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非同步傳輸模式網路之存活性研究之虛擬路徑重建問題*
SELF-HEALING ATM NETWORKS BASED ON VIRTUAL PATH RESTORATION

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摘要

為了使非同步傳輸模式網路能有容錯能力及降低因網路故障而導致的經濟損失和社會成本，路徑重建這個觀念便成為在發展更有效率及具容錯能力的非同步傳輸模式網路時的一項重要考量。在過去，有關研究路徑重建的文獻中，絕大多數的學者均著重於如何達成100%的資料修復，對於提高頻寬使用率方面卻著墨不多。在本論文中，針對網狀骨幹的非同步傳輸模式網路，我們提出了兩種新的路徑重建演算法來提高頻寬使用率，並且也盡可能地提高其資料修復率。我們也提出了一個新的效能評估標準「負載資料修復額度」(Restoration Reward)，以評估路徑重建演算法的效能。在這個評估標準下，當網路系統負載較大時，我們所提出的兩種新演算法其整體表現優於舊有的方法。

關鍵字：非同步傳輸模式網路，虛擬路徑，動態虛擬路徑繞線演算法，路徑重建

Abstract

Self-healing is a key issue in developing reliable and efficient Asynchronous Transfer Mode (ATM) networks, because it can provide the network with the failure recovery ability and reduce the economic and social damage caused by network failure. In the past, most of the self-healing algorithms proposed in the literature emphasize on how to achieve 100% fault restoration rate and leave the bandwidth utilization as a minor issue. In this paper, we propose two new self-healing algorithms for mesh typed ATM networks to improve the bandwidth utilization while keeping the restoration rate as high as possible. Both of these two algorithms combine restoration technique with dynamic VP routing strategy to improve the network resource utilization. The main difference between these two algorithms is the underlying VP bandwidth allocation mechanism. The performance of these two algorithms are evaluated through simulations and are compared to one existing algorithm. With the combination of self-healing and dynamic routing, the proposed two algorithms yield near zero blocking probability while maintaining reasonable restoration rate. A new performance metric, referred to as restoration reward, is also porposed to evaluate these two algorithms to show how much reward can be restored during a network failure.

Keywords: ATM, Virtual Path, Adaptive Routing, Self-Healing

1. Introduction

Since the rapid advances in optic transmission and switching technology and with the increased demand for various kinds of communication services (e.g., data, audio, video and/or mixed type), broadband ISDN (B-ISDN) nowadays has become more and more important. Due to the heterogeneous nature of traffic sources, the traffic carried within B-ISDN system requires a wide range of bandwidth, ranging from about a few Kbps up to hundreds of Mbps, and very different Quality of Service (QOS) requirements, such as end-to-end delay, jitter, and cell loss rate. Hence, the key to a successful B-ISDN system is the ability to support multiple classes of traffic with different service performance requirements.

The cell-switched Asynchronous Transfer Mode (ATM) technique has been proposed by ITU-T as the target technique for future B-ISDN [1]. To support multiple classes of traffic with different quality of service requirements, five classes of transport protocols, the ATM Adoption Layer (AAL) protocols, have been defined in ATM networks [2,3]. For example, AAL 1 and 2 protocols are defined for video applications and AAL 5 protocol is defined for efficient transmission of data

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traffic. To multiplex/demultiplex different types of traffic efficiently, ATM adopts the nonhierarchical, cell based multiplexing/demultiplexing technique. The information transported in ATM networks is packetized into a short fixed size unit, called cell. Based on simplified hardware and software, such cell switching technique enables ATM to provide flexible and efficient multiplexing/demultiplexing operations on transmission channels. Because of these advantages, ATM is able to meet the challenges for providing B-ISDN services and, hence, is considered as the best target technique for realizing B-ISDN.

In ATM networks, the concept of Virtual Path (VP) is proposed to reduce the nodal costs and simplify both the transport network architecture and OAM (operation, administration, and maintenance) functions by grouping connections sharing common paths through the network into a single unit [4, 5]. Intuitively, a VP can be thought as a single logical direct link between a source node and destination node. Especially, by reserving resources, such as bandwidth and buffer space, to VPs, a virtual channel (VC) of a VP can be setup at the source node, without invoking any call processing procedure at the transit nodes along the VP [4, 6]. On the other hand, we can set up a VP by merely reserving the Virtual Path Identifier (VPI) and do not reserve any resource to the VP in advance. The allocation of VP capacity is then deferred until a VC needs to be established on this VP. The later feature is especially useful for network to cope with unexpected sudden traffic changes, e.g., a link failure.

