An Inter-area SRLG-disjoint Routing Algorithm for Multi-segment Protection in GMPLS Networks

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***Abstract*— In this paper, we consider a mechanism for providing path protection with SRLG considerations in multi-area GMPLS networks, where routing domain is divided into multiple areas. Many LSP protection schemes have been proposed, but most of them assume a flat network consisting of only one area. However, in large-scale networks, like those of nationwide ISPs, the routing domain usually consists of multiple areas to avoid scalability problems. We propose a multi-segment SRLG protection scheme that can be applied to multi-area GMPLS networks, and also present the framework of inter-area GMPLS traffic engineering. The key to our proposal lies in the inter-area SRLG-disjoint routing algorithm, called ISDR, that enables us to find SRLG-failure-independent protection LSPs with multiple segments. We investigated the performance of our scheme through extensive simulations, and the simulation results show that our approach is sure to find a pair of SRLG-failure-independent paths at the cost of a moderate increase in bandwidth consumption.**

I. INTRODUCTION

The explosive spread of the Internet in recent years has led to various applications emerging on IP (Internet Protocol) networks. For example, VoIP (Voice over IP), electronic commerce, and IP-based VPNs (virtual private networks) are becoming very popular these days. IP networks are thus becoming an integrated infrastructure for the delivery of various services. Such applications require assured quality of service (QoS) and high network reliability [1].

The rapidly increasing bandwidth requirements of IP traffic mean that all-optical networks will provide the backbone of the next-generation Internet. GMPLS (generalized multiprotocol label switching) has been proposed as a suitable basis for optical networks in this role [2]. It extends MPLS to support the dynamic provision of lightpaths and provide network survivability through a protection and restoration technique.

For reliability, LSP (label switched path) protection is a commonly used approach to enhance the availability of a network. Many research groups have proposed LSP protection mechanisms, which use multiple disjoint LSPs between pairs of nodes [3], [4]. In these algorithms, one of the key issues is how to find multiple disjoint LSPs between pairs of nodes.

Algorithms for finding disjoint LSPs have been extensively studied. Lawler [5] proposed the well-known multipath algorithm, which can find k shortest paths. The computation complexity of his algorithm is $O(k(m+n\log n))$, where n and m are the numbers of nodes and links in the underlying network. Saito *et al.* [6] proposed multipath algorithms, which can be used for load balancing as well as failure recovery in MPLS networks. Their schemes use multiple multipoint-to-point LSPs. They formulate the MP-to-P LSP design problem as a 0-1 integer programming problem. However, those algorithms do not take into account the SRLG (shared risk link group) concept. Without considering SRLG, we cannot ensure the 100% recovery performance of path protection, even for a single point of failure in the network. Recently, from the viewpoint of reliability, algorithms for finding a pair of SRLG-disjoint paths have received much attention.

Oki *et al.* [7] proposed a heuristic SRLG-disjoint path finding algorithm for shared LSP protection in GMPLS networks. The disadvantage of their algorithm is that they cannot find SRLG-disjoint paths efficiently if the network contains“traps [8]”(described later). To avoid the “traps” problem, Qiao *et al.* [8] proposed an SRLG-disjoint routing algorithm. Their algorithm can avoid ”traps” by using a multi-segment protection technique, called PROMISE, and provide SRLG-failure-independent protection.

However, those algorithms assume a flat network, where each node has complete information about the network topology. In large-scale IP networks like those of nationwide Internet service providers (ISPs), however, the routing domain usually consists of multiple areas [9], [10]. In hierarchical networks, a node only has information about the area to which it belongs, except for area border routers (ABRs). Iwata and Fujita [11] proposed QoS path computation algorithms in hierarchical MPLS networks. Because the redundancy of ABRs was not considered in their algorithms, they could not construct disjoint LSPs that spanned multiple OSPF/IS-IS areas. From the viewpoint of reliability, it is important to construct end-to-end disjoint LSPs. If any link is shared by primary and secondary LSPs, the network cannot recover from its failure and all traffic on the path will be disconnected.

