

## On All-optical Buffering in Optical Packet Switched Cross Connects

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**Abstract** — It is widely recognized that all-optical packet switched telecommunication nodes require a form of all-optical buffering and synchronization to avoid congestion in the switching matrix<sup>[1]</sup>. We present a novel all-optical switching concept suitable for these purposes. We present the switching concept as well as some preliminary modeling results.

**Index Terms** — All-optical, packet switching, buffer, synchronization

### I. INTRODUCTION

Optically packet switched networks are seriously considered as a long-term route to evolving the present telecommunications network. In this paper, we address to buffering and synchronization issues related to all-optically packet switched networks. This implies that we strive for all-optical buffering and synchronization solutions and to limit the electronic control to a minimum.

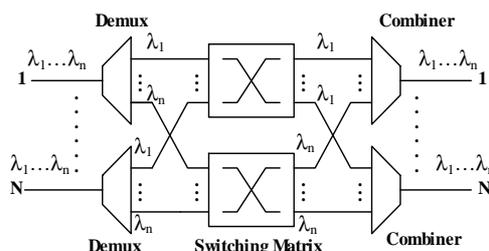


Fig. 1: Schematic example of an optical cross-connect

In Fig.1, a schematic example of a traditional optical cross-connect is presented. These types of cross-connects are usually employed in circuit switched wavelength division multiplexed (WDM) networks. In the optical cross-connect, firstly an optical demultiplexer separates the wavelength channels. The separated channels are then routed to an output gate by an electro-optical switching matrix. Finally, the channels are multiplexed and routed into the desired output fiber.

In circuit switched networks the switching matrix can be highly complex to deal with blocking properties of the cross-connect. The electro-optical switches, which are used, have adequate “on/off” ratio (low cross-talk), and low losses. Optical packet switched networks however require higher switching speed than circuit switched networks. Fast good quality all-optical switches are therefore a key issue. In the ACT-KEOPS project<sup>[3]</sup> and the WASPNET<sup>[4]</sup> project switching principles based on a combination of cross-gain modulation and cross-phase modulation are used. Other all-optical switching principles which operate at potential high speed include Mach-Zehnder based all-optical switches, and pulsed operated switches like terahertz optical asymmetric demultiplexers (TOADs), nonlinear optical loop mirrors (NOLMs) etc.

An important consideration is that all these switches are 1 x N (N > 2) all optical switches, which implies that a collision between two packets takes place if they arrive

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simultaneously at the same packet switch. In order to overcome congestion a form of all-optical buffering has to be implemented.

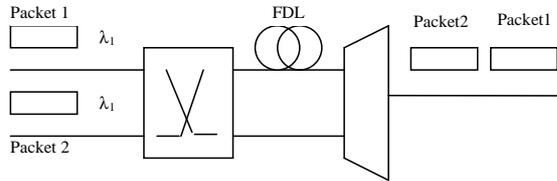
All-optical buffering issues were addressed to in the ACTS-KEOPS<sup>[3]</sup> project and the WASPNET<sup>[4]</sup> project. The philosophy presented in these projects consists of buffering by using optical delay lines and using the wavelength domain to increase the buffering depth<sup>[4]</sup>. Electronic controlled wavelength routing switches were used to obtain this goal.

In this paper we focus on all-optical buffering of packets. An all-optical solution has the advantage that the processing speed is much higher than electronically controlled buffering. A critical issue is the existence of a suitable all optical switch.

In the next section a new concept for all-optical buffering is introduced. Differently as in the ACTS-KEOPS project or as in the WASPNET project, we plan to employ all-optical processing for all optical buffering. We will therefore explain the system concepts in Section II. The success of this concept depends critically on the availability of a good quality optical switch with high “on/off” ratio (low cross-talk). Our first activity in the project is the design of such a switch. In section III, modeling results on such a switch are presented.