Due to the volume of traffic carried on VP is usually large, once the network failure occurs, such as fiber cut or nodes go down, a large number of applications that go through the affected VPs will suffer from the degraded transmission service or even not able to maintain the connectivity from source nodes to destination nodes. To minimize economic and social damage caused by node/link failure, and provide an robuster network environment, many researchers have devoted to the study of ATM VP-based Self-healing technique to enhance network reliability within B-ISDN system.

The goal of self-healing technique is to be able to detect and fully recover from network failures, either link or node failure, as soon as possible. In most past research, this goal is achieved by exclusively reserving certain redundant resources in advance in order to prevent any unexpected sudden accidents. Since the network traffic dynamically changes from time to time, the amount of redundant resources to be reserved must be conservatively estimated in order to ensure 100% failure restoration. Therefore, how to manage these spare resources efficiently and economically is a very important issue, because at one hand, the amount of reserved redundant resources must be large enough to ensure the 100% restoration. On the other hand, since the redundant resources are reserved exclusively for the use of failure restoration, we can expect that, during most of the time, they are wasted. The purpose of this study is, thus, to propose a new self-healing technique which combines restoration technique with dynamic VP routing to improve the network resource utilization.

The remainder of this paper is organized as follows: in section 2, we briefly survey the existing self-healing techniques. In section 3, our motivation for proposing new self-healing scheme is stated first, we then propose two new self-healing schemes. In section 4, performance of our schemes are evaluated through simulations. Finally, section 5 concludes this paper.

2 Literature Survey

Much research has been devoted to the development of the self-healing schemes for ATM networks based on the virtual path technique. Since the virtual path configuration is highly dependent on the network topology, self-healing schemes that have been proposed in the literature can be classified by their underlying network topologies. Specifically, the network topology of an ATM network can be either a mesh or a ring. Due to the special structure of the ring topology, the self-healing schemes for ring typed networks are much simpler than that of mesh typed networks. In this paper, thus, we only focus on self-healing schemes for mesh typed networks.

Many self-healing schemes for mesh typed ATM networks have been proposed in the literature [7–13]. Among these schemes, most of them are distributed algorithms. The platform of distributed self-healing schemes can be summarized as follows. When a link fails, the downstream site of the failed link becomes a sender node, and the upstream site becomes a chooser node. Once the sender node detects the failure, it broadcasts the restoration messages for all the affected VPs bundled within the failed link through every possible alternate path to the chooser node. While a restoration message arrives at an intermediate node, a nodal counter in the header is examined to prevent infinite broadcasting. If the counter has not exceeded some threshold, the intermediate node will modify the restoration message by filling out the spare capacity it captured and the ID of the next link on the alternate path. Then, the intermediate node broadcasts this modified message to all its neighboring nodes. On the other hand, if the counter has exceeded certain threshold, this restoration message will be discarded. When the chooser node receives these restoration messages, it will make a decision about which alternate path could be possibly used for failed VP restoration. This decision is made by simply extracting the information enclosed in these restoration messages. Once the chooser node has picked up one alternate path for path restoration, it updates its own VP routing table and sends a confirm message to all nodes along the selected route. Upon receiving a confirm message, certain amount of capacity will be reserved for restoring the failed VP. In the meanwhile, the chooser node also broadcasts a release message to all nodes on unselected alternate paths to release the previously reserved (captured) bandwidth.

In order to speed up restoration time and reduce the number of broadcasting messages, the concept of preassigned backup VP with zero bandwidth reservation by exploiting the ATM VP benefits has been introduced. Specifically, for every target VP, we can setup one or more backup VPs before failure occurs. The target VP and its backup VP are totally path disjointed at link level except that they share the same source node and destination node, as shown in Figure 1. When network failure occurs, the sender node detects the failure, it sends a restoration message to the chooser node through the preassigned backup VP only, rather than broadcasts the messages to all adjacent nodes. When the restoration message arrives at an intermediate node on the backup VP, the node captures its current free capacity and then bypasses the message to the next node on the backup VP. After the chooser node receives the restoration message, it switches the service traffic carried on failed VP to the preassigned backup VP, if there exists enough free capacity on the backup VP. Otherwise, this fault restoration is failed.

There are two issues need to be solved in this approach, namely, how to preassign a backup VP for each target VP and how to manage the redundant spare resource reserved on each VP/link. Assume the physical network topology, configuration of each target VP, and bandwidth allocated on each VP are already known, the following approaches are proposed in [7,10]. In order to prevent the condition that the target VP and its backup VP crash at the same time, the backup VP should be established independently from the target VP except their common terminator nodes. That is, the backup VP and the target VP are totally path disjointed at the link level. By separating target VP from backup VP, we can guarantee that any single link failure will not cause all the affected VPs and all their backup VPs go down at the same time. Another factor needs to be considered when establishing the backup VP is the length of the backup VP. In order to reduce the message transmission time, the length should be as short as possible.

