All-Optical Label Swapping Node Architectures and Contention Resolution

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All-optical label swapping (AOLS) is a promising approach of implementing label swapping techniques for transparent optical packet switching and forwarding in the optical layer at high-speeds close to fiber line-rates. In this paper, an AOLS-based all-optical packet switch node architecture for WDM simultaneous all-optical time-serial label processing is presented. Furthermore, contention resolution for this AOLS packet switch is also addressed.

I. Introduction

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. It is generally believed that optical packet switching (OPS) with appropriate granularity will greatly improve the optical network throughput and bandwidth utilization.

In recent years, packet forwarding based on swapping of short, local labels instead of locating the global unique Internet Protocol (IP) addresses has highly enhanced the throughput of the network nodes. Nevertheless, to support packet switching at fiber line-rates up to Tb/s, electronic packet header processing will no longer meet the demands. Node technologies that can realize packet handling in the optical layer are required. All-Optical Label Swapping (AOLS) is a new concept of implementing this label swapping technique for optical packets in the optical domain [1]. AOLS technologies combined with optical packet switching could be a solution for the next generation optical data networks. AOLS packet switches can be used in the optical core networks (wide area networks – WANs) interconnecting low-speed local or metropolitan area networks (LANs or MANs), or even high-speed “optical islands” in the future, for aggregated data traffic in the national/international backbone transmission (Fig. 1).

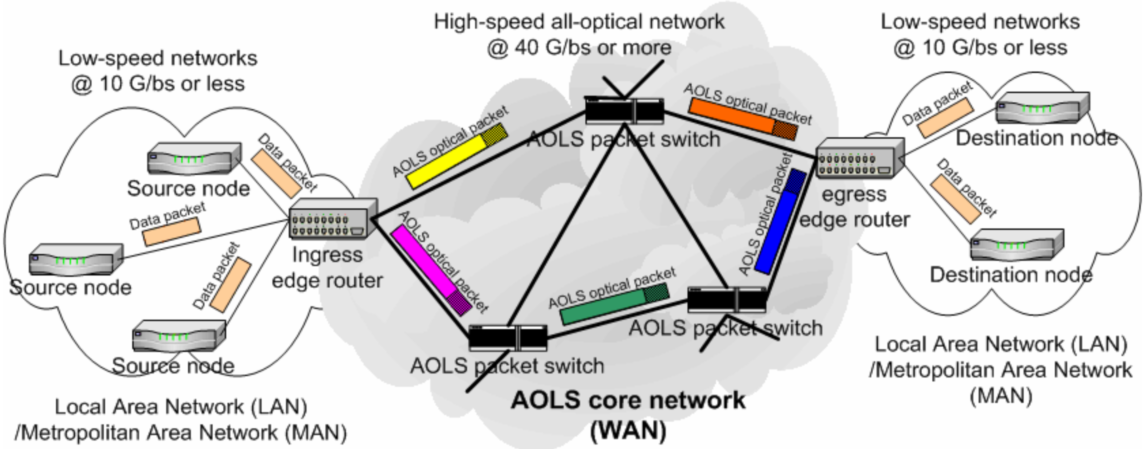

Fig. 1. AOLS network scenario

II. WDM AOLS Packet Switches

An AOLS packet switch design has been proposed in the IST-LASAGNE project for 40 Gb/s Wavelength Division Multiplexing (WDM) simultaneous all-optical time-serial label swapping for fixed-length optical packets. To date there have been research activities in the area of *time-serial optical label swapping* [1]; however, no study has been reported on a complete WDM time-serial AOLS packet switch design with all-optical label processing.

The main operating principle of the LASAGNE switch is to use all-optical eXclusive OR (XOR) correlators to match the incoming label with the keyword indexes of the node forwarding table, wavelength convert the whole label-swapped optical packet, and then switch the new packet to the right output port according to its wavelength by an Arrayed Waveguide Grating (AWG).

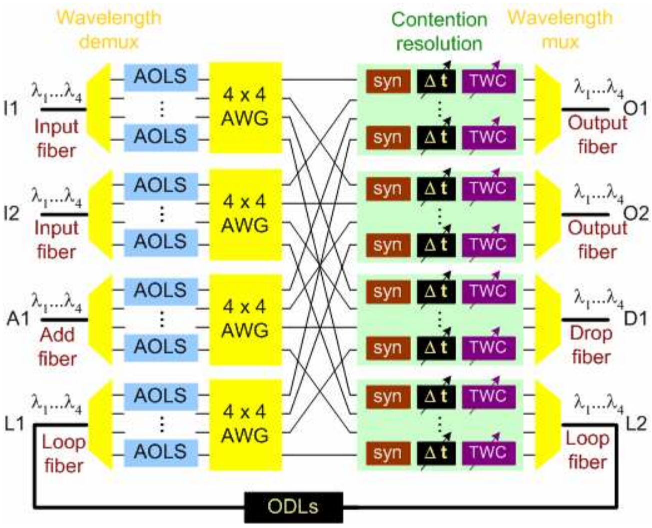

Fig. 2. A 2x2 AOLS WDM packet switch (AOLS: all-optical label swapper, AWG: arrayed waveguide grating, Demux: optical demultiplexer, Mux: optical multiplexer, ODLs: optical delay lines, syn: synchronization, TWC: tunable wavelength converter)

