All-optical Label Swapping Technologies and Node Architecture

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Abstract: All-optical label swapping (AOLS) is a promising approach for transparent optical packet switching and forwarding in the optical layer at high-speeds close to fibre line-rate. In this paper, an all-optical packet switch implementing AOLS technologies as functional subsystems is described. A node architecture based on state-of-art technologies for WDM simultaneous all-optical time-serial label swapping is presented.

1 Introduction

The rapid growth of Internet and multimedia data traffic is building up a potential challenge for the telecom transport networks. The enormous increase of data traffic demands the future backbone transport networks to be able to deliver multiplexed high bit-rate data packets with great efficiency. The huge capacity of optical fibre and the development of the Wavelength Division Multiplexing (WDM) technologies have largely increased the transmission link capacity. However, so far optical transport networks still deploy optical circuit switching (OCS) or Point-to-Point WDM links. It is generally believed that optical packet switching (OPS) technologies will greatly improve the optical network efficiency and bandwidth utilization [1].

In recent years, label switching techniques such as MultiProtocol Label Switching (MPLS) and Asynchronous Transfer Mode (ATM) significantly boosted the data packet handling speed of the transport nodes. Packet switching/forwarding based on swapping of short, local labels instead of locating the global unique IPv4 (Internet Protocol version 4) and IPv6 (Internet Protocol version 6) addresses has highly enhanced the throughput of the network nodes. Nevertheless, these techniques and protocols have been only employed in the electronic processing routers dealing with electronic data packets such as Internet Protocol (IP) packets.

To support packet switching and forwarding at fibre line-rate up to Terabit/s, node technologies that can realize packet handling in the optical layer are required. Electronic packet header processing will no longer meet the demands [2]. All-Optical Label Swapping (AOLS) is a new concept of implementing this label swapping technique for optical packets in the optical domain. AOLS technologies combined with optical packet switching could be a solution for the next generation optical data networks. AOLS packet switches can be used to connect "optical islands" for huge amount of aggregated data traffic in national/international backbone networks (Figure 1).

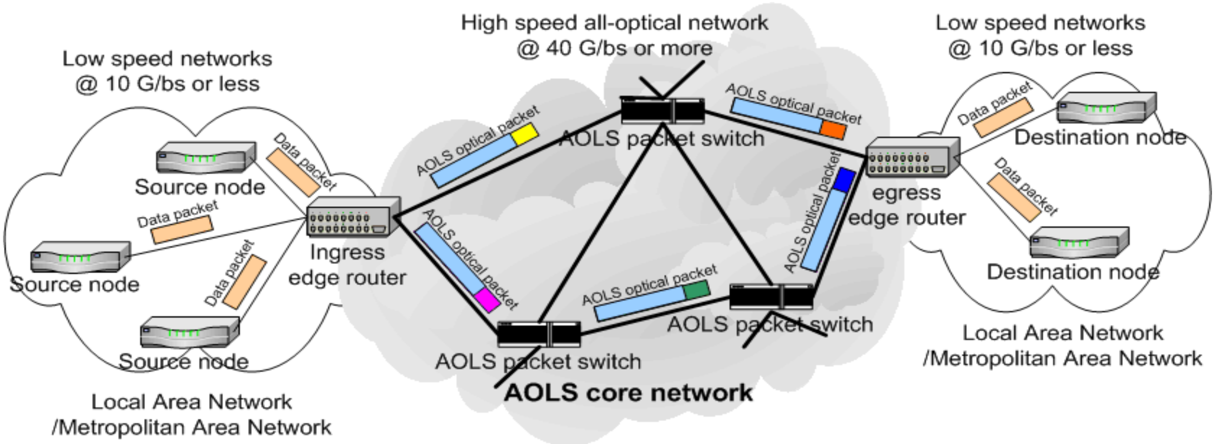

Figure 1 AOLS network scenario

In this paper, node technologies using Mach-Zender interferometer (MZI) – Semiconductor Optical Amplifier (SOA) optical logic gates for 40 Gb/s WDM simultaneous all-optical time-serial label swapping are presented. There have been research activities in the area of time-serial optical label swapping [2]; however, no complete study on a whole AOLS packet switch employing only all-optical technologies for WDM networks has been reported. Other activities have been focused on electronically or all-optically subcarrier optical label swapping [3]. We address here mainly true all-optical approaches for time-serial label swapping. All the functionality is realized in the optical domain, including packet label processing.

