세그먼트 자동복구 기반의 네트워크 장애 복구 알고리즘

(A Network Fault Recovery Algorithm based on a Segment Automatic Restoration Scheme)

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요 약 본 논문에서는 복구시간의 최소화 및 효율적인 복구자원 제공을 위해 세그먼트 자동복구 기법을 이용한 네트워크 고장 복구 방안을 제안한다. 세그먼트 자동복구는 대규모 통신망을 다수개의 소규모 서브네트워크로 분할하여 각 서브네트워크에서 자동복구를 수행하는데, 그 성능은 서브네트워크의 크기와 형태에 따라서 다양한 특성을 나타낸다. 대부분의 장애를 서브네트워크 내부에서 복구할 수 있기 때문에 복구시간이 줄어들게 된다. 본 논문에서는 서브네트워크의 분할에 있어서의 특성을 분석하고, 서브네트워크의 크기와 그에 따른 자동복구 방법의 성능을 비교하고 분석한다. 링크와 노드장애가 발생하는 환경에 대한 시뮬레이션 결과에서 제안된 세그먼트 자동복구 방법이 가장 짧은 복구 시간을 나타내었다. 특히 세그먼트 자동복구의 개념을 사용하는 SLSP(Shortest Leap Shared Protection) 방법과 비교했을 경우 복구 시간과 복구 자원 면에서 모두 우수한 성능을 나타내었다.

키워드 : 자동복구, 서브네트워크, 세그먼트 자동복구, 네트워크 장애복구

Abstract In this paper, we propose a network fault recovery algorithm based on a segment restoration scheme to reduce restoration time and restoration resource. The proposed segment restoration scheme is based on network partitioning which divides a large network into several small subnetworks. The restoration performance of the proposed segment restoration scheme depends on the size and the topology of subnetworks. Since most faults can be restored in a subnetwork, restoration time is reduced obviously. We compare and analyze restoration performance according to the size of subnetworks and restoration schemes. From simulation results, the proposed segment restoration scheme has the shortest restoration time compared with other restoration schemes. Especially the restoration performance of the proposed segment restoration scheme is better than the SLSP, which is also a segment-based restoration scheme, in terms of restoration time and required restoration resource capacity.

Key words : Automatic restoration, Subnetwork, Segment restoration, Network fault restoration

1. Introduction

A fault in high-speed networks, such as MPLS (Multi-Protocol Label Switching) [1-2] and WDM (Wavelength Division Multiplexing), may cause massive data loss and severe degradation in the quality of service. Therefore fast fault recovery is essential in high-speed transport networks.

Because of the flexible traffic engineering capability of MPLS, real-time applications and QoS-guaranteed multimedia services are to be provided by the MPLS network. Any degraded or disconnected LSP (Label Switched Path) will severely deteriorate end-to-end packet transmission, and consequently will degrade the end-to-end quality of service. So

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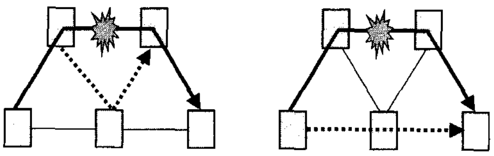
any degraded or faulty links/nodes should be identified as soon as possible, and user traffic should be quickly rerouted to an alternative path.

In order to maintain the MPLS LSP in a good operational state, performance monitoring and fast fault recovery are essential. Performance monitoring should continuously monitor the packet delivery performance of LSPs according to the agreed traffic parameters such as bandwidth, end-to-end packet transfer delay and jitter (delay variance) boundary. Fault handling functions should detect the occurrence of any fault condition in each protocol layer as soon as possible. When a link/node fault occurs in a specific layer, the fault management function should be able to minimize the spread of the effect of the fault to upper layers, and swiftly switch the service traffic of the faulty path to an alternative path as soon as possible. For fast recovery, prompt fault detection and fault notification functions are essential. Since MPLS networks require traffic engineering functions for optimized resource utilization, the restoration scheme for MPLS networks should have an efficient backup resource management function.

The link restoration scheme uses link layer information to trigger restoration processes and restores just faulty links on an end-to-end path regardless of the source and destination nodes of the affected working path as shown Fig. 1-(a). The link restoration scheme has the merit of fast restoration time, but the shortcoming of low restoration resource utilization [3].

The path restoration scheme establishes a backup path for an end-to-end working path as shown in Fig. 1-(b). This standby path can be preplanned or computed dynamically. And the path restoration scheme has the opposite characteristics of the link



(a) Link restoration (b) Path restoration

Fig. 1 Link restoration and path restoration

restoration scheme [3].

In our previous paper, we described a framework of the segment restoration scheme [4]. In this paper, we propose a segment restoration scheme based on subnetwork partitioning. This scheme has an advantage of short restoration time and high backup resource utilization. We also propose provisioning methods of the inter segment backup path and an efficient network partitioning algorithm for enhanced restoration performance. We compare and analyze restoration performance according to the size of partitioned subnetworks and restoration schemes.

The rest of this paper is organized as follows. In Section 2, we propose and describe a segment restoration scheme. In Sections 3 and 4, we develop the criteria for network partitioning and evaluate restoration performance, respectively. And we make the conclusion in Section 5.