To solve this issue, we proposed a mechanism for setting up end-to-end disjoint LSPs in hierarchical multi-area

MPLS networks. In [12], because our method was mainly focused on providing end-to-end disjoint LSPs in MPLS networks, we did not take the SRLG concept into consideration. Hence, the method proposed in [12] cannot be used to set up SRLG-disjoint LSPs in multi-area GMPLS networks. The main purpose of developing such algorithms is to provide pairs of SRLG-failure-independent protection LSPs in multi-area GMPLS networks.

Hence, in this paper, we propose a method for setting up end-to-end SRLG-disjoint LSPs in multi-area GMPLS networks. In our scheme, disjoint LSPs can be computed in a distributed manner, so there is no need for any servers that have complete information about the topology and calculate all disjoint LSPs in the network. Thus, our approach scales well and can be applied to large-scale GMPLS networks.

The rest of this paper is organized as follows. In Section 2, we briefly review the SRLG concept and then present the framework of inter-area GMPLS traffic engineering. Next, we propose a method for constructing pairs of SRLG-disjoint paths in Section 3, and report on the results of the extensive simulations we performed to evaluate the performance of our algorithm in Section 4. A brief conclusion is provided in Section 5.

II. Background

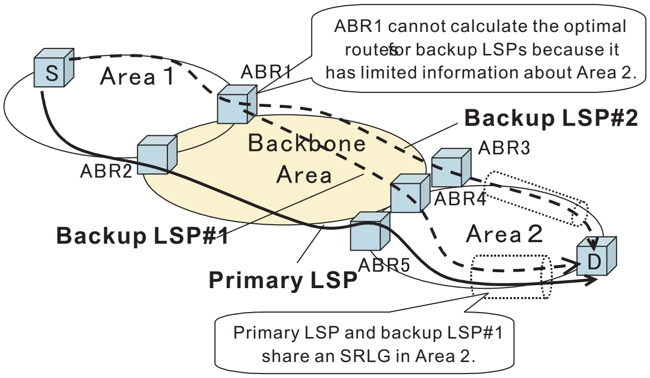
In multi-area GMPLS networks, one of the most challenging issues is calculating inter-area LSPs routing. This is because no node in the network has complete information about the entire network topology. We could deploy a centralized server that has complete topology information, but this solution would lead to scalability issues. Instead, we propose a distributed inter-area LSP routing calculation scheme. Before presenting our proposal, we briefly explain why inter-area LSP routing is challenging, and also introduce the SRLG concept.

A. Routing Information Exchange

In a multi-area GMPLS network, routing protocols such as OSPF (open shortest path first internet routing protocol) [10], [14] and IS-IS (the intermediate system to intermediate system routing protocol) [15] are used to exchange network topology information with other nodes, and a routing domain consists of multiple areas [9] as shown in Figure 1. In a hierarchical multi-area network, each node only has the information about the area to which it belongs, except for area border routers (ABRs).

The major difficulty in constructing LSPs that span multiple areas lies in inter-area LSP routing, especially disjoint LSPs routing. This is simply because no router has complete information about the entire network topology. To avoid the scalability issues, we use a distributed inter-area LSP routing calculation scheme. We must answer the following questions for solving inter-area LSP routing in a distributed manner:

- Which node provides the function of inter-area LSP routing?
- How does the node collect the routing information for computing the inter-area LSP route?



ABR1 cannot calculate the optimal routes for backup LSPs because it has limited information about Area 2.

Primary LSP and backup LSP#1 share an SRLG in Area 2.

Fig. 1. Example of a multi-area network.

As described in [9], one possible solution for setting up an inter-area LSP is to calculate the LSP route on a per-area basis. Using Figure 1, we briefly explain this approach and also point out the problem caused when setting up inter-area disjoint LSPs.

In Fig. 1, the network consists of two areas and one backbone area. We assume that the initiator (node S in Fig. 1) of an LSP is in a different ISIS/OSPF area from the terminator (node D in Fig. 1) of the LSP. There are two ABRs connecting Area 1 and the backbone area, and three ABRs belong to Area 2 and the backbone area. In Fig. 1, the solid line and dotted lines indicate a primary LSP and its associated backup LSPs, respectively.

