# Network Design for Highly Available VoIP

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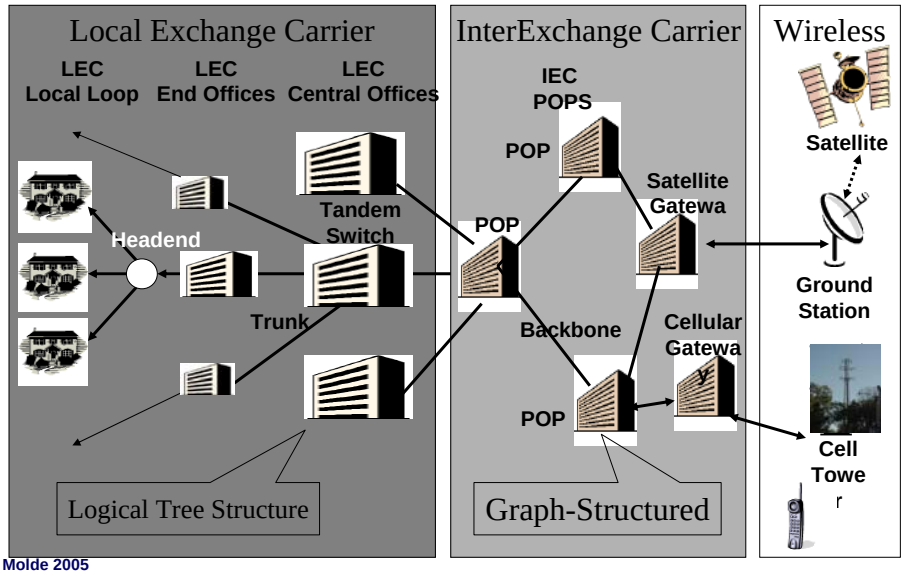
Slides 4

## What is Critical Infrastructure?

- *Critical Infrastructure (CI)* or *Critical National Infrastructure (CNI)* are the systems, assets and services upon which society and the economy depend
  - Energy and utilities
  - Information Technology and Telecommunications
  - Critical Services (food, health care, financial)
  - Transportation
  - Government and Emergency Services
  - Etc.
- Critical Infrastructures are expected to be reliable with high availability
- Current PSTN infrastructure is highly available – can VoIP provide similar availability?

# PSTN Architecture





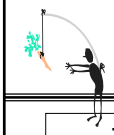

# Causes of Telecom Network Outages

- According to NIST study of FCC outage data main causes in decreasing order of occurrence
  - Accidents
    - cable cuts, car wreck, etc.
  - Human errors
    - incorrect maintenance, installation
  - Environmental hazards
    - fire, flood, etc.
  - Sabotage
    - physical, electronic
  - Operational disruptions
    - schedule upgrades, maintenance, power outage
  - Hardware/Software failures
    - Line card failure, faulty laser, software crash, etc.

# Network Survivability

- Definition
  - *Ability of the network to support the committed Quality of Services (QoS) continuously in the presence of various failure scenarios*
- Survivability Components
  - *Analysis*: understand failures and system functionality after failures
  - *Design*: adopt network procedures and architecture to prevent and minimize the impact of *failures/attacks* on network services.
  - ***Goal***: maintain service for certain scenarios at reasonable cost
    - Not only connectivity
    - But also QoS guarantee: call blocking
- Self – Healing network



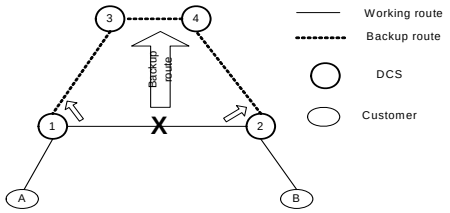


# Survivable Network Design

- Three steps towards a survivable network
  1. Prevention:
     - Robust equipment and architecture (e.g., backup power supplies)
     - Security (physical, electronic), Intrusion detection, etc.
  2. Topology Design and Capacity Allocation
     - Design network with enough resources in appropriate topology
     - Spare capacity allocation – to recover from failure
  3. Network Management and traffic restoration procedures
     - Detect the failure, and reroute traffic around failure using the redundant capacity

# Survivability – Basic Concept

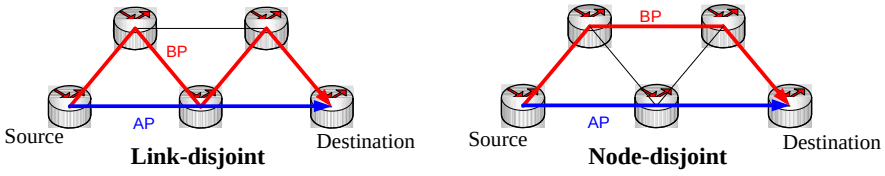
- Working path and Backup path (Protection path):
- Working path: carry traffic under normal operation
- Backup path: an alternate path to carry the traffic in case of failures