2. Segment Restoration

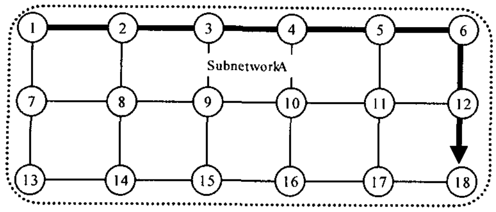
In this section, we propose a segment restoration scheme and describe its principle. We also describe related researches and compare with the proposed restoration scheme.

2.1 Principle of segment restoration

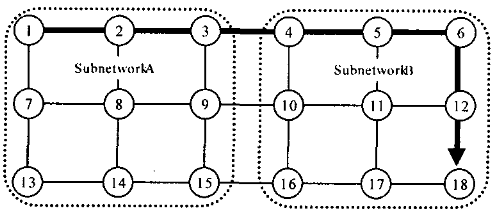
The proposed segment restoration scheme is based on network partitioning as shown in Fig. 2. In Fig. 2(b), a network is divided into Subnetwork A and Subnetwork B, and an end-to-end path is divided into two segments: 1-2-3 and 4-5-6-12-18. So a segment can be a part of an end-to-end path, the longest segment is an end-to-end path such as 1-2-3-4-5-6-12-18 as shown in Fig. 2(a) and the shortest segment is a link such as Link 1-2, or Link 3-4 as shown in Fig. 2(c). The length of segments is determined by the number of subnetwork.

In the segment restoration scheme, link/node failure is restored by the relatively short segment in each subnetwork, instead of the long end-to-end path. As a result, the fault restoration of segments can be generally much faster than the end-to-end path restoration.

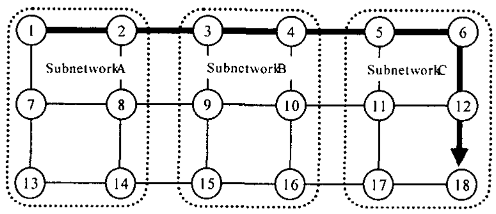
The proposed segment restoration scheme is



(a) 3×6 subnetwork



(b) 3×3 subnetwork



(c) 2×3 subnetwork

Fig. 2 Network partitioning

divided into the *intra segment restoration* scheme and the *inter segment restoration* scheme by fault types such as intra subnetwork fault, inter subnetwork fault.

2.2 Intra segment restoration

To apply the proposed segment restoration scheme to networks, we should consider two kinds of fault: intra subnetwork fault and inter subnetwork fault. Fig. 3 shows an example of intra segment restoration dealing with an intra subnetwork fault. A working path is established along nodes 1-2-3-4-5-6-12-18. When a fault occurs at Link 2-3, Node 3 (the egress node of the segment in Subnetwork A) detects the fault occurrence and notifies Node 1 (the ingress node of the path in Subnetwork A). As soon as Node 1 receives the notification message, it swiftly switches working traffic to backup path 1-7-8-9-3 within Subnetwork A. So working path

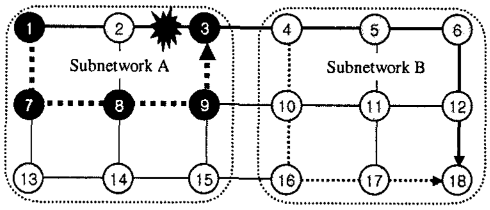


Fig. 3 Intra segment restoration

is changed to 1-7-8-9-3-4-5-6-12-18. The rest of the path after Node 3, is not changed. We call this scheme as *intra segment restoration*.

2.3 Inter segment restoration

When a fault occurs at Link 3-4 that connects Subnetwork A and Subnetwork B as shown in Fig. 4, the fault can't be restored by any single intra segment restoration in Subnetwork A or Subnetwork B. In this case, the fault is detected by Node 4, and Node 4 notifies Node 18(the egress node of Subnetwork B), and then Node 18 sends a fault message to Node 1(the ingress node of Subnetwork A). The fault management function for inter subnetwork fault restores using the pre-assigned inter segment backup path between Node 9(the previous node of egress node) which is on the backup segment 1-7-8-9-3 within subnetwork A and Node 10(the next node of ingress node) which is on the backup path 4-10-16-17-18 within subnetwork B. So user traffic through Link 3-4 is switched to a new path 1-7-8-9-10-16-17-18. Using two backup paths in Subnetwork A and Subnetwork B, any link fault between subnetwork A and B can be restored. We call this scheme as *inter segment restoration*.

When Node 3(the egress node of subnetwork A) fails, the restoration procedure is the same. When a

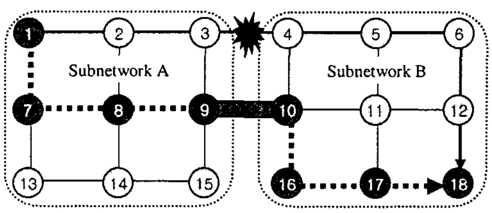


Fig. 4 Inter segment restoration

fault occurs on Node 4(the ingress node of subnetwork B), Node 5 detects the fault occurrence and notifies it to Node 18. Node 5 always detects fault occurrence whenever Node 4 or Link 4-5 is failed. For link failure, Node 5 performs the intra segment restoration, but for node failure, it performs the inter segment restoration. Therefore Node 5 should discriminate link failure from node failure. When a fault occurrence is detected and the control signal from Node 4 is received, Node 5 determines the fault as a link failure. When a fault is detected and the control signal is not detected, it determines the fault as a node failure.

