Towards All-Optically Packet Switched Cross-Connects

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We discus strategies towards all-optical packet switched cross-connects. A key component is an all-optical packet switch. We discus a 1x2 all-optical packet switch, in which the headers are processed by using a SLALOM structure, and the header information is stored by using an all-optical flip-flop memory.

Introduction

Optical packet switched networks are emerging as a serious future candidate in the evolution of optical telecommunication networks. During the last years a number of strategies towards optically packet switched networks have been developed and demonstrated (see [1] and the references therein). All the approaches presented in [1] have in common that they are hybrid electro-optical packet switching methods; the optical packet header is (partly) processed electronically while the packet payload remains in optics.

In this paper we focus on optical packet switched cross-connects that have a generic node structure as presented in Figure 1. Node architectures for hybrid electro-optical packet switched cross-connects were presented in [1]. Figure 1 shows an example of such a node architecture [2]. In the switching fabric three important signal processing steps take place: synchronization of the packets, buffering of the packets and switching of the packets. In [2], it was shown that electronically controlled wavelength routing switches could carry out all these operations. In this paper, we present an all-optical packet switching concept that that can be employed for optical synchronisation, optical buffering and optical packet switching purposes. Our 1x2 all-optical packet switch can switch non-return to zero amplitude-modulated data bits [3]. The header information is implemented at effectively lower bit rate than the payload. The payload is Manchester encoded. All the steps with respect to the processing of the header bits are executed in the optical domain.
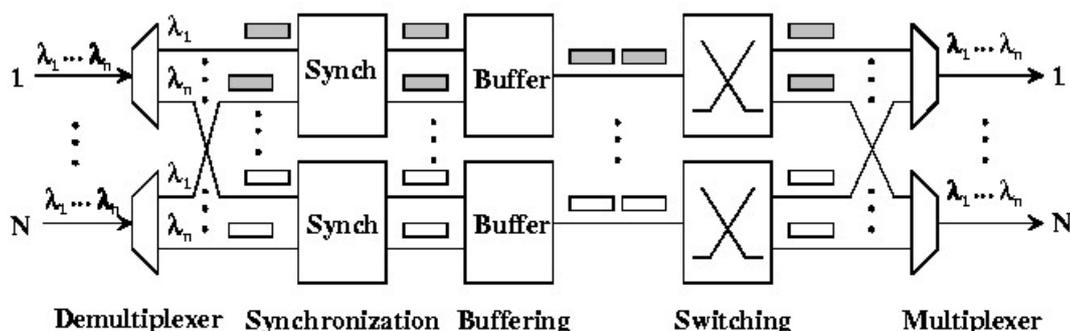

Figure 1: Generic node structure of an optical packet switched cross-connect

Operating principle

The all-packet switch is implemented using the structure shown in figure 2. An optical packet arriving at the packet switch is split in two equal parts. Half of the optical power of the packet is delayed and injected into a wavelength converter. The other half of the optical power is fed into the header processor.

The packet structure is shown in figure 2. We distinguish packets with two kinds of headers. The first header (header 1) consists of a repeated hexadecimal FF0FF00 pattern. The second header (header 2) consists of a repeated hexadecimal 0000000 pattern. Packets with alternating headers were used throughout the experiments. The packet's payload is Manchester encoded to avoid repetition of the header in the payload.

For the first stage of the optical header processing, the packet is fed into a SLALOM structure. Suppose that a packet with header 1 enters the SLALOM. It has been shown that the two-pulse correlation principle of SLALOM causes a correlation pulse to appear at the SLALOM's output [4,5]. The high bit-rate payload is suppressed because the SOA is driven in saturation [4,5]. The SLALOM's output is then passed through an optical threshold function to differentiate more strongly between the correlation pulse and the suppressed payload. The threshold function operation principle is similar to that of the optical flip-flop memory that is described later. The threshold function increases the contrast between the correlation pulse and the suppressed payload from 3dB at the output of the SLALOM to over 25 dB. The output of the threshold function is then amplified by an EDFA and filtered. If a packet with header 2 enters the SLALOM structure, then no correlation pulse is formed and consequently no pulse is generated by the header-processing block [4,5].
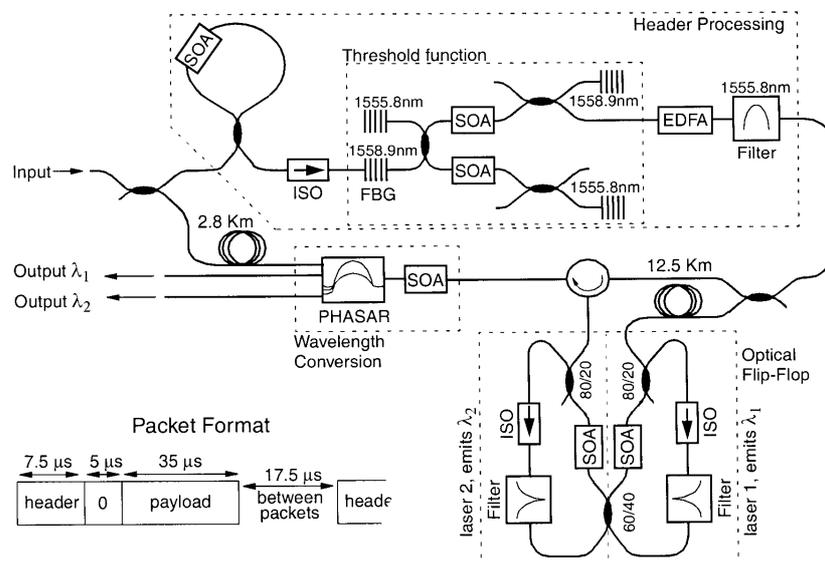

Figure 2: Experimental set-up to demonstrate the 1×2 all-optical packet switch. Traffic from the network is coupled in the packet switch at the input. The packet format is given.

