

COMPARISON OF ALTERNATIVE SERVICE PROTECTION MECHANISMS FOR WIDE AREA ATM NETWORKS

Satoru Ohta and Kazutoshi Nunokawa
NTT Optical Network Systems Laboratories
1-2356 Take, Yokosuka-shi 238-03, Japan

This paper compares service protection methods that are applicable to ATM networks. The considered methods include one digital section level protection scheme and two virtual-path level protection schemes. These methods are evaluated based on network cost and virtual path unavailability. The computational procedures of these parameters are presented. The evaluation results confirm that the virtual path level protection schemes are more advantageous than the digital section level protection scheme in network cost and unavailability.

1. INTRODUCTION

Some ten megabytes of user information may be transmitted within one second through a broadband telecommunication network using Asynchronous Transfer Mode (ATM). Thus, a significant amount of information will be lost if even one failure occurs. This fact explains why network survivability has become an important subject of study for ATM [1]-[3].

Several protection mechanisms have been studied to establish survivable ATM networks [1], [4]. These studies proposed protection schemes in which failed connections are changed over at the ATM virtual path level by utilizing the independence of virtual path bandwidth and routing. These virtual path level protection mechanisms are further categorized depending on whether or not standby capacity is shared among multiple virtual paths [1].

Although virtual path level protection is now available, failures can also be restored in a lower level such as in the digital section layer. For example, the prototype cross-connect system reported in Ref. [5] has a digital section level change-over function. This function can be used to restore services when a failure occurs in a duct or cable if a standby section is set in a different route from the working section route. Several conventional SDH (Synchronous Digital Hierarchy) level self-healing techniques [6] are also applicable to ATM networks.

The problem is finding the optimal protection method for ATM networks. Although related studies have been conducted for STM networks [7], there has been no investigation into the most recent ATM-based restoration schemes. The purpose of this paper is to

clarify, through numerical analysis, which protection method achieves the most economical and reliable ATM network. The employed measures are virtual path unavailability and network cost for 100% restoration against single cable duct failure. The results confirm the advantages of the virtual path level protection schemes.

This paper is organized as follows. Section 2 explores the protection methods to be compared. In Section 3, the assumption and methods of computing network cost are described. The method for deriving virtual path unavailability is described in Section 4. Finally in Section 5, the evaluation results are presented.

2. PROTECTION METHODS

As specified in international standards [8], ATM networks are configured in a hierarchical manner and are composed of several logical resource levels. Namely, the virtual channel level is supported by the virtual path level, and the virtual path level is supported by the digital section level. Furthermore, a digital section, the SDH transmission path, is set up in a fiber network, and the fiber is set up in a cable duct network.

If a failure occurs in a physical resource such as a fiber or a transmission line interface board of a cross-connect system, the affected connections must be changed over to standby routes to restore the services. For the hierarchical configuration described above, this protection can be executed in any of the virtual channels, virtual paths, and digital section levels. Since the reliability and cost of the network depends on which level is selected for protection, it is necessary to compare the performance of alternative protection levels and select the most appropriate method. This paper

compares one digital section level protection method and two virtual path level protection methods, which are considered to be established in present ATM technology.

The digital section level protection [5] is denoted DS-APS (Digital Section Automatic Protection Switch) in this paper. With DS-APS, every working digital section is protected by a standby digital section as shown in Fig. 1 (a). The standby section route is disjoint from the working section route. Thus, communication is restored by changing over the affected section due to a failure in a fiber cable or cable duct.

Virtual path level protection is further categorized depending on whether or not the spare capacity in a digital section is shared among several virtual paths. According to the terminology in Ref. [1], the method with which spare capacity is shared is denoted as VP-SH (Virtual Path Self-Healing) while the method with which spare capacity is not shared is denoted as VP-APS (Virtual Path Automatic Protection Switch).