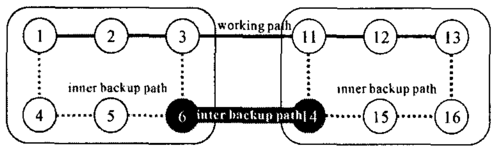
Backup path provisioning methods for inter segment restoration is divided into four types: using two backup nodes, using a backup and a working node, using a working and a backup node, and using two working nodes.

(a) Backup node to backup node bridge: An inter segment backup path is established using two backup nodes as shown in Fig. 5(a): one is the previous node of the egress node on the segment backup path, and the other is the next downstream node of the ingress node on another segment backup path. We call this method as *B2B(Backup node to Backup node) bridge.*

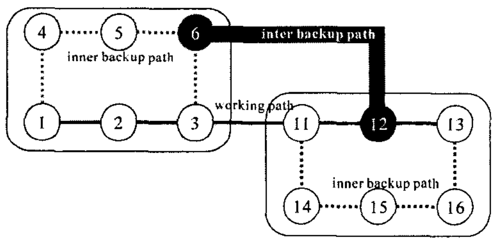
(b) Backup node to working node bridge: An inter segment backup path is established using a backup node and a working node as shown in Fig. 5(b): one is the previous node of the egress node on the segment backup path, and the other is the next downstream node of the ingress node on the segment working path. We call this method as *B2W(Backup node to Working node) bridge.*

(c) Working node to backup node bridge: An inter segment backup path is established using a working node and a backup node as shown in Fig. 5(c): one is the previous node of the egress node on the segment working path, and the other is the next node of the ingress node on the segment backup path. We call this method as *W2B(Working node to Backup node) bridge.*

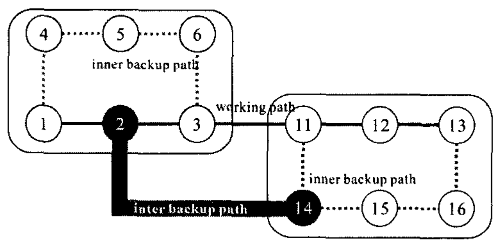
(d) Working node to working node bridge: Fig. 5(d) shows an inter segment backup path using two working nodes, which is the opposite case of using two backup nodes. The inter segment backup path is established using the previous node of the egress node on the segment working path and the next node of the ingress node on another segment working path. We call this method as *W2W(Working node to Working node) bridge.*



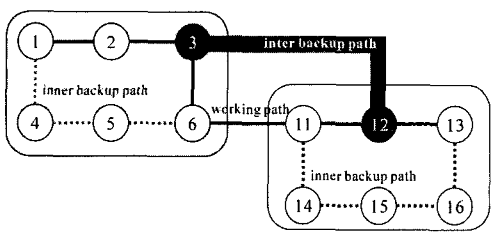
(a) B2B bridge - between two backup nodes



(b) B2W bridge - between backup node and working node



(c) W2B bridge - between working node and backup node



(d) W2W bridge - between two working nodes

Fig. 5 Bridge methods for inter segment restoration

After a working path is established, segment backup paths are established in each subnetwork for intra segment restoration. Inter segment backup paths are established after each intra segment backup paths are established. We select the path with lowest cost among the four inter segment backup paths which are calculated by the four bridge methods.

2.4 Related works

2.4.1 SLSP

The related researches of the segment-based restoration scheme are SLSP[5] and sub-path protection [6]. The SLSP has been proposed to enhance the link- and path-based protection; it partitions an end-to-end working path into several equal-length and overlapped segments. Each segment is assigned a protection domain for restoration after a working path is selected. The overlap between adjacent protection domains is designed to protect any boundary node failure along a working path. The SLSP scheme reduces restoration time obviously. In Fig. 6, working path 5-6-7-8 is divided into segment 5-6-7 and 6-7-8, and their backup paths are 5-1-2-3-7 and 6-10-11-12-8. Especially when domain size is 3(a segment consists of three nodes) as shown in the Fig. 6, the restoration time becomes the shortest.