An AOLS packet switch design has been proposed based on a network scenario of optical WDM packet-switched networks implementing label swapping techniques. The main operating principle of this AOLS packet switch is to use all-optical eXclusive OR (XOR) correlators to "read" the label, and then route the optical packet to the right output port by using an Arrayed Waveguide Grating (AWG), according to the packet wavelength. The EU FP5 IST-STOLAS (Switching Technologies for Optically Labelled Signals) project [4] did the groundwork on label-controlled optical packet-switching by means of wavelength conversion and AWG passive wavelength routing; however, in STOLAS combined labelling was used, by frequency-shift-keying modulating the label information on the intensity-modulated payload.

Section 2 takes a 2x2 AOLS WDM packet switch as an example describing the architecture and the general operation process of these AOLS packet switches. Section 3 explains in detail the proposed all-optical approaches in an AOLS unit and the principle and functionality of the AOLS unit subsystems. Section 4 addresses the AOLS packet format requirements for these AOLS packet switches. Section 5 concludes the paper.

2 WDM AOLS packet switches

These AOLS packet switches are designed for switching and forwarding optical data packets with their serial optical headers in front of the payloads on the same wavelengths. Such an AOLS packet switch includes the following functional stages: input fibre ports, wavelength demultiplexers, AOLS label swapping units, AWG routers, switching matrixes, contention detection and optical buffering, wavelength converters (WCs), wavelength multiplexers, and output fibre ports [5].

At the input fibre ports, the wavelength channels will be demultiplexed; an optical packet on a single wavelength will enter an AOLS unit. Inside the AOLS unit the packet label will be swapped, and according to the label information, the packet will be converted into a new wavelength, in order to be passively routed to the correct output fibre port by the AWG. Wavelength converters near the output fibre ports are used to convert the optical packets into proper external wavelengths for the output fibres to avoid wavelength contention at the output ports.

Figure 2 shows the schematic diagram of a 2x2 AOLS packet switch for 4-channel WDM AOLS networks. This 2x2 WDM AOLS packet switch has the minimum switching dimension configuration. The packet switch in Figure 2 also has an *Add fibre port* (connect to an ingress edge router), a *Drop fibre port* (connect to an egress edge router), and *Loop fibre ports* for possible multicast and contention deflection delay. In general, an AOLS packet switch can have more input/output fibre ports and more add/drop fibre ports, according to the network scenario.

