SHARED MESH RESTORATION IN OPTICAL NETWORKS

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Outline

- Introduction – Network & Restoration Arch Evolution
- Mesh Routing & Provisioning
- Fast Shared Mesh Restoration
- Re-provisioning for Improved Reliability
- Planning & Dimensioning
- Re-optimization
- Maintenance
- Summary

Network Evolution

- Network architecture
  - Mesh vs. Ring
  - Multi-tier network
    - Historical (DS0/DS1/DS3/STS-1/STS-48)
    - Not a question of if but when
- Technology
  - O/E/O switching
  - All-optical switching in opaque network
  - All-optical/transparent network
    - e.g., (R)OADM
- Difficulty is often not just the technology but one of network management and operations

Restoration Architecture Evolution

- 80's – DCS-based Mesh Restoration of DS3 Facilities
  - Centralized (EMS/NMS)
  - Path-based, failure-dependent, after fault detection and isolation
  - Capacity-efficient but slow (~ minutes)

- 90's – ADM-based Ring Protection of SONET/SDH Facilities
  - Distributed
  - Path-based (UPSR) or span-based (BLSR), pre-determined
  - Fast ("50 msec") but capacity-inefficient

- 2000's – OXC-based Mesh Protection/Restoration
  - Distributed
  - Path-based, failure-independent, pre-determined and pre-provisioned
  - Capacity-efficient AND fast (10's – 100's msec)

Restoration Architecture Evolution (cont'd)

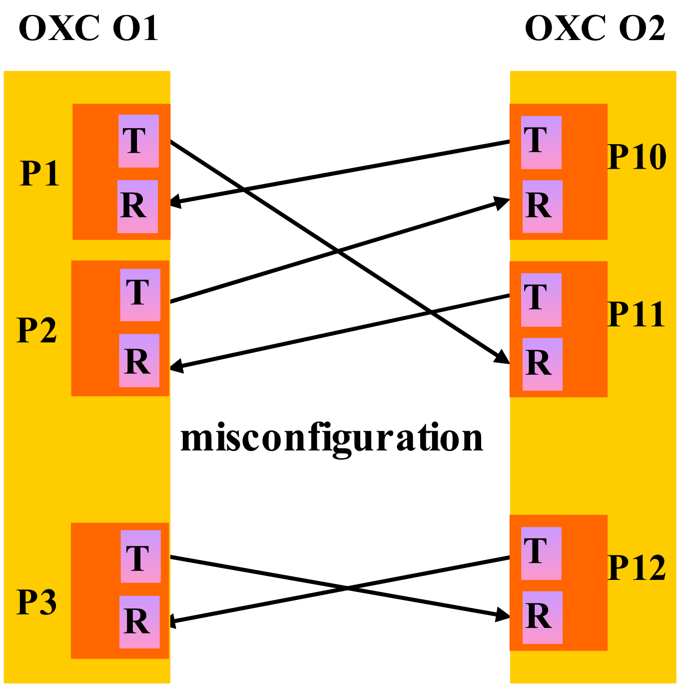
- Challenge: OXC-based mesh network architecture requires new network management, and new operations which can be more sophisticated than those in ring-based networks
- Question: can ring-based architectures be evolved instead?
  - Trans-oceanic ring architecture (G.841)
  - “p-cycle” (W. Grover et al.)
  - Next-gen SONET/SDH equip. can handle multiple rings
  - Ability to not close working or protection ring
  - Ability to share protection channels across rings
- End-result is an evolution towards mesh networking

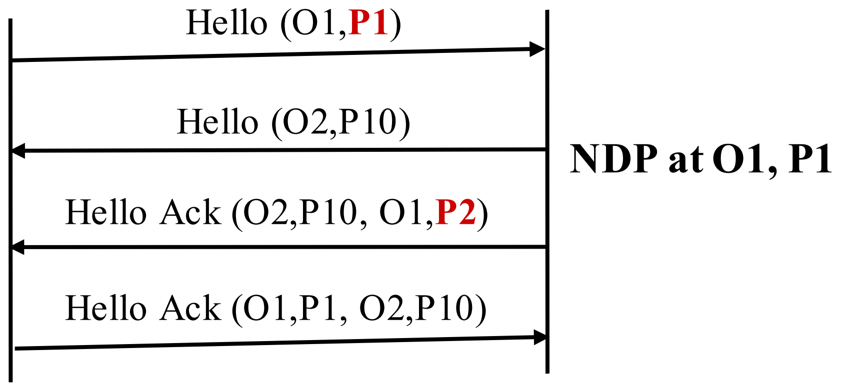
Mesh Operations – Routing & Provisioning

- Shared mesh restoration based on pre-determined, pre-provisioned restoration paths
- KEY requirement of mesh networking
  - Complete synch between network and its inventory
  - Cannot rely on manual entry of network inventory
- Provisioning Components
  - *Self-discovery of neighbour and port connectivity <-- the key feature*
  - Topology discovery
  - Route computation
  - Lightpath setup

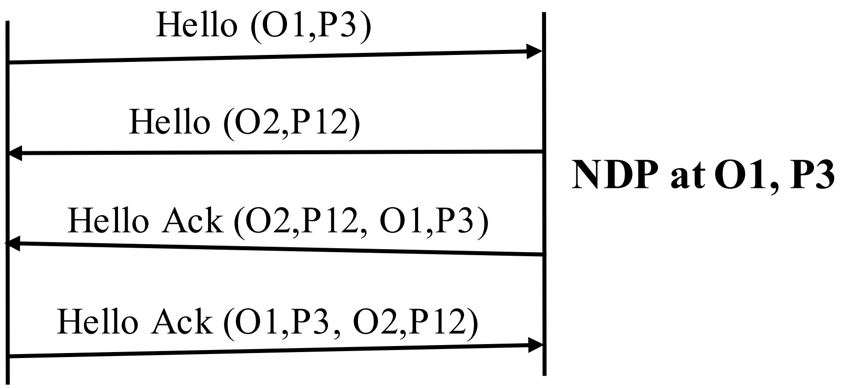
<u>Debate on management vs. control plane approach</u>

