SURVEY PAPER *Special Section on Feature Topics on Latest Trends in Optical Networks*

GMPLS Based Survivable Photonic Network Architecture

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SUMMARY The objective of this paper is to survey the Generalized Multi-Protocol Label Switching (GMPLS) based recovery technology for optical transport networks. This paper introduces standardization activities of the GMPLS based recovery technology in the Internet Engineering Task Force (IETF), and recent progress of related experiments. In addition, this paper extracts requirements for the GMPLS based recovery technology through the evaluation of existing network elements, which can be client nodes of the optical transport networks. The results of field evaluations on the GMPLS based recovery technology are also introduced in this paper. Then, this paper addresses the issues for future deployment of the GMPLS based recovery technology for the optical transport networks.

key words: *optical network, optical path, GMPLS, restoration*

1. Introduction

The recent prevalence of broadband access services such as Asymmetric Digital Subscriber Line (ADSL) or Fiber to the Home (FTTH) service requires a wide bandwidth for optical backbone networks. Thanks to the maturity of optical component device technologies such as optical amplifiers, wavelength multiplexers or de-multiplexers, and optical switching devices, the nationwide deployment of reconfigurable optical add/drop multiplexers (ROADMs) and optical cross-connects (OXCs) [1] is fast becoming a feasible solution for network operators to meet the recent intensive traffic demand. In ROADM/OXC networks, Operation, Administration, and Maintenance (OA&M) functionality is achieved through the ITU-T G.872 based optical transport network (OTN) architecture [2], which employs a three-layer architecture. In particular, the optical path layer plays a key role not only in the design of the network, but also in the assessment of reliability [3]. The recovery functionality in the optical path layer plays a critical role in achieving carrier grade reliability in the optical transport networks.

This paper surveys recent studies on network recovery schemes in optical transport networks. Many of the basic ideas and insights into recovery schemes originate from the study of the Synchronous Digital Hierarchy (SDH)/Synchronous Optical Network (SONET) [4], [5] or the Asynchronous Transfer Mode (ATM) [6], [7] networks. There are also several well compiled books in the market [8]. Therefore, this paper focus on the recovery schemes based on the emerging framework, Generalized Multi-Protocol Label Switching (GMPLS) [9], [10], which is a protocol set for the control plane. The main objective of the GMPLS as a derivative of the MPLS control technology [11] is the unification of network control among various types of network elements (NEs) across multiple network layers. From the early stages of the GMPLS standardization process, there has been much anticipation regarding GMPLS as the standardized technology to achieve highly resilient and reliable networks [10], [12]. The GMPLS based network recovery scheme paves the way for a consistent approach toward network recovery across the network layers. Also, this scheme can provide the opportunity to create a new reliability class of services for network operators.

Therefore, one important objective of this investigation is the clarification of the requirements and the remaining problems to satisfy those requirements regarding the GMPLS based network recovery scheme making use of signaling and routing functionality of the GMPLS technology. To provide background for this paper, Sect. 2 provides an overview of the GMPLS specification discussed in the Internet Engineering Task Force (IETF) and explains the relationship with historical studies conducted on the SDH/SONET and ATM networks. Section 3 surveys the current network equipment as the client of ROADM/OXCs and discusses the requirements for the network recovery schemes in the optical path layer. Section 4 surveys the current status of GMPLS based network recovery scheme including field trials over JGN II networks. Then, we discuss the issues facing its commercialization.

2. GMPLS Based Network Recovery Schemes

2.1 Position of GMPLS Based Network Recovery Schemes

2.1.1 Centralized Control Scheme

Network recovery schemes can be divided into three categories from the viewpoint of network control architecture. The first one is a centralized control scheme, which uses a centralized network management system to perform all restoration functions. AT&T's FASTAR and NTT's SUCCESS are well known systems that have a restoration func-

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Manuscript received October 17, 2006.
Manuscript revised February 16, 2007.

