Multi-ASON and GMPLS Network Domain Interworking Challenges

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ABSTRACT

This article describes the intercarrier external network-to-network interface development challenges at the Kei-han-na Info-Communications Open Laboratory. The E-NNI prototype that was developed provides interworking functionality between the automatically switched optical network control plane function of the ITU-T and the generalized multiprotocol label-switching control plane function of the IETF. In this article, an analysis of the differences between ASON network technologies and GMPLS network technologies, a detailed signaling protocol and routing protocol interworking mechanism, and the interworking experimental results of nationwide ASON and GMPLS network domains are described.

INTRODUCTION

Generalized multiprotocol label switching (GMPLS) [1] is a set of network control protocols designed to realize a next-generation high-performance transport network that uses control plane functions. From the architectural perspective, GMPLS-based transport networks are divided into two categories. One is the automatically switched optical network (ASON) architecture-based transport network [2] of the International Telecommunications Union —Telecommunication Standardization Sector (ITU-T), and the other is the GMPLS architecture-based transport network [1] of the Internet Engineering Task Force (IETF). Although both network technologies can use almost the same GMPLS protocols, each technology has slightly different user-to-network interface (UNI) protocols, the ASON UNI [3] and GMPLS UNI [4]. Because the architectural choice of GMPLS networks differs among carriers/service providers, the consideration to introduce a GMPLS-based external network-to-network interface (E-NNI) protocol is indispensable in order for carriers/service providers to provide seamless end-to-end call setup service to all users without being restricted by the adopted network architecture.

To provide seamless end-to-end call setup, interworking technologies such as signaling protocol interworking and routing protocol interworking among ASON architecture-based networks and GMPLS architecture-based networks should be developed. The National Institute of Information and Communications Technology (NICT) Kei-han-na Info-Communication Open Laboratory is promoting rapid development and deployment of the transport network control plane technology. This laboratory provides an opportunity to evaluate and improve GMPLS protocol interoperability among vendors and has been developing interworking technologies between ASON network domains and GMPLS network domains.

This article presents the interworking technologies developed in the Kei-han-na Open Laboratory and experimental results of interworking functions in the field environment.

The rest of this article is organized as follows. First, we analyze the differences between ASON network technologies and GMPLS network technologies, and then we describe detailed interworking function mechanisms. Finally, we present field trial results of six ASON and GMPLS network domains by using our developed E-NNI nodes.

DIFFERENCES BETWEEN ASON AND GMPLS NETWORK MODELS

BASIC REFERENCE POINT [2]

The interconnection between and within network domains is described in terms of reference points. Because domains are established using carrier/service provider policies, inter-domain reference points are service demarcation points. User devices can attach to the transport network at the UNI reference point, which represents a user-provider service demarcation point, whereas peer-level domains meet at the E-NNI reference point, which represents a service demarcation point supporting multi-domain connection establishment. The reference point within a domain is an internal network-to-network

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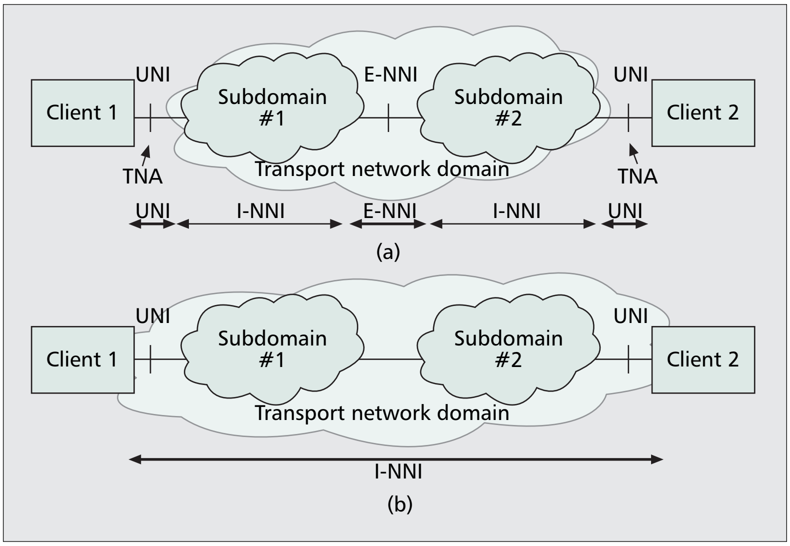


■ **Figure 1.** *ASON and GMPLS overlay network models: a) ASON overlay model; b) GMPLS overlay network model.*

interface (I-NNI), which represents a connection point supporting intra-domain connection establishment.