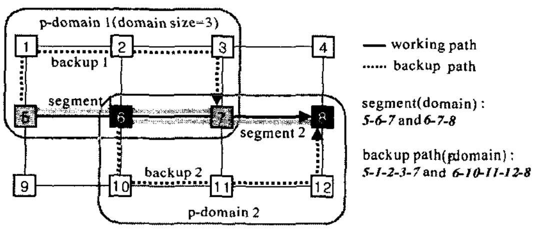


Fig. 6 Shortest Leap Shared Protection (SLSP)

But, the SLSP should partition each path in a network to several domains and provide protection domain for each domain regardless of the hierarchical subnetwork configuration of the given network. Therefore, when the number of path in a network increases, the processing complexity also increases. Moreover when the length of a path increases, it needs more protection resource, and it becomes difficult to make protection domains when a working path is established over a node which has just two links as shown in Fig. 7. Node 3 has just two links which are used by the working path. When a fault occurs on the segment working path 1-2-3, user traffic is switched to the segment backup path 1-4-5-6-3. So Link 3-6 is shared by the working path 1-2-3-6-9 and the segment backup path 1-4-5-6-3. It violates the requirement of SRLG (Shared Risk Link Group)[7].

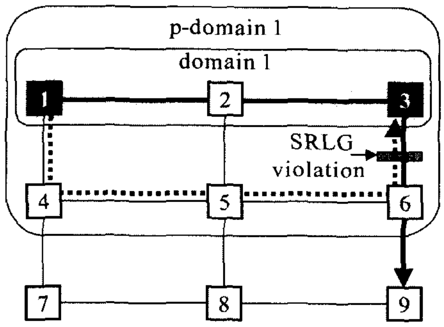


Fig. 7 SRLG violation of SLSP

The SLSP is based on logical path partitioning as shown in Fig. 6, but the proposed segment restoration scheme subdivides physical network to several subnetworks. The subnetwork partitioning is performed when a network is initially configured, or for the purpose of network configuration management at the major topological change. Table 1 shows the comparison of the proposed segment restoration scheme and the SLSP.

Table 1 The comparison of the proposed restoration scheme and the SLSP

	Proposed restoration scheme	SLSP
object of partitioning	physical network	logical path
length of segments	different length	equal length
number of partitioning	once or rare	frequent
recovery of single link failure	yes	yes
recovery of single node failure	yes	yes
recovery of multiple failure	yes	yes (but not perfect)

2.4.2 Sub-path restoration

Sub-path restoration patches backup path with a node which detects fault occurrence. When a fault occurs at Link 7-8 as shown in Fig. 8, the upstream node (Node 7) of the failed path does not send an alarm to the source node(Node 6) of the disrupted path; instead, it tries to patch a path by sending a setup message to the destination node (Node 10). Meanwhile, the downstream node(Node 8) sends a teardown message to the destination node(Node 10) of the working path. Since a backup path 2-3-4-5-10 is patched with Node 7, so user traffic is switched at Node 7 and rerouted along 6-7-2-3-4-5-10.

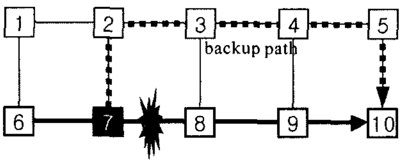


Fig. 8 Sub-path restoration

Sub-path restoration scheme reduced restoration time comparing to the path restoration scheme relatively. When a fault occurs around an egress node, restoration time is reduced obviously, but when a fault occurs around an ingress node, restoration time similar with the path restoration scheme. Since a backup path is provisioned after a fault occurs, restoration performance is lower than other restoration schemes which use backup path restoration scheme. So in this paper, we don't compare the proposed segment restoration scheme with sub-path restoration scheme.

3. Subnetwork partitioning

In this section, we describe the criteria for network partitioning to restore intra subnetwork fault and inter subnetwork fault. And we analyze its characteristics using several case studies.

3.1 Criteria for network partitioning

Since restoration performance depends on the size and the topology of subnetworks, an efficient network partitioning algorithm is essential to enhance the restoration performance. So we make several criteria for network partitioning as follows:

Rule 1) Subnetwork should have at least two edge nodes for connecting its adjacent subnetwork as shown in Fig. 9. This is required for the inter segment restoration; if there is just one node that connects two subnetworks, the inter segment fault can not be restored.

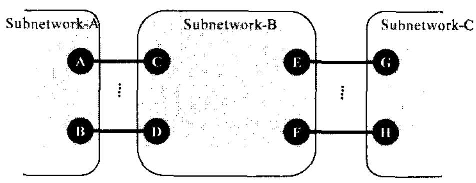
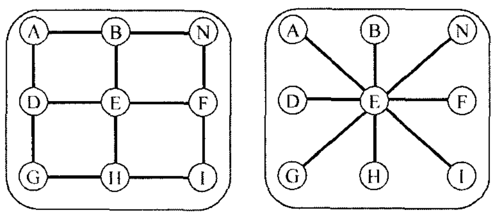


Fig. 9 Subnetwork partitioning rule 1

Rule 2) The link connectivity degree of all nodes within a subnetwork should be greater than or equal to 2 as shown in Fig. 10. Since link or node failure within a subnetwork, must be restored in the subnetwork, mesh topology provides better restoration capability than star or hub & tree topology. The rule 2 is essential requirements to perform the intra segment restoration.



(a) good subnetworking (b) bad subnetworking

Fig. 10 Subnetwork partitioning rule 2

3.2 Case studies of network partitioning

Network partitioning is a very important procedure in the segment restoration. Efficient subnetwork partitioning enhances restoration performance. Therefore, we subdivide a U.S. sample network to various subnetwork models for case studies, and evaluate their characteristics.

