

# All-Optical Time-to-Live Using Error-Checking Labels in Optical Label Switching Networks

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**Abstract** *This paper proposes and experimentally demonstrates a novel time-to-live method based on optical signal to noise ratio (OSNR) in optical label switching networks. This method can effectively drop packets with OSNR below 18dB using error-checking labels.*

## Introduction

Impressive growth in the data-centric traffic is driving the evolution of optical networks towards a simplified architecture of IP over WDM (wavelength division multiplexing). One promising solution for the IP/WDM network is the optical label switching (OLS). OLS achieves high-throughput ultra-low latency packet forwarding in the optical layer using all-optical switch fabrics and all-optical label processing.

Routing loop is a serious problem in packet-switching networks, which can cause severe overload and congestion in the network. The IP protocol employs a loop mitigation method called "time-to-live" (TTL), where each hop will reduce the value of the TTL field in the IP header and will discard the packet when the packet's TTL value reaches zero. For optical packet switching networks, recent works [1,2] have demonstrated optical TTL using ultrashort pulse bursts and non-linear effects. Because there is no effective all-optical logic processing capability, these TTL methods are complex and difficult. A preferred method of optical TTL would mitigate routing loop and at the same time discard errant packets caused by transmission errors. Unlike electronic IP networks, optical OLS networks can have long fibre links between optical router hops, and fibre transmission errors may create errant packets. This paper proposes and demonstrates a novel TTL method based on optical signal to noise ratio (OSNR). This method requires no modification of the label content or label swapping; and it accounts for the healthiness of the optical packet in the transparent OLS networks considering both fibre transmissions and router hops.

## All-optical time-to-live

The packets in transparent OLS networks remain in the optical domain where the OSNR of the packets will decrease as the packets go through more hops in the OLS network, due to repeated attenuation and amplifications at each OLS router and fibre links. Normal packets will travel through limited number of router hops and experience limited OSNR degradation. However, when packets are caught in a loop or become errant the OSNR will degrade at each hop. The OSNR based optical TTL method utilizes

this monotonously decreasing OSNR of abnormal packets; it identifies and drops all the packets below an OSNR threshold. The OSNR threshold is reasonably low to leave margin for normal OSNR degradation. The optical TTL method allows protocol and format transparency for the data.

The proposed TTL method uses time division multiplexing (TDM) label to monitor the OSNR of the packet. Each packet has a 48-bit TDM label at the front end. The last 8 bits of the label is a bit interleaved parity (BIP) check field, calculated according to the preceding 40 bits in the label. Each OLS router re-calculates a verifying BIP value when receiving a label, and then it will compare the verifying BIP value with the BIP value received in the label field. Bit error in the transmission history will cause the two BIP values to differ. Our experiment found a sharp OSNR threshold, below which bit errors would occur in the label. Our TTL method uses this threshold effect to detect looping packets. The OLS router will drop the packet if the BIP checking detects any error.

## Experiment

Figure 1 shows the experiment setup. The OSNR degradation at the EDFAs emulates the looping effect of packets. An OLS router then receives the packets. The pattern generator generates both the label and payload. The label is 155 Mb/s non-return to zero (NRZ) format while the payload is Manchester encoded at 10 Gb/s line rate. The payload content is  $2^{31}-1$  pseudo-random bit sequences (PRBS). The data rate difference between the label and the payload enables easy extraction and processing of the label. The pattern generator also fills the BIP field of the label with the correct value. The modulator then modulates the amplitude of the optical signal. A variable optical attenuator varies the input optical power to the EDFA in order to change the OSNR of the amplified optical signal. A second EDFA controls the power at the receiver end and keeps the power at a fixed level. A band pass filter (BPF) with 1 nm 3-dB bandwidth comes after the second EDFA and limits the total noise power that goes to the receiver. The optical signal then goes to the OLS router. An optical

spectrum analyser (OSA) monitors the signal OSNR at point M, using 0.1 nm reference bandwidth.