Overlay Model and Peer Model

There are two basic optional architectural models for deployment of the control plane in an operational context consisting of client-layer networks such as IP/MPLS routers and transport-layer networks.

Overlay model: One option is to use different instances of the control plane in the client-layer network and transport-layer network domains. In this situation, each instance of the control plane will operate independently of the other. Interworking between the two domains can be established through static configuration or UNI signaling. This option allows maximal control isolation.

Peer model: Another option is to use a single instance of the control plane that subsumes and spans client-layer devices and transport network layer devices. In such an environment, there is no distinct UNI between the client-layer device and the transport network layer device.

ASON Overlay Model

Figure 1a shows a basic multi-domain ASON transport network model. User devices (Client 1 and 2) are attached to the transport network domain via UNI (ASON UNI [3]). The transport network domain is composed of two sub-domains. These sub-domains are connected by E-NNI. Each sub-domain has its own I-NNI protocol. Therefore, proprietary I-NNI technologies can be applied to sub-domains according to the operation policies. On the other hand, standardized UNI and E-NNI protocols are applied to supply interoperable user side devices and transport network side devices. As described in Fig. 1a, UNIs, E-NNIs, and I-NNIs have completely distinct protocol sessions. Therefore, separate Resource reSerVation Protocol (RSVP) sessions are defined at the UNI, E-NNI, and also I-NNI if RSVP [5] is applied. In Fig. 1a, five RSVP sessions are defined. These sessions should be associated with an end-to-end relationship. The end-to-end relationship is identified through the source and destination transport network assigned addresses (TNAs) and the call ID. TNAs should be assigned from the globally unique address space. On the other hand, locally unique address spaces can be used for UNI, E-NNI, and also I-NNI sessions. Local addresses can be used in the RSVP SESSION and SENDER_TEMPLATE objects. To carry the source and destination TNAs over end-to-end sessions, a GENERALIZED_UNI object (G_UNI) is defined. TNAs are assigned by the network entity/authority itself, and the call end point is referenced by TNAs. The client device can be assigned its own address from the user. These user assigned addresses are not referenced in the transport network. This allows the complete separation of the user assigned address space and the transport network assigned address space.

GMPLS Overlay Model

Figure 1b shows a basic multi-domain GMPLS transport network model. User devices (Client 1 and 2) are attached to the transport network domain via UNI (GMPLS UNI [4]). The transport network domain is composed of two sub-domains. Three possible inter-domain label-switched path (LSP) set-up scenarios have been proposed [6]. The nested LSP option and the contiguous LSP option do not require distinct E-NNI sessions. The LSP-stitching option can use a distinct E-NNI session as an LSP segment. All three options require an end-to-end LSP set-up procedure at the final step. Therefore, there is one end-to-end I-NNI session between client 1 and 2. To make UNI functions, for example, hidden detailed transport network information to user devices, RFC 4208 GMPLS UNI interface is defined as a subset of RFC 3473 RSVP. Therefore, a single end-to-end I-NNI session with an RFC 4208 function is set between clients. The end-to-end relationship is identified by the tunnel end-point IP address and the tunnel sender IP address pair with the tunnel ID. The tunnel end-point IP address and tunnel sender IP address can be assigned from the network address space.

Interworking Function Mechanism

Interworking Scenario

As described in Fig. 1b, a multi-domain GMPLS transport network does not require a distinct E-NNI session when an end-to-end I-NNI session is signaled. To achieve signaling protocol, that is, RSVP, interworking between the ASON domain and the GMPLS domain, a signaling interworking function should be assigned at an ASON side border gateway node or a GMPLS side border gateway node.

When the project started, the inter-domain GMPLS signaling was under development and was not stable. Therefore, as a first step in meeting the ASON and GMPLS interworking challenge, we selected allocating signaling interworking functions at the GMPLS side border gateway node.

