Optical Label Switched Add-Drop Node for Low Latency and High Capacity Data Center Interconnect Metro Networks

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We investigate an optical label-switched add-drop node for data center interconnect metro networks. The switching node is capable of dynamically handling high-capacity waveband traffic within sub-microsecond switching latency. Experiments using prototyped nodes show 20 ns dynamic switching for per-channel 6λ×112 Gb/s DP-QPSK traffic. Scalability in terms of the number of wavebands and crossed nodes is studied in a 25 km looping set-up. Results show potential scalability up to 15 nodes and Terabit/s capacity with limited performance degradation.

Introduction

Driven by the ever-increasing multi-Terabit/s traffic in data center interconnects (DCI) and next-generation cloud and 5G mobile applications, novel metropolitan area network (MAN) technologies and sub-systems are required to handle high capacity multi-data rate and format traffic with low latency and low power consumption [1]. Transparent and low latency optical add-drop multiplexers (OADMs) capable to dynamically switch Terabit/s data channels is a key sub-system that allows the effective utilization of the spectral and time resources, while reducing the power by eliminating the dedicated data rate and format dependent O/E/O front cards [2]. Despite several solutions based on optical switching technologies [3,4] supporting statistical multiplexing to implement the OADM, fast sub-microsecond control and switching of multi-Terabit/s OADM could further improve the dynamicity, latency as well as network throughput performance.

Optical label switching (OLS) based technique has been proposed to facilitate fast switching control, fast per channel power equalization, and on-demand bandwidth utilization for the OADM node [5]. Promising results have been shown by employing single-λ 50 Gb/s OOK NRZ data. Targeting the high demand for higher capacity and lower latency especially for DCI applications, the capability of switching Terabit/s wavebands signal with multi-level modulated data in the nanoseconds scale is of paramount importance and has not yet been properly investigated.

In this work, we demonstrate a low-latency OLS-based OADM node capable of dynamically switching high-capacity waveband traffic for DCI MANs. Experiments using prototyped nodes confirm 20 ns dynamic switching for per-channel 6λ×112 Gb/s DP-QPSK traffic and potential scaling up to 15 nodes with capacity of 2.688 Terabit/s.

System operation

The schematic of the OLS-based OADM node supporting fast waveband switching is shown in Fig. 1(a). To speed-up the switching time and the power equalization operation, the OADM employs fast in-band optical label processing for each channel [5]. The optical label provides information on the node destination, therefore no specific wavelength has to be assigned to individual add/drop port. This results in a better utilization of the wavelength resources, which can be flexibly employed for increasing

the network dynamicity and capacity. Each optical channel contains one/multiple wavelength(s) which can be tailored according to the desired channel capacity.
At each node, WDM channels are first de-multiplexed and then divided by a 1×2 coupler into a drop arm and continue arm. In the continue arm, the traffic is fed into the SOA-based optical gate controlled by the FPGA-based controller. SOA technology guarantees nanoseconds switching and adjustable optical gain for power equalization operation. In the drop arm, a Label Extractor (LE) separates the in-band label from the payload by using a narrow-band fiber brag grating (FBG). The power is split into two parts, the first one is used for real-time monitoring to facilitate rapid channel equalization and the other is processed on-the-fly and in asynchronous fashion by the Label Processor (LP) to recover the label information (RF tone encoded label bits [5]). According to this, the FPGA determines if the packet has to be dropped/forwarded or dropped and forwarded (for multicasting) by controlling the SOAs in both arms. Note that all labels are processed in parallel, which allows the controller to have the full vision of available slots and reconfigure the node in nanoseconds scale.
A coherent receiver is used that the dropping wavelength(s) can be detected by fast (nanoseconds) tunable local oscillator (TLO) controlled by the OADM controller. In the add operation, the controller sets the fast tunable transmitter (TTX) and Label Generator (LG) for transmitting the packets and corresponding labels originally stored in the node electrical buffer. As shown in Fig. 1(a), the binary label bits generated from the node controller are coded on multiple RF tones and carried by the label TTX. Figure 1(b) shows the OADM prototype integrating the discrete SOA gates with dedicated electronic drivers, LG, LP, power equalizers, and the FPGA controller.