Now we consider how to calculate a backup LSP. In this approach, we can find the backup LSP that is disjoint within Area 1. However, when calculating the LSP route within the backbone area and Area 2, ABR2 can calculate the LSP route that is disjoint of the primary LSP within the backbone area. However, because ABR2 does not have topology information about Area 2, it is impossible for ABR2 to select an appropriate ABR. If ABR2 selects ABR5 as an ABR in Area 2, the obtained route will be a backup LSP #1, which shares some links or fibers with the primary LSP in Area 2. Thus, this route fails to provide disjoint LSPs.

To avoid this problem, in our approach, multiple ABRs that belong to different areas solve the inter-area LSP routing in a coordinated manner. The details of our proposal are described in the following section.

B. SRLG Considerations

Here, we briefly review the SRLG concept and also point out that segment protection schemes are useful to provide SRLG protection.

The SRLG concept has been developed in designing failure recovery mechanisms [16]. If a primary LSP and its backup LSP are assigned to different wavelengths in the same fiber, the single fiber cut would result in the failure of both primary and backup LSPs. To avoid this

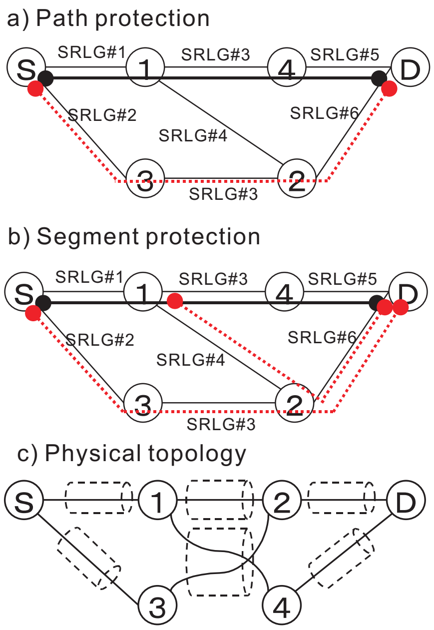


Fig. 2. SRLG protection.

problem, SRLG concept has been introduced to ensure the disjointness of those two LSPs. Figure 2 shows a network with SRLG, where the number associated with each link identifies SRLG. For example, in Fig. 2(a), links 1-4 and 3-2 have the same SRLG number (SRLG #3), which means that these optical links share the same fiber as shown in 2(c). This is the well-known "traps" problem in SRLG networks [8].

To ensure 100% recovery performance, we need to consider SRLG when computing primary and backup LSPs routes. An end-to-end path protection scheme is not suitable for providing SRLG-failure-independent protection [8]. Figures 2(a) and (b) show that a path protection scheme completely fails to provide end-to-end SRLG-disjointness (links 1-4 and 3-2 share the same SRLG) while a segment protection scheme ensures 100% recovery performance for any single point of SRLG failure (For the failure of SRLG #3, the backup path 1-2-D is used). The end-to-end path protection approach cannot avoid "traps" and fails to find SRLG-disjoint paths.

Qiao's approach [8] cannot be used when finding a pair of SRLG-disjoint LSPs in a multi-area GMPLS network, because their algorithms assumed a flat network. Hence, we propose an algorithm for finding a pair of SRLG-disjoint LSPs with multiple segments in a multi-area GMPLS network.

III. PROPOSED ALGORITHM

In this section, we describe our proposal that enables us to set up a pair of SRLG-disjoint LSPs in a multi-area GMPLS network. The key to our algorithm is the inter-area SRLG-disjoint routing (ISDR) algorithm, which finds a set of multipoint-to-point SRLG-disjoint paths. To provide 100% recovery performance for any single point of SRLG-failure, we use a segment protection approach. Our approach can find a set of SRLG-failure-independent protection paths while maintaining better bandwidth efficiency by sharing the link resource among backup paths for different SRLGs.

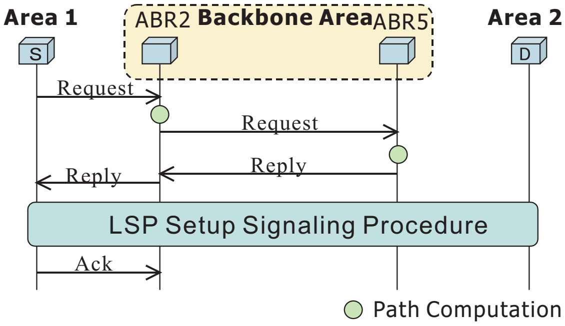


Fig. 3. Signaling sequence of the proposed algorithm.