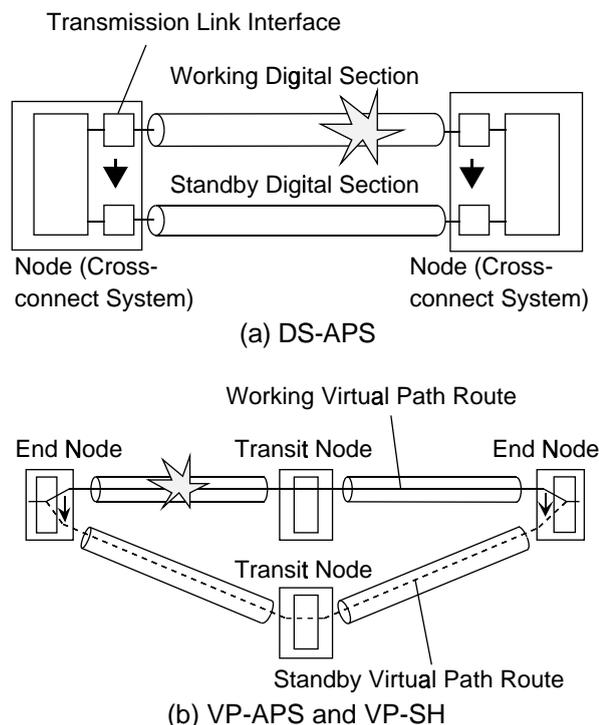


Figure 1. Considered protection methods.

With both VP-APS and VP-SH, two disjoint routes are provided for a virtual path: one is a working route used for transmitting information in a normal state and the other is a standby route used when a failure occurs in the working route. This pre-defined standby route

scheme is explored in Fig. 1 (b). With VP-APS, the capacity of a digital section must be larger than the sum of the total working route bandwidths and the total standby route bandwidths in order to restore services from a failure. Meanwhile, less capacity is needed for VP-SH because the capacity reserved for a standby route is shared by virtual paths.

These three protection schemes are evaluated through network cost and virtual path reliability. These measures are computed for a network that can restore any single failure in a cable duct. The following sections describe how these measures are obtained for each method as well as the results of the evaluation.

3. COST COMPUTATION

Network cost is evaluated by assessing the amount of physical resources such as the number of fiber systems or cross-connect systems for each protection method. This amount of resources is determined through a network design, which determines the following items so as to achieve a less expensive network for a given virtual path demand.

1. Appropriate virtual path routes in the transmission path network;
2. Appropriate transmission path routes in fiber systems; and
3. Appropriate fiber system routes in the cable duct network.

For a fair comparison of protection methods, the network should be optimized for each method. However, the optimization of such a hierarchical network is a very difficult problem, and the problem itself is a subject of comprehensive study. Thus, this paper assumes a trivial and primary design scheme for each protection method. Despite its simplicity, this scheme is useful in clarifying the characteristics of the protection methods.

This paper supposes that a fixed cable duct network is given first. A cross-connect system is placed at every node in the cable duct network. For DS-APS, a working fiber is routed between two adjacent nodes in the cable duct network directly through the cable duct between them. The standby fiber between these nodes is set through an alternative route, which is composed of several cable ducts different from the duct supporting the working fiber. This configuration is shown in Fig. 2 (a). For VP-APS and VP-SH, a working fiber is set in the same way as for DS-

APS. However, standby fibers are not used because high reliability is supported by virtual path level mechanisms. The fiber configuration for these methods is illustrated in Fig. 2 (b).

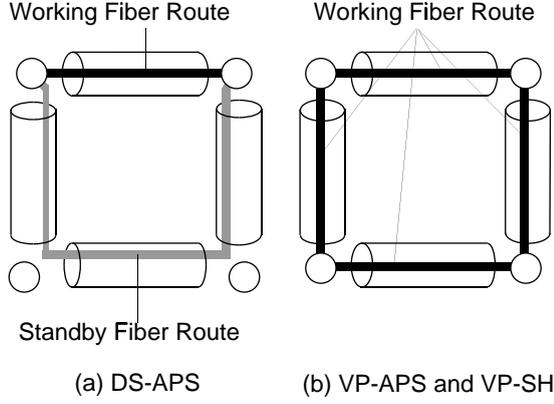


Figure 2. Fiber configuration.

