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Operational Cost Factor Consideration of Path Management Method for MPLS Networks

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Abstract—**The recent improvements in broadband networks are enabling network carriers and providers to provide multiprotocol label switching (MPLS)-based dedicated services for enterprise customers. These dedicated services will be widely introduced in interconnected networks to meet the demand of enterprise customers. Since end-to-end connection will be more complicated in interconnecting networks, path (end-to-end route) management will be important to enable quick reaction to failures to ensure customer satisfaction. We propose a path management method in MPLS networks, which is combined with the following two methods.**

- **A method in which a link stores an adjacent link identifier, and the edge node identifier is stored at an edge link**
- **A method in which all links store edge node identifiers**

The proposed method is evaluated in terms of operational cost factors for the ability to search for users whose service has failed and the ease of changing managed objects in interconnected networks.

Keywords: ***OSS (Operation Support system), path management, management system architecture, MPLS***

1 Introduction

Recent improvements in broadband networks are enabling network carriers and providers to provide a variety of new services. Dedicated services, such as wide-area Ethernet and IP-VPN, have become popular, especially among enterprise customers [1, 2, 3]. Such services introduce multiprotocol label switching (MPLS) [4] and virtual private network (VPN) techniques over a layer 2/layer 3 path to achieve the desired quality of service and to maintain security. These services will be widely introduced in several interconnected networks through an open interface in the next-generation network (NGN) era to meet the demands of enterprise customers. This is because enterprise customers are eager to use more attractive services at a low cost to communicate with their affiliate/alliance companies or branch offices efficiently, and they select suitable networks depending on their locations. Therefore, path (end-to-end route) connection will become complicated, and path management is the key factor for enabling quick reactions to failures to ensure customer satisfaction.

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MPLS is an effective technique for providing dedicated services for enterprise customers. Since the management (operation, administration, and maintenance) cost is far greater than initial (system development) cost, an effective and economic management method is required. Therefore, path management with low operational cost needs to be established in these conditions.

Uno and Kokubun give an overview of resource management architectures for access networks [5]. Matsuura et al. proposed the architecture of resource management in multilayer networks such as the cable, path, and circuit layers [6]. Kimura et al. [7], Ejiri and Iseda [8], and Fujii [9] discussed guidelines for the relationship between resources and service management functions. However, no papers have discussed the path management method from the operational point of view. We present a method for path management in MPLS networks where several networks are interconnected.

2 Feature of network and technology

2.1 Network assumptions

Network carriers provide IP-based dedicated services, such as IP-VPN and VLAN, for enterprise customers. We assume that each enterprise customer is provided the service on each network, that is," Network A "and" Network B "provide services to" Customer A "and" Customer B ", respectively, as shown in the upper part of Fig. 1. To integrate both services and make them useful for enterprise customers in the NGN era, both networks are interconnected through the network interface, and the services are offered in a wider area, as shown in the lower part of Fig. 1. The networks frequently change the path accommodating the user in that situation. Therefore, the number of managed paths increases and their management becomes complicated.

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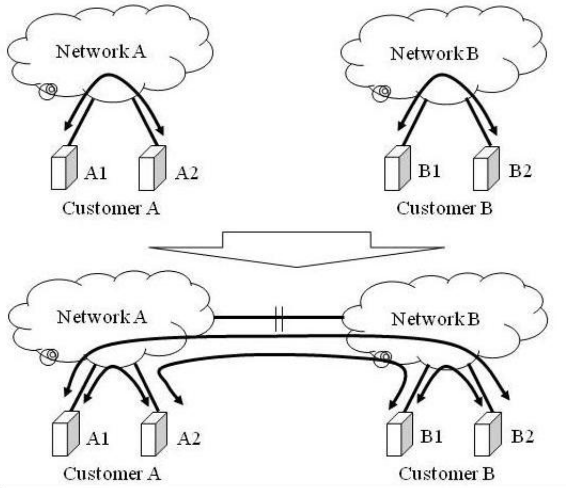

Figure 1: Service integration for enterprise use in NGN era.