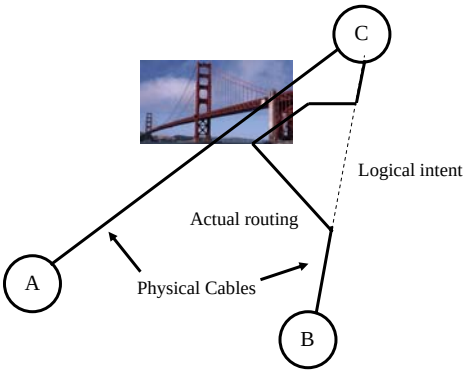



# Survivability – Basic Concept

- To survive against a network failure
  - working path and backup path must be disjoint
  - So that both paths are not lost at the same time
- Disjoint = ? (depending on a failure assumption)
  - Link disjoint
  - Node disjoint
  - (Shared Risk Link Group) SRLG disjoint



## Shared Risk Link Group (SRLG)




- Two fiber cables share the same duct or other common physical structure (such as a bridge crossing).
- Two cables can be failed simultaneously

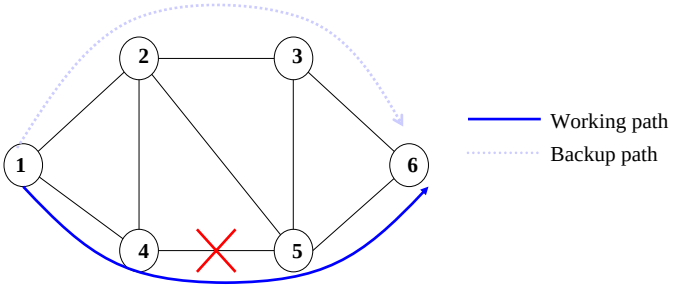


## Survivability Techniques

- Path-based (Global) versus Link-based (Local)
- Dedicated-Backup versus Shared-Backup Capacity
- Protection versus Restoration
- Ring versus Mesh topology
- Dual homing
- *P* cycle

## Path-based versus Link-based

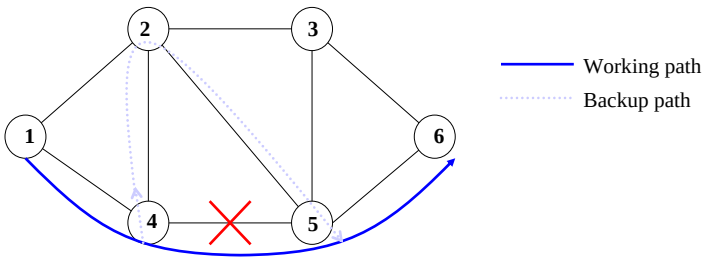
- Path-based Scheme (Global)
  - Disjoint alternate routes are provided between source and destination node





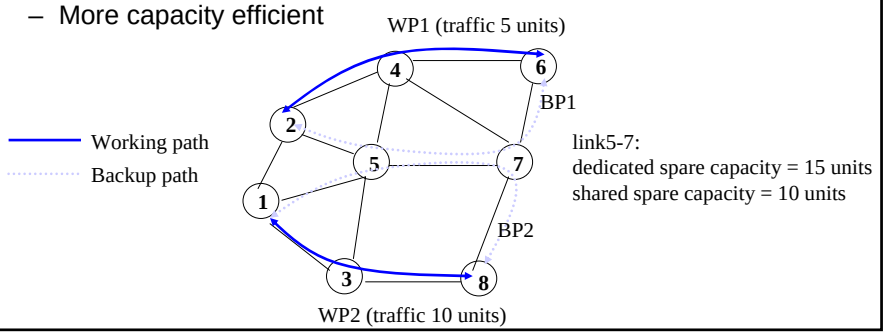

## Path-based versus Link-based

- Link-based Scheme (Local)
  - Alternate routes are provided between end nodes of the failed link



# Dedicated versus Shared - Backup

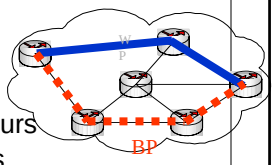
- Dedicated-Backup Capacity
  - Backup resource can be used only by a particular working path
- Shared-Backup Capacity
  - Backup resource between several working paths can be shared
  - Rule: backup resource can be shared only when corresponding working paths are not expected to fail at the same time
  - More capacity efficient

