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Short Paper

Resilience on Pre-assigned ATM Multicast Tree

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Networking technologies have greatly enhanced the Internet with respect to the backbone ATM (Asynchronous Transfer Mode) network. The ATM multicast Tree (AMT) is the Mbone of video/audio conferencing and other multicasting applications in ATM networks [5]. Temporarily moving switches changing optical fiber connections and, tangible or intangible network failure on ATM networks causes service disruption and motirates us to consider more carefully the system's SQOS (Survivable Quality of Service) [7]. A backup protection on the ATM multicast Tree (AMT) is proposed here. This scheme supports a point-to-point preplanned backup route for each root-leaf pair (RL pair) of an AMT. Usually, a restoration message needs to travel over a long backup route to restore disrupted services and point-to-point backup routes may overlap each other and waste bandwidth resources. This motivates us to develop a tree-structured backup AMT to support economical protection. For the providence and proof of performance of these new schemes, we also formulate Bellcore's LATA model to simulate restoration in two schemes. The simulation results show that the preplanned scheme supports fast restoration; however, a dynamic scheme is needed to compensate for and restore the blocked parts.

Keywords: ATM, restoration, self-healing, multicast tree, and survivability

1. INTRODUCITON

ATM (Asynchronous Transfer Mode) can be a main technique for use in the backbone or local infrastructure of the Internet. In future broadband networks, multicast services such as video conferencing and distance learning will become increasingly important. To support these multimedia services, one solution is to form an AMT (ATM Multicast Tree) to connect all the conferencing members. Two primary techniques have been developed to support multicast services in ATM networks (see Fig. 1). The first technique uses a centralized multicast server as a root for the AMT [4-5]. The server sets up a point-to-multipoint connection, which includes all the members in the multicast group. For each member, the system sets up a point-to-point connection from its node to the multicast server. Any member can broadcast its information to other members by sending cells to the multicast server. The server, then, forwards the cells to the AMT. The advantage of this mechanism is that each node maintains only two connections. However, the centralized server may become a bottleneck [4-5].

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The second technique is based on overlaid point-to-multipoint connections, where each node forms point to multipoint connections with all the other members in the group. Thus, N point-to-multipoint connections have to maintain multicasting at each node, where N is the number of nodes in the AMT. This scheme does not work well when N becomes large. The system also requires use of a registration process to manage the dynamic memberships in the tree. Nevertheless, due to its distributed characteristics, the failure of a node will not cause a multicast failure. In this paper, we investigate AMT restoration based on the above two techniques.

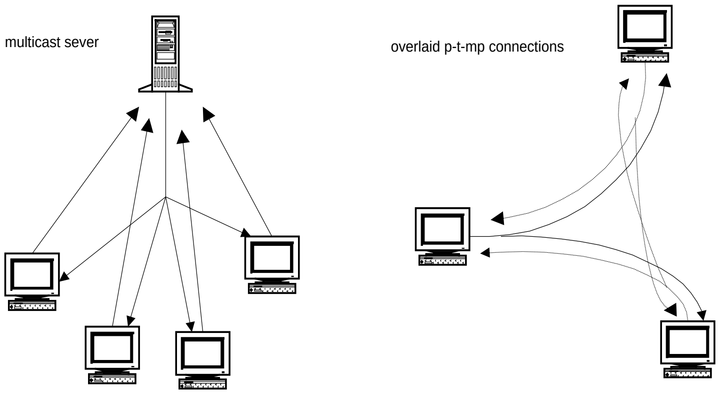
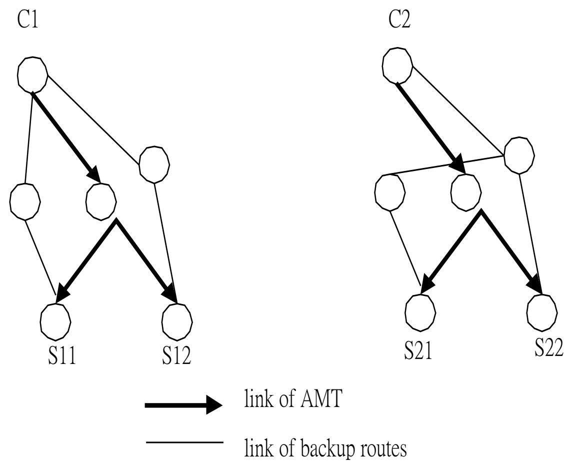


Fig. 1. Centralized multicast server and overlaid point-to-multipoint connections.

In order to minimize tangible and intangible damage due to network failure in an ATM Multicast Tree, a self-healing function is required in the broadband network since it can automatically fast restore disrupted real-time video/audio service. Many restoration schemes have been intensively studied in attempt to provide the VP/VC-based self-healing function [1-6]. There are two kinds of restoration schemes for ATM VP/VC: one is a dynamic restoration scheme, and the other is a pre-assignment (preplanned) scheme. The pre-designed schemes apply path-switching disjoint backup paths, but dynamic schemes use link-switching protection [9]. Generally, the restoration speed is the most important aspect to consider in designing a restoration scheme. Since backup VPs/VCs do not need time for connection-setup during restoration, the pre-assigned perform restoration faster than the dynamic scheme.