For the routing interworking, an exterior gateway protocol (EGP) should be run on the inter-carrier link to transport reachable node

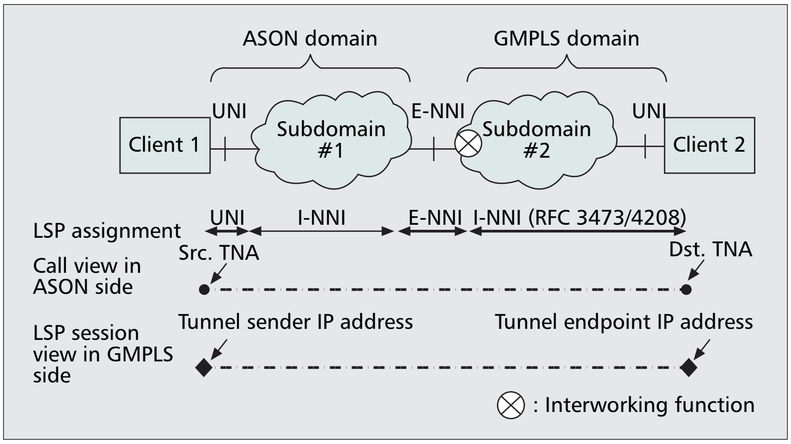


Figure 2. *Interworking scenario: call is set from ASON domain to GMPLS domain.*

information such as address, switching capability, and adaptation capability. EGP should be run not only between the ASON and GMPLS domains, but also between the ASON domains and between the GMPLS domains.

SIGNALING INTERWORKING

The targeted interworking scenario of ASON and GMPLS network domains is shown in Fig. 2. We assumed that globally unique IPv4 or IPv6 address space is used for TNAs in the ASON domain and for end-to-end I-NNI session start/end points in the GMPLS domain. TNA is not limited as an IP address, but in this article, IPv4 TNA is assumed (IPv6 also is possible).

There are four RSVP sessions. In the ASON domain, one UNI session and one I-NNI session are defined. In the GMPLS domain, one I-NNI session is defined. Between the ASON and GMPLS domains, one E-NNI session is defined.

As an example, an end-to-end call is set from the ASON side UNI to the GMPLS side UNI and will be described below.

ASON to GMPLS — From the viewpoint of the end-to-end call, the call source ID is indicated by the source TNA, and the call destination ID is indicated by the destination TNA. This source and destination TNA pair is carried by G_UNI object in the ASON domain and then the E-NNI. At the interworking function point, the end-to-end call is interpreted to the label switched path (LSP) session view of the GMPLS domain. The I-NNI session in the GMPLS domain is actually determined between the interworking function point and the UNI end point. However, the interworking function provides the LSP tunnel sender IPv4 address from the source TNA in the G_UNI object and provides the LSP tunnel end point IPv4 address from the destination TNA in the G_UNI object. Therefore, from the logical viewpoint of the end-to-end LSP session in the GMPLS domain, one LSP session (pseudo LSP session) can be defined between UNIs.

GMPLS to ASON — If call set up is initiated from the GMPLS UNI side, an end-to-end LSP session is initiated from client 2. The interworking function generates a G_UNI object for the E-NNI session from the I-NNI SESSION object and SENDER_TEMPLATE object.

GMPLS to GMPLS — This interpretation scheme using a G_UNI object in an E-NNI section also is applied to the case of interworking between GMPLS domains. The detailed pseudo LSP session mechanism is shown in Fig. 3. The interworking function is assigned to both nodes E1 and E2.

As described previously, we assumed that TNAs indicate IPv4 tunnel sender/end point addresses. This assumption limits the addressing flexibility in the ASON world.

The detailed interworking function is described as follows:

E-NNI to GMPLS I-NNI — The interworking function terminates the session of the E-NNI side and initiates a new session on GMPLS I-NNI side. The destination TNA of the G_UNI object is used as the IPv4 address of the local tunnel end point within the GMPLS I-NNI domain and put into the SESSION object. The source TNA of the G_UNI object is mapped into the SENDER_TEMPLATE object on the GMPLS I-NNI side as the tunnel sender IPv4 address. This mapping defines a pseudo end-to-end LSP tunnel between the source TNA and the destination TNA. TUNNEL ID and optionally, EXTENDED TUNNEL ID for the GMPLS I-NNI domain also are put into the SESSION object. If multiple pseudo end-to-end LSP tunnels are set between the TNA pair, the interworking function should manage the association among E-NNI sessions and pseudo end-to-end sessions.

The EGRESS_LABEL object in the G_UNI can indicate a destination interface ID in the unnumbered addressing case. It should be mapped into the EXPLICIT ROUTE object (ERO) to indicate the destination IPv4 address and interface ID.

