Performance Evaluation of Service-Aware Optical Transport System

Jiwook Youn, Jea-Hoon Yu, and Tae-Whan Yoo

We propose and experimentally demonstrate a service-aware optical transport system. The proposed service-aware optical transport system makes a flow based on service type and priority of traffic. The generated flow is mapped to a corresponding sub-λ for transport over an optical network. Using sub-λ provided by the centralized control plane, we could effectively provide quality-of-service guaranteed Ethernet service and best-effort service simultaneously in a single link. The committed information rate (CIR) traffic and best-effort traffic are assigned to different sub-λs. The bandwidth of the CIR traffic is guaranteed without being affected by violation traffic because the bandwidth is managed per each sub-λ. The failure detection time and restoration time from a link failure is measured to be about 60 μs and 22 ms, respectively, in the ring network. The measured restoration time is much smaller than the 50 ms industry requirement for real-time services. The fast restoration time allows the proposed service-aware optical transport system to offer high availability and reliability which is a requirement for transport networks.

Keywords: Carrier Ethernet, transport network, packet-optical transport system, quality of service.

I. Introduction

Legacy optical transport networks have been designed to provide time-division multiplexing (TDM) services such as voice traffic with high performance and low latency. However, the world of telecommunications is changing due to the accelerating demand for Ethernet services. Ethernet has been gaining greater interest from both data service providers and telecommunications service providers because of its low cost, flexibility, and bandwidth scalability. Moreover, optical transport networks are changing their properties to include burstiness and finer granularity. These changes are driving a move from circuit-based optical transport networks to packet-based optical transport networks in metro and core regions. However, to use Ethernet in a transport network, we should solve such problems pertaining to reliability, fast protection, end-to-end management, restoration, and quality-of-service (QoS) per flow [1]-[3]. Packet optical transport technologies have been studied to effectively support dramatically increasing data traffic over optical transport networks [4]-[8]. Moreover, service providers have been trying to use packet-optical transport systems (P-OTSs) in metro and/or transport networks.

In this paper, we propose a service-aware optical transport system and experimentally evaluate whether the proposed system can be used as a P-OTS. The bandwidth is controlled on a sub-λ basis using a centralized control plane. The sub-λ, which is a connection-oriented Ethernet tunnel, disables unpredictable functions, such as MAC learning and STP, to allow Ethernet to be managed as a circuit. The service-aware function and bandwidth control function are evaluated to apply the proposed system to a P-OTS.

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II. Service-Aware Optical Transport System

Figure 1 shows a functional block diagram of the proposed service-aware optical transport system. The proposed system is composed of a packet line card, circuit line card, packet-circuit line card, switch fabric, and manager. Both Ethernet and circuit networks can be used as a transport layer. The packet-to-circuit line card is used to support a synchronous digital hierarchy (SDH) network. In the case of connecting to an Ethernet network, TDM traffic is emulated in the circuit line card. Ethernet over SONET/SDH (EoS)-based resilient packet ring or unidirectional path switched ring (UPSR) protection is supported. The manager controls the traffic bandwidth and QoS. The bandwidth is controlled per end-to-end connection, and the QoS is controlled per flow. The proposed service-aware optical transport system has a connection-oriented configuration operating on a packet switch basis and provides an L2 virtual private network (VPN) and premium multimedia services based on the multiprotocol label switching (MPLS) protocol.

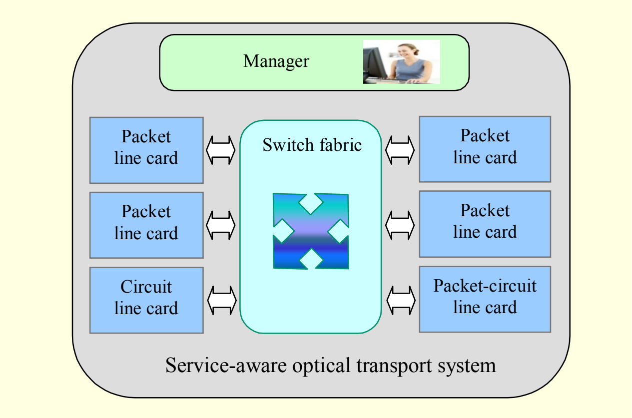

Fig. 1. Functional block diagram of the proposed system.

