

Optical Networking with IP over DWDM: Recent Advances, Trends, and Issues



Raj Jain
CTO, Nayna Networks
481 Sycamore Drive
Milpitas, CA 95035
raj@nayna.com

These slides are available at:

http://www.cis.ohio-state.edu/~jain/talks/opt_ind.htm





1. Market Developments
2. Hot Issues
3. Technology Developments
4. IP over DWDM: Issues and developments
5. Research Topics

Past...

Who started optical
networking?

Present

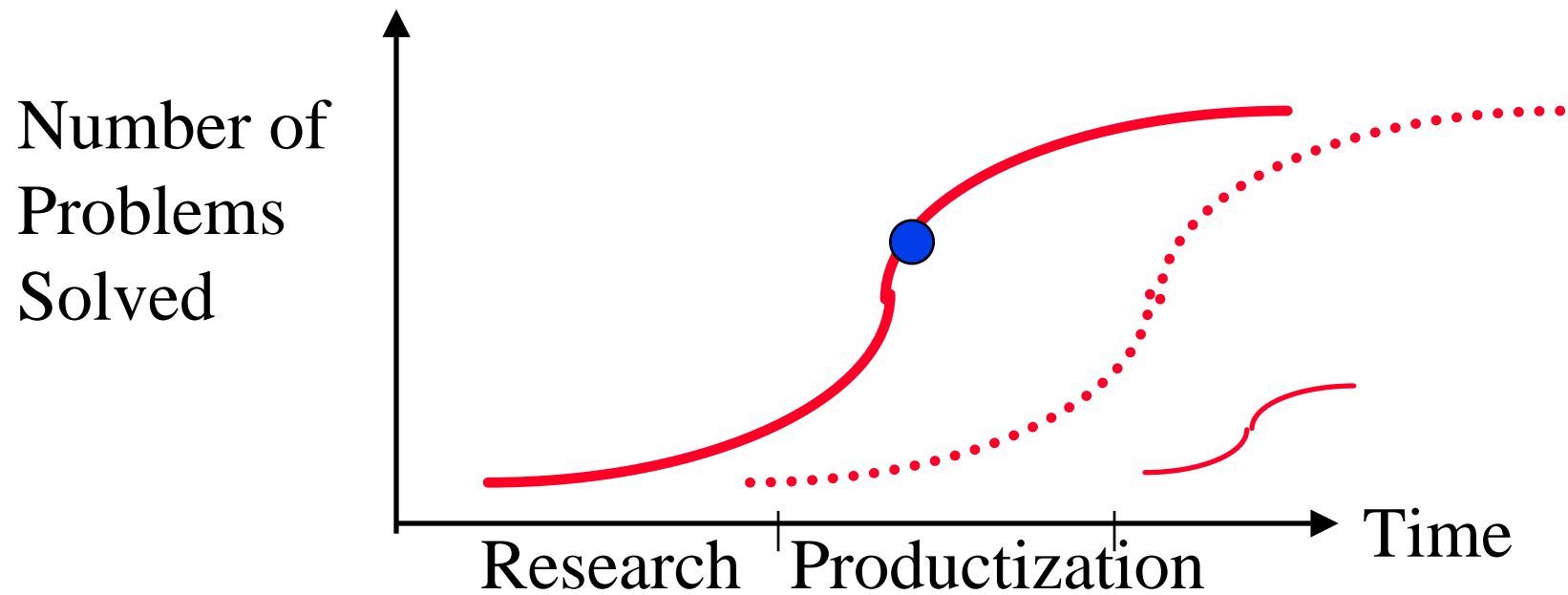
What's happening in
telecom?

Future

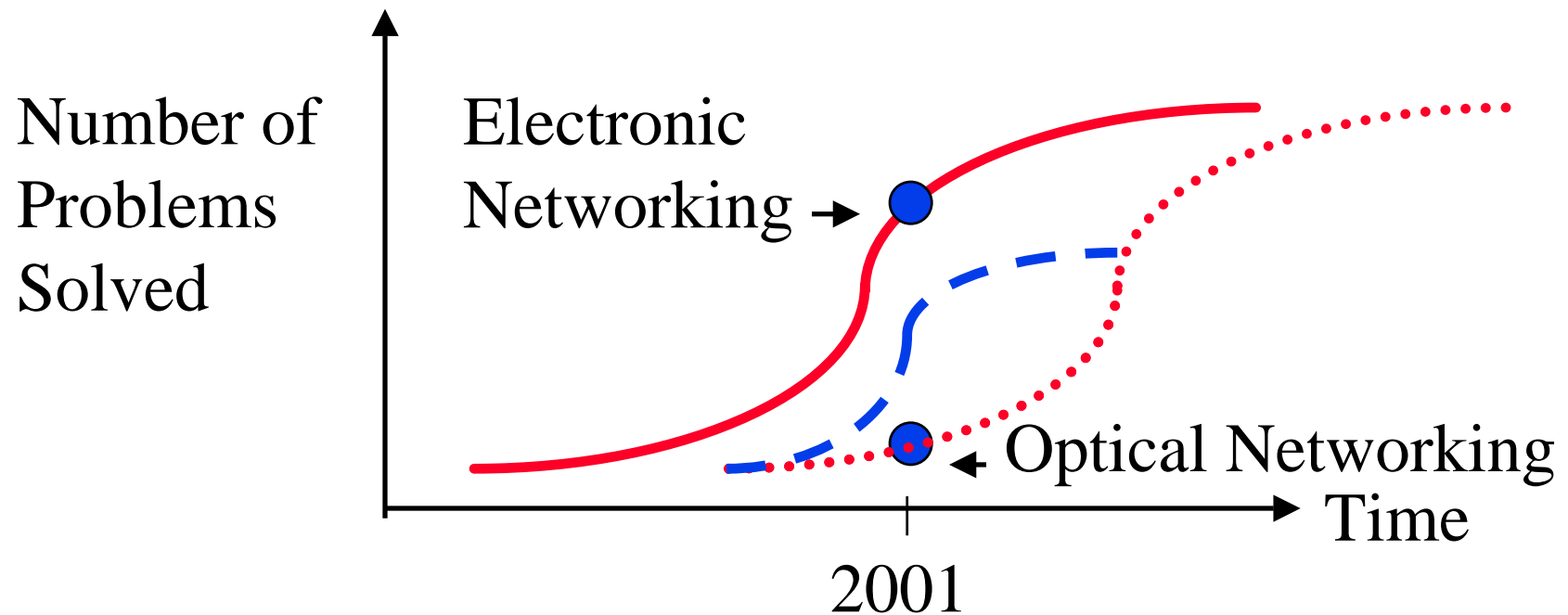


Is there any future in optical networking?

