Experimental Study on Dynamic Range of SOA Switch for Multi-Wavelength Optical Packet Switching

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Abstract—In this paper, we study on the input power dynamic range of SOA switches for MW-OPS. Power penalty are presented with approximately 15dB dynamic range for 16 wavelengths at an optical gain of 5dB.

Index Terms—Multi-Wavelength Optical Packet Switching (MW-OPS), semiconductor optical amplifier (SOA) switch, dynamic range

I. INTRODUCTION

The enormous popularization of Internet is becoming a big challenge for the technologies currently deployed in the network backbone. In future Internet, the number of Internet users will explosively increase and the bandwidth access will become fatter and fatter. Besides, bandwidth-intensive services such as super high-definition video distribution services will be supported as well as the traditional IP-centric services. As a result, the amount of the Internet traffic will grow more rapidly. In terms of transport, WDM technology has promise for accommodating such high-capacity traffic due to its tremendous capacity which can exceed 30Tb/s nowadays [1]. However, if we simply expand the current packet-based routers based on electric processing trying to support the huge bandwidth required in future Internet, total power consumption would grow out of realistic quantity [2].

In order to address this issue, optical packet switching (OPS) has been researched in these two decades [3]. OPS networks can support the packet switching-based services without O/E conversion with low power consumption. Especially, Multi-Wavelength Optical Packet Switching (MW-OPS) has been researched recently as a promising technology to provide high capacity with less number of optical devices due to its property that wavelength-multiplexed optical packets are switched with wide-band optical switches [4], [5]. Because this switching architecture does not depend on the number of wavelengths available in a fiber, the total power consumption of the MW-OPS nodes will not change as the number of available wavelengths for an optical packet increases. On the other hand, the optical switches applied for MW-OPS will be required with higher performance than those for the single-wavelength OPS, due to the fact that the lengths of Multi-Wavelength optical packets (MW-packets) in time domain get multiple times shorter than those of single-wavelength optical packets, depending on the number of available wavelengths for MW-packets.

SOA switches have been shown to be high extinction, low crosstalk, and fast switching speed [6] and have been already applied to several demonstrations of MW-OPS [7], [8], [9], [10]. With the SOA gate switches and couplers, broadcast and selection switching can be achieved and become large scale easily. However, for applying SOA switches to MW-OPS, it is very important to find appropriate parameters such as the number of wavelengths could be used, the interval among the wavelengths, and the optical gain of SOA switches. This is because nonlinear optical phenomenon such as four-wave mixing (FWM) will show up easily, depending on the parameters.

In this paper, we preliminarily investigate the performance of SOA switches for MW-OPS. Due to the limitation of our experiment environment, we measure the effects of different optical gains for multi-wavelengths 10Gb/s rate data this time. The measurement results of dynamic ranges are compared under different parameters.

II. SOA SWITCH FOR MULTI-WAVELENGTH OPTICAL PACKET SWITCHING

Different with the single-wavelength optical packet which a label and a payload are encoded in a same wavelength, a label of MW-packet is encoded in a particular wavelength and a payload is encoded in a wide-band. This will make the length of a MW-packet in time domain shorter than that of a single-wavelength optical packet. This property requires the switching speed of optical switches for MW-OPS to be faster as described above. In addition, as MW-packets encoded in wide-band are switched, the properties of optical switches for MW-OPS should include low wavelength dependency and low polarization dependency.

The dynamic range of input power into SOA switches has been studied only for single-wavelength optical packet switching [11]. According to the paper, low input power causes an increase in power penalty because of the SOA patten effect which degrades the optical signal to noise ratio (OSNR). As the input power is increased, the power penalty reaches a minimum. For high input power, the saturation distorts the signal and results in an increased power penalty. However, for MW-OPS, FWM could be a more significant factor than saturation while the input power increases. Herein, we particularly focus on these nonlinear effects of SOA switches in MW-OPS.
applications and investigate the dynamic range of input signal for various cases.