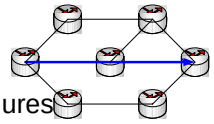





# Protection versus Restoration

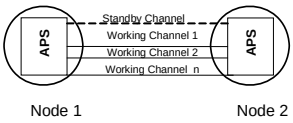
- When to establish the backup paths?
- Protection
  - Backup paths are fully setup before a failure occurs.
  - When failure occurs, no additional signaling is needed to establish the backup path
  - Faster recovery time
- Restoration
  - Backup paths are established after a failure occurs
  - More flexible with regard to the failure scenarios
    - backup paths are setup after the location of failure is known
  - More capacity efficient
    - due to its shared-backup nature,
    - Utilize any spare capacity available in the network
  - But cannot guarantee 100% restorability after failures



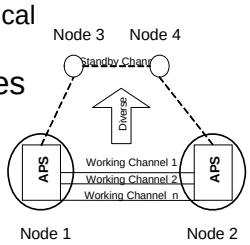



# Protection Switching Variations

- **Automatic Protection Switch (APS)**
  - Provide a mechanism for link-failure tolerance.
- **APS 1:1**
  - One standby cable for each working cable
- **APS 1:N**
  - One standby cable for N working cable



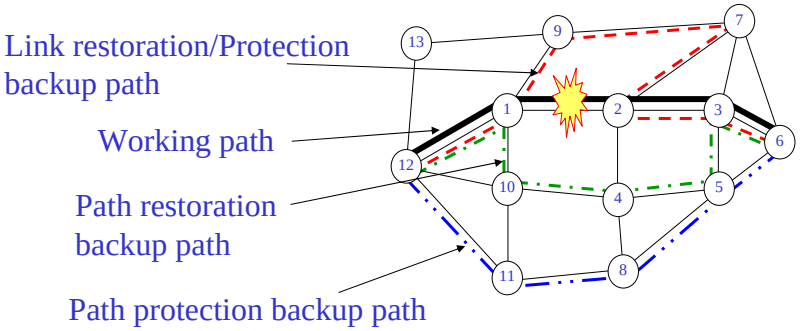

- **APS/DP** (APS with diverse protection)
  - Standby cable is placed on a different physical route than the working cable
- Fully restorable APS/DP system requires 100% capacity redundancy.



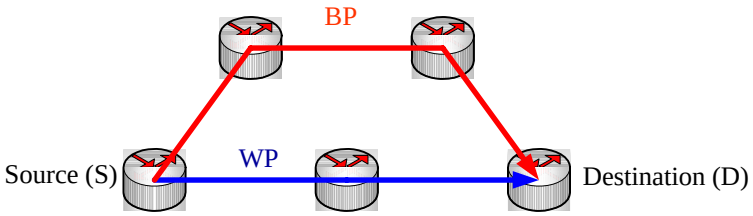



# Mesh Network

- WDM Optical Networks - lightpath
- Example:



# Dedicated-path Protection




- $A_i$ is an availability of link *i*
- Availability of a connection between S-D:

$$A_{no-protection} = \prod_{i \in WP} A_i$$

$$A_{protection} = \prod_{i \in WP} A_i + \prod_{i \in BP} A_i - \prod_{i \in WP \cup BP} A_i$$

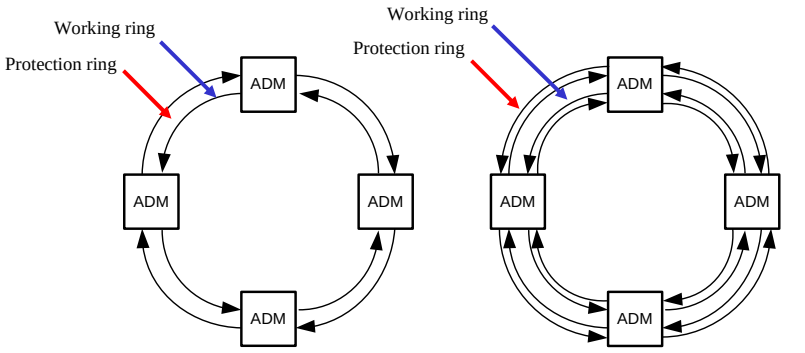
- Given $A_i$ = 0.998297,
  - $A_{no\text{-}protection}$ = 0.996597, $A_{protection}$ = 0.999983