A. Overview

First, we give a brief overview of our scheme, which enables us to construct end-to-end SRLG-disjoint LSPs in a GMPLS network consisting of multiple OSPF/IS-IS areas. Figure 1 shows an example of the hierarchical network used in our explanation. Now we explain how to set up end-to-end disjoint LSPs from an initiator (or ingress) node (node S) to a terminator (or egress) node (node D) using the proposed scheme. We assume that RSVP-TE is used for GMPLS signaling and OSPF is used as the interior gateway protocol (IGP) in this network. We assume that each area has at least two ABRs, which also belong to the backbone area. Note that the redundancy of ABRs is very important in designing highly reliable IP/GMPLS networks. If there is only one ABR in a certain area and the ABR fails, none of the nodes in that area can send or receive traffic to/from nodes in other areas.

Both ABR1 and ABR2 have topology information about Area 1 and the backbone area, and ABR3, ABR4, and ABR5 have the information on Area 2 and the backbone area. No node has the complete information about the entire network topology. The key to the proposed algorithm is the coordination among multiple ABRs belonging to different areas.

To describe our scheme, we introduce the term 'initiator area' and 'terminator area'. We refer to the area to which an initiator node belongs as an initiator area, and the area of a terminator node as a terminator area. In our scheme, we assume that each ABR in the network provides the function of computing inter-area LSP routing. In this case, ABR2 (or ABR1) calculates the LSP route within the initiator area (i.e., Area 1), and ABR5 (ABR3 or ABR4) solves the LSP routing within both the terminator area (i.e., Area 2) and the backbone area.

Before sending the PATH message to set up primary and backup paths, an initiator node sends a Path Computation Request message to one of the ABRs in Area 1 to solve the end-to-end LSP routing. In this case, node S selects ABR2 and sends the message. When it receives the message from node S, ABR2 calculates the route of both primary and backup LSPs within Area 1. Here, route S-ABR2 (the solid line in Fig. 1) is selected for the primary LSP, and route S-ABR1 is selected for the backup LSP. After that, ABR2 sends the Path Computation Request message to one of the ABRs in Area 2; in this case ABR5 is chosen. ABR2 asks ABR5 to find a pair of SRLG-disjoint paths from ABR1 and ABR2 to node D. To calculate such paths at ABR2 and ABR5, we need an algorithm for finding multipoint-to-point (or point-to-multipoint) SRLG-disjoint paths. To find such paths, we propose the inter-area SRLG-disjoint routing (ISDR) algorithm, which is described in Section 3C.

By executing ISDR, ABR finds route ABR2-ABR5-D for the primary path and route ABR1-ABR3-D (backup path #2 in Fig. 1) for the backup path. After having computed the route within the backbone area and Area2, ABR5 sends the result back to ABR2. Then ABR2 splices the route of Area 1 with that of Area 2 and the backbone area, and sends the route of end-to-end SRLG-disjoint LSPs to node S as the Path Computation Reply message.

Finally, initiator node S receives the Path Computation Reply message and sends the PATH message to set up the primary and backup paths. In the PATH message, node S encodes the routing information computed by ABR2 and ABR5 in an ERO (explicit route object). In this way, a set of SRLG-disjoint LSPs is constructed from initiator node S to terminator node D.

B. Model Description

Before presenting ISDR, we describe a network model and define the problem we are solving. For the algorithm used by ABR5 in Fig. 1, we need an algorithm for finding SRLG-disjoint paths originated by two different nodes and ending at the same destination. From here, our focus is mainly on an algorithm for finding a set of multipoint (MP)-to-point (P) SRLG-disjoint paths. To compute the route within an initiator area, we need an algorithm for finding P-to-MP SRLG-disjoint paths, but it is easily induced from the MP-to-P version of ISDR.

Now we describe the network model to explain our scheme. An optical layer network is modeled as a graph $G = (V, L)$, where V is a set of nodes (optical crossconnects) and L is a set of links. We assume that G has n nodes. Each node is denoted by V_i $(i = 1, \ldots, n)$ and the link between V_i and V_j is denoted by l_{ij}. Each link has a cost, and we denote the cost of link l_{ij} by c_{ij}. SRLG information is indicated by

$$srlg(i,j,k) = \begin{cases} 1 & if \quad l_{ij} \text{ is assigned to } SRLG\#k, \\ 0 & else, \end{cases}$$

where $i, j \in \{1, \ldots, n\}$, and k indicates the SRLG number.

