Designing Robust (Telecom) Networks

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Keynote Talk Presented at:
Workshop on Optimization of Optical Networks (OON '07), Concordia University, Montreal, Canada
May 2, 2007

Acknowledgement: NSF, Sprint, Alcatel, UC MICRO
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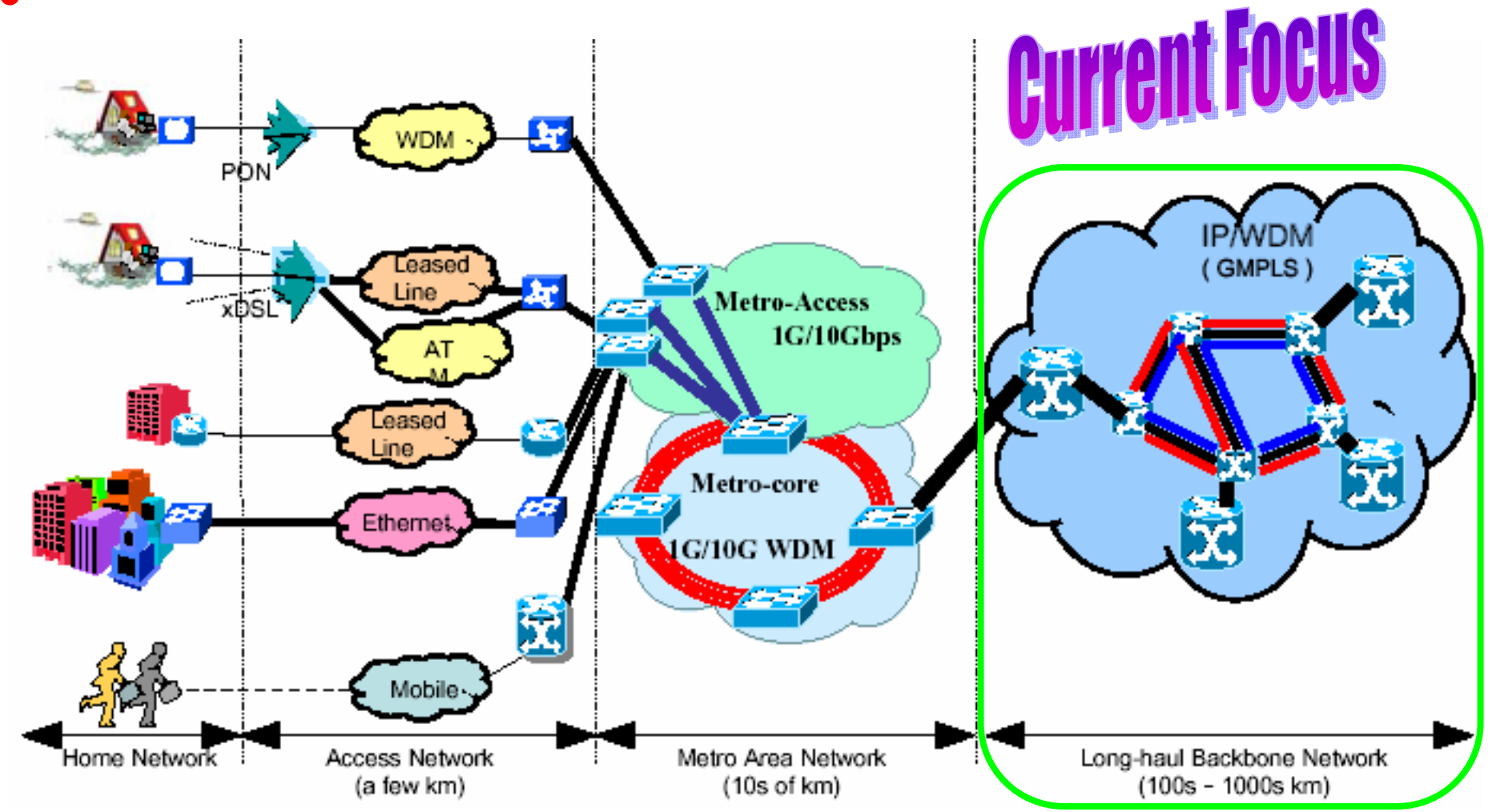
Telecom Network Hierarchy



What Is An Optical Network?

- It is **NOT NECESSARILY** all optical
  " " " " packet switched
- **Characteristics of an optical network**
  - **Transmission: optical**
  - **Switching:** could be optical, could be electronic, could be hybrid
    could be circuit, could be packet, could be burst
- **Most Promising Approach Today**
  - Electronic circuit switching with sub-lambda granularity (STS-1, STS-3, …)
- **Example Utility for IP Networking**
  - Connect any two IP routers (geographically far apart) with a direct ("virtual") bandwidth pipe… of whatever capacity (STS-1, … , STS-192)
  - Increase (or decrease or delete) the capacity on demand
  - Dynamically control the "topology" connecting the IP routers
  - Create a "separated control network" (of whatever bandwidth)
  - …

Carriers' Requirements for Optical Nets

(Carriers--AT&T, C&W, CSELT, Enron, GTS, Level 3, MCI Worldcom/UUNET, NTT, Sita Equant, Sprint, T-Nova DT, Williams)

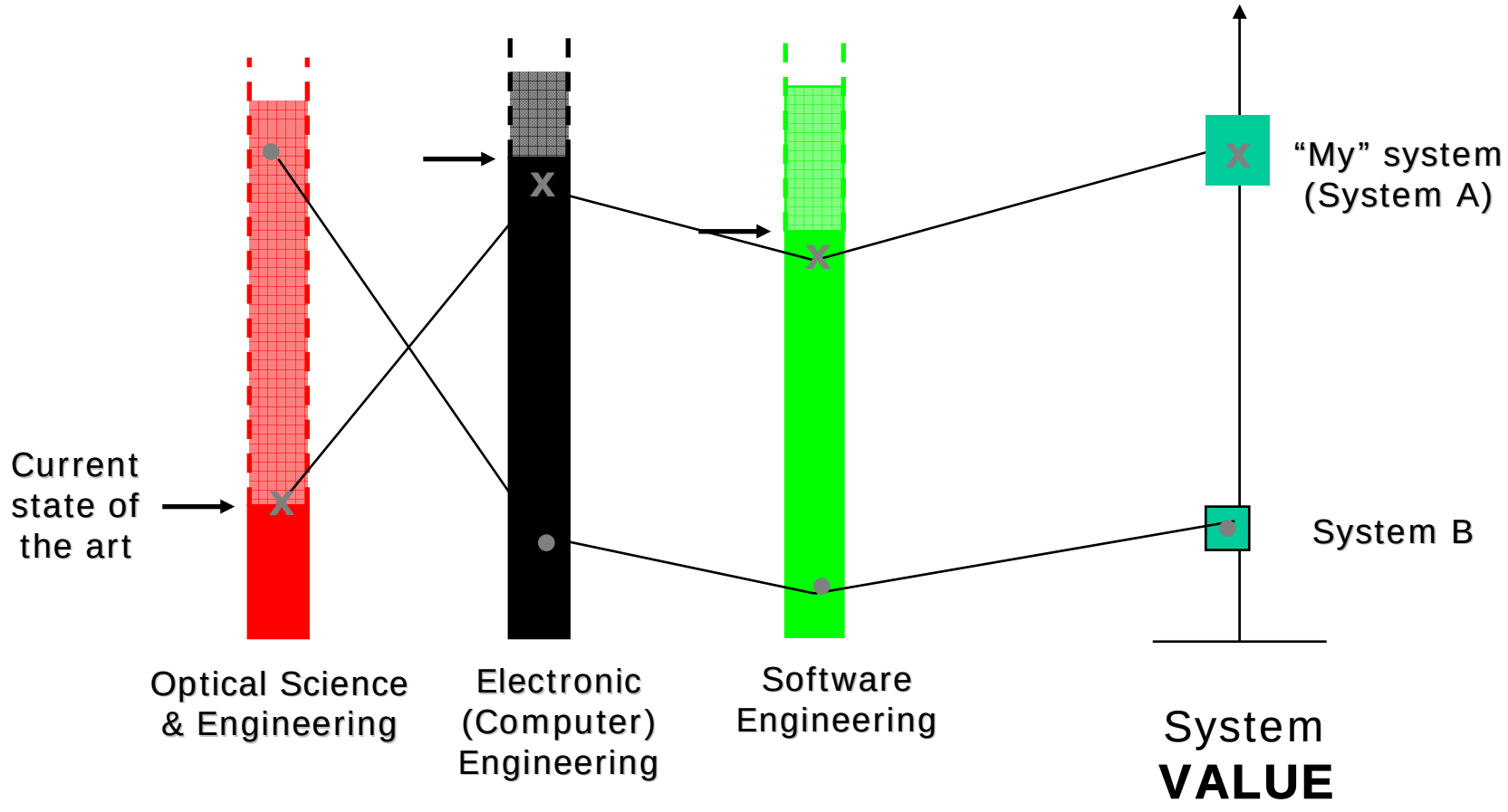
- Rapid automatic end-to-end bandwidth (lightpath) provisioning including routing
- Provide restoration, diverse routing, and other QoS features on a per-service-path basis
- Support policy-based call acceptance, peering policies, and usage-based accounting
- Offer carrier-specified "branded" services
- Rapid deployment of new technologies/capabilities with minimum service disruption
- Protect security and reliability of the optical (control plane) layer
- Preserve network operator's ability to control network resources
- Reduce need for carrier-written software through heavy use of open protocols/software
- Ensure scalabilty of the optical layer
- OXCs and other products from different vendors or employing different technologies should interwork at the control-plane level