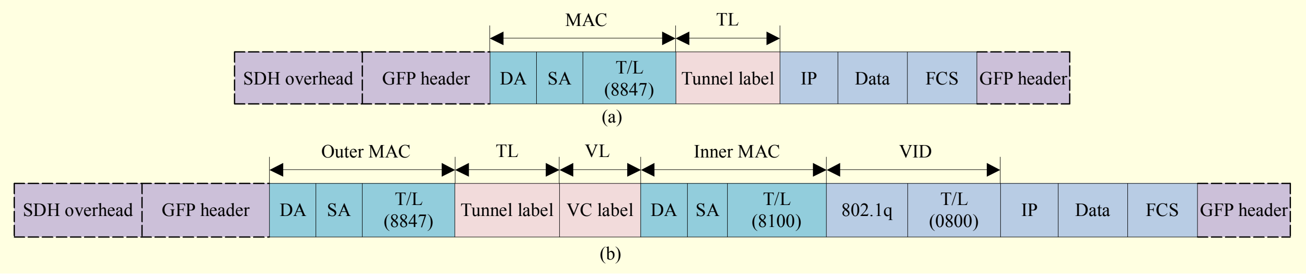

Fig. 2. Frame format for (a) premium multimedia and (b) L2 VPN services.

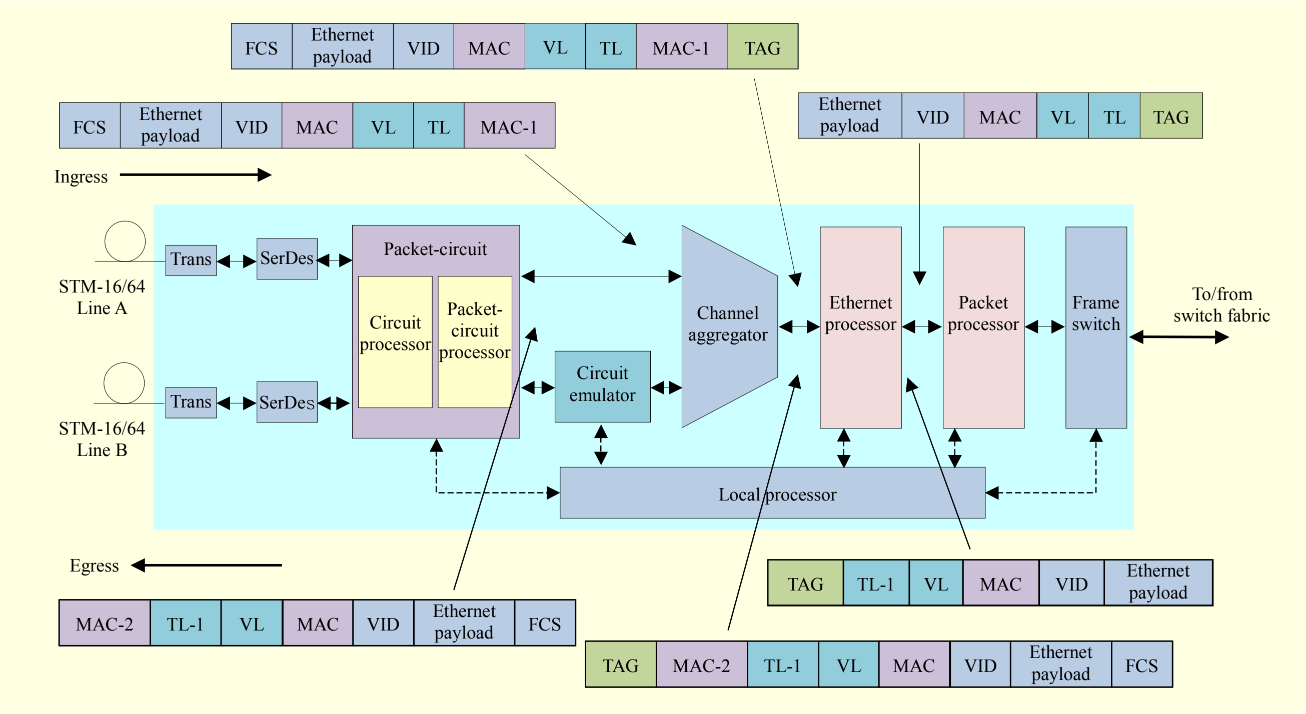

Fig. 3. Functional architecture of packet-circuit line card and frame format to support L2 VPN service.