For allocating redundant spare capacity on each link for backup VPs, a good algorithm is proposed in [10]. For a summary of this algorithm, the readers are referred to [10,15].

3 New Self-Healing Schemes

3.1 Motivation

In the literature, as discussed in the previous section, most researchers have focused on how to achieve 100% restoration under single network failure [7–13]. The bandwidth utilization and connection blocking probability are thus minor issues. In these self-healing schemes, each link in the network is preassigned sufficient redundant capacity in order to achieve the goal of 100% fault restoration. This redundant capacity, however, cannot be used until the network failure occurs. Since the network operates under normal condition, i.e., without network failure, during most of the time. Therefore, we can expect that, under this kind of bandwidth assignment policy, the network will have very low bandwidth utilization. The low bandwidth utilization also implies high connection blocking probability, especially under high traffic load conditions.

In this paper, we propose a new self-healing scheme which combines with dynamic routing algorithms to improve the network bandwidth utilization under normal network operations while still provides near 100% restoration rate under single link/node failure. The main idea is to allow routing algorithms to utilize the spare VP capacity when the network runs out of the target VP's capacity. Specifically, when a connection arrives at a source/destination pair, the connection is offered to target VP first. If the connection is blocked due to insufficient capacity on the target VP, the connection is then offered to the back up VP which may have reserved spare capacity, depends on the underlying VP capacity reservation strategy.

Clearly, under normal condition, which is true for most of the time, the spare capacity can be utilized to reduce the connection blocking probability. Thus the network bandwidth utilization can be improved. Of course, the ability to achieve 100% restoration when a network failure occurs becomes questionable. However, the key point is if the degradation of the amount of restored capacity under network failure is not very severe, e.g., the difference of the amount of restored capacity between our schemes and existing schemes is not significant, then we believe the trade-off between blocking probability and restoration rate is worthy. To evaluate the performance of self-healing schemes, we proposed a new performance metric, referred to as restoration reward, which indicates the actual fault recovery capability of self-healing schemes in terms of capacity of failure restoration. In our numerical results, we show that when traffic load is high, our new self-healing schemes yield higher restoration reward as compared to existing schemes. On the other hand, under low traffic load, although the restoration reward of our schemes is slightly lower than that of existing schemes, the restoration rate of our schemes is almost 100%.

Although our self-healing scheme cannot guarantee for 100% restoration rate under a network failure, in our numerical results, we will show that the restoration rate will be acceptable from the point of view of restoration reward. Therefore, we claim that our self-healing scheme is able to yield high network bandwidth utilization under normal condition while still provides high restoration rate under network failures.

3.2 VP Capacity Allocation Policies

We have noticed that the design of self-healing schemes is affected by the underlying VP capacity allocation policy. Therefore, in the following, we first describe two commonly used, but rather different, VP capacity allocation policies. In the next section, we will describe our self-healing schemes under these two VP capacity allocation policies.

The VP capacity allocation policy adopted in most of the self-healing schemes proposed in the literature reserves dedicated bandwidth to VPs. Under this policy, all VPs bundled in the same link have their own dedicated bandwidth, and the summation of these VPs' capacities is not allowed to exceed the total capacity allocated to the link. Furthermore, these bandwidth are assigned exclusively to each VP, and hence, these bandwidth are not permitted to share among VPs. Therefore, each VP can be viewed as a physical link under this policy. In order to achieve 100% restoration rate, dedicated spare capacity is reserved to back up VPs in [8]. Or the spare capacity is reserved to each link, but not to back up VPs in [10]. In either case, the reserved spare capacity is not used under normal condition.

The VP capacity allocation policy proposed in [14] is rather different from the previous policy. In this policy, VP capacity is allocated and deallocated "on demand". That is, a certain amount of bandwidth is allocated when the VP needs additional capacity, e.g., a new call arrives and finds no available bandwidth, and is released when there is too much bandwidth on the VP. The allocation and deallocation of a VP's bandwidth is done in units of *"block"* which is predefined by the network manager and is sufficient to accommodate several calls. The detailed VP bandwidth management algorithm under the second allocation policy is described as follows:

1. When a new call arrives at a VP,
   (a) if current allocated bandwidth is not enough for connecting a new arriving call, requests for a block of bandwidth.
   (b) If the request for increasing bandwidth is permitted, then allocates the bandwidth for the VP. Otherwise, blocks the call.
2. If unused bandwidth of the VP is less than certain threshold, deallocates a block of bandwidth.

