

Photonic Internet Lab.: Breakthrough for Leading Edge Photonic-GMPLS

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SUMMARY Photonic Internet Lab. (PIL) is shooting for the leading edge photonic-GMPLS (Generalized Multi-protocol Label Switching) that utilizes wide-band, cost-effective photonic technology to implement IP-centric managed networks. PIL is a consortium for researching the GMPLS protocol and advancing a de facto standard in this area. Members make leading edge GMPLS code modules and test them at the lab site. The experimental results, new ideas, and protocols are contributed to standardization bodies such as IETF and OIF. This paper also describes the world's first trial of GMPLS multi-region (multi-layer), multi-route, multi-vendor signaling.

key words: GMPLS, photonic, Internet, Internet operability

1. Introduction

The popularity of broadband access services is dramatically raising the amount of Internet backbone traffic. Broadband access is now adopted by more than 10 million users in Japan via ADSL (Asymmetric Digital Subscriber Line) and FTTH (Fiber To The Home) technology. These high-speed subscribers are stimulating new broadband services including content delivery such as still and moving pictures, and VoIP services. IP traffic in the backbone network and the number of users are shown in Fig. 1.

Fortunately, MPLS (Multi-protocol Label Switching) realizes reliable and managed networks that offer Multi-QoS capability [1]. To meet the growth in traffic, the photonic MPLS, the GMPLS protocol, and its extension have been proposed [2], [3]. In addition, new breakthrough optical device technologies such as the PLC (Planar Lightwave Circuit) and MEMS (Micromachine Electro Mechanical System) have been developed for WDM and photonic GMPLS. These technologies are now being prepared for service introduction.

To meet the traffic demands, we started researching on GMPLS future networking to advance three breakthroughs.

The first is universal operation that integrates IP, ATM, Ethernet, SDH, and WDM. GMPLS can realize a universal control mechanism for all those layers. In addition, its universal operation mechanism provides multi-layer (multi-region) switching that can integrate several layer switching capabilities (Fig. 2). It creates not only low cost operations but also flexibility for multi-layer resource control.

The second is multi-layer (region) integrated resource control. This is realized by the unified signaling/routing

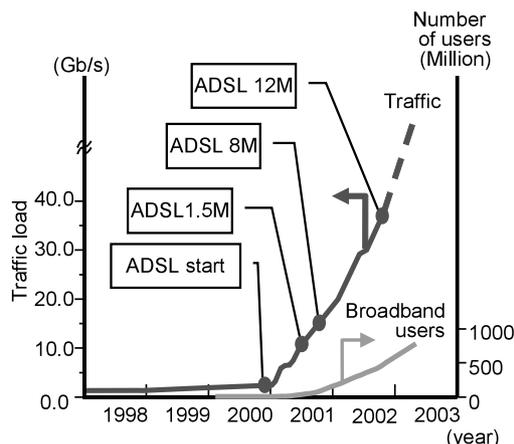


Fig. 1 National backbone traffic.

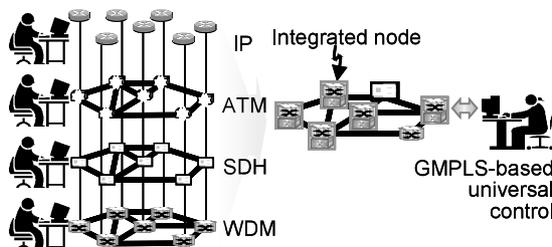


Fig. 2 GMPLS-based universal control.

protocol of GMPLS. Conventional resource control is realized individually, layer-by-layer. That means each layer optimizes each resource independently. However, GMPLS provides a unified routing and signaling protocol, so each node can know all layer resource information and can control any layer path as shown in Fig. 3 [4]. In Fig. 3, OLSP stands for optical label switched path. IP traffic demand between routers i and j is shown as R_{ij} and optical path resource between optical routers k and l is shown as O_{kl} . In addition, GMPLS also provides a unified signaling protocol, so any layer devices can be control by edge node. This multi-layer control can dramatically reduce the network resources needed. Some quantitative study results are shown in this paper. Details are described in Fig. 4.