R&D Priorities

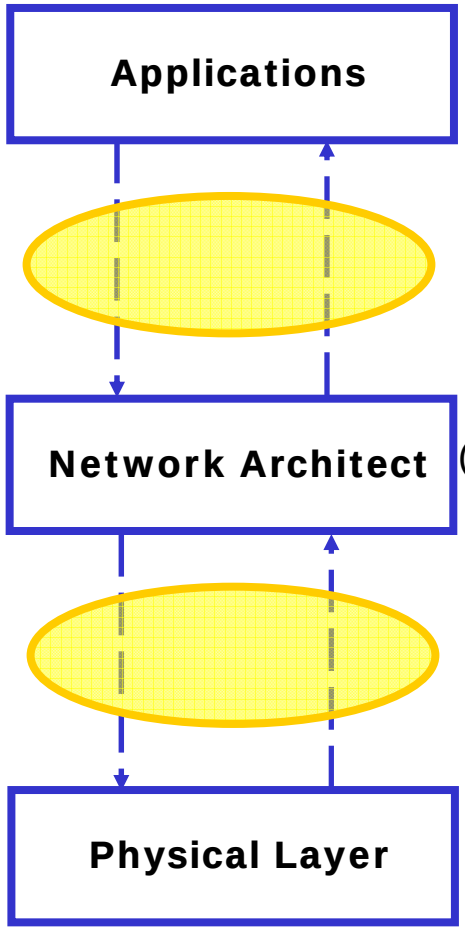
- **Access:** ***EPON architectures, Free-space optics***
- **Metro:** ***ROADM-based architectures***
- **Long-Haul:**
  - ***Provisioning Connections of Different Bandwidth Granularities***
    - Hierarchical Optical Switch (Crossconnect) Architectures
    - Traffic Grooming in WDM Mesh Networks
  - ***Fault Monitoring and Restoration***
    - Provisioning with Guaranteed SLA
    - "X-ms" guaranteed protection-switching time
  - ***Dynamic Network Planning, Topology Engineering***

  - Network Architectures and Algorithms to Combat Optical Signal-Quality Impairments
  - Optical Multicasting and "Light-Trees"
  - Optical Packet Switching (OPS) and Optical Burst Switching (OBS)

System: Value Proposition



Optical Network Architecture:
Extending Our "Boundaries"



("Customer" needs)

Differentiated Services:
Bandwidth: OC-192, OC-48, … , STS-1, VT1.5, …
Failure-Recovery Delay: The "50-ms myth!"
Network Economics: Pricing, SLA, …

(Brigitte, you, I,…)

+ routing protocols to combat optical channel impairments
+ breakthroughs needed in device technologies?
  - optical RAM, ultra-wideband amp, "tunable" AWG, …

(optical/wireless channel) -- materials, devices, subsystems

What is a God Box?

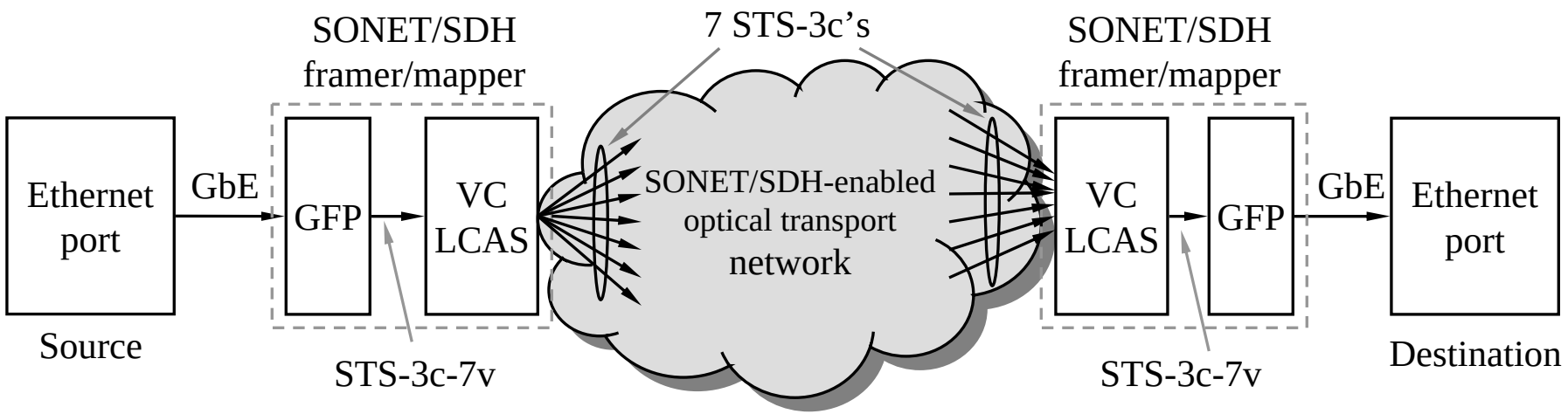
- aka MSPP: Multi-Service Provisioning Platform
- Maintains circuit and cell-based services while allowing packet-based services in a bandwidth efficient manner
  - Typically combines electronic switching with wavelength switching and includes optical transponders

CISCO ONS 15454 SONET MULTISERVICE PROVISIONING PLATFORM (MSPP)

Introduction

The Cisco ONS 15454 SONET Multiservice Provisioning Platform (MSPP) provides the functions of multiple network elements in a single platform. The Cisco ONS 15454 SONET provides TDM solutions with interfaces such as DS-1, DS-3, EC-1, and data solutions with 10/100/1000 Ethernet solutions with OC-3 to OC-192 optical transport bit rates including integrated DWDM wavelengths.