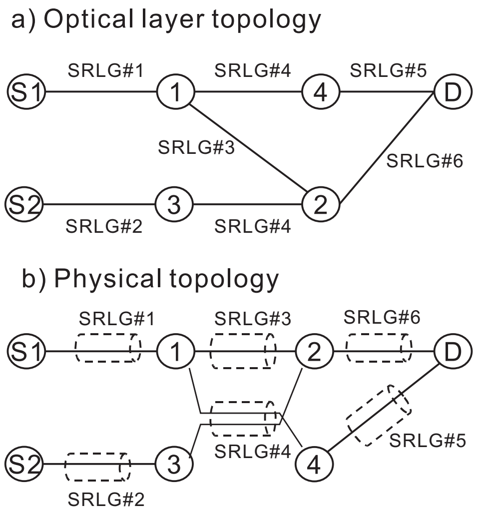


Fig. 4. Example of a network model.

If links l_{ij} and l_{mn} share the same fiber or conduit with SRLG #g, then

$$srlg(i,j,g) = srlg(m,n,g) = 1.$$

Without considering physical layer topology, we can manage SRLG by using the function $srlg(i,j,k)$. We also use the following notation.

- MBW_{ij}: Maximum reservable bandwidth of link l_{ij},
- RBW_{ij}: Residual bandwidth of link l_{ij} $(RBW_{ij} \leq MBW_{ij})$,
- BW_{REQ}: Requested bandwidth of the underlying primary path,
- P_{PP}: Route for the primary path,
- N_{SEG}: Number of backup segments,
- P_{BP}^{i}: Route for the backup path $\#i$ $(1 \leq i \leq N_{SEG})$,
- PS_i: i-th protection segment,
- α: Disjoint factor, $\alpha \geq 1$.

Primary path P_{PP} is divided into multiple backup segments PS_i, and SRLG failure within backup segment PS_i can be restored by backup path P_{BP}^{i}.

$$P_{PP} \cup_{i=1}^{N_{SEG}} PS_i \quad \text{and} \quad PS_i \cap PS_j = \phi \; for \; i \neq j.$$

Figure 4 shows an example of a network model. Here there are seven optical links assigned to 6 physical fibers or conduits. Note that the topology information about an optical layer network with SRLG is distributed to each node by OSPF.

Now we define the problem we are solving. The goal is to find multi-segment protection paths that provide protection from SRLG failure on the primary path while minimizing the bandwidth consumption. Note that these paths are routed from two different nodes to the same node.

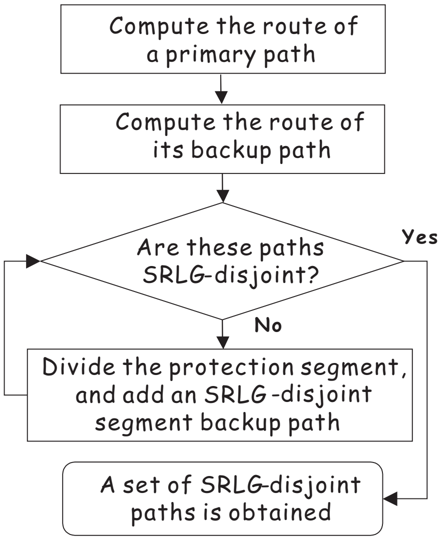


Fig. 5. Flowchart of the ISDR algorithm.

C. Inter-area SRLG-disjoint Routing (ISDR)

Now we describe the ISDR algorithm, which finds a set of SRLG-disjoint paths originating from two different nodes (V_{s1} and V_{s2}, where $s1, s2 \in \{1, \ldots, n\}$.) and destined for the same node (V_d, where $d \in \{1, \ldots, n\}$.), as shown in Fig. 4. The ISDR algorithm is expressed as follows.