# Self-healing Rings (SHRs)

- SHR is a topology connecting a set of nodes by one (or more) rings.
- Two types of SHRs :
  - Uni-directional ring (USHR)
    - Nodes are connected to two rings forwarding traffic in opposite direction.
  - Bi-directional ring (BSHR)
    - Four rings are used as two working and two standby routes.
    - An extension to 1:1 APS

# Types of Self-healing Rings




1:1 Uni-directional self-healing ring (USHR)

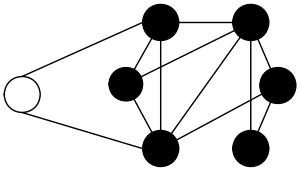
1:1 Bi-directional self-healing ring (BSHR)



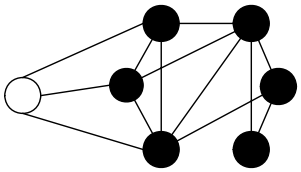
# Dual-homing and Multi-homing

- Dual-homing
  - Customer host is connected to two switched-hubs.
  - Traffic may be split between primary and secondary paths connecting to the hubs.
  - Each path is served as a backup for another.
- Multi-homing
  - Customer host is connected to more than two switched hubs.
  - Greater protection against a failure.

## Dual/Multi-homing Topologies



Dual-homing topology




Multi-homing topology

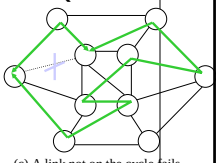


## Dual-homing Restoration Capability

- Dual-homing doesn't accomplish restoration by itself, must be used in conjunction with dynamic restoration techniques.
- 100% restoration can be achieved for a single link or a single switch failure via path rearrangement given that there is enough spare capacity at the link to alternate switched hub.
- Dual-homing approach guarantees surviving connectivity, but it may take time to restore priority circuits via path rearrangement.

## p-*Cycles: Basics*

- For meshed networks
- Pre-reserved protection paths (before failure)
- Based on cycles, like rings
- Also protects *straddling* failures, unlike rings
- Local protection action, adjacent to failure (in the order of some 10 milliseconds)
- Shared capacity



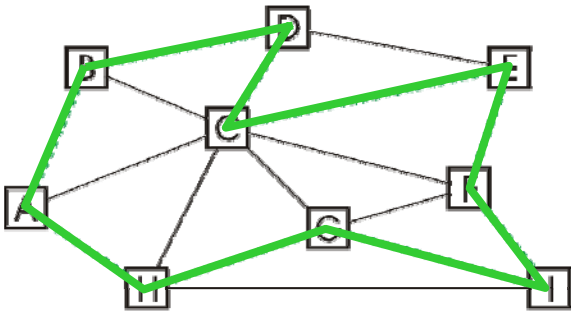
(c) A link not on the cycle fails

- "***p****re-configured* ***p****rotection* ***cycles***" → *p*-cycles
- Developed in Canada at TRLabs



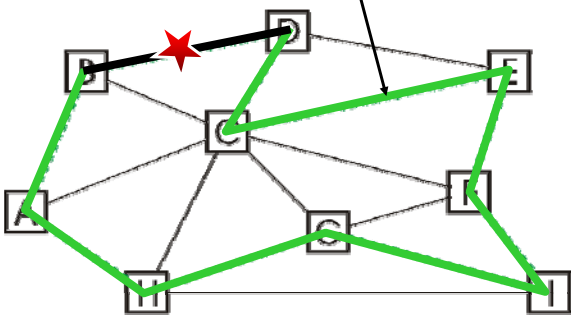
## p-*Cycles: Basics*

- A single *p*-cycle in a network:



## p-*Cycles: Basics*

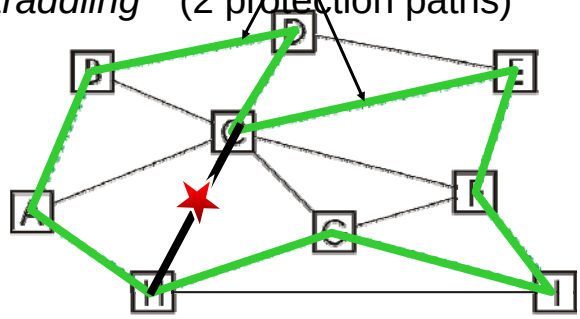
- Protected spans:
- *9 „on-cycle“* (1 protection path)





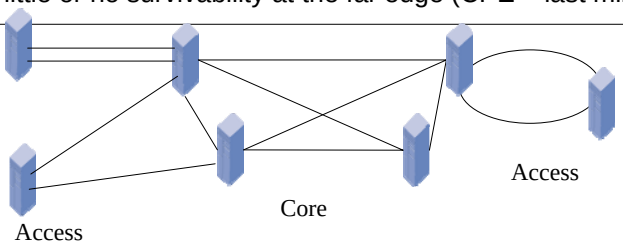
## p-*Cycles: Basics*

- Protected spans:
- *9 „on-cycle“* (1 protection path)
- *8 „straddling“* (2 protection paths)