Data over (Next-Gen) SONET/SDH



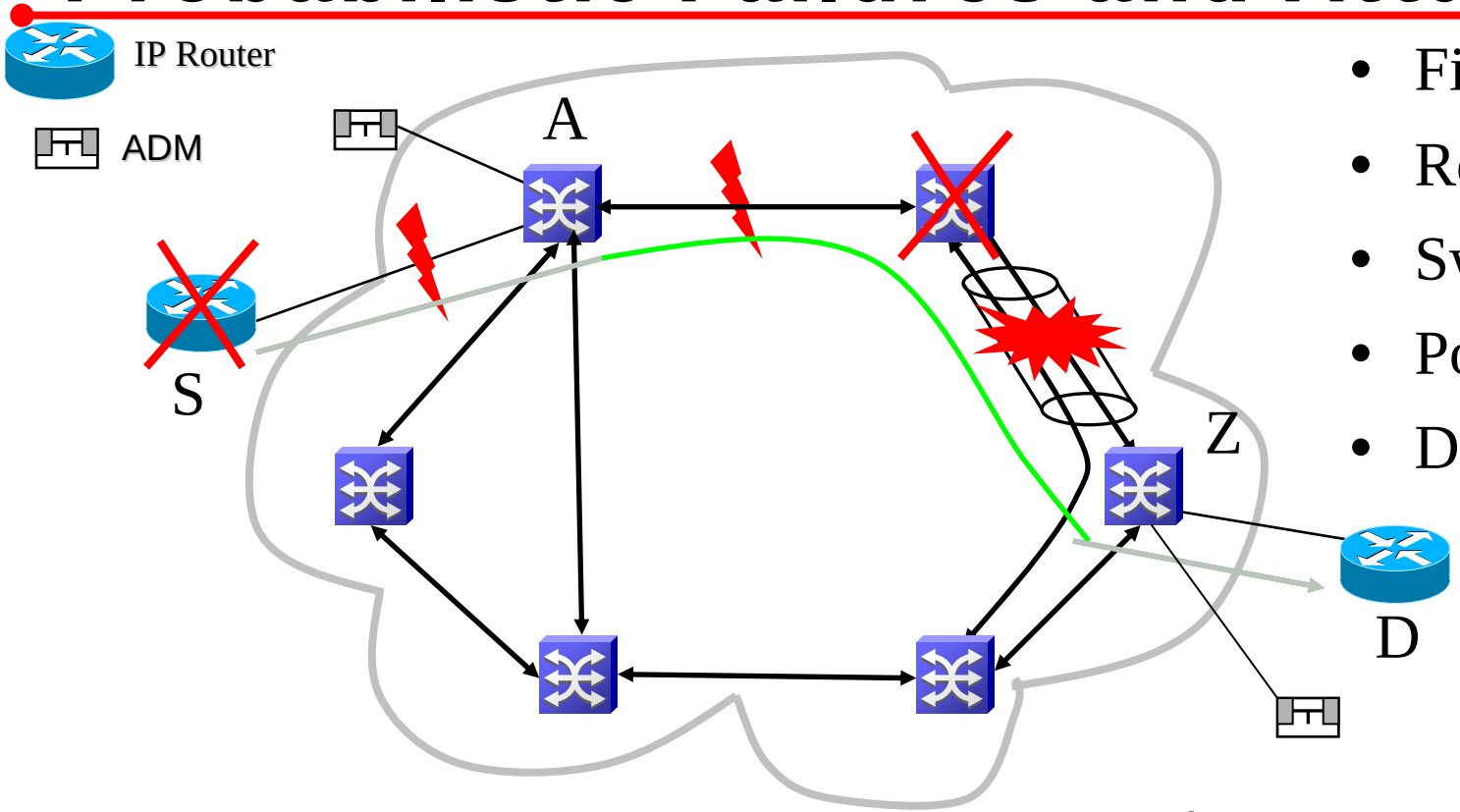
- Inverse multiplexing
- Relaxing time-slot contiguity/alignment
- Reassembly and jitter control

Next-Gen SONET Chip Availability

Company	B/W (b/s)	Trans. GFP	VC	VC Groups	Differential Delay	LCAS	Price
Agere	622M	No	High	16	±62.5 ms	N/S	$347
Agere	1.2G	No	High	16	±62.5 ms	N/S	$379
Agere	2.5G	No	High	16	±62.5 ms	N/S	$522
Agilent	2.5G	No	High	4	±80 ms	N/S	$475
Cypress	2.5G	Yes	High	16	±16 ms	N/S	$375
Galazar	2.5G	No	Low/High	24	±125 ms	H/W	$500
Multilink	10G	No	High	64	±128 ms	RISC	-
PMC-Sierra	2.5G	No	High	2	±25 ms	N/S	$340
Transwitch	155M	No	Low/High	8	±32 ms	H/W	$125
Transwitch	2.5G	Yes	High	48	±32 ms	RISC	$550
Vitesse	2.5G	Yes	High	48	±54 ms	H/W	$240
Vitesse	10G	Yes	High	64	±54 ms	H/W	$536
West Bay	2.5G	No	High	48	±24 ms	H/W	$400

Source: Light reading

Network Failures: Probabilistic Failures and Attacks



- Fiber cut
- Router failure
- Switch failure
- Port card fails
- Duct cut

FIT (Failure In Time): # of failures in 10^9 hours

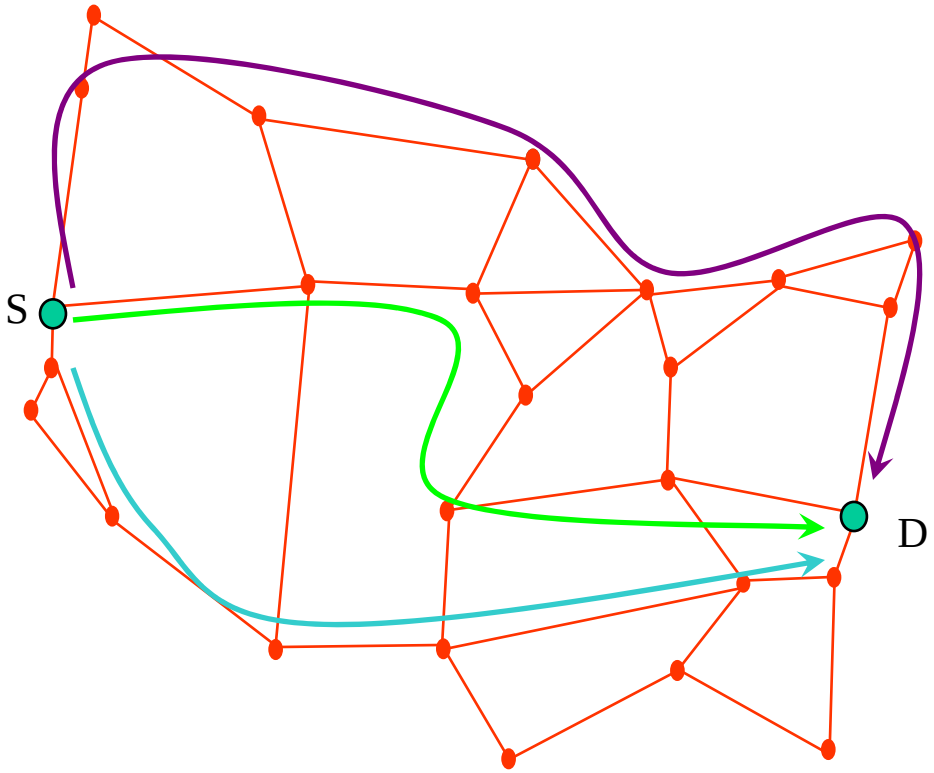
Fiber: 11,000 FIT per 10 km of fiber; Mux, coupler: 1000-10000 FIT

OXC: control & switch fabric 1+1 protected

Single-cable cut: 864 fibers/cable * 160λ/fiber * OC192/λ

≅ 1.38 Pbps

"A Fundamental Problem"