For simplicity, it is assumed that every transmission path (or digital section) is supported by one fiber system, that is, a digital section is not constructed by multiple fiber sections nor is it cross-connected at any node.

The route of a virtual path is determined by applying either the shortest path algorithm or the shortest disjoint path algorithm to each source-sink pair specified in a given virtual path demand. Since no standby virtual path route is necessary for DS-APS, the route is computed by the shortest path algorithm for a given source-sink pair. The distance between adjacent nodes is set to the physical length of the working fiber. For VP-APS and VP-SH, it is necessary to find a standby virtual path route for a given sink and source. The standby route must be node-disjoint from the working virtual path route. Such a route is found by the shortest disjoint path algorithm [9].

Through these route assignment rules, virtual path bandwidths are determined for each digital section. The bandwidths then determine the required number of SDH transmission paths and thus determine the number of fibers with a given capacity for the digital section. For DS-APS, the number of fibers is set sufficiently large to support the total bandwidth of virtual paths routed in the section. The number of standby route fibers is set equal to that of working route fibers. For VP-APS, the number of required fibers is determined by the total bandwidth of virtual paths, working or standby routes which pass through the section.

The bandwidth reserved for a section cannot be derived as a simple sum of the virtual path bandwidths for VP-SH. This is because the bandwidth portion reserved for standby is shared among multiple virtual paths. The standby bandwidth for each digital section is determined such that a virtual path would be restored against any single cable duct failure and any single transit node failure. The procedure for deriving the standby bandwidth for digital section i , denoted by $B_{stdby,i}$, is:

[Procedure for VP-SH standby bandwidth]

1. **for** each section i **do** $B_{stdby,i} := 0$;
2. **for** each virtual path VP_j **do**
3. **for** each resource x on the working route of VP_j **do**
4. **for** each section k on the standby route of VP_j **do**
- begin**
5. $B_k :=$ the bandwidth needed for section k to restore all paths passing x ;
6. **if** $B_{stdby,k} < B_k$ **then** $B_{stdby,k} := B_k$;
- end**

Using these assumptions on a design scheme, the amount of required physical resources is determined for a given virtual path demand and a given cable duct network. Then, network cost is derived from the amount and unit price of each physical resource.

In this paper, the network cost depends on the following physical network resources.

- fiber
- repeater
- transmission line interface of a cross-connect system
- common part of a cross-connect system

The cost of a fiber is proportional to its total length. The repeater cost is determined by the number of used repeaters. Since a repeater must be inserted at every specified distance, the number of repeaters is derived from the section distance and the number of fibers. The transmission line interface cost of a cross-connect system is proportional to the number of terminated fibers, while the cost of the common part is fixed and does not depend on the number of fibers. The network cost is computed by giving unit prices for the above resources.

4. RELIABILITY COMPUTATION

The unavailability of a specified virtual path is employed as a measure to evaluate network reliability achieved by each protection method. The virtual path unavailability is defined as the probability that the path is not useable for service. Its value is determined by those of the physical resources associated with its working and standby routes. The physical resource unavailability is associated with the following failures.

- 1) cable duct distraction
- 2) failure of a transmission line interface of a cross-connect system
- 3) failure of the common part of a cross-connect system

The cable duct distraction cuts off all fibers and thus virtual path routes included in the duct. A line interface failure occurs independently in a cross-connect system and affects only the virtual paths included in the failed interface. Meanwhile, a common-part failure damages all the virtual paths passing through and that are terminated at a cross-connect system. It is assumed that unavailability values of a transmission line interface, the cross-connect common part, and a cable duct are given.

When DS-APS is applied, a digital section is protected by the standby route. Thus, the unavailability of digital section i , $U_{sctn,i}$, is described as

$$U_{sctn,i} = U_{sctn_wkng,i} \cdot U_{sctn_stdby,i}$$

where $U_{sctn_wkng,i}$ and $U_{sctn_stdby,i}$ are the unavailability of the working route and standby route. The unavailability of each section route is determined by those of the cable duct and the line interfaces.

