Optical-Label Switching and Routing by Rapidly Tunable Wavelength Conversion and Uniform Loss Cyclic Frequency Array-Waveguide Grating

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Abstract: We experimentally demonstrate optical-label switching and routing by combining rapidly tunable wavelength conversion with an arrayed waveguide grating router. The subcarrier optical-label content was optically extracted and processed, which induced forwarding decision and optical routing with a new label content.

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1. Introduction

Rapidly increasing data traffic is demanding a scalable networking technology. While the convergence of data networking with multi-wavelength optical networking is a natural consequence of such imminent needs, equally important are the low latency and the traffic engineering features associated with the networking technology. Multiprotocol-Label Switching (MPLS) [1] is a recent development from the data networking perspective, and it combines desirable Layer 3 and Layer 2 features of Internet Protocol (IP) and Asynchronous Transfer Mode (ATM). Nearly concurrently with MPLS, Optical-Label Switching was proposed from the optical networking perspective [2,3]. Optical-Label switching incorporates a short 'optical-label' that contains routing information, integrates directly with the optical layer, and allows interoperability between optical-packet switching and circuit switching. While both MPLS and Optical-Label Switching attempt to simplify the protocol stacks and to add traffic engineering features, Optical-Label Switching capitalizes on a rich set of capabilities, such as wavelength conversion, offered by multi-wavelength networking technologies. There are two key challenges in implementing Optical-Label Switching systems and routers. They are the stringent requirements for viable optical header processing and optical switching technologies. It is also imperative that they involve as little electronic processing as possible while offering ultra-low latency. This paper discusses experimental demonstration of an optical-label switching and routing system incorporating optical–label detection, rapidly tunable wavelength conversion, optical-label swapping, and optical routing using array-waveguide gratings (AWG).

2. Experimental Description

Figure 1 shows a functional block diagram of the experiment. This system represents the core of an Optical Label Switching Router. It consists of an optical-subcarrier transmitter, an optical-header/data separator, a header detector, a forwarding table, a switch controller, a tunable wavelength converter including a tunable laser and a semiconductor optical amplifier (SOA), a uniform-loss-cyclic frequency (ULCF) AWG, header rewriters and receivers. The transmitter modulates the original header (header_1) at 622 Mb/s on a 14 GHz subcarrier, and combines it with the data payload packet at 2.5 Gb/s. The modulated signal will then include double side band subcarrier header appearing 14 GHz away from the center optical frequency of 192.7 THz (1549.3 nm). The optical-header/data separator consists of a Fiber Bragg Grating (FBG) with peak reflectivity centered at this optical frequency and an optical circulator. The FBG has higher than 99.9 % peak reflectivity with a pass band below 5 GHz Half-Width-at-Half-Maximum. Hence the data payload appearing at the center lobe will be nearly perfectly reflected, and the subcarrier header appearing at the double side band will be nearly completely transmitted. The optical circulator will separate the input signal, the reflected data payload, and the transmitted subcarrier header. Fig 4(a) and (b) respectively show RF spectra of the input packet signal and the reflected data payload extracted by the FBG and the optical circulator. Note essentially complete subcarrier removal in Fig 4 (b). The header detector detects the 40 bit long optical-label, the forwarding table compares against the content of the table, and the controller generates a switch control signal and a new optical-label content. The data payload is delayed via the 50 meter optical fiber providing approximately 250 nsec optical delay. This data payload is input to SOA whose gain will be modulated by the amplitude modulation on the data payload. This gain modulation will then be probed by the counter-propagating output of the tunable laser, which will now assume the inverted modulation information of the data payload. This counter-propagating geometry avoids the need for using an optical filter for transmitting tunable laser output, and also provides additional bandwidth limit to further reduce leakage of the subcarrier header at the higher modulation frequency. The inversion of the data payload modulation could be corrected by cascading another inverting wavelength converter in tandem. The switch control signal from the controller is sent to the rapidly tunable laser, instructing it to tune to the wavelength corresponding to the desired output destination port of the AWG. The experiment utilized two optical-label contents for two output wavelengths λ_1 (1538.18 nm) and λ_2 (1546.11 nm). The tunable laser covers a 45 nm tuning range between 1525 and 1570 nm by current tuning of multiple electrodes. Fig. 2 shows the tunable output spectra measured when adjusted for 200 GHz spacing discrete optical frequencies. The AWG has eight input and eight output ports, and incorporates a special design to equalize optical loss for all 64 paths and to operate cyclically over the wide optical frequencies. Fig. 3 shows the overlay transmission spectra of AWG output measured at the eight output ports when the first input port is illuminated. The measured peak transmission was uniform at -8.3±0.5 dB. At the output ports of the AWG, we placed additional optical modulators working as header rewriters to overmodulate a new subcarrier header on the routed data payload, and hence achieving optical-label swapping [4]. Each receiver detected the optical output of the AWG at each port. Fig 5(a) shows the measured output at port_1 of the AWG, and Fig 5(b) shows that at port_2. The receivers had a bandwidth limit at 3 GHz. During the time between t_0 and t_1, the optical label dictated the packet to be routed to port_1 via λ_1 and during t_1 and t_2, to port_2 via λ_2. Fig 5(c) is an expanded view of Fig 5(b) at the vicinity of t_1 and we notice clear bit sequences at 2.5 Gb/s and a very sharp transition from λ_1 (1538.18 nm) to λ_2 (1546.11 nm). Careful inspections of the output signals at port_1 and port_2 confirmed this transition time to be approximately 1 nsec. Fig. 6 shows packet bit-error-rates measured at port_1 and port_2. Both outputs showed error free operations, and the differing power penalty is expected to be from the SOA wavelength converter operating differently for two different output wavelengths λ_1 and λ_2.

