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GMPLS Interoperability Tests in Kei-han-na Info-Communication Open Laboratory on JGN II Network

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SUMMARY Generalized Multi-protocol Label Switching (GMPLS) technologies are expected a key technology that creates high-performance Internet backbone networks. There were many GMPLS interoperability trials. However, most of them reported the successful results only. How to set up a trial network and how to test it was generally not discussed. In this paper, as a kind of tutorial, detailed GMPLS field trials in the National Institute of Information and Communications Technology (NICT) Kei-han-na Info-Communication Open Laboratory, Interoperability Working Group (WG) are reported. The interoperability WG is aiming at the leading edge GMPLS protocol based Inter-Carrier Interface that utilizes wide-bandwidth, cost-effective photonic technology to implement IP-centric managed networks. The interoperability WG is a consortium for researching the GMPLS protocol and advancing a de facto standard in this area. Its experimental results, new ideas, and protocols are submitted to standardization bodies such as the International Telecommunications Union-Telecommunication standardization sector (ITU-T), the Internet Engineering Task Force (IETF), and the Optical Internetworking Forum (OIF). This paper introduces the activities of the interoperability WG; they include a nationwide GMPLS field trial using the JGN II network with multi-vendor, multi-switching-capable equipment and a GMPLS multi routing area trial that used a multi-vendor lambda-switching-capable network.

key words: *photonic network, control plane, GMPLS, interoperability, 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 for realizing distributed transport network control. Japanese carrier laboratories and international consortiums have already reported many GMPLS experiments and field trials [2]–[18]. However, most of them reported the successful results only. How to set up a trial network and how to test it was generally not discussed. The National Institute of Information and Communications Technology (NICT) Kei-han-na Info-Communication Open Laboratory [19], Interoperability Working Group (WG) is promoting rapid GMPLS development and deployment, and provides an opportunity to evaluate GMPLS interoperability among carriers and vendors; it has defined a type of Implementation Agreement (IA) in Japan.

This paper presents the framework, structure and topics, and interoperability activities of the interoperability WG from year 2003 to 2005 which includes a nationwide multi-vendor multi-layer GMPLS field trial and a multi-area routing domain GMPLS field trial over the JGN II network [20].

2. Framework of Kei-han-na Info-Communication Open Laboratory, Interoperability Working Group

2.1 Formation of the Interoperability Working Group

The NICT Kei-han-na Info-communication Open Laboratory was established in 2003. Figure 1 shows the organization of the Kei-hana-na Info-communication Open Laboratory. The interoperability WG belongs to the high performance network sub-committee with other two WGs. The Open Laboratory provides research facilities to the interoperability WG including rental laboratory space, IP routers, Synchronous Digital Hierarchy (SDH) cross-connect systems (XCs), the 10 Gbit/s high-performance network infrastructure, and access points to the JGN II network. The interoperability WG is actively studying photonic network inter-

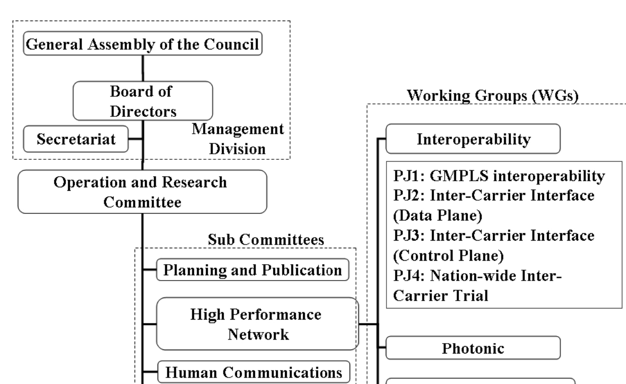

Fig. 1 Organization of the Kei-han-na Open Lab.

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operability technologies which include physical data plane and control plane technologies. The active members of the interoperability WG are as follows: NTT, NTT Communications, KDDI, KDDI R&D Labs., NEC, Furukawa Network Solutions, Fujitsu, Fujitsu Lab., Mitsubishi Electric, Hitachi, Hitachi Communications Technologies, Anritsu, Keio University, and NICT. The research and development target of the interoperability 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) [21]. The interoperability WG set three object items and was running four projects (PJs).

