

Photonic Packet and All-Optical Label Switching Technologies and Techniques

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Abstract: All-optical label swapping and associated functions including label coding, label erasure and rewriting, packet regeneration and packet-rate wavelength conversion will be described. Fiber and semiconductor implementations and system demonstrations will be reviewed.
OCIS codes: (000.0000) General

1. Introduction

Research in photonic packet switching [1][2][3][4] is aimed at developing techniques and technologies to route packets without passing the packets directly through an electronic layer. Optoelectronic conversion at every switching point can become costly and difficult to perform as the number of wavelengths, the packet bit rates and the aggregate number of packets per second increases. The prospect of creating a photonic packet switched network rests on overcoming multiple technological hurdles, some of which require advances in optical technologies and their integration. In this talk we will review all-optical label swapping architectures, the associated packet coding techniques and label swapping technologies. Research results from a DARPA NGI program at UCSB will be described as well as results from other AOLS research programs.

2. All-Optical Label Swapping

All-Optical Label Swapping (AOLS) is a promising approach to packet switching without optoelectronic conversion [5][6][7][8]. Individual IP packets or groups of packets are encapsulated with an optical label as they enter the optical packet network as shown in Figure 1. The optical label is erased and rewritten at each photonic packet switch while the IP packet is kept intact in the optical domain. Labels are electronically processed at each routing point in order to figure out which output port to send the packet to, which wavelength to convert the packet to and what is the new outgoing label. At each packet switch input, a small percentage of light is removed and the label recovered. The label is used to compute switch settings and a new wavelength/label pair for the outgoing packet. The label data rate is independent of the payload bit rate and is chosen to be compatible with burst mode electronics. For example both 40 Gbit/sec and 10 Gbit/sec packets can be routed using 2.5 Gbit/sec headers and electronic circuits [9].

In electronic routers, digital memory is used to hold packets for arbitrary amounts of time while a routing decision is made. However, all-optical buffer technologies that hold packets with arbitrary delays are difficult to realize with the arbitrary length inherent to IP packets. With AOLS, the optical label is converted to an electronic signal in an electronic processing plane where label and switching information is computed. The optical packet continues through an optical fiber delay set equal to the time it takes the electronic circuitry to make a routing decision. During the routing computation process, the optical packet passes through a combination of devices that erase the label, write a new label and switch the packet to a new wavelength and switch port optically. The optical switching technology must operate on the order of a nanosecond (10^{-9} sec) or less. Wavelength conversion using fast tunable lasers is a scalable switching technique that can meet the demands of optical packet switching applications. This approach is supported by a recent demonstration of switching between any pair of 36 ITU channels in less than 5 ns [10].

3. Label Coding

Two main approaches to optical label coding are bit-serial and optical subcarrier multiplexing [5]. Bit-serial labels (illustrated in Figure 2a) are placed at the head of the IP packet, buffered by an optical guard-band that facilitates label removal and reinsertion. With optical subcarrier multiplexed labels (Figure 2b) the optical label is first modulated onto a RF subcarrier and then onto the same wavelength as the IP packet. In both cases, the optical label bit-rate is chosen to balance the requirements for low cost label processing electronics and the duration of the label relative to the optical IP packet length. Encapsulation of IP packets using optical labels has advantages in that the contents of the original IP packet are not modified and the label is coded at the same wavelength as the IP packet.

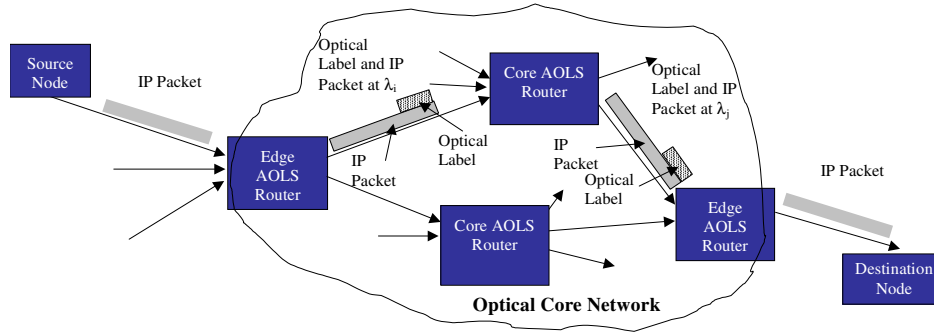


Fig. 1. Encapsulation of IP packets in a core network with AOLS.

