# Two-Hop All-Optical Label Swapping with Variable Length 80Gb/s Packets and 10Gb/s Labels using Nonlinear Fiber Wavelength Converters, Unicast/Multicast Output and a Single EAM for 80- to 10Gb/s Packet Demultiplexing

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**Abstract:** We demonstrate for the first time two hops of all-optical label swapping of variable length 80 Gb/s packets and10 Gb/s optical labels, with unicast/multicast capability using an all-optical fiber cross-phase modulation wavelength converter.

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## 1.0 Introduction

Future Internet routers will need to support optical fiber capacities that continue to double every 8-12 months and potentially terminate hundreds or thousands of optical wavelengths. The process of moving a massive number of packets per second (100 million packets/second and eventually beyond the 1 Billion packets/second mark) through the multiple layers of electronics in a router can lead to router congestion and exceed the capabilities of electronics and their ability to efficiently dissipate power. The problem of ultra-high capacity packet routing becomes especially difficult as the per-wavelength bit rate increases to 40Gb/s and out beyond 100Gb/s. It is in this later regime that optical packet switching offers the potential benefit of bit-rate and format transparency and routing capabilities not currently available with electronics. In order to address these issues, all-optical label swapping (AOLS) was developed to impart the functionality to direct packets through an optical network without the need to pass packets through electronics whenever a routing decision is necessary [1-3].

We report experimental results in AOLS that demonstrate several dramatic improvements over previously reported state-of-the-art optical packet switching and optical label swapping results:

- We demonstrate AOLS with variable length 80Gb/s packets and 10Gb/s labels. This involves the all-optical removal of the 10Gb/s label and its electronic recovery, all-optical conversion of the 80Gb/s variable length packet to a new wavelength with small power penalty and 2R regeneration, and the generation and reinsertion of a new 10Gb/s optical label.
- These three functions are achieved using a fiber cross-phase modulation wavelength converter [4] that has the capability to scale in operation to above 100Gb/s. Previously, this level of AOLS functionality had only been reported on fixed length 40Gb/s packets with 2.5Gb/s labels [5].
- First time demonstration of unicast/multicast operation of all-optical label swapping at 80 Gb/s.
- First time demonstration of packet 80Gb/s to 10Gpbs demultiplexing using a single EAM.
- BER measurements are made on a per packet basis on packets and labels after the for each of two wavelengths at the first hop output and for the final wavelength at the second hop output for each of the (8) 10Gb/s data streams in the 80Gb/s packet.

## 2.0 Architecture and Experimental Setup

The system architecture is illustrated in Figure 1. Input packets are multiplexed up to 80Gb/s and input to the ingress AOLS router. Layer-3 IP information and local routing tables are used to determine the ingress wavelength and ingress optical label. This wavelength/label pair are unique to the input port, destination address and possible routes the packet will take. Each packet is all-optically converted to the ingress wavelength and encapsulated with a 10Gpbs optical label and a guard band separating the two. In this example, two sequential 80Gb/s packets are converted to wavelengths $\lambda_1$ and $\lambda_2$ and encapsulated with optical labels $OL_1$ and $OL_2$ respectively. The core router function is to all-optically remove the label from each incoming packet, read the label and electronically compute a next hop wavelength and label based on the incoming label and local routing tables. The 80Gb/s packet is all-optically converted to the next hop wavelength (which can be different on a per packet basis) and the next hop optical label is computed and encapsulated with the outgoing packet. At the egress router, the optical label is removed and the 80Gb/s packet handed off for higher layer processing. In this experiment, the outgoing packets are demultiplexed back down to (8) 10Gb/s data streams for BER measurements.