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DOI: 10.1093/ietcom/e90–b.8.1952

tionality for VC-3 paths in SDH networks [13]–[15]. These systems incorporate failure detection, a route search engine to discover alternative routes, and a control mechanism to create or move the VC-3 paths. Since the centralized scheme manages all network resources, it is easier to discover proper backup paths based on global path accommodation design. However, the restoration speed is relatively slow because of the concentration of the processing load at the centralized Network Operation Center (NOC) and the round trip time of the control messages between NEs and the NOC.

2.1.2 Automatic Protection Switching (APS) Scheme

The second category is the Automatic Protection Switching (APS) scheme. This scheme achieves path layer recovery simply by controlling the protection switch at the termination point (TP) of the paths. The simplicity of the APS operation results in high-speed switching of less than 50 msec. We should also note that a 1+1 APS architecture can achieve hitless recovery of the paths.

The GMPLS control plane has a supplemental role in the APS operation. Namely, the GMPLS control plane provides only notification functionality to inform TPs of the switching status between them. However, this notification functionality plays an important role if the network operators try to achieve highly reliable network services using recovery scheme escalation [16], [17], or if the protection path is used as a Forwarding Adjacency LSP to accommodate client LSPs. The notification message can be utilized as a triggering message to change the switching status or Traffic Engineering (TE) parameters in routing protocols.

2.1.3 Distributed Control (Self-Healing Network) Scheme

The third category is distributed control schemes, which are often called "self-healing network" (SHN) schemes. In the APS scheme, the network operators are required to have more than double the network resources for working paths to accommodate both working and backup paths. The SHN scheme provides a backup resource sharing scheme amongst backup paths to reduce backup network resources [18], [19]. On the other hand, this scheme can achieve fast network recovery by eliminating not only the near-real time response requirement but also the database dependency in the NOC.

The concept of the SHN scheme under the distributed control plane architecture was proposed by Grover in 1987 [4]. As a part of the evolution in transport technology, many network researchers have been devoted to implementing the self-healing control mechanism into Asynchronous Transfer Mode Cross-connects (ATM-XCs) [6], [7]. The major difference between the SDH/SONET and the ATM networks is the granularity of the path bandwidth. For example, an SDH/SONET path should be a multiple of STS-1 or the VC4 bandwidth, while the ATM virtual path can be arbitrary. In particular, the pre-planned backup virtual path can be a zero bandwidth, which results in effective reduction in the backup network resources. MPLS technology [11] has been taking over many functionalities developed for the ATM networks. The MPLS based self-healing control mechanism is called MPLS Fast Re-Route (MPLS-FRR), which achieves fast restoration for Label Switched Paths (LSPs) [20]. The MPLS-FRR proposed achieves fast restoration mechanism in less than one second.

The GMPLS control-plane can also achieve the SHN scheme by utilizing the signaling mechanism of the GMPLS [21]. Namely, the GMPLS signaling mechanism is used not only to create or delete a path, but also to switch or revert traffic between the working and backup paths following a failure network state. Furthermore, a combination approach that utilizes GMPLS routing and signaling mechanisms achieves robust networking against multiple failure conditions.

2.2 Status of GMPLS Based Recovery Functionality Standardization in IETF

The standardization process of fundamental GMPLS based recovery drafts is in the final stage. Detailed information can be obtained from the IETF Web site (http://www.ietf.org) or a book by Farrel [22]. Discussion on the GMPLS based recovery was initiated in 2002 with the definition of terminology and clarification of the GMPLS functionality and recovery process. These discussions were filed as RFCs as follows.

- Functional Definition Draft RFC4426 [23]
  The Functional Definition Draft clarifies the GMPLS functionality to achieve various types of network recovery.
- Terminology Definition Draft RFC4427 [24]
  The objective of this draft is to define terminology regarding the network recovery schemes such as protection and restoration.
- Recovery Analysis Draft RFC4428 [25]
  The objective of this draft is the clarification of the recovery process using the terminology defined in RFC 4427. Through the analysis of this draft, various types of network recovery schemes are categorized from the viewpoints of routing strategy of both the primary and backup paths, path computation timing, and resource reservation timing of the backup paths.