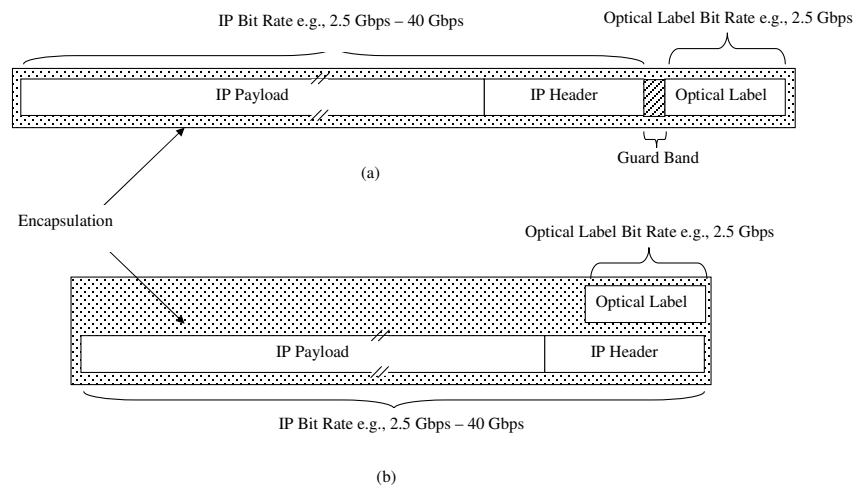


Fig. 2. AOLS (a) bit-serial and (b) OSCM Packet Coding Techniques.

4. AOLS Technologies

Various technologies have been used to implement AOLS functions including wavelength converters, fiber loop mirrors, wavelength agile sources, optical demultiplexers and packet transmitters. A summary of AOLS technologies demonstrated at UCSB is shown in Figure 3 and will be described in more detail in the talk as will approaches from other institutions. The horizontal axis depicts the basic AOLS functions including label recovery, label erasure, wavelength conversion, label writing and fast wavelength tuning. The vertical axis summarizes the bit serial and optical SCM label coding techniques as well as ultrafast multiplexing. Each AOLS function, for a given label coding technique, can be realized using a combination of technologies shown in the green boxes.

AOLS Packet Wavelength Converters

An AOLS packet wavelength converter can perform all or a subset of the functions of optical label erasure, packet rate wavelength conversion, IP packet regeneration and optical label rewriting. Depending on the combination of label coding technique and wavelength converter technology, the label tap may or may not handle the label erasure function. A tap that handles the function of erasure and label recovery is described in the next section on fiber loop mirrors. An important feature of AOLS wavelength converters is that they can simultaneously erase and rewrite labels during the conversion process. Two wavelength converters that will be discussed are semiconductor optical amplifier wavelength converters (SOA-WCs) and fiber cross phase modulation (XPM) converters. SOA based AOLS converters allow an intensity-modulated signal to be transferred from wavelength to another wavelength. SOA interferometric wavelength converters (SOA-IWCs) have been shown to operate to data rates beyond 40 Gbit/sec and are built using photonic integrated circuit (PIC) technology. In order to allow operation at ultra-high bit-rates (greater than 40 Gbps) fiber XPM wavelength converters may be used for AOLS [11][12][13].

Wavelength Agile Sources

Packet wavelength conversion depends on the switching speed and stability of the tunable laser used as the local source. New multi-element widely tunable lasers with the capability of tuning over hundreds of channels represent the current state of the art in semiconductor laser development. Two promising candidates are the Sampled Grating DBR (SGDBR) and the Grating assisted co-directional Coupler with Sampled Reflector (GCSR). Rapid tuning over a large number of channels (> 35) using GCSR lasers has been demonstrated [10].

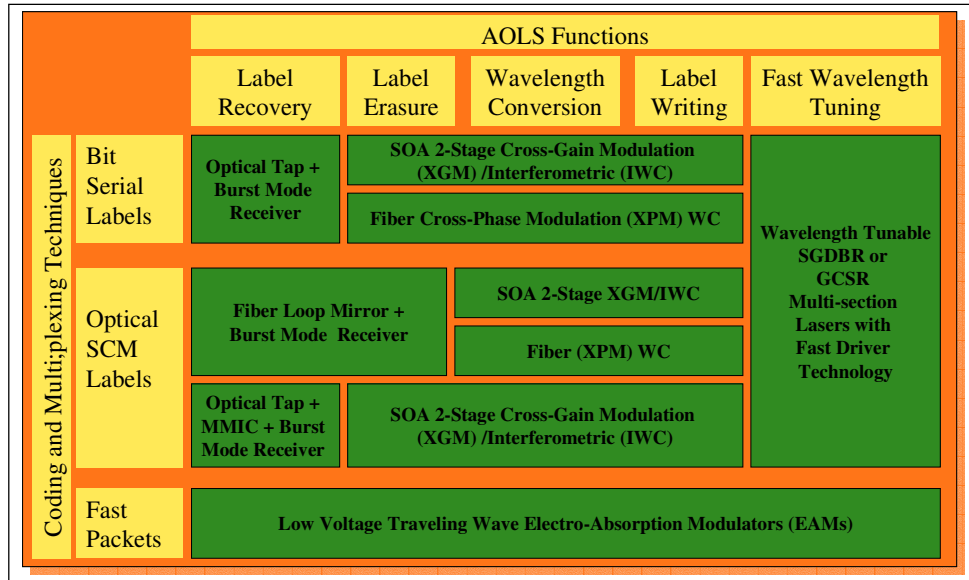


Figure 3. Summary of AOLS functions, coding and multiplexing techniques and implementation technologies.

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