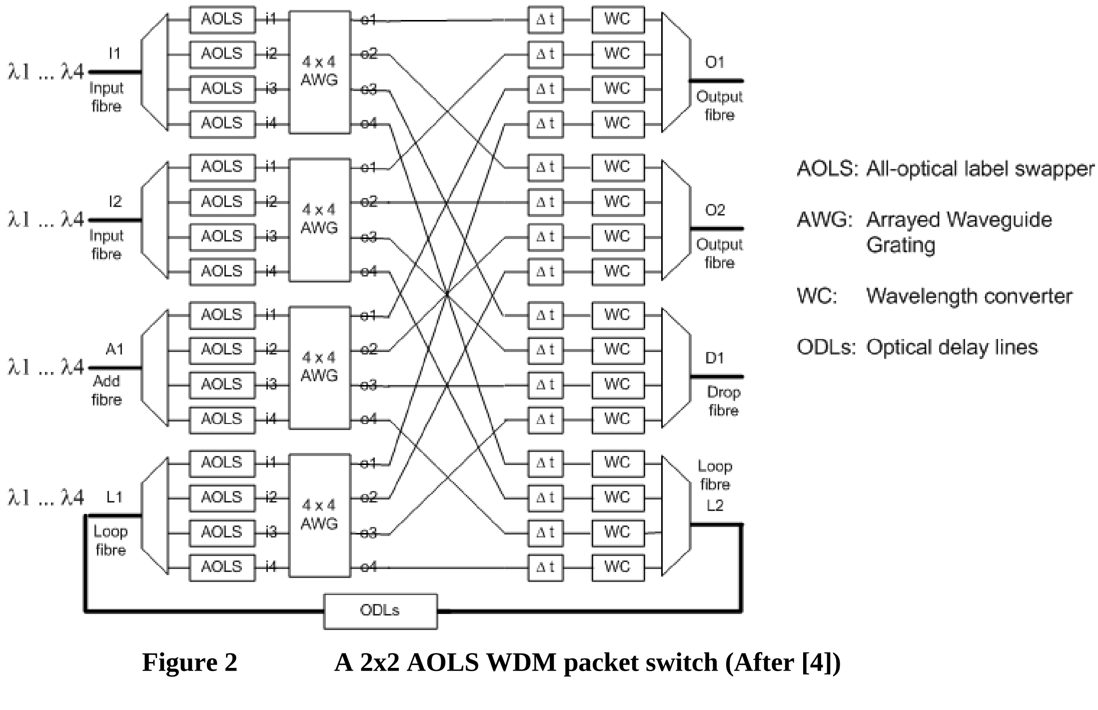

Figure 2 A 2x2 AOLS WDM packet switch (After [4])

3 AOLS unit and its subsystems

Figure 3 shows the AOLS unit block diagram. When an AOLS unit receives an AOLS packet, first the optical label of the packet will be extracted from its payload by the *label/payload separation circuit* [6], which employs an all-optical AND logic gate in combination with a packet clock recovery circuit [7] to separate the label from the payload. After the label extraction, the packet payload will be optically delayed by Optical Delay Lines (ODLs) to allow for the processing time of the label. The optical label goes into the *label comparison subsystem* [8]. An optical pulse is generated if an address match is found. This optical pulse will set the *control block* to emit a CW signal of a certain wavelength for the *wavelength conversion* of the optical packet. The optical pulse from the label comparison subsystem will also be used together with some ODLs to *generate a new label* for the packet. According to the forwarding table, the old label determines which new label to generate. This *new label is then inserted* in front of the payload using Optically Time-Domain Multiplexing (OTDM) techniques, before the whole packet being converted into the desired wavelength for the AWG routing.

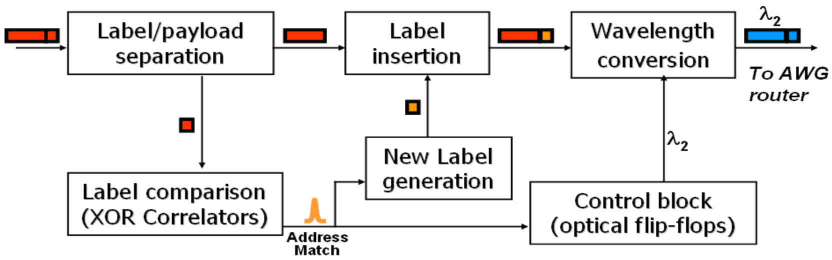

Figure 3 AOLS unit block diagram

The detailed diagram of the AOLS unit is shown in Figure 4. *Packet clock recovery* is required for the *label extraction* according to the time-domain multiplexing (TDM) approach. In the *label comparison* subsystem, the label bits will be copied and XOR correlated with locally generated optical address keywords using MZI-SOA optical logic gates. When there is an address match, the relevant *XOR correlator* generates an optical pulse, which sets the related *optical flip-flop* [9] in the control block. These optical flip-flops have two states of two different wavelengths. They are designed to be triggered by optical pulses from one state to the other, and they emit Continuous Wave (CW) signals of these two wavelengths accordingly. In the AOLS packet switch, before receiving optical packets, the original state of these optical flip-flops is set to λ_0. After the label comparison, one of these optical flip-flops will change state and emit another wavelength (in the example shown in Figure 3 and Figure 4, the second flip-flop is triggered into its λ_2 state). After a notch filter at λ_0, only this new wavelength will enter the wavelength converter as the CW control signal for the wavelength conversion.