Automated Discovery of Port and Neighbouring Node Connectivity





exchange reveals misconfiguration since sending P1 is followed by acknowledgment of P2



normal exchange

Comparing Control & Management Plane Approaches

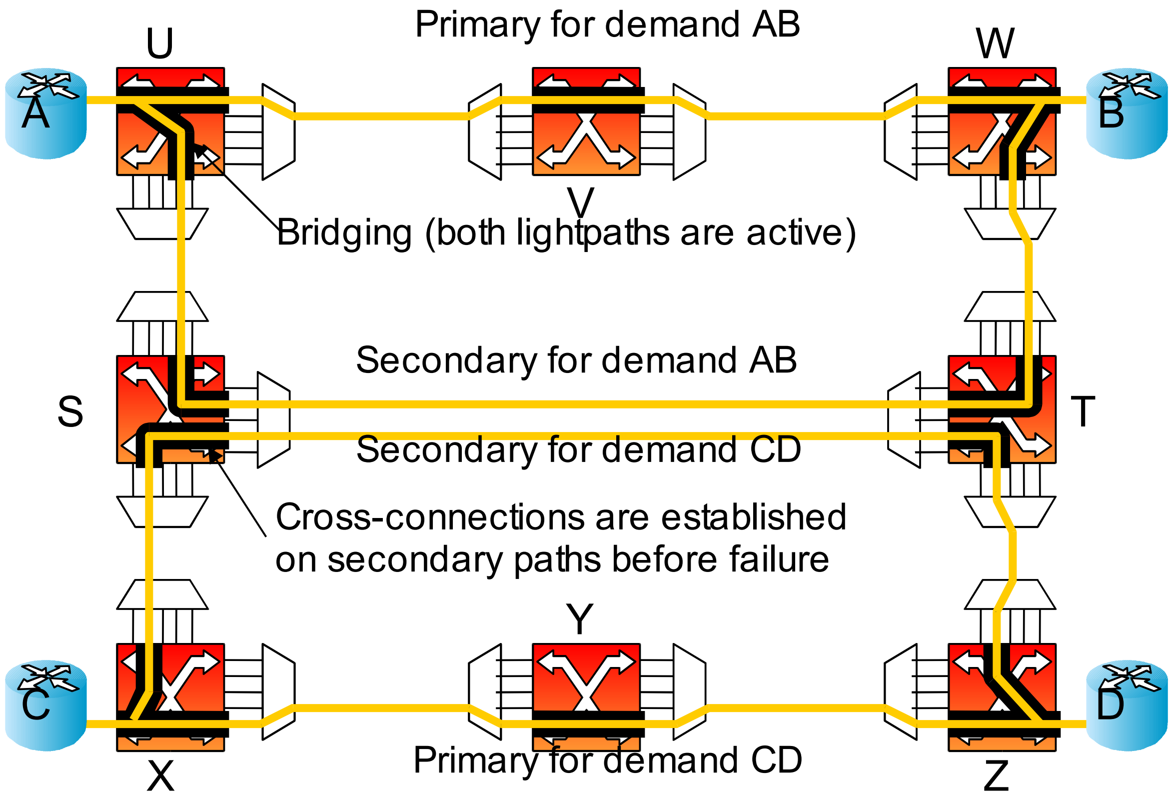
Management Plane Approach

- Neighbor discovery
  - Manually configured
- Topology discovery
  - Derived at NMS/EMS from neighbour & port adjacency information
- Route computation
  - NMS/EMS computes the primary and backup paths from the topology and lightpath databases
- Lightpath setup
  - NMS sets up lightpaths by configuring the NEs using TL-1 messages

Control Plane Approach

- Neighbor discovery
  - Done using neighbour discovery protocol (LMP) between NEs
- Topology discovery
  - Done by NEs by exchanging neighbour & port adjacency info (OSPF/IS-IS)
- Route computation
  - Done by NEs from topology database
  - NEs may not have complete lightpath database
- Lightpath setup
  - Done by NEs using a signaling protocol like RSVP-TE or CR-LDP

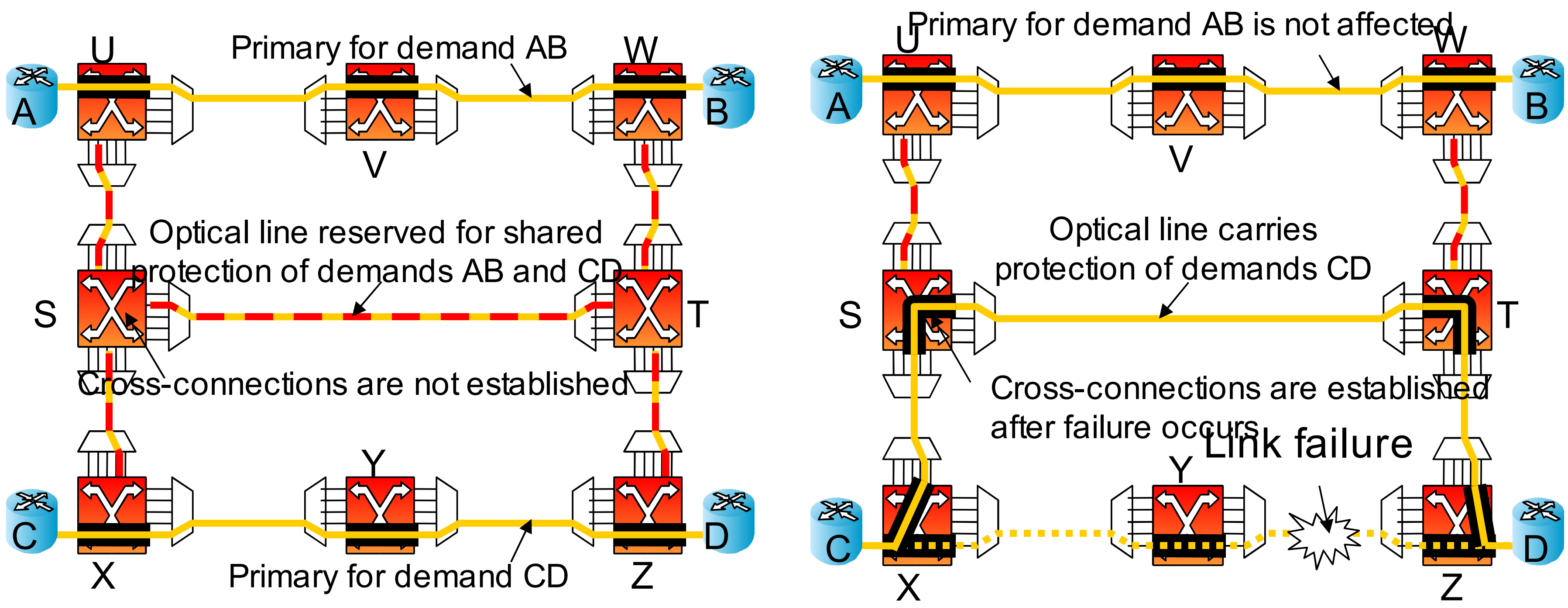
Dedicated Mesh (1+1) Protection



- source transmits to both working and edge/node-diverse backup paths
- The destination decides which path to select, based on the quality of the received signals.
- Fastest restoration but wasteful because backup path is permanently active, although not used under normal conditions.

