Configuration of Shared Backup Cycles for Local Restoration in ATM Mesh Networks  
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Abstract: This paper proposes an efficient backup network planning for survivable ATM networks. Distributed local restoration is performed using preplanned backup VPs that are residing on sharable backup cycles, in which both the backup path and spare capacity can be shared to restore different failed links. Each network link is assigned two backup cycles and each cycle protects half of the working capacity of a link in case of failure. The preconfiguration of the cycles and its spare capacity reservation can be derived directly from arbitrary network topologies if they are two-connected. The dual backup cycles concept provides an efficient solution for survivable network design and also simple backup management. The proposed technique needs spare capacity redundancy bounded from 50% to 100% of total working capacity of a network for guaranteed restoration of any single link failure, on average 60% for typical example networks, while providing highly acceptable robustness against multiple failure.

Keywords: ATM Network, virtual path, virtual path group, protection, restoration, survivability

1 Introduction

Survivability has been an indispensable issue in high-speed network design since even a single network link or node failure may cause an adverse effect on economic and social life that increasingly depends on networking. Recent achievement in optical network technologies, which explosively extends the capacity carried by a single link, made the survivability issue more critical. This paper proposes a new method of backup path configuration and spare capacity planning for ATM networks with arbitrary mesh topologies. Objectives of the proposed method include spare resource efficiency, robustness in multiple failure cases, and simple backup network design and management. 

General network restoration procedures consist of the following main functions under the assumption that separate fault detection functions [1] exist.

1. Compute the backup path as sequences of links or nodes.
2. Reserve spare capacity on links to meet the required reliability level.
3. Assign spare capacity to individual backup path.
4. Update digital cross-connects on backup paths to be activated.
5. Reconfigure the backup path and spare capacity placement after network failure, repair, or update.

Network restorations techniques can be categorized according to when to perform the above functions. Protection techniques, which include automatic protection switching (APS) and self-healing ring (SHR), perform all the above functions except the fifth function before failure with dedicated backup path and spare capacity. In runtime, only traffic switching is performed at either or both end nodes of a failed link or connection. Therefore, protection techniques provide very fast restoration within about 50-60 ms. The speed of protection techniques, however, is traded with large overhead of spare capacity: at least 100% capacity redundancy for typical self-healing rings and up to 180-300% for 1+1 or 1:1 APSs [2, 3].

For more economic spare capacity planning, dynamic restoration techniques and preplanned restoration techniques have been proposed. Dy-
dynamic restoration techniques [4, 5, 6] perform all the above functions after failure by backup path search algorithm like flooding and by on-demand spare capacity allocation, and need not perform the fifth function. The dynamic restoration provides efficient spare capacity utilization and flexible backup path routing since all possible restoration paths can be found on the remaining network resources which are not affected by failure. However, it requires complex runtime operation that may result in very slow restoration speed, and in addition, it cannot provide guaranteed restoration for given failure scenarios due to the absence of preplanning of spare resources.

Preplanned restoration techniques [7, 8] perform the first and the second functions before failure, while perform the third and the fourth functions after failure. The spare capacity on a link can be shared by multiple backup paths residing on the link. The preplanned technique, thus, provides efficient spare resource requirement and acceptable restoration speed for guaranteed restoration of given failure scenarios. Drawbacks of this approach are on performing the fifth function. It should manage one backup connection per primary working connection, which requires substantial overhead for backup management and shows poor scalability to network size.

In this paper, we propose a preplanned restoration technique that provides simple backup network design and management, which includes performing the fifth function, as well as spare resource efficiency. The proposed technique centers around the concept of dual backup cycles, which provides efficient spare capacity placement and sharing, and performs span restoration, i.e., restoration of the whole working capacity of a failed link using local rerouting around the failed link. The preconfiguration of the backup paths and placement of spare capacity is performed statically in the network design phase.

The remaining part of this paper is organized as follows. In Section 2, we describe the proposed method and present the backup paths configuration and spare capacity placement. Section 3 gives performance estimation of the proposed technique using simulations, and Section 4 concludes this paper.

2 Proposed Backup Configuration Method

2.1 Basic Idea

Figure 1 presents the basic concept of the dual backup cycles. In the figure, physical links are shown as solid lines, and five shared backup cycles has been found shown as dashed lines. Each network link is assigned two backup cycles, and each cycle is responsible for recovery of half of the working capacity on a failed link. Primary VPs on a link are partitioned into two virtual path groups (VPGs) [9, 2] so that one VPG covers half of the working capacity on the link. Then, each VPG can be restored by backup VPs residing on separate backup cycle. For example, if link (2-5) fails, primary VPs of one VPG on link (2-5) can be restored using backup paths (2-1-4-5), and the other VPs of another VPG using backup path (2-3-6-5), in which both backup paths are part of the backup cycles containing link (2-5). If a link is underutilized less than 50% of its working capacity, then all the primary VPs of the link are assigned to one VPG and the other VPG contains null primary VP.