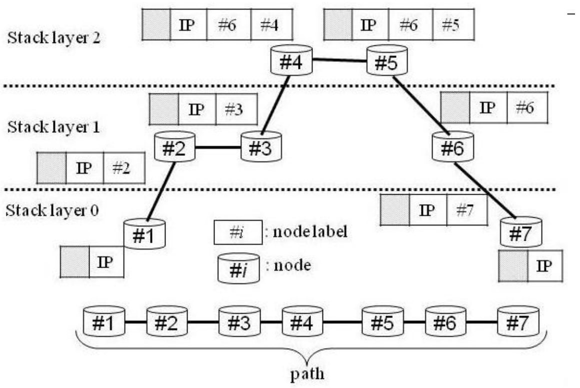

Figure 2: MPLS label stacking.

2.2 Features of MPLS in terms of path management

This paper focuses on MPLS for IP-based dedicated services. MPLS is a label-switching technique with an MPLS node for a label switching path (LSP) [4]. Label stacking is an efficient, hierarchical technique of MPLS, as shown in Fig. 2. An ingress node (node #1 in Fig. 2) adds a label (label #2 in Fig. 2) and forwards packets to an adjacent node (node #2 in Fig. 2). Node #2 swaps label #2 for label #3 and relays the packets to node #3. Node #3 swaps label #3 for #6 and adds (pops) label " #4 " to make a label stack. After the packets arrive at node #5, the stack label is removed (pushed). Node #6 swaps label #6 for label #7, and the packet reaches node #7 at the final step. In network resource management, the relationship between packet labels and label stack links should be maintained in addition to basic management of the relationship between nodes and links. A path is defined as the route from node #1 to node #7 in Fig. 2.

3 Basic methods of path management in networks

3.1 Requirements for path management

Quick failure diagnosis and confirmation of affected customers are the most important tasks from the viewpoint of restoring network operation after a failure. Moreover, the effect on customers caused by changing managed facilities should also be considered. The following two conditions are requirements for path management.

1)Confirm that the network accommodates the specified terminal information.

2)Confirm that terminals are accommodated by the specified network facility.

3.2 Representation

In this section, key items for managing the path are described. First, a graph is described for preparation.

For any N (node set) and L (link set), there is a graph such that

$G = (N, L)$, where $n_i \in N$ $(i = 1, 2, \cdots, |N|)$, $l_j \in L$ $(j = 1, 2, \cdots, |L|)$.

Define $n_i \in N$ $(i = 1, 2, \cdots, N')$, where $N' \leq |N|$ when a pair of nodes (n_i, n_j) is selected and the suffixes of nodes between them are reordered. We assume that there is only one route between two end nodes.

3.3 Following link identifier (FLID) method

As a basic rule, a terminal stores the identifier of the edge node to which it is connected, and an edge node stores the identifiers of all the terminals connected to it. Nodes and links store the identifiers of their corresponding links and nodes. We present a method of storing adjacent link identifiers on each link in which path management requirements are met, as shown in the following steps and in Fig. 3.

Algorithm 1 (A1)

#1: Store terminal identifiers u_1 and u_N in node identifiers n_1 and n_N, respectively

#2: Node identifier n_i stores adjacent link identifiers l_{i-1} and l_i $(i = 1, 2, \cdots, N)$ where l_0 and $l_N = \{\phi\}$

#3: l_i stores adjacent node identifiers n_i and n_{i+1} $(i = 1, 2, \cdots, N-1)$

#4: l_i stores adjacent link identifier l_{i-1} and l_{i+1} $(i = 1, 2, \cdots, N-1)$ where l_0 and $l_N = \{\phi\}$

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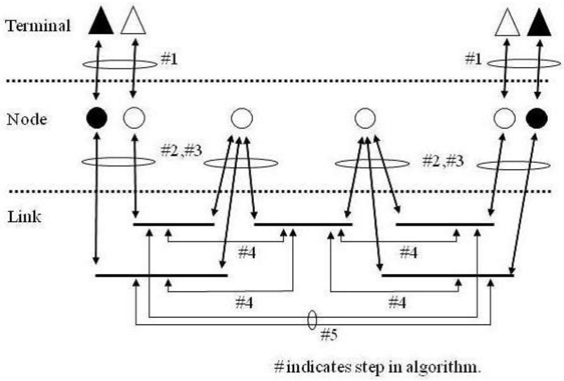

Figure 3: FLID.