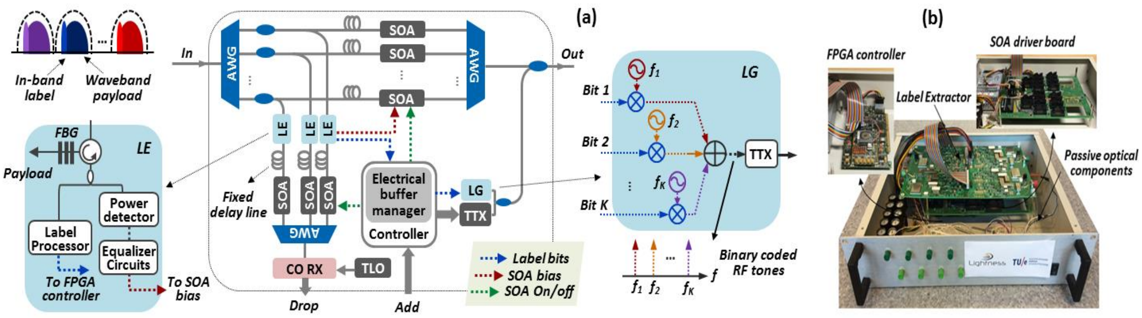

Fig. 1: (a) Schematic of the OLS OADM node for MAN network. (b) The node prototype.

Experimental results

The OLS based OADM is assessed with high-capacity waveband signal in a ring topology interconnecting 3 node prototypes, as shown in Fig. 2(a). Twelve 50GHz-spaced DWDM wavelength channels (1555.34 nm-1561.01 nm) are modulated using a 28 GBaud QPSK transmitter followed by the polarization and odd/even channel decorrelation stages, as shown in Fig. 2(c). The generated signal is distributed to the 3 nodes as add traffic (Add1-Add3) where it is separated into two waveband signals each containing 6λ×112 Gb/s dual-polarization (DP) QPSK data and controlled by the FPGA controller to emulate the tunable adding operations as shown in Figs. 2(b) and (c).
The experimental setup is given in Fig. 2(b). The payload packet with 2.5 μs duration and 100 ns guard time is attached with an optical in-band RF tone label, centered at 1556.55 nm and 1559.80 nm. 3-bit label are used to address the 3 possible destinations nodes and multicast destinations. The optical spectra of the input, drop ports for each

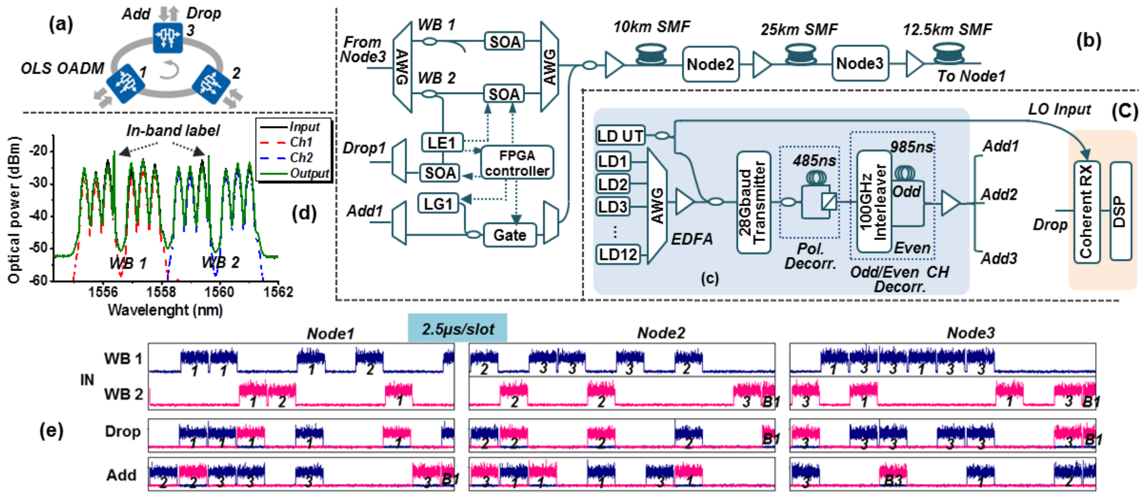

Fig. 2: (a) 3 nodes ring network. (b) Experimental setup. (c) 112Gb/s DP-QPSK traffic generation and detection. (d) Spectra of input, drop ports and output for Node 1. (e) Dynamic add/drop operation.

waveband, and the output of Node1 is illustrated in Fig. 2(d). The optical labels are filtered out by a FBG with 6 GHz 3 dB bandwidth. The controller fed with detected label bits, controls the SOA gates to drop / continue or drop & continue the packets. The destinations of the adding packets will be checked with the ones in continue arms for possible contention. Benefited from the parallel labelling and processing, <20 ns switching time is observed for add and drop operations. The traces recorded for dynamic add/drop operation is shown in Fig. 2(e). The packets have been labelled with destination Node 1-3 and B1-B3 stand for the multicasting originated from Node 1-3.