By carefully choosing the block size, the bandwidth management overhead cost the call blocking probability can be reduced. Consequently, the bandwidth utilization can be increased.

3.3 Two New Self-Healing Algorithms

As mentioned previously, with the VP bandwidth assignment policy changed, the design of self-healing scheme is varied. In this section, we, hence, propose two new self-healing algorithms. The first self-healing algorithm which is based on dynamic VP bandwidth allocation policy is referred to as algorithm SHD, and the second one is referred to as algorithm SHS and is based on static (dedicated) VP bandwidth allocation policy. Both of these two algorithms are distributed algorithms, have three phases, and utilize the dynamic VP routing algorithm to improve the bandwidth utilization. These algorithms are made possible under the assumption that the network topology, target VP's route and average bandwidth requirement (determined by average call arrival rates) are given.

The SHD algorithm is described as follows:

- **Phase 0 (initial phase):**
  A backup VP is preassigned to each target VP at this phase. The backup VP and the target VP are totally path disjoint at link level except their common terminator nodes (Figure 1). The length of backup VP should be as short as possible. This is for the reason of reducing message transmission time. Since under the dynamic VP bandwidth allocation policy, no dedicated bandwidth is reserved on VP, i.e., VP capacity is allocated/deallocated on demand, we thus reserve the redundant capacity on each link for the purpose of failure recovery. The total amount of spare bandwidth reserved on each link in the network could be obtained by Kawamura's method [10] as described in the section 2.
- **Phase 1 (fault detection phase):**
  When a link failure occurs in the network, the downstream node of this failed link becomes the sender node. Once the sender node detects this fault, then it will generate the restoration messages to respond to this event. For each affected VP, the sender node sends a restoration message for it to check if it can fully switch the affected traffic to backup facility. This message encloses the information about the volume of capacity allocated on this affected VP and some related information. The format of this message is shown in Figure 2.

  Field SUCC_FLAG indicates if the fully restoration for certain VP succeeds or not, its initial value is set on. The AFF_VPB field keeps the amount of VP bandwidth carried on an affected VP. This value is filled out by sender node. The amount of residual spare VP capacity left on backup VP is indicated in filed MIN_VPB. The initial value of MIN_VPB is set to maximum integer.

  The restoration message is transported to the chooser node along the preassigned backup VP only. While each intermediate node on the backup VP receives the restoration message, it will capture appropriate spare bandwidth from the link which it passed. Then, the intermediate node uses this value it just captured to compares with the amount of faulty VP's traffic extracted from restoration message. This is for the purpose of checking whether the residual spare capacity left on the link is enough for recovering the faulty VP. If the captured bandwidth is enough for 100% fault restoration, then the intermediate node modifies the restoration message. Namely, it writes down the volume of captured spare capacity to field MIN_VPB, if it is smaller than that recorded in field MIN_VPB. Otherwise, if the captured bandwidth is not enough for 100% fault restoration. Then the intermediate node turns the SUCC_FLAG off and writes down the captured bandwidth to field MIN_VPB, if it is smaller than that recorded previously in field MIN_VPB. After finishing these checking procedure, the intermediate node sends this modified restoration message to the next node along the backup VP.
- **Phase 2 (confirm phase):**
  When the chooser node receives the restoration message, it updates its own VP routing table and extracts the information enclosed in restoration message. If the SUCC_FLAG is on, that means the backup VP has enough spare bandwidth to achieve 100% restoration. The chooser node, then generates a confirmation message and sends it back to all the intermediate nodes for noticing each intermediate node to allocate AFF_VPB units of bandwidth for fault restoration. In the meanwhile, the chooser node switches the affected traffic to backup VP.

  Otherwise, if the SUCC_FLAG is off, that implies, the backup VP does not have enough capacity for 100% fault restoration. Then according to the volume of AFF_VBP and MIN_VPB, chooser node is able to know how many connections on this affected VP should be discarded, and by using certain decision rule to pick up those victims. Then it sends a confirmation message to each intermediate node to all allocate MIN_VBP units of bandwidth for restoration. This completes our first self-healing algorithm.

The SHS algorithm is similar to SHD algorithm and can be described as follows:

- **Phase 0 (initial phase):**
  A backup VP is preassigned to each target VP at this phase. The total amount of redundant capacity reserved on backup VP for the use of fault restoration is also computed at initial phase. As in the first algorithm, The backup VP and the target VP are totally path disjoint at link level except their common terminator nodes and the length of backup VP should be as short as possible. The total amount of spare bandwidth reserved on each link in the network could be obtained by Kawamura's method [10] as described in Section 2. Once the amount of spare capacity reserved on each link is determined, then the amount of spare capacity reserved on each backup VP can also be determined.
- **Phase 1 (fault detection phase):**
  All the operations in this phase are similar to those of fault detection phase which is described in SHD algorithm previously, except the intermediate node captures the spare bandwidth from the backup VP rather than from the link.
- **Phase 2 (confirm phase):**
  This phase is the same as the confirm phase of the SHD algorithm.

