All-optical queue buffer using optical threshold functions and wavelength converters

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A modular, cascadable, and self-controlled optical queue buffer is proposed, which can solve the packet contention at a 2 × 1 optical node. Controlled by incoming optical packets, the buffer can realize first-in-first-out queue buffering without the necessity of external control signals. By using optical threshold functions and wavelength converters based on semiconductor optical amplifier, the push and pop operations of packets on queue can both be achieved. In addition, preliminary experiment is carried out.

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As one of the key elements of all-optical packet switching, all-optical buffer has received intense research interest in recent years, and several schemes have been proposed. All-optical buffers were demonstrated by using optical switch and fiber delay line (FDL), in which the packet could be buffered for a pre-determined delay time[1−5]. Semiconductor optical amplifiers (SOAs) were used to make up optical buffers[6−9]. All-optical buffer was carried out by exploiting the slow light effect in micro-ring cavities[10].

In this letter, a novel modular, cascadable, and self-controlled optical queue buffer is proposed, which can solve packet contention at a 2 × 1 optical node with first-in-first-out (FIFO) property. With SOA based optical threshold functions (OTFs) and wavelength converters (WCs), the buffer is self-controlled by the incoming packets, and both push and pop operations of packets can be achieved without the necessity of external control. Due to the modular structure, the proposed buffer scenario can be easily extended. Additionally, preliminary experimental result is given.

The proposed optical buffer, which can solve packet contention for a 2 × 1 optical node, is shown in Fig. 1. The buffer has two inputs, and one output, in which input 1 has higher priority over input 2. When two packets arrive at the buffer simultaneously, the buffer will forward the packets from input 1 and push them from input 2 into queue since input 1 is connected to the output, whereas input 2 is connected to the data in ($\mathrm{D_{IN}}$) port of the last module. As shown in Fig. 1, the buffer is constructed by cascading several modules; it could also be extended easily by adding modules. In the buffer, the data out ($\mathrm{D_{OUT}}$) port of the lower-level module is connected to the $\mathrm{D_{IN}}$ port of the higher-level module, and the control in ($\mathrm{Ctrl_{IN}}$) port of the lower-level module comes from the $\mathrm{D_{OUT}}$ port of the higher-level module.

For each module, four in/out ports exist: $\mathrm{D_{IN}}$, $\mathrm{D_{OUT}}$, $\mathrm{Ctrl_{IN}}$, and control out ($\mathrm{Ctrl_{OUT}}$). To realize FIFO queue buffering, the $\mathrm{D_{OUT}}$ of the lower-level module is connected to the $\mathrm{D_{IN}}$ of the higher-level module, whereas the $\mathrm{Ctrl_{OUT}}$ of the higher module is connected to the $\mathrm{Ctrl_{IN}}$ of the lower module. Therefore, the queue buffer always transmits packets from the bottom to head, whereas the control signal comes from the head to bottom, indicating that higher-level modules has control over lower modules and no external control signal is required.

For each module, when there is no signal at the $\mathrm{Ctrl_{IN}}$ port, the packet circulating inside the module will be popped out from $\mathrm{D_{OUT}}$ (Fig. 2(a)) or if there is no packet in the module, the received packet from $\mathrm{D_{IN}}$ will be forwarded to $\mathrm{D_{OUT}}$ (Fig. 2(b)). On the other hand, when there is a $\mathrm{Ctrl_{IN}}$ signal coming into the module, the module will not pop out any packet and a signal will go out this module from the $\mathrm{Ctrl_{OUT}}$ port telling the next module not to pop out the packet (Figs. 2(c) and (d)). This high to low control priority in queue buffer ensures that there is only one packet circulating in each module.