The third is the optical transparent path that is a mid to long term target. This path is realized without any complicated electrical operation such as re-timing, re-shaping, or re-generating. In addition, SDH functions such as error monitoring, frame recovering and monitoring are also

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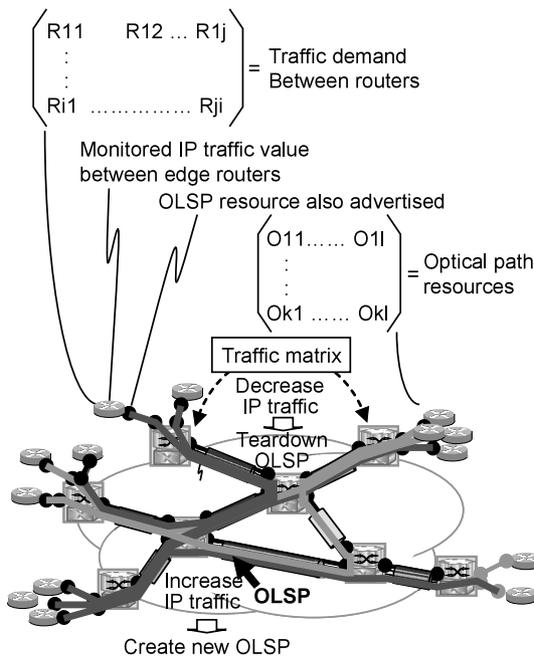


Fig. 3 Multi-layer (region) resource control that combines IP traffic and OLSP residual resources.

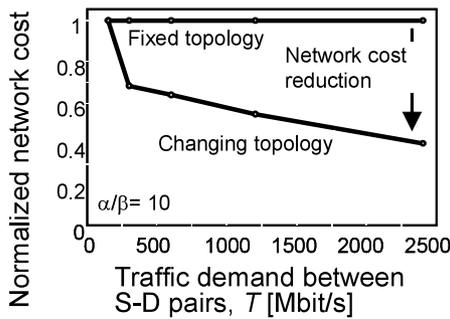


Fig. 4 Advantage of multi-layer traffic control.

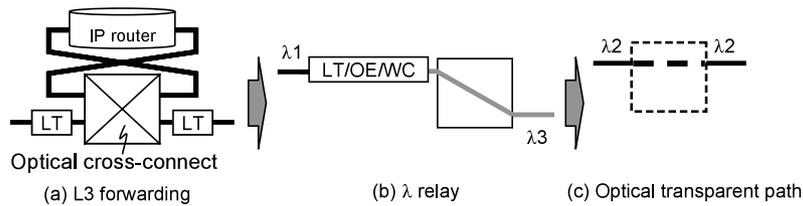


Fig. 5 Optical transparent path.

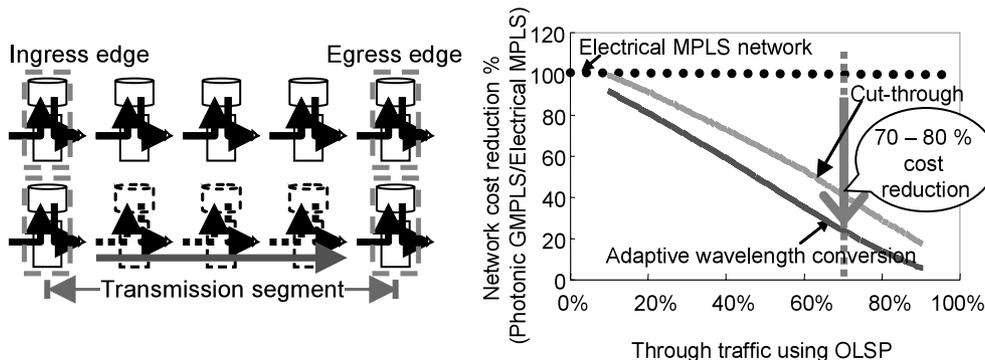


Fig. 6 Adaptive optical transparent path and its effectiveness.

omitted. The optical signal is transparently handled in a photonic layer. This means that the photonic GMPLS network can create a combination of Layer 3 forwarding, λ relay, and transparency adaptively as shown in Fig. 5. Figure 5(a) shows conventional IP forwarding, (b) shows λ relay, and (c) illustrates optical transparency. Optical transparency implies that the output wavelength equals the input wavelength. The two main problems with optical transparency are wavelength assignment failures due to an insufficient number of network-wide frequencies, and waveform degradation, which limit the transmission distance.