Since the advantage of backup routes is in source-based path protection and connections are set up earlier, the pre-assignment scheme is the method we usually use for protection. The diagram of failure management in the preplanned restoration scheme is shown on Fig. 2. For the AMT restoration problem, until 1996, the first paper [4] is mentioned on the requirement of AMT restoration problem. It uses a dynamic search algorithm to perform AMT failure recovery. In 1997, a pre-assigned method for an AMT self-healing method was proposed [10]. However, the protected backup routes found were not shortest paths and could cause restoration messages to traverse long delayed routes. However, if a disjoint backup AMT is constructed, some problems will occur [5]. First, the low building probability and complicated loading on constructing is the first considerable. Second, if only one link or node fails on an AMT, we need to reroute links and reserve bandwidth on the whole backup tree. Moreover, since the AMT usually transmits video images, the restoration rate will be decreased because only one branch of the backup tree does not endure the required bandwidth. In order to avoid restoring whole backup AMT when only one link failure occurs, in this paper, we propose a point-to-point pre-assignment scheme (see Fig. 2 for Case 1) on a backup AMT to protect against AMT network failure, discussed in Section 2. In the proposed pre-assignment scheme, some backup-VPs for an AMT are assigned before hand. The advantage of backup routes is that they enable source-based path protection; in addition, the connections are set up earlier, and the pre-planned alternative routes enhance restoration performance by consuming only bandwidth-capture time, not search or connection time. Moreover, in order to reduce the link number and utility of backup routes, we also propose a tree-structured pre-assignment closest-node algorithm (see Fig. 2 Case 2), which we can use to get an economical solution, as will be discussed in Section 2. For the proposed self-healing algorithms, in Section 4, the restoration performance is demonstrated through simulation results. Finally, we draw a conclusions in Section 5.



Case 1:Point-to-point Protection ***Case2: Tree-Structured Protection***

Fig 2. Two pre-assigned backup routes on an AMT.

2. POINT-TO-POINT PREPLANNED PROTECTION ON AMTS

First, we will introduce the pre-assignment scheme on the protection of VPs. The self-healing with preplanned restoration scheme has four phases: a network design phase, failure watch phase, restoration phase, and backup VP reconstruction phase [6-8]. Fig. 3 shows the cycle of network failure management with the preplanned restoration schemes.

During initial network setup, routes of primary and backup VPs and resource assignments are determined in the network design phase by the algorithms that search optimal VP routes so as to minimize the amount of network resources required [7-8]. If a failure occurs, NEs (Network Equipment) detect it in the failure watch phase, and the restoration phase begins. The OAM cells carry restoration messages used to inform the system for restoration and are routed along the backup route automatically to capture the required bandwidth rapidly and reliably. As arriving the terminate node of the backup route, the VP will switch to the backup VP. Under a heavy network traffic load or in the event of multiple failures, some backup VPs may not be available due to the exhaustion of spare resources on backup routes. In phase 2, a dynamic searching algorithm will start to search for another survivable route for un-restored VPs. To enhance the restoration performance, it is necessary to reconfigure all the backup VPs for optimal bandwidth reservation after restoration.

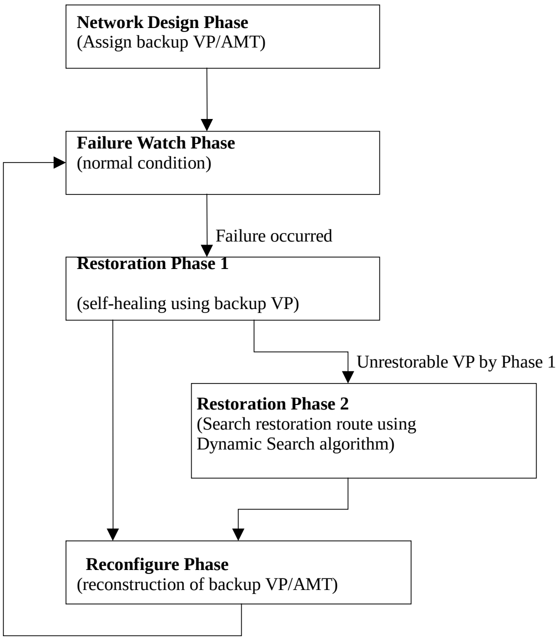


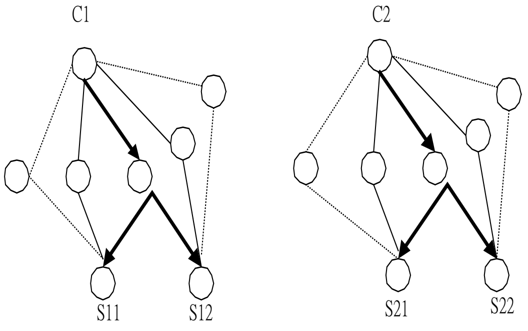
Fig. 3. Network failure management.