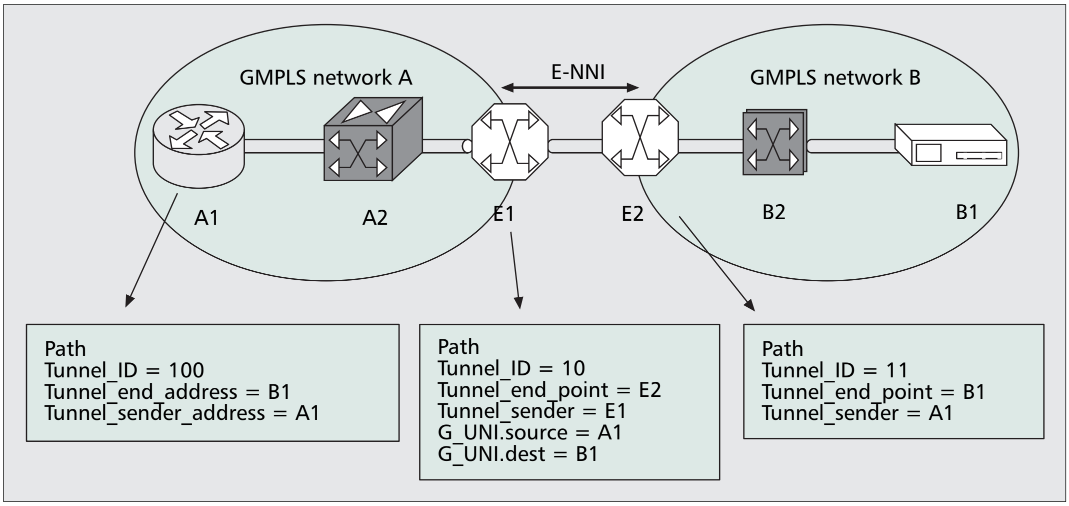
GMPLS I-NNI to E-NNI — The interworking function terminates the GMPLS I-NNI session and initiates an E-NNI session on the E-NNI side. It maps the IPv4 address of the local tunnel end point within the GMPLS I-NNI SESSION object into the destination TNA of the G_UNI object. The IPv4 address of the tunnel sender in the SENDER_TEMPLATE object is mapped into the source TNA of the G_UNI object.

In the unnumbered addressing case, the EGRESS_LABEL object in the G_UNI is mapped from the ERO.

The interworking function should generate the CALL_ID object because GMPLS I-NNI basically does not contain CALL_ID.

ROUTING INTERWORKING

As an EGP, the border gateway protocol version 4 (BGP-4) is used in current IP networks. BGP works on the border gateway routers; each autonomous system (AS) has its own border router(s). The border router makes an eBGP peer between another AS border router. The interior gateway protocol (IGP) collects a reachable network address set within the AS and passes it to BGP. The reachable network address set is exchanged among the eBGP peers.

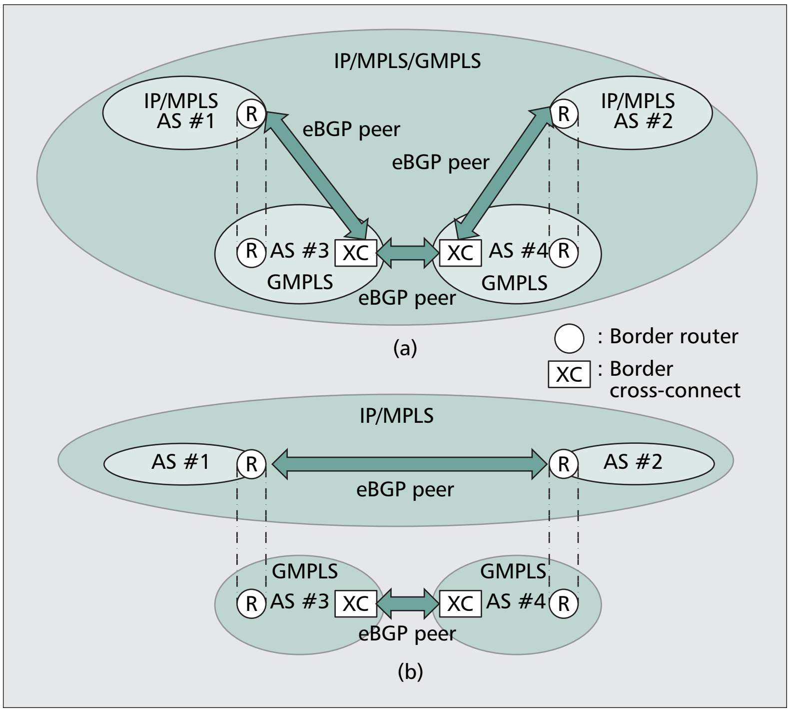


■ **Figure 3.** *An example of the pseudo single LSP session. The interworking function is worked in at nodes E1 and E2.*

