An optical-label controlled packet router for IP-over-WDM networks

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A novel two-level optical labeling method for highly efficient transport of IP packets through WDM networks is proposed. By assigning both a wavelength label and a label in DPSK or FSK format (orthogonal to the ASK format of the data payload), packets can be routed transparently through end-to-end optical paths. The design of a dual-label controlled optical router is presented, which features label swapping and multi-casting. Key element is an optically integrated wavelength converter and phase modulator. This work is part of the new IST project STOLAS – Switching Technologies for Optically Labeled Signals.

1. Introduction

Telecommunication networks are experiencing an explosive growth of packet-based data traffic, fueled by Internet usage. The past twelve months have shown a tripling of the worldwide Internet traffic. Putting IP packets directly into WDM channels, thus skipping the SDH and ATM transport layers, can yield a significant improvement of the network throughput. The recently suggested MPλS protocol enables IP-over-WDM, by providing wavelength-switched channels in a similar way as label-switched paths in the MPLS protocol [1]. In the near future, optical networks will operate at Tbit/s line rates, and optical routing of IP packets of which the majority has quite a small size (50% is less than 522 bytes) requires packet forwarding with very low latency. With Optical Label Switching, packets are marked with an optical label (e.g. a wavelength) which may be swapped in each network node [2]. Thus data packets can be routed transparently in the optical domain via end-to-end optical paths, aided by their optical label; they can bypass the electronic switching in the network core routers, thus significantly increasing the network's throughput. With the pervasive usage of IP-based devices, multiple optical addressing levels would be welcome for advanced routing and traffic engineering. Therefore, in addition to labeling with a wavelength, a second level of optical labeling is proposed in the IST STOLAS project [3], by modulating label information in a DPSK (or FSK) format which is orthogonal to the ASK format used for the payload data. This paper discusses the label-controlled router setup in more detail.

2. Label-controlled optical packet routing

In an optically routed packet transport network, packets entering the network from an underlying access or metropolitan network first need to get an optical label at the entrance point, the edge router. The two-level optical labeling proposed in this paper is done in two steps; see Fig. 1. The incoming IP packets are buffered and aggregated, and a label setting circuit determines the wavelength label to be assigned. The continuous wave output light of a fast tunable laser diode is amplitude modulated with low chirp in an external modulator by the IP packet payload data. Subsequently, the next-level label information is impressed in the orthogonal DPSK format by means of a phase modulator. A payload data rate of 10 Gbit/s is envisaged, and a label data rate of 155 Mbit/s. Scrambling of the payload data (e.g., with a 16^{th} order polynom, following ITU-T Rec. G.709) should provide enough bit transitions to be DPSK modulated. An alternative approach is to deploy FSK modulation. Again, the tunable laser needs to be set to the appropriate wavelength label, but the additional label information now can be attached by direct current modulation of the laser, delivering an FSK-modulated signal to the amplitude modulator. Thus a separate phase modulator is avoided; however, the line signal exhibits more chirp which will affect the transmission performance more.