The operation principle of queue buffering is shown in Fig. 3. The packet buffering in the optical buffer is marked as packet 0, while packets coming to the buffer from inputs 1 and 2 are marked as packet 1 and packet

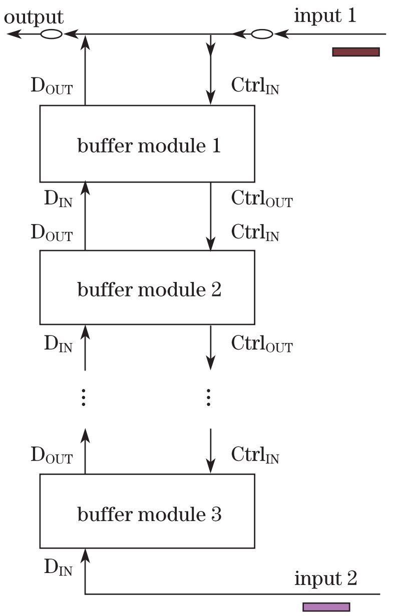

Fig. 1. Modular scheme of the optical buffer.

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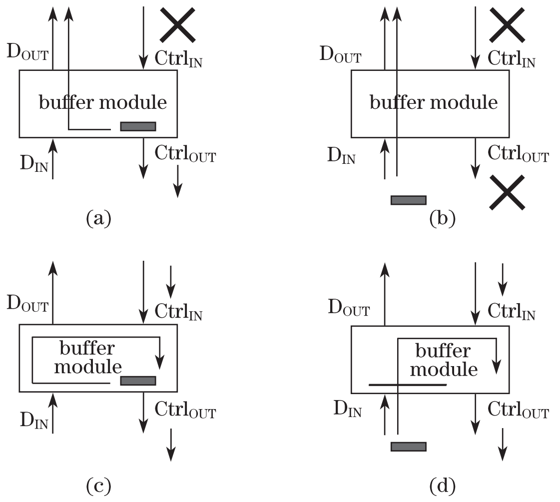


Fig. 2. Module operation, when there is no control signal at the Ctrl$_{\text{IN}}$ port and packet is (a) buffering in the module and (b) coming from D$_{\text{IN}}$; when there is control signal at the Ctrl$_{\text{IN}}$ port and packet is (c) buffering in the module and (d) coming from D$_{\text{IN}}$.

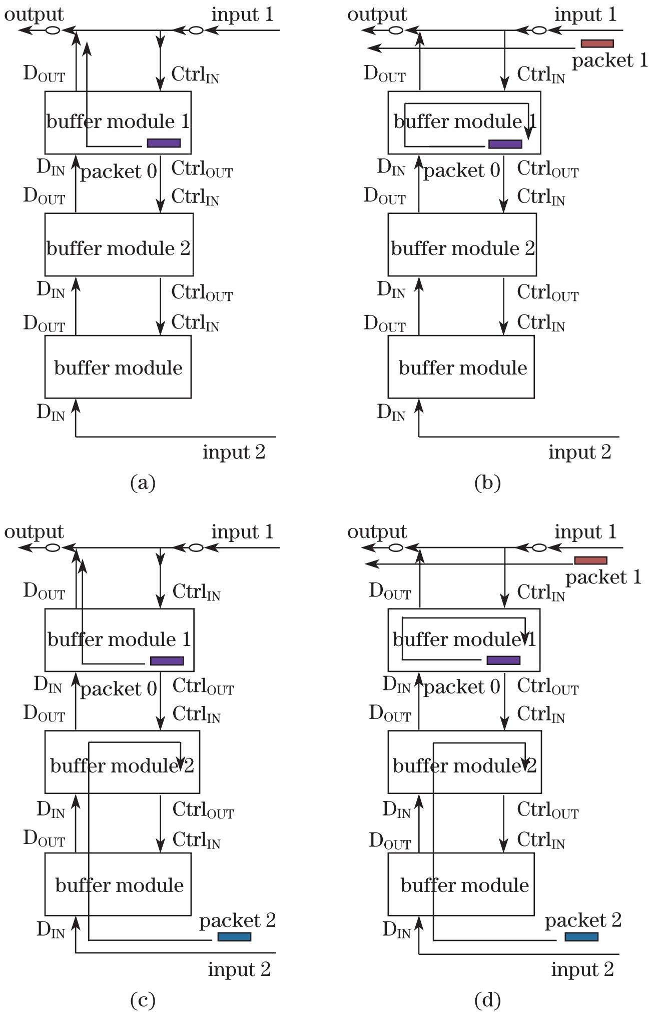


Fig. 3. Operation principles: (a) there is no packet arriving at the buffer from input 1 or input 2; there is only one packet arriving at the buffer from inputs (b) 1 and (c) 2; (d) there are packets arriving at the buffer from both inputs 1 and 2.