The adaptive optical transparent path is shown in Fig. 6 [5]. Layer 3 forwarding is used if traffic is relatively small and IP level aggregation is used if necessary. On the other hand, optical cut through paths are created if traffic loads are heavy. Such paths attempt to use the same wavelength dispense with wavelength conversion and 3R-functions. This would dramatically reduce network cost as shown in Fig. 6. In Fig. 6, 0% through traffic using OLSP represents a pure IP router network. In this case, there is no optical cross-connect system or wavelength converter in the network. On the other hand, 100% through traffic using OLSP represents an all optical cross-connect network. This network does not use any IP router. According to our evaluation result, 70% OLSP cut-through is possible and yields a 70–80% cost reduction. This is another very important target for photonic GMPLS.

To create these three photonic GMPLS technologies and protocols, PIL started to submit contributions to standardization bodies. They include ITU as well as IETF and OIF.

PIL consists of two working groups, Technical Testing WG and Standardization Strategy WG. These activities are done at NTT Musashino Labs. and CRL Keihanna Labs [3]. The following section will provide details of the activities

and the structure of PIL.

2. PIL Organization

Photonic Internet Laboratory, PIL, was founded in September 2002 to promote research on and development of the next-generation photonic network and to encourage global standardization activities. PIL currently consists of seven companies: Nippon Telegraph and Telephone Corp. (NTT), NEC Corporation, Fujitsu Laboratories Ltd., The Furukawa Electric Co., Ltd., Mitsubishi Electric Corporation, Oki Electric Industry Co., and Ltd. and Hitachi, Ltd. PIL activities are supported by research and development aimed at establishing international technical standards as part of the Strategic Information and Communications R&D Pro-

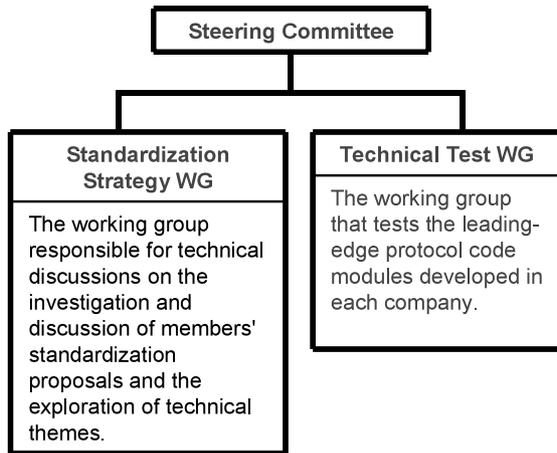


Fig. 7 PIL organization.

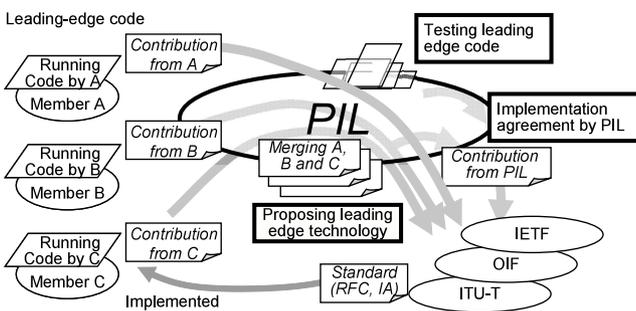


Fig. 8 PIL's standardization approach.

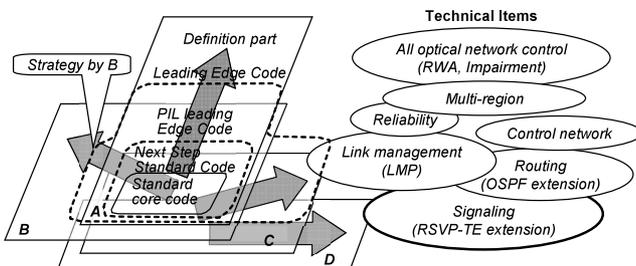


Fig. 9 Leading edge code for next generation photonic network.

motion Scheme of the MPHPT (Ministry of Public Management, Home Affairs, Posts and Telecommunications), which is funding selected IT activities [6], [7].