Step 1. Eliminate links that cannot satisfy the bandwidth requirement. That is, $c_{ij} = 0$, for $j, k \in \{1, \ldots, n\}$ such that $RBW_{ij} < BW_{req}$. Set the initial number of backup segment N_{SEG} to 1.

Step 2. Compute the shortest path from V_{s1} to V_d for the primary path P_{PP}. Then, set the initial backup segment PS_1 to P_{PP}.

Step 3. Rewrite the cost c_{ij} on P_{PP}. Here, $c_{ij} = (1+\alpha)\, c_{ij}, \quad$ for i, j such that $l_{ij} \in P_{PP}$.

Step 4. Compute the shortest path from V_{s2} to V_d using new cost c_{ij}. The result is P^1_{BP}.

Step 5. Check the SRLG-disjointness of P_{PP} and P^i_{BP} within PS_i ($1 \leq i \leq N_{SEG}$). If P^i_{BP} and P_{PP} share some SRLG, that is, $\exists k$ such that $srlg(i, j, k) = srlg(m, n, k) = 1$, for $l_{ij} \in P_{PP} \cap PS_i$ and $l_{mn} \in P^i_{BP} \cap PS_i$, then go to **Step 6**. Else go to **End**.

Step 6. Divide protection segment PS_i into PS_i and $PS_{N_{SEG}+1}$. Next compute the route of backup path $P^{N_{SEG}+1}_{BP}$ to be disjoint of P_{PP} within $PS_{N_{SEG}+1}$, and $N_{SEG} = N_{SEG} + 1$. Then go to **Step 5**.

End.

P_{PP} and P^i_{BP} ($1 \leq i \leq N_{SEG}$) are used for SRLG-failure-independent protection with multiple segments. Figure 5 shows the flowchart of the ISDR algorithm.

Now we explain how ISDR finds such paths in the network shown in Fig. 4. First, we compute the route for a primary path from node S1 to node D. The route S1-1-4-D is selected. Second, we find the route for a backup path from node S2 to node D. The route S2-3-2-D is selected for the backup path. Then, we check the SRLG-disjointness of those two paths, and we find two links share an SRLG on links 1-4 and 3-2. Now we try to divide the protection segment PS_1 (S1-1-4-D) into PS_1 (S1-1) and PS_2 (1-4-D). Next we compute the backup path within PS_2, and the route 1-2-D is selected. For any SRLG failure on the primary path (S1-1-4-D), we can recover from the failure by switching over to either P^1_{BP} (S2-3-2-D) or P^2_{BP} (1-2-D). Note that the bandwidth of link 2-D is shared by P^1_{BP} and P^1_{BP} to achieve better utilization of network resources.

IV. Performance Evaluation

We performed extensive simulations to evaluate the performance of the proposed algorithm in terms of the network resource efficiency and reliability. We used the network topology shown in Figure 6, which consists of one backbone area and two areas. Each area consists of four nodes, and there are six nodes in the backbone area. The cost of vertical and horizontal links in the network was set to 2 and the cost of a diagonal link was set to 3, and 17 optical links are assigned to 15 distinct SRLGs, which means two pairs of links share an SRLG.

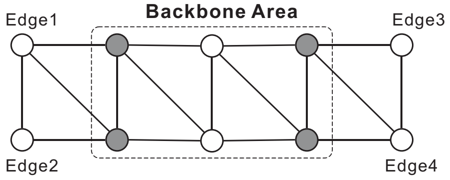


Fig. 6. The 10-node and 17-link ladder-type network topology used in our simulations. Two pairs of optical links are assigned the same SRLG number.

We compared the performance of the proposed algorithm with a conventional inter-area multipath algorithm proposed in [12]. The conventional algorithm, which uses an end-to-end path protection approach, can find a pair of disjoint paths in a multi-area single-layer network, but it does not consider SRLG-disjointness.

A. Efficiency

First, we compared our algorithm with the conventional algorithm and an unprotected approach in terms of network resource efficiency for various numbers of wavelengths per link. Note that the unprotected approach does not use any backup paths, so it does not provide recovery from any failure on primary LSPs. We used it as a benchmark of the network resource efficiency.

