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A Routing Loop Control Scheme in Optical Layer for Optical Packet Networks

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1. Introduction

The popularization of Internet applications has aroused drastic increase in demand of Internet Protocol (IP) network bandwidth and quality of services (QoS). In view of this trend, optical label-switching (OLS)[1] has emerged as a promising solution for the future Internet. OLS achieves low-latency high-speed packet forwarding in the optical layer using all-optical label swapping techniques,[2,3] while the multi-protocol label switching (MPLS) control component offers traffic engineering capability enabling end-to-end QoS.

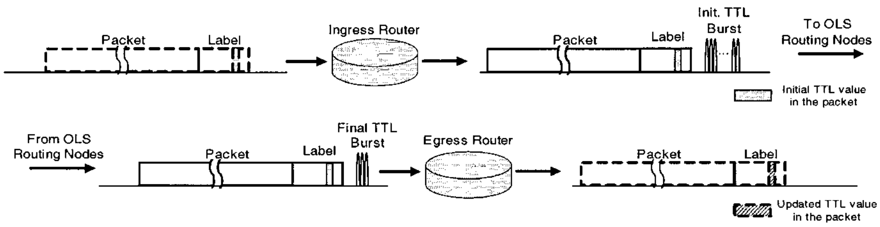
The OLS control component consists of an IP routing engine, a label binding and distribution routine, and a forwarding table maintenance routine for optical label assignment. Although the use of IP routing engine facilitates the seamless integration of IP network with the optical layer, an unavoidable problem, namely the routing loop problem, is frequently encountered in OLS/MPLS networks.[4] Whenever a routing loop is formed, the data packets will be forwarded hop by hop along the routing loop endlessly, leading to severe network traffic congestion.

There are two approaches to alleviate this problem: loop prevention and loop mitigation. Loop prevention algorithms prevent the formation of looping label switched path (LSP) by using additional control message and complicated path establishment protocol.[5] Loop mitigation, on the other hand, is carried out by the forwarding component to minimize the adverse effect imposed by the possible packet looping. IP packet "Time-To-Live" (TTL) count-down is one of the methods to achieve loop mitigation. This method reduces the value of the TTL field in the IP header by one after the packet passes through a router. The packet will be discarded when the TTL value reaches zero. Thus the packet will not loop infinitely in the network. As this method requires direct packet processing, in a high-speed OLS/MPLS network, this should be performed in the optical layer so as to minimize the latency.

In this paper, we propose and experimentally demonstrate a novel scheme to perform the TTL count-down in the optical layer so as to achieve routing loop mitigation.

2. Optical Loop Mitigation Scheme

To enable loop mitigation directly in the optical layer, we adopt an approach similar to the TTL count-down method commonly employed in IP routers. Due to the lack of an efficient optical logic processor, it is difficult to detect and decrement the TTL field directly inside the packet labels. Here, we propose a new TTL field format, specially adapted for high-speed optical processing. As illustrated in Figure 1, when a packet enters the ingress router of OLS, header processor extracts its TTL value and constructs an optical burst to be placed in front of the optical packet. The optical burst comprises a number of short pulses corresponding to the remaining number of hops that the packet can travel.



ThGG111 Fig. 1. Optical TTL field for OLS network routing loop control.

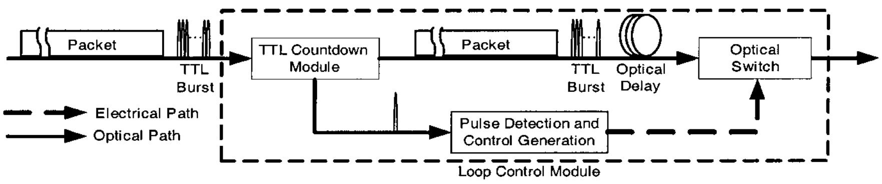
Upon reaching a routing node, the packet first passes through an optical packet loop control module as illustrated in Figure 2. This module attempts to extract an optical pulse from the TTL pulse burst in front of the packet. If a pulse is successfully extracted, this pulse will trigger a control signal to close the optical switch, allowing the remaining pulses and the packet to proceed to the next stage of packet processing. When there is no pulse left in the TTL burst, which means the lifetime of the incoming packet has expired, no control signal will be produced at the control pulse generation unit. Thus, the optical switch will remain in open state and the incoming packet is discarded. When a successfully routed packet exits the current OLS network, the egress router updates the TTL value inside the packet label to reflect the number of hops the packet has traversed in the network.