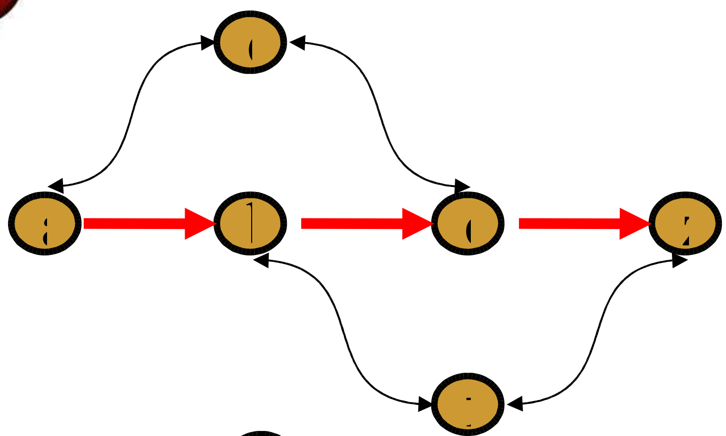
Shared Mesh Restoration

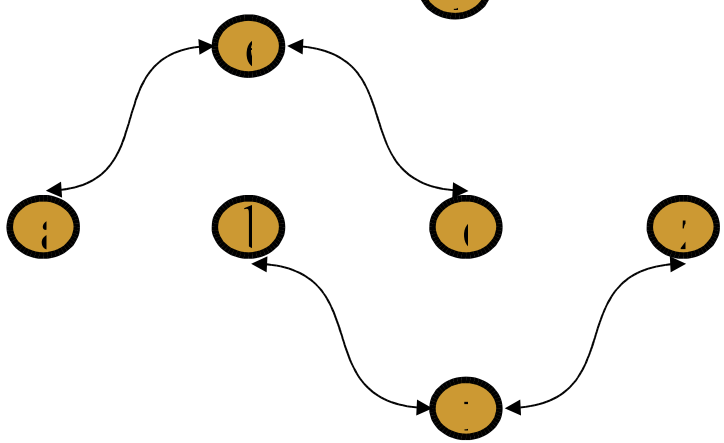
- Shared mesh restoration reserves the capacity for the backup path, and activate the backup only when necessary
- Enable the same capacity to serve multiple backup paths if the paths are not expected to be activated simultaneously. This condition is satisfied if their working paths are “diverse”



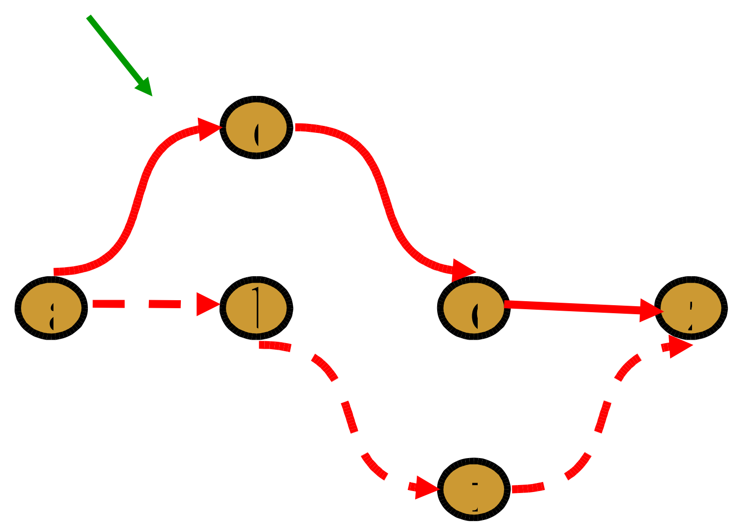
BEFORE FAILURE **AFTER FAILURE**

Diversity of Paths

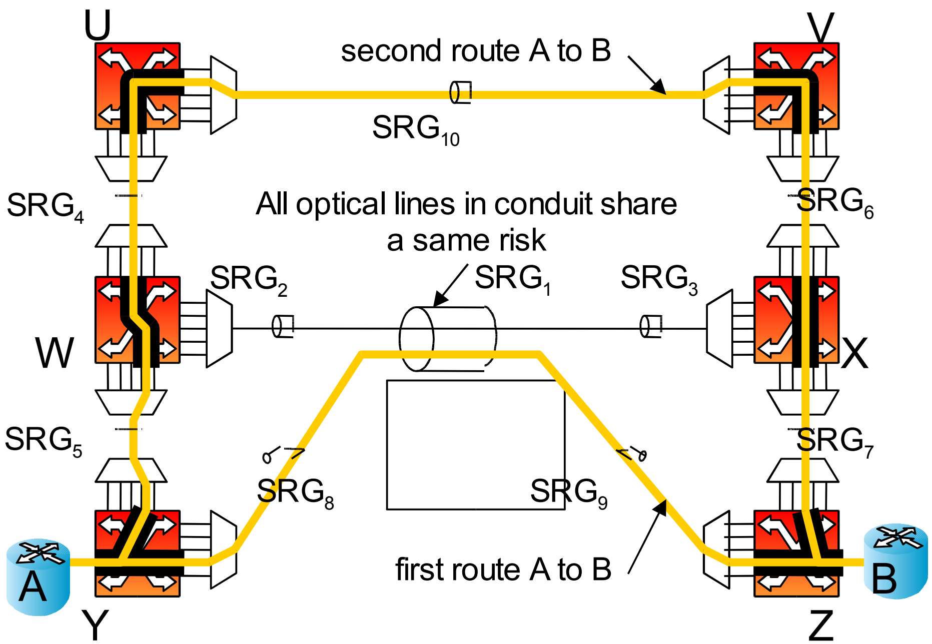


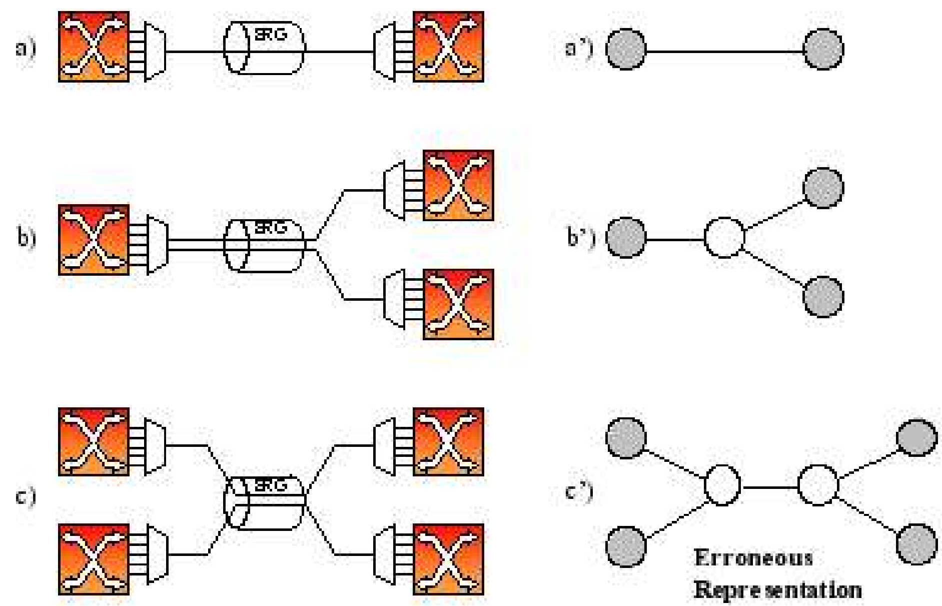


After computing the working path using a shortest path algorithm, and removing the edges to compute the backup. The residual graph becomes disconnected, and we find no corresponding backup path even though one exists.



