as shown in Fig. 3(b). Two EVM curves are depicted in Fig. 3(c), where ~10% EVM difference is observed with Δφ=0.

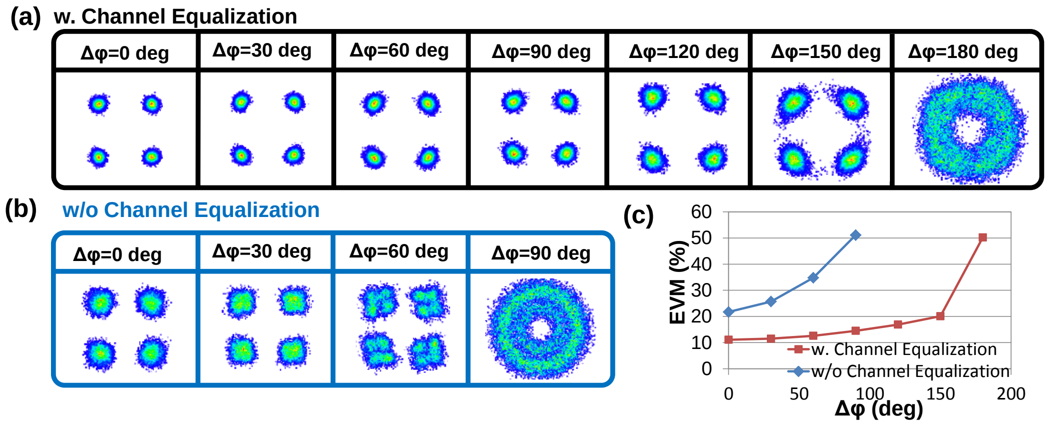

Fig. 3. Constellation comparison of a 20-Gbaud QPSK by tuning the relative phase offset (Δφ) between two channel slices (a) with static channel equalization and (b) without static channel equalization in the coherent receiver; (c) measured EVMs with different Δφ.

Figure 4 shows the BER comparisons for different channel baudrates and modulation formats. It is noted that Fig. 4(a) shows the channel equalization would bring a ~3dB OSNR improvement at a BER of 1e-3. Therefore, the remainder of the measurements includes channel equalization. Compared to a B2B system, the OSNR penalty is ~1dB for a 20/28 G-baud QPSK system and ~2dB for a 20-Gbaud 16QAM system at a BER of 1e-3.

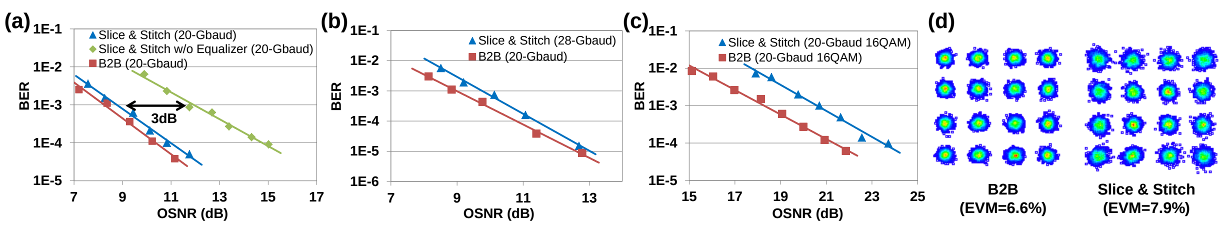

Fig. 4. BER measurements for (a) a 20-Gbaud QPSK system, (b) a 28-Gbaud QPSK system and (c) a 20-Gbaud 16QAM system; (d) EVM comparison between B2B and channel slicing & stitching for a 20-Gbaud 16QAM data channel.

The application to dynamic bandwidth allocation is demonstrated using six emulated WDM channels, in which the available slots (Slot-1 and Slot-2) are too small to fit a 20-Gbaud QPSK channel. With the proposed scheme, the channel can be successfully inserted into the two available slots as shown in Fig. 5(a). Compared to direct insertion, the channel suffers less ICI in Fig. 5(b) and Fig. 5(c) shows more than 6dB OSNR improvement at a BER of 1e-3.

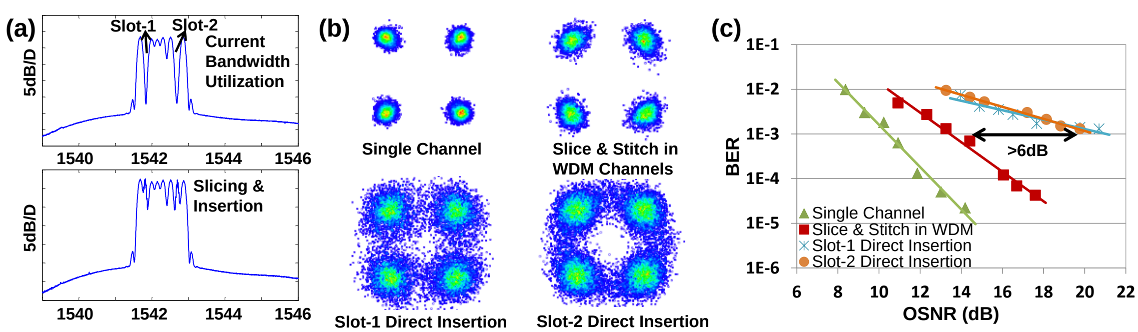

Fig. 5. (a) Spectra before/after dynamic bandwidth allocation; (b) constellations comparison under different scenarios; (c) BER measurements.

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