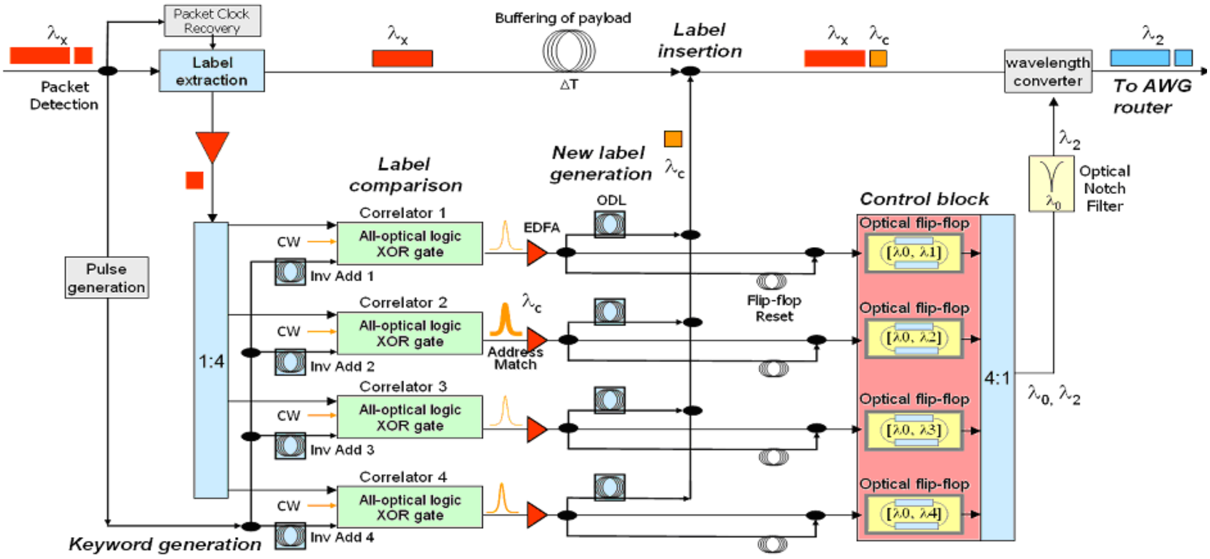

Figure 4 AOLS unit in details (after [5])

4 AOLS packet

AOLS optical packets contain 40 Gb/s intensity-modulated Return-to-Zero (RZ) signal. In the AOLS optical header, guard band is included for the separation of different header fields, i.e. the label bits and the Class of Service (CoS) bits. There might be guard bands between the time-domain multiplexed data packet payload for the proper operation of edge routers; however, these possible guard bands inside the payload as well as the multiplexed data payload are transparent to the AOLS packet switch.

To define fixed-length AOLS packets potentially simplifies the packet format, AOLS packet switch design and network protocol configuration. A possible optical payload length can be in the range of microseconds [10].

Several aspects have to be taken into account deciding an AOLS packet payload length. Factors in favour of longer payload length include *packet efficiency* (the percentage of the packet payload length in the total packet length including guard bands), *bandwidth utilization efficiency*, and *aggregation time at the edge routers*, and so on. Factors in favour of shorter payload length include *packet payload overhead* for fixed-length packets and *node resource occupation balance*. Considering an AOLS packet with a 20-bit optical header (including guard bands), Figure 5 shows the AOLS packet efficiency in function of different AOLS optical payload length.

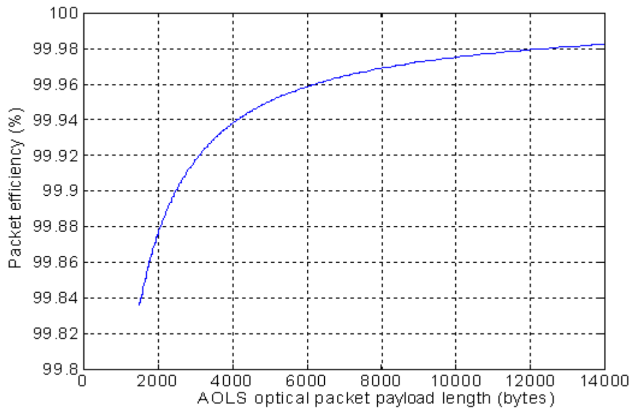

Figure 5 AOLS packet efficiency (considering a 20-bit AOLS packet header)

5 Conclusions

AOLS packet switch functionality and the required technologies are explained. An all-optical packet switch implementing state-of-art AOLS node technologies for WDM simultaneous all-optical time-serial label swapping is presented. AOLS packet format requirements are discussed.

Acknowledgments

This research is done under the framework of the EU FP6 IST-LASAGNE (all-optical LAbel SwApping employing optical logic Gates in NEtwork nodes) project. The authors would like to acknowledge the European Commission for funding this project. The authors would also like to thank our project partners in Eindhoven University of Technology, Valencia Nanophotonics Technology Center, National Technical University of Athens, Telecom Italia, Interuniversity MicroElectronics Center (Gent, Belgium), COM Research Center of Technical University of Demark, and other partner institutes and companies.

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