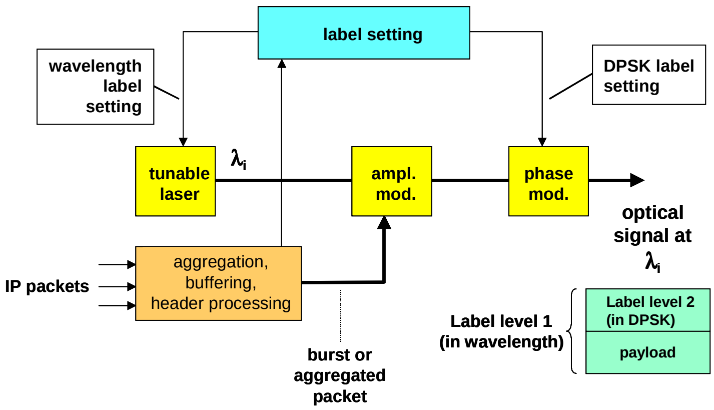

Fig. 1 Two-level optical labeling in edge router

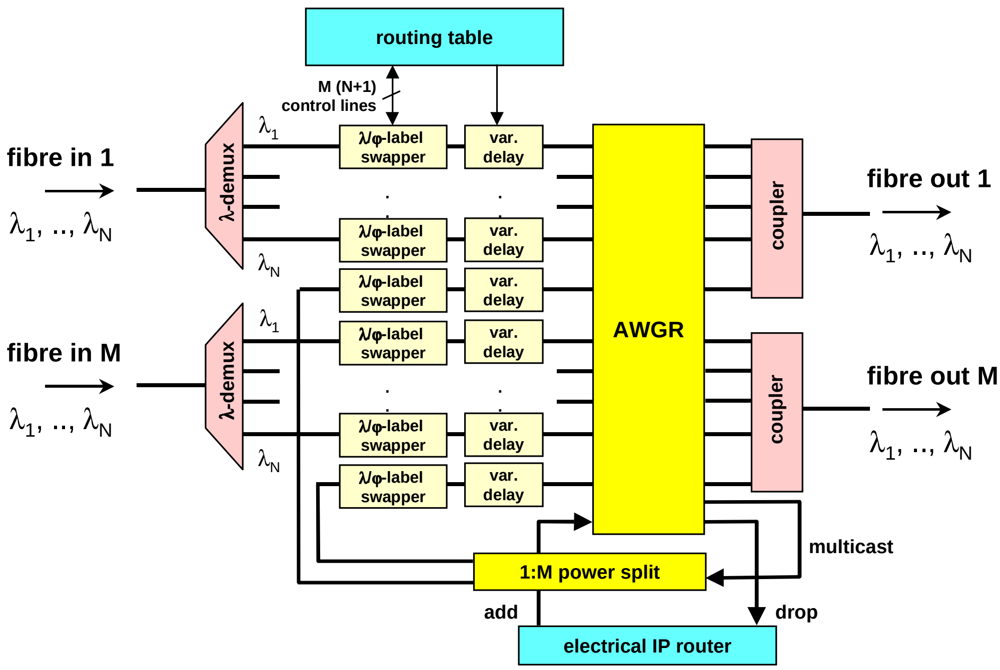

Fig. 2 Optical label-controlled router

In the network routing nodes, both the wavelength and the DPSK (or FSK) label are inspected, and new labels are set with the aid of a routing table. The general setup of such a label-controlled router is shown in Fig. 2. It enables routing of packets in any of the *N* wavelength channels at any of the *M* fibre input lines to any wavelength channel at any fibre output line. At every inlet a wavelength demultiplexer separates the individual wavelength channels, and subsequently in a wavelength-and-phase information swapper a new two-level label is assigned to each packet as commanded by the routing table. In an Arrayed Waveguide Grating Router (AWGR), by means of its wavelength the packet is directed to the appropriate output port. To avoid packet collision when two or more packets are contending for the same output port, a packet can be buffered in a variable delay line. As illustrated in Fig. 3, 8 distinct delay times can be stepwise set with a three-stage switchable delay line using fibre delay loops with length ratios 4:2:1.

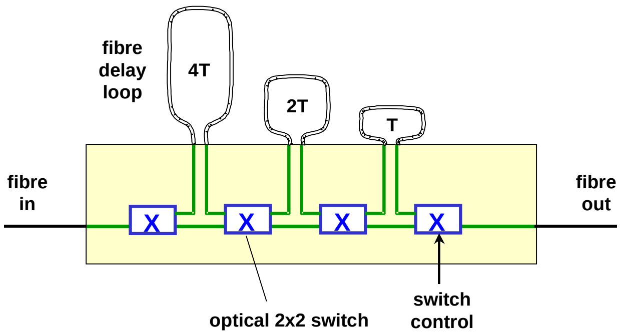

Fig. 3 Switchable delay line

The router setup also provides means for multicasting packets optically. By assigning the appropriate wavelength, a packet emerges at a multicast outlet of the AWGR, from where it is fed via a power splitter to a number of label swappers at the inputs of the AWGR, by which the packet is multicasted to the appropriate output fibres.

For a router handling 4 wavelengths and having 2 input and 2 output fibres, a 12x12 AWGR would be needed. The same functionality, however, can be obtained with three 4x4 AWGRs, as shown in Fig. 4; this modular setup is easier to realise.

