Bitwise-controlled All-Optical Wavelength Converter

Lixin Xu,1,2 L. F. K. Lui,1 P. K. A. Wai,1 Hwa-yaw Tam,2 and M. S. Demokan2

1Photonics Research Centre and Department of Electronic and Information Engineering, The Hong Kong Polytechnic University, Kowloon, Hong Kong. E-mail: enwai@polyu.edu.hk.

2Photonics Research Centre and Department of Electrical Engineering, The Hong Kong Polytechnic University, Kowloon, Hong Kong.

1Department of Physics, University of Science and Technology of China, Hefei, 230026, China. E-mail: xulixin@ustc.edu.cn.

Abstract: We demonstrated a bitwise-controlled all-optical wavelength converter. Intelligent wavelength conversion of packets is performed based on bitwise all-optical processing of data packet headers. The header and payload rates are 5 Gb/s and 10 Gb/s respectively.

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OCIS codes: (230.1150) All-optical devices; (140.3520)Lasers, injection-locked; (190.4380) Nonlinear optics, four-wave mixing

1. Introduction

Optical networks utilizing fast packet switching are expected to provide the required capacities and flexibility in the next-generation high-speed networks. Recently, we have demonstrated a 1×4 all-optical packet switch with all-optical header processing [1] and intelligent all-optical packet add-drop functions [2] for all-optical packet-switched networks. In all-optical packet-switched networks, one way to resolve packet contentions is to utilize wavelength-division multiplexing (WDM). Wavelength channels are exploited as parallel links and all-optical wavelength converters are used to shift contention packets from one wavelength channel to another. However, intelligent all-optical wavelength converters which can direct self-routing optical packets from one wavelength to another are not available yet. In this work, we report to the best of our knowledge the first bitwise controlled all-optical wavelength converter (BC-AOWC). Intelligent wavelength conversion of packets is performed based on all-optical processing of packet headers. The header and payload rates are 5 Gb/s and 10 Gb/s respectively.

2. Operating principle

For the data packet headers, we adopted a self-routing address format in which every wavelength channel is identified by a single bit in the packet header [3]. Each of the proposed BC-AOWC is designed to process just one single bit in the packet header. If a bit in packet header is set to ‘1’, the corresponding BC-AOWC will convert the packet to a different wavelength channel. Figure 1(a) depicts the schematic of the proposed BC-AOWC which comprises of an all-optical header processor (AOHP) and an all-optical wavelength converter (AOWC). Data packets, pk_1, pk_2, …, pk_n, at wavelength λ_d input to the BC-AOWC are first split into two parts. One part of the data packets is injected into the AOHP together with a local control signal at wavelength λ_c. If the bit in the packet header corresponding to the wavelength channel controlled by the BC-AOWC is set, the AOHP will output a packet long control signal at λ_c. The switched control signal from the AOHP output is then injected in the AOWC together with the other part of the input data packets. The AOWC will then convert the data packets from wavelength λ_d to another wavelength λ_wc. If the corresponding bit in the data packet header is not set, the AOHP will not output any control signal at λ_c. Wavelength conversion will therefore not occur at the AOWC.

We implemented the AOHP by using the multi-wavelength injection locking property and bistability characteristics of a Fabry-Perot laser diode (FP-LD) [4]. Figure 1(b) shows a schematic of the AOHP. The location of the single ‘1’ bit (the trigger) in the header of the special two-level control signal determines which bit position in the data packet header the BC-AOWC will monitor. The wavelengths of the data packets and the control
signal determine the wavelength $\lambda_{wc}$ after conversion. In Fig. 1(b), the control signal is set to monitor the first bit in the packet header. For pk_1, the control signal trigger matches with the ‘1’ bit in the data packet header in the time domain. Injection locking of the FP-LD at the control wavelength $\lambda_c$ is initiated and sustained through the duration of the data packet due to the bistability characteristic of the injection locking. The output of the FP-LD at $\lambda_c$ is therefore high (ON state). For pk_2, the control signal trigger does not match with the ‘1’ bit in the header. Injection locking of the AOHP at the control wavelength $\lambda_c$ is not initiated either at the control signal trigger or at other part of the control signal. The output of the FP-LD at wavelength $\lambda_c$ is therefore low (OFF state). We implemented the AOWC uses four wave mixing (FWM) in a highly nonlinear fiber (HNLF) because of the high conversion efficiency and sub-picosecond response time. In the HNLF, the switched control signal from the FP-LD and the other part of the data packets together generate new wavelengths through partially degenerated FWM. The FWM process serves as a logic “AND” gate. Thus, only those data packets whose headers match with that of the local control signal can be converted to a different wavelength channel.

