ABSTRACT

IP+Optical networking technology is a key technology for realizing high-performance Internet backbone networks. Dynamic optical path cut through can create high-throughput as well as low power consumption networks. National Institute of Information and Communications Technology (NICT) Kei-han-na Info-Communication Open Lab, Interoperability Consortium, is shooting for the leading edge photonic Generalized Multi-protocol Label Switching (GMPLS) Inter-Carrier Interface that utilizes wide-bandwidth, cost-effective photonic technology to implement IP-centric managed networks. Kei-han-na Open Lab is a consortium for researching the GMPLS protocol and advancing a de facto standard in this area. Its experiments, new ideas, and protocols are submitted to standardization bodies such as International Telecommunications Union-Telecommunication standardization sector (ITU-T), Internet Engineering Task Force (IETF), and Optical Internetworking Forum (OIF). This paper details a nationwide GMPLS field trial that used multi-vendor, multi-switching capable equipment.

Keywords: GMPLS, interoperability, multi-vendor, field trial

1. INTRODUCTION

Generalized Multi-protocol Label Switching (GMPLS) \(^1\) is a set of network control protocols to realize the next generation high performance transport network. Various institutions are continuously researching and developing GMPLS technologies, and some early field trials of GMPLS based networks \(^2,3\) and consortiums \(^4,5\) have already been reported. However, these trials mainly focused on single layer operation based on Lambda Switching Capable Label Switched Paths (LSC-LSPs) and/or single domain (carrier) operation. Each of these conventional trials demonstrated GMPLS-enabled IP routers and GMPLS-controlled Photonic Cross-connect systems (PXC)s, provided by just one vendor for trial. The National Institute of Information and Communications Technology (NICT) Kei-han-na Info-Communication Open Laboratory \(^6\) is promoting rapid GMPLS development and deployment, and provides an

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opportunity to evaluate GMPLS interoperability among carriers and vendors; it has defined a sort of Implementation Agreement (IA) in Japan.

In this paper, we detail the interoperability activities of multiple vendors and multiple carriers as associated with the Kei-han-na Open Lab Interoperability Consortium. First, the structure and topics of the Consortium are shown. We evaluated the interoperability of GMPLS signaling, routing, and link management protocols using two types of GMPLS controlled networks depending the type of equipment. To set nationwide trials, we used three sites (Koganei, Otemachi, and Kei-han-na in Japan), which are physically connected by a 10 Gbit/s link and layer 2 connection of JGN II networks. Through interoperability evaluations, we have confidence that we can accelerate the deployment of GMPLS technology to the point of allowing actual operational deployment.

\section{GMPLS Target and Study Issues}

\subsection{Motivations for GMPLS}

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 Asymmetric Digital Subscriber Line (ADSL) and Fiber-to-the-Home (FTTH) technologies. These high-speed subscribers are stimulating new broadband services including content delivery such as still and moving pictures, and Voice over IP (VoIP) services. IP traffic in the backbone network and the number of users in Japan are shown in Fig. 1.

Fortunately, Multi-Protocol Label Switching (MPLS) realizes reliable and managed networks that offer Multi-QoS capability. To meet the growth in traffic, the photonic MPLS, the GMPLS protocol, and its extension have been proposed. In addition, new breakthrough optical device technologies such as the Planar Lightwave Circuit (PLC) and Micro-machine Electro Mechanical System (MEMS) have been developed to support Wavelength Division Multiplexing (WDM) and photonic GMPLS networks. 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, Asynchronous Transfer Mode (ATM), Ethernet, Synchronous Digital Hierarchy (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 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. In Fig. 3, Optical Label Switched Path (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-term 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 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, $\lambda$-relay, and transparency adaptively as shown in Fig. 5. Figure 5 (a) shows conventional IP forwarding, (b) shows $\lambda$-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. 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 (OXC) or wavelength converter (WC) 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, we started to submit contributions to standardization bodies. They include the International Telecommunications Union-Telecommunication standardization sector (ITU-T) as well as the Internet Engineering Task Force (IETF) and the Optical Internetworking Forum (OIF).

2.2 Create new GMPLS services.

GMPLS create multi-layer network operation. In other words, OLSP can be controlled by the user, IP router and Internet service provider (ISP). Because conventional optical network is static and there is no sophisticated control method. Then dynamic provisioning and dynamic bandwidth setup are creating new services.

Figure 7 shows “Bandwidth on Demand” service images. User or application click mouse to setup or release λ-path dynamically. For example, Digital Versatile Disk (DVD) movie downloading is automatically created Gb/s order λ-path and only less than 10 sec. is needed to download new HD-level contents.

