Capacity Requirements for Network Recovery from Node Failure with Dynamic Path Restoration

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Node failure is not as frequent as span failure but recent events have emphasized its importance in network planning. We study the effects on capacity design if full or partial recovery from node failures is provided using failure-specific path restoration.

1. Introduction

Most studies of restorable networking consider span failures as the primary class of failure scenario. It is, however, often noted that because of its end-to-end orientation, a path restoration mechanism has an inherent ability also to respond to node failures. The spare capacity that ensures 100% span restorability is not necessarily adequate to ensure any particular target level of recovery from a node failure, however. Planned path protection (SBPP) [1] does inherently protect transiting flows against node loss if primary and backup paths are all node disjoint. But SBPP also generally requires more spare capacity than dynamic path restoration and, due to its fixed pre-planned nature, has an inherently lower availability against dual failure scenarios. It is of interest, therefore, to consider how much extra adaptive path restorable network needs to support node recovery, beyond that needed for span restorability.

2. Methods and Results

To address these questions, we extend the prior model for dynamic adaptive path-restorable capacity design [5] and assume that there is at least enough wavelength conversion at each OXC node to make wavelength blocking insignificant. Three new design models were developed.

A) Design for 100% span and node failure restoration

This design model finds the minimal amount (and distribution) of spare capacity that guarantees 100% span restorability and 100% recovery of transiting demands at failed nodes. It is based on the conventional capacity design model for path restoration [5] with the addition of restorability and spare capacity constraints for each node failure scenario. This is the most straightforward (and potentially expensive) design approach.

B) Design to support Multi-QoP

This is an extension of the first model to consider three QoP levels. These are: (1) Rs restoration: this is a wholly best-efforts class with no assured restorability, (2) Rs+n: this class is assured of restorability against any node failure, but receives only best efforts recovery for node failure. (3) Rs+n+1: A lightpath in this class enjoys assured restorability against any span or node failure (other than its own end-nodes). The design model places spare capacity so that all the affected traffic demands that require Rs or Rs+n+1 restorability can be fully restored upon a span failure, and all the affected traffic demands that require Rs+n restorability can be fully restored upon a node failure. Rs working capacity is effectively ignored in the spare capacity design problem, but would receive best-efforts restoration in real time within the spare capacity remaining after re-routing for Rs or Rs+n+1 service classes.

C) Maximal node recovery under a spare capacity budget

This design model allows us to set a budget on total spare capacity (above that where 100% span restoration is feasible) and optimize the distribution of spare capacity for the highest achievable node failure recovery level as well. In Models A and B the objective function is minimum cost or capacity, but here it is to minimize the total un-restored transiting 100% node failures. By varying the budget amount this model can be used to systematically study the trade-off between cost and node recovery level.

We evaluate the performance of the design models on five well-known topologies: ARPA2 (21-nodes 25-spans), NSFNET (14,21), SmallNet (10,22) from [5], Cost 239 (11,26), and the (55, 63) topology from www.level3.com. Lightpath demands were generated following a uniform random distribution on the range [1…20] for each node pair. For the larger Level3 test case only the largest 30% of demand pairs were selected and the (55, 63) topology from www.level3.com. Lightpath demands were generated following a uniform random distribution on the range [1…20] for each node pair. For the larger Level3 test case only the largest 30% of demand pairs were selected and the (55, 63) topology from www.level3.com. Lightpath demands were generated following a uniform random distribution on the range [1…20] for each node pair. For the larger Level3 test case only the largest 30% of demand pairs were selected and the (55, 63) topology from www.level3.com.