We extend the VP restoration concept to the AMT case. Each AMT has a source node, called the root, and multiple destination nodes, called leaves. Some members of multicast tree are placed on the trunk of the tree. We can set these nodes as logical leaves. Therefore, we can set each pair consisting of a root and a leaf with one preplanned zero-bandwidth backup VP. Furthermore, the backup VP is the shortest disjoint path to the route from the leaf to the root. Each route of an RL pair can be protected under a backup route.

The backup VP for each root and leaf pair in an AMT is selected by the shortest path algorithm in order to get the fastest restoration performance on the shortest traverse route. When failure occurs, an AIS (Alarm Indication Signal) traverses the AMT's downstream nodes of the failed link or node to announce failure. As the AIS arrives at each leaf, it starts the bandwidth-capture procedure from the pre-assigned backup VP. The AMT restoration procedure also has four phases as shown on below. The network failure management phase uses the same architecture as the VP-based pre-assignment scheme in [6], depicted in Fig. 2.

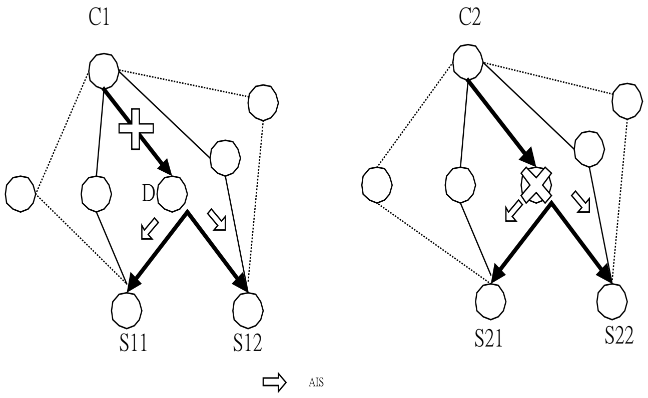
(a) **Network Design Phase:** (see Fig. 5) As each AMT is built, the backup AMT is formulated as the shortest backup VPs for all RL pairs.

(b) **Failure Watch Phase:** (see Fig. 6) The downstream node detecting failure sends AIS or other alarms to notify the destination nodes (leaves) of the failure. If the node is the destination node (leaf) of the failed AMT, it starts the restoration process.



Case 1:Link Failure	***Case2: Node Failure***
C1 is root.	C2 is root.
S11 and S12 are leaves.	S21 and S22 are leaves.

Fig. 5. Network design phase in point-to-point pre-assignment protection.

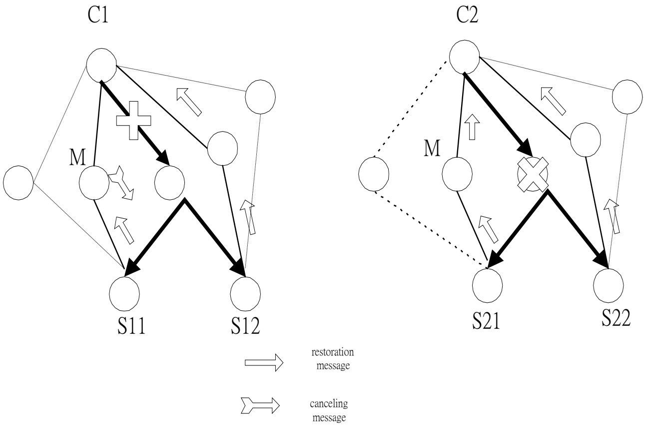


Case 1:Link Failure	***Case2: Node Failure***
D detects a failure and sends an AIS to S11 and S12.	S21 and S22 detect the failure.

Fig. 6. Failure watch phase in point-to-point pre-assignment protection.

(c) **Restoration Phase:** (see Fig. 7) When a leaf node receives an AIS, a restoration message is sent along the mapped backup VP to the mapped root of the AMT. (The restoration message must capture the required bandwidth and switch traffic from the failed AMT to the backup VP to successfully capture bandwidth on the whole backup route.) When it receives a restoration message, each intermediate node checks the available spare capacity on the link of the backup route. If the available spare capacity is sufficient, it captures the required bandwidth on the link and then transmits the restoration message to the next node on the backup route. Otherwise, a cancellation message is backoff the mapped leaf to inform that the backup route is un-restorable in bandwidth capture failure. If a node receives the cancellation message, it releases the captured bandwidth. If the canceling message backoff the leaf which started the bandwidth capture process, it sends a starts source-based dynamic restoration algorithm [1-5] to find another restoration route. If the mapped root node receives successful restoration messages, it switches traffic from the failed route to the backup route. Then, the restoration process is completed.