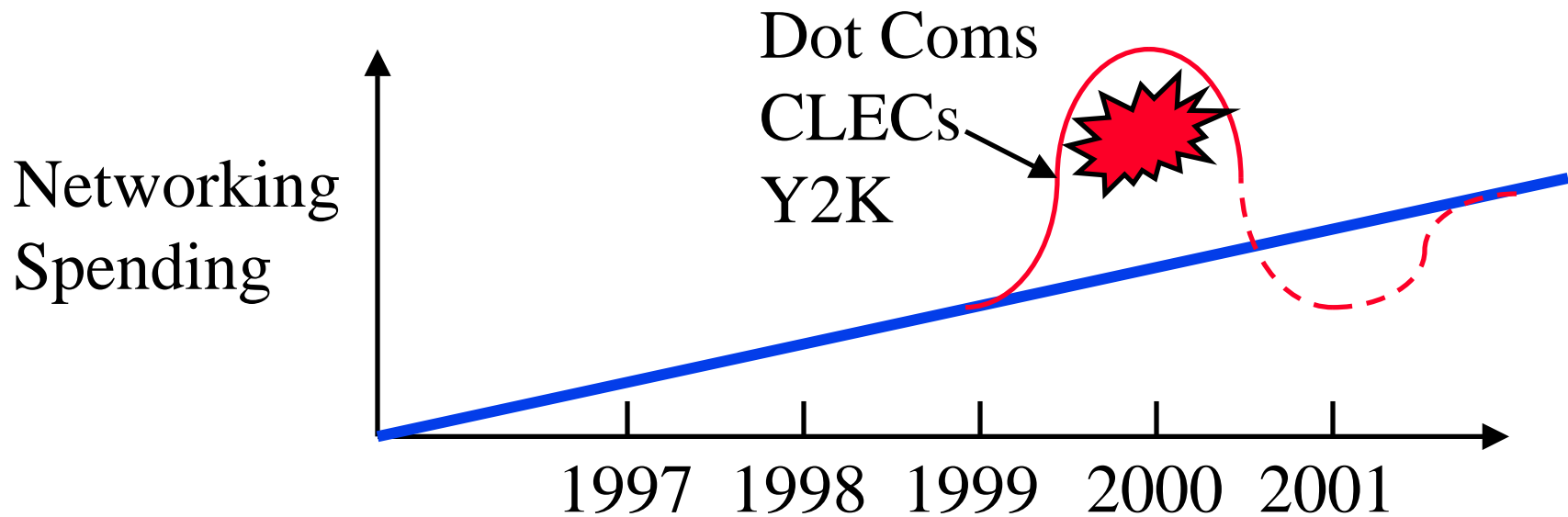
Life Cycles of Technologies



Life Cycles of Technologies



The Bubble



- ❑ Sidgmore: Internet Traffic doubling every 40 days, 30 days, ... \Rightarrow Over-projection data networking equipment
- ❑ Nearly 1/3 of all tech IPOs over the last 21 years happened in 1999 and 2000. Source: Morgan Stanley/Chi at Opticomm

Trend: Back to ILECs

1. CLECs to ILECs

ILEC: Slow, steady, predictable.

CLEC: Aggressive, Need to build up fast

New networks with newest technology

No legacy issues

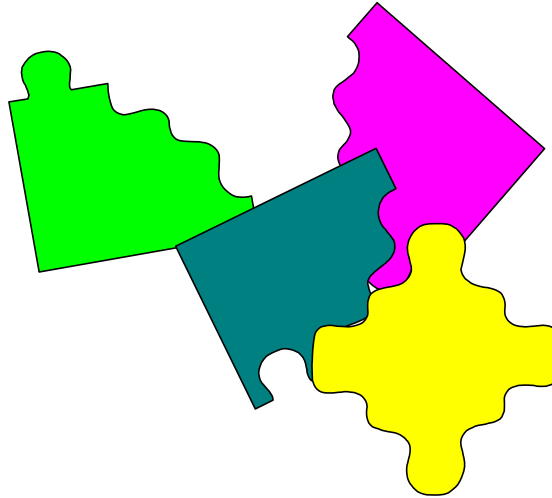
2. Back to Voice

CLECs wanted to *start* with data

ILECs want to *migrate* to data

⇒ Equipment that support voice circuits but allow packet based (hybrids) are more important than those that allow only packet based

Current Issues



1. Bandwidth Glut vs Traffic Growth
2. OOO vs OEO
3. Ethernet vs SONET
4. Mesh vs Ring

Is Internet Growing?

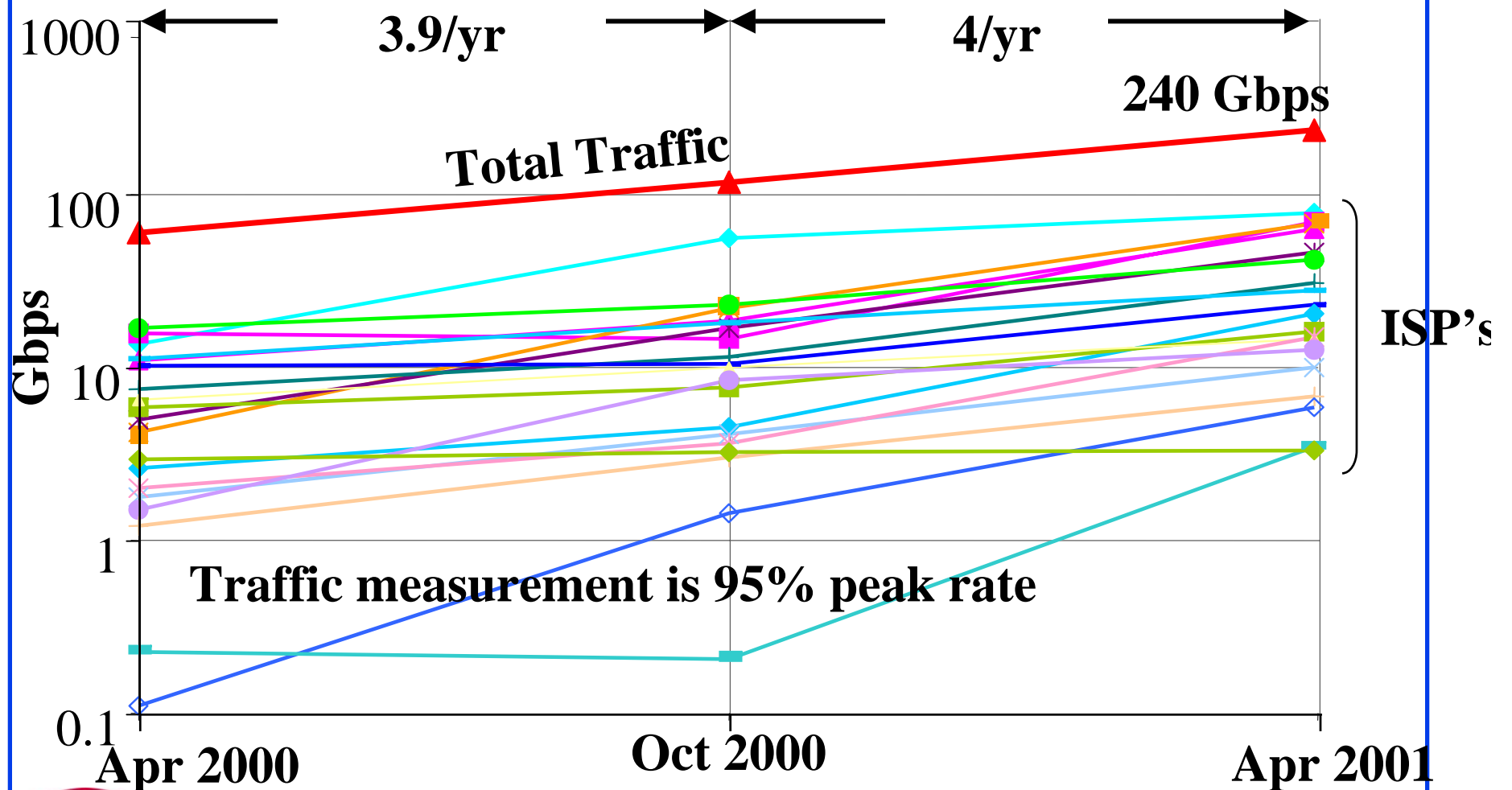
- ❑ IP Traffic Growth will slow down from 200-300% per year to 60% by 2005
 - McKinsey & Co and JP Morgan, May 16, 2001
- ❑ 98% of fiber is unlit - WSJ, New York Times, Forbes (Fiber is a small fraction of cost. Laying is expensive.)
- ❑ Nortel blamed sales decline on falling IP traffic
- ❑ Carriers are using only *avg 2.7%* of their total *lit* fiber capacity - Michael Ching, Marris Lynch & Co. in Wall Street Journal

