All-Optical Buffering by Using an All-Optical Threshold Function

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A novel all-optical method for all-optical buffering is presented. It is demonstrated that an optical packet can be routed all-optically into an optical fiber delay line for buffering in case of potential contention between two optical packets. Crucial in this method is an optical threshold function that is made from two coupled lasers, having more than 45 dB contrast ratio between the output states. The optical threshold function has two functions. First it acts as an arbiter to decide whether a potential collision between two packets takes place. In addition, it controls a wavelength converter switch. The feasibility is verified by experimental results.

I. Introduction

All-optical routing has been proposed as an approach to realize a optical packet switch [1]. An important research topic is packet congestion will occur if when two or more optical packets arrive simultaneously at the same packet switch. Optical buffering can avoid this problem [2][3].

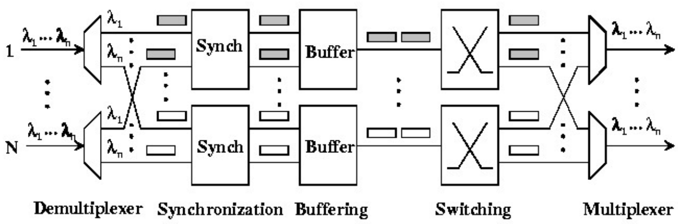

Fig. 1 Generic node structure of an optical packet switched cross-connect

We consider all-optically packet switched cross-connects that have a generic node structure as presented in Fig.1 (see [1]). The WDM channels are initially demultiplexed. In the switching fabric three important steps take place, synchronization of the packets, buffering of the packets and switching of the packets. Afterwards, the packets are multiplexed and fed into the optical transmission line.

Several techniques for optical buffering have been proposed and some promising results have been achieved. In the ACT-KEOPS project [1], optical buffering was realized by using electronically controlled wavelength routing switches and optical delay lines. Since optical technologies demonstrate remarkable advancement in speed compared to electronic technologies, it appears to be an inevitable trend that buffering will be implemented in the optical domain. In this paper, we present an all-optical buffering concept that can handle two packets contention by using all-optical signal processing techniques. The crucial element in this buffering concept is an optical threshold function that has two functions: first, it can act as an arbiter to decide the potential contention of two packets. In addition, it can control a wavelength routing switch to switch one packet into buffer in case of packet contention. We demonstrate experimentally that an optical packet can be routed in an optical fiber buffer by using a wavelength converter that is controlled by an optical threshold function (OTF). This paper is organized as follows. In Section II, the operation principle of OTF is explained. All-optical buffering concept is presented in Section III. Experimental results are given in Section IV. The paper is concluded with a discussion.

II. Operation principle of optical threshold function

The OTF that we use is based on two coupled ring lasers. The device is depicted in Fig. 3. The semiconductor optical amplifiers (SOAs) act as the gain mediums and the Fabry-Perot filters act as wavelength selective elements. The operation of the OTF is similar to an optical flip-flop memory that is described in detail in [4]. For specific injection currents and amount of coupling between the lasers the system can form a threshold function rather than a flip-flop memory. In [4] it is shown that a system of two coupled lasers can have two possible states. In State 1, light from Laser 1 suppresses lasing in Laser 2. Conversely, in State 2, light from Laser 2 suppresses lasing in Laser 1. The SOA currents are biased asymmetrically so that the system is in State 1 if no external light is injected. To change states, lasing in the dominant laser is stopped by injecting light, not at the dominant laser's lasing wavelength, into the dominant laser [4]. Hence, Laser 2 becomes the dominant laser (State 2). However, the asymmetrically biased SOA currents ensure that the system returns to State 1 if injection of external light is stopped.

III. All-optical buffering concept

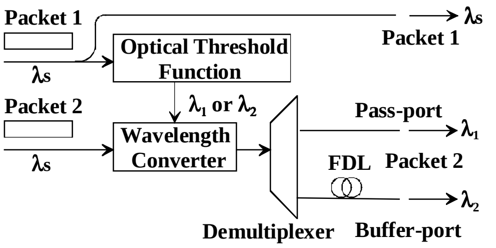

Fig. 2 System concept for all-optical buffering. FDL: fiber delay line.