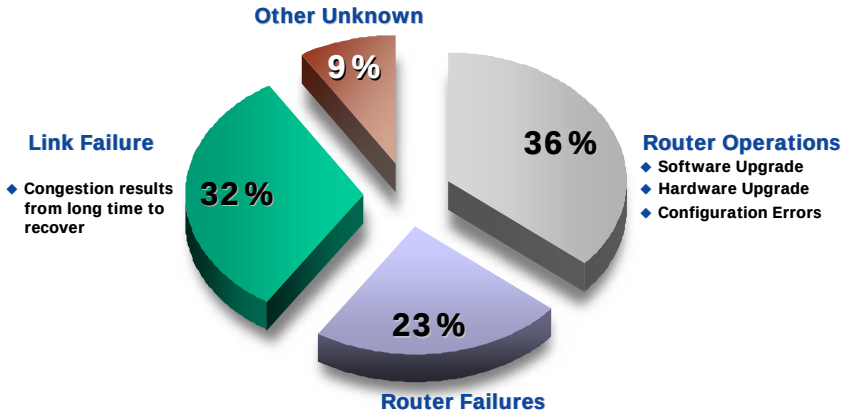
# Transport Survivability

- Number of techniques exist
  - Automatic Protection Switching (APS)
  - Multi-homing (with or without trunk diversity)
  - Link restoration
  - Path restoration
  - Self healing rings
  - p-cycles
- See a mixture of techniques in real networks
- Usually little or no survivability at the far edge (CPE – last mile)



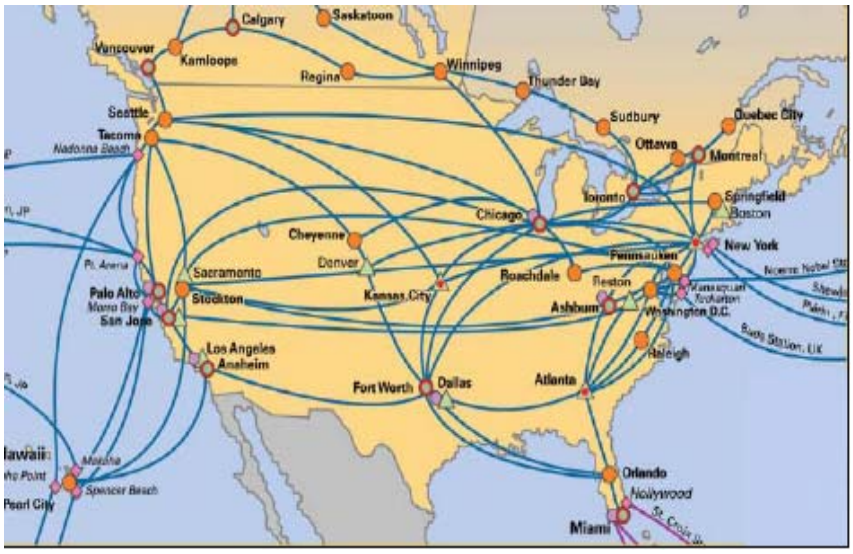



# Failure in IP Backbones




Source: University of Michigan, 2000

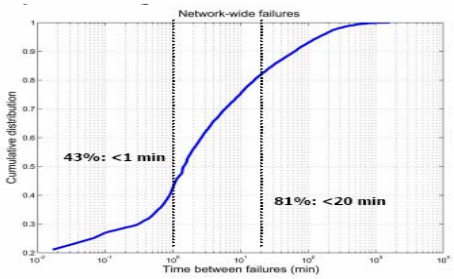
## Sprint IP Backbone






## Failures

- Failures are frequent in IP networks
  - Software failures, line card resets/failures, etc
- Example according to Sprint
  - Network topology is very dynamic
    - Links are reported down every 30 minutes on average
    - In 80% of the cases links come back up in <10 min



