Optical Packet Switching Routers and Networks: Technologies, Architectures, and Applications

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Abstract: This paper covers new optical packet switching router technologies, system architectures, and the future photonic Internet. In particular, we will discuss all-optical label switching routers scalable to 42 Petabit/sec switching capacity, experimental demonstrations of 11 hop cascaded operation, and a 477 km fiber link field trial.

Introduction
Optical packet switching routers allow integration of data and optical networking towards the photonic Internet of the future. Optical-Label switching (OLS) facilitates introduction of optical packet switching by providing a shim layer between IP and WDM, and allows seamless upgrades from optical circuit switching and burst switching networks. This paper discusses successful systems integration of OLS routers, OLS network demonstrations, and future applications.

Architecture and Protocol

Fig. 1 Fast connection setup using the optical signaling label for the accompanying data payload. Optical Label Switching Routers (OLSR) with Label-Processing interfaces quickly read the label and forward the packet. If there is switching contention on the preferred path, the OLSR will attempt to route using an alternate wavelength, to delay the transport, or to route on an alternate path.

The key underlying networking concept behind Optical-Label Switching [1] is an efficient and transparent packet forwarding method using an optical-label switching mechanism which can co-exist with legacy WDM technologies on the same fiber. Fig. 1 depicts the underlying concept for a fast connection setup. New signaling information is added in the form of an optical signaling label which is carried in-band within each wavelength in the multi-wavelength transport environment. The optical-label containing routing and control information such as the source, the destination, the priority, and the length of the packet, will propagate through the network along with the data payload. Each optical-label switching router will sense this optical-label, look-up the forwarding table, and take necessary steps to forward the packet. If the packet is to be routed to a wavelength/path where there is already another packet being routed, the optical label switching router (OLSR) will seek routing by an alternate wavelength, by buffering, or by an alternate path. This wavelength, time, and space domain contention resolution is a key to implementing optical-router without heavily relying on time-buffers as conventional electronic routers do [2, 3].

OLSR requires no optical-to-electrical, electrical-to-optical conversion of the data payload at the core, and the data plane is completely transparent to protocol and format of the data payload from end-to-end. Further, optical-label switching accommodates data packets of any length, flows of an arbitrary number of packets, a burst of a long datagram, and even a circuit-connection. Highest degrees of interoperability is possible in optical-label switching. Optical-Label Switching dynamically supports various degrees of QoS (Quality of Service), CoS (Class of Service), and ToS (Type of Service) parameters. The priority based routing gives ‘Class of Service’. Higher priority packets are far less likely to be deflected in wavelength, in time, or in path than lower priority packets. The packet loss probability, latency, and bit-error-rate are also significantly lower for the higher priority packets as they attempt to occupy the preferred wavelength/time/path [2].
Systems Integration
We have successfully integrated optical-label switching routers with wavelength-time-space domain contention resolution capabilities. Fig. 2 illustrates the schematic of the integrated OLSR. The OLSR consists of the optical router controller, the optical label extractor, the optical label rewriter [4,5], the optical label detector, a switch fabric, and client interfaces. The optical router controller, implemented by a field programmable gate array (FPGA) includes the forwarding table, the scoreboard, and the arbitrator incorporating the wavelength-time-space domain contention resolution algorithm. The optical-label switching transmitters and receivers employ subcarrier multiplexing for the label and the data payload, and all-optical label extraction is achieved by fiber-Bragg grating and optical-circulators [4]. The switching fabric consists of rapidly tunable wavelength converters and arrayed wavelength grating routers (AWGR) [6] and fixed wavelength converters. The client interfaces are essentially edge routers capable of generating and extracting optical-labels interfacing with legacy client machines like IP routers or ATM switches. Network control and management system and GMPLS extension development are also in progress. With the GMPLS extension, the OLS system is designed to interoperate with MPLS, MPLambdaS and IP [7].

Results

![Fig. 3. Variable length packet contention resolution experiments in time, space, wavelength domains.](image)

![Fig.4 Variable length packet contention resolution experimental bit error rate results.](image)

Refs [3, 8, 9, 10, 11] discuss successful demonstration of the integrated OLSR. Fig. 3 shows variable length packet switching experimental diagram, and Fig. 4. shows the packet BER measurements. Packet-by-packet contention resolution in time, space, wavelength domains have been successfully demonstrated. Recent experiments have also shown 11 hop cascaded stage experiment with BER below 1E-9, a successful field trial across 477 km San Francisco bay dark fiber NTON-Sprint networks, and a demonstration of IP-client-to-IP-client packet switching across an all optical label switching network using the OLS edge routers.

Conclusion
OLS seeks seamless integration between data and optical networking. Successful demonstration of cascaded stages of OLS routing experiments, all-optical variable size packet contention experiments, and 477 km field trials with excellent BER performance imply its viability for future photonic Internet applications.

Acknowledgments
The author is indebted to K. Okamoto and S. Kamei for AWGRs and the UC Davis Optical Switching and Communications Systems Lab for technical contributions. This work was partially funded by DARPA and AFRL under agreement number F30602-00-2-0543, by NSF under grant number ANI-998665, and by the support of OIDA JOP program supported by DARPA and NSF.

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