Shared Risk Groups



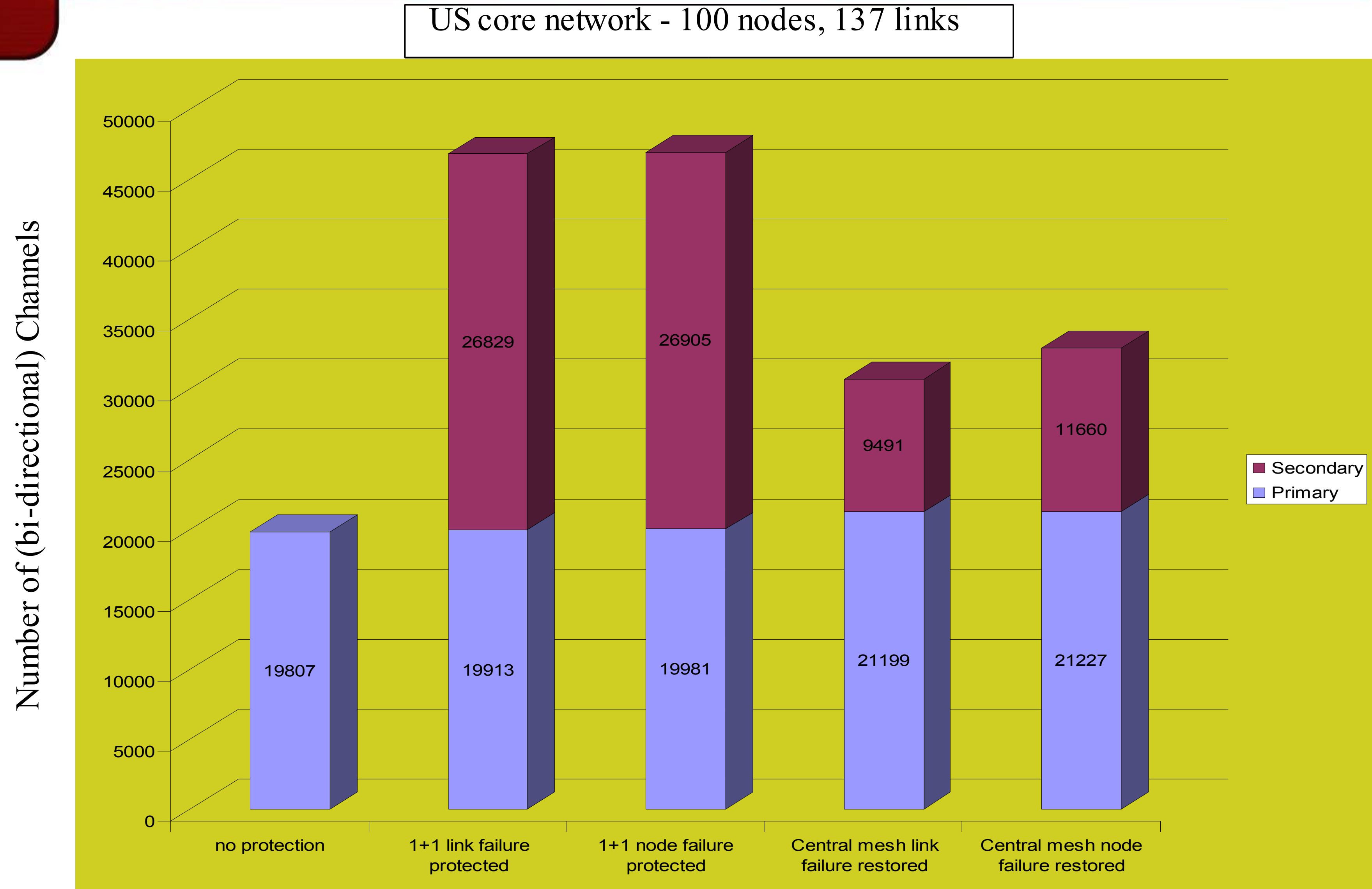


- SRGs are used to represent sets of edges that may be affected by a common failure, such as fibers routed through a given conduit, etc.
- Non-trivial SRGs are the norm rather than the exception in telecom networks.
- There is no known optimum algorithm for arbitrary SRGs.

Dedicated vs. Shared Mesh Case Study - Network

100 Nodes
137 Links
~ 3000 OC-48 equivalent demands

Dedicated vs. Shared Mesh Case Study - Results



Restoration: Scope & Objectives

- Scope
  - Guaranteed restoration after “single failure” events
    - TR failure
    - Amplifier failure
    - Fiber/Cable cut
  - Recovery via re-provisioning after multiple concurrent failures

- Objectives
  - Fast response
  - High degree of robustness
  - Support for different service levels
    - Dedicated (1+1) diverse protection for lowest restoration latency
    - Shared diverse restoration for capacity efficiency
    - Non pre-emptible non-restorable service
    - Pre-emptible service

Mesh Networking and Ring-like Restoration

Fast restoration

- Pre-computed and pre-provisioned backup paths
- Bit-oriented failure notification & restoration signalling (using SONET/SDH overhead bytes)
- Fast intra-system communication

