Optical Packet Switching Technology for Future Global Sensing Networks

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Abstract: In this paper, we demonstrate 320 Gb/s Multi-wavelength Optical Packet Switching with contention resolution mechanism based on feed-forward input buffer. The feasibility has been confirmed by monitoring the waveforms and the eye-patterns of output signals.

1. Introduction

The amount of Internet traffic in current backbone networks has grown enormously due to wide deployment of broadband Internet access and new multimedia applications such as sensing data sharing and real-time streaming. In regard to optical transport technology based on Wavelength Division Multiplex (WDM), available bandwidth within single fiber could be over 20Tb/s, according to the most recent reports [1, 2]. Consequently, the router which handles such high-capacity traffic in current and future networks is necessary.

Optical packet switching (OPS) technology has been researched in order to efficiently utilize such broad bandwidth with lower power consumption than current switching architecture with O/E/O conversion and higher link-utilization ratio than optical circuit/burst switching (OCS/OBS). In a network based on general OPS architectures, an optical packet consisting of a header and a payload is encoded into single wavelength. An independent optical packet is, therefore, encoded into each wavelength available within single fiber. This property makes several kinds of devices necessary for function an incoming packet such as header processing and contention resolution proportional to \(W \times P\), where \(W\) is the number of the wavelengths available in the WDM network and \(P\) is the number of input ports in the core node.

The increase of the number of these devices could make the implementation of the node unrealistic in terms of physical size and cost especially in the future WDM networks in which the number of available wavelengths in a single fiber is over a thousands[3].

Multi-Wavelength OPS (MW-OPS) has been researched as one of solutions that can reduce the number of these devices. Core nodes based on MW-OPS use optical switches independent of wavelengths and forward optical packet encoded into multiple wavelengths, for instance, header data is encoded into a wavelength and payload data is encoded into other wavelengths. This characteristics makes the necessary number of optical devices processing incoming packets in a core node proportional to \(P\), compared to traditional OPS architecture. In addition to that, the control complexity in MW-OPS nodes could be lower than that in traditional OPS nodes. Due to these characteristics, MW-OPS could be considered as more scalable architecture.

There are currently three proposed node architectures based on MW-OPS: Onaka’s 100 (10\(\lambda\) \times 10) Gb/s MW-OPS node using SOA switches[4], Furukawa’s 160 (16\(\lambda\) \times 10) Gb/s MW-OPS node using LiNbO\(_3\) switches[5], and our 80 (8\(\lambda\) \times 10) Gb/s MW-OPS node using PLZT switches[6]. Each of them has confirmed the feasibility of MW-OPS using the corresponding type of switches.

In this paper, we demonstrate 320 (8\(\lambda\) \times 40) Gb/s MW-OPS with contention resolution mechanism using PLZT switches in order to evaluate its feasibility. The major characteristics of PLZT switches are four: 1) high switching speed (< 6ns), 2) low polarization dependency, 3) noise robustness, and 4) low drive voltage. On the other hand, SOA switches have the issue on OSNR degradation due to ASE noise and LN switches require higher drive voltage for removing polarization dependency, while both provide higher switching speed (< 1ns). In addition, DC drift phenomenon can not be ignored for LN switches. Therefore, PLZT switches are considered practical and suitable for OPS[7].

2. MW-OPS Node Architecture with Contention Resolution

In our MW-OPS networks, an optical packet consists of a header data encoded in a wavelength and a payload data encoded in different multiple wavelengths. The encoded packet is switched at core nodes in accordance with its label in the header, after O/E conversion is done only for the header. All other wavelengths encoding the payload are forwarded without any O/E/O conversion.

Fig.1 illustrates the diagram of the node performing \(N \times N\) MW-OPS with contention resolution mechanism based on FDL. The node consists of three major components: 1) Contention Resolution Unit, 2) Switching Unit, and 3)
Controller Unit. The contention resolution unit, which is based on feed-forward input buffer, consists of $K$-level FDLs connected to a $1 \times K$ optical switch and a $K \times 1$ coupler. Input packet which will not cause contention is switched into 0th FDL which is the shortest. Packets causing contention will be switched into suitable FDLs after the controller schedules. The switching unit consists of an $N \times N$ optical switch and switches the packet from the contention resolution unit into appropriate output port in accordance with the destination label described in its header. The controller manages occupations of each FDL, schedules incoming packets in accordance with its arrival time and length, and controls other two units.

