# Optical Label Switching Technology and Energy-Efficient Future Networks

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**Abstract**: This paper discusses optical label switching routers capable of handling packet, burst, flow, and circuit traffic with extremely low energy consumption and high goodput.

**Keywords**: Optical packet switching, optical label switching, energy efficient networks.

## 1. Introduction

The future Internet is rapidly emerging with a new set of very challenging requirements. It must support exponentially rising traffic volume with scalability, performance, and low power consumption. At the same time, new emerging applications require higher degrees of security, utilization, and quality of service. A unified networking platform in support of voice, data, and multimedia applications is attractive especially on a high-capacity optical layer. Optical packet switching (OPS) provides a platform for unified optical networking using the packet as a common denominator for supporting diverse traffic. On the other hand, quality of service (QoS), class of service (CoS), and type of service (ToS) requirements of future Internet traffic requires a control plane with more elaborate capabilities. Optical-label switching (OLS) [1] supports optical packet switching (OPS), optical burst switching (OBS), optical flow switching (OFC), and optical circuit (OCS) with full interoperability and support for QoS, CoS, and ToS [2]. Typical packet switching systems require sophisticated buffer and control electronics that can consume relatively high power. Optical-label switching (OLS) supports extremely low latency and high throughput networking without requiring a large amount of buffer. Intelligent edge routers can support OLS functions with high goodput measured at the application layer.

## 2. Energy-Efficiency in Networks

### 2.1. Metric for energy efficiency in networks

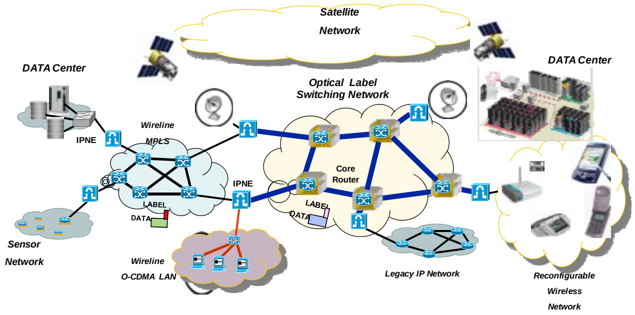


Figure 1. Future Internet with optical-label switching, wireless, and wireline networking in support of cloud computing, multi-media, voice, and various data applications.

Recently there has been strong interest [3] in energy-efficient networking by observing 'energy per bit' as a metric. However, the 'bits' at the physical layer include logically insignificant bits that are used for framing, and stuffing, etc. Then more meaningful measure may be 'energy per throughput', however, this too can be affected by TCP Ack/Nck, etc. A better metric can possibly be the ratio of 'how much work gets done' against 'how much energy was consumed' seen by aggregate end-to-end applications (goodput). The impact to the environment is often measured by the life cycle analysis (LCA) of the green house gases measured in terms of carbon (equivalent) footprint (from the material to the disposal/recycling). Hence possibly the most meaningful figure of merit can be given as:

$$\text{Figure of Merit for Green Networks} \approx \frac{\text{Life Cycle Integrated Goodput}}{\text{Life Cycle Carbon Footprint}}$$

While in 'benchmarking' for computing is carefully done for different applications (multimedia, floating point, fixed point operations), no careful studies have been conducted so far for benchmarking for networking. The same network can exhibit very different figure-of-merit depending on applications, statistics, and traffic patterns. OLS is possibly the most flexible and complete technologies adapting to various traffic patterns. The industry has taken a greatly simplified Energy Efficiency Index (EEI) which includes estimated idle time and weighted importance.

### 2.2. OLS Router Architecture

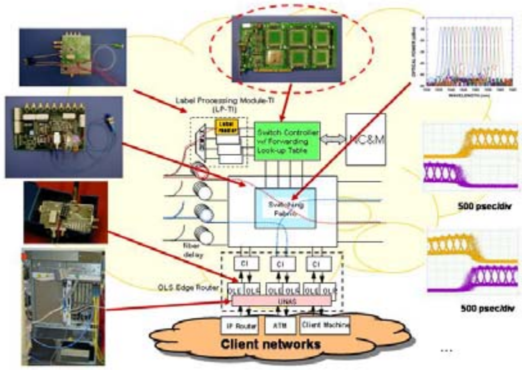


Figure 2. An integrated optical-label switching router system. [5]

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. Figure 2 illustrates the schematic of the integrated OLS core router with edge router [4]. The OLS core router consists of the optical router controller, the optical label extractor[5], the optical label rewriter, the optical label detector, a switch fabric, and client interfaces. The optical router controller, implemented by a field programmable gate array (FPGA) incorporates the wavelength-time-space domain contention resolution algorithm. Figure 3 shows the arbitration and scheduling architecture with resulting FPGA [6] implementation with extremely low latency. The switching fabric consists of rapidly tunable wavelength converters and arrayed wavelength grating routers (AWGR) [7] and fixed wavelength converters. With the GMPLS extension, the OLS system is designed to interoperate with MPLS, MPLambdaS and IP [2]. Successfully integrated OLS core routers achieved 1,001-hop cascaded operation thanks to all-optical 3R burst mode regeneration [8] incorporated in the OLSR. Figure 4 shows the experimental data. Recent experiments also demonstrated a successful field trial across 477 km San Francisco bay dark fiber NTON-Sprint networks[9], and a demonstration of IP-client-to-IP-client multimedia demo with multicast packet switching across an all optical label switching network using the OLS edge routers.