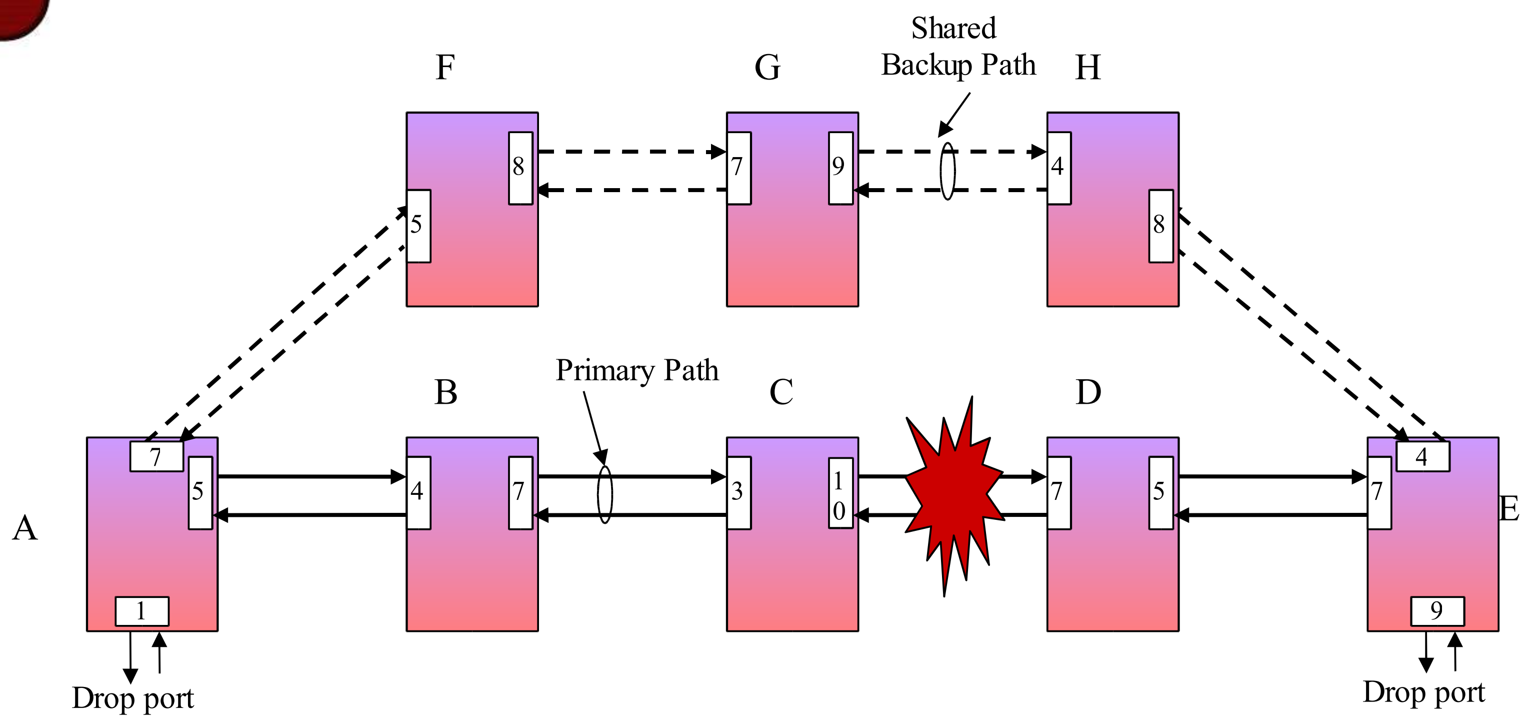
Robustness

- Bit-oriented failure notification & restoration signalling
- Per-channel independent signaling for each lightpath
- Connection after verification

Optimized for the common case

- Fast and guaranteed restoration for single SRG failure
- Re-provisioning for multiple concurrent failures

Restoration Protocol Overview

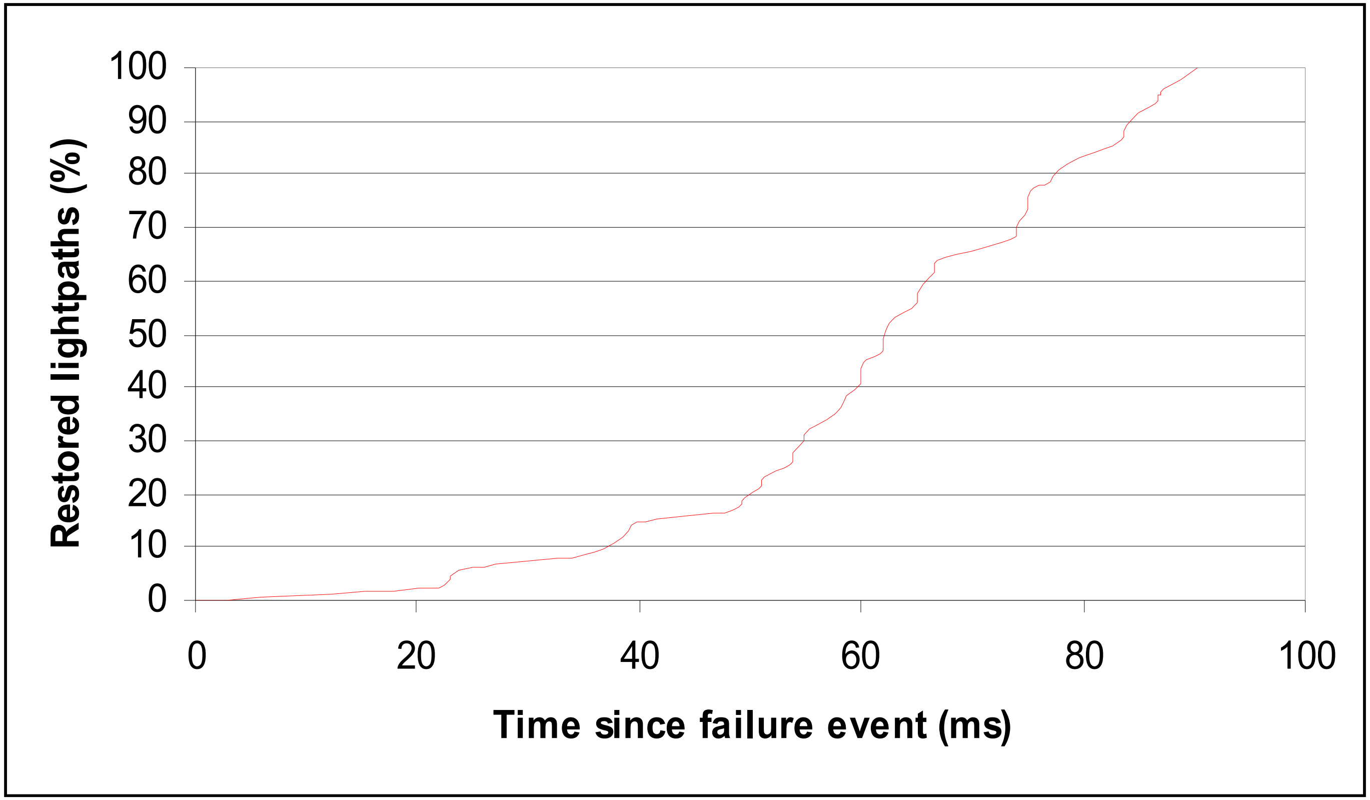


- A shared backup path is "soft-setup" for each shared mesh restorable primary path
  - Channels on the backup path may be shared with other backup paths
  - Crossconnects are not setup during provisioning
- Path restoration triggers are sent to the end-nodes
- End-to-end signaling over the backup path activates it and completes the path restoration

Mesh Restoration Simulation

Why simulation?