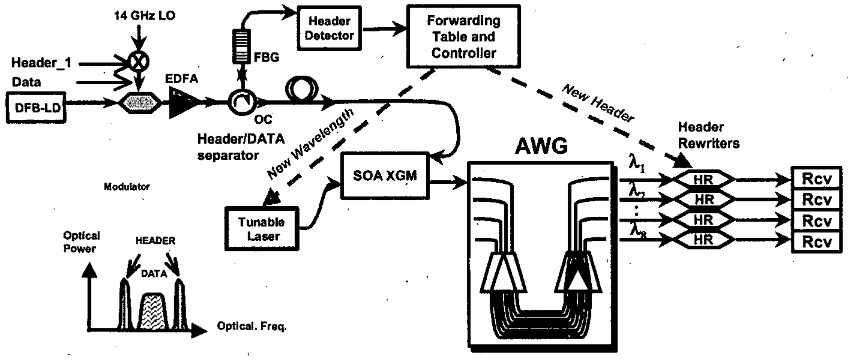

Figure 1. Experimental Setup

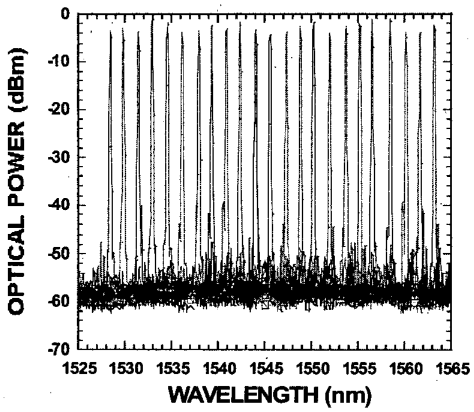

Figure 2. Measured optical spectra of the tunable-laser

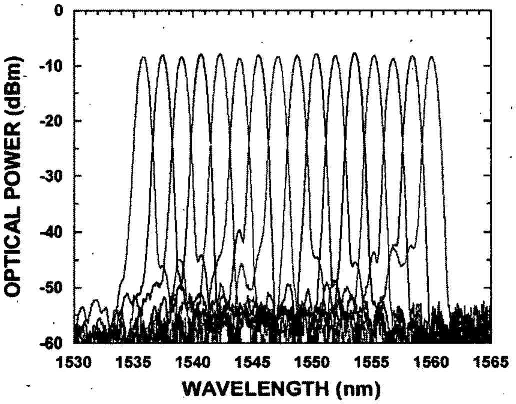

Figure 3. Measured AWG transmission spectrum

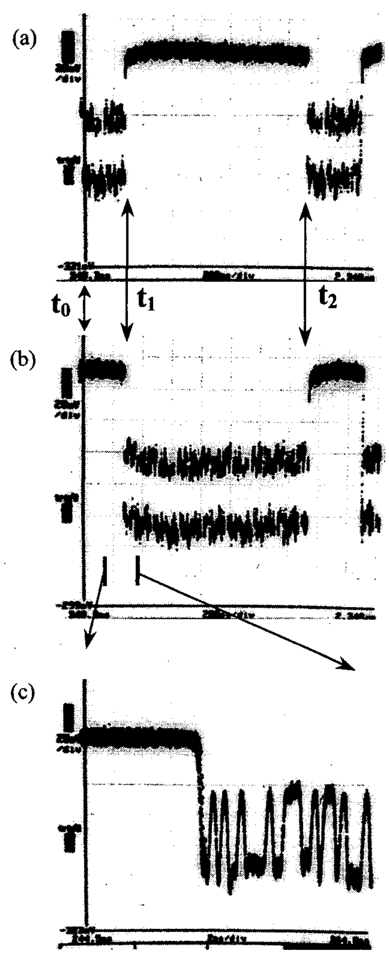

Figure 5. Oscilloscope traces at (a) the port_1 and (b) the port_2, (c) Extended view of the port_2 at the vicinity of t_1

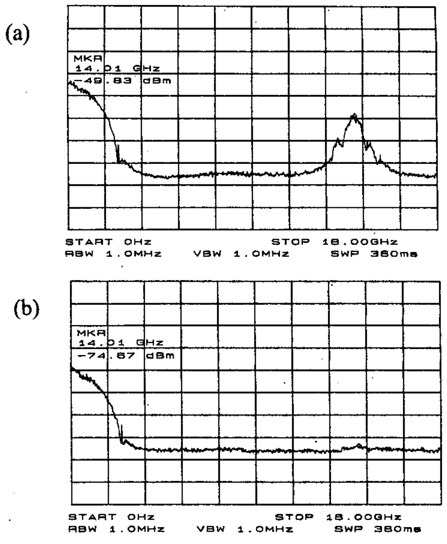

Figure 4. Measured RF spectra for (a) the incoming packet data and (b) the extracted payload data

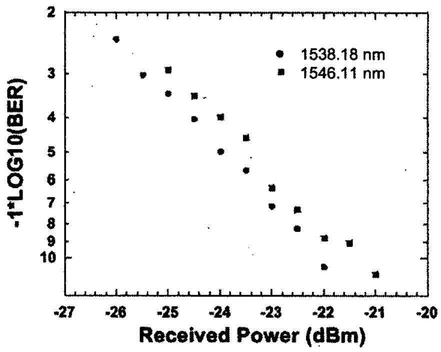

Figure 6. Measured packet BERs at the port_1 and the port_2

3. Summary

We report, for the first time, optical-label switched optical routing of optical packets. The routing system consisted of an optical-subcarrier transmitter, an optical-header/data separator, a header detector, a forwarding table, a switch controller, a tunable wavelength converter including a tunable laser and a semiconductor optical amplifier (SOA), uniform-loss-cyclic frequency (ULCF) arrayed-waveguide grating (AWG), header rewriters and receivers. The optical header extraction and rapid packet routing with optical header swapping have been demonstrated. The rapidly tunable wavelength converter with ~ 1 nsec transition time and high performance ULCF AWGs indicate the possibility of realizing an ultra-low latency optical-label switching router system.

4. References

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