#5: In using the label stack technique, the link stores the corresponding link identifier.

That is, when the route between l_h and l_k introduces label stacks, l_{h-1} and l_{k+1} store the identifiers of l_{k+1} and l_{h-1}, respectively.

The number of stored link identifiers increases at a link using label stacking when the number of stacks increases. The route between terminals and the terminals contained in a link can be calculated using this path management method.

3.4 Following node identifier (FNID) method

As a basic rule, the terminal stores the identifier of the connected edge node and vice versa. Nodes and links store each other's corresponding links and nodes. A method where all links store edge node identifiers is presented to meet the requirements of path management, as shown in the following steps and in Fig. 4.

Algorithm 2 (A2)

#1: Store terminal identifiers u_1 and u_N in node identifiers n_1 and n_N, respectively

#2: Node identifier n_i stores adjacent link identifiers l_{i-1} and l_i $(i = 1, 2, \cdots, N)$, where l_0 and $l_N = \{\phi\}$

#3: l_i stores adjacent node identifiers n_i and n_{i+1} $(i = 1, 2, \cdots, N-1)$

#4: For any l_i $(i = 1, 2, \cdots, N)$, store identifier of a pair of $\{n_1, n_N\}$

The number of stored terminal identifiers increases at a link when the number of terminals increases. This path management method can be used to calculate the route between terminals and the terminals contained in a link.

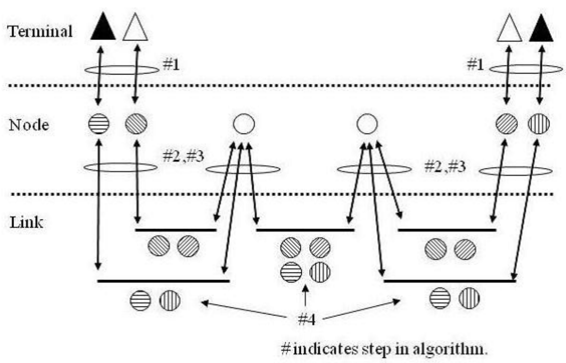

Figure 4: FNID.

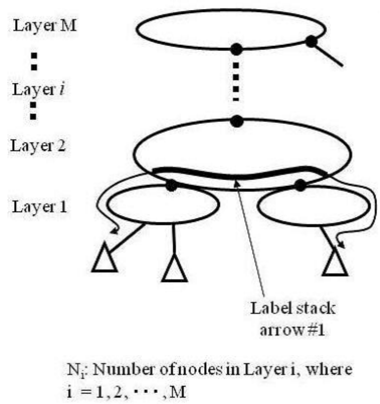

Figure 5: Layered ring network.

4 Application to interconnected networks

4.1 Layered ring networks

A telecommunication transport network generally consists of access and core networks. An access network is the lowest layer network, while a core network contains several layer networks depending on transmitted traffic volume and area coverage. Furthermore, to assure high reliability with a redundant route, the dedicated services are provided by the network based on a ring topology. Therefore, we assume that a network consists of a layered ring network, as shown in Fig. 5. We apply the label stack technique when the two edge nodes connect through the upper-layer networks, as indicated by label stack arrow #1 in Fig. 5.

4.2 New management methods

Generally speaking, the layered ring network has the following features.

- The lower the layer, the more links and nodes there are. Therefore, lower-layer networks accommodate many customers.

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- Changes in managed object accommodation seldom occur in upper-layer networks, whereas the frequency of changing managed objects is high in lower-layer networks.

A method for shortening the searching time is effective for a lower layer, while a method for reducing the number of changes is effective for an upper-layer one. We present the following method, which is based on the two previously described methods.

Proposed algorithm Combination Method (CM):

Let C define the boundary layer between upper and lower layers. We apply the following algorithms for a given i.

1. If $i \leq C$, then apply FNID.
2. If $i > C$, then apply FLID. Identifiers stored at the link represent edge nodes in $i = C$.
3. Manage $i = C$ and $C + 1$ as follows.

   In the case of a network with $i = C+1$, the adjacent boundary link in a C network should be stored at the boundary link. In the case of an $i = C$ network, both boundary edge nodes in a $C + 1$ network should be stored at all corresponding links in the C network.