Item #1: Verification of inter-connectivity of new inter-carrier or inter-autonomous system (AS) interface (E-NNI).

Item #2: Cooperative development from Japan, proposing international standards to bodies such as the International Telecommunications Union Telecommunication standardization sector (ITU-T), Internet Engineering Task Force (IETF), and the Optical Internetworking Forum (OIF).

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

2.2 Objective of the Interoperability Working Group

Figure 2 shows the target reference model of the interoperability WG. There are two types of E-NNIs. E-NNI (a) is denoted as an Intra-Carrier E-NNI. This interface is used when connecting the vendor islands and connecting different divisions' or business unit's networks, such as a metro network division and a core transport network division. E-NNI (a) is being developed in OIF [22]. On the other hand, E-NNI (b) is for Inter-Carrier connections. E-NNI (b) was not addressed by any standardization body in 2003. However, considering the technical progress of GMPLS controlled photonic networks, inter-carrier photonic network services such as basic seamless global call setup and tear down services, layer 1 virtual private network (VPN) services, and optical VPN services, will be provided in the near future. Also, a neutral and open framework among carriers and vendors is very valuable for developing the specifications of inter-carrier interfaces. Thus, the interoperability WG choose E-NNI (b); i.e. inter-carrier E-NNI, as its main objective. To develop a new inter-carrier E-NNI and examine it in the field environment, three steps approach was defined. Step one: developing equipment that supports a GMPLS based Internal Network to Network Interface (I-NNI) protocol and a User to Network Interface (UNI) protocol [23]. Step two: developing the new E-NNI protocols and testing with I-NNI protocols. Step three: examine the end-to-end call set up under the multiple carrier environment. As a first step, the interoperability WG began by examining of the GMPLS I-NNI protocol interoperability test. The rest of this paper describes the activities of the GMPLS I-NNI protocol interoperability tests.

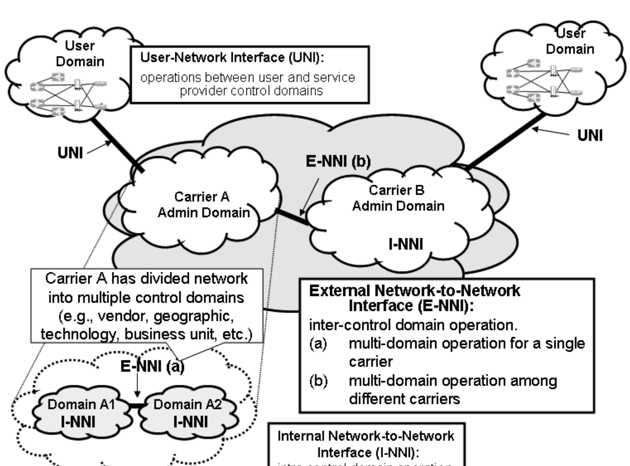

Fig. 2 Reference model of multi-carrier networks.

3. GMPLS Protocol Interoperability Experiments at Kei-han-na

3.1 Overview of the GMPLS Interoperability Trials

Approximately every 3 months, from June 2003 to July 2005, nine active members of the interoperability WG held a GMPLS protocol interoperability test using NICT Kei-han-na Open Laboratory, NICT Koganei Laboratory, and NICT JGN II facilities. First, GMPLS signaling protocol; Resource reSerVation Protocol (RSVP) [24] was tested. This trial did not use a routing protocol or a link management protocol. As the next step, GMPLS routing protocol, Open Shortest Path First (OSPF) [25], was added as a test item and a combination of OSPF and RSVP was also examined. Interoperability of link management protocol (LMP) [26] was also tried and established.

These basic trials confirmed that it is critical to construct the control plane network in a multi-vendor environment. This is because each vendor's implementation fails to consider interconnectivity. Three types of implementation were considered.

(1) Plain IP.
(2) Generic Routing Encapsulation (GRE) tunnel [27].
(3) IP over IP tunnel [28].