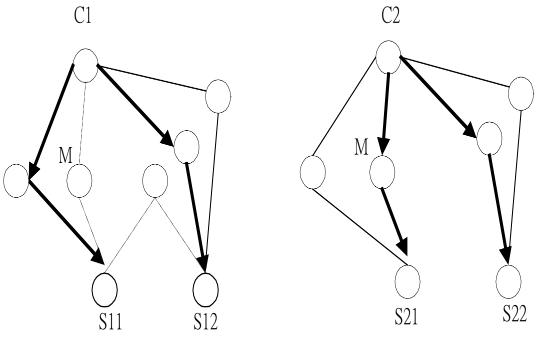
(d) **Reconstruction Phase:** (see Fig. 8) The system must reconfigure the backup VPs to perform next protection as in the network design phase shown in (a).



Case 1:Link Failure
S11 and S12 send reservation messages
reserve required the bandwidth.
M sends a back canceling message
(since link M-C1 does not have enough bandwidth).

Case2: Node Failure
S11 and S12 send reservation to
reserve the required bandwidth.

Fig. 7. Restoration phase in point-to-point pre-assignment protection.



Case 1:Link Failure
Rebuild new p-t-p alternative routes.

Case2: Node Failure
Rebuild new p-t-p alternative routes.

Fig. 8. Reconstruction phase in point-to-point pre-assignment protection.

To aid explanation, we give some definitions as follows:

Given a Network topology G constructed by V and A_c , and a Capacity assignment C,
$G = (V, A_c , C)$
V: the node set (ATM switch);

A_c: a set of directed arcs (optical trunks);
$C = (C_a)$, a vector of arc capacity, $a \in A_c$;
Cap(p): the capacity function used to represent the bandwidth of VP p;
$E = \frac{|A_C|}{2}$, where E is a set of undirected links;
$\prod$: a set of VP commodities in the network;
A: a set of M primary AMTs;
A^b: a set of M backup AMTs;
$\sum_{i=1}^{M} N_i = |\prod|$;
$A_i = \{P_{ij}\}$, $i = 1, 2, \ldots, M$, $j = 1, 2, \ldots, N_i$: a set of flows (RL pairs) on A;
$A_i^b = \{P_{ij}^b\}$: a set of backup flows (RL pairs) on A^b.

The point-to-point AMTs construction algorithm is shown below.

```
Generate all primary AMT sets, $A = \{A_1, A_2, A_3, \ldots, A_M\}$ by
For i=1 to M do
    Generate $N_i$ VPs in $A_i = \{p_{i1}, p_{i2}, p_{i3}, \ldots, p_{iN_i}\}$.
Loop
Generate all backup AMT sets, $A^b = \{A_1^b, A_2^b, A_3^b, \ldots, A_M^b\}$ by
For i = 1 to M
  For j = 1 to $N_i$
    Use the shortest path algorithm to find a set of $r_{ij}$ shortest backup routes
    $P_{ij}^b = \{p_{ij1}^b, p_{ij2}^b, p_{ij3}^b, \ldots, p_{ijr_{ij}}^b\}$
    Set $p_{ij1}^b$ be the backup route of $p_{ij}$.
  Loop
Loop
```

3. TREE-STRUCTURED PREPLANNED PROTECTION ON AN AMT

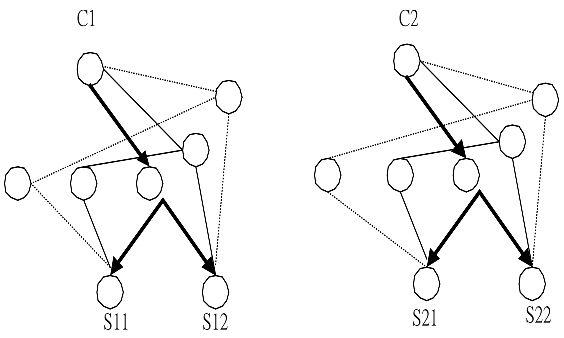
Some overlapping segments of pre-assigned backup VPs will waste bandwidth resources. Therefore, we have developed a mechanism to combine the separate backup VPs of the AMT to form a backup AMT. First, we build a backup VP from the first leaf to root. Secondly, we select the second backup VP for the second RL pair. As connection setup, if the last created backup VP overlaps the previous selected part, then the connection stops and force it to connect with the original one. And so on, the next backup VP of last RL pair can be created and connected into a backup AMT.

Network failure management uses the same architecture as follows.

(a) Network Design Phase: (see Fig. 9) As each AMT is built, the backup AMT is formulated for all RL pairs.

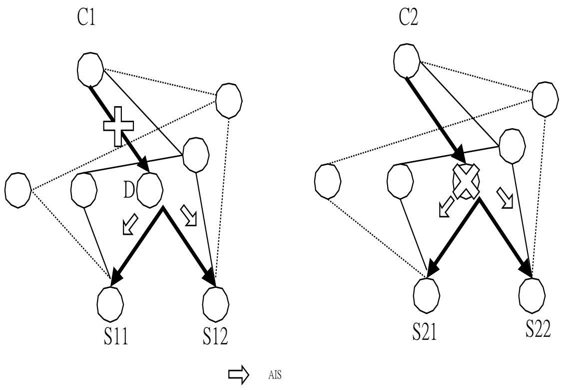
(b) Failure Watch Phase: (see Fig. 10) The downstream node detecting failure sends AIS or other alarms to notify the destination node (leaves) of the failure. If the node is the destination node (leaf) of the failed AMT, then it the restoration process is started.