Fig. 2 shows the schematic diagram of a 2x2 AOLS packet switch for 4-channel WDM AOLS networks. At the input fiber ports, the wavelength channels are demultiplexed; an optical packet on a single wavelength then enters an AOLS. Inside the AOLS the packet label is swapped, and according to the matching of the old label with the keyword indexes in the node forwarding table, the packet is converted into a proper new wavelength, in order to be passively routed to the correct output fiber port by the AWG. Tunable wavelength converters (TWCs) near the outputs are used to convert the optical packets into proper external wavelengths to avoid wavelength contention at the output fiber ports.

III. All-Optical Label Swapper: Subsystems and Principles

Fig. 3 shows the block diagram of the proposed AOLS design in the LASAGNE project. When an AOLS receives an optical packet, the optical label of the packet is first separated from the payload by the *label/payload separation* circuit [2], which employs an all-optical AND logic gate in combination with a packet clock recovery circuit. After the label extraction, the packet payload is 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 [3]. An optical pulse is generated if an address match is found.

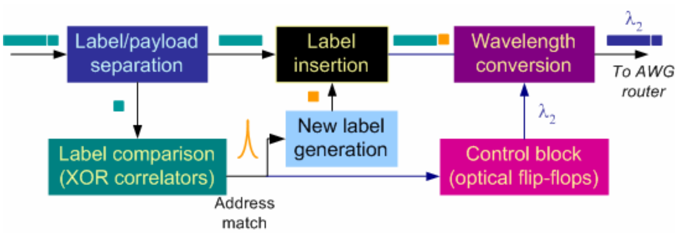

Fig. 3. AOLS original: subsystems block diagram

This optical pulse then sets the *control block* to emit a continuous wave (CW) signal of a certain wavelength for the *wavelength conversion* of the optical packet. The optical pulse from the label comparison subsystem is also used together with ODLs for the *new label generation* [4]. After that the new label is sent to the *label insertion* subsystem and is then placed in front of the payload by means of an optical coupler. Finally the whole packet is converted into the desired wavelength for the AWG routing. The details of the AOLS forwarding information base are shown in Fig. 4.

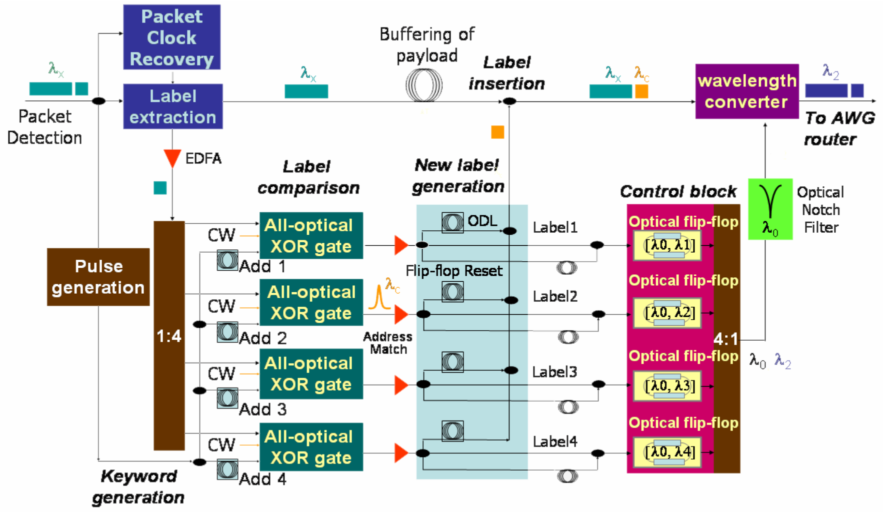

Fig. 4. AOLS original: forwarding information base

IV. AOLS Packet Switch Contention Resolution

Electronic control is a requisite to realize the contention resolution (CR) blocks for the output-buffered AOLS packet switch in Fig. 2. In this section, all-optical input-buffered contention resolution for the AOLS packet switch is presented. The layout of such a contention free, non-blocking AOLS packet switch design is shown in Fig. 5. The main principle of this contention resolution scheme is by deploying more internal and external wavelengths in the AOLS systems and networks. 16 wavelengths $\{\lambda_1\text{-}\lambda_{16}\}$ are used instead of 4, which consist of 4 groups of 4 wavelengths that the 4x4 AWG treats respectively the same [5]. Based on this characteristic of AWG, we configure the second wavelengths of the optical flip-flops in Fig. 5 in an ordinal way from λ_1 to λ_{16}. Consequently, the optical packets coming out of the AWGs during the same period can have up to 16 different wavelengths. Therefore, waveband demultiplexers are introduced at the input fiber ports to separate the 16-channel WDM traffic into 4 groups of the 4 wavelengths that every AOLS-array (per AWG) can process at the same time. Fixed optical delay units (Δt) are