The plain IP method is simple and scalable. It is easy to change the GMPLS network topology. Network element (NE) of this type requires an exclusive IP based control network for GMPLS use only. Therefore, it is difficult to share the control network with other (non-GMPLS) systems.

Both tunnel methods require pre-configuration to set up tunnels between adjacent nodes. This type of NE constructs an exclusive GMPLS control network on the existing data communication network (DCN). This is a merit but tunnel configuration is complex. To maximize flexibility, implementing all three methods is ideal, but it is enough to use two kinds at the same time in the NE. In case of the interoperability WG's trial, some NEs support only (1): group-1, some NEs support only (2): group-2, and fortunately some NEs support both (1) and (2): group-3. It was impossible

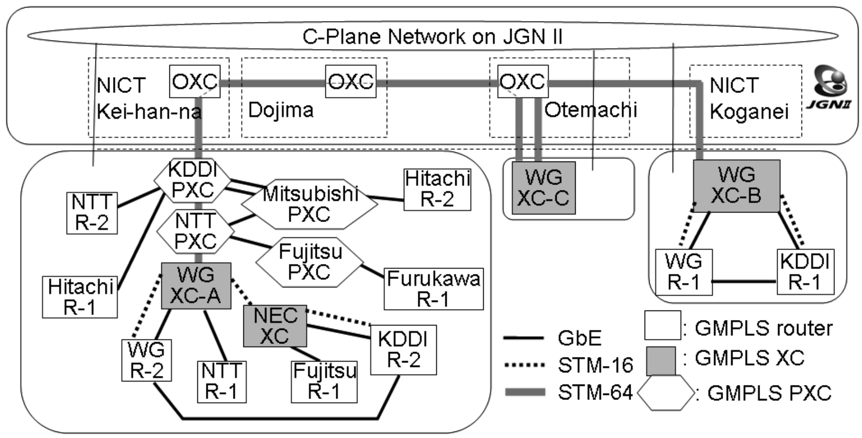

Fig. 3 GMPLS multi-vendor multi-layer interoperability field trial test setup in the Kei-han-na Open Laboratory.

to test the interoperability between group-1 and group-2. However, group-3 NEs can bridge group-1 NEs and group-2 NEs. The interoperability tests between group-1 NE(s), group-2 NE(s), and group-3 NE(s) were possible.

Next, OSPF implementation of the Hello message exchange method was evaluated. There were three implementations.

(1) Multicast destination address over the non point-to-point network (broadcast network).
(2) Multicast destination address over the point-to-point network (link).
(3) Unicast destination address over the non point-to-point network (OSPF point to multi-point mode).

It is necessary to use these modes properly according to the DCN design and the network operator's requirement. Therefore, the vendor should support all three methods. For test purposes, method (2) was used.

In these trials, many troubles have been observed. Most of them were based on miss handling of optional objects and proprietary objects. Some vendors treated an optional and a proprietary object as a mandatory object, some vendors treated an unsupported optional object as an undefined object. Another problem is an order of objects. Some implementations were quite order sensitive. They did not allow the different order of objects in RSVP messages. The most serious trouble was regarding with a state machine implementation. If some errors are occurred by the received message, the system should return an error message to the sender. However, many dumb systems which did not return any messages and were crashed by themselves wasted the test time for rebooting.

The above clarifications and others were summarized to IAs and shared among the interoperability WG members.