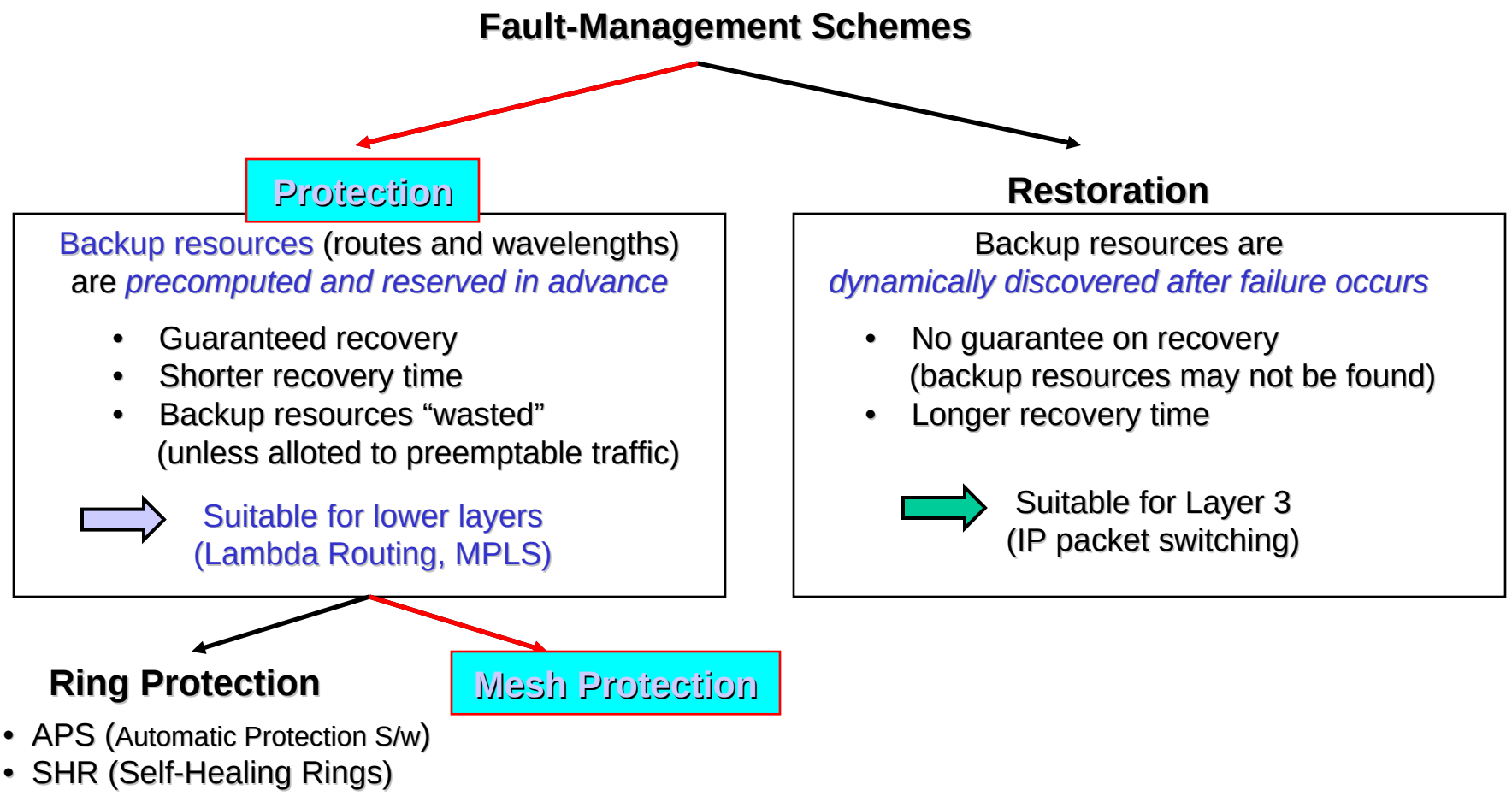


- Need a path from S to D with availability 99.9% (say)
- How to route the path?
- Will one path be enough to provide required availability?
- Or do we need more paths?
  - Dedicated protection, e.g., 1+1
  - Shared protection (M:N)
  - Or even more? 2+1?

Fault Management "Tutorial"

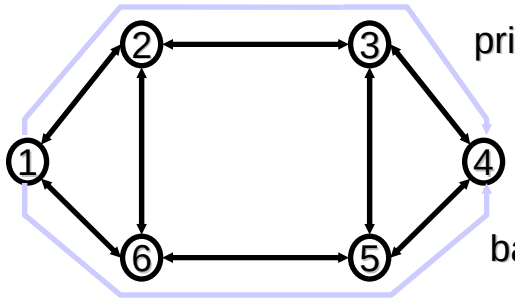
- FIT (Failure in Time): # of failures in 10^9 hrs.
- Failure frequencies:
  - Fiber: 11,000 FIT per 10 km of fiber (~ once every 11.85 yr)
  - Mux, coupler: 1000 – 10000 FIT
  - SONET equipment: 10^5 – 10^6 FIT
- The "50-ms-recovery-time" myth:
  - *Persistence of hearing*… human ear can tolerate 100-ms delay
  - For voice traffic, ok to have 50 ms recovery time
  - *For data traffic, minimize recovery time as much as possible*
- Need for fast recovery for data traffic:
  - Fiber cut ➔ bundle or conduit cut… need "fiber-risk-group" awareness
  - Example: 864 fiber strands/bundle, 10 bundles/conduit, 160 lambdas/fiber, OC192/lambda
  - Total (maximum) data rate (per conduit) = 13.824 Petabits/sec
  - Up to 13,824 gigabits of data lost per ms of "down time"
  - Need fast recovery ➔ *to minimize loss of data (and revenue!)*

Fault Management "Tutorial"



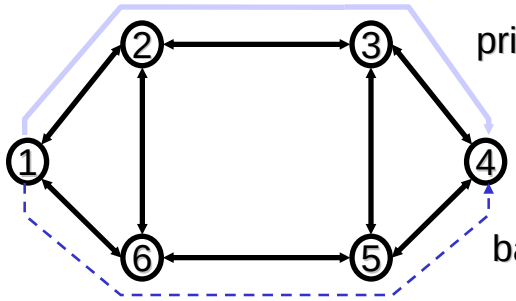
Fault Management "Tutorial"

1+1 Protection



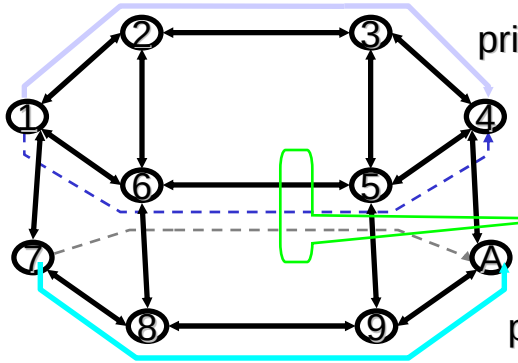
Both primary and backup are carrying "live" traffic

1:1 Protection



Backup activated after failure detected…normally, can carry other low-priority preemptable traffic

M:N Protection



"Multiplexed" protection… more efficient than 1:1

Different categories of recovery…

- 1+1
- 1:1
- "X ms" guaranteed recovery time
- M:N
- 0:1 Not preemptable
- 0:1 Preemptable

more expensive

less expensive

"Soft Optics" Feature Set

- Network topology discovery (OSPF based)
- Lightpath provisioning
  - Intelligent routing (MPLS/CR-LDP based)
  - User-selectible routes
  - Conduit identification (for shared risk groups)
- SONET/SDH configurable interfaces
- Lightpath monitoring
- Fault detection and recovery (rerouting around failed links)
  - Differentiated fault-recovery schemes
  - Guaranteed recovery-time service
- Hitless upgrade of network segments: lightpath rolling
- Efficient grooming of sub-rate circuits
- Optical OSPF areas
- Optical VPNs
- Network Planning Tool

Lightpath Create (OIF UNI…)

- Lightpath Bandwidth
  - 0x00: Reserved
  - 0x01: OC-48
  - 0x02: OC-192
  - 0x03: OC-768
  - 0x04: STS-1
- Lightpath Priority
  - 1 (lowest) … 8 (Highest)

- Protection Mode TLV

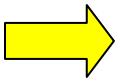
  Mode
  - 0x00: Unprotected & not preemptable
  - 0x01: Unprotected & preemptable
  - 0x02: 1+1, end-to-end "1+1" protection
  - 0x03: Shared-path protection

  Reversion
  - 0x01: Revert to primary path after repair
  - 0x02: Do not revert

- Retention Mode TLV
  - 0x01: Retain unrestorable primary path
  - 0x02: Delete unrestorable primary path