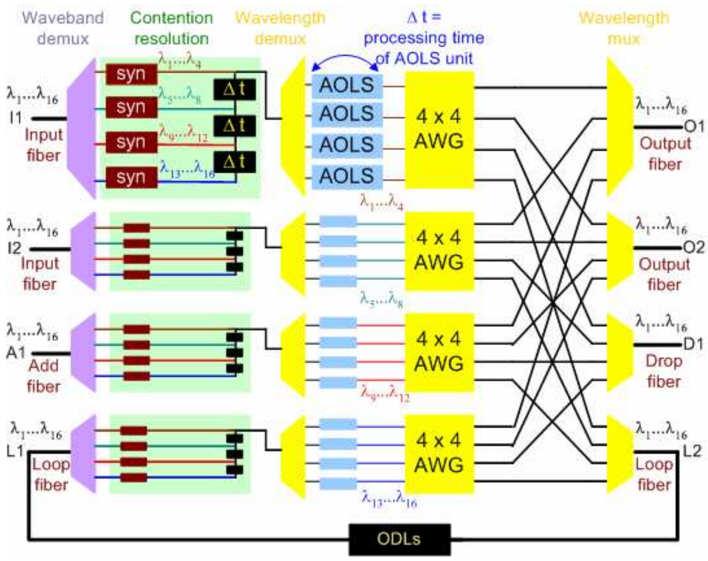

Fig. 5. Regular AOLS packet switch schematic configuration with contention resolution

deployed to allow for the processing time of the optical packets in different wavelength groups. Δt is determined by the AOLS processing duration for one optical packet, so its value is fixed and can be estimated beforehand.

The following *preconditions* exit and are satisfied: i) AWGs have cyclic characteristics [5]; ii) The AOLS does not process the wavelength information of the incoming packets; iii) The wavelength receiving and operation ranges of the AOLS are beyond $\{\lambda_1\text{-}\lambda_{16}\}$; iv) WDM allows us to use the enormous fiber bandwidth; v) For high data processing rate, negligible latency is caused by the queuing in different wavebands.

The *advantages* of the scheme include: i) Contention is completely solved. It is at the moment, to our knowledge, the only all-optical contention resolution for this kind of AOLS packet switches; iii) Apart from the wavelength resource, it technically does not add any more difficulty or complexity on the AOLS packet switch buildup; iv) The operation principle is simple and intelligible; v) Only input packet synchronization is required; vi) After an optical packet travels through the AOLS, the wavelength of the converted packet actually carries information about from which input fiber port of that AOLS packet switch the packet originally comes in, which can possibly be used in the future for prioritized packet handling and traffic engineering.

The *disadvantages* include: i) usage of more wavelength resource; ii) The queuing of the wavebands might introduce unnecessary delay; iii) Further investigation needs to be carried out concerning the all-optical synchronization of different wavebands.

V. Conclusions

A technically viable concept for a commercially oriented *all-optical packet switching node* based on label swapping has been presented. The revolutionary aspect of the study and trial of this AOLS switch is to advance and combine the existing technologies for a completely all-optical WDM packet switch that can switch and forward fixed-length optical packets directly in the optical layer. An input-buffered all-optical *contention resolution* approach for the AOLS packet switch was also introduced and discussed.

Acknowledgement

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References

[1] D. J. Blumenthal, B-E Olsson, G. Rossi, T. E. Dimmick, L. Rau, et al., “All-optical label swapping networks and technologies”, *IEEE J. Lightwave Technol.*, vol. 18, no. 12, Dec 2000.

[2] C. Bintjas, N. Pleros, K. Yiannopoulos, G. Theophilopoulos, M. Kalyvas, et al., “All-optical packet address and payload separation”, *IEEE Photon. Technol. Lett.*, vol. 14, no. 12, Dec. 2002.

[3] J. M. Martinez, F. Ramos, and J. Marti, “All-optical packet header processor based on cascaded SOA-MZIs”, *Electron. Lett.*, vol. 40, no. 14, Jul. 2004, pp. 894-895.

[4] D. C. Rogers, J. V. Collins, C. W. Ford, J. Lucek, M. Shabeer, G. Sherlock, et al., “Optical pulse pattern generation for self-synchronizing 100 Gbit/s networks”, *Optical Fiber Communication (OFC’96)*, Tech. Dig., Feb./Mar. 1996, pp. 98-99.

[5] J. Cheyns, J. Jennen, E. V. Breusegem, M. Pickavet, and P. Demeester, “Optical packet switches based on a single arrayed waveguide grating”, *IEEE Conf. High Performance Switching and Routing (HPSR’03)*, paper 3872, 2003.