On the other hands, dark network service is new service for internet service provider as shown in Fig.8. There are two carrier layers for new service. Hole-Seller has an infrastructure or fibers. However Hole-Seller’s fiber resources can be controlled by IP/MPLS service provider. GMPLS interface can create such service. We call this service as “Dark network service”. The IP/MPLS service provider selects any Hole Seller. So they can achieve high-reliable and cost effective infrastructures.
To meet those needs and motivations, we try to establish sophisticated GMPLS protocols and interoperability with some carriers, vendors and academias.

3. FRAMEWORK OF KEI-HAN-NA INFO-COMMUNICATION OPEN LAB.

3.1 Objective of the interoperability working group

The NICT Kei-han-na Info-communication Open Lab. was established in 2003 with the objective of carrying out research and development activities. Figure 9 shows an organization of the Kei-han-na Information Open Lab. Under the management division: General Assembly of the Council, Board of Directors and the secretariat, the Operation and Research Committee is located. This Committee has four sub-committees. The Open Lab owns research facilities including IP routers, Time Division Multiplexing (TDM) cross-connect systems (XCs), the 10 Gbit/s high-performance network infrastructure, and access point to the JGN II network. These facilities are available to universities, manufacturers, research laboratories, venture companies, and local governments, etc. While belonging to the Kei-han-na Open Lab. High Performance Network Research sub-committee, the interoperability working group (WG) consortium is actively studying photonic network interoperability technologies which include physical and control layer technologies. The active members of WG are as follows:

- NTT
- NTT Communications
- KDDI
- KDDI R&D Labs.
- NEC
- Furukawa Network Solutions
- Fujitsu
- Fujitsu Lab.
- Mitsubishi Electric
- Hitachi

![Fig.9: Organization of the Kei-han-na Open Lab.](image-url)
• Hitachi Communications Technologies
• Anritsu
• Keio University
• NICT

The research and development target of WG is the control and transport interface in the photonic transport network layer between carriers. This interface is called the External Network to Network Interface (E-NNI). WG set three object items and work with four projects (PJs).

#1: Verification for inter-connectivity of new inter-Carrier or inter-AS interface (E-NNI).

PJ2: Transparent 10 Gigabit Ethernet (10GbE) LAN-Phy over Optical Transport Network (OTN) technologies.

PJ3/4: Developing GMPLS based E-NNI protocols and test in the filed.

#2: Cooperative development from Japan, proposal for international standardization such as ITU-T, IETF, and OIF.

#3: Extended GMPLS connectivity experiment and construction of the interoperability open site.

PJ1/4: Multi-vendor GMPLS interoperability test and field demonstration.

Figure 10 shows the target reference model of the WG. There are two types of E-NNIs. E-NNI (a) is an Intra-Carrier E-NNI interface. This interface is used in case of connecting the vendor islands and connecting different divisions’ networks; such as a metro network division and a core transport network division. E-NNI (a) is developing in OIF \(^\text{17, 18}\). On the other hand, E-NNI (b) is for Inter-Carrier connections. E-NNI (b) is the most important target to advance the deployment of GMPLS-based photonic networks into carriers' networks. This is because, for example, Carrier A may employ the ITU-T Automatically Switched Optical Network (ASON) architecture \(^\text{19}\), while Carrier B employs the IETF GMPLS architecture \(^\text{1}\). Carrier

![Fig.10: Reference model of multi-carrier networks.](image)
Interworking is essential to create seamless global call setup and tear down services for users. Therefore, WG chooses E-NNI(b), i.e., inter-carrier E-NNI, as a main objective.

3.2 Target network architecture

GMPLS supports a variety of switching capabilities (SCs) such as packet switch capable (PSC), layer 2 switch capable (L2SC), time division multiplex switch capable (TDM), lambda switch capable (LSC), and fiber switch capable (FSC). Within these SCs, LSC equipment such as optical cross-connect system (OXC) and PXC are expected to construct the core transport network: i.e., a photonic network. Therefore, it is natural to allocate OXC or PXC as a border node between carriers. This means that next generation carrier networks will be connected at photonic network level. Therefore, E-NNI is set between LSC equipment. On the other hand, between the user and carrier, transport network edge equipments should support different SC according to provided services. Therefore, User to Network Interface (UNI) can be set in the PSC level, L2SC level, TDM level, LSC level, and FSC level. A basic network architecture described above is shown in Fig. 11. In Fig. 11, five GMPLS control planes (C-Planes) (A) to (E) are independently managed and basically not reachable one another. The E-NNI reference points are defined between LSC equipment. Reachability information such as UNI Transport Network Assignd (TNA) address, UNI link address, UNI SC, and node address will be exchanged via an E-NNI routing protocol. Carrier’s networks are an ASON overlay GMPLS network or an IETF overlay GMPLS network. The E-NNI protocol should support ASON - ASON, ASON - IETF, and IETF - IETF combinations. WG is developing the GMPLS base inter-carrier E-NNI interface protocols.