(c) Restoration Phase: (see Fig. 11) When a leaf node receives an AIS, a restoration message is sent along the mapped backup VP to the mapped root of the AMT. (The restoration message must capture the required bandwidth and switch traffic from the failed AMT to the backup VP so as to capture bandwidth on the whole backup route.)



Case 1:Link Failure	***Case2: Node Failure***
C1 is root. S11 and S12 are leaves.	C2 is root. S21 and S22 are leaves.

Fig. 9. Network design phase in tree-structured pre-assignment protection.

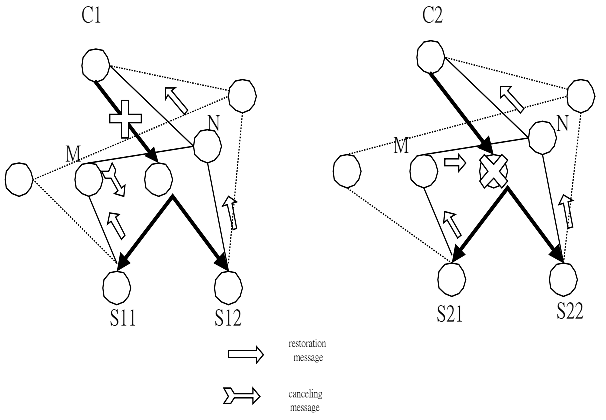


Case 1:Link Failure	***Case2: Node Failure***
D detects a failure and sends an AIS to S11 and S12.	S21 and S22 detect the failure.

Fig. 10. Failure watch phase in tree-structured pre-assignment protection.

While receiving the restoration message, each tandem node checks the available spare capacity on the link of the backup route. If the available spare capacity is sufficient, it captures the required bandwidth on the link and then retransmits the restoration message to the next node on the backup route. Otherwise, a cancellation message is backoff the mapped leaf to inform that the backup route is un-restorable in bandwidth capture failure. If the mapped root node receives successful restoration messages, it switches traffic from the failed route to the backup route. Then complete the restoration process is completed. Otherwise, if a switch node had been passed by a search message, the search message stops the bandwidth capture process. If a node receives the cancellation message, it releases the captured bandwidth. If the canceling message backoff the leaf which started the bandwidth capture process, it sends a start source-based dynamic restoration algorithm [1-5] to find another restoration route. If the canceling message get a switch node, it broadcasts canceling messages to the downstream links which had passed by search messages.

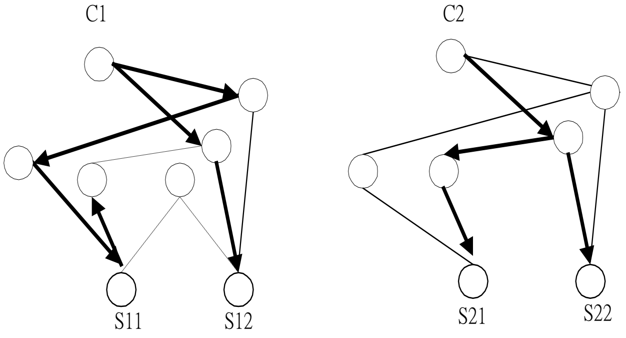
(c) Reconstruction Phase: (see Fig. 12.) The system must reconfigure the backup AMTs in order to perform protection as in the network design phase shown in (a).



Case 1:Link Failure
S11 and S12 send reservation messages to reserve the required bandwidth.
M sends a back canceling message
(since link N-M does not have enough bandwidth).

Case2: Node Failure
S11 and S12 send reservation messages to reserve the required bandwidth.

Fig. 11. Restoration phase in tree-structur pre-assignment protection.



Case 1:Link Failure
Rebuild the new tree-structured backup tree.

Case2: Node Failure
Rebuild the new tree-structured backup tree.

Fig. 12. Reconstruction phase in tree-structure pre-assignment protection.