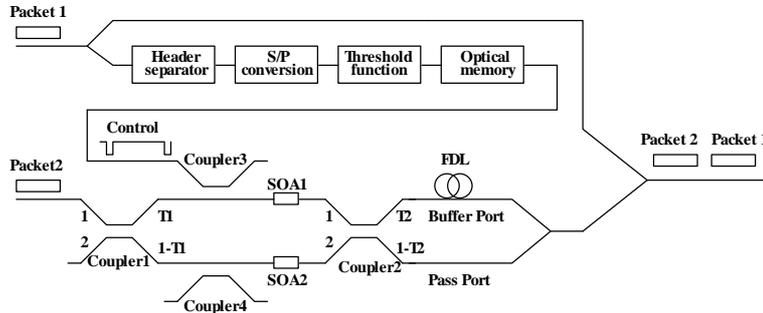
### II. SYSTEM CONCEPT

In order to avoid the collision of optical packets one of these packets has to be buffered. The system presented in Fig.2 represents a schematic solution for avoiding collisions. If two packets, hereafter to be called packet 1 and packet 2, both having the same wavelength  $\lambda_1$ , arrive at the packet switch simultaneously, a potential collision takes place. This means that one of the packets, say packet 2, has to be switched into a fiber buffer so that packet 1 can pass the node directly. This function requires a fast optical switch with a high “on/off” ratio. Moreover, the packet switch should be controlled by an optical signal. For the moment, we assume that such a control signal is a continuous wave, which is generated by the all-optical header processor as described in Ref.<sup>[5]</sup>.



**Fig. 2:** All optical solution to traffic contention

All-optical switching principles based on a combination of cross-gain modulation and cross-phase modulation allows high switching speeds and an acceptable “on/off” ratio. It has been demonstrated that integrated Mach-Zehnder based all-optical wavelength switches have excellent behavior with respect to the optical transmission<sup>[8]</sup>. Moreover, all-optical controlled wavelength switches allow buffering concepts that use the wavelength domain, as proposed in ref.<sup>[4]</sup>.



**Fig. 3:** System that can be used for all optical buffering

An optical system, which has the functions, as presented in Fig.2 is presented in Fig.3. Here the all-optical switch is a Mach-Zehnder based all-optical switch, which is controlled by a control signal, which is generated by processing the header information of the other optical packet. The optical processing of the header information is described in Ref<sup>[5]</sup>.

The basis of the system is an optically controlled Mach-Zehnder optical switch. The switch is made of two directional couplers and two semi-conductor optical amplifiers. Coupler 1 has a coupling ratio of 60/40, whereas the second coupler has a coupler ratio of 40/60. If an optical packet arrives at the Mach-Zehnder switch while no control signal is present, the packet is directed to the “pass” port (see Fig.3). However, if another packet arrives at the same time a control signal is generated by the optical header processor described in Ref.<sup>[5]</sup>. The injected control signal quenches gain in SOA 1 and changes the refractive index in the semi-conductor optical amplifier. As a result of this one the part of the signal propagating through the upper branch has a different phase and gain than the signal propagating through the lower branch. As a result of this the signal is switch to the “buffer” port in the second semiconductor optical coupler and receives an additional delay.

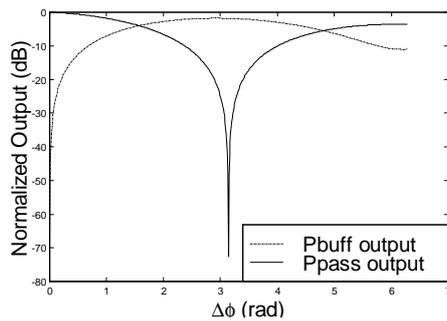
### III. MODELING OF THE OPTICAL SWITCH

For demonstrating the set-up as presented in Fig.3, an all-optical Mach-Zehnder based switch with a high “on/off” ratio is required. To design an all-optical switch with a high “on/off” ratio, we firstly have to determine how high the “on/off” ratio can be. We define the “on/off” ratio to be:

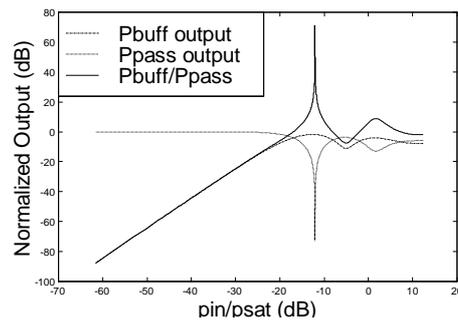
$$r_{on/off} = \frac{P_{pass}}{P_{buff}}$$

Here,  $P_{pass}$  indicates the optical power in the “pass” port given the fact that the signal indeed should be routed to that port.  $P_{buff}$  indicates the leakage power measured in the “buffer” port. Thus, the “on/off” ratio represents the signal leakage (or the cross-talk) in the optical switch. We want to remark that in general Mach-Zehnder Interferometer (MZI) switches are not symmetric so one should also specify the signal leakage to “pass” port while signal is routed to the “buffer” port.