2, respectively.

In Fig. 3(a), there is only packet 0 buffering in the buffer and no packets coming to the buffer. When there is no packet coming from input 1, module 1 has no Ctrl$_{\text{IN}}$, thus packet 0 is popping out the buffer. In Fig. 3(b), there is only one packet coming to the queue buffer from input 1. Due to the presence of packet 1, module 1 has Ctrl$_{\text{IN}}$, which prevents packet 0 from popping out; meanwhile, packet 0 in module 1 is feed into the Ctrl$_{\text{IN}}$ of module 2. Therefore, packet 1 is directly forwarded to the output, while packet 0 still circulates in module 1, waiting for packet 1. In Fig. 3(c), there is only one packet coming to the buffer from input 2. Packet 0 in module 1 is feed into the Ctrl$_{\text{IN}}$ of module 2, thus packet 0 is popping out the buffer and packet 2 is captured in module 2, waiting for packet 0. In Fig. 3(d), there are packets coming to the buffer from both inputs 1 and 2. Due to the presence of packet 1, module 1 has Ctrl$_{\text{IN}}$, which prevents packet 0 from popping out; meanwhile, circulating packet 0 in module 1 is feed into the Ctrl$_{\text{IN}}$ of module 2 and causes packet 2 to be stored in module 2. Hence, packet 1 is directly forwarded to the output; packet 0 still circulates in module 1, waiting for packet 1; packet 2 is captured in module 2.

In summary, due to their higher priority, packets from input 1 will be forwarded to the output, while packets from input 2 will be pushed into the queue buffer, circulating in buffer modules and waiting until all previous packets in the queue buffer are popped out. It should be emphasized that the buffer is self-controlled by packets, with each module controlled by its higher neighbor module.

The buffer module, which consists of an OTF and WCs, is shown in Fig. 4. When there is no signal at Ctrl$_{\text{IN}}$, the output of the OTF is continuous wave (CW) light at λ_{A}. When there is signal at Ctrl$_{\text{IN}}$, the output of the OTF is CW light at λ_{B}. The WC will convert the input data to the same wavelength as the CW light from the probe input port.

When there is signal coming to the module from Ctrl$_{\text{IN}}$, as shown in Fig. 5(a), the packet will be converted to λ_{B} and circulate in the module, regardless if the packet is coming from D$_{\text{IN}}$ or circulating in the buffer. When there is no signal at the port of Ctrl$_{\text{IN}}$, the packet coming from D$_{\text{IN}}$ or circulating in the buffer will be converted to λ_{A} and forwarded to the D$_{\text{OUT}}$ port of the buffer, as shown in Fig. 5(b).

To achieve the buffer scheme, the SOA-based OTF and WC could be used to construct the buffer modules and the optical buffer. Figures 6(a) and (b) show the structures of the OTF and WC, respectively.

The setup of the OTF and WC is shown in Fig. 6. The SOA-based OTF[8] is combined by two SOA fiber ring lasers. The output of the master laser is coupling into slave laser through two optical couplers (OCs) and an isolator (ISO). Each SOA fiber ring laser is composed of a SOA, band-pass filter (BPF), ISO, and OCs. The master and slave ring lasers operate at wavelengths λ_{A} and λ_{B}, respectively. The master laser has an optical input to control the output of the OTF.