3.2 Multi-Vendor Multi-Layer Field Trial

The interoperability WG has reported a nation wide scale GMPLS interoperability field trial [29]. Their report described multi-layer interoperability among multi-vendor products such as Multi-Protocol Label Switching (MPLS) Label Switched Path (LSP), Time Division Multiplex (TDM) LSP, and Lambda Switch Capable (LSC) LSP. Figure 3 shows the experimental set up in the field trial. Three sites in Japan, Koganei, Otemachi, and Kei-han-na, were used. All sites were physically connected by a 10 Gbit/s Synchronous Transport Module (STM)-64 link using JGN II Optical Cross-Connect (OXC) service for constructing a data plane (D-Plane) and a layer 2 link using JGN II L2 service for constructing a control plane (C-Plane) network. Two types of GMPLS controlled networks, network-A and network-B, were set up on this trial network. Network-A was used to examine multi-layer (MPLS/TDM/LSC) interoperability. Network-B was used to confirm multi-vendor LSC interoperability. To validate GMPLS multi-vendor interoperability over three layers, GMPLS routers, which originally handle IP/MPLS routers (WG R-1 and R-2, KDDI R-1 and R-2), SDH XCs (WG XC-A, XC-B, XC-C, NEC XC), Photonic Cross-Connect Systems (PXCs) (NTT PXC, KDDI PXC) were set in all three sites. All of them support both a data plane function and a control plane function and were used to construct network-A. To connect the three sites, STM-64 soft permanent connections (SPCs) were set in the JGN II OXC network during the period of the field trial. Therefore, OXCs in the JGN II were not visible to NEs of the GMPLS field trial.

Table 1 summarizes tested vendors and their network functionalities. NEs from nine vendors (A to I in Table 1) were used. Each NE was operated as either a PXC, an SDH XC, an IP router, or an IP/MPLS router. Figures 4 and 5 show the configuration of network-A and network-B, respectively. Devices with just GMPLS controller were included in network-B, so as to evaluate GMPLS interoperability among as many vendors as possible.

3.2.1 Trial Results in Network-A

Hierarchical LSP creation of packets (MPLS) on TDM over LSC was examined. In order to manage GMPLS routing

Table 1 Evaluated network element types.

Vendor/ supplier	Equipment type
A	IP/MPLS Router
B	IP/MPLS Router
C	SDH XC
D	IP/MPLS Router, PXC
E	PXC
F	IP router
G	PXC
H	PXC
I	IP router, PXC

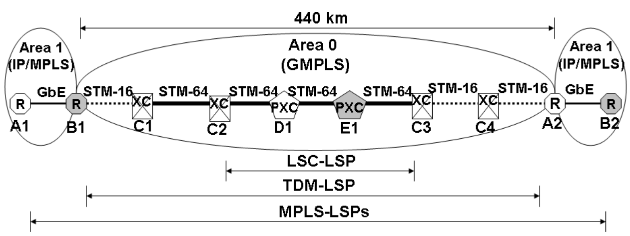

Fig. 4 Detailed configuration of the network-A.

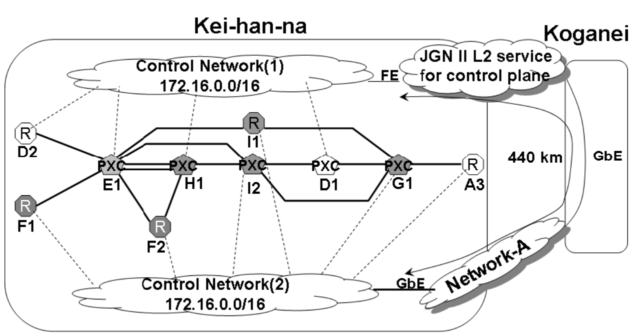

Fig. 5 Detailed configuration of the network-B.

information separately from IP/MPLS routing information, different OSPF areas were assigned. Area 0 was assigned for GMPLS and area 1 was assigned for IP/MPLS. No area border router (ABR) was configured. Therefore, the OSPFs did not interact with each other. Multilayer LSP set up procedure was as follows:

(1) At the initial phase, each piece of GMPLS NE correctly exchanged the GMPLS OSPF information and GMPLS neighbors were successfully established in area 0.
(2) Creating a LSC-LSP initiated from the SDH-XC. For example, XC C3 in the Kei-han-na site sent the RSVP PATH message to XC C2 in the Otemachi site via PXC E1 and D1. C2 sent back the RSVP RESV message to C3 via D1 and E1. PXC D1 and E1 made cross-connection as signaled. This entire process took 3.2 seconds in this experiment.
(3) Created LSC-LSP was advertised as a forwarding adjacency (FA) LSP by GMPLS OSPF.
(4) Creating a TDM-LSP initiated from the GMPLS router. For example, GMPLS IP router A2 sent the PATH message to router B1 via SDH-XC C4, C3, C2, and C1. B1 sent back the RESV message to A2 via XCs. XCs C1, C2, C3, and C4 made cross-connection as signaled. Created TDM-LSP was not advertised to MPLS domains. It took 11.0 seconds to set up the TDM-LSP.
(5) A GMPLS router exchanged MPLS OSPF-TE information for area 1 within the TDM-LSP tunnel in-band and they became OSPF neighbors in area 1. Establishing OSPF neighbors took an additional several seconds to a few tens of seconds.
(6) A pair of unidirectional MPLS LSPs between MPLS router A1 and B2 was initiated.