## Equipment Reliability

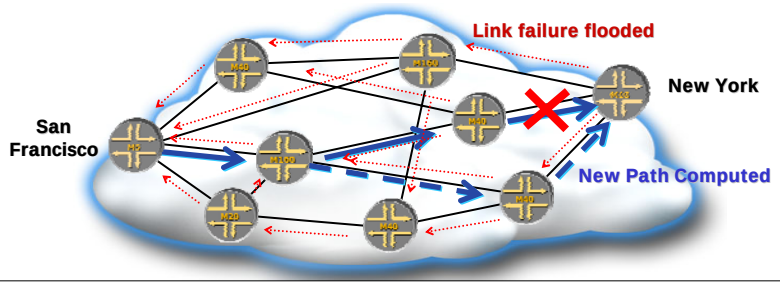
- Routers, routing protocols, and management thereof must be highly available and secure
- Core and Edge Routers and becoming more reliable with adoption of fault tolerant hardware architectures
  - (hot swappable line cards, backup switch cards, redundant cooling, power, etc )
- Software failures a major concern
  - many more lines of code in comparison to OXC or Telco switch – redundancy improvement??
- Service/upgrade downtime needs improvement



## Survivability Options

- Several techniques to improve survivability
- IP layer –
  - adjust link weights and timers for faster failure recovery
  - prestore second shortest paths, etc,
- Adopt Optical Transport techniques from Telco operators (survivable rings, APS, path restoration, etc.)
- MPLS logical layer restoration

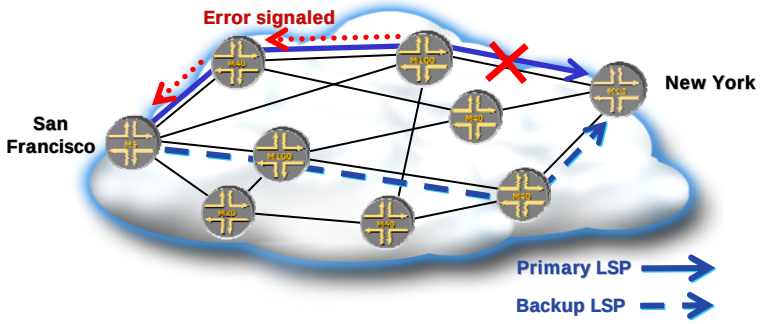
# IP Dynamic Routing




- OSPF or IS-IS computes path
- If link or node fails, New path is computed
- Response times: Typically a few seconds
  - Can be tuned to ~1000's milliseconds
  - According to Sprint data – usually ~ 7secs to recover
  - Too Long for VoIP – PSTN will hang up if VoIP/ PSTN call



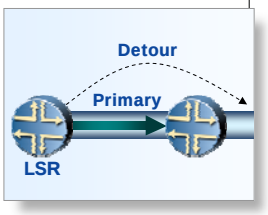
# Backup Label Switched Paths




- Primary & backup LSPs established a priori
- If primary fails
  - Signal to head end, Use backup
- Faster response, requires wide area signaling

# MPLS Fast Reroute

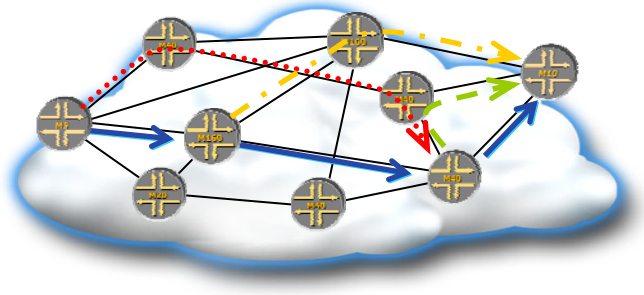
- Increasing demand for "APS-like" redundancy
  - MPLS resilience to link/node failures
  - Control-plane protection required
  - Avoid cost of SONET APS protection
- Solution: MPLS Fast-reroute
  - RSVP Extensions define Fast Reroute
  - LSPs can be set up, a priori, to backup:
    - One LSP across a link and optionally next node, or
    - All LSPs across a particular link



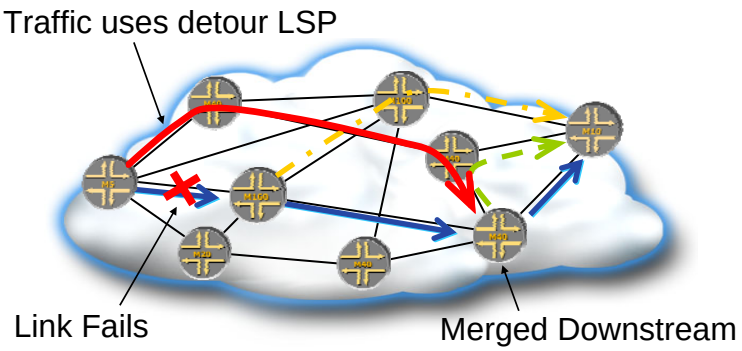



# 1:1 Protection

- For each LSP, for each node
  - Set up one LSP as backup
  - Merge into primary LSP further downstream
  - B