The closest-node AMT construction algorithm is shown below.

```
Generate all primary AMT sets, $A = \{A_1, A_2, A_3, \ldots, A_M\}$ by
For i = 1 to M do
    Generate $N_i$ VPs in $A_i = \{p_{i1}, p_{i2}, p_{i3}, \ldots, p_{iN_i}\}$.
```

```
Loop
Generate all backup AMT sets, $A^b = \{A_1^b, A_2^b, A_3^b, ..., A_M^b\}$ by
For i = 1 to M
  For j = 1 to $N_i$
      Use the closest-node algorithm according to the following steps to find a set of $r_{ij}$
      shortest backup routes: $P_{ij}^b = \{p_{ij1}^b, p_{ij2}^b, p_{ij3}^b, ..., p_{ijr_{ij}}^b\}$ of $P_{ij}$.
      Step1: Considering a one-root multiple-leaf tree, begin to build backup VPs for the
      RL pairs in the conventional manner.
      Step 2: If it is found that the newest connection duplicates a node used in the
      previous VP, then this is the closest common node and is designated as a branch.
      Step 3: Repeat the next leaf in the tree and continue until a closest-node backup
      AMT has been created.
      Set $p_{ij1}^b$ be the backup route of $P_{ij}$.
  Loop
Loop
```

We have found that the closest-node algorithm is more useful than the point-to-point algorithm. It induces that the restoration capability of the closest-node method is better than that of the point-to-point method. We will present the proof in Lemma 1 and simulation results to provide further evidence in Section 4.

Lemma 1: Resource utilization in the closest-node method is better than that in the point-to-point method.

Proof: The closest-node algorithm creates an alternative route from a leaf to the root when it selects the shortest path from the leaf to the root. The connection process is continued until it meets the connected node belonging to the temporarily selected backup-tree. It does not consider the part of the next segment about unconnected path is same or not to the found shortest path. Because, if the segment from the connected node to the root is different from the last part of the unconnected part in the selected candidate, which two segments are with same two end nodes. Based on the shortest path definition, we know that the length of the two segments must be the same since they are the same length in total (the shortest path) but overlapped the part from leaf to connected node. Therefore, since the closest-node AMT can be formulated using the point-to-point AMT, there must exist a point-to-point backup route candidate which is overlapped a part of in the closest-node RL pair. This it means that resource utilization in the closest-node method can be reduced on the part of overlapped segments.

4. SIMULATION RESULTS

To verify the characteristics of the proposed scheme and evaluate its restoration performance, we developed a simulation network. The simulation network topology, which was also used in [1, 3-5], is shown in Fig. 4. The network consisted of 25 nodes and 28 links. The total working and spare capacity was 403 and 230 DS3 capacity, respectively. The processing time was estimated to be 5 ms, and the propagation delay was 2 ms at each node. Each VP had the same bandwidth and was equal to the capacity of DS-3.

We implemented the AMT-based simulation LATA model to verify the simulation characteristics of the proposed pre-assignment method. There were 214 AMTs generated randomly using this topology. By means of backup AMT generation, 389 backup VPs were built using the preplanned scheme. The restoration rate R_{amt} was defined as the ratio of the number of restored RL pairs r_{rlp} to the number of disrupted RL pairs f_{rlp} when failure occurred:

$$R_{amt} = \frac{r_{rlp}}{f_{rlp}}$$

The restoration rate was defined by the users. Since there were many users in a multicast tree, each user considered whether service was good. If one node or link failure occurred, not every was affected in the multicast tree but only some of them. After restoration, some users could continue to perform services if they were in the restored part of the failed multicast tree. Therefore, we cannot think they are not restored but ought to consider them be restored. Hence, we measured the restoration rate based on the number of restored users/the number of failed users.

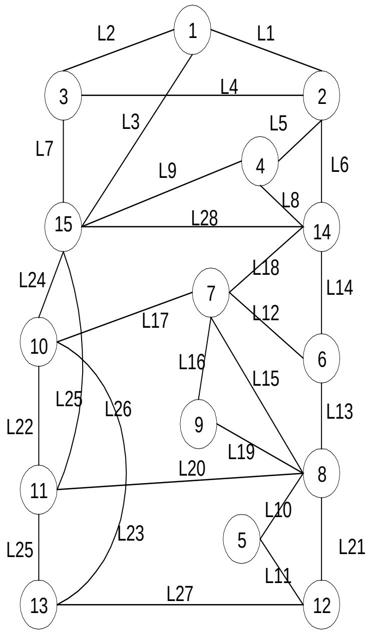
Since the restoration process usually finished in 2 seconds, we set a time-out of 1000 ms to observe the restoration capability of the proposed schemes. The restoration rate versus restoration time results for a single link and node failures are depicted in Figs. 13-14.

First, we performed the simulation for the point-to-point pre-planned protection on link and node failure. As for node failure, the total number of failed RL pairs was 1316, and the total number of restored VPs was 536. The restoration rate was 0.407. There were 387 bandwidth capture failures. As for link failure, the total number of failed RL pairs was 1316, and the total number of restored VPs was 533. The restoration rate was 0.405. There were 411 bandwidth capture failures (see Fig. 13).

Next, we performed the simulation for the tree-structured preplanned protection on link and node failure. As for node failure, the total number of failed RL pairs was 1316, and the total number of restored VPs was 634. The restoration rate was 0.482. There were 387 bandwidth capture failures. As for link failure, the total number of failed RL pairs was 1316, and the total number of restored VPs was 653. The restoration rate was 0.496. There were 363 bandwidth capture failures (see Fig. 14).