LSC-LSP setup time was measured by the time duration between the path creation command entering and observation of link up indication lump up. Therefore, control plane setup time, data plane setup time, and management plane setup time within the XC was included in 3.2 seconds. TDM-LSP setup time was 11.0 seconds. The main part of the setup time is a hardware response time needed to setup a cross-connection at XCs C1, C3, and C4, because of the control plane processing time of each XC was 10 msec order. These XCs were configured with switching granularity of 50 Mbps. Therefore, to setup 2.4 Gbps path, 48 times switching and connection verification were occurred. If switching granularity was set to 2.4 Gbps, TDM-LSP setup time could be reduced to less than 1 second. After six procedures shown above, IP packets could be exchangeable, total over 20 seconds were required in this experiment.

3.2.2 Trial Results in Network-B

Creating an LSC-LSP was targeted to improve interoperability among different vendors. Five IP routers (four vendors) and five PXCs (five vendors) were virtually connected as shown in Fig. 5. Because some devices did not support the D-Plane function, only the interoperability of GMPLS controllers was examined. Each GMPLS controller was connected to one of two control networks, referred to as Control Network (1) and Control Network (2) in Fig. 5. These two control networks, 440 km apart, were connected by using a local Fast Ethernet (FE) link, JGN II Layer2 service, and a Gigabit Ethernet (GbE) connection created on the TDM LSP in network-A. RSVP Path messages from D2 to A3, for example, traverse a maximum of 1,320 km. This means that the control plane network and virtual data link connections of the network-B were nationwide scale. In this trial, four different LSC-LSPs were established. They were:

(1) A3-G1-I2-H1-E1-D2
(2) A3-G1-D1-I2-E1-D2
(3) I1-G1-A3
(4) I1-E1-D2

Each vendor's NE implemented the RSVP objects in a slightly different way in terms of the generalized payload identifier (G-PID), encoding type, protection object, and proprietary objects, etc. Therefore, in this trial, a special functional node (PXC I2) was inserted at an intermediate location, to observe these differences and align the RSVP messages so as to ensure consistency among all nodes. This type of functional node is quite helpful for establishing LSPs. However, making an actual IA and implementing it is the most important issue to maximize the interoperability and to construct an actual GMPLS network.

3.3 Multi-Vendor Multi-OSPF Domain Trial

To construct an actual GMPLS carrier operating network, scalability in terms of the number of NEs is important. In general, the scalability of the routing protocol restricts the scalability of the GMPLS network. The routing scalability limitation can be eased by the use of the multi-domain approach; i.e. OSPF multi-area. As the next step in the GMPLS interoperability trial, a multi-vendor multi-OSPF domain environment was examined.

Five interoperability WG members attended this trial. The Kei-han-na site and the Koganei site were connected by the JGN II OXC service for the D-Plane and the JGN II L2 service for the C-Plane. The detailed trial network configuration is shown in Fig. 6. Ethernet over SDH technology was used to provide Ethernet links between the Koganei site and the Kei-han-na site. Five IP routers, A1, A2, B2, I3, and I4, three PXCs, D1, H1, and I2, were connected. Set up of GbE over lambda encapsulation LSP links over multiple OSPF areas was examined.

