Optical label switching functionalities employing semiconductor optical amplifiers

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Abstract: Optical labelling of data packets enables high router throughputs and hybrid circuit-packet-switched networks. Semiconductor optical amplifiers (SOAs) are key building blocks to implement the various functionalities required for optical label switching. We report on the performance and requirements of SOAs for enabling optical label controlled packet routers.

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1. Introduction

Today's networks show an ever-continuing growth of packet-based data traffic, driven by heavy internet usage, peer-to-peer traffic, on-line gaming, etc. The throughput of a packet-routing node can be increased significantly by switching the payload data transparently without opto-electrical-optical conversion. In order to control this routing, each packet carries a label that can be split off easily and processed separately. Various ways have been reported to embed the label information in the data packets [1] each having its pros and cons, by e.g. requiring extra bandwith for the label, strict synchronization between payload and label, increasing sizeable the line rate, etc. In the EU FP5 project STOLAS, which has been concluded recently, an alternative labeling approach has been pursued, the so-called 'orthogonal labeling', which uses two basically independent modulation dimensions for the payload and the label [2]. Although, the label information is processed electronically, the payload data is kept entirely in the optical domain. The ongoing EU FP6 project LASAGNE explores techniques to process all-optically (without any control electronics) the label information. Semiconductor optical amplifiers (SOAs) are used as building blocks to perform the required label processing functionalities. This paper discusses the implementation of several optical label switching functionalities, based on the use of SOAs, its performance and requirements.

2. Label-controlled routing node

As shown in Fig. 1 (left), packets from metro/access networks are fed to the metro/core network through an edge router. In the label-switched packet routing approach, the edge router sets out a label-switched path through the network based on the packet header's addressing information, and attaches the appropriate label to the packet. While traversing through the network, at each node, the label is inspected, translated into a new label setting out the next appropriate links of the path. This new label replaces the old label, and the packet is routed onto the next link. This label processing can be done at medium speed in the electrical domain or alternatively by employing advanced optical signal processing by all-optical means. The payload data, however, is remaining in the optical domain, and may only have its wavelength changed. A general design for a label-controlled node is presented in Fig. 1 (right). In this design, packets bursts are routed by means of a passive wavelength router (AWGR, arrayed waveguide grating

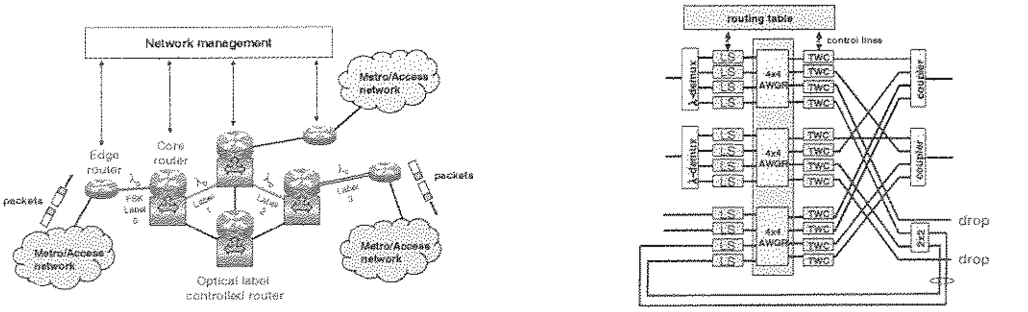

Figure 1. Left: Packet routing using label swapping. Right: Optical label-controlled routing node. LS: label swapping module. TWC: tunable wavelength converter. AWGR: arrayed waveguide grating router.

router). The label information from each packet burst is interpreted and by consulting a forwarding label information module its wavelength is changed accordingly which will in turn determine the output port of the router. In the STOLAS approach, the new wavelength is provided by an agile tunable laser source while in the LASAGNE concept, it is provided by an optical flip-flop. In the following section we explain an implementation where the label information is processed electronically and one employing all-optical signal processing by employing optical logic gates based on SOAs.

2.1 All-optical payload by-pass, electronic label processing

In STOLAS, the label information is modulated orthogonally to the data payload: while the data is intensity-modulated (IM) on a specific wavelength channel, the label is frequency shift-keyed (FSK) modulated on the same channel. The payload data rate is much higher than the label rate, e.g. 10 Gbit/s versus 155 Mbit/s, respectively. The tunable wavelength converter (TWC) is composed of a fast-tunable laser, which can be FSK modulated, and a Mach-Zehnder interferometer using intensity-driven cross-phase modulation in SOAs (MZI-SOA); see Fig. 2 (left). As only the IM is transferred onto the new wavelength in such a wavelength converter, the FSK label is erased. Through FSK modulation of the tunable laser, a new label is attached. In order to avoid collision of packet bursts heading for the same output fiber port of the node, a second set of TWCs is applied after the passive router. By FSK modulating the CW output of the tunable pump laser in each of these TWCs, new labels can be affixed to the outgoing packet bursts. The passive router is composed in a modular way of multiple AWGRs, which enables scaling of the node to more input/output fibers and wavelength channels.