Example Network Planning Problem – Path Protection

- Problem Statement (Network Planning)
  - Given:
    - Network topology
    - *Static* traffic demands
  - Need/Requirements/Constraints:
    - Set up a primary path and a backup path for each demand
    - The two paths must be link disjoint (node disjoint too?)
    - Dedicated or shared backup (based on problem specs)
    - Guaranteed to recover from a single fiber cut
  - Goal: minimize cost, e.g., # of wavelength channels

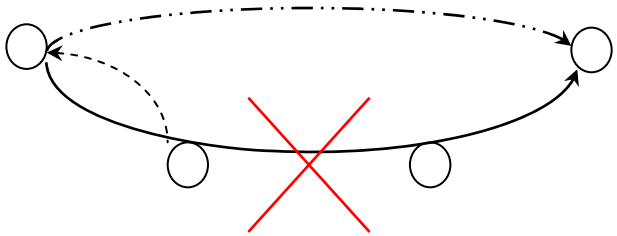


- See [Ramu-jlt03] for solution method (ILP)
  - see also [Laxman-jsac02] for WDM protection vs. IP restoration

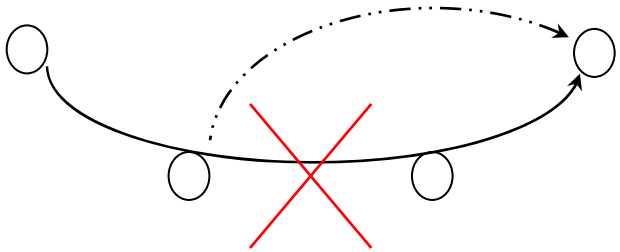
Example TE Problem – Restoration

- Problem Statement (Traffic Engineering)
  - Given:
    - Network topology (including # of wavelengths per fiber)
    - *Dynamic* traffic demands (or connections)
  - Need/Requirements/Constraints:
    - Set up only one path (primary path) for each connection
    - Try to quickly restore the connection when a fault occurs
    - Control signaling (GMPLS?) for connection setup + restoration
    - Note: This method can handle multiple network failures
  - Three restoration methods: path, sub-path, link
    - Performance tradeoffs:
      - *availability, restoration time, restoration success rate*, …
- See following slides (and [Jian-commag02] for details)

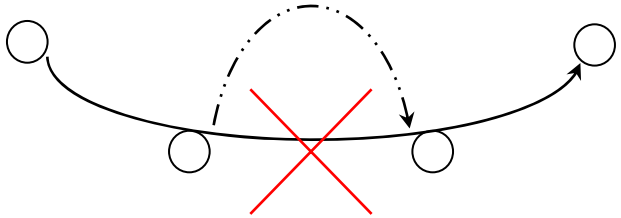
Three Restoration Techniques



Path restoration



Sub-path restoration



Link restoration

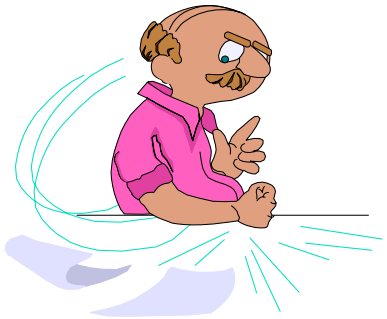
- **Note:**
  - These approaches can easily handle multiple (link/node) failures
  - Pros vs. cons of restoration

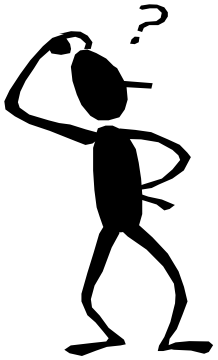
Additional Problems and Current Trends in Survivability Research

- Availability-aware provisioning [Jing-ofc03]
  - Differentiated (reliability) services
  - Take into account component failure rates and user SLA
- Detailed link model [Grace-jlt04]
  - New parameter: Link and resource availability (LRA)
- Backup reprovisioning after fault occurs [Jing-icc04]
- Sub-path protection [Sam-jsac04]
- Differentiated Quality of Protection (QoP) [Sam-net04]
  - Guaranteed recovery time
- Survivable traffic grooming [Sam-jsac03]
  - Note: connection bandwidth may be OC-1, OC-3, OC-12, OC-48, …
- Survivable Virtual Concatenation (VCAT) [Sam-ofc04]
  - Ethernet/Data over SONET/SDH over WDM

- **Availability-Aware Connection Setup**
  - Treated as a Network Planning Problem
  - Next several slides
  - See [Jing-ofc03] for details

Motivation – SLA and Provisioning





Customer's concerns:

- Bandwidth
- Availability
- Fee
- etc.

SLA

Operator's concerns:

- Resource
- Protection
- Penalty

Profit = Revenue - Cost

Traffic engineering decision is very important

Differentiated Services: Availability

- Service Availability

Service Type	Availability	Down Time / Year
Basic	99%	87.6 hours
Premium	99.50%	43.8 hours
Silver	99.9%	8.76 hours
Gold	99.99%	52.56 mins
Platinum	99.999%	5.26 mins

- Leads to differentiated services in mesh networks
  - Customer paying more can get better quality of service
- Leads to "availability-aware provisioning"
  - Calculate shortest paths with "multiplicative" parameter

Availability of Network Components

- Can be calculated based on the component's failure statistics --- MTTF/(MTTF+MTTR)

Failure Type	Typical Value
Equipment MTTR	2 hours
Cable Cut MTTR	12 hours
Cable Cut Rate	4.39/year/1000 miles
Tx failure rate in FIT	10867
Rx failure rate in FIT	4311

– **MTTF** (Mean Time To Failure): average "On" time.
– **MTTR** (Mean Time To Repair): average repair time.
– **FIT** (Failure in Time): # of failures in 10^9 hrs (app. 114,155 yrs).

Availability of a Connection

- **Unprotected connection**
  - Available when *all* the network components used are available
- **Dedicated-path protected connection**
  - Available when *either* the primary path *or* backup path is available
- **Shared-path protected connection**
  - More complex…

General Problem Statement

Formulated here as a Network Planning Problem [Jing-ofc03]

- Given
  - Physical topology
    - Network nodes and links
    - Availability of each component (link)
    - Free wavelengths on each link
  - Static traffic demands (T)
    - Source, destination, and availability requirement of each demand

- Objective
  - Provision each connection
    - Decide route and protection scheme
  - Minimize overall network cost
    - Wavelength links or wavelength mileage

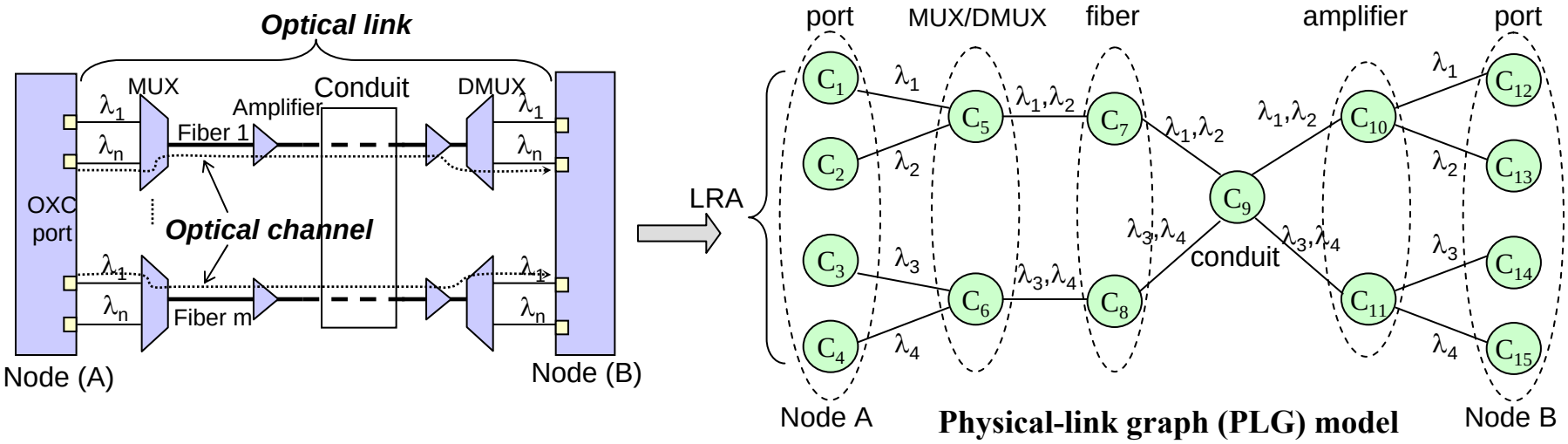
Provisioning Strategies

- Integer Linear Program (ILP)
  - Scheme I: no protection for any connection
  - Scheme II: dedicated protection for all connections
  - Scheme III: dedicated protection for selected connections
  - Can also invent other schemes (e.g., shared protection)