Internet Growth (Cont)

- Demand on 14 of 22 most used routes exceeds 70%
-Telechoice, July 19, 2001
- Traffic grew by a factor of 4 between April 2000-
April 2001
-Larry Roberts, August 15, 2001

Robert's Traffic Measurements

19 Largest Tier 1 U.S. Internet Service Providers

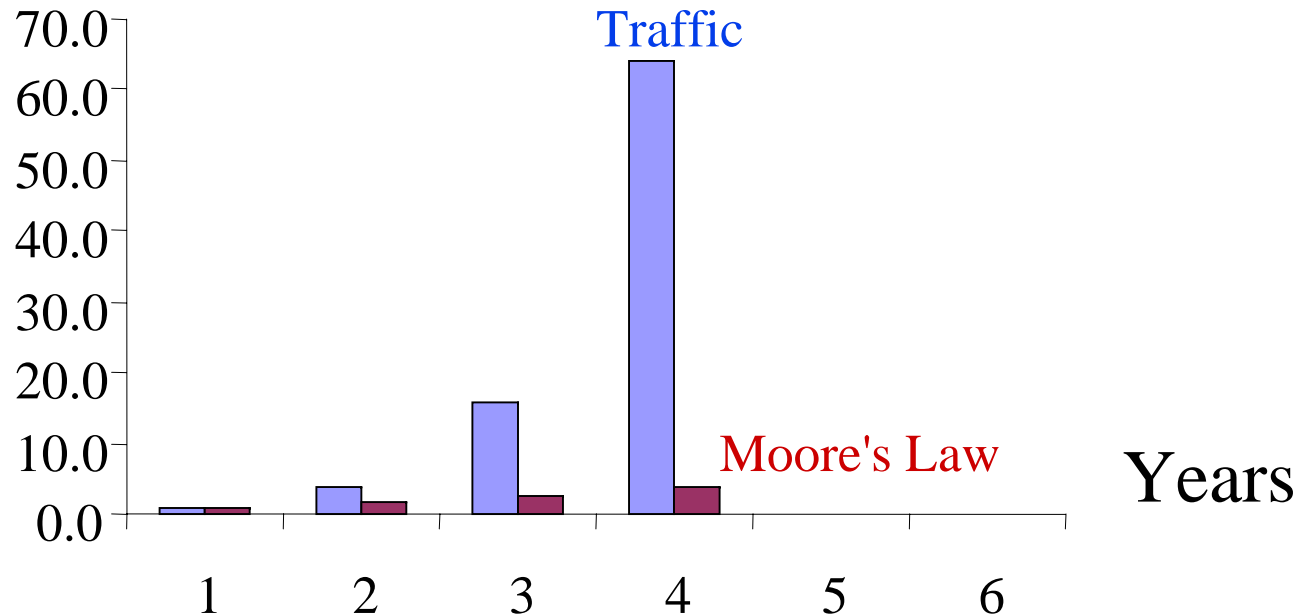


Source: L. Roberts at Opticomm 2001

IEEE Distinguished Lecture Tour - India December 2001

Raj Jain

Moore's Law is Too Slow



- ❑ Moore's Law: Factor of 2 every 1.5 years
⇒ 60%/year
- ❑ Internet Traffic: Factor of 4 per year
⇒ Need Optical Switching

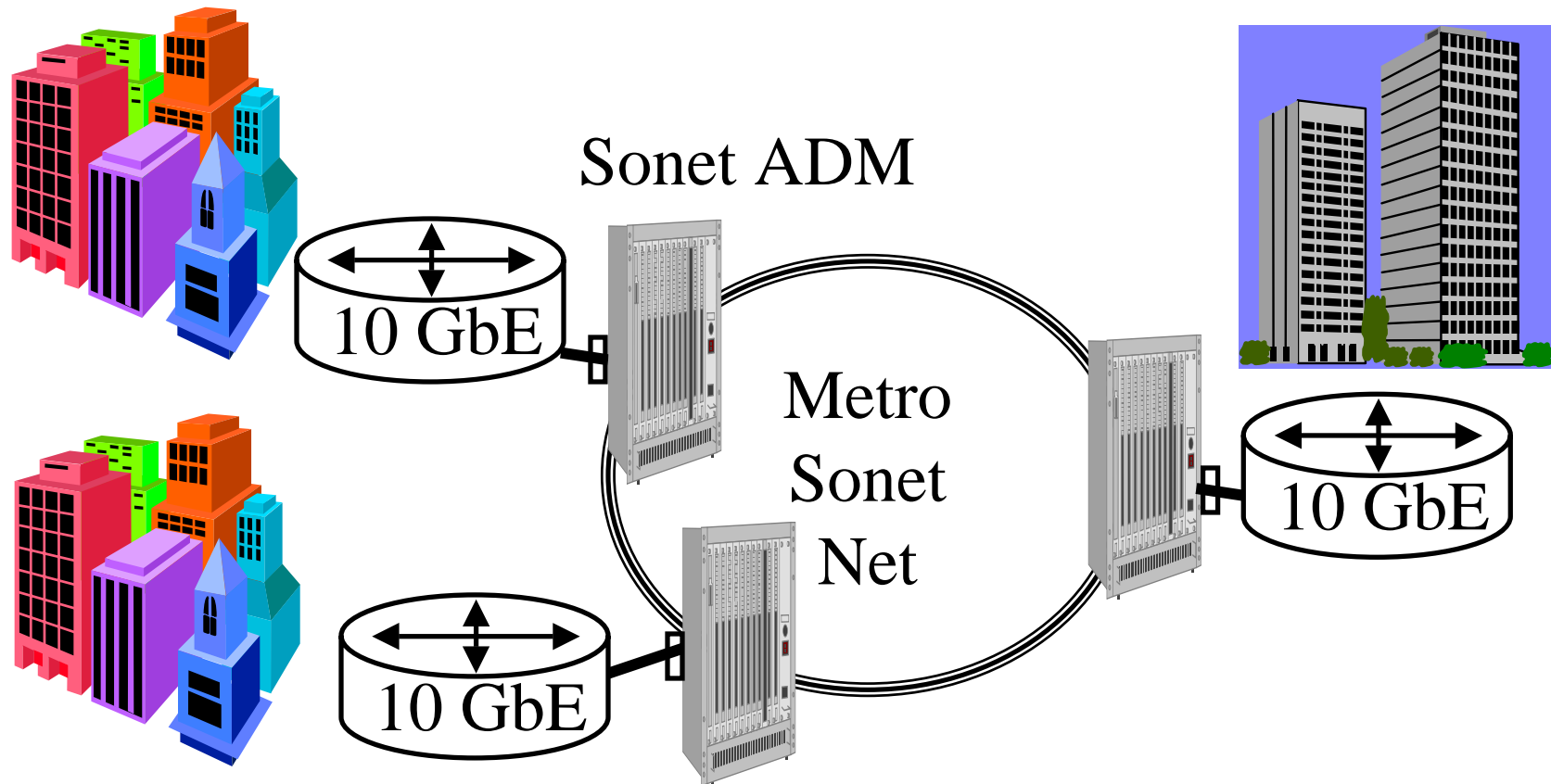
OEO vs OOO

Feature	OEO	OOO
Data Format Independence	No	√ Yes
Cost/Space/Power independent of rate	No	√ Yes
Upgradeability to higher rate	No	√ Yes
Sub-Wavelength Switching	√ Yes	Future
Waveband Switching	No	√ Yes
Performance Monitoring	√ Bit error rate	Optical signal degradation
Wavelength Conversion	√ Built-in	1+ year away

