Photonic packet switching using all-optical header processing and storage of header information

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Abstract: A novel all-optical packet switching concept with all-optical header processing and all-optical storage of the header information is presented. The header bits are processed by an optical threshold function, which acts as a flexible all-optical logic gate. The storage of the header is performed by an all-optical flip-flop based on coupled laser diodes. To demonstrate these concepts, a test bed is currently under construction in the Electro-optical communications group of Eindhoven University of Technology. We present the status of the project and experimental results.

I. Introduction

As telecommunications and computer communications continue to grown, more network capacity is demanded. For this reason considerable attention is given to the development of optical networks. Currently, there are basically two techniques for multiplexing data on a single fiber; optical time division multiplexing (OTDM) and wavelength division multiplexing (WDM). The use of ultra-fast OTDM can simplify some areas of system implementation since only a single wavelength is used in the network. On the other hand, OTDM has its own set of technical challenges such as network synchronization and non-linearities in the system due to the high peak power of ultra-short pulses. A great deal of recent research in optical networks has been focussed in the area of WDM technology [1]. WDM provides promising solutions for the utilization of the benefits quoted above as it allows the potential terahertz bandwidth to be multiplexed into parallel channels.
The work in this paper is related to all-optical packet switching related to WDM technology. In general, optical packet-switched networks can be divided into two categories: slotted (synchronous) and unslotted (asynchronous). In both cases, bit-level synchronization (buffers) and fast clock recovery, packet header recognition and packet delineation are required. Possible solutions for WDM all optical nodes are demonstrated in several projects such as the ACTS KEOPS project and the WASPNET [2] project. Moreover new techniques are being developed as components and systems for photonic packet switching networks: optical tag switching [3], photonic slot routing [4] and optical burst switching [5].

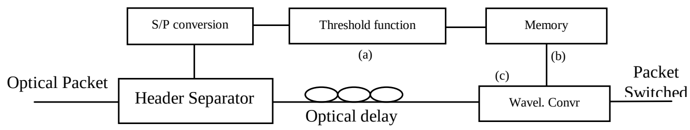

Figure 1: Schematic all-optical packet switch

In this article we present a new method to implement all-optical packet switching. The system is, at the moment, tested experimentally for optical packets with only one header bit. The advantage of optical packet switching is that the routing of optical packets takes place without using electronics. This makes all-optical packets switched networks have the potential to operate at high speed. Moreover, the concepts presented in this paper allow extension to packet with more header bits. Finally, the technology presented in this paper allows monolithic integration. In the following section, a description of the optical packet switch is presented.

We describe the several optical signal-processing stages.
In Section III, experimental results with respect to data transmission are given. The paper is concluded with a discussion on the results and a description of future activities.

II. Description

The concepts of our all-optical packet switch are presented in Figure 1. A header separator block extracts the packet header from the payload. Afterwards the serial header information is converted into a parallel pattern. This can be done by using an optical delay line circuit. For the optical header processing we firstly consider the all-optical header processing block (a). The function of this block is to process the parallel header bits. We do this by using an all-optical threshold function, which processes the header bits into an output pulse of a unique wavelength. The output pulse is converted into a continuous wave by the optical flip-flop memory (b). The continuous wave is injected as a control signal into an all-optical switch based on wavelength conversion (c). Below, we describe these functions in more detail.

Header processor

An all-optical header processor is implemented by a laser based all-optical threshold function. The threshold function is a laser with an extended cavity, which allows two modes. The laser with the extended cavity is obtained by coupling two semi-conductor optical amplifiers (SOAs) with two fiber Bragg-gratings (which act as wavelength selective mirrors) and a wavelength independent mirror, made from a directional coupler, as indicated in Figure 2. The system is set in such a way that the mode of the second cavity is dominant. The SOA in second cavity acts as a saturable attenuator, which attenuation depends on the externally injected optical power. In such way the change of the reflectivity in the second cavity causes suppression of the second mode, and hence the first mode becomes dominant
In Figure 4, the relation between the two modes and the externally injected power P_{inj} is experimentally shown. It can be observed that the optical power in the second cavity decreases if the external light injected in the second SOA increases. Using an all-optical header processing based on laser technology guarantees a device with an adequate output power. Also the contrast between the modes can be made sharp. The device is stable and robustness for environmental changes. Also a drift in the wavelength of the input, caused by temperature changes will not create a problem. Moreover, this concept can be extended to an all-optical header processing concept that allows parallel processing of optical headers consisting of more address bits.

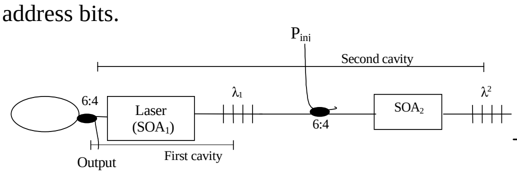

Figure 2: All-optical header processor

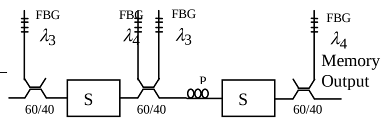

Figure 3: All-optical memory

All-Optical flip-flop memory

The all-optical flip-flop memory that we use is based on two coupled identical laser diodes with separate cavities. The device is depicted in Figure 3. The two lasers form a master-slave arrangement of the two lasing cavities. The system 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. To change states lasing in the master is stopped by injecting light not at the masters laser's lasing wavelength. The precise operation of the device is described in [6]. The flip-flop memory is implemented by lasers formed by a semiconductor optical amplifier and two fiber Bragg-gratings (see Figure 3). Figure 5 shows the oscilloscope traces that illustrate the changing of the states (mode 1 and 2) when external light pulses are injected in the flip-flop memory.