The U.S. sample network with 20 nodes and 38 bi-directional links(76 uni-directional links) is shown in Fig. 11. The U.S. sample network has near mesh topology.

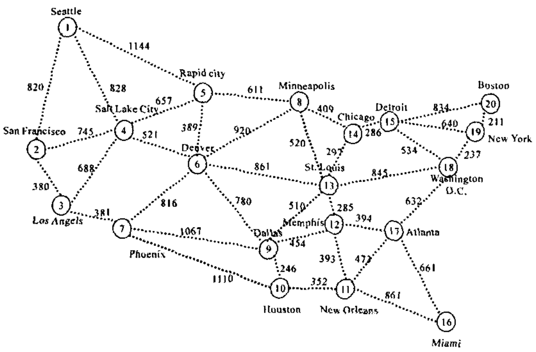


Fig. 11 U.S. sample network

3.2.1 Case 1 (4 subnetworks)

In Fig. 12, the U.S. sample network is divided into 4 subnetworks. But this subnetwork model is not useful. SUB-1, SUB-3, and SUB-4 have near mesh topology, but SUB-2 does not have mesh topology. So this model can't provide intra segment restoration completely, and violates rule 2. And Node 8 has just one link in its subnetwork, so the intra segment restoration scheme can't restore when a fault occurs at Link 8-6. This violates rule 2.

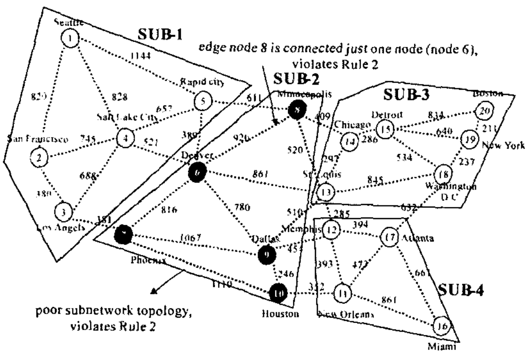


Fig. 12 Partitioned network - case 1

3.2.2 Case 2 (3 subnetworks)

Fig. 13 violates rules 1 and 2. SUB-2 and SUB-3 have no problem and these are very well-partitioned subnetworks. But there is only one node for connecting SUB-1 and SUB-3, so it can't provide the inter segment restoration completely when a fault occurs at Node 7. This violates the rule 1. In SUB-1, Node 7 is an edge node connecting with SUB-3, but Node 7 has just one link in its subnetwork (SUB-1). It violates rule 2 and can't provide intra segment restoration completely, when a fault occurs at Link 3-7.

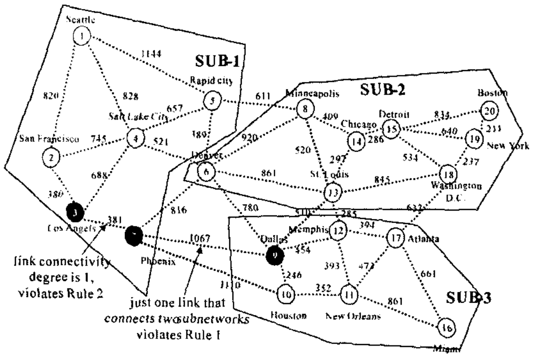


Fig. 13 Partitioned network - case 2

3.2.3 Case 3 (3 subnetworks)

Fig. 14 shows a very well-partitioned subnetworking model. All subnetworks(SUB-1, SUB-2, and SUB-3) are near mesh topology. All edge nodes in subnetworks have 2 or 3 links in each subnetwork, and have three links to connect with two adjacent subnetworks (SUB-1 to SUB-2, SUB-1 to SUB-3 and SUB-2 to SUB-3). It satisfies rules 1 and 2. So we use this subnetwork model for simulation.

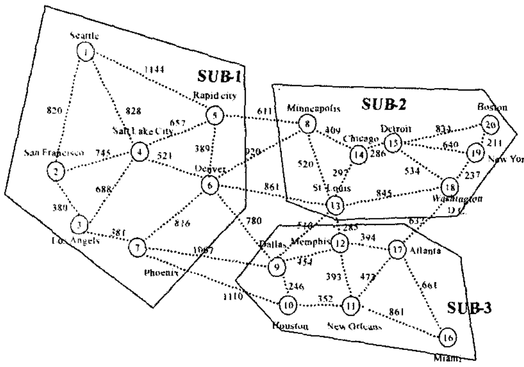


Fig. 14 Partitioned network - case 3

3.2.4 Case 4 (2 subnetworks)

Fig. 15 shows another case of well-partitioned subnetworking model. SUB-1 is near mesh topology, and has three edge nodes(Node 6, Node 7 and Node 8) which are connected to SUB-2. Edge nodes in each subnetwork have enough links to connect with two adjacent subnetworks So this model satisfies rules 1 and 2. So we also use this subnetwork model for simulation, too.