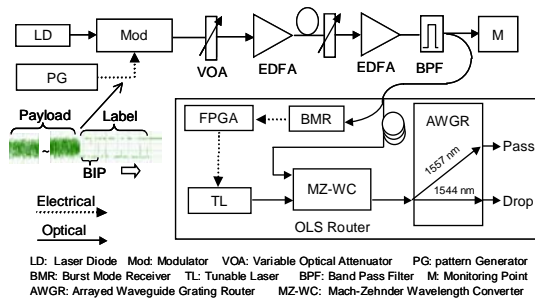


Fig. 1 All-optical TTL experiment set-up

At the OLS router, a coupler sends 90% of the optical signal to the fibre delay line and feeds 10% of the optical power to the burst mode receiver (BMR). The BMR then recovers the clock and data of the label, at the same time erases the payload signal using an electrical low pass filter. The field programmable gate array (FPGA) implements the control logic of the OLS router. The FPGA receives the label and performs BIP error checking. If there is no error in the received label the FPGA instructs the tunable laser (TL) to tune to the wavelength corresponding to the pass-through port (1557 nm) of the arrayed waveguide grating router (AWGR), therefore the packet will pass through the OLS router. If the BIP checking detects any label error, the FPGA will drop the packet by tuning the TL wavelength to 1544 nm, which corresponds to the drop port of the AWGR. A Mach-Zehnder wavelength converter converts the packet from the input wavelength to the wavelength of the tunable laser. The delay of the fibre delay line matches the 260 ns label processing time of the FPGA, therefore the FPGA will finish tuning the wavelength of the tunable laser before the packet arrives at the Mach-Zehnder wavelength converter.

In this experiment, the tunable laser power is distributed between the pass-through port and the drop port; the average optical power at each port is approximately proportional to the packet arrival rate at that port. At each OSNR level, an OSA monitors the power of the pass-through port and drop port simultaneously for 40 minutes. The averaging function of the OSA gives the average power of each port during that period. Fig. 2 shows the average power of the two ports at various OSNR levels. When the signal OSNR decreases from 20 dB to 18 dB, the pass-through port power drops 32 dB (from -18 to -50 dBm), while the drop port power increases 30 dB (from -50 to -20 dBm). The 2 dB power difference is caused by tunable laser power ripple. Noticing the background power is -50 dBm, this result shows that our all-optical TTL method can drop all the packets with OSNR below 18 dB and pass all the packets with OSNR above 20 dB. The transient state between all-drop and all-pass only corresponds to a narrow 2

dB OSNR range. This indicates that the packet drop rate has a sharp threshold at 19 dB OSNR. The sharp threshold prevents forwarding of degraded looping packets and effectively achieves all-optical TTL functions.

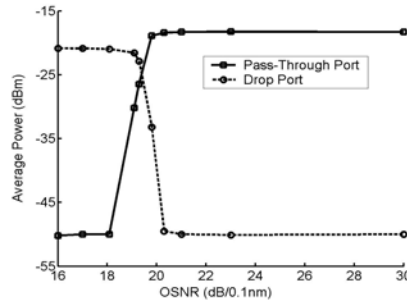


Fig. 2 Packet dropping effect as OSNR decreases

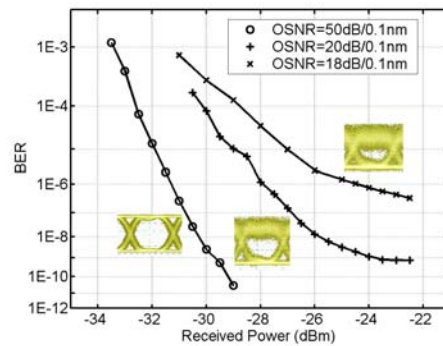


Fig. 3 BER at different OSNR levels

On the other hand, the 19 dB OSNR threshold allows enough margin for normal OSNR degradation; therefore the TTL function will not mistakenly drop normal packets. Fig. 3 shows the bit error rate (BER) of the system monitored at point M. At 50 dB OSNR level, BER shows no error floor. But at 18 and 20 dB OSNR levels, the BER curves have error floors at  $10^{-7}$  and  $10^{-9}$  levels, respectively. The error floors show the packets have experienced significant performance degradation before being dropped.

## Conclusions

The TTL function is imperative for the stability and robustness of transparent OLS networks. This paper proposes an all-optical TTL method based on the monotonously decreasing OSNR of looping packets. This TTL method uses BIP error checking over optical labels to monitor the OSNR. The error checking experiment achieves 18 dB OSNR sensitivity and demonstrated effective dropping of OSNR degraded packets.

## References

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- 3 S.J.B. Yoo, et al, IEEE Photonics Technology. Letter Vol.14 (2002), pp.1211-1213.