10 G Ethernet

- ❑ Two versions: LAN (10 Gbps), WAN (9.5 Gbps)
- ❑ Point-to-point full duplex only
- ❑ Several different physical layer designs for different distances
- ❑ 9.5 Gbps WAN version compatible with SONET in data rate but incompatible in clock jitter

10 GbE over Sonet/SDH



- Using WAN PHY. Legacy Sonet. Protection via rings.
ELTE = Ethernet Line Terminating Equipment

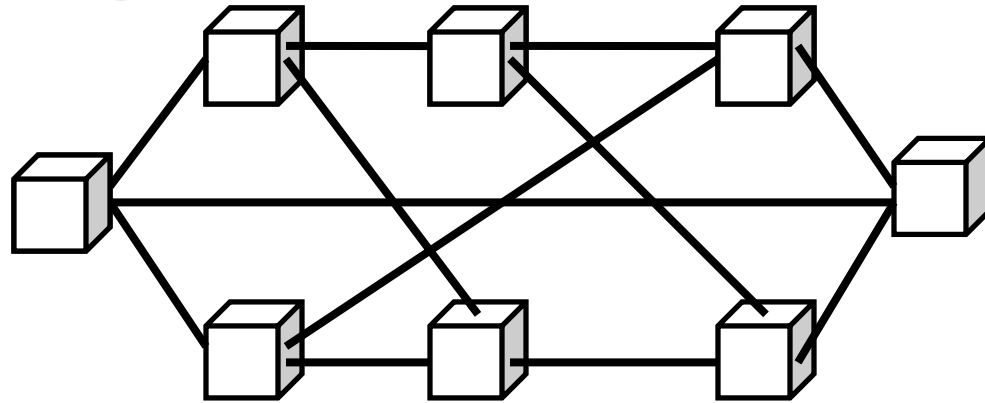
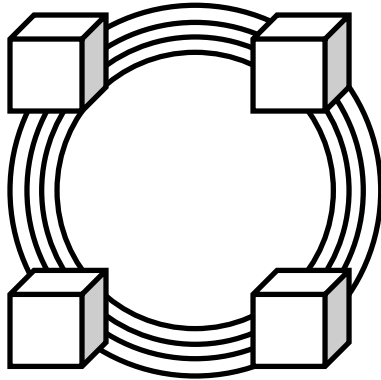
Ethernet vs Sonet

Feature	SONET	Ethernet
Bit Rate (bps)	155 M, 622 M, 2.5 G, 10 G, 40 G, ...	1M, 10 M, 100 M, 1 G, 10 G, ...
Timing	Isochronous (Periodic 125 μ s)	Plesio-Isochronous
Multiplexing	Bit	Packet
Clocks	Common	Independent
Clock jitter	<i>4.6 to 20 ppm</i>	100 ppm (May change)
Usage	Telecom	Enterprise
Volume	Millions	100's of Millions
Price (10 Gbps)	>10k	\approx 1k
Recovery	<i>50 ms</i>	Few Minutes
Topology	<i>Rings</i>	Mesh

Ethernet: Future Possibilities

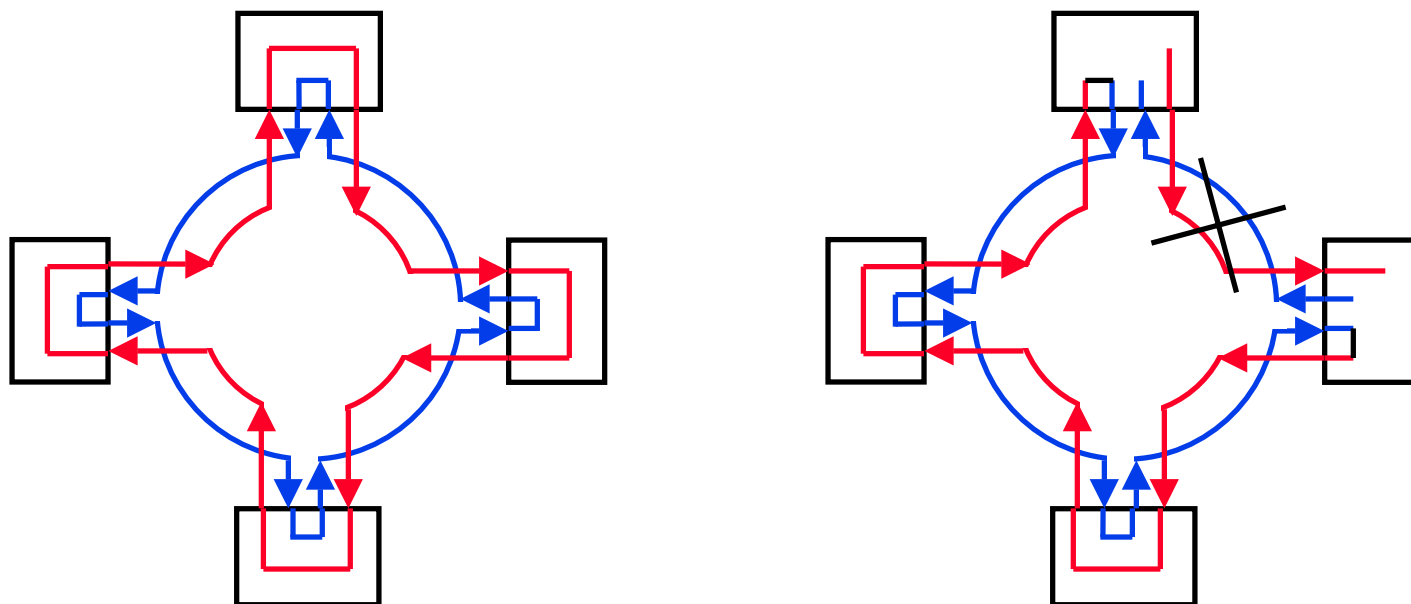
- ❑ 40 Gbps
- ❑ 100 Gbps:
 - $16\lambda \times 6.25$ Gbps
 - $8\lambda \times 12.5$ Gbps
 - $4\lambda \times 12.5$ using PAM-5
- ❑ 160 Gbps
- ❑ 1 Tbps:
 - 12 fibers with $16\lambda \times 6.25$ Gbps
 - 12 fibers with $8\lambda \times 12.5$ Gbps
- ❑ 70% of 802.3ae members voted to start 40G in 2002

Ring vs Mesh



- ❑ On rings: All links same capacity \Rightarrow Not good for non-homogeneous or long-distance traffic
- ❑ Upgrade: All stations on the ring must be upgraded.
- ❑ Mesh typically requires 50% less restoration and 50% less working capacity than rings
- ❑ Mesh save more as degree of connectivity increases