Fig. 1. $N \times N$ MW optical packet switching node diagram

3. Experiment

In order to verify a switching node based on our proposed architecture described above, we have implemented $2 \times 2$ MW-OPS node with 2-level FDLs for only one input port and conducted 320 (8$\lambda$×40) Gb/s MW-OPS experiment in the environment illustrated in Fig.2.

The experimental environment consists of the $2 \times 2$ MW-OPS node and subsystems for its verification. There are three subsystems: 1) MW-OPS Payload Generator, 2) Label Generator, and Packet Monitor.

The parameters for the experiment is shown in Fig.2 (b).

The contention resolution unit consists of two PLZT switches and two FDLs of different lengths as shown in the figure. The length of the 1st FDL is 100m approximately equivalent to 500ns delay. The latter switch is applied for reducing crosstalk influence. This avoids coherent interference of signals and OSNR degradation. The switching unit is a $2 \times 2$ PLZT switch with two pair of a polarization controller and an EDFA. The controller consists of band path filter (BPF), photo detectors (PD), and an FPGA. The FPGA controls all PLZT switches in the node.

In MW Payload Generator Subsystem, the 320Gb/s MW payloads are generated through following processes. First, eight optical signals of different wavelengths generated by Light Source are multiplexed at the multiplexer (Mux) and the multiplexed signal is modulated into 40Gb/s 2$^7$−1 PRBS by LN Modulator (LNM). Then, two AWGs and eight FDLs of different lengths remove bit-level correlations among the eight wavelengths. The 3dB coupler duplicates the input signal and each of the duplicated signals is cut into an envelope by either of AO Modulator (AOM) and the PLZT switch. The lengths of two envelopes are 200ns (Payload1) and 300ns (Payload2) respectively. These envelopes are used as payloads in the experiment.

In Label Generator Subsystem, two PLZT switches generate two labels by modulating duplicated optical signals from the Light Source in time for the payloads. The modulated label is either of “101” and “111”. Each represents Output Port1 and 2 respectively. The bit rate of both labels is 25Mb/s due to the limitation of the FPGA. Each of the labels is multiplexed with the corresponding payload at the 3dB couplers.

Packet Monitor shows the state of each packet recorded at the points of (a)-(j). The results are shown in Fig.3. The results of (a),(b), and (c) are the spectrum, the eye-pattern, and the waveform at Input Port1 respectively while (d) represents the waveform at Input Port2. Fig.3 (c-d) shows incoming packets at Input Port1 and 2. The waveform of labels are zoomed in because the intensity of labels are too week against that of payloads. This figure shows that the 4th packet at Input Port1 and the 2nd packet at Input Port2 will contend each other. In this case, the latter packet reaches the node earlier than the other. In order to avoid contention, the packet at Input Port1 will be switched into the 1st FDL and received by the PLZT switch after 500ns delay. The waveform after the contention resolution unit in (g) shows that the latter switch of the unit reduces the influence of crosstalk caused by the 4th packet as expected. The waveforms of (i) and (j) show the output packets out of the node and confirm that every packets is correctly switched in accordance with its label. In addition to that, the delayed packet is monitored after correctly avoiding the contention.

The figure (k) shows the eye-pattern of the optical signal at Output Port1. These results confirm that 320Gb/s MW-OPS
with contention resolution mechanism based on feed-forward input buffer has been successfully demonstrated.

| Bit Rate | 25Mb/s NRZ |
| Data Length | 120ns |
| Data Length | 200ns (Packet1) or 300ns (Packet2) |
| Data Rate | NRZ |
| Data Signal | “101” or “111” |
| # of λ | 1 or 8 |
| Range of λ | 1549.31 nm |
| of λ | 1551.72–1557.36nm (100GHz interval) |

Fig. 2. Experimental Setup (a) and Parameters (b)

4. Conclusions

320 (8λ x 40) Gb/s multi-wavelength optical packet switching with contention resolution mechanism based on feed-forward input buffer has been demonstrated, using PLZT switches. The future work includes signal quality evaluation such as BER and multi-hop forwarding demonstration.

Fig. 3. Experimental Results

References