The core solution draft of the GMPLS recovery functionality is filed in the "End-to-End Recovery Draft" [26]. In particular, the extensions of a protection object and primary path route object are described for signaling messages. The End-to-End Recovery Draft provides a comprehensive solution to create working and protection paths employing the APS scheme, and provides several SHN schemes such as pre-planned restoration and dynamic restoration (full LSP re-routing). Here, the pre-planned restoration pre-calculates the route of backup paths and allocates resources for the backup path in advance of failure events. On the other hand, dynamic restoration calculates the route for backup paths after a failure event occurs. Figure 1 shows the categorization

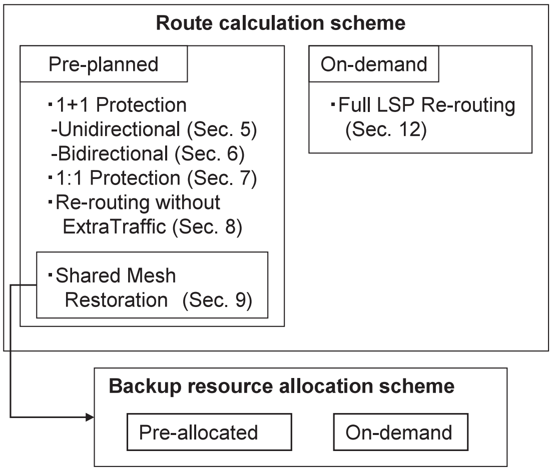

Fig. 1 Categorization of GMPLS based restoration schemes in [26].

of the recovery scheme discussed in the End-to-End Recovery Draft. The other solution draft is the “Segment Recovery Draft” [27]. This draft specifies the protocol extensions to create a segment backup path between branches and merge nodes in the backup path. The switching schemes between the branch and merge nodes follow the specifications in the End-to-End Recovery Draft.

At this moment, the GMPLS cannot support control of Sub-Network Connection Protection (SNCP) and ring protection schemes such as the Multiplex Section Shared Protection Ring (MS-SPRING) [28].

2.3 Status of Studies on GMPLS Based Recovery

As discussed in the previous section, the GMPLS can achieve pre-planned restoration and full-rerouting restoration. The study of the pre-planned restoration scheme by using the distributed control plane has been conducted from the early stage of this research field. A research group of NTT demonstrated fast optical path recovery within 1 sec by using the ATM OA&M cell based signaling in the control plane in 2002 [29]. Recently, an OTN signaling approach was also proposed by Mori et al. [30]. They demonstrated fast optical path recovery within 30 msec in the optical domain.

In 2001, an AT&T research group evaluated the performance of the GMPLS control plane to switch over multiple LSPs using simulation networks without real optical switches [31]. In 2004, a subsequent NTT study achieved GMPLS based pre-planned restoration supporting M:N shared mesh restoration [32], [33]. A recent study by CNIT achieved fast restoration of less than 50 msec by using GMPLS signaling [34]. Also, there was an inter-operability study of the GMPLS based pre-planned restoration [35] and a study by Alcatel on an implementation evaluation [36]. A joint research group comprising NICT, NTT, and KDDI successfully demonstrated inter-carrier GMPLS networking in an actual operational environment [37]. The demonstration also employed a hierarchical signaling architecture.

The GMPLS based dynamic restoration scheme has several functionalities. This scheme calculates the route for the backup path in the event of a primary path failure. This scheme achieves optical path recovery in the range of 800 msec to 7 sec [38]–[40]. In addition, the concept of the User Network Interface (UNI) shared restoration was proposed and UNI link failure restoration was shown to achieve stable IP/Ether network operation even in the case of IP/Ether interface failure making use of corporative optical recovery between OXC and its client IP/Ether Switches [41].