Resilient Packet Rings



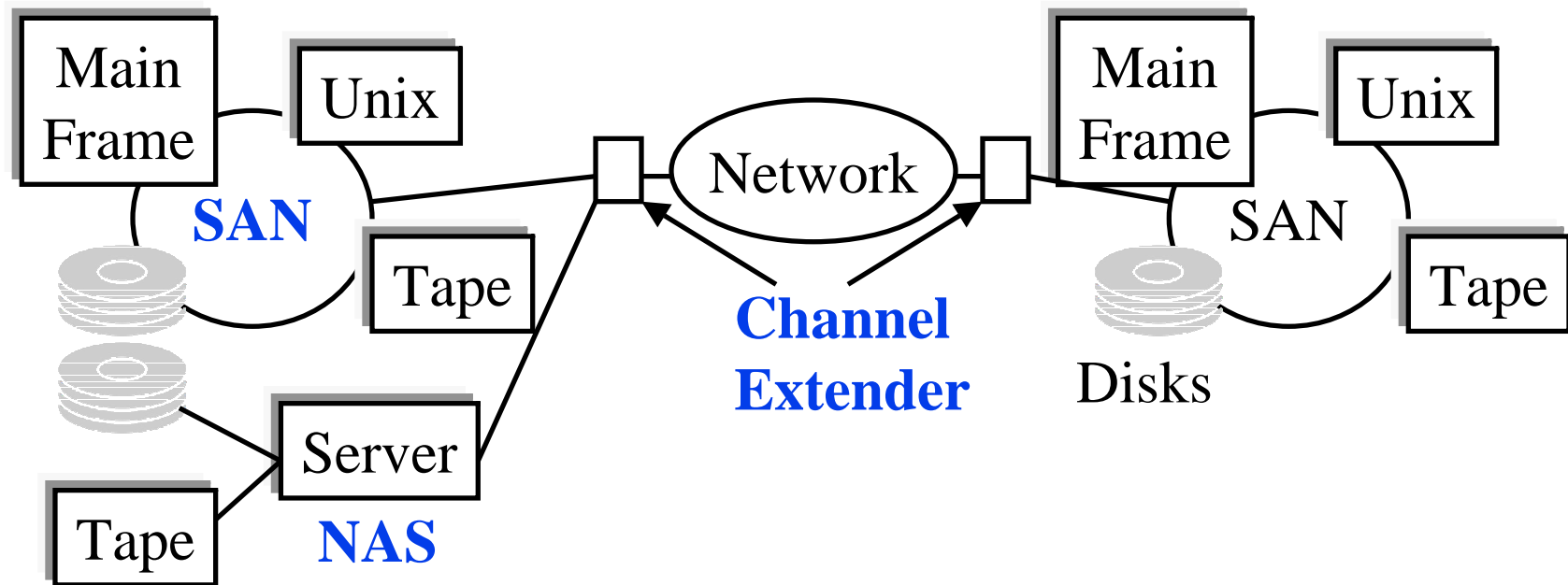
- ❑ Dual Counter-rotating rings help protect against failure
- ❑ Used in SONET and FDDI
- ❑ Need to bring these concepts to Ethernet and IP



New Developments

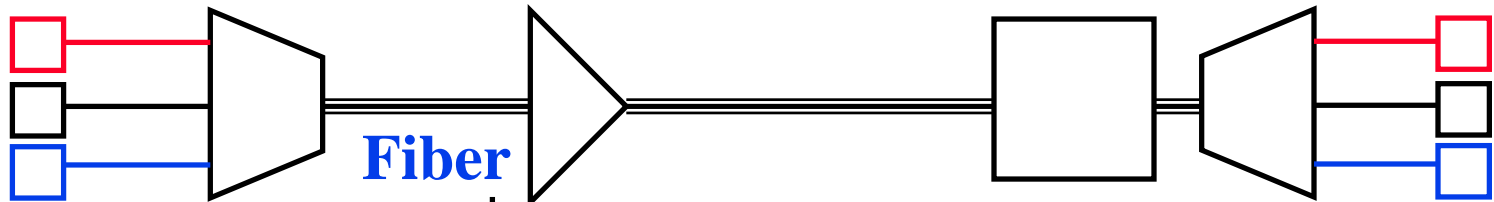
1. New Applications: Storage, VPN, LAN extension, Data hosting
2. Higher Speed: 40 Gbps
3. More Wavelengths per fiber
4. Longer Distances
5. Larger Crossconnects
6. Newer places to install fibers

Storage: New Traffic Demands



- ❑ Fiber Channel SAN limited to 10 km
- ❑ SAN extender switches allow connectivity over metro and long-haul optical networks \Rightarrow Outsourced storage
- ❑ Multiservice switches allow IP, ATM, Sonet, ESCON, ...

40 Gbps



Transmitter Sources
Modulators
Wavelengthers

Mux/Demux Filters
Interleavers

Fiber

Amplifier Gain Equalizers
Performance Monitors
Dispersion compensators
PMD compensators

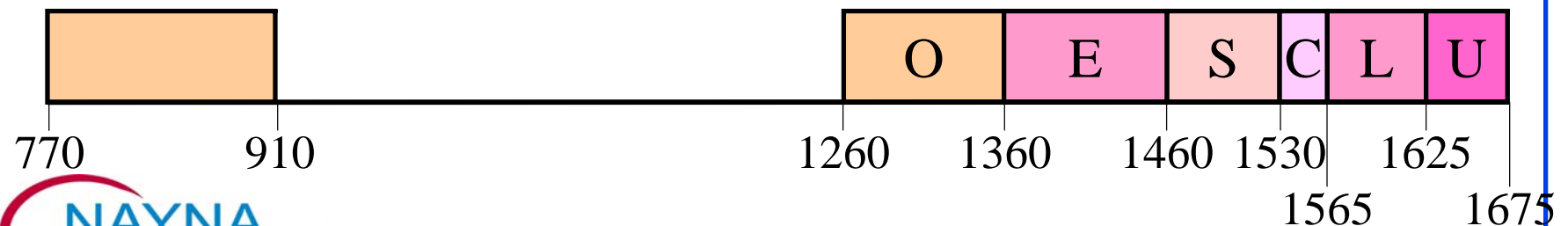
Switching ADM

Receivers Detectors

- ❑ Need all new optical and electronic components
- ❑ Non-linearity's reduced distance by square of rate.
- ❑ Deployment may be 2-3 years away
- ❑ Development is underway. To avoid 10 Gbps mistake.
- ❑ Cost goal: 2.5×10 Gbps

More Wavelengths

- C-Band (1535-1560nm), 1.6 nm (200 GHz) \Rightarrow 16 λ 's
- Three ways to increase # of wavelengths:
 1. **Narrower Spacing**: 100, 50, 25, 12.5 GHz
Spacing limited by data rate. Cross-talk (FWM)
Tight frequency management: Wavelength monitors, lockers, adaptive filters
 2. **Multi-band**: C+L+S Band
 3. **Polarization Muxing**



More Wavelengths (Cont)

- More wavelengths \Rightarrow More Power
 - \Rightarrow Fibers with large effective area
 - \Rightarrow Tighter control of non-linearity's
 - \Rightarrow Adaptive tracking and reduction of polarization mode dispersion (PMD)

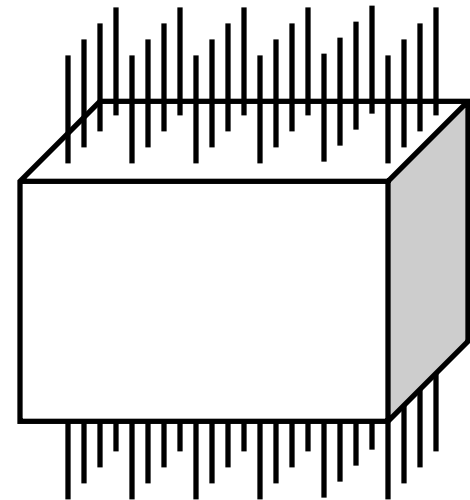
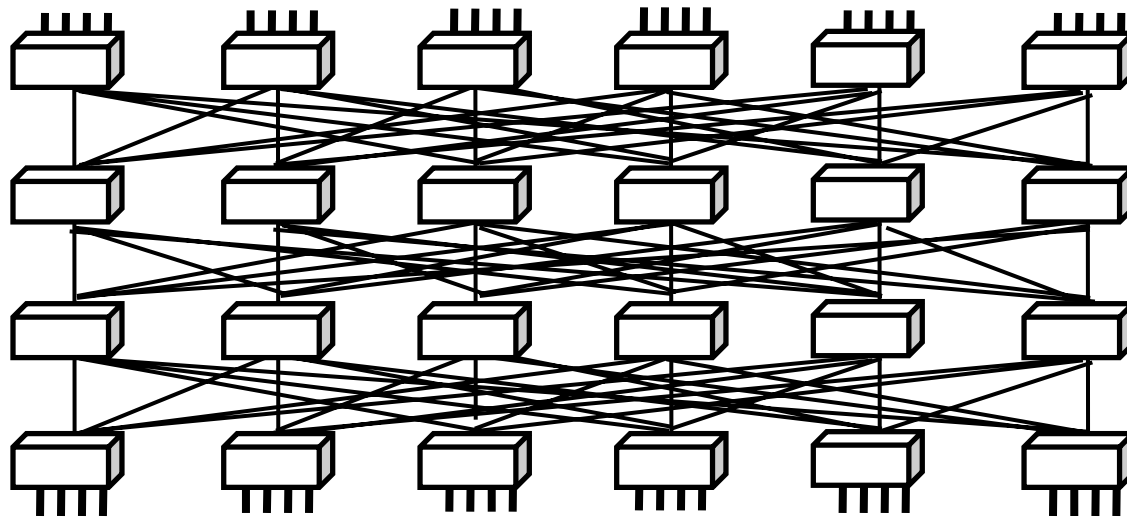
Ultra-Long Haul Transmission