The dropped channel is detected by the coherent receiver and captured by a real-time 40 GSa/s oscilloscope for demodulation by offline DSP, as depicted in Fig. 2(c). The total input optical power to each node is 1 dBm and the SOA gates are biased at 80 mA. BER curves for the dropped channel at λ=1557.36 nm at the three different nodes are illustrated in Fig. 3(a). The measured OSNR penalty is < 0.8 dB at BER=1E-3. Figure 3(b) reports the BER for all channels at drop port of Node1 with 16 dB OSNR received. Similar performance over 12 wavelengths has been observed and the small difference is mainly due to the residual unbalanced input power. It can be seen that the dispersion is well compensated by DSP [6] and wavelength independent operation with limited OSNR penalty caused by the SOA ASE noise has been achieved.

The capability of switching more wavebands is also investigated for the OADM node. Fig. 3(c) shows the BER curves of the switched traffic when three (18λ) and four wavebands (24λ) are processed. Compared with the back-to-back BER curve, negligible penalty is found when scaling the number of waveband channels. This indicates that the OADM is capable of processing multiple wavebands with very limited performance degradation.

We have further assessed the scalability performance of the multiple waveband channels crossing a large number of OADM nodes by employing the 25-km length recirculating loop set-up shown in Fig. 3(d). Two wavebands are sent into the loop with input power controlled by an attenuator. To guarantee a BER below 7% HD-FEC limit, the minimum input optical power for different number of loops is reported in Fig. 3(e). Large dynamic range (>7 dB) improving the tolerance to power fluctuation is achieved for 9 loops (225 km). Then the BER and OSNR for 2, 3 and 4 wavebands are tested and the results are shown in Fig. 3(f). OSNR degradation from the amplifiers results in a

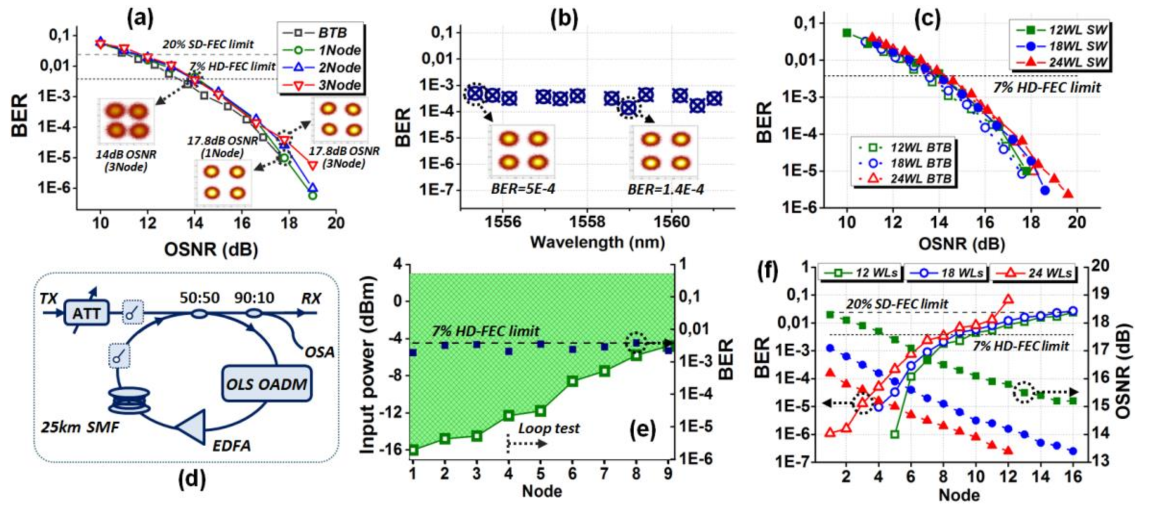

Fig. 3: (a) BER curves for 3 nodes. (b) Wavelength dependency. (c) BER curves for 2, 3, and 4 wavebands. (d) 25km loop setup. (e) Input dynamic range. (f) BER and OSNR for 2, 3, and 4 wavebands in looping test.

linear (0.25 dB/node) decrease of received OSNR. For 2 wavebands (12λ), 9-node (225 km) and 15-node (375 km) operation is obtained below HD-FEC and SD-FEC limit, respectively. Scaling the number of wavebands has small expense due to the lower OSNR caused by the gain sharing. For 4 wavebands (24λ) traffic, 8-loop and 11-loop operation is obtained below HD-FEC and SD-FEC limit, which accounts for 2.688 Terabit/s total capacity over 200 km and 275 km, respectively.

Conclusion

We have demonstrated a high-capacity and low-latency DCI metro network using OLS-based OADMs. Investigation using node prototypes with 6λ×112 Gb/s DP-QPSK waveband traffic shows 20 ns dynamic switching with <0.8 dB OSNR penalty. Scalability in terms of the number of wavebands and crossed nodes is studied in a 25 km loop set-up. >7 dB dynamic range has been obtained for 2 wavebands (12λ) signal up to 15-node (225 km). 4 wavebands operation providing 2.688 Terabit/s capacity across 11-node 275 km distance is also achieved with limited performance degradation.

Acknowledgements

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