For efficiency, we used i) the number of accepted LSPs normalized by the number of all generated LSPs and ii) the average network resource allocated to a pair of primary and backup LSPs as the performance measures. In our simulations, 50 LSPs were randomly constructed between

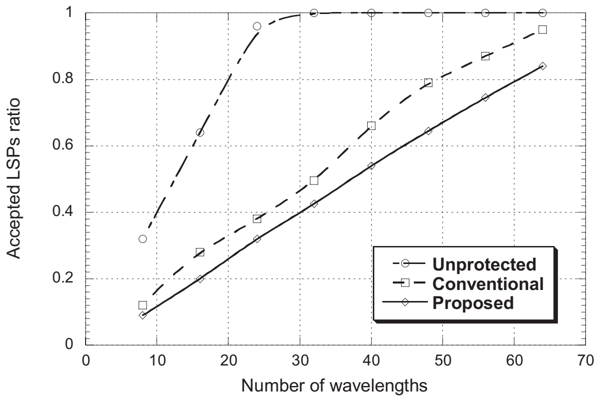


Fig. 7. Comparison of the proposed algorithm and conventional algorithm in terms of the number of accepted LSPs normalized by the number of all generated LSPs.

four edge nodes, and the number of wavelengths was varied from 8 to 64.

Figure 7 compares the accepted LSP ratio in each algorithm as a function of the number of wavelengths. The results show that the unprotected approach (the dotted line) always shows better performance than the other algorithms, and the performance of the conventional algorithm (the broken line) is slightly better than the proposed algorithm (the solid line). However, the maximum difference in the performance of those two algorithms was at most about 10% for 64 wavelengths. To investigate the difference in performance, we also investigated the average amount of network resources allocated to a pair of primary and backup LSPs in each algorithm. Figure 8 shows the results. For example, the average amount of network resources of the proposed algorithm is about 10.5 for 32 wavelengths, while that of the conventional algorithm is about 9.6. This means that the proposed algorithm uses 10% more network resources on average than the conventional algorithm to establish a pair of primary and backup LSPs. The increase in bandwidth usage is mainly caused by using more than one backup path to ensure SRLG-failure-independent protection in the proposed algorithm.

B. Recovery Performance

Next we investigated the performance of each algorithm in terms of recovery performance. Figure 9 shows the recovery performance of each algorithm when SRLG failures were randomly generated. The conventional algorithm (the broken line) completely fails to provide recovery from SRLG failure on primary paths, while our algorithm (the solid line) achieved 100% recovery performance for any single point of SRLG failure. This is because the conventional algorithm does not take SRLG into account while our algorithm finds a set of SRLG-disjoint LSPs by using a multi-segment protection approach.

From our simulations, we conclude that our algorithm consumes slightly more bandwidth than the conventional path protection approach, but this increase in bandwidth usage is necessary to ensure 100% recovery performance from SRLG failure.

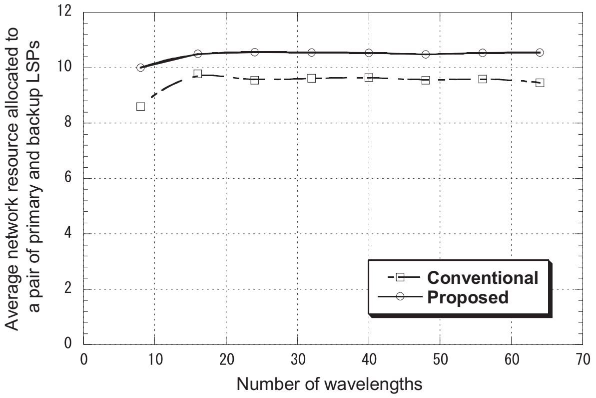


Fig. 8. Comparison of the proposed algorithm and conventional algorithm in terms of the average network resource allocated to a pair of primary and backup LSPs.

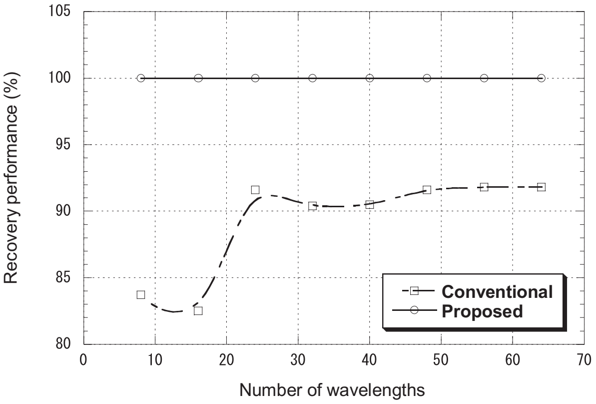


Fig. 9. Comparison of the proposed algorithm and conventional algorithm in terms of recovery performance for a single point of SRLG failure.

