Effects of Cumulative PDG on the Scalability of SOA-based Optical Packet Switching Networks

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Abstract: Using a re-circulating loop we study the extreme cases of cumulative PDG in SOA-based packet switching nodes. We show that node polarization dependence could limit the physical layer scalability of optical packet switching networks.

OCIS codes: 250.5980 Semiconductor optical amplifiers; 200.4650 Optical interconnects; 230.5440 Polarization-sensitive devices;

1. Introduction

Optical packet switching (OPS) interconnection networks are a promising means of routing high bandwidth optical packets in applications ranging from data communications and storage to high-performance computing. In most OPS networks, the predominant switching element is the commercially available optical semiconductor amplifier (SOA) due to its broad gain bandwidth, fast switching and potential for integration. The broadband SOA-based switching node routes individual WDM packets transparently by operating the SOA in the linear regime with a gain that compensates only for the losses induced by the node structure [1]. The polarization properties of such OPS networks have not been specifically investigated, primarily because current switching node technologies include SOAs with very low polarization dependent gain (PDG < 0.3 dB) [2], and passive elements such as couplers with low polarization dependent loss (PDL < 0.1 dB).

In this paper we show that as packets propagate through a cascade of SOA-based switching nodes, the accumulation of small PDG could break the node transparency and therefore limit the physical layer scalability of an OPS network. Our re-circulating loop configuration allows us to change the packets' polarization evolution in a controlled fashion and thus enables measurements of the cumulative effects through a cascade of nodes in a network. Our results establish a limit for the switching node PDG of 2/N dB, where N is a number of cascaded nodes. For example a network with a maximum packet path of 14 nodes, a node PDG of 0.14 dB would insure BER of below 10^{-9} for all possible input states of polarization (SOP) for any payload WDM channel across over a 20nm band.

2. Re-circulating Loop

A schematic of the re-circulating loop setup containing an SOA-based switching node such as the one used in the data vortex OPS networks [1], is shown in Fig. 1a. The node is designed to transparently route broadband packets containing multiple WDM payload channels. In this experimental test-bed, three distributed feedback (DFB) cooled lasers emitting at 1531 nm (λ_B), 1543 nm (λ_G) and 1553 nm (λ_R) are multiplexed into a single fiber. The channels are modulated with a Mach-Zehnder modulator at 10 Gbps driven by an NRZ pseudo-random bit sequence of length 2^9-1 produced by the fast pattern generator (PPG1). A packet length of 25.6 ns is created using a separate SOA to gate the continuous data stream. The loop is constructed by connecting one of the node outputs to its input using a deflection fiber. Packets ingress through the input and are routed back through the node or out of the loop. The node is then controlled by a programmable pattern generator (PPG2) that sends a timed switching signal to eject the packet from the loop after a predetermined number of nodes circulations (N). A mechanical polarization controller (PC1) is added inside the node structure to adjust the PDG of concatenated loops. The launched state of polarization (SOP) of the payload channel is adjusted using a polarization controller (PC input) placed at the input of the loop structure.

The two SOAs inside the switching node are commercial devices (Kamelian OPB-10-10-X-C-FA) specified with a noise figure of 6.5 dB and a saturation input power of approximately 0 dBm. The devices have a transparency current of about 18 mA and their ASE spectrum is concentrated near 1515 nm. The SOA operates in the linear regime with a gain compensating for approximately 6.5 dB of loss due to the two couplers and connectors. Because SOA gain is generally wavelength dependent, the gain is set for the middle channel at 1543 nm. At the output, an optical receiver follows a narrow bandpass filter that selects the WDM channel under measurement. Bit error rate measurements are performed on all three channels of the packet using a BER tester externally gated by a pulse signal generated by PPG2.

The loop output powers versus number of nodes propagated for the middle channel (1543 nm) as measured by the polarimeter (HP8509) for two different input SOPs, are shown in Fig. 1b. Polarization controller PC1 is set so that the PDG of consecutive loops are added and thus the cumulative PDG is maximized. It is expected therefore that the power difference between the two input SOPs increase linearly with the number of loops. Note however that the minimum and maximum powers change in a nonlinear fashion: they saturate after an initial linear increase. In fact, for one of the input SOPs the power drops below its launched value because the gain for that SOP becomes smaller than the node losses. We believe that as the number of loops increases, the accumulated ASE noise quenches the gain seen by this channel.