The new proposed self-healing algorithms have following characteristics:

1. Dynamic routing scheme is used to improve the bandwidth utilization. Since our two new proposed self-healing algorithms combine with the dynamic routing scheme to increase the VP bandwidth utilization, the usage of these redundant capacities is hence not only for the use of fault restoration when network fails, but also for allowing routing algorithm to utilize it when the network is under normal operation. Explicitly, when a connection arrives at a source/destination pair, the connection is first offered to the target VP between the source node and destination node. If the residual capacity on this target VP is insufficient for carrying this connection, the connection is then offered to backup VP.

   In our second self-healing scheme, the backup VP has reserved spare capacity. However, in our first scheme, in stead of reserving dedicated bandwidth on backup VP, we reserve spare capacity on the link which the backup VP passes through. The backup VP, hence, need to grab blocks of bandwidth from the link on demand. At most of the time, connections can be carried by backup VP if the bandwidth left on the target VP is not enough for accommodating one more new connection. By utilizing spare capacity of backup VP for alternate routing, our self-healing schemes are able to achieve higher bandwidth utilization and lower connection blocking probability.
2. Near non-blocking property for establishing new arrival connections. Since the spare capacity is intended for 100% restoration, it tends to be quite large. Therefore, from our simulation results, our self-healing schemes are able to provide near zero connection blocking probability.
3. No guarantee for 100% fault restoration. As the bandwidth utilization increased under our self-healing schemes, the connections which are carried by our new proposed schemes are much larger than those carried by existing scheme. Since the bandwidth is fixed and finite, 100% fault restoration rate is not able to be achieved under our self-healing schemes. The degradation, however, is controlled within certain level even when the call arrival rate is high. When traffic arrival rate is decreased, the fault restoration rate is quickly approximating 100%. The new proposed self-healing schemes provide a new point of view to measure the efficiency of self-healing scheme. By slightly relaxing the constraints of 100% fault restoration, the redundant spare resource reserved for failure recovery is well-utilized with the dynamic routing policy. Note that, as discussed in the previous section, if we use the restoration reward as the measurement to evaluate the restoration performance of the existing self-healing algorithms and our new proposed self-healing algorithms, we find that under this performance metric, the amount of capacity restored by our s schemes due to network failure is quite close to that of existing schemes or even better. We will show the numerical results and explain this observation in more detail in section 4.

   When the residual spare capacity left on backup VP or on the link which the backup VP passes through is insufficient for recovering all the affected connections, a decision rule is needed to help the chooser node to pick up victims and then to drop them. The decision rule used for disconnect a connection can be designed based on priority oriented approach. The high priority traffic can be served safely, low priority traffic, however, will be served with no guarantee when network fails. The classification of priority of service connection could be set according to the fee paid by users. For instance, the more user has paid, the higher priority he will get. Or it could be set by considering practical routing issue. For example, connections routed on direct VP receive higher priority than connections routed on alternate path.

4 Numerical Results

In this section, we evaluate our two new proposed self-healing schemes via simulations and compare their performance with one of the existing self-healing schemes. The design of self-healing algorithm strongly depends on the underlying network topology, the VP bandwidth allocation policy and the volume of traffic carried in the network system. Hence, before discuss the computer simulation results, we first describe our network models.

4.1 Network Model and Routing Scheme

- Network Model:

We have evaluted our self-healing schemes on two network models: a 5-node model and the TANet model. Here, we only present our results on the TANet model. For the results on the 5-node model, the readers are referred to [15]. Currently, TANet consists of 9 nodes and 24 unidirectional physical links. Thus, by assigning each source/destination pair a virtual path, its logical virtual path network can be viewed as a $K9$ graph and has 72 unidirectional virtual paths.

Because of the layout of physical links, some of the virtual paths will traverse more than one links while others will pass through merely one link. We use the virtual paths which only pass through one link as our backbones of backup VPs for the use of fault restoration. According to our new self-healing algorithms, we will preassign one backup VP for each target VP. Furthermore, the backup VP and target VP should be path disjointed at link level.