- Heuristics: fixed-alternate-routing based

  (K routes – K_1 single routes; K_2 link-disjoint route pairs)
  - Minimal-cost
  - Most-reliable
  - Just-above-threshold
  - Iteratively-select (randomly select with backtracking to minimize cost)

Link Model — Optical



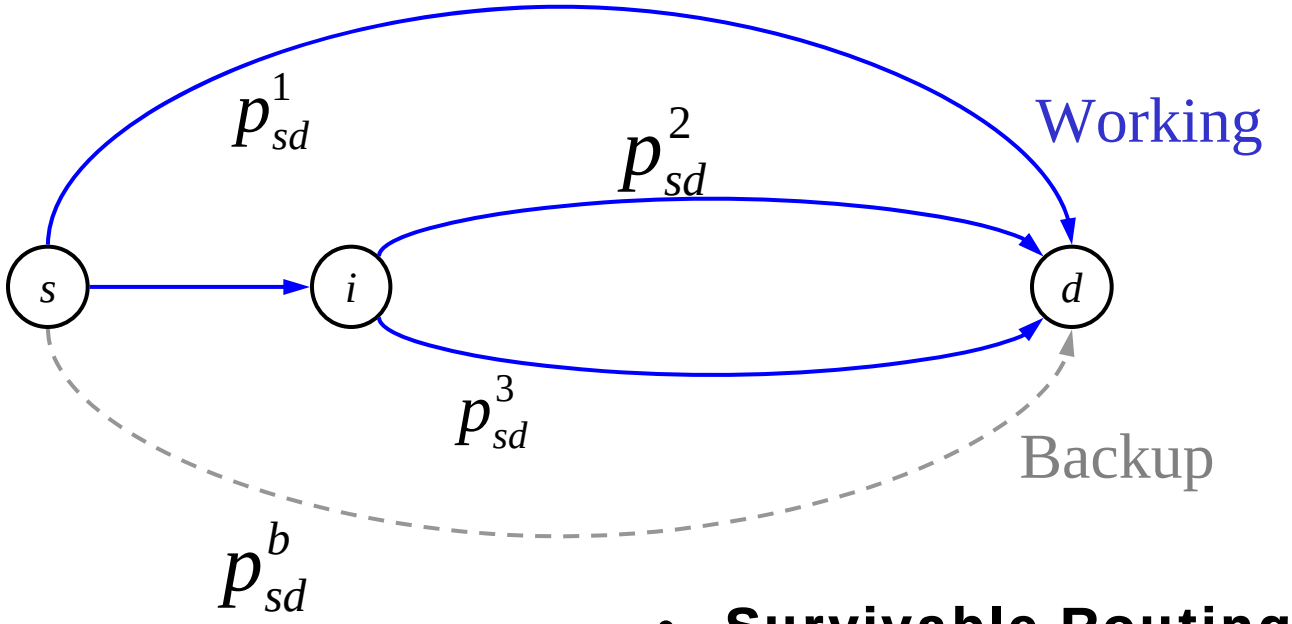
- LRA defines the probability that at least one wavelength channel is free and alive in a link.
- Compute LRA by a recursive procedure
  - Decompose a physical-link graph into *simple graphs* where LRA can be computed.
  - A simple graph consists of *M* failure-independent parallel component sets while each set has *K* failure-independent serial components.

QoP: Differentiated Protection-Switching Time

Problem Statement (TE problem) [Sam-net04]

- QoP = Quality of protection
  - Could be different for different connections
- Given a network state
  - A network
  - Primary & backup of existing lightpaths
  - A new lightpath request
- Objective
  - To compute a primary & backup for the request with customer-desired protection-switching time while minimizing additional resources used (using shared backup path protection)

Multi-Path Routing

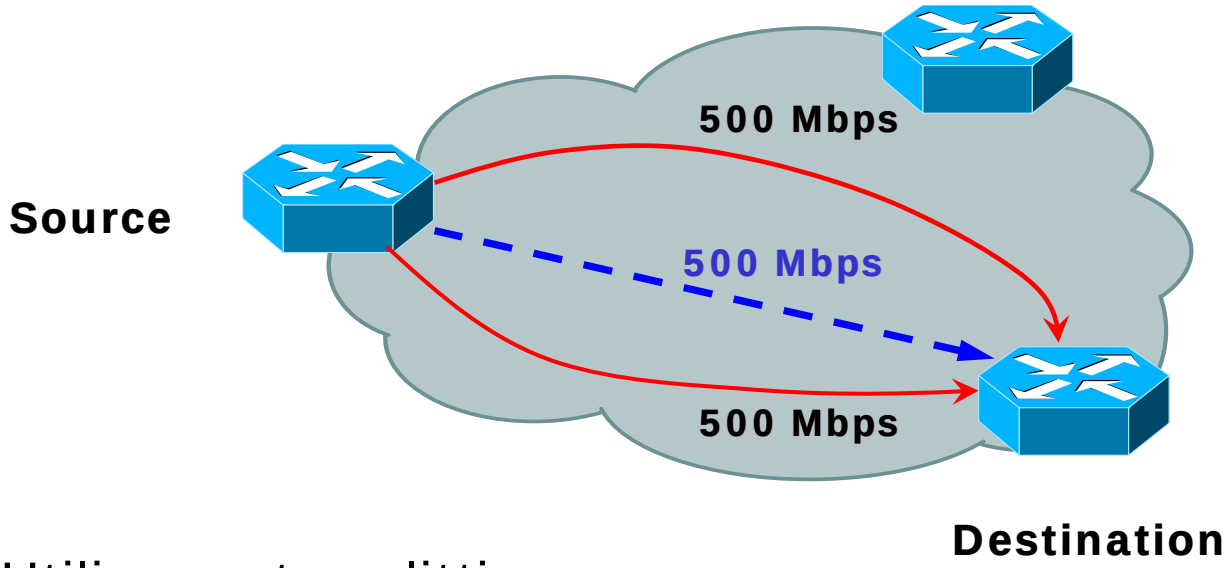


- **Issues**
  - How many paths?
  - State-dependent path capacities
  - Virtual concatenation (VC) ("traffic grooming")

- **Survivable Routing**
  - Primary + backup path(s)
  - Precomputed backup (?)
  - Shared backup (?)
  - Need reliable path (five-9's)
    - Component/link availability
  - Need fast recovery

EoS: Service Resilience

- EoS = Ethernet over SONET/SDH
  (or Ethernet/data over SONET/SDH over WDM)
- Protect a GbE connection with 500 Mbps "paths"
  - e.g., peak rate = 1 Gbps, minimum guaranteed rate = 500 Mbps
- See [Sam-ofc04] for details