3. Requirement Survey

The research team of Bellcore analyzed the influence of transport path failure to each service [5]. Through this research, they categorized the target of the restoration time into five classes as shown in Table 1. The important target range in this paper is represented by Categories I and II. Category I is the restoration time of less than 50 ms. This category achieves recovery without interruption for most services. Category II is the restoration time ranging from 50 ms to 200 msec. This category achieves service recovery in less than 5% of the telephone call outages. However, the Bellcore research is more than ten years old. An analysis on current equipment would be useful in the service networks mentioned in this section, since the NEs used for the service network have been replaced by Ethernet Switches and IP routers over the last decade. Thus, the key issue of the survey conducted in this section is the performance evaluation of the failure detection time after a physical link failure and the processing time to change the packet or frame forwarding table in IP routers or Ethernet Switches, respectively.

Figure 2 shows the evaluated performance of various IP routers and Ether switches. The failure detection time of most sets of vendor equipment is approximately 100 ms. On the other hand, one set of vendor equipment achieves failure detection in 17 ms. Thus, there are client NEs that fit into Category I that sense a failure in less than 50 ms. Considering future technical advancements, the NEs will have some device that can conceal the state of network failures while activating the GMPLS based recovery process. Without such functionality, the optical path layer recovery may compete with the recovery process in the upper layer.

Figure 3 shows a subsequent evaluation of an IP router by measuring the down time of IP forwarding as a function of the link failure time. Excess down time is not observed if the failure time of the physical link is less than 100 ms. In the range of 100 ms to 10 s, the NE shows unstable behavior that causes an outage in the IP forwarding of more than 1 s. If the link failure time exceeds 10 seconds, the Border Gateway Protocol (BGP) session detects a failure and this results in a longer failure recovery time in the IP layer.

In conclusion, the target of the GMPLS based restoration scheme should be Category II, but the upper limit should be 100 ms not 200 ms to achieve ideal and feasible optical path layer recovery. However, the recovery time of

Table 1 Restoration time categories.

Category	Restoration Time
I	< 50 ms
II	50 ms < 200 ms
III	200 ms < 2 s
IV	2 s < 10 s
V	10 s < 5 min

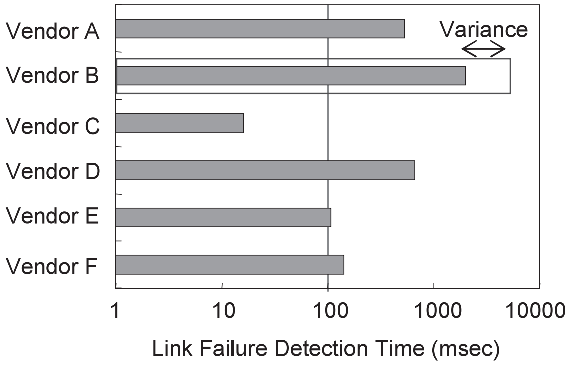

Fig. 2 Measured detection time for physical link failure.

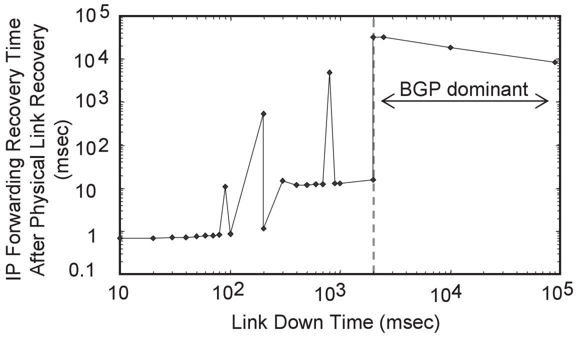

Fig. 3 Processing time to recover IP transport as a function of the physical link failure time.

less than 100 ms is a difficult target for the distributed control plane as discussed in [5]. Thus, some mechanism is essential that conceals the failure in the optical path layer or delays the activation of failure recovery process in the Ether or IP layer in coordination with the GMPLS control plane. Through this process, the network operator can achieve the stable GMPLS based optical path recovery by avoiding the contention of recovery process across the network layers.