The output of the header processor produces an optical pulse when there is a packet containing header 1, indicating that the packet should be routed to wavelength λ_1. The optical power of the pulse is split into two. One half of the pulse is sent directly to the set input of the optical flip-flop. This pulse sets the output wavelength of the flip-flop to wavelength λ_1. The other half is delayed and resets the flip-flop output back to

wavelength λ_2, after a delay equal to the packet length. The all-optical flip-flop memory that we used is based on two coupled laser diodes with separate laser cavities. The system can have two possible states. In state one, light from laser 1 suppresses lasing in laser 2. Conversely, in state 2, light from laser 2 suppresses lasing in laser 1. 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 [6]. The particular implementation used here employed coupled ring lasers with Fabry-Perot filters in their cavities. This implementation provided a low noise light source suitable for wavelength conversion. For specific injection currents, the system of coupled lasers can form a threshold function rather then a flip-flop function. The threshold function was implemented using two coupled lasers made from SOAs and fiber Bragg gratings, as was shown in [6].

Finally, the flip-flop output was then fed into a SOA where the packets were converted to the flip-flop output wavelength via cross-gain modulation [7]. The output of the wavelength converter SOA was then passed through a phased array demultiplexer to spatially separate the two output wavelengths.

Experiment

The data rate of the packet payload was 2.5 Gbit/s and the wavelength was 1550.92nm. The header pattern was repeated for a duration of 7.5 μs. The payload consists of a data stream of 35 μs of Manchester encoded pseudo-randomly generated bits. Header and payload were separated by a guard band of 5 μs. The time between to packets was 17.5 μs. Repetition of the header pattern was necessary to make the optical flip-flop change states [6]. This was due to the large laser cavities, which had long round-trip times. Integration of the flip-flop memory into an optical chip would overcome this problem. All the couplers used in the experiment were 50/50 couplers except those couplers used in the flip-flop. Their coupling ratios are given in figure 2. The fiber Bragg-gratings in the threshold function formed wavelength selective mirrors at 1555.8 nm and 1558.43 nm. The optical flip-flop memory was implemented using Fabry-Perot filters as wavelength selective elements operating at 1549.26 nm and 1552.52 nm, corresponding to the wavelength λ_2 and λ_1 respectively. The SOAs were manufactured by JDS Uniphase and employs a strained bulk active region. The wavelength outputs 1 and 2 were converted to electrical signals via photodiodes and observed on an oscilloscope. We sent subsequently packets with header 1 and header 2 through the packet switch. The resulting waveforms are shown in figure 3. The switching of packets between the two wavelengths can be clearly observed. Also shown in figure 4 is an eye diagram of the converted output data when the flip-flop was set to wavelength λ_2. The eye is open indicating that the data packets can be transmitted error free through the packet switch.

Conclusions

The packet payload data rate of the switch was 2.5 Gbit/s, which was only limited by the wavelength converter, and could potentially reach 100 Gbit/s [7]. The header data rate was much slower, with the header length needing to be of the order of microseconds. This was due to the particular implementation of the optical threshold function and flip-flop used in the experiment. The lasers used to form these functions were constructed from standard commercially available fiber pigtailed components having cavity lengths of many meters. Thus the component lasers had low intrinsic modulation bandhwidths,

which limited the speed of the threshold function and the flip-flop. However integrated versions of these functions using lasers with cavity lengths of less than a millimeter could attain speeds in the GHz range, allowing high header data rates and short packet lengths. In principle, this concept can be extended to a 1xN switch since a SLALOM structure can be used to recognize more complicated header patterns [5].
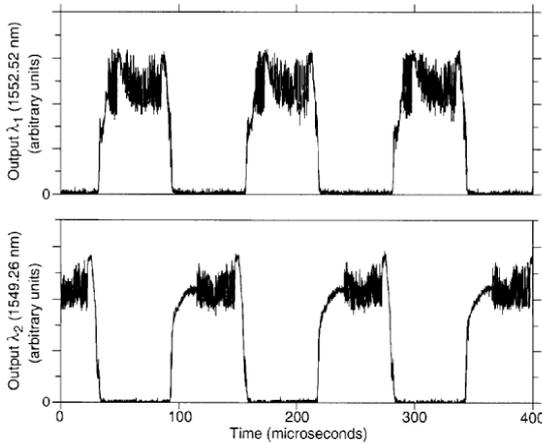

Figure 3: Oscilloscope traces of the optical power at the two switch outputs. The two different packets are directed to outputs at wavelength λ_1 and λ_2. It can be observed that if a packet with a specific header arrives at the packet switch, the designated output wavelength is switched-on, and the packet information is modulated on that specific wavelength.
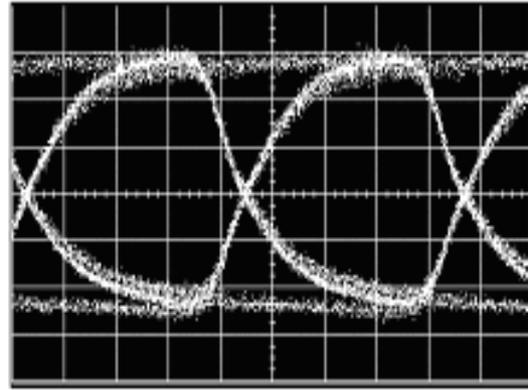

Figure 4: Eye-diagram of the converted output data when the flip-flop was set to λ_2. The timescale is 100 psec/div and the volt scale is 50mv/div.

Acknowledgements

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