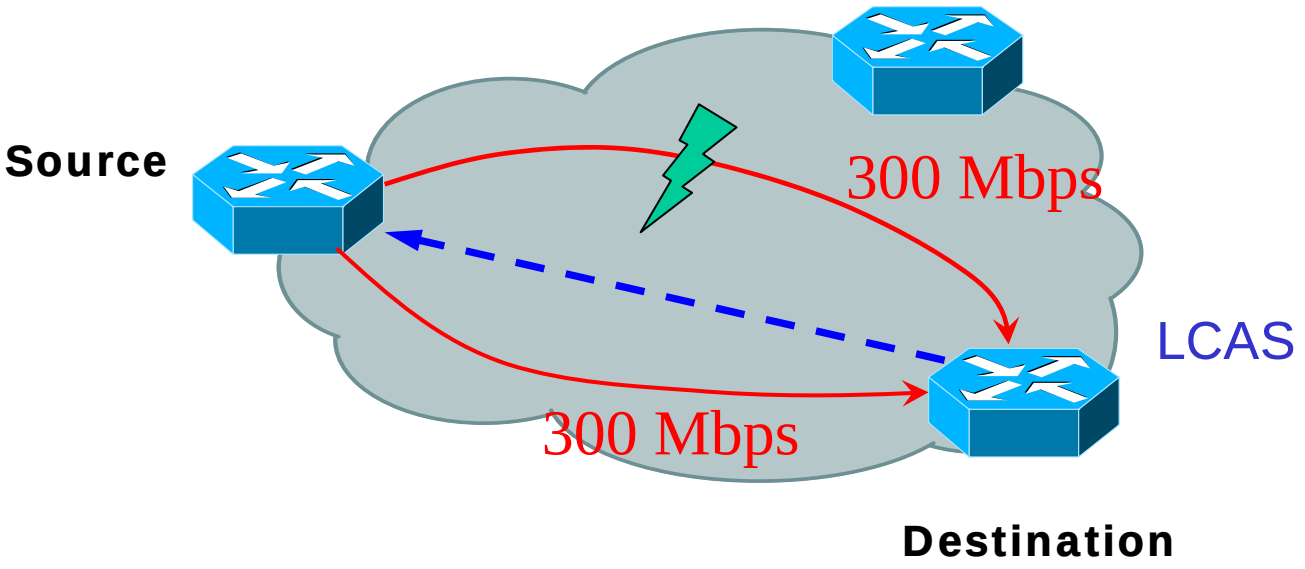


? Utilize route splitting

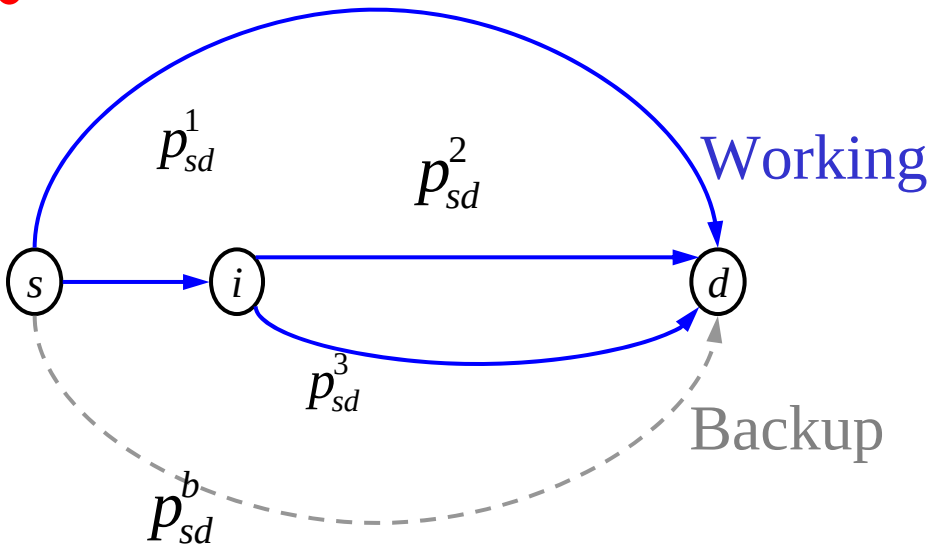
? Take advantage of backup sharing

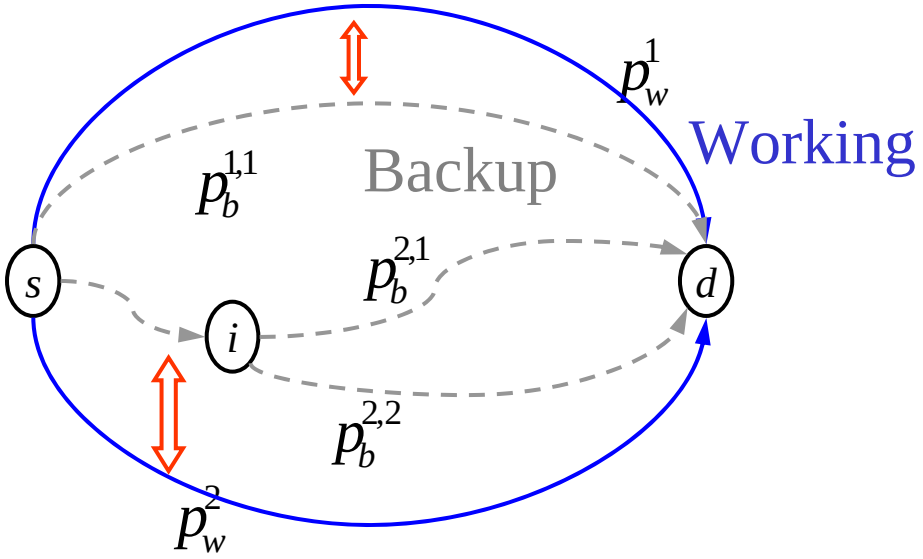
EoS: Service Resilience (2)

- Route splitting enables *degraded services*
  - Ethernet service: peak rate 600 Mbps, guaranteed rate 300 Mbps (against single network-element failure)
  - Need LCAS



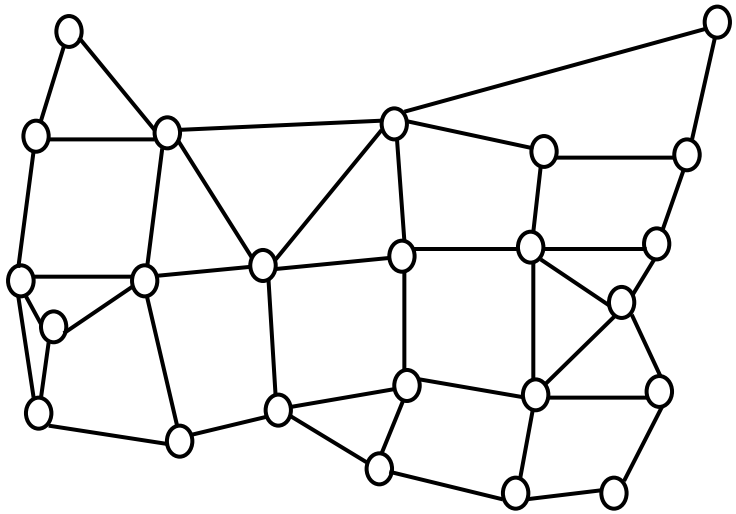
Which Method?



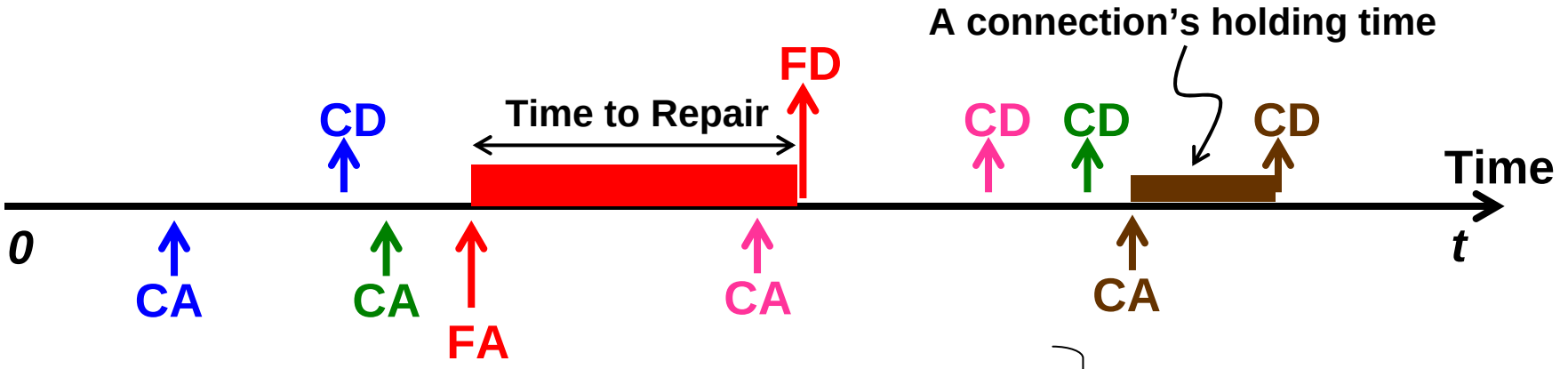


- **PREV: Provisioning fast REstorable VCG**
  - One backup path per node pair
- **PIVM: Protecting Individual VCG Member**
  - One working VCG per connection
  - One backup VCG per working VCG member