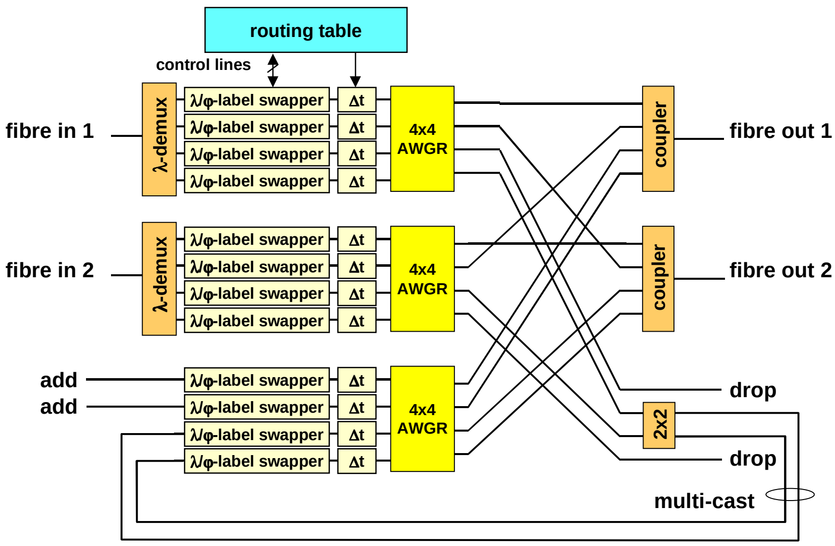

Fig. 4 2x2 Label-controlled router with 4x4 AWGRs

Similarly, by deploying just a single input and output fibre, a label-controlled add/drop node can be constructed with drop-and-continue functionality.

3. Two-level label swapper

The proposed setup of the wavelength-and-phase information swapper is shown in Fig. 5. A small part of the input signal power is fed to the label processing circuit, which subsequently sets a new wavelength label by means of a tunable laser diode. Via an optical delay line (which compensates for the delay time in the label processor), the payload data is fed into a wavelength converter built with a Mach Zehnder Interferometer (MZI) equipped with Semiconductor Optical Amplifiers (SOAs) in its arms. By means of cross phase modulation in the SOAs induced by the amplitude modulation of the data payload, the data packet is transposed to the new wavelength label. The phase information contained in the DPSK label, however, is not contributing to the cross phase modulation process, and therefore is not transferred. Thus a new DPSK label can be written, by means of the phase modulator integrated together with the MZI wavelength converter in a single InP chip.

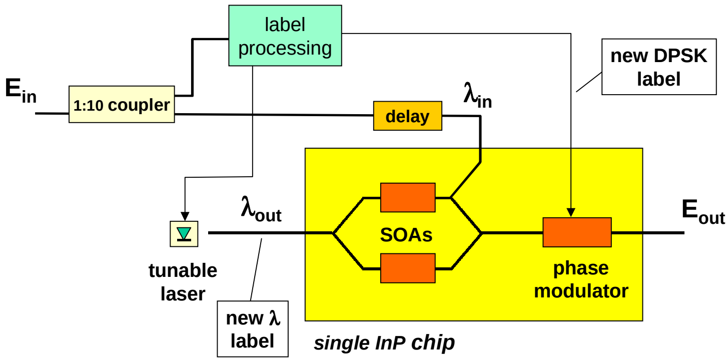

Fig. 5 Two-level label swapper

In case of FSK labeling, the FSK label of the input signal is lost in a similar way in the wavelength conversion stage, and a new FSK label can be assigned by modulating the tunable laser's frequency.

First simulations using the VPI software package have been done to assess the performance of the label swapper. Due to the interferometric process, careful adjustment of the signal input power and of the injection current of the SOAs is needed for a good wavelength conversion. A wider input power dynamic range requires an input power control stage, e.g. an optical pre-amplifier with automatic gain control.

4. Conclusions

Two-level optical labeling significantly increases the routing and forwarding efficiency of IP-over-WDM networks. End-to-end transparent optical paths can be supported by applying both a wavelength label and a label in a modulation format orthogonal to that of the payload.

5. Acknowledgement

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