Let us consider the case of interconnected networks. If we assume $C \neq 1$, the number of links to search for affected customers is very large. This is because the number of rings in lower-layer networks is much larger than that in upper-layer networks. Therefore, much time will be needed to search for affected customers. Therefore, $C = 1$ is suitable in interconnected networks to reduce the management work.

4.3 Network model assumptions

Let us make the following assumptions for constructing and evaluating our proposed method by referencing real networks.

- For "M" as the highest layer, the maximum number of rings in layer i is given by 4^{M-i}.
- $1 \leq N \leq 4$ for any i where $2 \leq i \leq M$, that is a ring in Layer 2 or the upper-layer networks has a connection with 4 lower-layer rings.
- $1 \leq N \leq 10$ for $i = 1$; that is, a ring has 10 edge nodes at most.
- $M \leq 4$, which corresponds to 4 layers like the Japanese PSTN.

4.4 Evaluation of ability to search for affected customers

Let us compare CM with FLID and FNID quantitatively. The following assumptions are made for this evaluation.

- The failure rate for the section (the route among two adjacent nodes including the bundle of links) is constant independent of the layer and area.
- We consider one section failure; multiple failures do not occur.

  Let the failure rate of the section be represented by P_f. Then the failure rate has the following relationship.
  $\Sigma(P_f) \leq 1$

Let us define the number of searched links for affected customers when a section failure occurs as $H_{FLID(l)}$, $H_{FNID(l)}$, and $H_{CM(l)}$.

(1) Total number of searched links for FLID:
$H_{FLID} = \Sigma(P_f H_{FLID(l)})$

(2) Total number of searched links for FNID:
$H_{FNID} = \Sigma(P_f)$

(3) Total number of searched links for CM:
$H_{CM} = \Sigma_{l'}(P_f) + \Sigma_{l''}(P_f H_{FLID(l)})$

The results are compared in Fig. 6. The Hs of all methods increase as M increases. Since H is the number of searched links for affected customers during the observing period, it is necessary that $H < 1$. H_{FNID} is the smallest, while H_{FLID} is very large because of the large number of layer-1 rings. $H_{FLID} > 1$ as M increases, so it is impossible to use it in this situation. Since H_{CM} applies to FNID for layer-1, $H < 1$ is achieved even in the case of M = 4.

4.5 Evaluation by ease of changing managed objects

CM is quantitatively compared with FLID and FNID in terms of how easy it is to change managed objects. The following assumptions were made for this evaluation.

- Although it is impossible to know the number of occurrences of each case during a year, all cases are assumed to have occurred during a year. An end-to-end path was installed in advance among all nodes in layer-1 rings.
- Customers provided with point-to-point service were considered in the evaluation.

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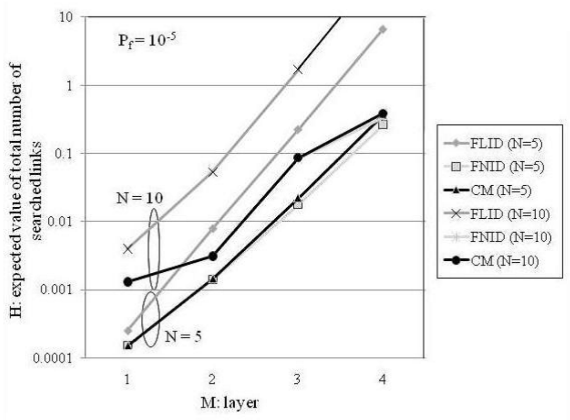

Figure 6: Comparison of number of searched links for affected customers.

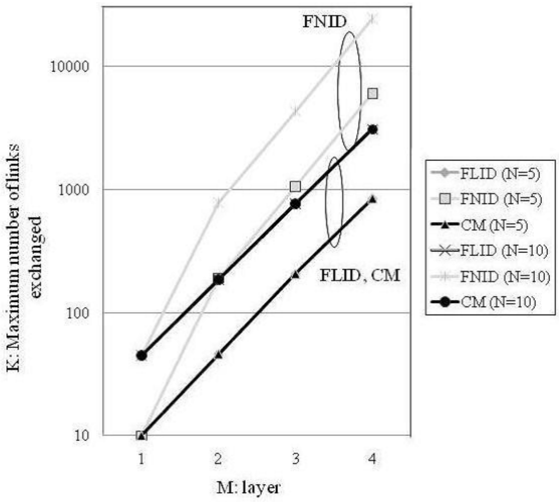

Figure 7: Comparison of number of changed links.