Telecom Network: Four State-Change Events



A sample telecom network topology



CA: Connection Arrival

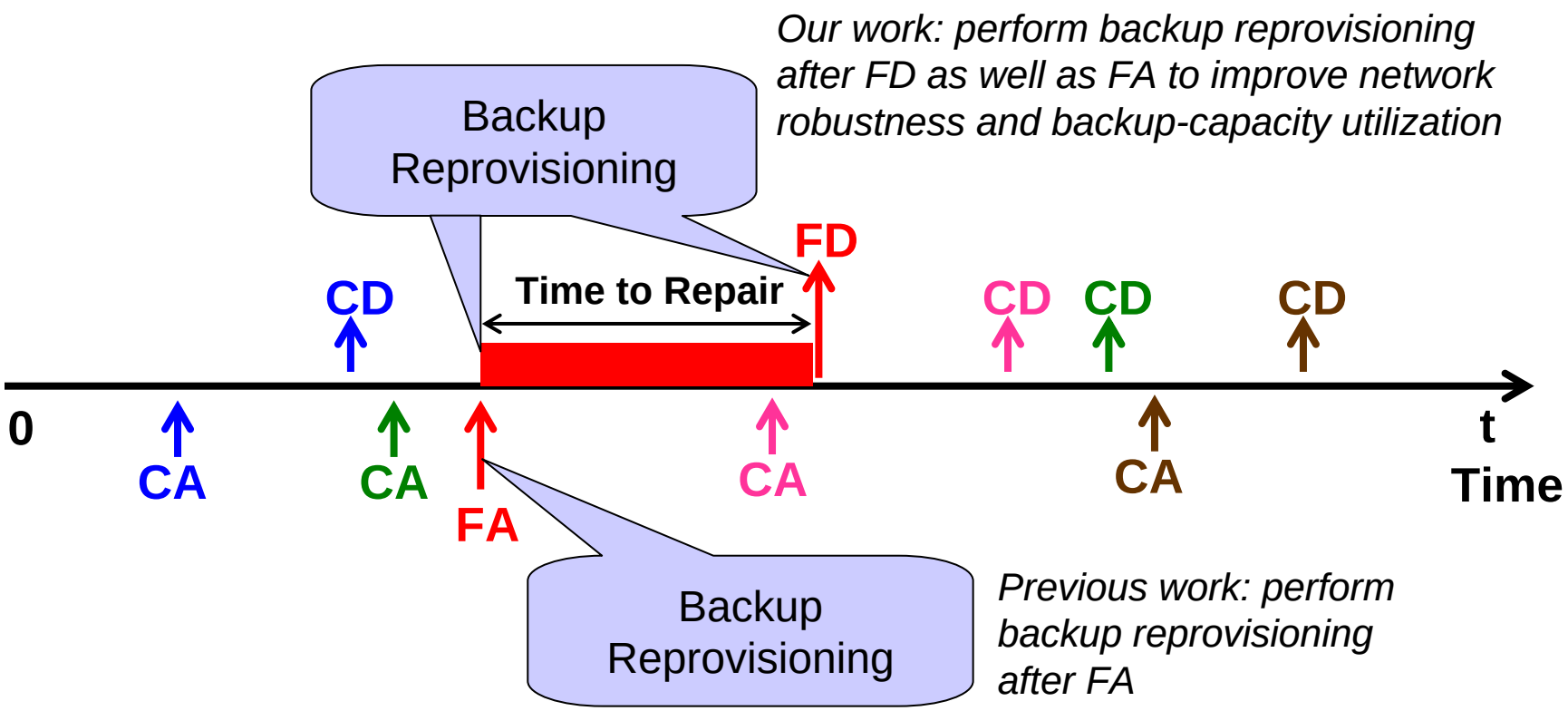
CD: Connection Departure

FA: Failure Arrival

FD: Failure Departure (Repair)

These four events cause network-state updates

Telecom Network: Four State-Change Events



CA: Connection Arrival

CD: Connection Departure

FA: Failure Arrival

FD: Failure Departure (Repair)

Other Related Research: A Sampling

- Application to MPLS "restorable tunnels" [Kodialam03]
  - Comparable to our studies with fine (continuous) bandwidth granularity and full wavelength conversion at each node

  Note: The survivability research studied in this presentation has wide applicability… e.g., to *IP / MPLS restorable tunnels*… with appropriate adjustments on bandwidth granularity and wavelength conversion

- Comprehensive review of shared-path-protection methods [Sam-jlt04]
- "p-Cycles" (or protection cycles) [Grover00]
  - Virtual ring embeddings on mesh for ring-type protection in mesh nets
- A very good treatment of relevant issues [Doshi99]
- Very good treatments of practical issues [Ori00a, Ori00b]
- Shared-Leap Shortest Path [Pinhan02]
  - An alternate "sub-path" method which also provides node protection
- Path protection with duct-layer constraints [Hui-ton03]

Review of Shared-Path-Protection Methods [Sam-jlt04]

COMPARISON OF RELATED WORK ON DYNAMIC SHARED-PATH-PROTECTED LIGHTPATH/CONNECTION PROVISIONING ON WDM/MPLS MESH NETWORKS

Research Work	Objective	Path Link	Centralized Distributed	Info.	Wavelength Conversion	Deterministic Probabilistic	Contributions (in brief)
Bouillet et al. [1], [2]	Minimize the total cost of working and backup paths for each lightpath	P	C	A	Y	P & D	Stochastic approaches; cost model; K-shortest path routing.
Elie-Dit-Cosaque et al. [7]		P	D	F, P	Y	D	Protection-sharing table.
Mohan et al. [16]		P	C	A	N	D	Primary-backup sharing; Cost model for route computation.
Ramamurthy et al. [18]		P	D	F	Y	D	Performance comparison of different schemes.
Su et al. [20], [21]		L	D	F	Y	D	Bucket-based link metric; ILP & two-step heuristic.
Xin et al. [24]		P	C	F	Y	D	K-shortest path routing.
Xiong et al. [25]		P	C & D	F & P	Y	D	ILP formulations.
Our work		P	C	A	Y	D	NP-complete proof; heuristic for optimization; heuristic for finding a feasible solution.
Kodialam et al. [10], [11]	Minimize the total cost of working and backup paths for each connection	P & L	C & D	F, N, P	Y	D	ILPs for different scenarios & a heuristic based on primal-dual and LP-relaxation.
Li et al. [12]		P	C	F	Y	D	Two-step heuristic using a bucket-like link metric; distributed signaling.
Liu et al. [13]		P	D	A	Y	D	Aggregating per-flow information with a matrix; successively updating existing backups.
Qiao et al. [17]		P	D	P	Y	D	ILP & two-step heuristic; distributed signaling.

Path/Link: Path protection or link protection.
Centralized/Distributed: Whether the algorithm is centralized or distributed.
Info.: The amount of information needed. A: aggregated lightpath/connection information; F: full per-lightpath/connection information; N: no information about existing lightpaths/connections; P: partial information about existing lightpaths/connections.
Wavelength conversion: Whether the work applies to wavelength-continous network or wavelength-convertible network.
Please note that the basic ideas of the work in [10], [11], [12], [13], [17] (which is devoted to MPLS networks) are applicable to WDM networks.

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