An all-optical concept suitable for these purposes is presented schematically in Fig. 2. We assume that packets arrive in a synchronized way and that Packet 1 has a higher priority than Packet 2. The optical power of Packet 1 is firstly split into two parts: the first part passes the node directly and is not delayed. Another part is injected into an OTF that acts as an optical arbiter to decide if packet contention occurs. If packet contention occurs, Packet 2 is delayed.

The output light of the OTF is used to control a wavelength converter that converts the wavelength of Packet 2. A demultiplexer is used to route Packet 2 into a pass-port or a buffer-port, depending on the converted wavelength of Packet 2. When Packet 1 and Packet 2 are present, a potential collision takes place. Due to the presence of Packet 1, the OTF is forced into State 2 and emits continuous wave light at wavelength λ_2. Hence, the wavelength of Packet 2 is converted to λ_2 and routed into the fiber buffer. Packet 1 can pass the node directly.

In the following section, it is shown experimentally that the OTF can be employed for all-optical buffering purposes.

IV. Experiment and results

The experimental setup for demonstration of all-optical buffering by using an OTF is presented in Fig. 3. An external modulator is used to generate optical packets. The bit rate is 2.5 Gbit/s, and the wavelength is 1560.61 nm. The bit patterns in the packets have a non-return to zero (NRZ) data format and form a pseudorandom binary sequence (PRBS). The packets are then amplified by an EDFA and subsequently filtered by a

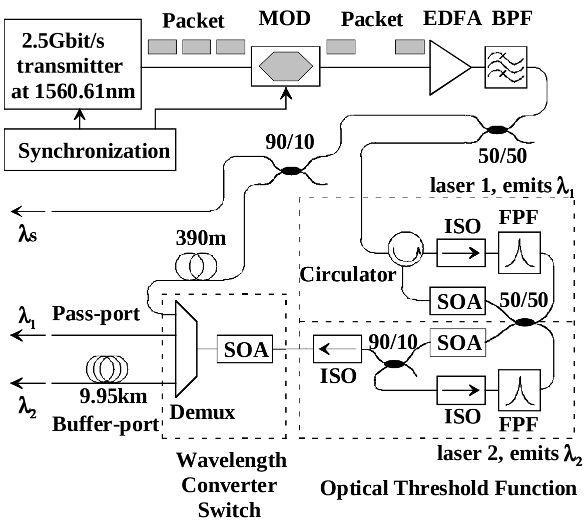

Fig. 3 Experimental setup. MOD: external optical modulator, EDFA: erbium-doped fiber amplifier, BPF: optical bandpass filter, SOA: semiconductor optical amplifier, ISO: optical isolator, FPF: Fabry-Perot filter, and Demux: optical demultiplexer

tunable band pass filter. An optical splitter is used to direct half of the optical power of the packet into the OTF via an optical circulator, The other half of the optical power is coupled into a 90/10 coupler.

The 90/10 coupler splits the optical power of the packet into two parts: one part goes directly to the output. Another part is firstly delayed by 1.95 μs (390 meter of fiber) corresponding to the time that is needed to let the OTF change states, and then fed into the wavelength converter. The wavelength of the packet is converted via cross-gain modulation (XGM). The demultiplexer spatially directs the packet into a different port based on the wavelength of the packet. In the buffer-port, 9.95 km fiber is employed for buffering purposes. This corresponds to a delay of 49.75μs for the packets.

In the first experiment we demonstrate the operation principle of the OTF. As shown in Fig. 3, the OTF is implemented by using two coupled ring lasers. The wavelength of each laser is λ_1=1549.32 nm and λ_2=1552.52 nm. The spectrum of the OTF is presented in Fig. 4. It can be observed from Fig. 4 that contrast ratio between the two states in the OTF is over 45 dB. In Fig.5 the switching characteristics of the OTF is presented. In the upper panel of Fig. 5, the optical packet is shown. The dynamic behavior of the OTF is presented in the middle and lower panel of Fig. 5. It can be observed from Fig. 5 that the state (the output wavelength) of the OTF changes if an optical packet is injected. As soon as injection of the packet is stopped the OTF switches back to its original state.