The tree-structure backup AMT scheme can outperform the point-to-point scheme due to economical tree-structured backup AMT construction. The restoration performance is not excellent for two reasons. First, the pre-assigned backup routes limit the choices for the restoration paths. Second, since this model is designed for full dynamic restoration on [1], we find that some backup VPs can not be formulated. For example, in Fig. 4, for an RL pair whose connections are in node sequence 3 → 15 → 14 → 6, a segment consisting of connections 15 → 14 crosses the network separates the network into two parts. The upstream and downstream nodes except for the segment are located in different parts. No disjoint backup route for this VP is found in the network. These observations decrease the restoration rate obtained in the simulation. Due to the simulation result shows up, the preplanned protection method needs a dynamic search algorithm [1-5] to support network survivability into higher restoration rate.

We also performed a simulation to optimize the proposed self-healing schemes using the most-decent search algorithm to deal with single link failure in order to enhance the restoration rate of the two proposed schemes. The optimization algorithm was based on the most-decent search algorithm given in the Appendix. Since the load on the network affected the restoration capability, we also considered two load cases in the simulation, 5:10 and 10:10 (average spare capacity: average working capacity on a link). In the simulation, we defined the lost flow rate as being equal to the blocking rate, and the restoration performance described by lost flow are shown in Figs. 15-16. The simulation showed that the two schemes could be enhanced into local-optimal minimum lost flows, which strengthen the system's restoration capability.



Link #	Orig. Node #	Dest. Node#	Distance (Km)	Working	Spare
1	1	2	9	12	4
2	1	3	6	4	4
3	1	15	21	8	8
4	2	3	14	5	4
5	2	4	6	8	6
6	2	14	11	12	10
7	3	15	16	7	1
8	4	14	8	11	3
9	4	15	11	9	5
10	5	8	7	8	7
11	5	12	7	7	8
12	6	7	5	13	10
13	6	8	7	22	6
14	6	14	10	16	12
15	7	8	11	9	4
16	7	9	11	10	23
17	7	10	12	20	7
18	7	14	8	19	3
19	8	9	1	23	10
20	8	11	7	39	0
21	8	12	13	10	13
22	10	11	5	31	6
23	10	13	23	6	9
24	10	15	10	22	15
25	11	13	13	15	24
26	11	15	19	18	9
27	12	13	8	20	19
28	14	15	11	19	0
				403	230

Fig. 4. Simulation of a LATA network.

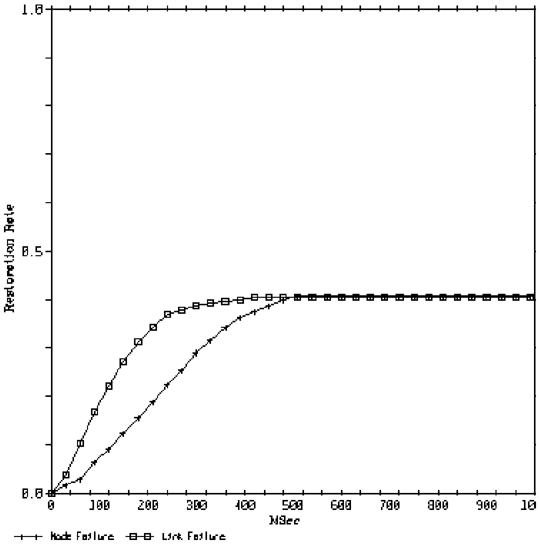


Fig. 13. Restoration performance for point-to pre-assignment protection.

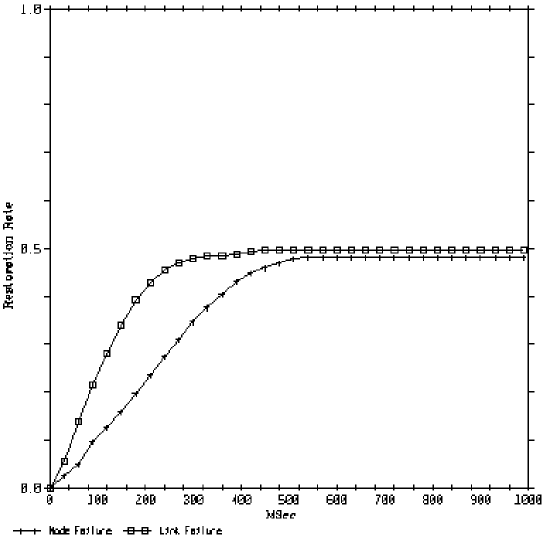


Fig. 14. Restoration performance for tree-structure pre-assigment protection.

5. CONCLUSIONS

The backup AMT concept has been proposed to support higher survivability on ATM Multicast Trees. The pre-assignment protection method can fast restore multicast service for each member of a multicast tree. We have proposed two schemes to implement the restoration process. One is a point-to-point pre-assigned method, and the other is a tree-structured backup AMT method. To verify the restoration performance, we performed a simulation single link and node failure cases.