The key element for the realization of this loop control scheme is the optical TTL count down module. In the rest of this paper, we will describe the principles and the experimental demonstration of an asynchronous optical packet TTL countdown unit.

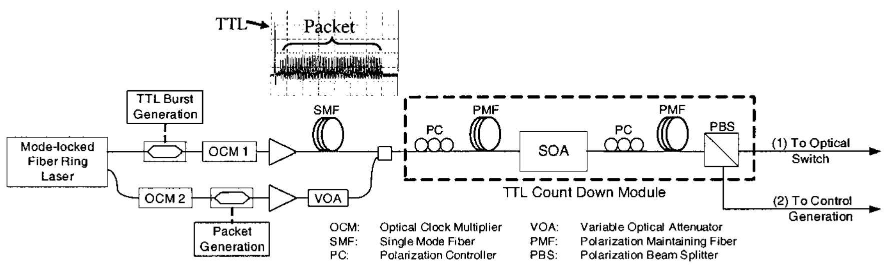
3. Experimental Demonstration

Figure 3 illustrates the experimental setup to demonstrate TTL count down. A mode-locked fiber ring laser (MLFRL) (Pri-tel UOC-3) producing 10-GHz 3-ps RZ pulses was used to generate 20-Gbps optical packets and their corresponding 40-GHz TTL burst as illustrated in the inset. The guard band between the TTL field and the packet was 150 ps. The peak power of TTL pulse was about 3 dB higher than that of packet. The TTL count down module consisted of two segments of 7-meter-long polarization-maintaining (PM) fiber, a semiconductor optical amplifier (SOA) and a polarization beam-splitter (PBS). By controlling the polarization controller (PC) preceding the first PM fiber segment, incoming optical pulses were split into orthogonal polarizations with a temporal delay of 12.5 ps. The pulse components passed through an SOA operating at a pump current of 90 mA. The subsequent PC and PM fiber reversed the relative temporal displacement on the polarization components. Finally, the signal exited through a PBS.

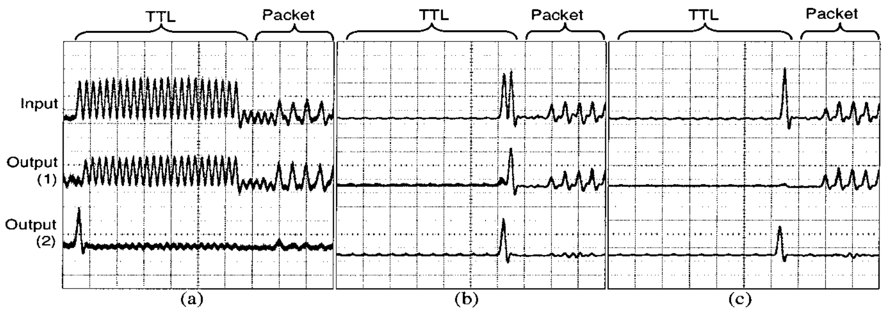
The operation principle of this module can be understood by considering the case when the input is a number of optical pulses having a period shorter than the carrier recovery time of the SOA. When the first optical pulse enters the module, the 'fast' polarization component will enter the SOA before the 'slow' one. If the power of the 'fast' component is large enough to saturate the SOA, it will induce a phase shift on the 'slow' component. As a result, a π phase difference is introduced between this two polarization components. When the subsequent optical pulses enter the module, however, both of their polarization components will experience the same amount of phase shift, as the SOA is continuously saturated by incoming pulses before it has enough time to recover its carrier density. As a result, when this pulse burst recombines at the PBS, the first pulse will have a different polarization from the rest of the pulses in the burst. Thus it exits at a different port. This extracted optical pulse can then be



ThGG111 Fig. 2. Optical Loop Control Module.



ThGG111 Fig. 3. TTL Countdown Demonstration (Inset: an example of packet with TTL pulses).



ThGG111 Fig. 4. Input pattern, output pattern at port (1) and output pattern at port (2) in Figure 3 for (a) 24, (b) 2 and (c) 1 pulse(s), respectively in the TTL burst (20 mV/div, 100 ps/div).

used to generate electrical control signal to turn on the optical switch that determines whether a packet should be discarded or not. By using this process, an asynchronous TTL count-down module for optical packet loop control can be realized.

It should be noticed that when the incoming optical pulses has a lower data rate (around 20 Gb/s in our case) and the peak power is below SOA saturation power, the above-mentioned process does not occur. By making use of this fact, the optical packet, which comes at a lower data rate and lower power than the TTL burst, is able to pass through the module without being modified.