- **Traffic model:**
  We assume calls arrive at each source-destination pair according to a Poisson process and the call holding time is exponentially distributed with mean of unity.
  In the TANet model, we assume there are two classes of calls, referred to as class A and class B. The bandwidth required by class A calls is one unit and by class B calls is 12 units. Class A traffic is used to model narrow-band traffic while class B traffic is to model broadband traffic. As we believe broadband traffic is more important than narrow-band traffic, thus, when network failure occurs, we will try to restore class B traffic first, then class A traffic.
  The arrival rates of class A and class B range from (52,3.2) to (60,4), the increasing step size is 2 and 0.2 for class A traffic and class B traffic, respectively. Throughout this paper, we define Offered Traffic Load (OTL) at a VP as follows,

$$\textit{offered traffic load} = \sum_{i=1}^{k} \lambda_i b_i$$

  where k is the total number of classes of traffic, b_i is the bandwidth required for carrying a class i call, λ_i is the arrival rate of class i traffic. In the TANet model, the offered traffic load pairs of class A and class B traffic range from 90.4 to 108.
- **Routing Scheme:**
  The routing scheme used here is *Least Loaded Routing* approach which is proposed by [16]. In this paper, the least loaded alternate path is defined as the backup VP with the maximum residual bandwidth. The maximum residual bandwidth of backup VP is obtained by taking the minimum bandwidth of the virtual paths (or links) it traverses. If the least loaded alternate path has the enough bandwidth for accommodating the call, then this incoming call is accepted, otherwise, this call is blocked. To prevent network performance degradation due to excessive alternate routing, the trunk reservation method [17] is exercised in our computer simulation.

4.2 Computer Simulation Results

Performance of three self-healing schemes are evaluated through simulations in this section. The performance of the two self-healing schemes we proposed is compared to a base line algorithm proposed by Kawamura *et. al.* in [10]. In Kawamura's algorithm, the spare redundant bandwidth is not allowed to use until network fails. For fair comparison, LLR routing is also implemented in Kawamura's algorithm to reduce the blocking probability.

When evaluating the performance of self-healing schemes, besides the traditional performance metric, restoration rate, we also examine the call blocking probability and the restoration reward of self-healing schemes. The restoration reward is defined by following equation:

$$\textit{restoration reward} = \sum_{i=1}^{k} c_i r_i$$

where k is the number of classes of traffic, r_i is the reward for carrying a class i call, and the c_i is the number of restored connections under network failure.

Figure 3 and 4 show the comparison of call blocking rate of our schemes and kawamura's scheme. The comparison of restoration rates of the three schemes are show in Figure 5-7. Based on these Figures, we can make following observations.

1. We do not observe any call blocking for both traffic under the SHD and SHS algorithms for all simulation runs. However, under Kawamura's scheme, the call blocking rate is increased as offered traffic load increased. Especially, class B traffic experiences much larger call blocking probability (near 28%) than class A traffic does. This is because the traffic of class B demands 12 units of bandwidth.
2. Under kawamura's scheme, the restoration rate of class A and class B traffic are 100%.
3. Under SHS and SHD algorithms, while the offered traffic load increases, the restoration rate is decreased. The reason for such degradation is because that the system resources are finite. If there exists too many connections in the network, they will occupy a lot of capacity. Thus, when network fails, the residual capacity is not enough for fault recovery.
4. Under the SHD and SHS algorithms, the restoration rate of class B traffic is higher than that of class A traffic since class B traffic is given higher priority for restoration. Under the SHD algorithm, the restoration rate is almost 100% for class B traffic and very close to 100% for class A traffic [1]. In general, the restoration rate of the SHD algorithm is larger than that of the SHS algorithm. Under the SHS algorithm, the restoration rate is still above 99% for class B traffic, however, is only about 82% at high traffic load for class A traffic. Since class A traffic only requires one unit of bandwidth, the restoration rate for class A could be much higher without degrading the restoration

[1] The worse restoration rate for block size of 10 is 99.99% for class B and 98.15% for class A.

rate of class B if the SHS scheme gives class A traffic higher priority for restoration.

5. As the offered traffic load becomes higher, both SHS and SHD algorithms will yield higher restoration reward than that of Kawamura's scheme.
6. Under SHD scheme, increasing the block size will decrease the restoration rate. The reason could be explained as larger block size will reduce the usable residual capacity. The restoration reward is, thus, decreased as block size increasing. However, the degradation is small.

In conclusion, we believe that during most of the time, the network should operate under normal condition. Therefore, the goal of our schemes is to provide high bandwidth utilization while maintain the capability to restore most of the affected traffic during network failures. By utilizing the spare capacity of backup VPs, our schemes are able to yield zero blocking probability under normal condition while still provide reasonable restoration rate under single network failure. From the simulation results, we can observe that our schemes are able to provide near 100% restoration rate at low traffic load. Although the restoration rate degrades at high traffic load, our schemes actually can restore more reward than the base-line algorithm. The restoration rate degradation is simply due to the fact that under our schemes, much more calls are carried (since our schemes provide zero blocking probability).