- Unlike ADM-based rings, restoration speed dependent on network loading and routing
- Predict restoration performance (e.g., for SLA compliance)



Restoration Simulation Methodology

Use calibrated simulation tool to predict network performance, using identical traffic loading and routing as real network

- Equipment model
  - System architecture – racks, shelves, interface modules, control modules
  - Internal communication architectures
  - Processing queues
- Restoration protocol model
  - Parameterize basic events, processes and queuing delays
- Measure restoration latency in a test network of real systems
  - Tune parameters to calibrate simulation tool

Summary – Mesh Restoration

- Shared mesh restoration is fast! - 10's to 100's of msec
  - Very different from centralized mesh restoration in DCS networks (order of minutes)
  - Distributed ring-like implementation
- Simulation critical for mesh network operations
  - Similation tool with calibration, identical protocols and routing algorithms as in real network
  - Integration with planning and operations systems
- Ring restoration will be slower with next-gen products
  - Because same equipment will terminate 10's of rings
  - Restoration processes will compete for resources
  - Restoration times will be dependent on network loading

Network Reliability & Service Availability

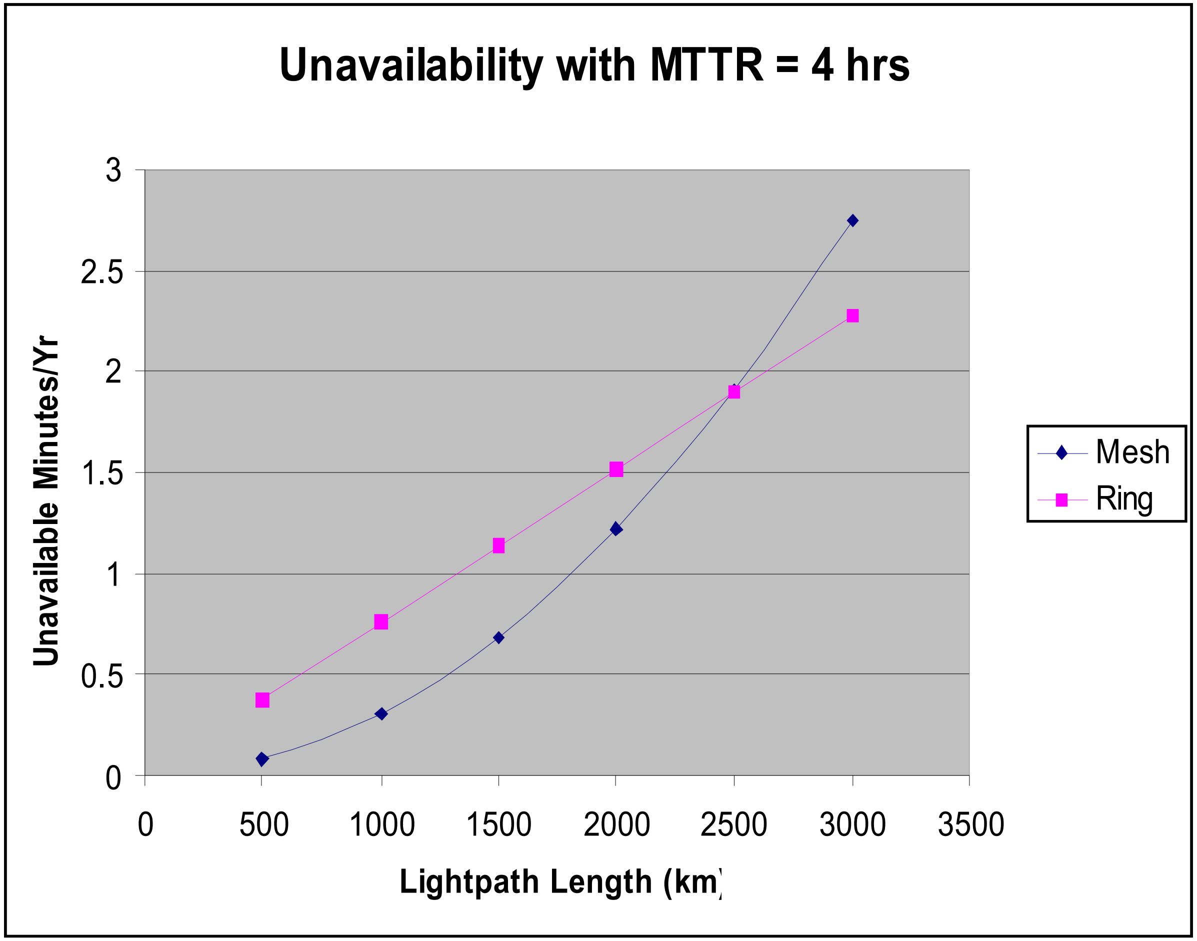
- Speed of restoration is not that important for service availability
  - A = MTBF/(MTBF + MTTR)
  - Impact of MTTR ranging from msec to sec is insignificant
  - Impact of MTTR of several hours if physical repair is needed (in case of double failure) is significant

- Ability to protect against double failure is key to high service availability

Service Unavailability

- Mostly due to double failures for protected services
- Service unavailability is roughly proportional to
  - Length of path for unprotected service
  - Product of length of working and protection path for protected service (higher unavailability of shared mesh over dedicated mesh due to impact of sharing)
- But decreases when network is split into independent restoration domains, so
  - For limited geographical span, longer protection path on ring causes higher unavailability
  - For larger geographical span, presence of many rings decreases chances of two failures happening in single ring, and ring-based architecture can achieve lower unavailability