In order to realize a switch with high “on/off” ratio, optimizing the MZI is necessary. After simulation, it was found that using asymmetric couplers leads a potential high “on/off” ratio. The model we used in our simulation was based on the theory presented in Ref.<sup>[7]</sup>.



**Fig. 4:** Output power of each ports versus the phase change induced by the control



**Fig. 5** The relationship among the two output power of MZI, “on/off” ratio and input power of the control,  $P_{sat}$  is the saturation power of the SOA1

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Fig.4 and Fig.5 depict simulation results if the linewidth enhancement factor of the semiconductor optical amplifier  $\alpha_n=7.4$  and coupler ratio of  $T_1$  is 60/40 whereas the coupler ratio of  $T_2$  is 40/60 (see Fig.3). From Fig.4, we obtain the relationship between power of two output ports and the phase change induced by the control light. The solid curve represents output power of "pass" port, while the broken curve represents output power of "buffer" port. It follows from Fig.4 that the maximum difference between the "pass" port and the "buffer" port is more than 20dB when  $\Delta\phi=0$ . A similar result is obtained when  $\Delta\phi=\pi$ . The case in which  $\Delta\phi=0$  corresponds to switch "off" state. In this state the signal is routed to the "buffer" port. Conversely, the case in which  $\Delta\phi=\pi$  corresponds to the "on" state. In this state the signal is route to the "pass" port. We can conclude from Fig.4 that an "on/off" ratio of more than 20 dB.

In Fig.5, relationship between the "on/off" ratio and the control power is given. It follows from Fig.5, that there is an optimal input power, which leads in principle to more than 20dB "on/off" ratio if the switch is in the "on" state. Actually, this input power also induces a  $\pi$  radian phase shift, which is in agreement with the results presented in Fig.4. Moreover, it follows from Fig.5, that there is a narrow range for variation of the input power to obtain an "on/off" ratio, which is larger then 20 dB. This implies that the control power must be exactly adjusted to the switch "on" state.

Therefore, by choosing optimal asymmetric couplers, in which the coupling ratio is related to the linewidth enhancement factor  $\alpha_n$ , we expect that a MZI switch with an "on/off" ratio, which is more than 20dB, can be realized.

## CONCLUSIONS

From these results we can conclude that it is possible to make a MZI switch with an "on/off" ratio of more then 20 dB. Additional computations have to be carried out to optimize the operation with respect to the optical powers and the SOA currents. We plan realize such a switch by using fiber optic methods and to demonstrate the buffering as indicated in Fig.3.

## ACKNOWLEDGEMENT

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## REFERENCES

- [1] David K. Hunter, et al, "Buffering in Optical Packet Switches", J. of Lightwave Tech. Vol.16, No. 12, pp. 2081-2094, Dec., 1998
- [2] Imrich Chlamtac, et al "CORD: Contention resolution by Delay Lines", IEEE J. on Selected Areas in Commun. Vol. 14, No. 5, pp. 1014-1029, June 1996
- [3] Christian Guillemot et al "Transparent Optical Packet Switching: The European ACTS KEOPS Projct Approach", J. of Lightwave Tech. Vol.16, No. 12, pp. 2117-2134, Dec., 1998
- [4] David K. Hunter, et al, " WASONET: A Wavelength Switched Packet Network ", IEEE Commun. Magazine, pp. 120-129, Mar., 1999
- [5] N.Calabretta et al "Photonic Packet Switching Using All-optical Header Processing and All-optical Storage of Header Information", in Proc. 5<sup>th</sup> Annual Symposium of the IEEE/LEOS Benelux Chapter, Oct., 2000
- [6] P.B.Hansen et al "20Gbits Experimental Demonstration of an All-optical WDM Packet Switch", in Proc. European Conf. Optic. Commun. (ECOC'97), pp.13-16, 1997
- [7] J.Leuthold et al, "All-optical Space Switches with Gain and Principally Ideal Extinction Ratios", IEEE Journal of Quantum Electronicvol.34, No.4, pp.622-633 April, 1998
- [8] T.Fjelde, et al " 20Gbit/s Optical Wavelength Conversion in All-active Mach-Zehnder Interferometer", Electronic Letters, vol.35, pp.913-914, May, 1999