Then, the unavailability of a virtual path that employs DS-APS, denoted by U_{DS-APS} , is

$$U_{DS-APS} = \sum_{\text{section } i \text{ on VP}} U_{sctn,i} + \sum_{\text{node } j \text{ on VP}} U_{cmmn,j}$$

where $U_{cmmn,j}$ is the unavailability of the common part of a cross-connect system.

Meanwhile, for VP-APS, the virtual path unavailability, U_{VP-APS} is expressed as follows, considering that a virtual path is protected on the end-to-end basis.

$$U_{VP-APS} = U_{wkng_rt} \cdot U_{stdby_rt} + \sum_{\text{end node } j} U_{cmmn,j}$$

where U_{wkng_rt} and U_{stdby_rt} are the unavailability of the working and standby virtual path routes. The former is defined as,

$$U_{wkng_rt} = \sum_{\text{section } i \text{ on route}} U_{sctn,i} + \sum_{\text{transit node } j \text{ on route}} U_{cmmn,j}$$

Similarly, U_{stdby_rt} is defined.

It is more complex to derive the virtual path unavailability for VP-SH. There are the following cases for which a virtual path becomes unavailable with VP-SH.

Case 1) A failure occurs at one of the cross-connect systems that terminates the virtual path.

Case 2) Resources included in the working and standby routes fail simultaneously.

Case 3) Failures occur simultaneously in the working route and in a resource not included in the working nor standby routes, and there is insufficient capacity to restore both failures.

The unavailability brought about by Case 1 and Case 2 is calculated in the same way for VP-APS. This means that the unavailability is no better for VP-SH than for VP-APS. When Case 3 occurs, an affected virtual path may or may not be restored depending on the spare capacity on a link of the standby route and the order in which the paths are restored. Therefore, it is difficult to compute the exact unavailability for Case 3. Nevertheless, it is possible to obtain the upper bound for the unavailability by assuming that a virtual path always becomes unavailable for Case 3. This upper bound will give a safe-side evaluation for the reliability achieved by VP-SH. The algorithm that computes the upper bound is:

[Procedure for VP-SH unavailability]

1. $U_{VP-SH} := U_{wkng_rt} \cdot U_{stdby_rt} + \sum_{\text{end node } j} U_{cmmn,j}$;
2. **for** each resource x included in the working virtual path route **do**
3. **for** each resource y not included in the working route nor in the standby route **do**
4. **if** there is not enough spare capacity in a link on the standby route for simultaneous failures in x and y **then**
begin
5. $U_x :=$ the unavailability of x ;
6. $U_y :=$ the unavailability of y ;
7. $U_{VP-SH} := U_{VP-SH} + U_x \cdot U_y$;
- end**

5. EVALUATION

This section shows the results of network cost and virtual path unavailability. Figure 3 shows the cable duct network model used in the evaluation. This model is a rough approximation of the long distance network in Japan.

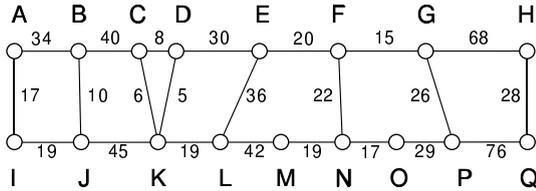


Figure 3. Network model.

For the cable duct network, the following types of virtual path demand were given.

Pattern A: The same number of virtual paths with the same bandwidth were set between every source and destination pair. That is, the traffic is uniform for any node pair.

Pattern B: Traffic is concentrated on two nodes in the network. Let $N_{i,j}$ be the number of virtual paths set between node i and node j . Then,

$$N_{i,j} = \left\lfloor \frac{A W_i W_j}{\sum_{k,l} W_k W_l} \right\rfloor,$$

where W_i is the weight assigned for node i ($W_i > 0$), A is a constant, and $\lfloor \cdot \rfloor$ is the largest integer not greater than \cdot . The bandwidth is set constant for every virtual path.