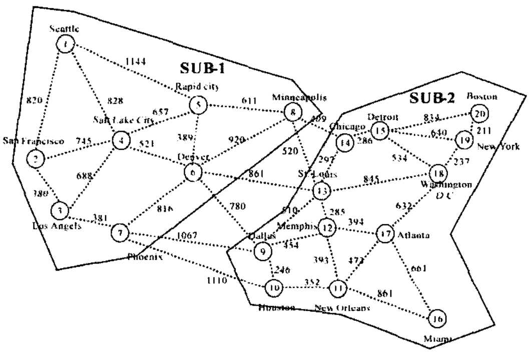


Fig. 15 Partitioned network - case 4

Table 2 summarizes four network partitioning case studies according to the number of subnetworks, violated rules and restoration problems.

4. Simulation Results

In this section, we simulate the proposed restoration algorithm using U.S. sample network. We also summarize restoration performance as a function of the size of subnetworks and restoration schemes.

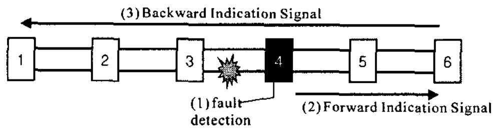
4.1 Assumptions and the restoration procedure

In the simulation of this paper, we use the U.S sample network with 20 nodes and 76 uni-directional links. We make the following assumptions:

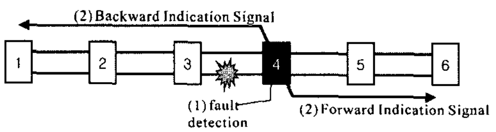
- All working paths and backup paths are established along their shortest routes.
- Backup path should belong to the different SRLG(Shared Risk Link Group) of the working path.
- Backup resource is pre-assigned before fault occurrence.

The restoration procedure consists of three steps: fault detection step, fault notification step and fault recovery step.

- Fault detection step: Fault detection function might be performed by physical layer detection capability, MPLS OAM(Operation, Administration and Maintenance), and MPLS signaling such as CR-LDP(Constraint-based Routing with Label Distribution Protocol) and RSVP-TE(Resource Reservation Protocol with Traffic Engineering Extension).
- Fault notification step: Fault notification functions consist of FIS(Forward Indication Signal) and BIS (Backward Indication Signal). FIS and BIS may be sent sequentially or simultaneously. Fig. 16 shows sequential fault notification and simultaneous fault notification, respectively.



(a) Sequential fault notification



(b) Simultaneous fault notification

Fig. 16 Fault notification type

Table 2 Comparison between case studies

	Case 1	Case 2	Case 3	Case 4
# of subnetworks	4	3	3	2
Violated rules	2	1, 2	None	None
Problems	- can't perform intra segment restoration in SUB-2	- can't perform intra segment restoration in SUB-1 - can't perform inter segment restoration between SUB-1 and SUB-2	None	None

- Fault recovery step: As soon as an egress node and an ingress node receive FIS and BIS, respectively, user traffic is switched from faulty working path to backup path.

In the *sequential notification procedure,* the next downstream node(Node 4) of the link which detects the fault occurrence generates FIS and sends it to the egress node. And then the egress node sends a fault notification message(BIS) to the ingress node for rerouting user traffic as shown in Fig. 16(a). In this paper, we use the sequential fault notification procedure.

In the *simultaneous notification procedure,* the node which detects a fault occurrence, generates a fault notification message and sends it to the egress node and the ingress node simultaneously as shown in Fig. 16(b). The simultaneous notification procedure reduces the notification time obviously than the sequential notification procedure.

Fault notification function is performed by signaling such as CR-LDP and RSVP-TE signaling[9-12] or extended MPLS OAM functions proposed in [13-16]. CR-LDP notification messages and RSVP-TE notification messages can carry the severe performance degradation or link/node failure alarm notification information. Since MPLS signaling messages are forwarded hop-by-hop to destination nodes, the fault notification message by MPLS signaling functions may take a little longer time than the MPLS OAM fault notification packets. The detail of notification message is beyond the scope of this paper.

Fig. 17 shows the procedure of segment restoration for simulation, and Fig. 18 shows sequence diagram for implementation of the segment restoration.

To measure practical restoration performance, we simulate the segment restoration, the link restoration scheme, the path restoration scheme and the SLSP using the U.S. sample network which has 20 nodes and 38 bi-directional links(76 uni-directional links) as shown in Fig. 11. Each link distance is