1. Strong out-of-band Forward Error Correction (FEC)
Changes regeneration interval from 80 km to 300km
Increases bit rate from 40 to 43 Gbps
2. Dispersion Management: Adaptive compensation
3. More Power: Non-linearity's \Rightarrow RZ coding
Fiber with large effective area
Adaptive PMD compensation
4. Distributed Raman Amplification:
Less Noise than EDFA
5. Noise resistant coding: 3 Hz/bit by Optimight

Trend: Large Port Count

- ❑ Increasing traffic
 - ⇒ Increase number of ports or increase speed per port
- ❑ Increasing the port speed increases the number of muxing/demuxing (grooming) points
 - Increases # of hops.
- ❑ Trend: Number of hops is decreasing (Avg 1.8)
 - ⇒ Larger number of ports per router
 - E.g., Avici
- ❑ Also, larger # of wavelengths per fiber

Trend: Larger Crossconnects

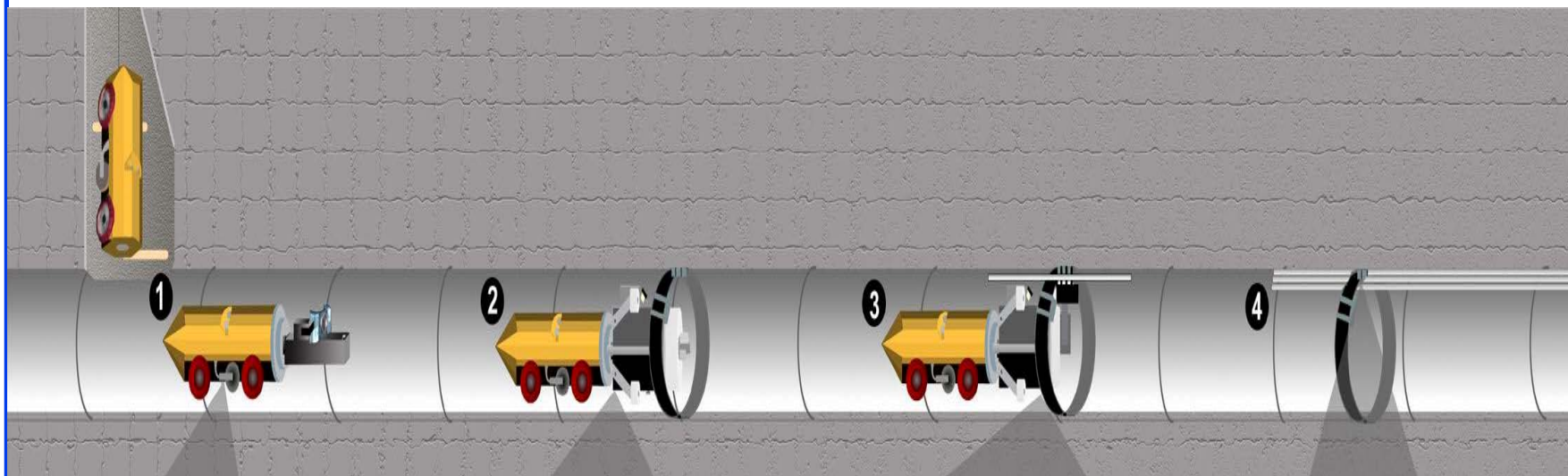


- Example: 24×24 using 4×4 switches \Rightarrow 24 switches
 \Rightarrow 48 External ports, $8 \times 24 = 192$ total ports
 \Rightarrow 25% port efficiency
- Crossconnect or routers with large number of ports are more cost effective

Fiber Access Thru Sewer Tubes (FAST)

- ❑ Right of ways is difficult in dense urban areas
- ❑ Sewer Network: Completely connected system of pipes connecting every home and office
- ❑ Municipal Governments find it easier and more profitable to let you use sewer than dig street
- ❑ Installed in Zurich, Omaha, Albuquerque, Indianapolis, Vienna, Ft Worth, Scottsdale, ...
- ❑ Corrosion resistant inner ducts containing up to 216 fibers are mounted within sewer pipe using a robot called Sewer Access Module (SAM)
- ❑ Ref: <http://www.citynettelecom.com>, NFOEC 2001, pp. 331