V. Concluding Remarks

We proposed a mechanism for providing segment protection with SRLG considerations in multi-area GMPLS networks, where the routing domain is divided into multiple areas. The key to our proposal lies in an inter-area SRLG-disjoint routing algorithm, called ISDR, that enables us to find SRLG-failure-independent protection LSPs with multiple segment. The basic process of inter-area LSP routing is that multiple ABRs that belong to different areas compute the inter-area SRLG-disjoint LSP routing in a coordinative manner. We investigated its performance in terms of efficiency and reliability through extensive simulations, in which we compared the performance of our algorithm with other commonly used algorithms. The simulation results show that our algorithm achieves 100% recovery performance from any single point of SRLG failure in multi-area networks at the cost of a moderate increase in bandwidth consumption.

References

[1] N. Yamanaka, T. Kurimoto, T. Miyamura and M. Aoki,“MSN Type-X: Next generation Internet backbone switch/router architecture,” *Proc. IEEE ICC 2002*.

[2] E. Mannie *et al.*, “Generalized Multi-Protocol Label Switching (GMPLS) Architecture,” IETF, `draft-ietf-ccamp-gmpls-architecture-02.txt`, March 2002.

[3] G. Swallow and R. Goguen, “RSVP Label Allocation for Backup Tunnels,” *IETF*, Internet Draft, `draft-swallow-rsvp-bypass-label-01.txt` , November 2000.

[4] A. Atlas, C. Villamizar and C. Litvanyi, “MPLS RSVP-TE interoperability for local protection/fast reroute,” *IETF*, `draft-atlas-rsvp-local-protect-interop-01.txt`, July 2001.

[5] E.L. Lawler, “A procedure for computing the K best path solutions to discrete optimization problems and its application to the shortest path problem,” *Management Science*, **18**, 401-405 1972.

[6] H. Saito, Y. Miyaho and M. Yoshida, “Traffic engineering using multiple multipoint-to-point LSPs,” *Proc. IEEE INFOCOM’00*, 894-901 2000.

[7] E. Oki *et al.*, ”A Disjoint Path Selection Scheme with SRLG in GMPLS networks,” *Proc. of IEEE HPSR’2002*, 88-92, May 2002.

[8] C. Qiao *et al.*,“ A Novel Segment Protection Approach for SRLG Networks, ” *Proc. of HSN’2003*, 2003.

[9] K. Kompella and Y. Rekhter, “Multi-area MPLS traffic engineering,” *IETF*, `draft-kompella-mpls-multiarea-te-01.txt` , March 2001.

[10] J. Moy, *OSPF: Anatomy of an Internet routing protocol*, Addison-Wesley, 1998.

[11] A. Iwata and N. Fujita, “A hierarchical multilayer QoS routing system with dynamic SLA management,” *IEEE J. Select. Areas Commun.*, **18**, 2603-2616 2000.

[12] T. Miyamura, T. Kurimoto and M. Aoki,“A Scalable Multipath Algorithm in Hierarchical MPLS Networks,” *Proc. WTC/ISS 2002*.

[13] D.A. Dunn, W.D. Grover and M.H. MacGregor, “Comparison of k-shortest paths and maximum flow routing for network facility restoration,” *IEEE J. Select. Areas Commun.*, **12**, no. 1, 88-99 1994.

[14] K. Kompella and Y. Rekhter, “Routing Extensions in Support of Generalized MPLS,” IETF, `draft-ietf-ccamp-gmpls-routing-05.txt`, August 2002

[15] R. Callon, “Use of OSI IS-IS for Routing in TCP/IP and Dual Environments,” IETF, **RFC 1195**, December 1990.

[16] J. Strand and A.L. Chiu, “Issues for routing in the optical layer”, *IEEE Commun. Mag.*, **39**, no. 2, 81-87, 2001.