Pattern C: Traffic is larger for closer nodes. For this pattern, the number of virtual paths is

$$N_{i,j} = \left\lfloor \frac{A (1/L_{i,j})^\alpha}{\sum_{k,l} (1/L_{k,l})^\alpha} \right\rfloor,$$

where $L_{i,j}$ is a distance between node i and node j . The bandwidth is set constant for each virtual path.

For all demand patterns, the bandwidth of a virtual path was set at 10 Mb/s and the total virtual path bandwidth is set to nearly 10 Gb/s. The fiber capacity was selected to be 600 Mb/s. For demand pattern B, W_i was set at 7 for nodes K and N, and 1 for the other nodes.

Figures 4, 5, and 6 show the network cost for demand patterns A, B, and C. In these figures, the portions of link and node cost are also explored. The figures show that DS-APS yields the largest network cost for any demand pattern. Particularly, link cost is much higher for DS-APS than VP-APS. Since link cost is a dominant factor in the total network cost, VP-APS is a more economical alternative to DS-APS.

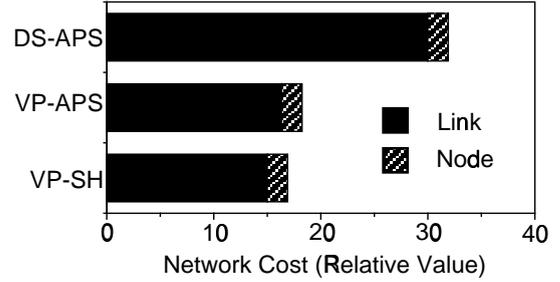


Figure 4. Network cost for demand pattern A.

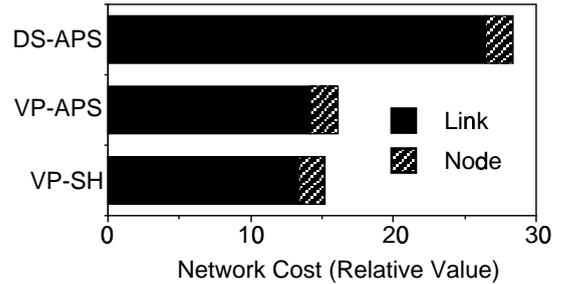


Figure 5. Network cost for demand pattern B.

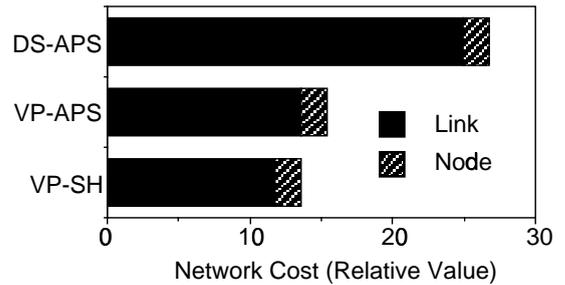


Figure 6. Network cost for demand pattern C.

It is expected that VP-SH has a cost advantage because spare capacity is shared by multiple standby virtual path routes. However, the figures show that the advantage of VP-SH depends on the demand patterns. For pattern C, the cost for VP-SH is 12.3% lower than that for VP-APS. Thus, network cost decreases considerably with VP-SH for this demand pattern. Meanwhile, the cost is only 5.5% lower for VP-SH than for VP-APS for

pattern B. This means that VP-SH is not very advantageous for this demand pattern.

Figure 7 compares the virtual path unavailability between nodes A and N in the network model for each protection method. The employed demand pattern is C, which affects the performance by VP-SH. The figure shows that DS-APS is less reliable than the others. This is because DS-APS is not effective for a transit node failure. Thus, the unavailability of transit nodes are dominant for the total virtual path unavailability. Therefore, the reliability achieved by DS-APS becomes worse than those achieved by VP-APS and VP-SH which are effective for transit node failures. For VP-APS and VP-SH, the path unavailability almost equals the total unavailability of both end nodes because duplicated routes bring high reliability to other portions of a path. Thus, there is only a slight difference between these.