5 Conclusion

In this paper, we have proposed two new self-healing schemes for mesh typed ATM networks based on virtual path technique. From the survey of existing mesh typed self-healing schemes in ATM, we found that all existing self-healing algorithms emphasis 100% fault restoration and thus, suffer from low bandwidth utilization. Our new self-healing algorithms improve the bandwidth utilization without significantly degrading the restoration rate. Our first algorithm is based on dynamic VP bandwidth allocation policy and the second one is based on dedicated VP bandwidth allocation strategy. These schemes provide much higher bandwidth utilization by relaxing the constraints of complete restoration. However, the degradation is acceptable.

We believe that under the ATM networks environment, during most of the time, the network failure would not happen. Therefore, we prefer to provide the network with the high bandwidth utilization and low call blocking probability environment. From our numerical results, we claim that our self-healing algorithms are able to yield high network bandwidth utilization under normal condition while still provide acceptable restoration rate under network failure.

References

[1] ITU-T SG. XVIII, "Draft Recommendation I.121: Broadband Aspects of ISDN." Geneva, May 1990.

[2] ITU-T SG. XVIII, "Draft Recommendation I.362: B-ISDN ATM Adaptation Layer (AAL) Functional Description." Geneva, 1993.

[3] ITU-T SG. XVIII, "Draft Recommendation I.363: B-ISDN ATM Adaptation Layer Specification." Geneva, 1993.

[4] ITU-T SG. XVIII, "Draft Recommendation I.371: Traffic Control and Congestion Control in B-ISDN." Geneva, June 1992.

[5] ITU-T SG. XVIII, "Some Key Features on UNI and NNI Considering ATM (A framework for discussion)." Seoul Meeting, 25 Jan. - 5 Feb. 1988.

[6] K.Sato, S.Ohta, and I.Tokizawa, "Broad-band ATM Network Architecture Based on Virtual Path," *IEEE transcation on Communications*, vol. 38, pp. 1212–1222, August 1990.

[7] N. D. Lin, A. Zolfaghari, and B. Lusignan, "ATM Virtual Path Self-Healing Based on a New Path Rastoration Protocol," in *GLOBECOM'94*, pp. 794–798, 1994.

[8] K. Murakami and H. S. Kim, "Near-Optimal Virtual Path Routing for Survivable ATM Networks," in *INFOCOM'94*, pp. 2b.4.1–2b.4.8, 1994.

[9] A. Gersht and A. Shulman, "Optimal Dynamic Virtual Path Bandwidth Allocation and Restoration in ATM Networks," in *GLOBECOM'94*, pp. 770–776, 1994.

[10] R. Kawamura, K. ichi Sato, and I. Tokizawa, "Self-Healing ATM Networks Based on Virtual Path Concept," *IEEE Journal on Seclected Areas in Communications*, vol. 12 no. 1, pp. 120–127, january 1994.

[11] J. Anderson, B. T. Doshi, S. Dravida, and P. Harshavardhana, "Fast Restoration of ATM Networks," *IEEE Journal on Seclected Areas in Communications*, vol. 12 no. 1, pp. 128–137, january 1994.

[12] H. Fujii and N. Yoshikai, "Restoration Message Transfer Mechanism and Restoration Characteristics of Double-Search Self-Healing ATM Network," *IEEE Journal on Seclected Areas in Communications*, vol. 12 no. 1, pp. 149–158, january 1994.

[13] T. V. Landegem, P. Vankwikelberge, and H. Vanderstraeten, "A Self-Healing ATM Network Based on Multilink Principles," *IEEE Journal on Seclected Areas in Communications*, vol. 12 no. 1, pp. 139–148, january 1994.

[14] S. Ohta and K.-I. Sato, "Dynamic Bandwidth Control of the Virtual Path in an Asynchronous Transfer Mode Network," *IEEE transcation on Communications*, vol. 40 no. 7, pp. 1239–1247, July 1992.

[15] H.-S. Huang, "Self-Healing ATM Networks Based on Virtual Path Restoration," 1995.

[16] G.R.Ash, "Use of a Trunk Status Map for Real-Time DNHR," in *Eleventh International Teletraffic Congress,(Kyoto,Japan)*, pp. 885–887 Vol. 30, September 1985.

[17] J.M.Akinpelu, "The Overload Performance of Engineered Networks with Nonhierarchical and Hierarchical Routing," in *Tenth International Teletraffic congress*, June 1983.