The simulation results for single preplanned protection on an AMT show that bandwidth capture failure is the most affect point on the restoration of preplanned way. It appeals to a source-based dynamic restoration scheme to overcome this weakness becoming very important.

APPENDIX

In preplanned restoration schemes, the backup route of each primary VP has to be determined in advance during connection setup. Thus, at network initialization, we assume that the traffic demand is given, and the network transmission capability is constructed in a way such that the spare resource requirement on each link can guarantee complete restoration. Since optimization is conducted jointly over capacity assignment, commodity flow assignment and restoration flow assignment, the complexity of the problem grows tremendously. In this paper, the optimal capacity and flow assignment for the self-healing AMT based on end-to-end path protection. There are tradeoffs between network resource utilization and restoration performance in terms of rapid restoration time and full restoration rate. Therefore, the optimal or near-optimal routing problem combined with the spare capacity planning and fast restoration algorithms is strongly important. Let us consider the VP-based Survivable Virtual Path Routing Problem (SVRP) [8], which can be described as follows. Given an ATM network graph G, $G = (V, A_c, C)$, where V is a node set representing ATM switches and A_c is an arc set, of which member is unidirectional link, and given that $C = [c_a]$ denotes the capacity vector for each arc $\alpha \in A_c$, we have the following computing rule: Only those backup VPs whose primary VPs are routed independently can share reserved bandwidth on each link. In AMT restoration, the alternative routes of an AMT are formulated by some backup VPs. (In particular, some point-to-point backup VPs used to protect the same AMT can converge to looks as one backup AMT.) Let there be M backup AMTs, and let each AMT have N_i, $i = 1, \ldots, M$ backup VPs. We extend the SVRP into the Survivable AMT Routing Problem (SARP) as follows.

Let f be a vector of total flows and $L(f)$ be the lost flow objective function. The SAPR problem can be expressed as follows:

Minimum expected lost flow on a link:

min $L(f)$

over $f = (f_{ij})$, $\forall i \in A^b$, $\forall j \in A_i^b$

SUBJECT TO

1. a capacity constraint:

$$cap(p_{ijr}{}^{b}) \geq cap(p_{klr}), \quad \forall i \in A^b, \quad \forall j \in A_i^b, \quad \forall k \in A, \quad \forall l \in A_k$$

2. a conservation constraint:

$$x_j = \sum_{\forall f_i \text{ represent all flows}} f_i \cdot \phi_{i,j}\ ;$$

$$x_j \leq c_j;$$

$$x_j \geq 0,\ c_j \geq 0,\ \forall j \in A_c,$$

where

$$\phi_{i,j} = \begin{cases} 1 & \text{if } \ f_j \ \text{pass arc } i \\ 0 & \text{if } \ f_j \ \text{do not pass arc } i \end{cases}$$

3. a length constraint:

$|l_{ij}| < l_{max}$ and $|l^b_{kl}| < l_{max}$, $\forall i \in A^b$, $\forall j \in A_i^b$, $\forall k \in A^b$, $\forall l \in A_i^b$, where l_{max} is the maximum node number from root to all leaves in an AMT.

Since the lost function can not be formulated, we introduce a search algorithm to heuristic ally find the optimal routes of the SARP. Overflow assignment, heavy loading, capacity unbalance, or bandwidth contention failure cause lost flows. The lost function is defined as a function used to calculate the number of blocking flows [7, 8] when network failure occurs. The main idea of the search algorithm, here called the most-decent search optimal algorithm, is to use the a search method to get the lost flow value. Initially, we choose a flow assignment and the following is to do next choice by exchanging only one RF pair. Each RF pair in the candidate set can be selected and judged using the minimum lost flow rule. This is like the heuristic algorithm in most-decent rule of selection. If the flow value can be decreased, the new choice is kept and does next until no improvement is found. On stopping rule, we set a threshold value ε (generally close to zero) to limit the decent lost flow δ . The algorithm is introduced as follows:

```
Let $f_0$ is the initial flow assignment
Let minima_found = 1
Let $\delta = 1$
Let $k = 0$
While (minima_found = 1) and ( $\delta > \varepsilon$ ) Do
Let minima_found = 0
  For all $A_i^b$ in $A^b$, $i = 1$ to $M$
    For all $P_{ij}^b$ in $A_i^b$ , $j = 1$ to $N_i$
      For each $P_{ijr}^b$ in $P_{ij}^b$ Do, which $r = 1$ to $r_{ij}$
        Let $f_k'$ be the flow replace $P_{ijr}^b$ into $P_{ij}^b$ in $f_k$
        If $L(f_k') < L(f_k)$
          Let minima_found = 1
          Let $\delta = L(f_k) - L(f_k')$
          Replace the backup route $p^b_{ijl_j}$ by $P_{ijr}^b$ in flow $f_k$
          $L(f_k') < L(f_k)$
```

```
            Endif
         Loop
      Loop
   Loop
Loop_while
```

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