PIL's structure is shown in Fig. 7. There are two Working Groups (WGs). Technical test WG tests leading-edge protocol code modules developed by member companies. On the other hand, the standardization strategy WG is responsible for technical discussions on standardization proposals. It has submitted 22 standardization proposals to IETF and OIF as of June 2003. All the contributions are posted on PIL's WWW site [8].

The framework of the standardization strategy WG is shown in Fig. 8. As shown in Fig. 8, each member company researches and develops new ideas, protocols and running code modules. The topics tackled by PIL are organized by the steering committee. Each proposal is discussed and tested by PIL.

PIL member strategies and topics are shown in Fig. 9. Each member has a different direction or strategies for standardization. PIL promotes the core part of the protocol and its extension. In addition, the next step in standards submission and leading edge code developments are the key activities of PIL. Technical items are listed in Fig. 9. PIL has already tested the signaling and routing parts of GMPLS. We intend to cover multi-layer (region) traffic control frame work, reliability, and control network issues from now.

3. Multi-Layer (Multi-Region), Multi-Route, and Multi-Vendor Testing

PIL members, NTT, NEC Corporation, Fujitsu Laboratories Ltd., The Furukawa Electric Co., Ltd., and Mitsubishi Electric Corporation successfully concluded the world's first GMPLS signaling interoperability test using a multi-layer (region) network consisting of packet, TDM, wavelength, and fiber layers. Given the quality requirements set by the application or traffic state, it is possible to select the appropriate communication path from among all possible paths that can be established on the multi-layer network [9], [10].

GMPLS enables unified control management of the network layers as described in Sect. 1. In the conventional network, each layer network is constructed independently. The conventional network management system requires the operator to administer each layer independently. For example, in conventional electrical or optical cross-connects, the network operator uses a special terminal set up as centralized control device. This device issues instructions that control the cross-connect equipment and hence the setup of TDM or wavelength paths. If the cross-connect equipment supports GMPLS control, a path can be set up by exchanging control packets between these control devices as well as IP routers. Therefore, a network operator who has IP expertise can manage both IP/MPLS router and cross-connects.

In the demonstration, control software programs for setting up and releasing paths in the multilayer network were newly developed and installed in the network control devices of each company. The fact that these control de-

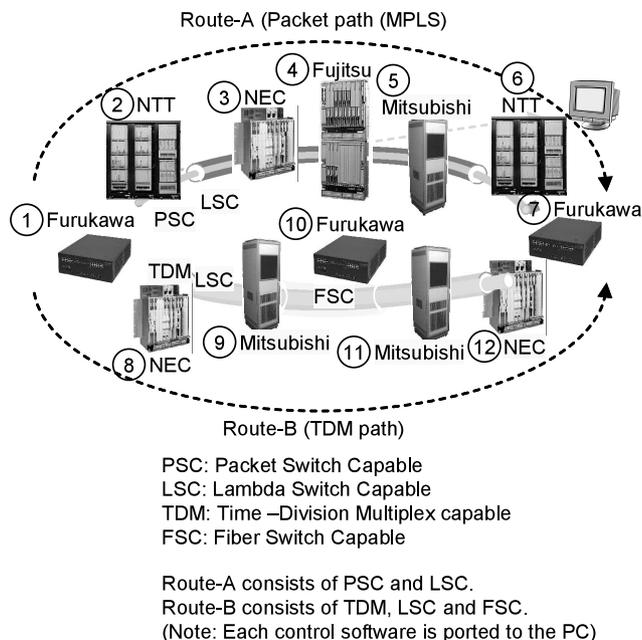


Fig. 10 PIL's GMPLS C-plan interoperability testing demonstration.