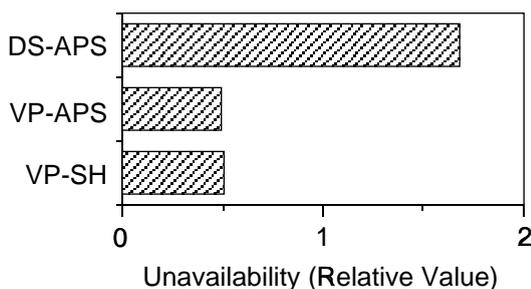


Figure 7. Virtual path unavailability for each protection method.

From the above results, it is concluded that DS-APS is not as beneficial as the others in terms of cost and reliability. VP-SH yields a lower network cost than does VP-APS while providing as high a level of reliability as VP-APS. However, the superiority of VP-SH is still inconclusive. The reasons for this are:

1) The cost advantage of VP-SH depends on the demand pattern. The above results show that VP-SH is less effective for a concentrated demand pattern. Unfortunately, the demand in the real world is expected to be similar to this pattern: traffic will be centered on a few large cities. Thus, the cost advantage of VP-SH is uncertain.

2) It is more difficult to implement and operate VP-SH than VP-APS. For example, VP-SH requires a mechanism that checks the spare capacity at change over. This mechanism is unnecessary in VP-APS. In addition, more complicated network design and change back

operation at a repair of a failure are needed for VP-SH.

Considering all the above points, it is concluded that VP-APS is the best choice for real ATM networks if the demand is uncertain. Only if the demand is found to be suited to VP-SH, and only if all the technical difficulties are removed in the viewpoint of implementation, network design, and operations, then VP-SH should be introduced into ATM networks.

6. CONCLUSION

This paper compared three protection methods DS-APS, VP-APS, and VP-SH from the viewpoints of network cost and virtual path unavailability. The results show that VP-APS and VP-SH are more advantageous than DS-APS. The results also support the conclusion that VP-APS is more practical because the advantage of VP-SH is uncertain.

ACKNOWLEDGMENTS

The authors wish to thank Dr. Ikuo Tokizawa and Dr. Toshinori Tsuboi.

REFERENCE

- [1] R. Kawamura and I. Tokizawa, "Self-healing virtual path architecture in ATM networks," *IEEE Communications Magazine*, 33, 9, pp. 72-79, 1995.
- [2] E. Oki, N. Yamanaka, and F. Picho, "Multiple-availability-level ATM network architecture," *IEEE Commun. Mag.*, 33, 9, pp. 80-88, Sept. 1995.
- [3] K. P. May, P. Semal, Y. Du, and C. Herrmann, "A fast restoration system for ATM-ring-based LANs," *IEEE Commun. Mag.*, 33, 9, pp. 90-98, Sept. 1995.
- [4] H. Fujii and N. Yoshikai, "Restoration message transfer mechanism and restoration characteristics of double-search self-healing ATM network," *IEEE J. Select. Areas Commun.*, 12, 1, pp. 149-158, Jan. 1994.
- [5] H. Ueda, H. Obara, H. Uematsu, and H. Ohta, "ATM cross-connect system technology," *NTT R&D*, 42, 3, pp. 357-366, Mar. 1993.
- [6] W. E. Falconer, "Service assurance in modern telecommunications networks," *IEEE Commun. Mag.*, 28, 6, pp. 32-39, June 1990.
- [7] T. Wu, D. J. Kolar, and R. H. Cardwell, "Survivable network architecture for broadband fiber optic networks: model and performance comparison," *J. lightwave technology*, 6, 11, pp. 1698-1709, Nov. 1988.
- [8] ITU-T Recommendation I.311, "B-ISDN general network aspects".
- [9] J. W. Suurvalle, "Disjoint paths in a network," *Networks*, 4, pp. 125-145, 1974.