In order to assess the scalability of the label-swapping concept, experiments have been done in a laboratory testbed. Two label-swapping TWCs have been put in cascade, using an ER of 7 dB and of 12 dB. Four wavelength channels were used with 200 GHz spacing (1555.75, 1557.36, 1558.98, and 1560.61 nm). Passing through a single TWC, a power penalty of 2.7 dB at BER=10^{-9} is incurred for an ER=7 dB, and of 1.9 dB for ER=12 dB. Passing two TWCs, the penalties are 5.3 dB and 4.4 dB, respectively. These cumulative penalties are largely due to insufficient speed of the SOAs inside the TWC, which causes patterning effects. With a payload rate of 10 Gbit/s, and a dynamic range of 20 dB for the payload receiver, the insufficient TWC speed limits the cascadability to 4 nodes. At a lower payload speed of 2.5 Gbit/s, the penalties are found to be remarkably lower (<2 dB after passing 6 nodes); hence much more nodes could be cascaded [3]

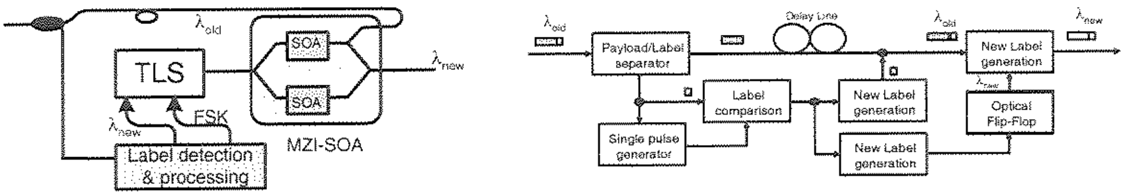

Figure 2. Left: STOLAS label swapping element based on tuneable wavelength converter (TWC) followed by a Mach-Zehnder Interferometer with SOA (MZI-SOA). Right: LASAGNE all-optical label swapping node employing SOA based optical logic gates. TLS: tuneable laser source.

2.2 All-optical label processing and switching

In the LASAGNE project, an all-optical label swapping node is investigated, whose schematic diagram is shown in Fig. 2 (right). For each incoming optically labeled packet, its payload and label section are extracted. The optical label is processed by a label comparison subsystem, which is formed by optical XOR correlators, based on MZI-SOA elements that generate an optical pulse if an address match is found [4]. The label comparison block generates a pulse signal which sets both the new label generation block and the optical flip-flops. The new label generation block creates the new label that contains the information required to forward the burst to the next hop. At the same time, the optical flip-flop emits a continuous wave signal at a certain wavelength, which will be used as a probe signal for the wavelength conversion block [4].

We have demonstrated experimentally an asynchronous, variable length, label and payload separator for return-to-zero intensity modulated label and payload data in a time serial scheme [6]. The separator exploits the nonlinear polarization rotation effect in an SOA. The results show a suppression ratio higher than 7.5 dB. Furthermore, the scheme is highly efficient in terms of bandwidth utilization and may be upgraded to higher bitrates. Besides, it has potential of integration in a photonic circuit because of the use of SOA-based devices [6].

Table 1. Main optical label processing functionalities and implementations based on semiconductor optical amplifiers.

Functionality	SOA based implementation
Label and payload separator	-Non-linear polarization rotation in a single SOA -MZI-SOA based logic gates
Routing	-Wavelength conversion in a MZI-SOA
Label erasure	-FSK labels erased during wavelength conversion in MZI-SOA -Gating in a MZI-SOA
Label comparison	XOR correlators in cascaded MZI-SOA logic gates
Routing control	Optical flip-flops based on coupled MZI-SOA gates
Label insertion	Wavelength conversion in MZI-SOA
Multicasting	Multi-wavelength conversion in MZI-SOA

In this paper we have presented results for the performance of label swapping performed by MZI-SOA wavelength converters where both erasure and insertion of FSK modulated labels are performed in a single wavelength conversion stage. We also show that an all-optical payload and label separator module can be built by exploiting the non-linear polarization effect in a SOA. SOAs also find applications for other required label switching functionalities such as label comparison and optical flip-flops [4,5]. In Table 1 we list the main label processing functions required in a label-controlled routing node and their possible implementation by using SOAs.

Conclusion

Employing the STOLAS' orthogonal packet labelling concept, the routing of data packets can be most efficiently handled in network nodes while keeping the packet payload data in the optical domain. By using fast tuneable wavelength converters and passive wavelength routing elements, a scalable modular router node with high reliability can be implemented. The number of cascadable nodes is mainly limited by the speed of the label-swapping wavelength converters. Orthogonal labelling may find a first attractive application in routing of overspill packets in hybrid optical circuit-/burst-switched networks [7]. In a longer-term perspective, the orthogonal label-controlled optical burst switching as proposed in the STOLAS project may combine the advantages of the transparent payload routing offered by optical circuit switching with the improved efficiency offered by packet switching. The ultimate goal is to increase the speed of operation and throughput up to terabit/s. This is envisaged to be enabled by the introduction of ultra-fast all optical packet switching technologies [5]. In the ongoing IST LASAGNE project, an approach based on the use of optical logic gates and optical flip-flops is explored for implementing all-optical label switching nodes [4].

For the realization of all-optical label switching functionalities, optical logical gates and optical flip-flops, based on SOA are key elements promising ultra-fast operation [4,5]. In general, for all the above mentioned label switching functionalities, improvement and desirable features from SOAs are: high speed of operation supporting high-speed wavelength conversion and ultra-fast logic operations, low polarization dependence on the incoming signals and pulse patterning free operation. In optical networks the incoming optical power level to a routing node may vary on a packet by packet basis, and therefore wide dynamic range operation is mandatory. In summary, optical semiconductor amplifier remains a promising technology for building ultra-fast optical packet routing nodes.

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