4. Evaluation of GMPLS Based Restoration Scheme

NTT conducted both a laboratory test and a field trial on GMPLS based restoration. The objective of the laboratory test is to evaluate the statistical performance of the GMPLS based restoration. On the other hand, the objective of the field trial is to verify the performance of the GMPLS based restoration including Wavelength Division Multiplexing (WDM) transmission systems. The evaluated restoration scheme is the pre-planned restoration scheme, which dynamically creates backup resources in the event of a primary path failure.

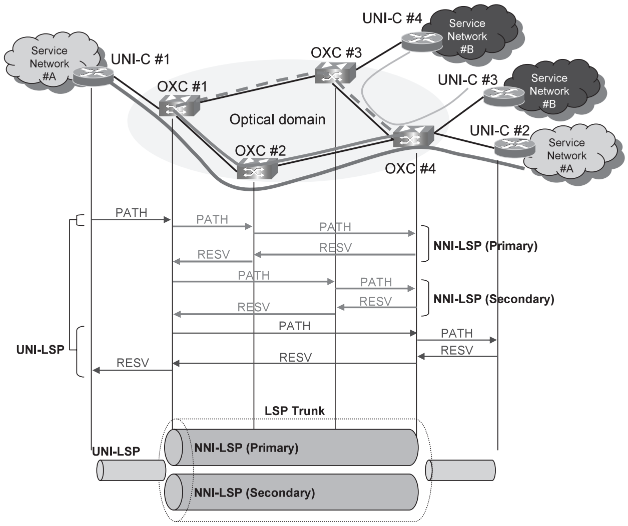

Fig. 4 Network and logical path architecture defined.

4.1 Laboratory Test

NTT conducted an evaluation of the multi-service gateway proposed in [42], which coordinates Internal Network Node Interface (I-NNI) signaling and UNI/External Network Node Interface (E-NNI) signaling entities based on the hierarchical signaling architecture.

Figure 4 shows the proposed Label Switched Path (LSP) architecture. Note that one UNI-LSP is the UNI section LSP (UNI-LSP) between UNI Signaling Agent Client (UNI-C) routers is logically "stitched" onto both primary and secondary NNI section LSPs (NNI-LSPs) between the OXCs when the service class is pre-planned restoration. This functionality seems trivial but simplifies the association of the NNI-LSP and UNI-LSP in the management plane. Also, this architecture provides a novel solution to applying the GMPLS based pre-planned restoration scheme to the UNI-LSP, because the UNI-LSP is protected by the end-to-end of the corresponding NNI- LSP. Thus, the sub-network restoration for UNI-LSP is achieved in the optical domain without using the protocol extensions for the segment LSP recovery. In this LSP architecture, a UNI-LSP is created as shown in Fig. 4.

A user RSVP PATH message launched from UNI client 1 (UNI-C #1) is sent to OXC #1. At OXC #1 this message triggers the NNI-LSP between OXCs #1 and #4. OXC #4 returns RSVP RESV messages to OXC #1. At this point, the NNI-LSPs are successfully established. The initial user RSVP PATH message is forwarded to the termination node of NNI-LSP, i.e., OXC #4, then to UNI-C #2. UNI-C #2 returns a RSVP RESV message to create a UNI section LSP (UNI-LSP) between UNI-C #1 and UNI-C #2 over the NNI-LSP.