- The total number of links changed is defined as the link count.

Let us define the total number of links changed as $K_{FLID}, K_{FNID}, K_{CM}$, respectively.

Total number of changed links for FLID:
$K_{FLID} = \Sigma_{i=1}^{M} N_i(N_i - 1)/2 \times 4^{M-i}$

Total number of changed links for FNID:
$K_{FNID} = N_1(N_1 - 1)/2 \times 4^{M-1} + N_1(N_1 - 1) \times \Pi_{i=2}^{M} N_i(N_i - 1)/2$

Total number of changed links for CM: $K_{CM} = K_{FLID}$

The results are compared in Fig. 7. The Ks of all methods increased as M increased. K_{FLID} and K_{CM} where the smallest, while K_{FNID} was very large because of the large number of links changed. Since the numbers of links changed for K_{FLID} and K_{CM} were much smaller than that of K_{FNID}, the probability of miss-operation for FLID and CM is small.

Considering both results, CM is far superior to FLID and FNID.

5 Interconnecting procedures

Let us consider interconnecting networks. There are three patterns: (1) both networks are managed by FLID, (2) both networks are managed by FNID and (3) one network is managed by FLID and the other is managed by FNID. The application of each pattern depends on which layers are interconnected. Figure 8 shows the methods in these three cases.

1. Managed with FLID

   Figure 8(a) shows both Networks A and B managed with FLID. In this case, each boundary link in each network stores adjacent boundary link identifiers. The link in a lower layer of the label stack stores the corresponding link identifier if the connected link is in a higher layer of the label stack.

2. Managed with FNID

   Figure 8(b) shows both Networks A and B managed with FNID. In this situation, all links in both networks between two edge nodes should store both edge node identifiers.

3. Managed with both algorithms

   Figure 8(c) shows Network A managed with FLID while Network B managed with FNID. In the case of Network A, the adjacent boundary link in another network should be stored at the boundary link. Moreover, the link in a lower layer of the label stack should store the corresponding link identifier, if the connected link is in the higher layer of the label stack. In the case of Network B, all links in Network B should store another edge node identifier as additional input.

6 Conclusions

Dedicated services based on MPLS networks will be widely introduced in interconnected networks to meet the demand of enterprise customers. Since end-to-end connection will be more complicated in interconnecting networks, path management will be important to enable quick reaction to failures to ensure customer satisfaction.

The specification of key items was firstly described with the following methods for path management.

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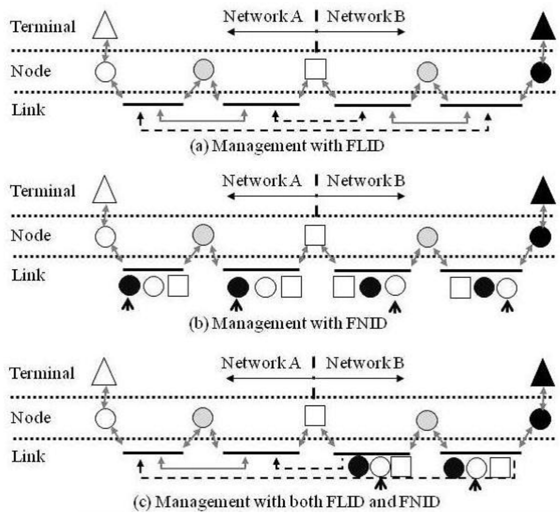

Figure 8: Interconnecting procedures.

1. The method in which a link stores an adjacent link identifier and the edge node identifier is stored at an edge link (FLID),

2. The method in which all links store edge node identifiers (FNID).

We assume that the interconnected networks consist of a layered ring network, and a new method applies FNID in lower-layer networks and FLID in upper-layer networks (CM).

CM was evaluated quantitatively in terms of operational cost factors for the ability to search for users whose service has failed and the ease of changing managed objects in interconnected networks.

A consideration of partial failure of links for these mechanisms is a topic for further study.

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