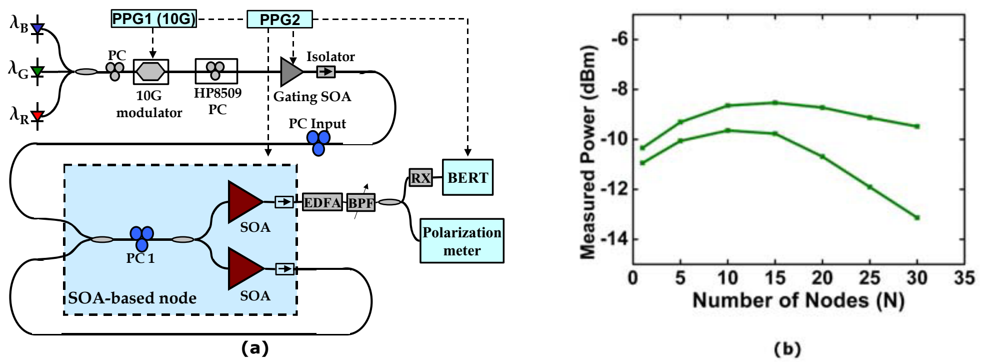

Fig.1. (a) Re-Circulating Loop. PPG: pulse pattern generator; SOA: semiconductor optical amplifier; EDFA: erbium doped fiber amplifier; BPF: bandpass filter; RX: optical receiver module; PC Input: polarization controller to change input SOP; PC 1: polarization controller to change node PDG. Optical path (solid line); Electrical path (dashed line). (b) Minimum and maximum power for various input SOPs measured at channel λ_G (1543 nm) with maximized PDL in the loop.

3. Results and discussion

To illustrate polarization effects in an OPS interconnection network, we first find the maximum accumulation of PDG of the cascaded nodes by appropriately setting PC1 for each wavelength. The received payload maximum and minimum power recorded with respect to the number of cascaded nodes for all input SOPs are shown in Fig. 2a. The maximum cumulative PDG increases linearly with 0.22 dB/node at 1531 nm (λ_B) and 1543 nm (λ_G), and with 0.20 dB/node at 1553 nm (λ_R). Thus we conclude that the PDG of a single node is nearly constant with wavelength and roughly within the specification of the SOA. However, the cumulative PDG value is largely determined by the SOP rotation between consecutive SOAs. In our case SOP rotations occur in the node deflection fiber and PC1 which are both wavelength dependent. Thus when a particular PC1 setting maximizes the cascaded PDG for one wavelength, it results in lower PDG values for the other two as shown in Fig. 2b. The cumulative PDG can be also minimized by varying PC1. We obtained minimal PDG of within 0.5 dB at 1543 nm (λ_G) for any number of nodes up to 35. However, since such minimization can be done for one wavelength at a time, polarization optimization of the cascaded nodes does not seem to be viable for a multi-wavelength packet structure.

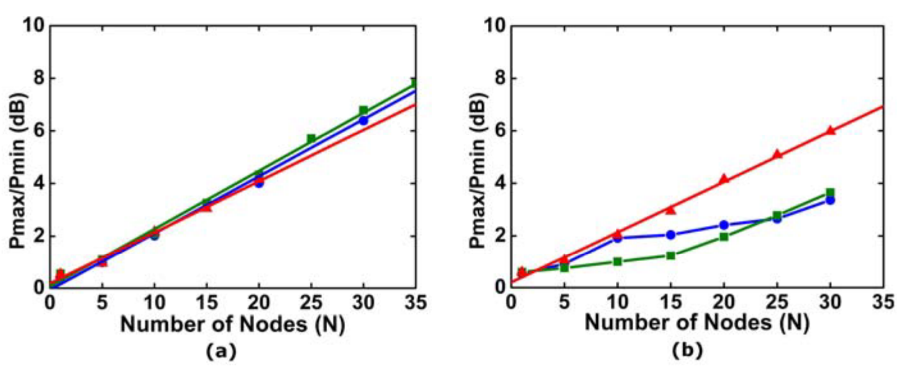

Figure 2: (a) Maximed PDG for λ_G (green) with corresponding PDG on λ_B (blue), and λ_R (red) (PC1 setting is the same for each wavelength. (b) Maximum cascaded PDG for λ_B (blue), λ_G (green) and λ_R (red) (PC1 setting is different for each wavelength).