In the second experiment we demonstrate that an OTF in combination with a wavelength routing switch can be used for buffering purposes. An optical packet is injected into the OTF and changes the state of OTF into State 2 (Laser 2 dominant). Thus, the dominant wavelength of the OTF is λ_2. Meanwhile, another packet, representing Packet 2 (see Fig. 2) is coupled into the wavelength converter and its wavelength is converted to λ_2 via XGM. The result is shown in Fig. 6. The eye pattern of converted pulses in the packet after the wavelength conversion is also presented in Fig. 6. The open eye indicates error-free propagation through the wavelength converter. In Fig. 7, the result of the all-optical buffering is presented. Fig. 7 (a) shows the oscilloscope traces of the packets that pass the node directly with the wavelength λ_s. These packets represent Packet 1 (see Fig. 2). Fig. 7(b) shows the oscilloscope traces of the packets that are directed into the buffer-port and experience 49.75μs delay caused by a 9.95 km fiber delay line. These packets represent Packet 2 (see Fig. 2). Fig. 7 clearly shows that the all-optical buffering functions correctly when two packets contend for the output port.

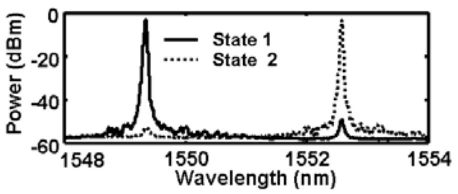

Fig. 4 Spectral output of two states of the OTF.

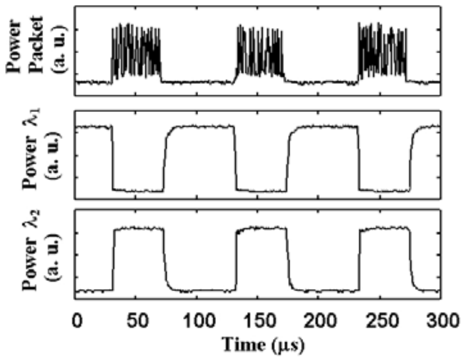

Fig. 5 Dynamic output of the OTF with and without the presence of packet input.

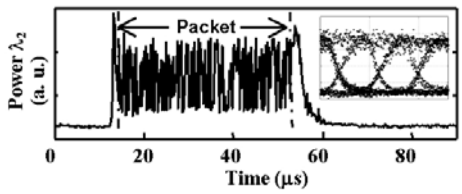

Fig. 6 Oscilloscope trace after wavelength conversion showing that the whole packet is converted to wavelength λ_2 within the duration of wavelength λ_2

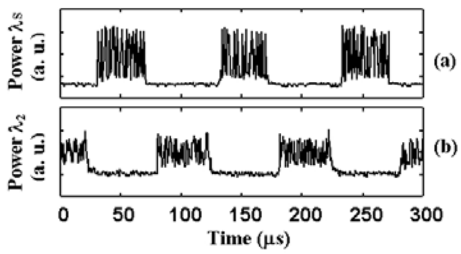

Fig. 7 Oscilloscope traces for 2.5 Gbit/s packets showing the all-optical buffer is realized.

V. Conclusions

We have presented a new method for all-optical buffering. It has been demonstrated experimentally that an optical packet can be routed all-optically into an optical fiber buffer in case of potential contention between two optical packets.

Crucial in our method is the OTF that controls a wavelength converter switch. Experimental results indicate that a contrast ratio of more than 45 dB between the output states in OTF can be obtained. Moreover, error-free propagation through the wavelength converter can be obtained.

The specific implementation of the optical threshold function in this paper has only a limited speed due to the long laser cavity length. However, integrated versions of the threshold function could attain high speeds.

Finally, the concept of the OTF can be extended to a multilevel state OTF so that multi-packets contention can be handle.

References

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