1. Frame Format

Figure 2 shows the frame format for service types in the proposed service-aware optical transport system. If an SDH network is used as a physical layer, the SDH overhead and generic frame procedure header with a dotted line are added to each frame format. Input traffic is mapped into one of two different frame formats according to the service type. The frame format of Fig. 2(a) is a 1-label stacking configuration with 30 bytes overhead to provide MPLS-based multimedia and internet access services. In this case, the IP address determines the traffic destination. The QoS is guaranteed on a differentiated service code point/experimental (DSCP/EXP) basis. Figure 2(b) shows the frame format of the 2-label stacking configuration with 52 bytes overhead to provide MPLS-based L2 VPN service. The traffic destination is decided by the virtual LAN (VLAN) ID, and QoS is provided based on the priority bit of a VLAN tag. Figure 3 shows the details of the functional block diagram of a packet-circuit line card. The frame format represents L2 VPN service at the transit node. A MAC (MAC-1) address and tunnel label are changed at the transit node, while the virtual channel label is changed only at the edge node. The TDM packetizer carries out a circuit-emulation function to support TDM leased line service. A TAG is an internal label for use only within the proposed system. An Ethernet processor was implemented with a field-programmable gate array to process the L2 function, while a packet processor was made by an application-specific integrated circuit to guarantee QoS at the line speed. The packet processor classifies input traffic per flow and assigns the QoS profile to the flow.

2. Bandwidth Assignment

If the proposed service-aware optical transport system connects to the existing SDH network, a virtual concatenation group can be used as a sub-λ, which is a virtual tunnel to provide end-to-end connectivity. A sub-λ is a connection-oriented virtual tunnel to transport traffic that has the same destination. Using a sub-λ, we can effectively manage the network resources and traffic bandwidth. The proposed system generates the flow using the service type, QoS, and destination and controls the bandwidth per end-to-end connection. The proposed service-aware optical transport system can support both a shared sub-λ and dedicated sub-λ simultaneously on a single link. The shared sub-λ, which allows a statistical multiplexing function at layer 2, is used to provide L2 VPN service, premium multimedia service, and best-effort service. On the other hand, a dedicated sub-λ, which supports a traffic add/drop function at layer 1, provides legacy TDM service, leased line service, or L2 VPN service. L2 VPN service can be supported using a dedicated sub-λ or shared sub-λ according to the SLA. In the case of an SDH network, a sub-λ is composed of virtual containers (VCs) (VC-11/12 or VC-3/4) having a differential QoS profile. Figure 4 shows an example of sub-λ partitioning according to the service type. A shared sub-λ1 transports CIR traffic such as VPN, VoIP, and real-time video services with strictly bounded delay and jitter. The shared sub-λ2 transports both CIR traffic and excess information rate (EIR) traffic. EIR traffic comprises services that have properties such as reuse, non-real-time functionality, and minimum bandwidth guarantee. A shared sub-λ3 transports only best-effort traffic. Dedicated sub-λs are assigned to a leased line and TDM traffic. If a failure occurs on a shared sub-λ1, which transports CIR traffic, CIR traffic is switched from shared sub-λ1 to shared sub-λ3, transporting best-effort traffic so that only the best-effort traffic is dropped instead. In the case of congestion, the bandwidths of sub-λs are controlled independently by a shaping algorithm based on the priority bit of the VLAN tag or DSCP/EXP field without affecting other sub-λs. The proposed service-aware optical transport system generates flows using the service type, priority, and destination address of input traffic. The bandwidth is controlled based on the generated flows. We applied a non-work conserving fair queuing algorithm for guaranteed traffic and used an adaptive flow-based random early drop algorithm for non-guaranteed traffic. The packet scheduling algorithm for guaranteed service and non-guaranteed service is described in detail in [9].