The ISO between the master laser and the slave laser could stop the light of the slave laser coupling into the master laser. This indicates that only the light of the

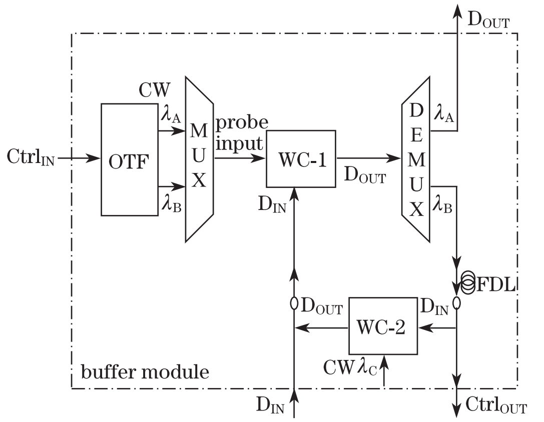
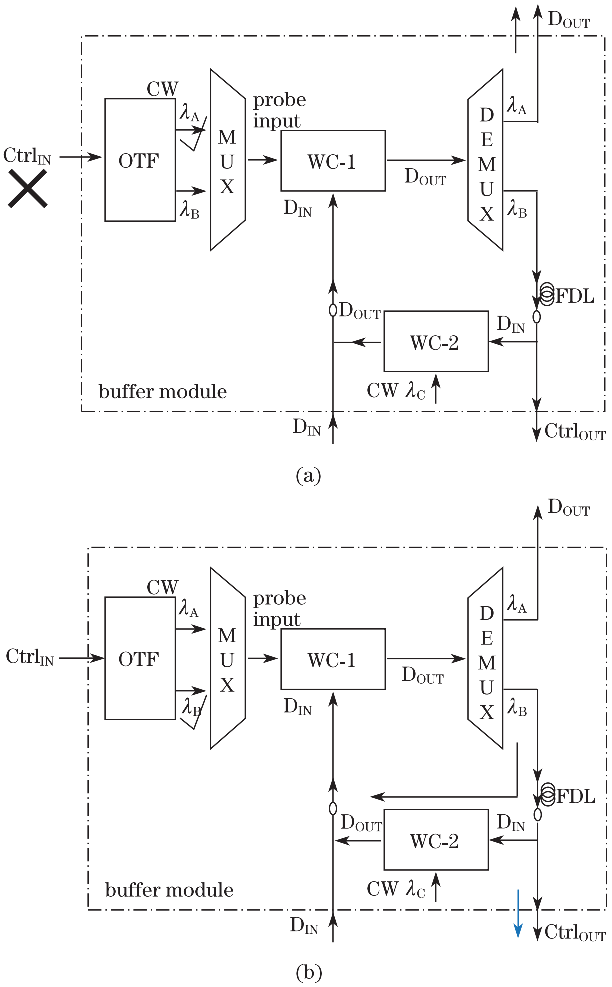


Fig. 4. Buffer module structure (MUX: multiplexer; DEMUX: demultiplexer).



(a)

(b)

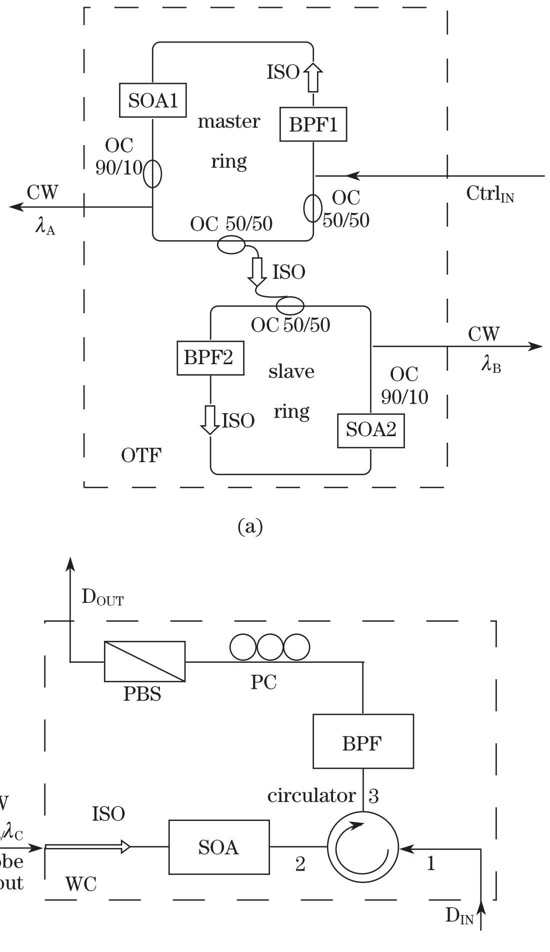
Fig. 5. Module operation. (a) There is control signal at $Ctrl_{IN}$; (b) there is no control signal at $Ctrl_{IN}$.