Figure 4 shows possible eBGP peer relationships among IP/MPLS network domains and GMPLS network domains. In Fig. 4a, IP/MPLS network domains (AS #1 and #2) are connected by GMPLS network domains (AS #3 and #4). eBGP peers are defined between AS #1 and #3, AS #3 and #4, and AS #4 and #2. In this case, network address spaces of GMPLS networks (AS #3 and #4) are advertised to IP/MPLS networks (AS #1 and #2). Figure 4b shows another eBGP peer relationship. There are two eBGP peers. One is set between IP/MPLS network domains (AS #1 and #2). Another is set between GMPLS network domains (AS #3 and #4). There is no eBGP peer between the IP/MPLS network and the GMPLS network. Therefore, IP/MPLS packet networks and GMPLS non-packet networks can use independent network address spaces. We selected the latter relationship for developing BGP extensions. This relaxed the backward compatibility issues of developed BGP extensions, because BGP extensions are used only in GMPLS networks.

A BGP in GMPLS networks exchanges GMPLS related end-point information, such as an end-point address, an interface ID, the switching capability, and adaptation information. This traffic engineering (TE) information is exchanged by newly developed BGP4-TE extensions [7, 8]. In the past, BGP-TE extensions were rejected many times in the IETF because they smash the scalability of the Internet. However, our selected eBGP peer relationship limits the scope in GMPLS networks, not the whole IP network. Therefore, the scalability problem of the BGP-TE extension is relaxed.

The exchanged reachable end-point information can be redistributed within the domain. To do this, extensions of IGP also are required. This extension can cause a scalability or stability problem if reachable end-point information aggregation is not possible. In such a case, the number of information data is the same as the number of attached client devices. We implemented the extension as an open shortest path first (OSPF) extension using NODE ATTRIBUTE type-length-value (TLV) with UNI LINK ADDRESS sub-TLV. A constraint-based shortest path first (CSPF) at the LSP ingress node can calculate a route to the domain border node by using values in the UNI LINK ADDRESS sub-TLV.

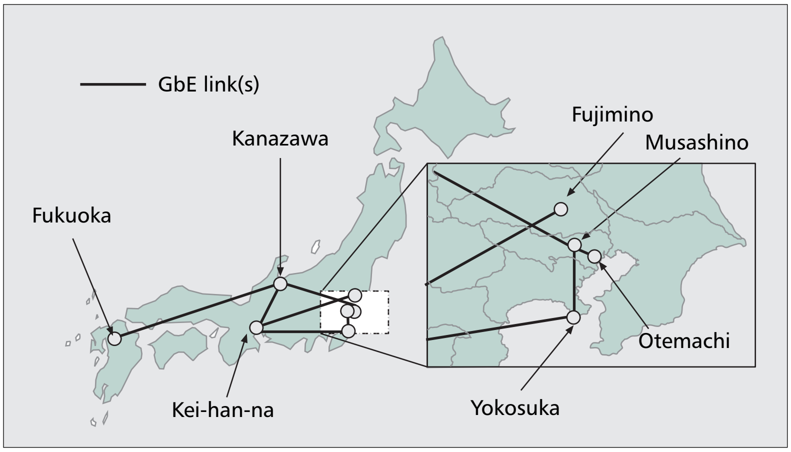


■ **Figure 4.** *Examples of the eBGP peer relationship: a) IP/MPLS networks and GMPLS networks share the same IP address space; b) separate IP address space among IP/MPLS networks and GMPLS networks.*

Field Trial Results of Six ASON and GMPLS Network Domains

Field Trial Network Construction

As described in the previous section, we defined the inter-carrier ASON and GMPLS interworking functions. These functions are implemented as an E-NNI gateway node; the E-NNI gateway



■ **Figure 5.** *Field trial network overview. Seven sites are connected by GbE links.*

#1	NICT ASON from/to NTT ASON
#2	NICT ASON from/to NTT GMPLS
#3	KDDI GMPLS from/to NTT GMPLS
#4	KDDI GMPLS from/to NTT ASON
#5	JGN II GMPLS to KDDI GMPLS
#6	JGN II GMPLS to NTT ASON
#7	JGN II GMPLS to NTT GMPLS
#8	NICT ASON from/to NICT GMPLS
#9	NTT ASON from/to NTT GMPLS

■ **Table 1.** *Successfully established multidomain calls.*

support ASON-ASON, ASON-GMPLS, and GMPLS-GMPLS inter-carrier connection types.