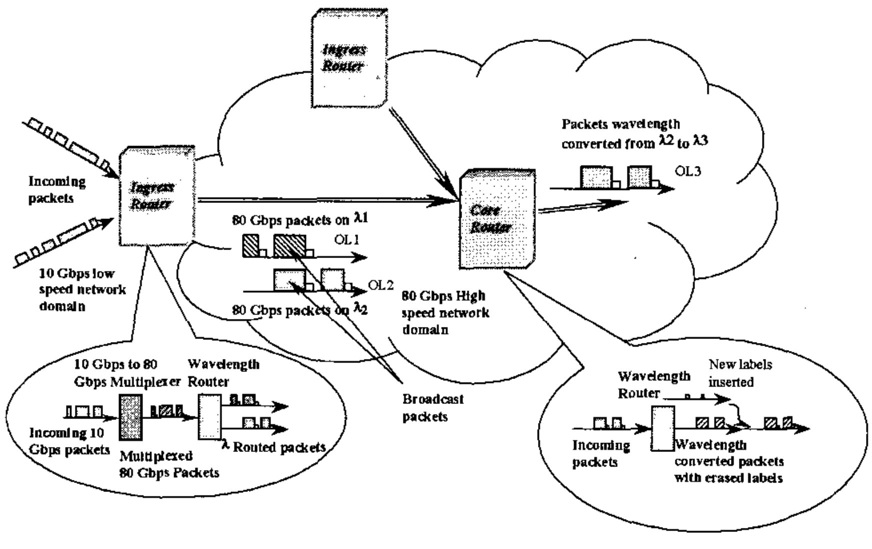



*Figure 1. AOLS system architecture example with ingress, core and egress routers.*

The experimental setup is shown in Figure 2. A 10 GHz fiber-ring laser and pulse compressor is used to generate 1.5-2.0 ps pulses at 1555nm. The ring laser output is modulated with a variable length 10Gb/s (PRBS $2^{31}$-1) packet source (BERT) and three lengths of packets were generated, 1.0, 1.2 and 1.5μs in duration. A 1:8 interleaved multiplexer is used to up-convert the packets to 80Gb/s. At the ingress node, the 80Gb/s packets are wavelength converted using an ultra-fast fiber XPM wavelength converter [4] and the labels are attached. The XPM-WC consists of an EDFA, 500m of DSF and a 2-stage bandpass optical filter. The labels are generated using a 10Gpbs label generator and placed at the head-end of the converted 80Gb/s packets and at the same wavelength. The 1.0 and 1.5μs packets are converted to 1543nm and the 1.2 and 1.5 μs packets are converted to 1548nm. Therefore the 1.5 microsecond packet can be either unicast or multicast while the other two packets are unicast only. At the core router, all packets are converted back to 1555nm using the fiber XPM-WC, the optical label removed and a new optical label generated and replaced at 10Gb/s. At the core node output, the label is removed using a high-efficiency Traveling-wave Electroabsorption Modulator (TW-EAM) [6] to gate the packet. The TW-EAM was employed to demultiplex the 80Gb/s packets down to 10Gb/s using a 8-9ps demultiplexing window. At 1555nm, the TW-EAM has >20dB/V modulation efficiency and >47dBm extinction ratio. The TW-EAM was driven by a $10V_{pp}$ 10GHz microwave signal.

## 3. Experimental Results

Figure 3 (a) shows the BER curve after the first hop and Figure 3(b) shows the BER curves after the second hop. In figure 3(a) the solid lines are the BER curves for the original 1555nm packet. A power penalty of about 2dB is observed for the 1548nm wavelength converted packets, shown by the dashed lines, while a power penalty of about 3dB is observed for the 1542 nm wavelength converted packets, shown by the dash-dot lines. The increase in the power penalty for the 1542nm packets is due to the increased loss in the EAM. Figure 3(b) shows the BER curve after the second hop. The dashed line indicates the BER curve for the 1556nm packets. A power penalty of about 3dB is observed between the 1548nm packets and the 1556nm packets. This power penalty is due to extinction ratio degradation, as a result of non-optimal filtering. Figure 3(c) shows the BER curves for the labels, a power penalty of 3dB is observed due to the addition of the payload.