Service Unavailability – Ring vs. Mesh



Service Availability – Re-provisioning

But mesh networks can be made much more robust by

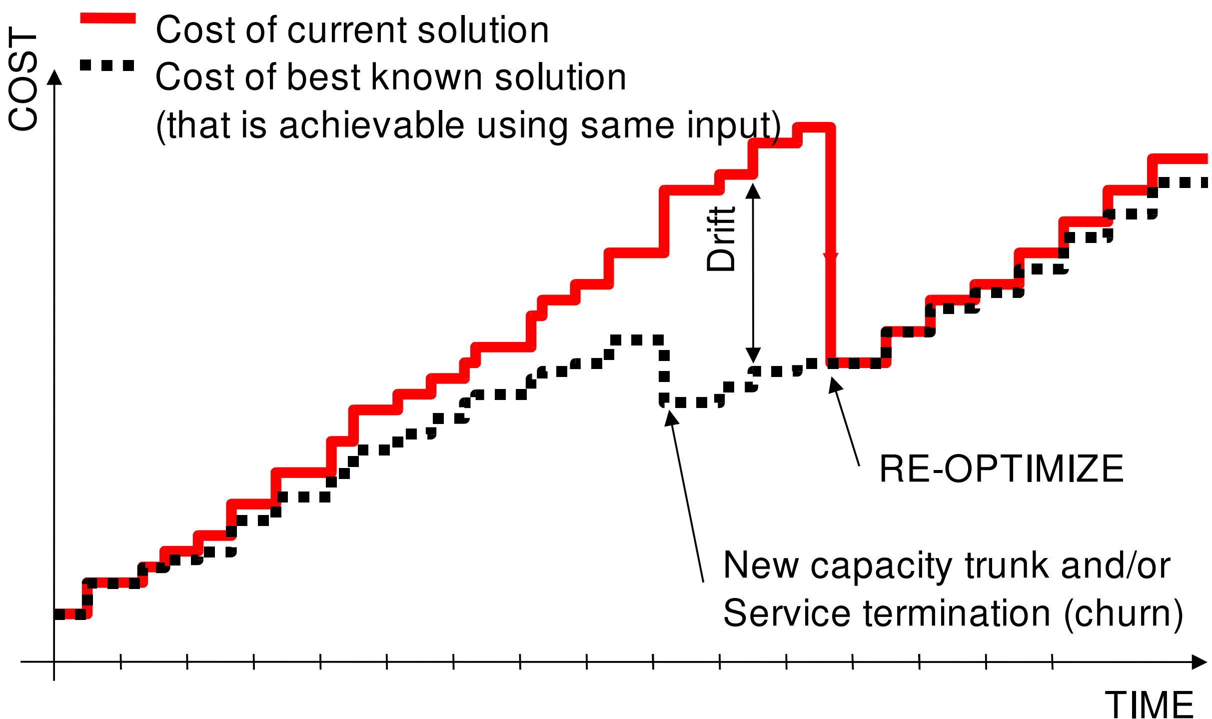
- splitting into multiple domains
  - e.g., US/trans-Atlantic/European domains
- Using end-to-end re-provisioning in case of double failures
  - EMS/NMS-based with fault detection and localization
  - Take 10's of sec instead of hours with manual intervention
  - Can be 100% succesful with enough spare capacity

Planning & Dimensioning

- Mesh networks are more robust than ring networks to traffic forecast uncertainties
  - Many rings have low utilization because traffic did not materialize where and when predicted
  - Will become less true with next-gen SONET/SDH equipment supporting many rings
  - But ability to re-optimize mesh network
- Dimensioning mesh networks
  - Can be modeled and analyzed mathematically (e.g., random graphs, Moore bound,...)
  - Properties, approximations, asymptotic behavior (e.g., ratio of protected to working capacity)

Why Re-optimization?

- Over-time, a network routing diverges from optimality
  - On-line results in drift toward sub-optimal solutions,
  - Service churn, capacity upgrade, and new additions to the network infrastructure, create opportunities for improvement
- Periodically re-optimize the routes to seize on these opportunities and espouse the network dynamics as it grows



Re-optimization: Objectives and challenges

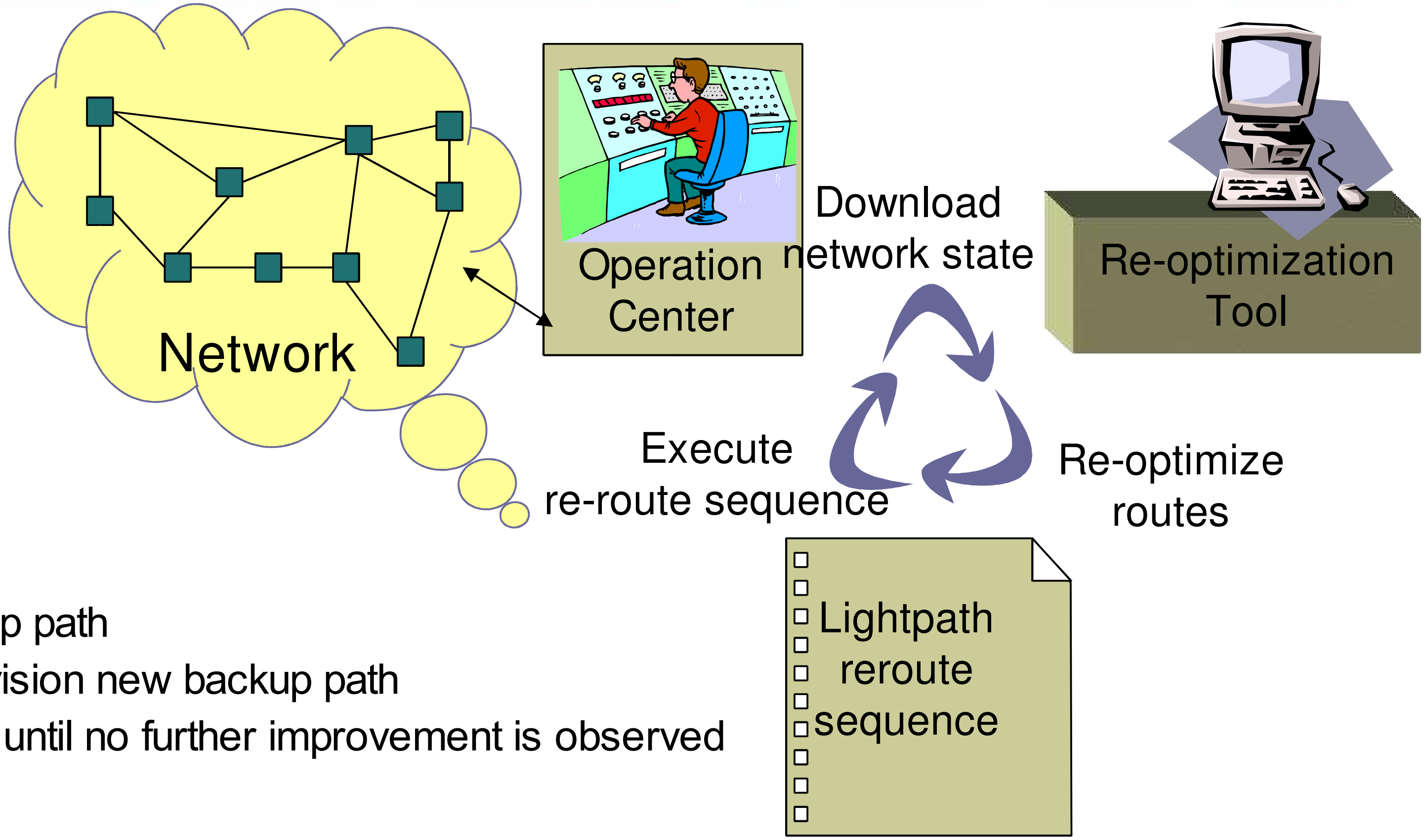
- Objectives of re-optimization
  - Increase routing efficiency and utilization, increase capacity availability to offer more services at no additional cost
  - Decrease paths lengths (reduce latency), improve service quality

- Challenges
  - Re-optimization is executed from the network operation center, using existing network infrastructure and given capacity
  - Minimize undesirable impacts to services
  - Minimize risks of major service disruptions in case of network failures, i.e. keep protection mechanism functional during re-optimization
  - Ability to pause and resume the re-optimization, in order to cope with unexpected events

Types of Re-optimization

- Complete: re-optimize both primary and backup paths
  - Most effective, but
  - Requires service interruption to switch from old to new primary path
- <u>Partial: re-optimize the backup path only</u>
  - No impact on primary, thus transparent to the client layer,
  - Almost as effective as a complete re-optimization,
- Type can be decided on a per-lightpath basis
  - Complete re-optimization for services with lower SLA
  - Partial re-optimization for services with stringent requirements

How Re-optimization is Done?