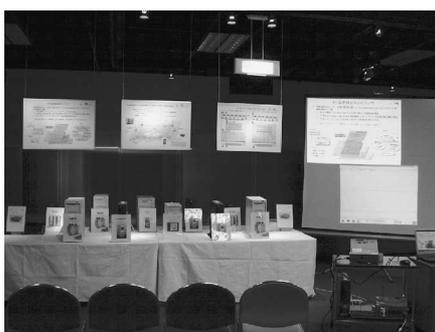


Fig. 11 Overview of demonstration test set.

vices could be mutually interconnected is a key factor in the success of the interoperability test that examined path setup of multilayer signaling: a world first. These control devices exchange signals based on the protocol RSVP-TE [11], extended to GMPLS, to set up and release multilayer paths on the multilayer network.

The test setup is shown in Fig. 10 and an overview photograph is shown in Fig. 11. It was designed to replicate a multilayer network with various kinds of network equipment including packet routers, electrical connections, optical cross-connects, and optical switches for fiber port switching. The devices are listed in Table 1. Each system's control plane was ported to a personal computer, PC and tested.

The multi-layer, multi-route test established two routes: route-A and route-B. Route-A is a packet path and route-B is a TDM path. Both paths are initiated by device 1 and terminated by device 7.

The experiment was realized as follows. It provides control functionality for both packet and TDM paths using

Table 1 List of devices.

Device number	Vendor / Supplier	Switching capability
1, 7	Furukawa	Packet, TDM
2, 6	NTT	Packet, Wavelength
3	NEC	Wavelength
4	Fujitsu	Wavelength
5	Mitsubishi	Wavelength
8, 12	NEC	TDM, Wavelength
9, 11	Mitsubishi	Wavelength, Fiber
10	Furukawa	Fiber

control devices 1 and 7. Control device 1 can freely set the packet path of route A and the TDM path of route B. Control device 2 on Route A has path control functions or switching capability for both packet and wavelength paths. Control devices 2 to 6 are for optical cross-connect function, and so can set up the wavelength paths. They newly set up a wavelength path for the packet path from devices 1 to 7. Thus, the setup and release of a multilayer path can be performed by exchanging a control signal among all the control devices handling a particular layer.

More details of the sequence for multi-layer signaling is shown in Fig. 12. Device 2 establishes a wavelength path to device 6 via device 3, 4 and 5. Next, a packet path is set up to device 6. This is one example of multi-layer operation. There are many new findings for GMPLS multi-layer operation and some.

Given the quality requirements set by the application or traffic state, it is possible to select the appropriate communication path from among all possible paths that can be established on the multilayer network.

GMPLS allows network operations to be unified. Significant reductions in network operation costs can be expected because the most economic path can be selected by configuring the appropriate configuration of network resource from among all layers of the network. In addition, novel network services can be created, such as a wavelength-dedicated line that changes wavelength path connection points according to user demand. For this reason, GMPLS has been attracting attention as the base technology of the next-generation broadband IP network [12].

In addition, it is easy to integrate multi-layer resource control into one controller. If packet (IP) flow traffic increases, a new photonic path is created automatically [19]. The setting of photonic paths between source-destination IP routers depends on IP traffic. Therefore, the topology of the photonic layer would change dynamically according to the fluctuation in IP-traffic demand to optimize network resource utilization. For this purpose, our objective is to minimize network cost Z formulated as follows [13]

$$\begin{aligned}
 Z &= C_{node} + C_{link} \\
 &= \alpha \sum_i \sum_p r_{ip} + \beta \sum_i \sum_j \sum_p \sum_k l_{ijpk}, \quad (1)
 \end{aligned}$$

where r_{ip} is the cost of port p in router i , l_{ijpk} is the cost of wavelength path k at port p in fiber link ij . α/β is the node/link ratio. α/β is set to more than one, because IP

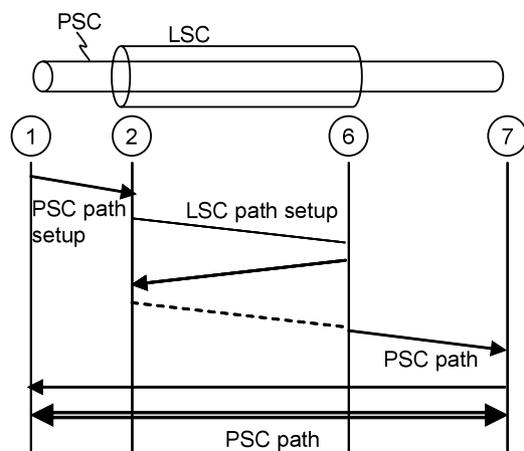


Fig. 12 Multi-layer signaling example for route-A.

routers have IP-packet processing functions such as table look up and packet-based switching in addition to wavelength routing functions.