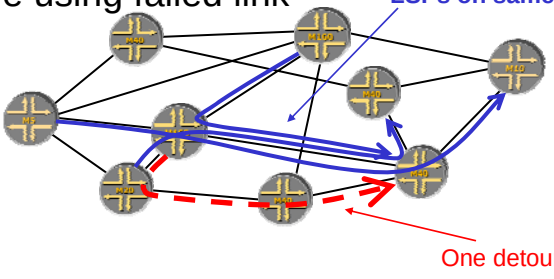
# 1:1 LSP Protection



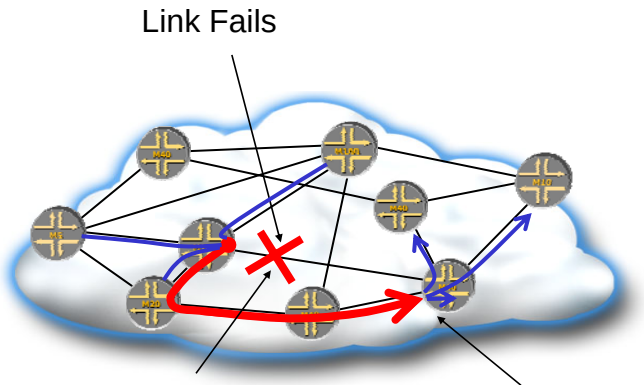



# 1:N Link Protection

- For each link, for each neighbor
  - Set up one detour LSP to backup the link
  - Uses LSP Hierarchy to backup all LSPs which were using failed link



# 1:N Link Protection






# 1:N Link and Node Protection

- For each link
  - For each node 2 hops away
    - Detour LSP backs up link & intermediate node
    - Uses LSP Hierarchy to backup all LSPs to that node
    - If there are two 2-hop paths to that node, setup two detour LSPs
  - For each node 1 hop away
    - Detour LSP backs up LSPs ending at that node

## MPLS Fast Reroute

- Provides fast recovery for LSP failure
  - Based on a priori backup of detour LSPs
  - (eg, ~5 millisecond for tens of LSPs with 1:1)
- There are significant tradeoffs between the approaches
  - Number of LSPs required
  - Whether node failures are protected
  - Ability to reserve resources for backup LSPs
  - Optimality of routes

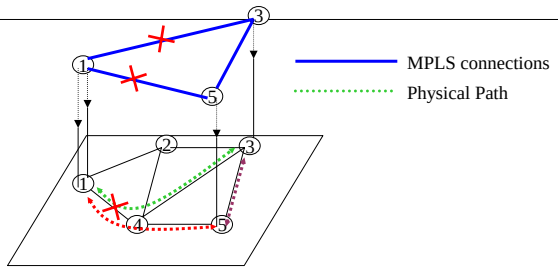


## Summary of MPLS Methods

- End-to-End backup LSPs
- MPLS Fast Re-Route
  - 1:1 LSP protection
  - 1:N Link protection
  - 1:N Link plus node protection
- All of these are interoperable based on IETF standards
- Sink Trees are under study
- Does MPLS solve all the problems???

# Multilayer Networks

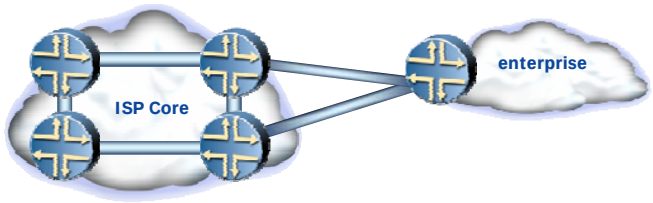
- Backbone networks have multiple technology layers
  - Converging toward IP/MPLS/WDM
- Multiple Layers present several survivability challenges
  - Coordination of recovery actions at different layers
    - Which layer is responsible for fault recovery?
  - Spare Capacity Allocation **(SCA)**
    - How to prevent over allocation, when each layer provides spare resources?
  - Failure Propagation between layers
    - Lower layer failure can affect multiple higher layer links!