To evaluate the developed E-NNI gateway, a total of six ASON and GMPLS trial network domains were constructed. The evaluated overall network consisted of ASON and GMPLS trial networks by NTT Laboratories, a GMPLS trial network by KDDI Laboratories, ASON and GMPLS trial networks by NICT, and the NICT JGN II GMPLS network. All networks were extended to the NICT Kei-han-na site, and an interworking point was created there. All sites in the trial networks were physically connected by Gigabit Ethernet (GbE) links. We evaluated the interoperability of a lambda switch capable (LSC) layer of the ASON/GMPLS networks and successfully achieved GbE call set up over multiple ASON and GMPLS network domains [9].

Figure 5 shows the overview of the field trial network. Seven locations were connected by GbE links. These GbE links formed the data plane. The control plane of each network domain was formed by dedicated Ethernet connections. The inter-carrier E-NNI point was constructed at the NICT Kei-han-na site. As shown in Fig. 6, six network domains were interconnected by the E-NNI gateway node. Nine GbE E-NNI links were created among domains. The E-NNI gateway nodes worked as a photonic cross-connect (PXC) system.

Routing Interworking Results

In the ASON domain, a globally unique IPv4 TNA was assigned to all UNI links as a reachable end-point address. All TNAs, as well as adaptation information such as the switching capability of the UNI node and an encoding type of UNI link in each domain, were advertised to the E-NNI node as reachability information by using an I-NNI routing protocol, namely, OSPF. In the GMPLS domain, a globally unique IPv4 address was assigned to all end points as reachable addresses. It is desirable to automatically extract only required reachability information, namely, the reachable TNA/IPv4 address and adaptation information, in order for the E-NNI node to distribute them to other domains. However, in this trial, some equipment did not support this function. The reachability information to be advertised was manually configured at E-NNI nodes.

All reachablity information was successfully exchanged by the developed BGP4-TE. The reachability information advertised from other domains was summarized by the E-NNI gateway node and redistributed to its domain by OSPF with proprietary extensions. Some equipment did not support this feature. Therefore, an OSPF AS-EXTERNAL-link state attribute (LSA) also was used to redistribute a reachable TNA/IPv4 address list. A route-calculation engine based on CSPF can use the redistributed reachability information and/or the AS-EXTERNAL-LSA to determine the route to other domains and create ERO for signaling. Thanks to appropriate address assignment, as well as our developed routing protocols implemented in E-NNI nodes, we could successfully exchange routing information among E-NNI nodes to support end-to-end call set-up signaling.

Signaling Interworking Results

Several combinations of multi-domain call set up were examined. Some that successfully set up the call and video signals over IP were transferred on the GbE links. The successfully established calls between domains are listed in Table 1. They include ASON from/to ASON, ASON from/to GMPLS overlay, ASON from/to GMPLS peer, and GMPLS peer from/to GMPLS overlay. Interworking at the E-NNI node enables us to create a seamless call without considering the architecture difference.

In this trial, the reachable IPv4 address was assigned to the egress link. Several types of non-IP router equipment were in favor of the unnumbered addressing. Unfortunately, we did not implement EGRESS_LABEL support. Therefore, a node-ID was utilized as a destination address and at the E-NNI gateway-assigned destination interface ID statically. This should be resolved in a future trial.

Future Work

For this challenge, basic call set-up and tear-down functionality among ASON and GMPLS network domains was evaluated. There are many optional features such as end-to-end protection and restoration, multi-homing, numbered addressing versus unnumbered addressing, IPv4 destination address versus IPv6 destination address, and multi-layer network connections. We already examined this E-NNI gateway function, and it could be applicable to not only the LSC layer network, but also to the time division multiplex (TDM) switch capable network [9] and the layer2 switch capable (L2SC) network [10]. The development of a multilayer inter-carrier E-NNI, for example, supporting L2SC and LSC is our next challenge.