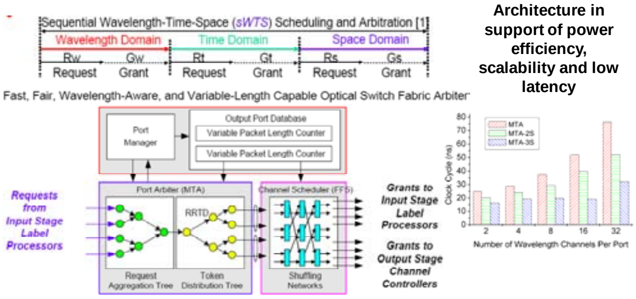
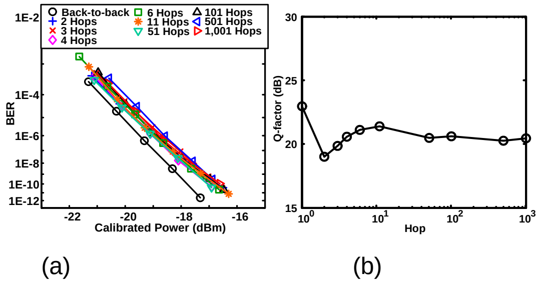


Figure 3. Arbitration and scheduling exploiting wavelength-time-space domains and resulting extremely low latency



(a) (b)

Figure 4. Cascaded OLSR performance measurement up to 1,001 hop operation showing (a) BER v.s. calibrated optical packet power, and (b) Q-factor evolution for calibrated power of -12 dBm.[9]

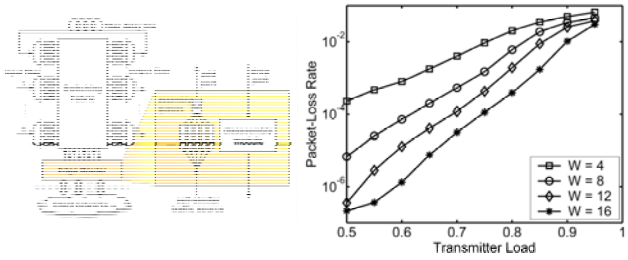


Figure 5. OLS Edge router schematic and end-to-end packet loss rate.

While the OLS core router uses almost no buffers, the OLS edge router exploits advanced queueing functions often found in conventional IP routers and edge routers. The foward-equivalent-class based queuing and packet aggregation greatly help improve [10] the network performance in terms of reducing the packet loss rate and enhancing the throughput and the goodput in the network.

## 2. Photonic Integration and Future Network Applications

The next frontier for OPS and OBS lies in Photonic Integration and in networking applications [11]. We believe that the future networks will ubiquitously exploit OLS routers, and low-power consumption and miniaturization will be essential. Figure 6 shows a UC Davis testbed with OLS routers handling variety of applications including video-streaming and file transfers with unicast and multicast achieved on all-optical label switching routers and edge routers. Asynchronous packet and burst switching exploiting optical label based QOS and Unicast/Multicast signalling proves to be effective [12, 13].

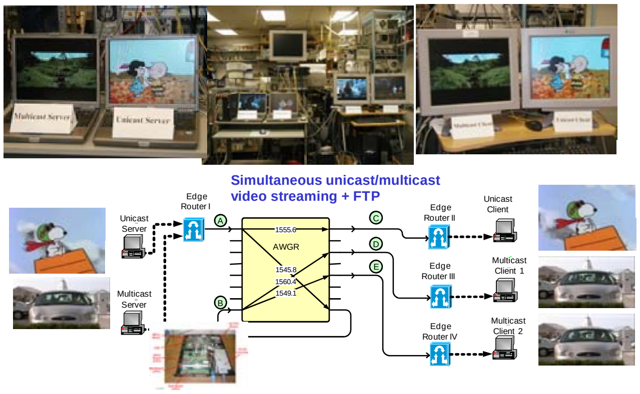


Figure 6. OLS testbed at UCDavis with unicast and multicast video and file transfer all-optically on OLS routers [12, 13].

## 3. Aknowledgment

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