Figure 5 shows the experimental setup consisting of four actual OXCs, OXC emulators, and UNI-C routers. The

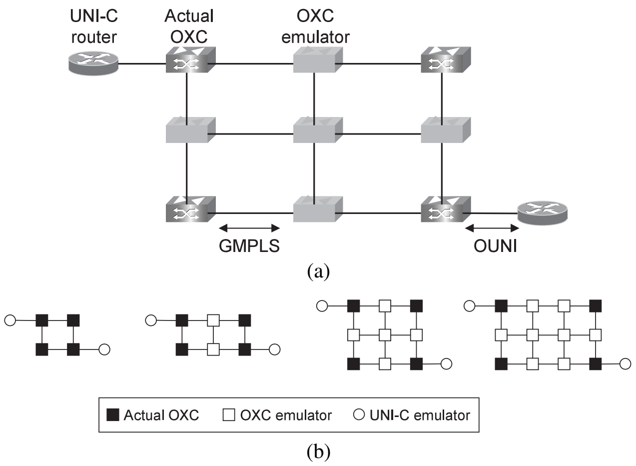

Fig. 5 Configuration of experimental setup.

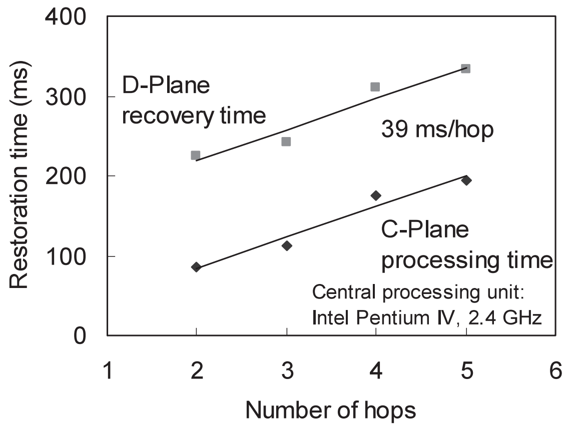

Fig. 6 Performance of the pre-planned restoration as a function of the number of hops of backup paths.

actual OXC comprises 8 × 8 matrix switches and interfaces with an optical signal regeneration functionality. The OXC emulators have no actual switching fabric. The recovery time of the optical signal is approximately 200 ms in the case of 5 hops.

Figure 6 shows the statistical performance of the pre-planned restoration when evaluating the IP packet recovery time of the IP packet (D-Plane recovery time) and control plane (C-Plane) recovery processing time. When the number of hops in this network is two, the C-Plane recovery processing time is 87 ms. The C-Plane recovery processing time is increased at the rate of 39 ms/hop. We also confirm that the recovery of the IP packet takes 100 msec in addition to the recovery in the optical domain. We confirm that the performance of the optical receiver is also important to achieve fast restoration in order to satisfy the requirements described in the previous section.

4.2 Field Trial over JGN II Testbed

Another important technical issue is the verification of the GMPLS based restoration over WDM transmission systems. NTT conducted an operational evaluation of the optical path restoration functionality over the JGN II testbed including the restoration operation triggered by the backward defect indication (BDI) signal.

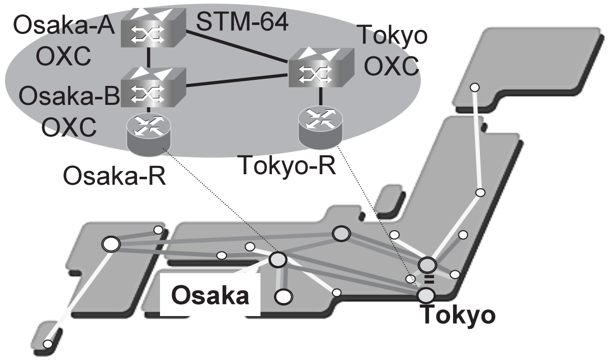

Fig. 7 Network configuration constructed over JGN II testbed.