# Resilient Edge Connectivity

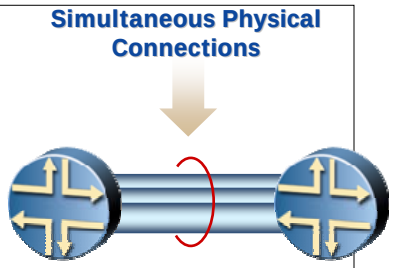
- Multi-Homing for resilient Internet and IP-VPN connectivity
  - Stub network with backup access (static routing)
  - Multi-Homed Network with load sharing




Multi-Homed Stub Network

# Link Redundancy

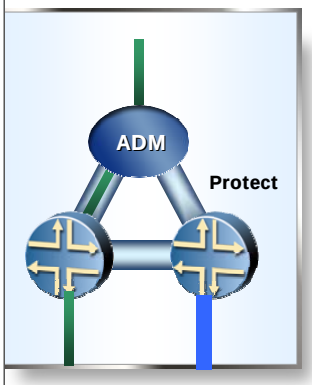
- Link Bundling
  - Link failure does not affect forwarding
  - Load redistributed among other members
- Parallel Link Technologies
  - MLPPP – T1/E1 Link aggregation
  - 802.3ad – Ethernet aggregation
  - SONET/SDH aggregation
  - Multi-Link Frame Relay





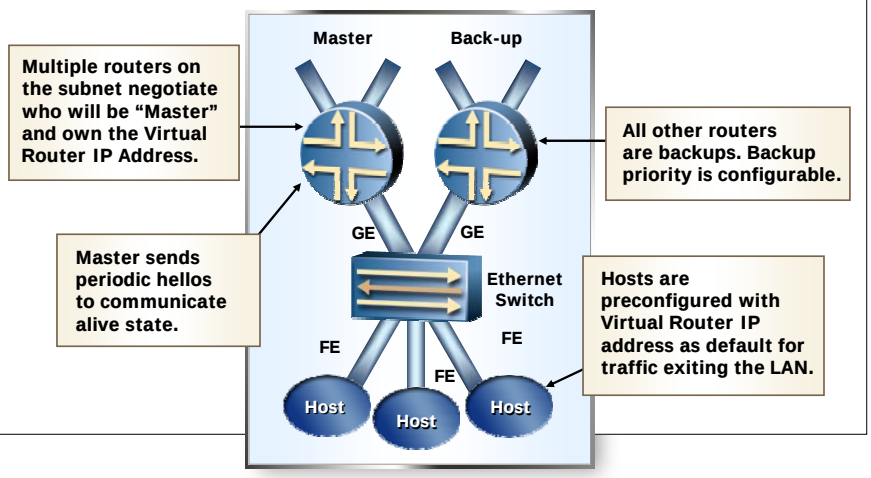

# Optical Protection

- Protection switching with ADM
  - Redundant routers share uplink
- Rapid circuit failure recovery
  - Used on router-to-ADM links
  - 50 ms at physical layer
  - Faster than layer 3 routing protocol convergence
- Interoperable with standard ADM
- Working & protect circuits
  - May reside on different routers
  - May reside on same router



## Virtual Router Redundancy Protocol

- Redundant default gateways:VRRP (RFC 2338)






## Summary

- VoIP Availability can be greatly improved by adopting
  - Reliable network components
  - Stable survivable network design
  - Protocols configured for quick recovery
  - Also need defined procedures for reporting and resolution of outages.
- Cost is an issue
  - VoIP the most demanding application in terms of Availability? Can cost be justified?

# VoIP Trends

- Market Situation
  - Deregulation and competitive Voice environment
  - Many ISP have built out network with QoS support
    - Diff Serve or MPLS
  - Businesses are considering VoIP
    - Economist Magazine Survey of 254 executives on corporate networking notes
    - 43% report they are using, testing or planning to implement VoIP within the next two years
    - Concerns: Quality, Availability, Features (new and PSTN)
  - Significant Cost advantages to VoIP
    - AT&T study : Business ROI positive if phone bill greater than $350 month or 3 cents/minute or $50 month international calls
    - In some cases this is due to avoiding taxes and settlement fees
    - Business Case for VoIP service provider unclear in some cases



# VoIP Trends

- Technical situation
  - VoIP technology maturing
    - Easier to setup, manage, interoperate, better quality, tradeoffs known etc.
    - Possible to make a good quality network/service
  - Hurdles still exist
    - No single standard, Interprovider QoS support, QoS over access links, 911, PSTN feature set, signalling control and QoS, etc
  - Much focus on developing new telephony features
- VoIP phone technology of the future?

## Course Summary

- Overview of VoIP Architecture and Protocols
  - VoIP Configurations, H.323, SIP, MGCP
- VoIP Quality Factors
  - Vocoding, Echo, Delay, Jitter, Packet Loss, Availiability
- Network Quality of Service and VoIP
  - QoS Techniques, Diff Serve, MPLS
- Reliability and Network Design