The proposed method provides some potential advantages. First, it provides spare capacity efficiency since a backup cycle, thus the spare capacity on it, can be shared to restore different links on a same cycle, and the required spare capacity of a backup cycle is only half of the failed working capacity if the dual cycles have link disjoint paths. Usually, span restoration provides poor spare ca-
pacity efficiency compared with an end-to-end path restoration [8]. However, the proposed method shows very efficient spare capacity requirement that is comparable to that of an end-to-end path restoration, as will be presented later.

Second, it provides improved robustness against multiple failure. In a single ring cover protection or restoration techniques, if two links on a same cycle fail together, it is impossible to protect any of the working capacity on the two links. However, in dual backup cycles scheme, there are still possibilities that 50% of the working capacity on a failed link can be restored using another backup cycle.

In addition, it provides simplicity to survivable network design and management. Restoration is performed locally by a small number of preconfigured cycles with evenly partitioned spare capacity reservation units, in contrast to other preplanned restoration techniques where the amount of spare capacity to be reserved on each link is variable. The preconfiguration of backup cycles can be derived directly from the network topology, which is independent of the working traffic status. The reconfiguration of the backup cycles due to network update is performed locally without global recomputation of backup paths and spare capacity planning.

The proposed method is applicable to arbitrary two-connected mesh networks, i.e., a network presented by a graph that at least two links should be deleted to disconnect (partition) the graph. In this paper, we assumed two-connected arbitrary mesh networks where nodes are connected by bidirectional links with same total working capacity, for example, OC-48 or OC-192, in which each link can deliver different amount of primary working flows that are assigned by demanded traffic routing where the traffic demands change over time.

### 2.2 Dual Backup Cycles Configuration

Dual backup cycles are determined only once for a given network topology $G = (N, E)$, where $N$ is the set of nodes and $E$ is the set of edges. Our first goal is to find a set of cycles that covers each link at least twice to configure dual backup cycles per link. To perform efficient spare capacity planning, the dual backup cycles of a link should have the least number of joint links which would reduce the sharability of spare capacity. Therefore, the first goal should be updated to reflect this fact that each link should be included in a pair of cycles that have the least number of joint links. If we consider the restoration speed and the QoS of restored connections, short backup cycles are preferred to long backup cycles. Therefore, our final goal is to find a set of cycles that satisfies the following conditions.

- each link is covered by at least two cycles.
- each link is included in two of the cycles that share the link and have the least number of joint links.
- each link is included in the shortest possible cycle that satisfies the above two conditions.

For relatively small planar networks, we can find a set of cycles that satisfies the above conditions by using the cyclic double cover (CDC) conjecture. The CDC is a well known conjecture in graph theory and used in [10]: a set of cycles exists in a two-connected graph $G$ that each edge of $G$ is included exactly two of the cycles. For planar networks, every inner cycle that surrounds each region and one cycle that traverses the outmost links consist a set of CDC cycles, and this set of cycles can be used as dual backup cycles. The set of cycles shown in Figure 1 is configured by using this method.

A drawback of the method using CDC conjecture is that the length of the outmost cycles may be too long in a large network. A long backup cycle needs more time to complete restoration than shorter one, and has adverse effect on the spare capacity efficiency and the robustness for simultaneous or subsequent failure. In addition, for nonplanar graphs, the second condition may not be satisfied, i.e., the set of cycles found using CDC conjecture may not be disjoint enough.

Here we present a heuristic algorithm to find a set of cycles that meets the above conditions.

**Heuristic:** Configuration of dual backup cycles

Set of cycles $S = \{ \}$

For each edge $e \in E$ in graph $G = (N, E)$:

1. delete $e$ from $G$, which results in updated graph $G'$;
2. find k-shortest paths between the two end nodes of e in \( G' \), \( P_e = \{p^1, p^2, ..., p^k\} \);
3. a candidate cycle \( c^k_e \) is obtained by e join \( p^k \), \( C_e = \{c^1_e, c^2_e, ..., c^k_e\} \);
4. select a pair of cycles \( c^i_e, c^j_e \in C_e \) that share the least number of links and that have shortest total cycle length as the dual backup cycles of link e;
5. update \( S \), \( S = S \cup \{c^i_e, c^j_e\} \);

### 2.3 Backup VPs Establishment

The primary VPs on a link are partitioned into two VPGs, VPG \( A \) and VPG \( B \), and each VPG is restored by one of the dual backup cycles. In this paper, local backup VPs are residing on the dual backup cycles, thus the local backup VPs should also be partitioned into two backup virtual path groups (BVPGs): BVPG \( A \) and BVPG \( B \). In other words, backup VPs for VPG \( A \) are preassigned on one of the dual backup cycles, and backup VPs for VPG \( B \) is on the other cycle, and the backup VPs on a same backup cycle are grouped into a BVPG. These local backup VPs are established between the two end nodes of a link using part of the backup cycles of the link. The number of backup VPs included in BVPG \( A \) (\( B \)) should be equal to or greater than the number of primary VPs in VPG \( A \) (\( B \)). A BVPG for null VPG has only a signaling VP.