The cascaded nodes performance is characterized for the extreme PDG conditions by the following procedure. First, PC1 settings which minimize the cumulative PDG for one of the wavelengths are found and a BER curve is recorded (dashed lines in Fig. 3). Then the cumulative PDG is maximized for the same wavelength and two BER curves are taken for two input SOPs (solid lines). The first SOP is aligned with the maximum cumulative gain direction (empty symbols), whereas the second is aligned with the minimum gain direction (full symbols). The same procedure is then repeated for the other wavelengths.

Fig. 3 shows that the maximum number of cascaded nodes through which a packet can successfully propagate (BER < 10^{-9}) for large cumulative PDG depends on the packet's input SOP and on the packet wavelength. This number ranges from 12 to 28 nodes (1531 nm), from 15 to 22 nodes (1543 nm) and from 12 to 16 nodes (1553 nm). For minimized PDG, the maximum number of nodes is 19 (1531 nm), 18 (1543 nm) and 14 nodes (1553 nm) for any input SOP. In our system, any channel with any input polarization will be error free (BER < 10^{-10}) when propagating through less than 10 nodes. This corresponds to a maximum cumulative PDG of 2.0 dB. We thus conclude that in our SOA-based OPS network, the maximum packet path is therefore limited to a cascade of N switching nodes when the PDG of each node is less than 2/N dB.

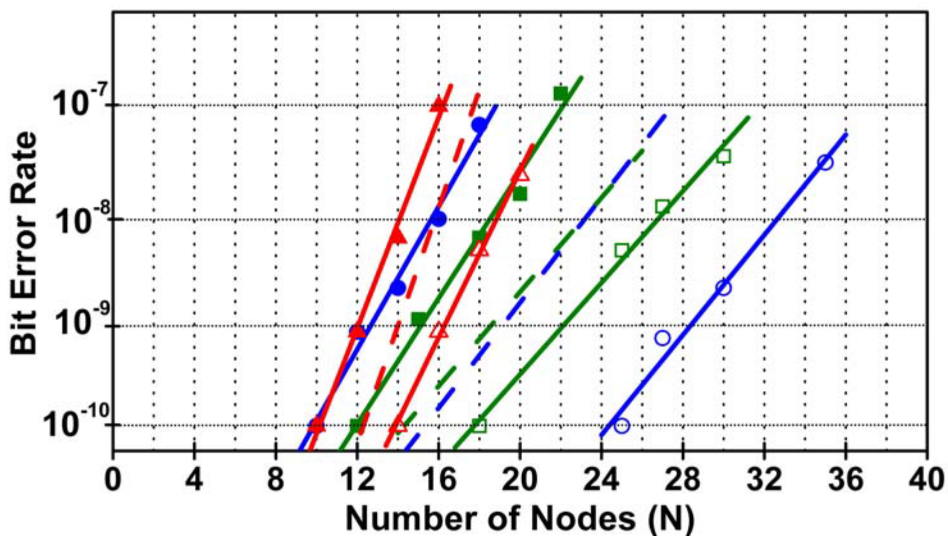

Fig. 3. BER measurements on all three payload channels (blue circles: 1531 nm; green squares: 1543 nm; red triangles: 1553 nm).

4. Conclusions

The cumulative PDG in an SOA-based OPS network is investigated using a re-circulating switching node testbed. We find that for cascaded nodes the PDG may become a performance-limiting factor on the physical layer, thus affecting ultimate scalability of OPS networks. An upper bound for the single node PDG required to maintain better that 10^{-9} BER across the multi-wavelength payload is found to be 2/N dB where N is the number of nodes traversed by the packet.

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5. References

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