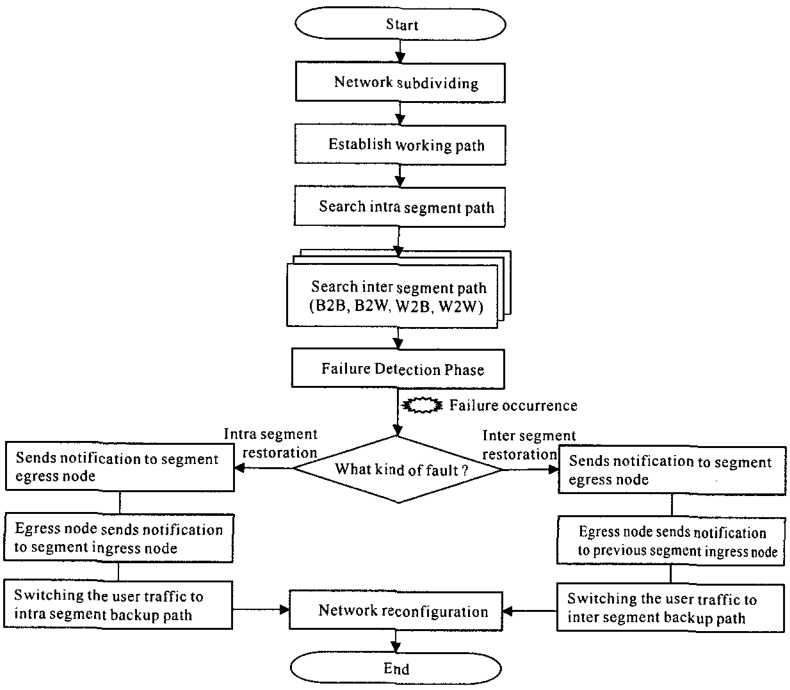


Fig. 17 Procedure of segment restoration

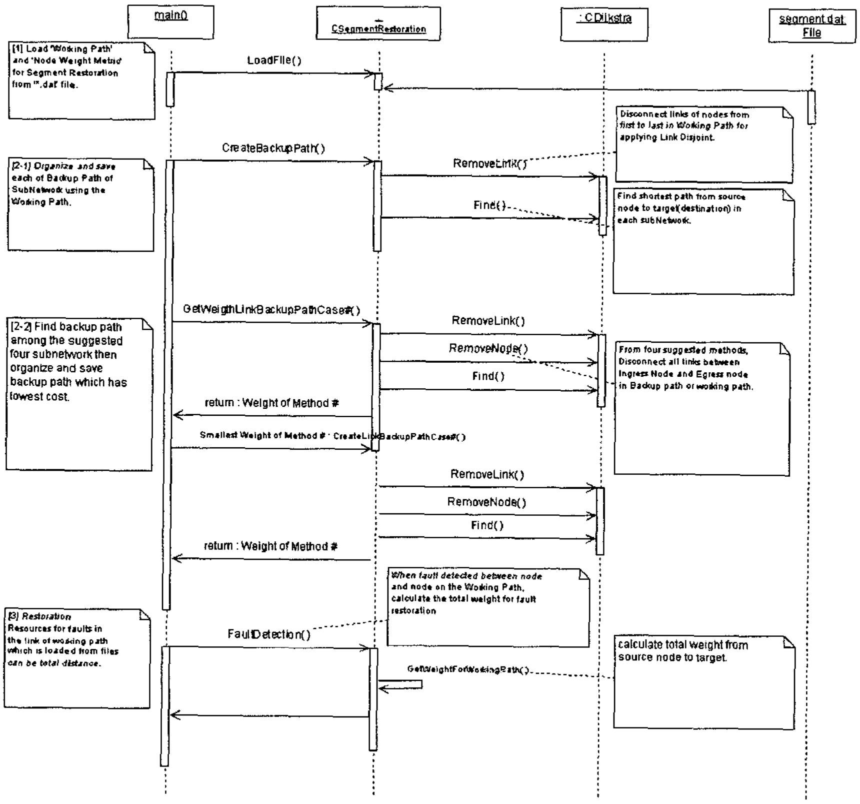


Fig. 18 Sequence diagram of segment restoration

different and data propagation speed is 2×10^8 m/s. First of all, we partition the U.S. sample network to 1-, 2-, 3- subnetworks as shown in Fig. 14 and Fig. 15, and compare each restoration performance. And we compare restoration performance among restoration schemes which are the link restoration scheme, the path restoration scheme and the SLSP.

4.2 Effect of the size of subnetworks on the restoration time

Fig. 19 shows the restoration time as a function of the size of subnetworks. In the proposed segment restoration scheme, the restoration time depends on the number of subnetworks. From Fig. 19, we can find that the restoration time of sub-3 is less than sub-1 and sub-2. So we can conclude when a network is divided into smaller subnetworks, the restoration performance can be improved.

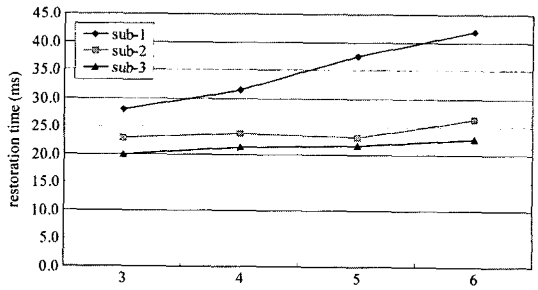


Fig. 19 Restoration time as a function of the size of subnetworks

4.3 Effect of the size of subnetworks on the required backup resource ratio

To compare backup resource capacity, we measures the ratio of the required resource of backup paths to working paths. Fig. 20 shows backup resource requirement as a function of the size of subnetworks. In the proposed segment restoration scheme, the restoration resource capacity is increased when a network is divided into smaller subnetworks.