In runtime, the preconfigured backup VPs are activated by assigning required spare capacity to individual backup VP, which is identical to other local VP restoration. However, the rerouting is not performed on individual VP level but performed on backup cycle level, from a failed primary VPG to a related BVPG that resides on a backup cycle.

### 2.4 Spare Capacity Placement

Spare capacity reservation is performed based on shared risk group (SRG) concept. A set of connections on a link that have the same level of risk of failure is called a shared risk group [11]. In this paper, a shared risk group on a link \( e \) is defined as a set of BVPGs that are assigned to \( e \) and share one or more links except \( e \). BVPGs of a same shared risk group can be activated at the same time when a single link failure occurs. For example, the link (1-2) in Figure 2 will be resided by one activated BVPG in the failure case shown in (a), but will be resided by two activated BVPGs simultaneously in the failure case shown in (b). The spare capacity requirement on link (1-2) is determined by the maximum number of BVPGs that can be activated simultaneously, which represents the maximum value among the spare capacity requirements of the SRGs on link (1-2).

Therefore, the amount of spare capacity to be reserved on a link for single link failure is determined as follows.

\[
R_e = \max(R_{SRG1}, R_{SRG2}, ..., R_{SRGm})
\]

where \( R_e \) is the spare capacity requirement of a link \( e \) and \( R_{SRGk} \) is the spare capacity requirement of \( k^{th} \) shared risk group. If we assume that all the BVPGs have the same spare capacity requirement, i.e., exactly the half of the working capacity of a link, the total spare capacity overhead of a network is bounded from 50% to 100% of the total network working capacity: 50% for networks that every link has link disjoint dual backup cycles, 100% for networks that no link has link disjoint dual backup cycles (ex. ring networks).

### 3 Performance Estimation

We performed simulations to estimate the per-
<table>
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<th>Network</th>
<th>no. of nodes</th>
<th>no. of spans</th>
<th>avg. degree</th>
<th>Spare Capacity overhead</th>
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<td>.500</td>
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Table 1: Spare capacity redundancy ratio to total network working capacity for various example mesh networks

formance of the proposed backup cycle configuration method. The dual backup cycles are found using the algorithm presented in Section 2.2 and spare capacity requirements on links are computed using the method presented in Section 2.4.

First, we tested the spare capacity efficiency of the proposed method using 10 example mesh networks with different properties. The properties of the example networks are summarized in Table 1. In the table, Net.2, Net.3, Net.6, and Net.7 represent the New Jersey LATA network, the NSF network, the ARPANET, and the US long haul network, respectively. Net.1, Net.4, Net.5, Net.8, and Net.9 are arbitrary mesh networks used in [8]. Net.10 is a 10 × 10 grid network with large number of nodes and links.

The spare capacity overhead shown in Table 1 is the ratio of total amount of spare capacity to total amount of working capacity in a network for 100% restoration of any single link failure. The results distributed from 50% to 74%, and on average 59.2%. These results strongly insist that the proposed method provides very efficient spare capacity overhead compared with other preplanned restoration techniques. In [8], the average spare capacity overhead is reported 66% for end-to-end path restoration and 87% for local span restoration, for demanded primary working flows.

Next, we tested the robustness of the proposed method for multiple failure. Here, the robustness is defined as the ratio of the amount of restored working capacity to the amount of total failed working capacity in multiple failure cases. We estimate the robustness for all double link failure cases in Net.2, and the average result is presented. Figure 3 shows the result that are compared with the result reported in [12] which provides a novel approach to reveal the tradeoff between spare capacity and robustness with a loopback based protection technique. The proposed method provides 82% of robustness with 63% of spare capacity ratio, and shows substantial improvement on robustness for the static loopback provisioning, and marginal improvement for dynamic loopback provisioning.

Figure 3: Robustness versus Spare Capacity Ratio in Net.2
4 Conclusion

In this paper, we presented a new backup path configuration method for preplanned restoration in ATM mesh networks. The proposed method centers around the concept of dual backup cycles. The whole working capacity of a link available to demanded primary VPs is restored using local backup cycles that are resided by backup VPs. By partitioning the working capacity of a link into two even restoration unit of VPGs, the spare capacity efficiency for single link failure and robustness against multiple failure are substantially improved. In addition, the proposed method provides simplicity to backup network design and management by enabling cycle level configuration and update.

We think that the proposed method in this paper can be applicable to other mesh networks like WDM networks. Our future work will include it and also the examination of the effect of different numbers of backup cycles on spare resource efficiency and robustness.

References