Wavelength Switching

A wavelength converter is used to convert the input packet to the derived wavelength. Figure. 6 shows a wavelength converter using cross-gain modulation (XGM), in the counter-propagating configuration. The flip-flop output is the CW wavelength at which we perform the packet switching. The SOA is used as a nonlinear element to perform the wavelength mixing. The filter is used to stabilize the power fluctuation of the memory output. The multiplexer has two functions. At first it is used as a filter that might be placed after the erbium doped fiber amplifier (EDFA). Secondly, it is used as a circulator to couple the optical power between the two branches. Polarization controllers are needed due to the polarization depending of the modulator and the SOA. For more details on this schema see [7].

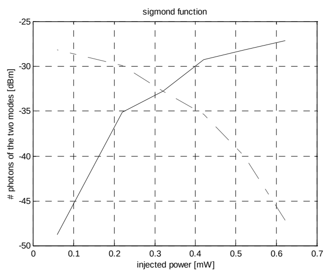

Figure 4: Switching modes vs. injected light.

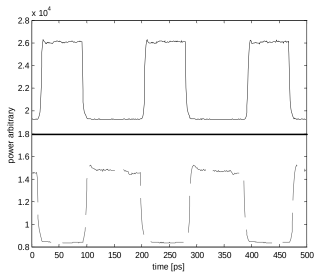

Figure 5*:* Experimental results.

III. Experimental results

As a first experiment we test a system consisting of an all-optical flip-flop memory and a wavelength converter switch as shown in Figure 7. The optical payload is generated by a DFB laser at $\lambda = 1544{,}6$ *nm* and modulated externally by a signal generator at 622Mbit/s. This signal is amplified and afterwards sent to the wavelength converter. The optical flip-flop memory is driven by an external light source at $\lambda = 1530{,}3\,nm$, which makes that the flip-flop memory toggles between its two states. In Figure 5, the flip-flop memory output is traced by an oscilloscope to show the changing flip-flop states. The injected currents to the two SOAs are set to $I_1 = 121\,mA$ and $I_2 = 108\,mA$ respectively.

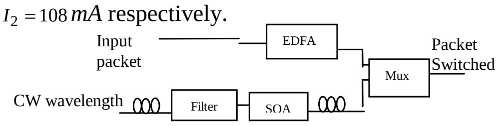

Figure 6: System for wavelength switching using XGM in the counter-propagation configuration.

The flip-flop operation wavelengths are set by the fiber Bragg-gratings at $\lambda_3 = 1558{,}93$ *nm* and $\lambda_4 = 1552{,}82$ *nm*. Directional couplers are used to connect the devices. The polarization controller is used to optimize the polarization dependence of SOAs and connectors. The wavelength converter performs the routing of the input packet. A filter is used to stabilize the power fluctuation of the memory's CW wavelength. The SOA is used as a non-linear element to perform the wavelength mixing and is driven by an injected current $I_{S\_C} = 304\,mA$.

Additional polarization control is needed. The EDFA is used to amplify the input optical packet as required by the cross-gain modulation wavelength converted and has an injected current $I_{E\_C} = 197{,}62\,mA$. Finally, the multiplexer is used as a circulator and filter. The eye pattern of the signal after wavelength conversion is shown in Figure 8. We can conclude that we have an open eye diagram at a speed of 622 Mbit/s. The use of pig-tailed devices makes that the external cavity of the optical flip-flop memory is several meters. This, in a combination with the use of fiber Bragg-gratings as mirrors causes mode instabilities in the flip-flop states. We expect that that operation at higher speed is possible if other types of wavelength selective mirrors are used (for instance Fabry Perot filters).

IV. Conclusions

We have presented a network concept that could potentially be used for all-optical packet switching. At the moment we have demonstrated data transmission obtained by combining an all-optical flip-flop memory and a wavelength conversion switch at 622 Mbit/sec. We have obtained open eye-diagrams at this wavelength. In the future, we plan to investigate data transmission at higher bit rates. Moreover, we also plan to include all-optical header processing (for more then only one bit) in our experiments. To do this it is important to improve the mode-dynamics of our optical signal processing functions

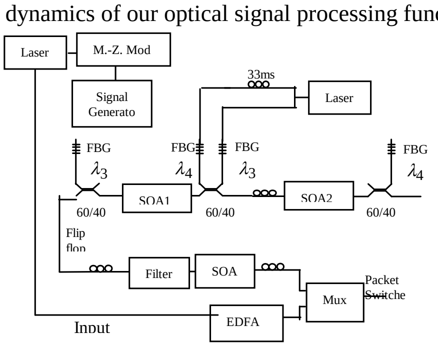

Figure 7: Experimental set-up of the experiment

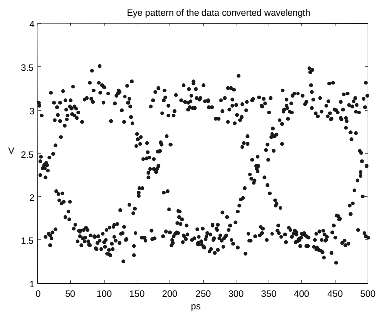

Figure 8: Eye pattern of the converted packet.

V. Acknowledgement

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VII. References

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