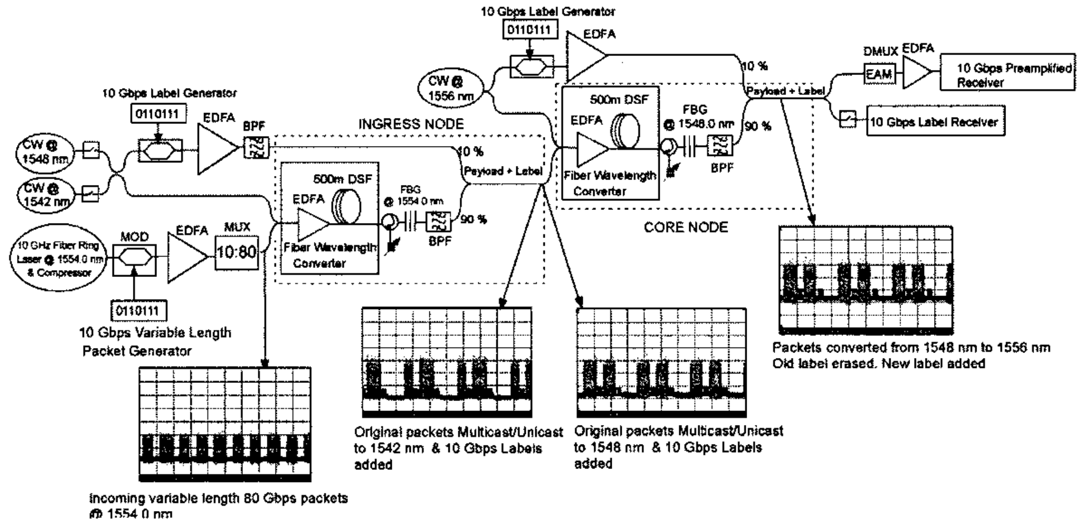
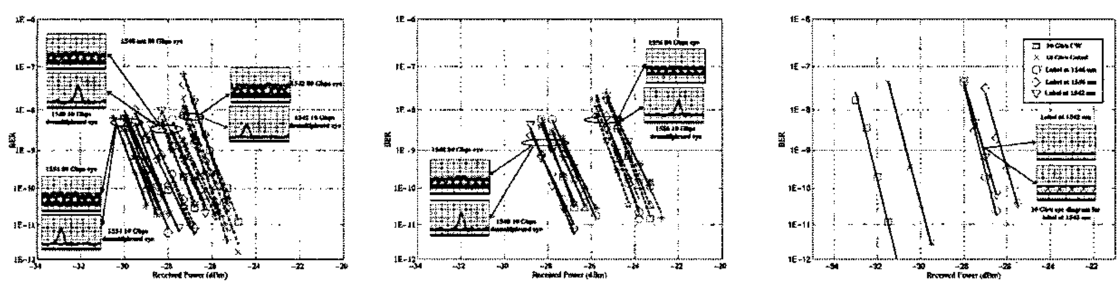



*Figure 2. Experimental setup for demonstration of 80Gb/s packet/10Gb/s optical label multihop AOLS*



(a) (b) (c)

*Figure 3. Measured packet BER results and eye diagrams for all (8) 10Gb/s packets within each 80Gb/s packet at the input to egress node (btb), (a) after first hop (for each output wavelength), (b) after second hop and (c) for optical labels at each hop.*

In conclusion we have demonstrated operation of an all-optical label swapping system with variable length packets operating at 80Gb/s with 10Gb/s optical labels. Two hops are demonstrated using ingress node and core router node architectures. Both unicast and multicast operation are demonstrated. BER measurements are made on a per packet basis with a power penalty under 2dB after the first hop and under 5dB after the second hop. The second hop power penalty is only due to non-optimal filtering at the wavelength converter output and can be improved in future experiments. Also demonstrated is packet demultiplexing of 80Gb/s down to 10Gb/s using a single EAM receiver.

## 7. References

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