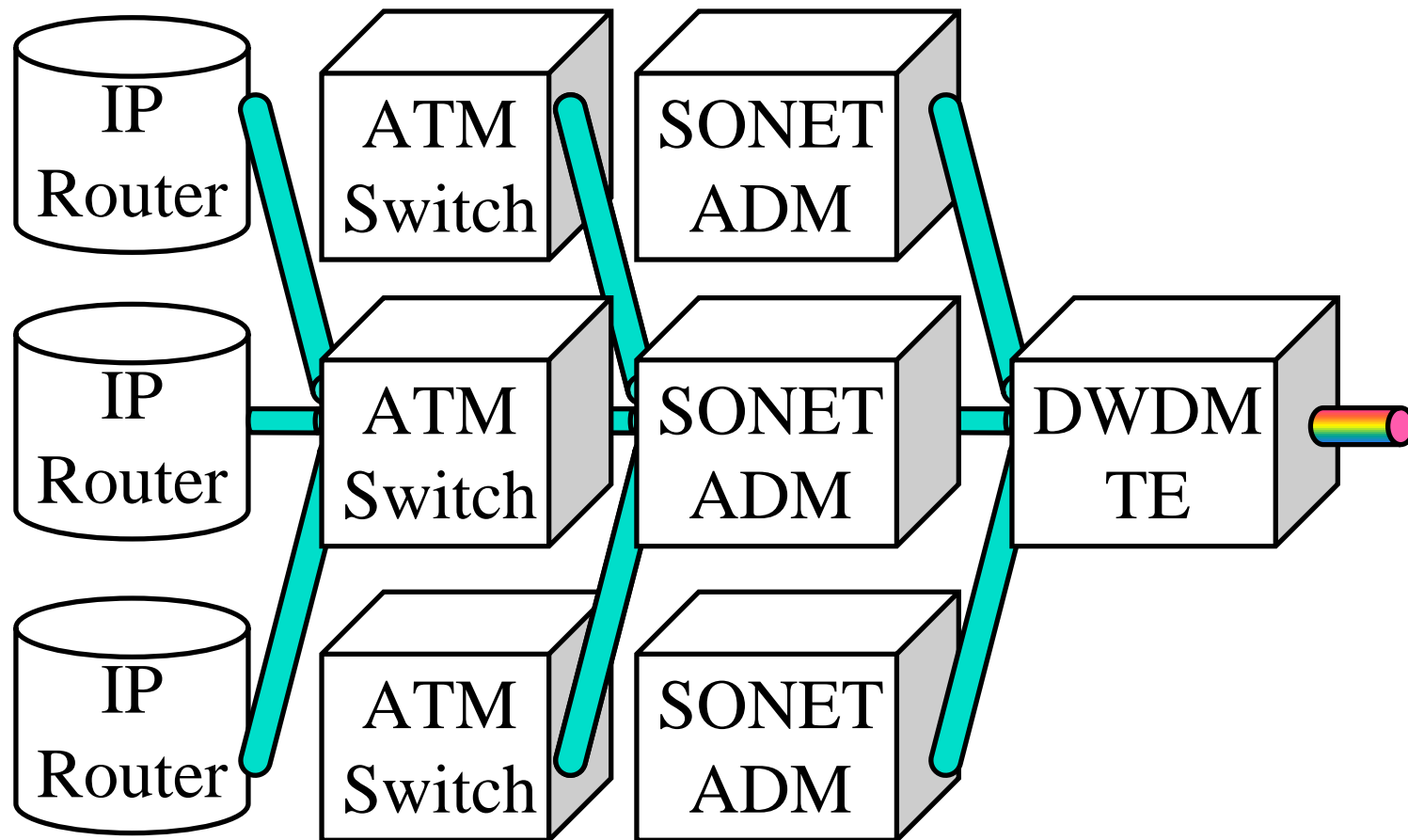
FAST Installation



1. Robots map the pipe
2. Install rings
3. Install ducts
4. Thread fibers

Fast Restoration: Broken sewer pipes replaced with minimal disruption

IP over DWDM (Past)

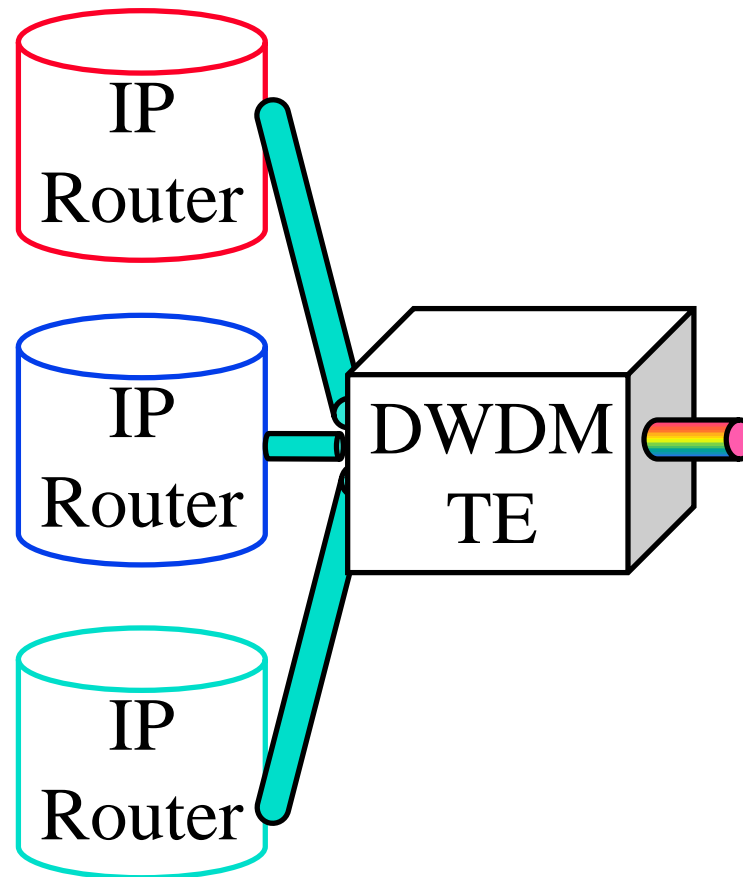


IP over DWDM: Protocol Layers

1993	1996	1999	2001	2003
IP	IP	IP/MP λ S	IP/GMPLS	IP/GMPLS
ATM	PPP	PPP	Ethernet	Ethernet
SONET	SONET	SONET Framing	SONET Framing	
DWDM	DWDM	DWDM	DWDM	DWDM
Fiber	Fiber	Fiber	Fiber	Fiber

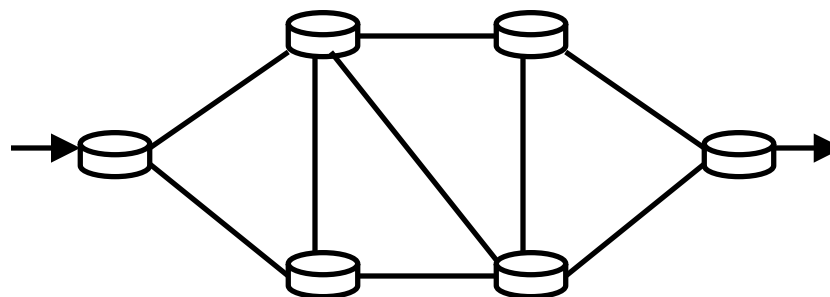
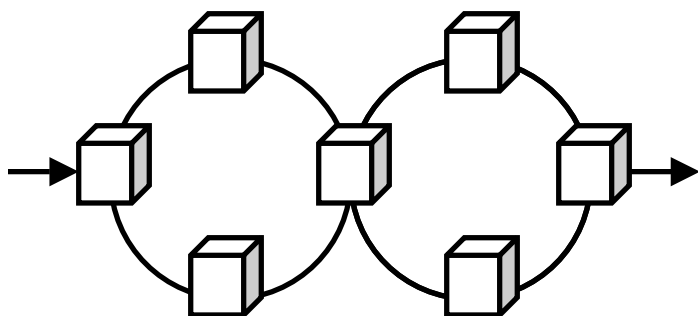
- ❑ IP is good for routing, traffic aggregation, resiliency
 - ❑ ATM for multi-service integration, QoS/signaling
 - ❑ SONET for traffic grooming, monitoring, protection
 - ❑ DWDM for capacity
 - ❑ Problem: Restoration in multiple layers, Sonet Manual
- ⇒ Intersection of features and union of problems

IP over DWDM (Future)



Telecom vs Data Networks

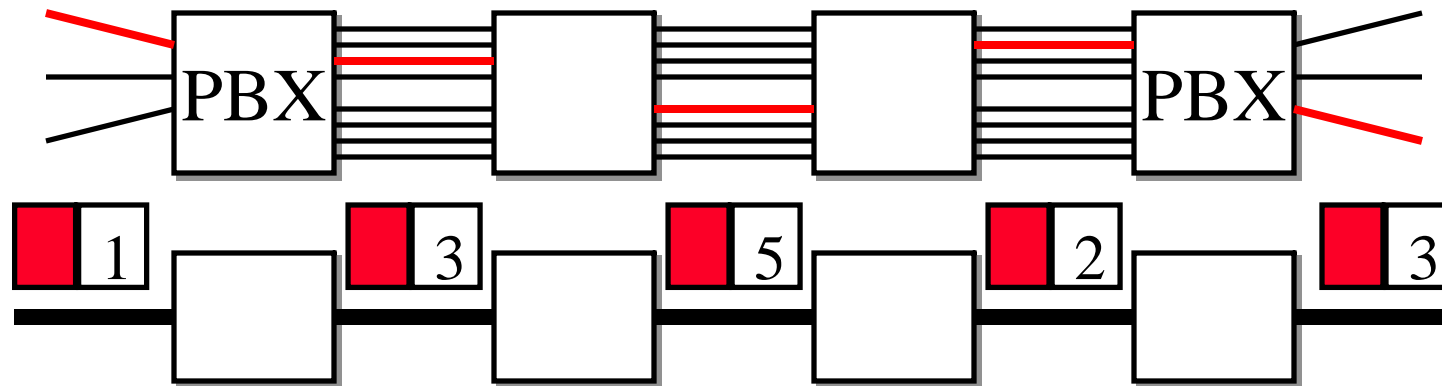
	Telecom Networks	Data Networks
Topology Discovery	Manual	Automatic
Path Determination	Manual	Automatic
Circuit Provisioning	Manual	No Circuits
Transport & Control Planes	Separate	Mixed
User and Provider Trust	No	Yes
Protection	Static using Rings	No Protection