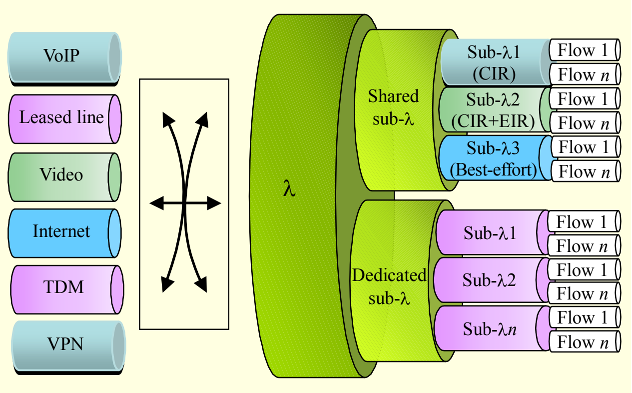

Fig. 4. Sub-λ partitioning for service types.

3. Network Architecture

Figure 5 shows the network architecture for the proposed service-aware optical transport system. The proposed system can be used in metro and core networks. The proposed system can be located at the metro edge to provide access network connectivity through the L2/L3 switch, router, and MSPP. The proposed system provides Internet access service and

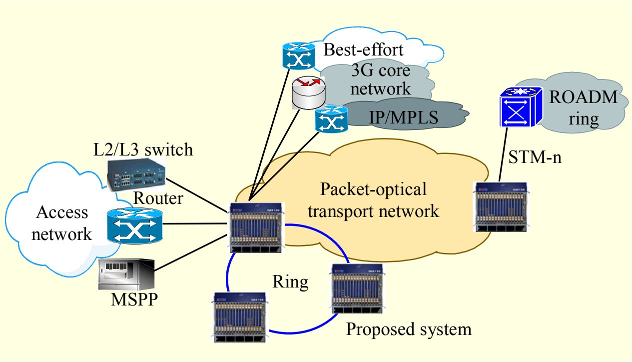

Fig. 5. Network architecture for the proposed system.

IP/MPLS service via a legacy router. Connectivity to a wavelength division multiplexing/reconfigurable optical add-drop multiplexer (WDM/ROADM) network is also supported through a SONET/SDH link. The proposed system can be applied to a P-OTS system. In this case, the physical layer can be configured using an Ethernet or SDH network. The protection switching scheme is basically 1+1 linear protection switching, and it supports ring protection switching.

III. Experiments and Results

Figure 6 shows the experimental setup to evaluate the performance of the proposed service-aware optical transport system. The experimental setup comprised a packet analyzer and three service-aware optical transport systems with a UPSR protection scheme. The working and protection links had a link capacity of 2.5 Gbps and consisted of eight sub-λs. To evaluate the system performance, we calculated and compared the encapsulation efficiency according to the Ethernet frame size for service types and measured the data rate against the frame size for multimedia service and restoration time. We also tested the flow-based bandwidth control per sub-λ.

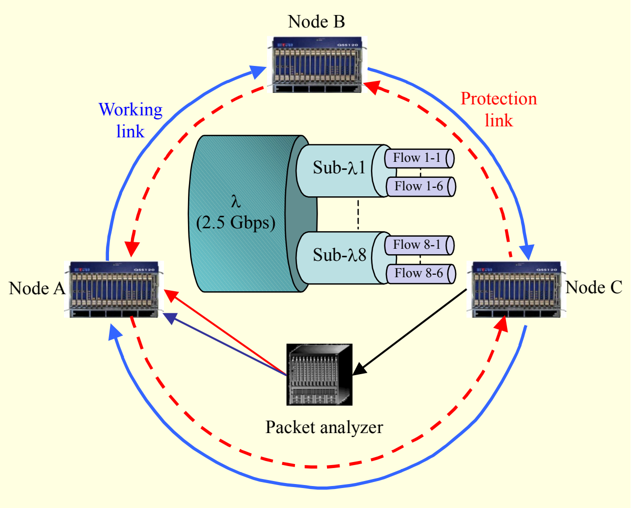

Fig. 6. Experimental setup to evaluate the service-aware optical transport system.