CONCLUSIONS

This article discussed small differences between the ASON control plane function and the GMPLS control plane function. These differences can be overcome by the interworking function described in this article. Seamless call set up over multi-c--arrier domains becomes possible. The demonstrated interworking operation is expected to relax the choice of the adopted control plane functions for carriers/service providers, because ASON networks and GMPLS networks can be interworked easily. The interoperability of signaling and routing can be ensured over multiple domains of different models, and as a result, this leads to the acceleration of the deployment of ASON and GMPLS networks. However, regarding the routing protocol extensions, some scalability issues must be analyzed and the problems should be solved.

The authors note that this activity can help enhance the functional advancement of the heterogeneous control plane technology, for example, ASON and the homogeneous control plane technology, for example, GMPLS each other.

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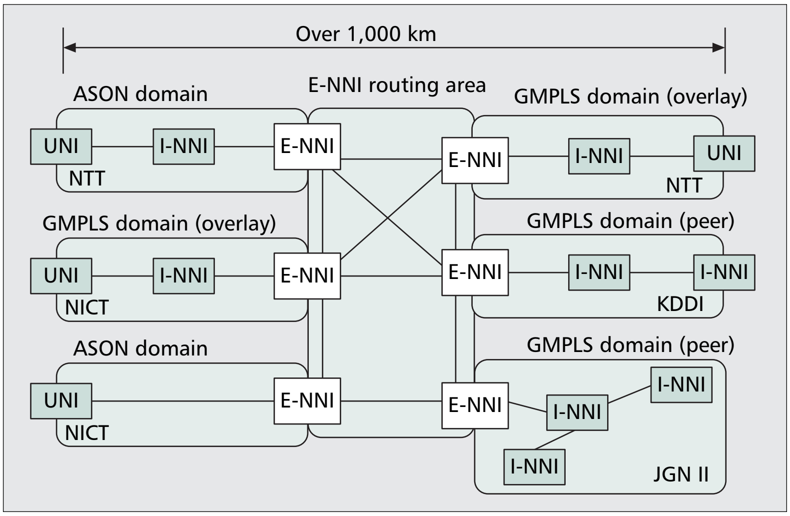

Figure 6. *Six trial networks. Two ASON LSC network domains and four GMPLS LSC network domains.*

REFERENCES

[1] E. Mannie, ed., "Generalized Multi-Protocol Label Switching (GMPLS) Architecture," IETF RFC3945, Oct. 2004.

[2] ITU-T Rec. G.8080, "Architecture for the Automatically Switched Optical Network (ASON)," June 2006.

[3] ITU-T Rec. G.7713.2, "Distributed Call and Connection Management: Signaling Mechanism Using GMPLS RSVP-TE," Mar. 2003.

[4] G. Swallow *et al.*, "Generalized Multiprotocol Label Switching (GMPLS) User-Network Interface (UNI): Resource ReserVation Protocol-Traffic Engineering (RSVP-TE) Support for the Overlay Model," IETF RFC 4208, Oct. 2005.

[5] L. Berger, Ed., "Generalized Multi-Protocol Label Switching (GMPLS) Signaling Resource Reservation Protocol-Traffic Engineering (RSVP-TE) Extensions," RFC 3473, Jan. 2003.

[6] A. Farrel, J.-P. Vasseur, and A. Ayyangar, "A Framework for Inter-Domain Multiprotocol Label Switching Traffic Engineering," RFC 4726, Nov. 2006.

[7] T. Otani *et al.*, "GMPLS Inter-Domain Traffic Engineering Requirements," internet draft draft-otani-ccamp-gmpls-interas-te-07.txt, Dec. 2007, work in progress.

[8] H. Otsuki, "Issues on GMPLS Inter Carriers ENNI and a Prototype Node Based On Linux," *Proc. MPLS '06*, Oct. 2006, p. 414.

[9] S. Okamoto *et al.*, "Field trial of Signaling Interworking of Multi-Carrier ASON/GMPLS Network Domains," *Proc. OFC '06*, Mar. 2006, PDP47.

[10] H. Otsuki *et al.*, "L2SC Inter-Carrier Interface Interoperability Trial," *Proc. MPLS '07*, Oct. 2007, p. 314.

BIOGRAPHIES

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