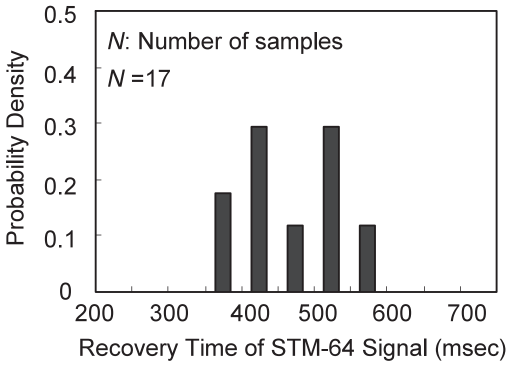

Fig. 8 Histogram of restoration time measured in STM-64 layer.

Figure 7 shows the experimental network configuration constructed over the JGN II network. One Tokyo OXC is connected to two OXCs at Osaka via STM-64 links. The GMPLS control plane was constructed using Layer 2 service in the JGN II network. The measured average round trip time using the Internet Control Message Protocol (ICMP) was 7.5 msec between Tokyo and Osaka.

Figure 8 shows the probability density of the recovery time of an STM-64 signal for the optical path restoration scenario. Here, the fiber accommodating the primary optical path was cut at the egress side of the optical path. The average time to recover from the cut fiber to the STM-64 signal level was 432 msec. This is longer than 200 msec measured in the optical domain evaluation of the 2-hop backup path scenario as discussed in the previous section. Here, the recovery time of the STM-64 signal is measured using the SDH analyzer by monitoring the Alarm Indication Signal (AIS). We believe that the major portion of the 200-msec delay is the response time of the STM-64 interfaces.

5. Discussion

As shown in the previous section, the recovery time of the GMPLS based optical path restoration scheme is in the range from 200 to 400 msec for a 5 node network and the restoration time increases 39 msec per hop. This level of performance is insufficient to satisfy the requirements from the client NEs. Considering the fact that some types of vendor equipment can detect a physical link failure in approximately 10 msec, the implementation of a data-plane alarm signal control mechanism in coordination with the control plane is mandatory to minimize the impact on the change in the IP layer status. Furthermore, we recognized that the startup time of the optical receivers is non-negligible, since it takes approximately 100 to 200 msec after optical signal recovery for typical STM-16/64 receivers to synchronize SDH/SONET frames. We recognized some issues that need to be improved for the GMPLS protocols. In particular, the current OSPF-TE protocol does not have the capability to advertise a shareable bandwidth to achieve resource sharing among the backup paths. It is also mandatory to extend the GMPLS protocols to satisfy the requirement of the optical path accommodation design considering differential delays between the primary and backup paths considering the current operational requirement.

6. Conclusions

In conclusion, this paper focused on the survey of GMPLS based "self-healing" networking technology. Our conclusion of the requirement survey is that the target of the GMPLS should be 100 msec; however, there are several issues that must be addressed to satisfy this requirement. The first issue is the performance of the RSVP-TE functional block to achieve fast forwarding of restoration messages without delay. In order to satisfy this requirement, the hardware implementation for the part of RSVP-TE processing can be one of choice. The evolution of Field Programmable Gate Array (FPGA) technology can enable cost-effective implementation of a part of RSVP-TE protocol processing and [43] confirmed micro-second order processing time of RSVP-TE protocols. The second issue is the performance of the receiver to achieve fast synchronization with the optical data stream. Finite design of the optical receiver circuit is required to satisfy this requirement.

As for the architectural discussion, our research group proposed a hierarchical architecture. The client LSPs are "stitched" to the NNI-LSP in the optical domain. The operation of NNI-LSP provides an excellent scheme to cope with failure recovery and maintenance activity using the end-to-end control to the NNI-LSP. Through the process of combinational study including such operational considerations and the remaining problems discussed above, we expect that the GMPLS based self-healing network scheme will provide profitable opportunities for both the network operator and their clients.

Acknowledgments

The authors thank Kazuo Hagimoto, Yoshihiro Takigawa, and Yoshinori Hibino of NTT Network Innovation Laboratories for their support of this study. The authors also thank Mitsunori Fukutoku of NTT West, Koji Sasayama of NTT Network Service System Laboratories, and Shuto Yamamoto for their helpful discussions.

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