Table 1. Encapsulation efficiency for service types.

Frame size (byte)	Ethernet (without VLAN)	L2 VPN (with VLAN)	Multimedia (without VLAN)	
		Flow (VC-3/VC-4)	Flow (VC-3/VC-4)	Flow (Mbps)
64	76.19	66.30/66.81	80.46/81.09	250.28
100	83.33	74.16/74.73	85.31/85.97	265.37
200	90.90	86.97/87.64	90.14/90.84	280.39
500	96.15	90.18/90.88	93.31/94.03	290.25
1,000	98.03	92.78/93.50	94.42/95.15	293.69
1,500	98.68	93.68/94.41	94.79/95.53	294.85

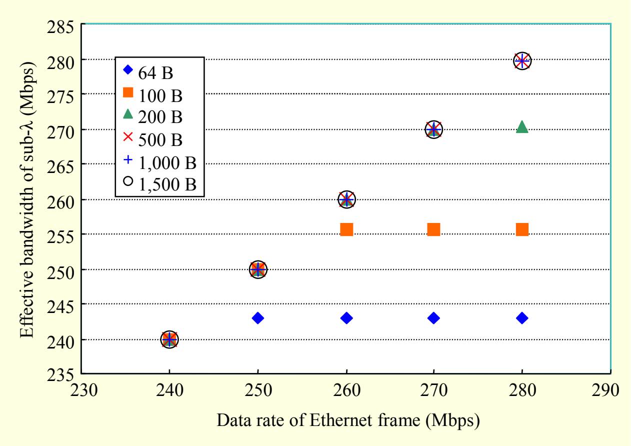

Fig. 7. Data rate against Ethernet frame size for multimedia service.

1. Encapsulation Efficiency

In Fig. 6, the Ethernet frame was generated from a packet analyzer and transported over the working and protection links after mapping to the corresponding sub-λ at node A. The working and protection links consisted of eight sub-λs with 311 Mbps capacity. Each sub-λ consisted of six flows (VC-3) with a differential QoS profile. The network control program assigned differential bandwidth to each sub-λ according to the flow profile and service type. The maximum data rate of each sub-λ was calculated and measured experimentally according to the Ethernet frame size for native Ethernet service, L2 VPN service, and multimedia service. If the Ethernet frame is mapped into the SONET/SDH frame to be transported over an optical transport network, the real data rate is changed because the frame structure of SONET/SDH is different from that of an Ethernet frame. The service type also affects the data rate because the overhead size of an Ethernet frame varies with the service type.

Table 1 shows the encapsulation efficiency and maximum data rate of a sub-λ according to the service type and frame size. The encapsulation efficiency is defined as the percentage of link bandwidth used by an Ethernet frame when transmitting Ethernet traffic with the line rate. An Ethernet frame includes only a MAC header and not an interframe gap or preamble/start-of-frame delimiter. As seen in Table 1, L2 VPN service had the lowest encapsulation efficiency due to the added overhead of 52 bytes, while multimedia service with an overhead of 30 bytes had the best encapsulation efficiency when the Ethernet frame size was less than 200 bytes. Figure 7 shows the experimental results of the effective bandwidth of sub-λ against the Ethernet frame size for multimedia service. For an Ethernet frame size below 200 bytes, the effective bandwidth of sub-λ was reduced. The experimental results had about a 3% error compared with the calculation results of Table 1 because an internal label was added to each Ethernet frame for internal processing. In this experiment, the bandwidth of sub-λ was calculated based on the Ethernet frame size including the internal label.