In the rest of the, the activities of PJ1 and PJ4; i.e., interoperability of GMPLS I-NNI protocols, will be described.

4. GMPLS PROTOCOL INTEROPERABILITY EXPERIMENTS AT KEI-HAN-NA

4.1 Overview of the GMPLS interoperability trials

Approximately every 3 months, WG holds a GMPLS protocol interoperability test using NICT Keihan-NA Open Lab., NICT Koganei Lab., and NICT JGN II facilities. First, GMPLS signaling protocol (RSVP) was tested. In this trial, routing protocol and...
link management protocol were not used. As a next step, GMPLS routing protocol (OSPF) was added for the test item and a combination of OSPF and RSVP was also examined. Interoperability of link management protocol (LMP) was also established.

A recent field trial of the nationwide GMPLS interoperability was reported. In this field demonstration, the multi-layer, LSC and TDM, interoperability among multi-vendors indicated.

Figure 12 shows an experimental setup in the field trial. To demonstrate this trial on a nationwide scale, three sites (Koganei, Otemachi, and Kei-han-na in Japan) were used. All sites were physically connected by a 10 Gbit/s link using JGN II OXC service and a layer 2 link using JGN II L2 service. Two types of GMPLS controlled networks named network-A and network-B were set up on this trial network. The network-A was used to examine multi-layer (MPLS/TDM/LSC) interoperability. The network-B was used for multi-vendor LSC interoperability.

### 4.2 Field trial configuration

To make the trial match the actual operating environment as much as possible, three locations separated more than 400 km apart were used. To validate GMPLS multi-vendor interoperability over three layers, GMPLS routers which were naturally work as IP/MPLS routes (WG R-1 and R-2, KDDI R-1 and R-2), SDH TDM XCs (WG XC-A, XC-B, XC-C, NEC XC), PXC (NTT PXC, KDDI PXC) were set. All of them support both a data plane function and a control plane function. The data plane and the control plane were formed by a 10 Gbit/s (OC192/STM-64) link and by a layer-2 based Ethernet connection, respectively. Both planes are provided by JGN II services as mentioned before. Table 1 summarizes tested vendors and their network functionalities. Nine vendors (A to I in Table 1) equipment were used.

<table>
<thead>
<tr>
<th>Vendor/suppliers</th>
<th>Equipment type</th>
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<tbody>
<tr>
<td>A</td>
<td>IP/MPLS Router</td>
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<tr>
<td>B</td>
<td>IP/MPLS Router</td>
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<tr>
<td>C</td>
<td>SDH XC</td>
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<tr>
<td>D</td>
<td>MPLS XC, PXC</td>
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<td>E</td>
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<td>F</td>
<td>IP router</td>
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<td>PXC</td>
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<td>H</td>
<td>PXC</td>
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<tr>
<td>I</td>
<td>IP router, PXC</td>
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</tbody>
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Figure 13 and 14 show a configuration of the network-A and network-B respectively. Devices having only GMPLS control plane were included in the network-B, because of evaluating GMPLS interoperability with as
many vendors as possible.

4.3 Trial results in the network-A

Hierarchical LSP creation of packets (MPLS) on TDM over LSC for different combinations of vendor equipment was examined. In order to manage GMPLS routing information separately from IP/MPLS routing information, different OSPF area were assigned. Area 0 was assigned for GMPLS and area 1 was assigned for IP/MPLS.

Multi-layer LSP set up procedure was as following:

1. Creating a LSC-LSP between SDH-XCs via PXCs.
2. Advertise created LSC-LSP as a forwarding adjacency (FA) LSP.
3. Creating a TDM-LSP between GMPLS routers via SDH-XCs.
4. A GMPLS router initiated an exchange of OSPF-TE information for area 1 and they became OSPF neighbors with each other.
5. Finally, a pair of unidirectional MPLS LSPs between MPLS router A1 and B2 was initiated.

4.4 Trial results in the network-B

Creating an LSC-LSP was focused to improve interoperability among different vendors. Five IP routes (four vendors) and five PXCs (five vendors) are virtually connected as shown in Fig. 14. Because some devices did not support the data plane function.

In this trial, 4 different LSC-LSPs were successfully established. They are:

1. A3-G1-I2-H1-E1-D2
2. A3-G1-D1-I2-E1-D2
3. I1-G1-A3
4. I1-E1-D2
5. CONCLUSIONS

IP+Optical technology is the key for future high-performance backbone networks. To realize this key technology, NICT is supporting the interoperability research consortium at Kei-han-na Open Lab. This consortium is determined to develop a practical GMPLS inter-carrier interface. A recent advance is the nationwide GMPLS field trial that used the multi-switching capable equipment of nine vendors. Through these interoperability evaluations, we are confident that we can accelerate the deployment of GMPLS technology into carriers' infrastructure.

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