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

Prof. Steven S. Lumetta, Prof. Muriel Médard, and Yung-Ching Tseng
University of Illinois at Urbana-Champaign, Dept. of Electrical and Computer Engineering, Coordinated Science Laboratory

Motivation and Contribution

Problem Statement: Given an existing all-optical network
- fully protect against single link failures
- protect against multiple link failures when possible
- use backup capacity efficiently

Design Goals for Solution
- generality: impose few, local constraints on network topology
- scalability: allow growth through localized, incremental changes
- distribution: require no centralized control for reliability
- speed: provide very fast restoration (O(10 milliseconds))

Characteristics of Good Solutions
- link restoration: reroute traffic for failed link between endpoints of link (required for speed and distribution)
- preplanned: traffic actively rerouted down prearranged backup fibers (required for speed)
- mesh topology: requires two link-disjoint paths between any two nodes (alternative is rings; mesh required for generality and scalability)

Key Design Tradeoff: Capacity versus Robustness
- network should recover from as many failure modes as possible
- network should use available bandwidth efficiently
What is the appropriate balance between these goals?

Example of tradeoff
Should blue fibers be used to protect black fibers or to carry more traffic?

This work provides:
- a solution that meets the stated goals
- a solution that allows flexibility in the capacity/robustness tradeoff
- a quantitative basis for reasoning about that tradeoff

Solution

Generalized Loopback
- flood traffic from failed link down all arcs in backup digraph
- use NACK’s to tear down unnecessary paths
- supports multicast lightpath recovery
- for recovery from any single-link failure, strongly connected backup digraph is sufficient
- implication: not all backup fibers need be used for backup (such links are termed non-critical)
- unused fibers can carry additional (unprotected) traffic

Effect in example networks:
- NJ LATA: 48% additional capacity (shown)
- LATA X: U.S. telephony backbone, 40%
- National: another U.S. model, 45%
- COST239: European backbone, 46%
- ARPANET: ARPANET model, 38%

Conclusions and Future Directions

Summary
- allows capacity-efficient recovery from single failures (node failures not discussed on poster)
- provides up to 40% additional capacity for sample networks
- metrics focus on ability to recover from two-link failures
  - typically close to optimal behavior
  - while providing 20% additional capacity

Related and Future Work
- development of additional robustness metrics
  - single node failures with capacity
  - double-cycle cover not robust to node failures
  - dynamic identification of spare capacity
  - heuristic and genetic algorithm optimization of non-critical edge selection
- integration of link restoration and path protection
- integration with direct access networks

Comparable Related Work

Double Cycle Covers
- embed directed rings in mesh such that
  - every edge covered by exactly two rings
  - in opposite directions
  - robust to all single link failures, but not single node failures
  - requires all secondary fibers for backup
  - solid lines in graph superior to d.c.c., dashed lines inferior

Recall

Evaluation

Two-Link Failure Recovery Metrics
- robustness: percentage of two-link failures from which the network recovers
- reliability: minimum over all arcs [U, V] of the percentage of other links that, should they fail, do not prevent recovery of [U, V]
  - first-failure reliability: [U, V] fails first
  - second-failure reliability: [U, V] fails second

Graphs compare generalized loopback
- preplanned shortest path: one path per arc, chosen in advance
- optimal solution (NP-complete)