2. Flow-Based Bandwidth Control

A legacy optical transport system cannot effectively manage the bandwidth of each flow. Therefore, an excess of traffic affects adjacent flows as well as the corresponding flow, which degrades the system performance. On the other hand, the proposed service-aware optical transport system generates flows using the service type, priority, and destination address of input traffic and controls the bandwidth of traffic based on the generated flow [9]. Each Ethernet frame was classified by flow profile based on the service type and QoS. The bandwidth of each flow is guaranteed independently without affecting the adjacent flows under congestion. Figure 8 shows an example of flow-based bandwidth control. In a legacy optical transport system, violation traffic, which exceeds the predetermined bandwidth of the flow, affects not only the corresponding flow but also adjacent flows. As a result, traffic is dropped in every flow, and there is no bandwidth guarantee per flow. On the other hand, in the case of the proposed service-aware optical transport system, a traffic drop happens only on a violation flow without affecting adjacent flows. Figure 9 shows the experimental results for flow-based bandwidth control. We established two sub-λs between node A and node C in the experimental configuration of Fig. 6. Sub-λ1 was a virtual tunnel to transport CIR traffic. Sub-λ2 was a virtual tunnel for best-effort traffic. The input traffic was classified as CIR traffic and best-effort traffic using service type and QoS. The input traffic comprised an Ethernet frame with a fixed size of 64 bytes.

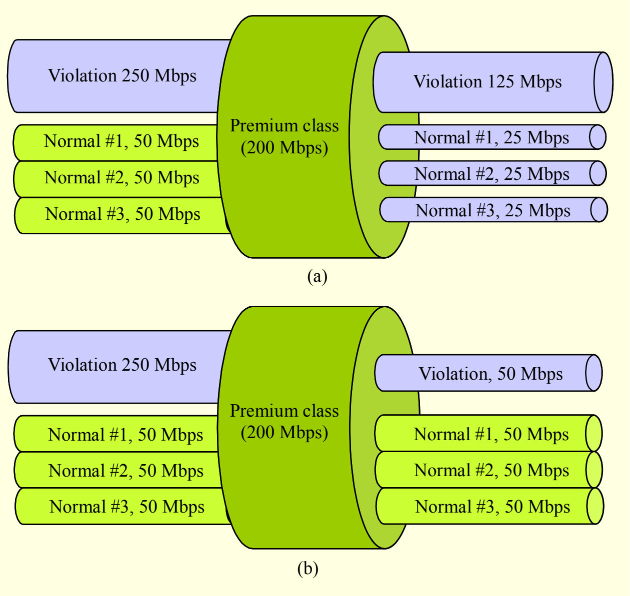

Fig. 8. Flow-based bandwidth control in (a) a legacy optical transport system and (b) the proposed service-aware optical transport system.

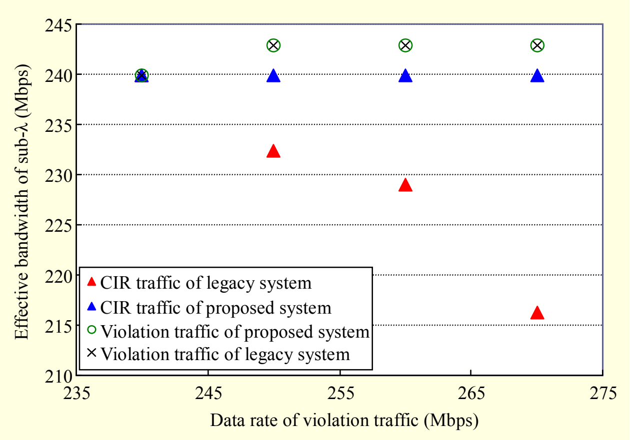

Fig. 9. Measurement results for flow-based bandwidth control.

We set up a bandwidth with 311 Mbps for both sub-λ1 and sub-λ2. The data rate of the best-effort flow mapped to sub-λ2, which means violation traffic, was changed from 240 Mbps to 270 Mbps, while the traffic of sub-λ1 continued the data rate of 240 Mbps. As seen in Fig. 7, the maximum data rate of sub-λ was 242.9 Mbps for an Ethernet frame with a fixed size of 64 bytes. If the traffic input sub-λ2 is in excess of the assigned bandwidth, the effective bandwidth of sub-λ2 increases up to 242.9 Mbps, and excess traffic is then dropped. From Fig. 9, the legacy optical transport system, which has no flow-based bandwidth control function, cannot guarantee bandwidth per flow when violation traffic is input. Violation traffic affects CIR traffic. As a result, the effective data rate of traffic transmitted via sub-λ1 decreased in proportion to the excess of violation traffic input to sub-λ2. However, in the case of the proposed service-aware optical transport system supporting flow-based bandwidth control, the effective data rate of sub-λ1 maintained 240 Mbps without being affected by the excess traffic of sub-λ2. In conclusion, the proposed optical transport system can effectively transport CIR traffic, EIR traffic, and best-effort traffic simultaneously.

