

# Capacity versus Robustness: A Tradeoff for Link Restoration in Mesh Networks

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Motivation and Contribution	Solution	Evaluation
<p><b>Problem Statement:</b> Given an existing all-optical network</p> <ul style="list-style-type: none"> <li>fully protect against single link failures</li> <li>protect against multiple link failures when possible</li> <li>use backup capacity efficiently</li> </ul> <p><b>Design Goals for Solution</b></p> <ul style="list-style-type: none"> <li><b>generality:</b> impose few, local constraints on network topology</li> <li><b>scalability:</b> allow growth through localized, incremental changes</li> <li><b>distribution:</b> require no centralized control for reliability</li> <li><b>speed:</b> provide very fast restoration (<math>O(10)</math> milliseconds)</li> </ul> <p><b>Characteristics of Good Solutions</b></p> <ul style="list-style-type: none"> <li><b>link restoration:</b> reroute traffic for failed link between endpoints of link (required for speed and distribution)</li> <li><b>preplanned:</b> traffic actively rerouted down prearranged backup fibers (required for speed)</li> <li><b>mesh topology:</b> requires two link-disjoint paths between any two nodes (alternative is rings; mesh required for generality and scalability)</li> </ul> <p><b>Key Design Tradeoff: Capacity versus Robustness</b></p> <ul style="list-style-type: none"> <li>network should recover from as many failure modes as possible</li> <li>network should use available bandwidth efficiently</li> </ul> <p>What is the appropriate balance between these goals?</p> <p><b>Example of tradeoff</b> Should blue fibers be used to protect black fibers or to carry more traffic?</p>	<p><b>Generalized Loopback</b></p> <ul style="list-style-type: none"> <li>flood traffic from failed link down all arcs in backup digraph</li> <li>use NACK's to tear down unnecessary paths</li> <li>supports multicast lightpath recovery</li> <li>for recovery from any single-link failure, strongly connected backup digraph is sufficient</li> <li>implication <ul style="list-style-type: none"> <li>not all backup fibers need be used for backup (such links are termed <i>non-critical</i>)</li> <li>unused fibers can carry additional (unprotected) traffic</li> </ul> </li> </ul> <p><b>Effect in example networks:</b></p> <ul style="list-style-type: none"> <li><b>NJ LATA:</b> 48% additional capacity (shown)</li> <li><b>LATA X:</b> U.S. telephony backbone, 40%</li> <li><b>National:</b> another U.S. model, 45%</li> <li><b>COST239:</b> European backbone, 46%</li> <li><b>ARPANET:</b> ARPANET model, 38%</li> </ul>	<p><b>Two-Link Failure Recovery Metrics</b></p> <ul style="list-style-type: none"> <li><b>robustness:</b> percentage of two-link failures from which the network recovers</li> <li><b>reliability:</b> minimum over all arcs <math>[U, V]</math> of the percentage of other link links that, should they fail, do not prevent recover of <math>[U, V]</math> <ul style="list-style-type: none"> <li><b>first-failure reliability:</b> <math>[U, V]</math> fails first</li> <li><b>second-failure reliability:</b> <math>[U, V]</math> fails second</li> </ul> </li> </ul> <p>graphs compare</p> <ul style="list-style-type: none"> <li>generalized loopback</li> <li>preplanned shortest path: one path per arc, chosen in advance</li> <li>optimal solution (NP-complete)</li> </ul>
<p>This work provides:</p> <ul style="list-style-type: none"> <li>a solution that meets the stated goals</li> <li>a solution that allows flexibility in the capacity/robustness tradeoff</li> <li>a quantitative basis for reasoning about that tradeoff</li> </ul>	<p><b>Comparable Related Work</b></p> <p><b>Double Cycle Covers</b></p> <ul style="list-style-type: none"> <li>embed directed rings in mesh such that <ul style="list-style-type: none"> <li>every edge covered by exactly two rings</li> <li>in opposite directions</li> </ul> </li> <li>robust to all single link failures, but not single node failures</li> <li>requires all secondary fibers for backup</li> <li>solid lines in graph superior to d.c.c., dashed lines inferior</li> </ul>	<p><b>Conclusions and Future Directions</b></p> <p><b>Summary</b></p> <ul style="list-style-type: none"> <li>allows capacity-efficient recovery from single failures (node failures not discussed on poster)</li> <li>provides up to 40% additional capacity for sample networks</li> <li>metrics focus on ability to recover from two-link failures <ul style="list-style-type: none"> <li>typically close to optimal behavior</li> <li>while providing 20% additional capacity</li> </ul> </li> </ul> <p><b>Related and Future Work</b></p> <ul style="list-style-type: none"> <li>development of additional robustness metrics <ul style="list-style-type: none"> <li>single node failures with capacity</li> <li>double-cycle cover not robust to node failures</li> </ul> </li> <li>dynamic identification of spare capacity</li> <li>heuristic and genetic algorithm optimization of non-critical edge selection</li> <li>integration of link restoration and path protection</li> <li>integration with direct access networks</li> </ul>