master laser could couple into the slave laser. When there is no signal coming to the $Ctrl_{IN}$ port, the master laser could be lasing and the light is coupled into the slave laser. Thus, the slave laser is suppressed by the light of the master laser. Meanwhile, when there is signal coming to the $Ctrl_{IN}$ port, the master laser is switched off and there is no light injecting into the slave laser. Thus, the slave laser could be lasing.

The OTF has two states: the steady state and the unsteady state. When there is no signal at the $Ctrl_{IN}$ port, the OTF operates at the steady state in which only the master laser works; the output is CW light at λ_A. When there is signal coming to the $Ctrl_{IN}$ port, the OTF operates at the unsteady state in which only the slave laser works; the output is CW light at λ_B. For SOA-based OTF[11], the rising and falling time when it is integrated will be as short as 40 and 12 ps, respectively.

The WC based on cross-gain modulation (XGM) in SOA is shown in Fig. 6(b), where the CW outputs of the threshold function are used as probe and the input packets as pump. By exploiting XGM, the information of the optical packets is inversely modulated on the CW probe, having the wavelength converted. Due to the opposite logic of XGM, the output packet has inverse polarization with the input.

To evaluate the feasibility of the buffer scheme, a preliminary experiment built up by SOA-based OTF and WC, is carried out, as shown in Fig. 7. Using packets as the control signal, the OTF – together with the WC – switches the input packets to the corresponding output port. Figure 8 shows the eye diagrams of the input and output packets. The eye diagram is totally open, and its deterioration is mainly caused by the noise of the OTF output and waveform distortion induced by



(a)

(b)

Fig. 6. Scheme of the (a) OTF and the (b) WC (PC: polarization controller; PBS: polarization beam splitter).

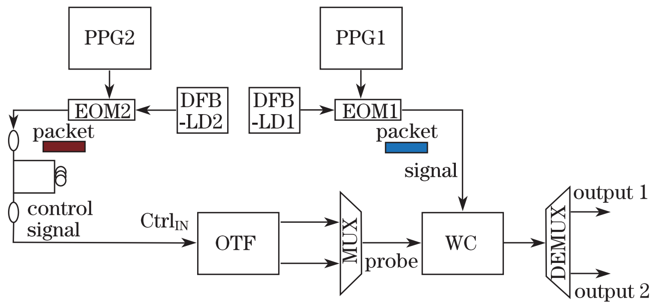
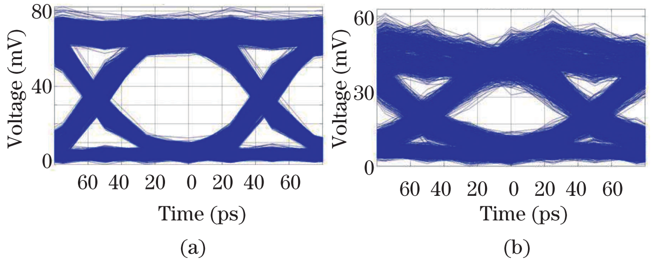


Fig. 7. Preliminary experimental setup (PPG: pulse pattern generator; EOM: electro-optic modulator).



(a) (b)

Fig. 8. Eye diagrams for (a) input and (b) output packets.

the WC.

In conclusion, we propose a modular, cascadable, and self-controlled optical queue buffer by using SOA-based OTFs and WCs. With FIFO control priority, our buffer can solve packet contention at a 2 × 1 optical node. The setup can be easily extended by adding new modules, and the system complexity only increases linearly with the buffer capacity.

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