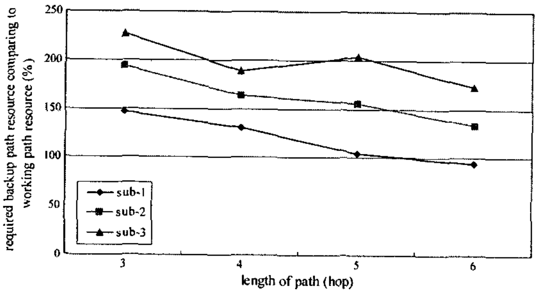


Fig. 20 Required backup resource ratio as a function of the size of subnetworks

4.4 Restoration time as a function of restoration schemes

Fig. 21 shows restoration time as a function of restoration schemes. In the case of the path restoration scheme, the restoration time increases in proportion to the length of paths. In the case of the link restoration scheme, the SLSP and the proposed segment restoration, the restoration time is near uniform because each restoration scheme is performed in a limited area such as link, segment(or p-domain) or subnetwork.

The restoration time of the segment restoration scheme is shorter than the path restoration scheme and the SLSP, but longer than the link restoration scheme. We assume only link failure in this simulation because the link restoration scheme can't

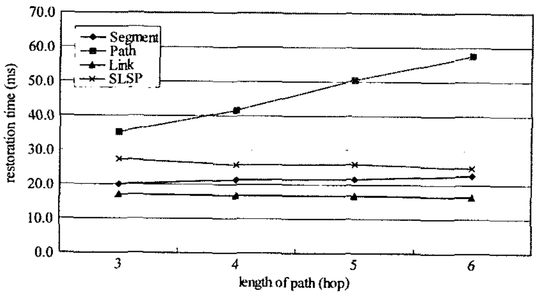


Fig. 21 Restoration time as a function of restoration schemes

restore any node failure and we can't measure the restoration time of the link restoration scheme when a node failure occurs. So the proposed segment restoration has the shortest restoration time in the mixed fault environments. Especially, the proposed segment restoration scheme has better restoration speed than the SLSP.

4.5 Required backup resource ratio as a function of restoration schemes

Fig. 22 shows required backup resource ratio as a function of restoration schemes. For 100% 1:1 restoration, the path restoration scheme requires around 120% backup resource capacity. But the SLSP and the link restoration scheme require over 230% backup resource capacity and the segment restoration scheme requires around 200% backup resource capacity.

The path restoration scheme prepares backup resource for a whole path, but the link restoration scheme, the SLSP and the proposed segment restoration scheme prepare backup resource for every link, domain or subnetwork respectively; therefore more resources are required compared to the end-to-end path restoration. From the result, we can see that the path restoration scheme requires the least backup resource, while the proposed segment restoration requires more backup resource, but less than the SLSP and the link restoration scheme.

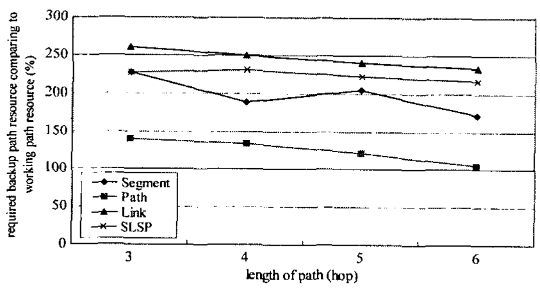


Fig. 22 Required backup resource ratio as a function of restoration schemes

4.6 Comparison of restoration performance

We summarize restoration performance as a function of the size of subnetworks and restoration schemes in Table 3.

Table 3 Comparison of restoration performance

		Restoration time	Required backup resource ratio
proposed segment restoration	subnetwork-2	24.0 ms	162 %
	subnetwork-3	21.4 ms	198 %
link restoration		16.8 ms	250 %
SLSP-3		25.6 ms	227 %
path Restoration		46.2 ms	132 %

The link restoration scheme has the shortest restoration time in this simulation, but it can't restore any node failure. So the proposed segment restoration has the shortest restoration time when link and node failure occur. The path restoration scheme has the longest restoration time but has the smallest backup resource capacity compared with other restoration schemes.

Especially, the comparison of proposed restoration scheme and the SLSP is very important because both are segment based restoration schemes. The simulation result shows the proposed segment restoration has better restoration time and less backup resource than the SLSP.

5. Conclusion

In this paper, we proposed a segment restoration scheme. Most restoration schemes for telecommunication network are based on link-based restoration or path-based restoration. The link restoration scheme has shortest restoration time, but requires highest backup resource capacity. The path restoration scheme has opposite characteristic. It is difficult to satisfy both fast restoration speed and high resource utilization. But high-speed networks, such as MPLS networks, require traffic engineering for optimized resource utilization. So restoration schemes for high-speed network must have fast restoration functions and efficient backup resource management functions. The proposed segment restoration is based on network partitioning that partitions a large network into several small subnetworks. Because most faults are restored in subnetworks, fault restoration time is reduced obviously. And backup resource capacity is also less than the SLSP and the link restoration scheme.

From the simulation results, we verified that the segment restoration scheme has advantages in both restoration time and backup resource capacity. The proposed segment restoration can provide a good restoration performance for high-speed transport networks.

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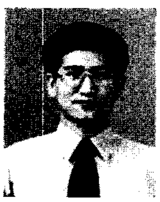

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