First, three OSPF areas, Area 0, 2, and 3, were set. PXC D1 and I2 became ABR. OSPF summary link state advertisements (LSAs) [30] were successfully exchanged between ABRs and re-distributed to all NEs. All NEs recognized the other areas' NEs. However, an opaque LSA [31], which contained GMPLS traffic engineering link information, was not advertised to the other areas. As a result, an NE that could initiate an LSP could not calculate the entire path to the destination NE in another area. This problem is recognized in the MPLS and GMPLS community. Two solutions are being discussed.

a) Path computation element (PCE) method [32].
The ingress NE orders a PCE to perform path calculation. The PCE can communicate with the PCEs of other areas. Finally, a full and definitive explicit route object (ERO) is provided to the ingress NE.
b) Per-domain path calculation method [33].
LSP initiator may provide source and destination NE information. Therefore, ingress NE can calculate a path to ABR and specify the egress information in the RSVP ERO. ABR can calculate a path to the next ABR or to the egress NE when the egress NE belongs to the same area as the ABR.

These two methods were evaluated. First, a manually assigned full strict ERO was provided to IP routers. GbE over lambda LSPs were successfully established between IP routers via PXCs. Next, a partially assigned strict ERO was tested. The strict ERO from ingress NE to ABR was assigned either manually or by Constrained Shortest Path First (CSPF) in the NE. The egress node was indicated by a loose hop ERO. The PXC I2 supported per-domain path calculation. LSPs were established between B2 and A1, and I3 and A1, and vice versa.

Findings raised in this trial are given below.

1) The PCE approach is useable. The ingress NE requires communication with the PCE. Newly development of a communication protocol and implement it to NEs is required.
2) Per-domain calculation is useable. The ingress NE must be provided with CSPF calculation using summary LSA information to determine the path to the ABR. ABRs must support per-domain path calculation.

4. Conclusions

GMPLS networking technology is the key to future high-

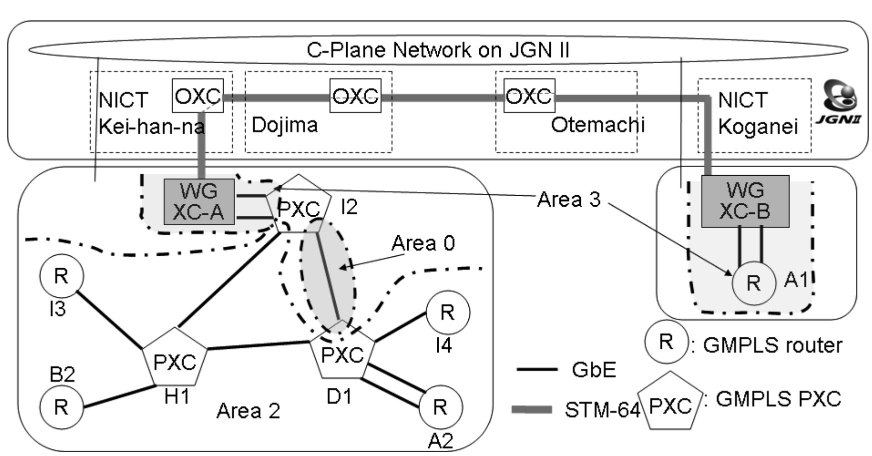

Fig. 6 GMPLS multi-vendor multi-OSPF domain interoperability field trial test setup in the Kei-han-na Open Laboratory.

performance backbone networks. To realize this key technology, the interoperability working group will continue to develop and examine GMPLS protocols. From these experiments, we found that IETF RFCs were not enough to implement the actual system. A kind of implementation guide which describes a selected feature list, a selected parameter list, a state machine for error handling, identifier addressing concept, and detailed IP addresses assignment, etc. is necessary to develop the stable network elements. The interoperability WG is determined to develop a practical GMPLS inter-carrier E-NNI interface. To develop the E-NNI, enhancement of the interoperability of GMPLS I-NNI protocols is also important. Recent advances include the nationwide GMPLS field trial that used the multi-switching capable equipment of nine vendors, the multi-area routing GMPLS trials, and inter-carrier seamless call set up trials. Through these interoperability evaluations, all members of the interoperability WG have become confident in the deployment of GMPLS technology into carriers' infrastructure.

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