3. Experimental results

Figure 2 shows the experimental setup of the proposed BC-AOWC. For the AOHP, the 10 Gb/s data packets at wavelength ($\lambda_d$) 1541.88 nm are generated by externally modulating another tunable laser (TL-1) using a 10 Gb/s non-return-to-zero (NRZ) pulse pattern generator and a LiNbO$_3$ modulator. The data packets are split into two parts. One part is sent to the AOHP for header processing while the other part is sent to the AOWC for wavelength conversion. The injected power to the FP-LD is $-2.0 \, \text{dBm}$ and the wavelength detune from one of the longitudinal modes of the FP-LD is $+0.06 \, \text{nm}$. The control signal at wavelength ($\lambda_c$) 1540.14 nm are generated using another 10 Gb/s NRZ pulse pattern generator, a 155 MHz pulse pattern generator, and two 10 Gb/s LiNbO$_3$ modulators on the output of a tunable laser (TL-3). The injected power is 2.0 dBm and the wavelength detune is $+0.21 \, \text{nm}$ from another longitudinal mode of the FP-LD. The output of the 155 MHz pulse pattern generator is triggered by the clock/32 output of the 10 Gb/s NRZ pulse pattern generator for synchronization. The two 10 Gb/s pattern generators are synchronized using an external 10 GHz clock. The cw stabilizer signal at 1537.14 nm is generated by a third tunable laser (TL-2) with an injected power of $-11 \, \text{dBm}$ and the wavelength detune is $+0.01 \, \text{nm}$ from yet another longitudinal mode of the FP-LD. The bias current of the FP-LD is 2.0 $I_{th}$ where $I_{th}$ is the threshold current. The data packet header is 4-bit long corresponding to four different wavelength channels. The bit period at the data packet header is 200 ps long for a header rate of 5 Gb/s. The input data signals consist of packets with headers ‘1000’, ‘0100’, ‘0010’, and ‘0001’ for pk_1 to pk_4 corresponding to wavelength channel 1 to 4 respectively. The data packet payload is 48 bits long. The payload rate is 10 Gb/s and the guard period is 800 ps. The header of the control signal is ‘0010’ corresponding to wavelength conversion for pk_3 only. Figures 3(a) and 3(b) respectively show the synchronized timing diagrams of the two-level control packets and four consecutive data packets at the input of the AOHP. Figure 3(c) shows the switched control signal at the AOHP output. Only the control signal corresponding to pk_3 is in “ON” state. Figure 4(a) shows the output spectrum of the AOHP. The switched control signal from the AOHP is then filtered by a tunable band pass filter (TBPF). We used an EDFA to boost the powers of the switched control signal and the data packets to 5.67 dBm and 10.21 dBm, respectively before injecting into the HNLF. For the HNLF, the length is 1.1 km, the zero dispersion wavelength is 1498 nm, the dispersion parameter is 2.6 ps/nm at 1550 nm, and the nonlinear parameter is $\approx 17 \, \text{W}^{-1}\text{km}^{-1}$ at 1550 nm. New wavelengths at $\lambda_{wc1} = 1538 \, \text{nm}$ and $\lambda_{wc2} = 1543.63 \, \text{nm}$ are generated in the HNLF through partially degenerated FWM because the wavelength separation of the control signal and data packets is 1.74 nm. Since the FWM process acts as a logic “AND” gate, only pk_3 undergoes wavelength conversion. Both wavelengths $\lambda_{wc1}$ and $\lambda_{wc2}$ carry pk_3. Figure 4(b) shows the output spectrum of the BC-AOWC. Figures 3(d) and 3(e) show the data packets at $\lambda_{wc1} = 1538 \, \text{nm}$ of the BC-AOWC output at 3 ns/div and 1 ns/div respectively. We observed that pk_3 is successfully wavelength converted while pk-1, pk2, and pk-4 are blocked. From Fig. 3(e), the data is not distorted by the wavelength conversion process except for the last three bits which are suppressed by the falling edge of the switched control signal. The problem can be easily eliminated by using a longer guard period between the data packets to account for the falling edge of the control signals.

4. Conclusion

In conclusion, we have demonstrated a bitwise control all-optical wavelength converter. Intelligent wavelength conversion of packets is performed based on bitwise all-optical processing of data packet headers. The header and
payload rates are 5 Gb/s and 10 Gb/s respectively. The header processing rate can be increased by using FP-LDs with larger mode spacing.

5. References


Fig. 1. The schematic of the (a) bitwise all-optical control wavelength converter, and (b) all-optical header processing (AOHP) in (a).

Fig. 2. Experimental setup of bitwise control all-optical wavelength converter (BC-AOWC).

Fig. 3. Synchronized timing diagrams for the data packets and control signals at the BC-AOWC: (a) input control signal to the AOHP; (b) input data packets to both the AOHP and AOWC; (c) switched control signal from the AOHP output; (d) the output data packets from the BC-AOWC at 1538 nm ($\lambda_{wc1}$) and 3 ns/div; and (e) the output data packets from the BC-AOWC at 1538 nm ($\lambda_{wc1}$) and 1 ns/div.

Fig. 4. Output spectra of (a) all-optical header processor (AOHP) and (b) all-optical wavelength converter (AOWC).