To minimize Z , we adopt the extended version of the BXCQ (branch exchange with quality-of-service constraints) scheme presented in [14], named EBXCQ. The BXCQ scheme was originally intended for multi-layer ATM network design. In BXCQ, the addition-and-elimination of links is iterated to solve a topological optimization problem with quality-of-service constraints, such as delay and blocking probability. In EBXCQ, the number of ports in both IP routers and wavelength routers, as well as the number of wavelengths per fiber are also considered as constraints in addition to the constraints considered in BXCQ.

In the conventional network, photonic paths form a semi-fixed network and IP packets are discarded or overflowed if traffic increases. As previously shown in Fig. 4, multi-region resource operation reduces of more than 60%. The details are described in [13]. All those multi-layer, multi-route experiments were demonstrated at the PIL workshop held in the Tokyo Kokuyo Hall in Feb. 19, 2003.

4. Future Works

Most PIL activities are discussed openly on our WWW site and in the press. Some however involve confidential know-how and shared only among members.

PIL is proceeding in two directions. One is globalizing our standardization efforts, and the other is conducting real field trials. Because basic GMPLS code modules are being standardized by international standardization bodies, tests on leading edge code modules and interoperability tests must be performed globally. To realize this, PIL is collaborating with the global standards test consortium, ISOCORE [15]. Some test items are shared and also results are exchanged. In addition, PIL has become a test user of the CRL Keihanna open laboratory [16] that has WDM national wide network. PIL will test newly developed GMPLS protocols on the national wide network. In addition, GMPLS base restoration [17], [18] and management for GMPLS are next

topics for PIL standardization and test.

5. Conclusion

The Photonic Internet Lab. (PIL) was founded by Nippon Telegraph and Telephone Corporation, NEC Corporation, Fujitsu Laboratories Ltd., Furukawa Electric Co., Ltd., Mitsubishi Electric Company, Oki Electric Industry Co., Ltd., and Hitachi, Ltd. for achieving global standards and leading-edge technologies.

Its targets include GMPLS, a combination of photonic technology and multi-layer, managed control. PIL is active in advancing GMPLS standardization and conducting tests on leading edge code modules. The two working groups are testing and contributing new leading edge GMPLS protocols.

In addition, PIL members have successfully developed and demonstrated the world's first multi-layer, multi-route and multi-vendor GMPLS signaling test.

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Naoaki Yamanaka graduated from Keio University, Japan where he received B.E., M.E. and Ph.D. degrees in engineering in 1981, 1983 and 1991, respectively. In 1983 he joined Nippon Telegraph and Telephone Corporation's (NTT's) Communication Switching Laboratories, Tokyo Japan, where he was engaged in research and development of a high-speed switching system and high-speed switching technologies for Broadband ISDN services. Since 1994, he has been active in the development of ATM

base backbone network and system including Tb/s electrical/optical backbone switching as NTT's Distinguished Technical Member. He is now researching future optical IP network, and optical MPLS router system. He is currently a senior research engineer, supervisor, and research group leader in Network Innovation Laboratories at NTT and representative of Photonic Internet Lab. (PIL). He has published over 126 peer-reviewed journal and transaction articles, written 107 international conference papers, and been awarded 182 patents including 21 international patents. Dr. Yamanaka received Best of Conference Awards from the 40th, 44th, and 48th IEEE Electronic Components and Technology Conference in 1990, 1994 and 1998, TELECOM System Technology Prize from the Telecommunications Advancement Foundation in 1994, IEEE CPMT Transactions Part B: Best Transactions Paper Award in 1996 and IEICE Transaction Paper award in 1999. Dr. Yamanaka is Technical Editor of IEEE Communication Magazine, Broadband Network Area Editor of IEEE Communication Surveys, and was Editor of IEICE Transaction as well as TAC Chair of Asia Pacific Board at IEEE Communications Society. Dr. Yamanaka is an IEEE Fellow.