III. EXPERIMENT AND PERFORMANCE MEASUREMENTS

The experimental setup designed to measure the dynamic range is depicted in Fig. 1. In this experiment, at most 16 wavelengths (1550.12nm−1562.23nm) with 100GHz spacing which are modulated to 10Gb/s PRBS $2^{31} - 1$ signal by the $LiNbO_3$ (LN) modulator with PPG (Pulse Pattern Generator) are used as the data signal. Two AWGs and 16 FDLs of different lengths remove bit-level correlations among the 16 wavelengths. All channels are aligned to a same polarization state by using a polarizer. With an EDFA and a Variable Optical Attenuator (VOA), the input power of the SOA switch becomes adjustable.

![Fig. 1. Experimental Setup](image)

In this study, we compare the power penalties, considering three scenarios shown in Table I. Bit error rates (BERs) are measured for a range of input powers into the SOA switch. Power penalty is measured against BER at $10^{-9}$ through the SOA switch. The dynamic range achieving power penalty under 2 dB are measured by varying the input power into the SOA switch. The results are shown in Fig. 2. In all cases, the power penalty is plotted against the input power of the single channel (CH8:1555.75 nm) for fair comparison.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Num. of wavelengths</th>
<th>Interval</th>
<th>SOA gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario A</td>
<td>1</td>
<td>-</td>
<td>5dB</td>
</tr>
<tr>
<td>Scenario B</td>
<td>16</td>
<td>100GHz</td>
<td>5dB</td>
</tr>
<tr>
<td>Scenario C</td>
<td>16</td>
<td>100GHz</td>
<td>12dB</td>
</tr>
</tbody>
</table>

In every scenario, we can see that power penalty increased with low input power because of the degradation of the OSNR, while high input power caused an increase in power penalty due to the nonlinear optical phenomenon. With the appropriate input power, the power penalty reached a minimum. In scenario A in which only one wavelength was used as data signal and SOA only provided an optical gain of 5dB, dynamic range of approximately 20dB was achieved. In scenario B in which the number of wavelengths was 16, the power penalty around the input power higher than -15 dBm increased more rapidly than that in scenario A as the input power increased. This resulted in a narrower dynamic range of approximately 15dB. This is because the total input power into SOA is multiplied due to the wavelength-multiplexed signal. In scenario C, with the 16-wavelengths signal and the SOA gain of 12dB, the power penalty did not become 0dB and only 10dB dynamic range was achieved. This is because the saturation and the FWM showed up more easily with the higher optical gain. In order to comprehend the results, we compared the spectrum results captured at two points with the similar input power in scenario B and C. Fig. 3 shows the spectrum results at the points as well as the input signal. Fig. 3 (a) shows the input spectrum and Fig. 3 (b) and (c) show the output spectrum. From the spectrum results we can see that, the saturation should have been the major factor to cause the dynamic range limitation because the influence of FWM was very small. The FWM could also have caused additional penalty. Besides, in case of multi-stage using of SOA, dynamic range should be worse due to the saturation and FWM phenomenon.

![Fig. 2. Results of Dynamic Range Measurement](image)

![Fig. 3. (a) Input spectrum, (b) Gain= 5dB, 16 wavelengths, Pin= -13.45dBm and (c) Gain= 12dB, 16 wavelengths, Pin= -13.37dBm](image)

IV. CONCLUSIONS

In this paper, we preliminarily investigate the dynamic range of SOA switches for MW-OPS. Providing a low optical gain, approximately 15dB input power dynamic range was achieved for 16 wavelengths multiplexed with 100GHz spacing. As the gain became higher, the transmission performance of SOA switches for MW-OPS got worse.

In future work, we plan to study the input power dynamic range at 40Gb/s modulation rate, considering the effects of three factors: the number of wavelengths, intervals among the wavelengths, and SOA gains.

REFERENCES