3. Protection and Restoration

Figure 10 shows the experimental setup used to evaluate the link protection scheme for a ring network. The experimental setup was composed of an SDH analyzer and three proposed optical transport systems which construct both a working ring (blue line) and protection ring (red line). Traffic of the working ring was transported in the direction opposite that of the protection ring. The traffic was generated by the SDH analyzer and input into working port A and protection port B at node A using an optical coupler (50:50).

The traffic input into the working port of node A was transported to node C via node B, while traffic input into the protection port of node A was transported directly to node C. Under normal conditions, node C outputs the traffic received from working port A to the SDH analyzer connected to protection port B using an internal switch within the packet-circuit line card. The traffic input to node C via the protection link was terminated at the packet-circuit line card. In Fig. 10, the traffic is only on the solid lines, not the dotted lines. If a failure occurs on the working link between node B and node C, the traffic is switched from the working link to the protection link at node C. In the experiment, we cut the working link between node B and node C to create a loss of signal (LOS). We measured the detection time for a link failure and restoration time from the failure with the SDH analyzer. We also measured the switching time of the internal switch itself within the packet-circuit line card. As shown in Table 2, the restoration time from a link failure (T_R) was measured to be about 22 ms from (1). The detection time of a failure such as LOS or loss of frame was about 60 µs. The manual switching time was about 4 µs.

$$T_R = \frac{\text{Lost frames}}{\text{Frame rate}}. \qquad (1)$$

We achieved a restoration time much shorter than the telecommunications standard of 50 ms for real-time services. In this paper, we measured only restoration time of the optical layer to evaluate whether the proposed service-aware transport system can be used as a P-OTS system. In the future, we will consider Ethernet ring protection (ERP) as an Ethernet layer protection scheme. The ERP technique is being developed at ITU-T G.8032 to attain the same protection level as that of transport networks based on SONET/SDH.

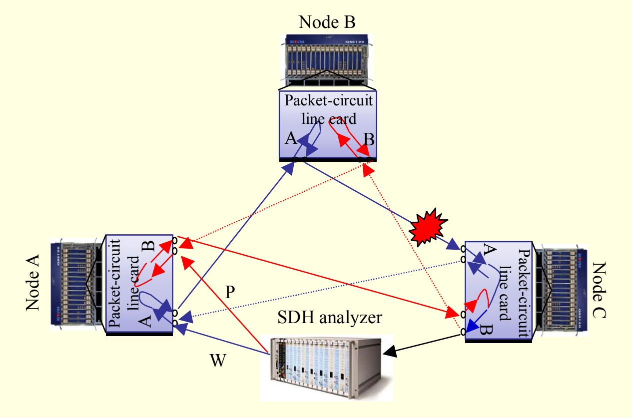

Fig. 10. Experimental setup for link protection.

Table 2. Experimental results for link protection.

Items	Measurement results
Restoration time	22 ms
Failure detection time	60 µs
Manual switching time	4 µs

IV. Conclusion

In this paper, we discussed how to effectively employ an Ethernet service in an optical transport network. Currently, the use of Ethernet has been increasing in both metro and core networks. However, establishing an Ethernet network in a transport network has many limitations in terms of cost and technology. To solve these problems, we proposed a service-aware optical transport system and experimentally evaluated whether it can be used as a packet-optical transport system. By providing the end-to-end connection using a sub-λ, the proposed service-aware optical transport system can effectively provide QoS-guaranteed Ethernet service and best-effort service simultaneously over a single link. We measured the restoration time and the data rate for various Ethernet frame sizes for multimedia service. In the future, it will be interesting to measure the delay time and jitter for various service types.

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