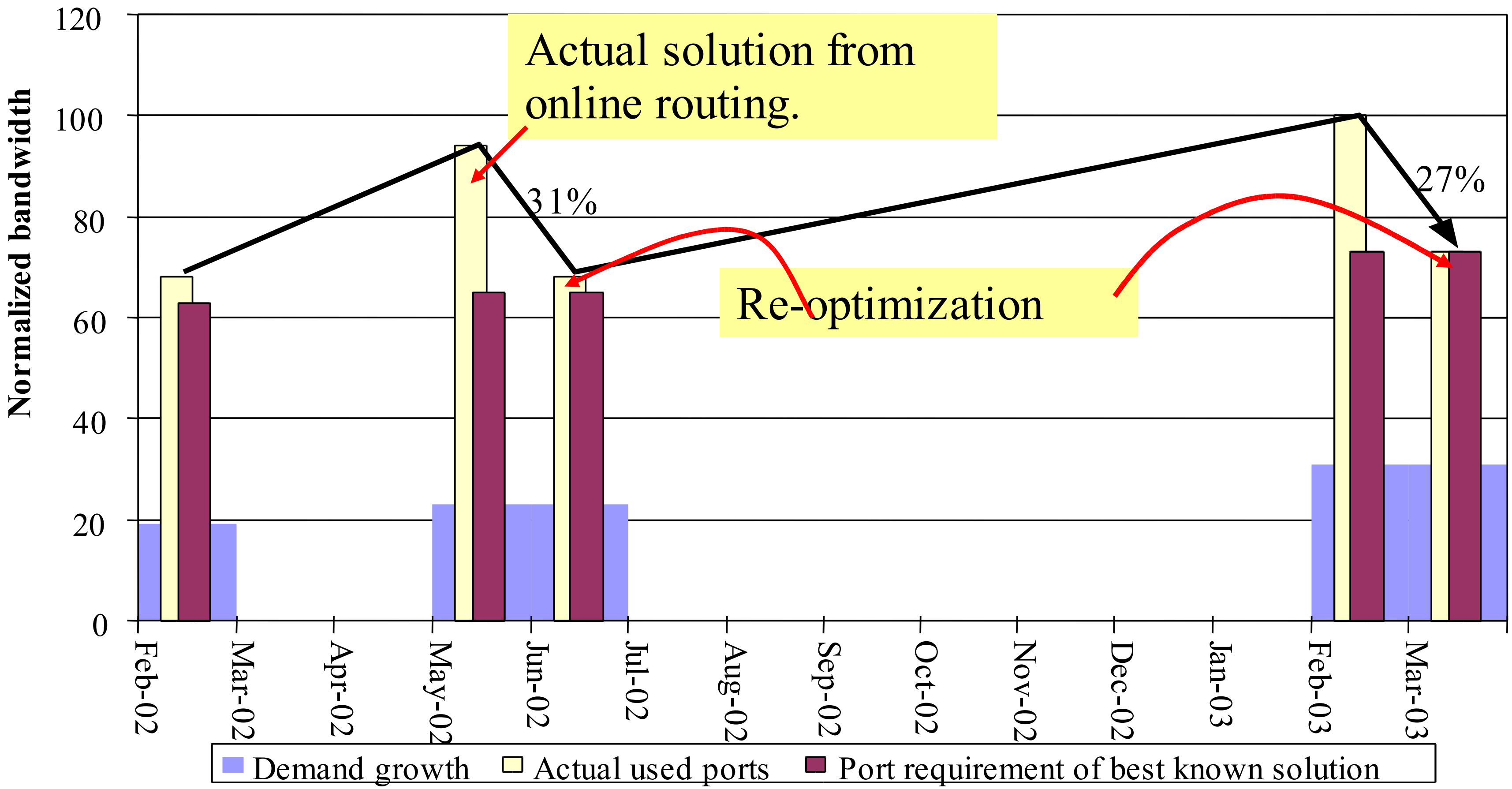


1. Select a lightpath
2. Remove it's backup path
3. Compute and provision new backup path
4. Iterate over 1 to 3 until no further improvement is observed

- Backup paths are re-routed one at a time, the corresponding lightpath is unprotected during re-routing
- The backup paths of some lightpaths may be re-optimized more than once to perform "capacity swaps"
- **Intelligence**, in selecting the proper lightpaths and proper sequence to achieve the most effective results

Network Re-optimization

A Real Network Example (45 cities across US)



Network Re-optimization - Summary

- Experience clearly demonstrates benefits of re-optimization
  - The nature of network operations leads to inefficient routing over time
  - Up to 20% capacity saving: freed capacity can be reused for future services (capital avoidance)
  - Backup latency is 30% shorter
- Procedure is safe
  - Primary paths unaffected, no service interruption
  - One demand at a time is briefly unprotected, while backup path is being re-provisioned
  - Operates within actual network capacity, all operations are performed from network operation center
- Possible thanks to increased flexibility and efficiency offered by mesh optical networks, based on intelligent optical switches
  - Not applicable to ring-based networks

Maintenance

- Maintenance operations need to be adapted to mesh networks
  - In ring networks, no interference of maintenance activities between geographically distant rings
  - In mesh networks, back-up capacity in one location can be shared by geographically distant lightpaths
- Operations can rely on accurate inventory of routes to schedule maintenance activities
  - Ability to constrain routing of lightpaths and sharing
  - Ability to reroute back-up path (as during re-optimization)

Summary

- Mesh - Overall long term strategic architecture evolution thanks to
  - Capacity efficiency of shared path-based restoration
  - Shared mesh restoration speed (10's to 100's msec)
  - Improved reliability with re-provisioning
  - Re-optimization
- Network control, management, and operations need to be adapted
  - Consistent set of planning and modelling software tools, in addition to management system, critical for operating a mesh network efficiently
  - All tools must be able to interact with each other to transfer data
  - Sophisticated algorithms required for maximum benefits of a mesh network
- Set of tools along with mesh network intelligence provide higher efficiency, lower cost, higher reliability and service flexibility