Figure 4 illustrates the optical TTL field countdown demonstration for packet with 1, 2 and 24 pulses in the TTL burst, respectively. It was shown that for all these cases, one pulse was separated from the TTL burst for control generation while the rest of the TTL burst, together with the packet, proceeded to the next stage of processing.

4. Conclusions

In future OLS network, optical layer routing loop control is crucial for maintaining the network stability. In this paper, an optical loop control scheme using optical TTL count down is proposed and experimentally demonstrated for the first time. Asynchronous TTL count-down up to 24 bits for 20-Gb/s packets is demonstrated.

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A Burst Assembly Algorithm in Optical Burst Switching Networks

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1. Introduction

Optical WDM network evolves from the traditional IP/ATM/SDH/WDM to IP over WDM network, by eliminating the ATM switching layer and SDH transport layer. In this situation, the current use of the wavelength-routing mechanism for carrying bursty IP traffic will suffer from various drawbacks associated with circuit-switched networks. Wavelength routing results in a low bandwidth utilization if the traffic is bursty and provides a low granularity. But optical packet switching technology is still facing significant cost and technological barriers because of optical Random Access Memory buffer problem and slow switching speed.[1] Optical burst switching attracts the spot light because it compromises IPoW circuit switching and pure optical packet switching with limited use of optical buffer. In this paper we propose a new burst assembly algorithm using hysterisis characteristics in the queueing model in the edge node of optical burst switching network. We first discuss the functional model.

2. Optical burst switching network architecture

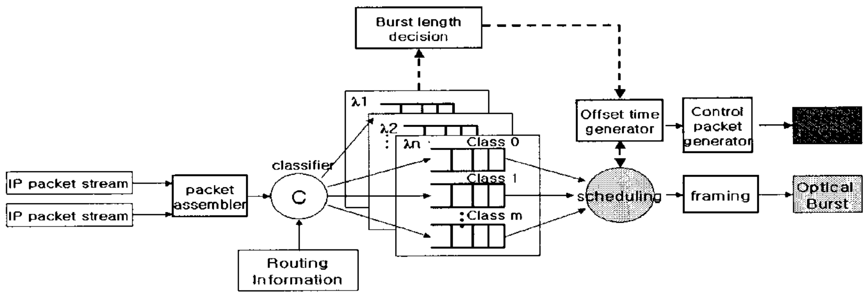
OBS network is consists of ingress node, core node and egress node. In the ingress node, edge routers decide data burst-size and offset-time considering the input IP traffic, which implies the burst-size is variable. The control packets, which contain information on source, destination and quality of service go ahead on separate control wavelengths and main data burst follows the control packet after given offset-time. These control packets are converted to electrical signals for processing at every intermediate node.[2] At the core node, bandwidth is reserved for the transmission time of data burst. For traffic engineering, blocking probabilities, latency and processing time are the elements to be monitored. These information helps ingress node to decide optical path. In the egress node, data burst will be deframed and disassembled into multiple IP packets in a rather simple manner.

The parameters, including offset time, burst size and QoS values are essential in achieving OBS network. These are assigned in ingress node of OBS networks. In the followings, we describe more details about the functions of ingress edge node. The first step to aggregate incoming bursty IP traffic streams into data burst is to assemble the bursty data at the packet assembler. Then assembled data is classified into several classes depending on the priority of IP traffic. Traffic can be further classified into congestion-controlled traffic and non-congestion-controlled traffic in IPv6. In the case of non-congestion-controlled traffic, the traffic is divided into eight classes based on the blocking rate. Therefore eight or more classes are possible in classification. Another consideration for classification is routing information and QoS. Routing information contains specific combination on fiber (or port number) and wavelength. Assembling packets in separate queues provide more differences in grades than using unified class queue.

In the burst-length decision step, the burst size is determined by the burstiness of input IP data (queueing length), QoS, and etc. In OBS network, offset time is generated based on the burst length decision and lower class (or higher blocking rate) data burst affects higher class (or lower blocking rate) data burst because higher class traffic is protected by adding extra offset-time to base offset-time.[3] The control packet generator generates the control packet, which contains various information such as offset-time, burst size and class number. The data in the buffer is scheduled and framed for transmission through the designated fiber.

3. Burst assembly algorithm in optical burst switching networks

At the edge node of OBS network, the edge routers assemble bursts by merging multiple IP packets. The data burst should vary as less as possible, because large data burst size variation requires more extra-offset time for QoS which result in more delay. Therefore, a burst assembly



ThGG112 Fig. 1. Functional model of the ingress node in OBS networks.