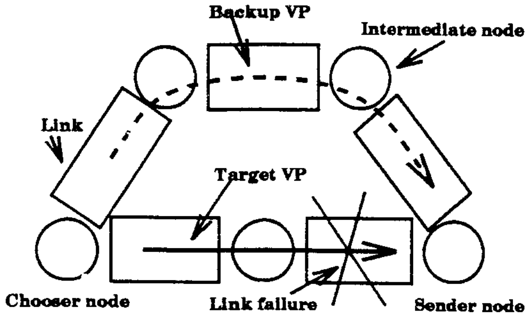

Figure 1: The backup VP

SUCC_FLAG	AFF_VPB	MIN_VPB

Figure 2: The format of restoration message

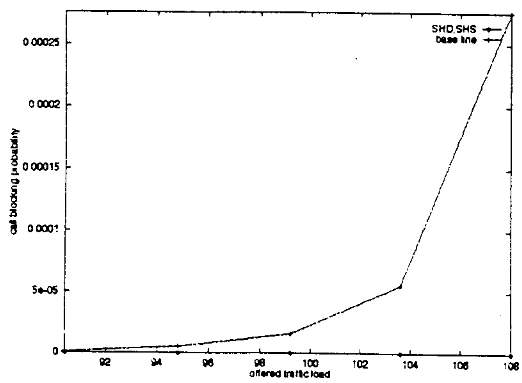

Figure 3: Comparison of call blocking rate of our schemes and Kawamura's algorithm for class A calls in the TANet model

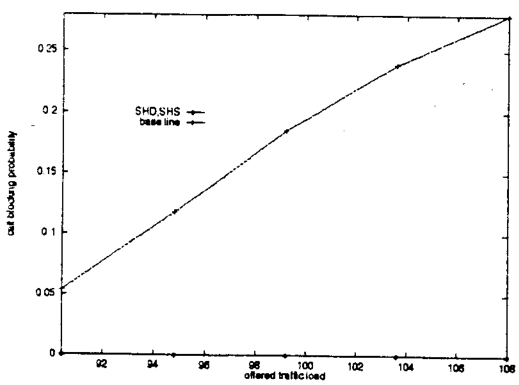

Figure 4: Comparison of call blocking rate of our schemes and Kawamura's scheme for class B calls in the TANet model

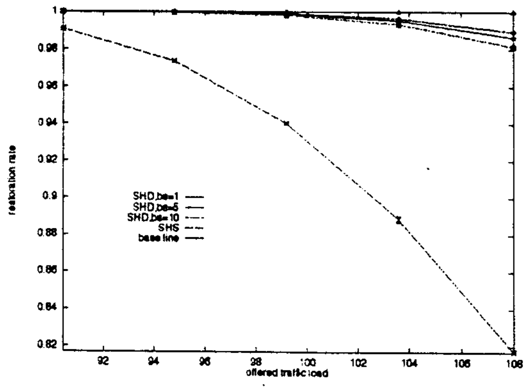

Figure 5: Comparison of restoration rate of our schemes and Kawamura's scheme for class A calls in the TANet model

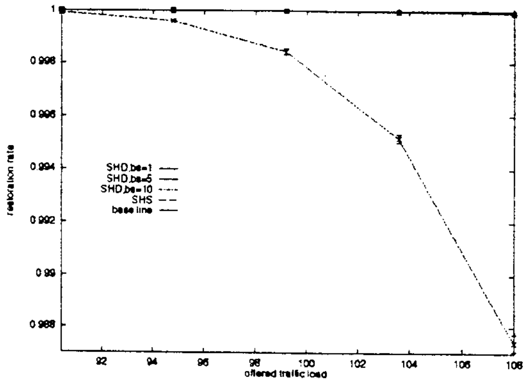

Figure 6: Comparison of restoration rate of our schemes and Kawamura's scheme for class B calls in the TANet model

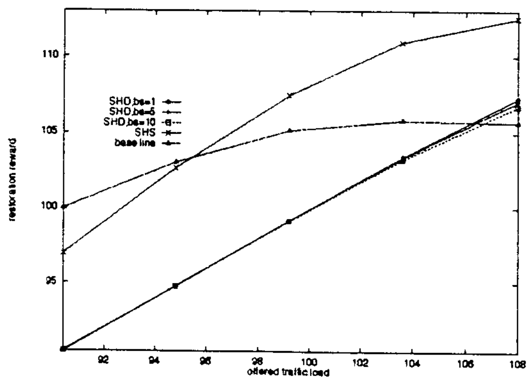

Figure 7: Comparison of restoration reward of our schemes with Kawamura's scheme in TANet model