Table 1. Node failure restorability, redundancy increase, and total cost increase for various network design cases

<table>
<thead>
<tr>
<th>Network</th>
<th>ARPA2</th>
<th>NSFNET</th>
<th>SmallNet</th>
<th>Cost239</th>
<th>Level3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrinsic node capacity (R0)</td>
<td>91.35%</td>
<td>99.56%</td>
<td>85.30%</td>
<td>78.89%</td>
<td>95.39%</td>
</tr>
<tr>
<td>Rs (node) only</td>
<td>91.35%</td>
<td>99.56%</td>
<td>85.30%</td>
<td>78.89%</td>
<td>95.39%</td>
</tr>
<tr>
<td>Rs+n (node)</td>
<td>88.43%</td>
<td>99.23%</td>
<td>89.40%</td>
<td>82.83%</td>
<td>99.89%</td>
</tr>
<tr>
<td>Rs+1 (node)</td>
<td>10.6%</td>
<td>0.02%</td>
<td>2.5%</td>
<td>3.4%</td>
<td>4.1%</td>
</tr>
<tr>
<td>Rs+n (node) requires</td>
<td>9.7%</td>
<td>0.02%</td>
<td>2.5%</td>
<td>3.4%</td>
<td>4.1%</td>
</tr>
<tr>
<td>Rs+1 (node) requires</td>
<td>5.2%</td>
<td>0.02%</td>
<td>1.7%</td>
<td>2.9%</td>
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</tbody>
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Fig. 1. Node failure restorability change under different R0, Rs, Rs+n, and Rs+n+1 service classes.

Fig. 2. Failure spare capacity increase with different percentage of span restorability.
Additional spare capacity over the conventional designs, a network can still serve a large number of higher-level QoS services.

3. Concluding Remarks
This work shows that, overall, it is surprisingly easy to support node recovery in path-restorable networks. Very high levels of premium service class guarantees (services assured of both span and node recovery) can apparently be supported with no more spare capacity than needed to give all services span restorability alone. Conversely, if 100% node recovery is desired by design it took at most 10% extra spare capacity to provide this. This knowledge and related design methods are useful in themselves and to further inform the comparison of failure-specific path restoration to the SBPP pre-planning scheme.

4. References

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We present a novel technique for rapid restoration in optical/electrical mesh networks that does not incur any signaling or setup cross-connect stack latencies. We show that it easily meets the 50ms requirement in most scenarios.

Introduction
The last few years have witnessed the introduction of optical and electrical mesh networks as an alternative to SONET ring networks. One of the key benefits of mesh networks is the improved bandwidth utilization coming from shared restoration. Unlike the traditional 1+1 protection schemes which reserve 50% of the bandwidth for protection, shared restoration allows multiple demands to share backup links and hence reserves less capacity. However, the speed of restoration is an issue with this scheme. Many classes of traffic, especially bursty traffic, require paths to be restored very fast, often within 50ms [2]. It is easy to meet this requirement with 1+1 protection - data is always sent on the primary and backup paths and the end node picks the best signal. This is not the case with shared restoration where the backup paths are only set up after the failure. Typically, this process involves signaling to setup cross-connects (XCs) which can be time-consuming in large networks using slower XC technologies.

Motivated by these issues, we have developed a rapid restoration mechanism that works for both optical and electrical mesh networks, with a primary goal of eliminating the signaling and XC latencies.

Related Work: Much of the earlier work on shared restoration has focused on routing and design algorithms and our technique is complementary to those results. A mechanism called ROLEX for fast restoration was proposed in [1] and its implementation in GMPLS/RSPV was given in [3]. However, ROLEX also incurs cross-connect and signaling latencies, which are the primary bottlenecks addressed in our solution.

Solution
We consider a mesh network consisting of cross-connect nodes (XCs) connected by DWDM systems. Each wavelength between two adjacent nodes is considered to be a link. The edge nodes are assumed to have 100% OBS capability. Traffic consists of unit-wavelength demands between the edge-nodes, protected through shared restoration. Each demand is associated with a primary path and a precomputed backup path for the entire path or per link. For clarity, we assume bi-directional traffic using the same path in both directions and bi-directional failures for our discussion and present the modifications for unidirectional cases where necessary.

The basic idea behind our solution, called FASTeR (Fast Signal-free Traffic Restoration), is as follows: Even before any failures occurs, all the backup paths are set up using certain special features of the XCs, in contrast with the traditional approach where the backup paths are only precomputed but have no OBS capability. Traffic consists of unit-wavelength demands between the edge-nodes, protected through shared restoration. Each demand is associated with a primary path and a precomputed backup path for the entire path or per link. For clarity, we assume bi-directional traffic using the same path in both directions and bi-directional failures for our discussion and present the modifications for unidirectional cases where necessary.

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