IP over DWDM Issues

1. Circuits
2. Data and Control plane separation
3. Signaling and Addressing
4. Protection and Restoration

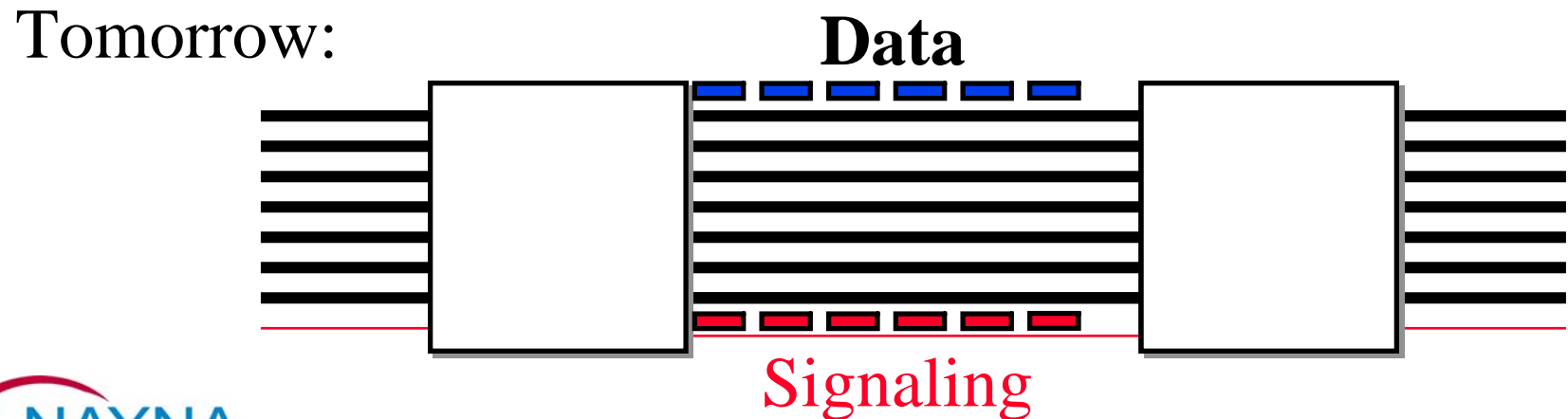
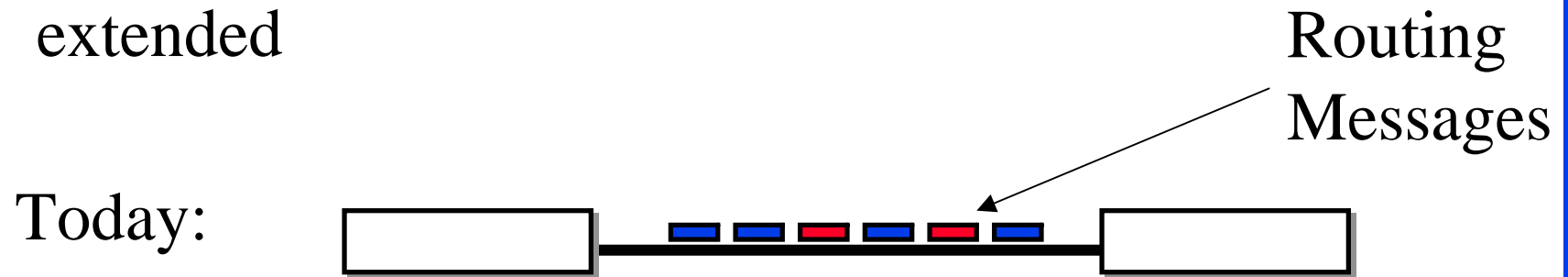
Multiprotocol Label Switching (MPLS)



- ❑ Allows circuits in IP Networks (May 1996)
- ❑ Each packet has a circuit number
- ❑ Circuit number determines the packet's queuing and forwarding
- ❑ Circuits have to be set up before use
- ❑ Circuits are called Label Switched Paths (LSPs)

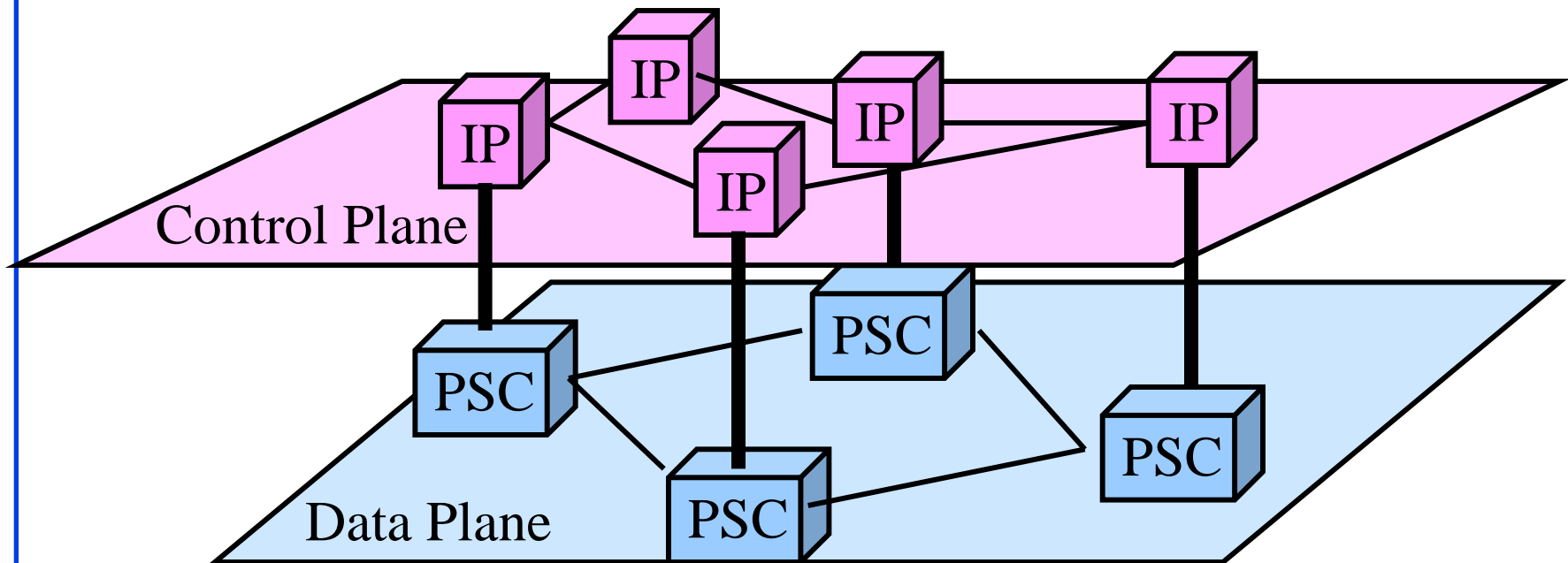
Issue: Control and Data Plane Separation

- ❑ Separate control and data channels
- ❑ IP routing protocols (OSPF and IS-IS) are being extended

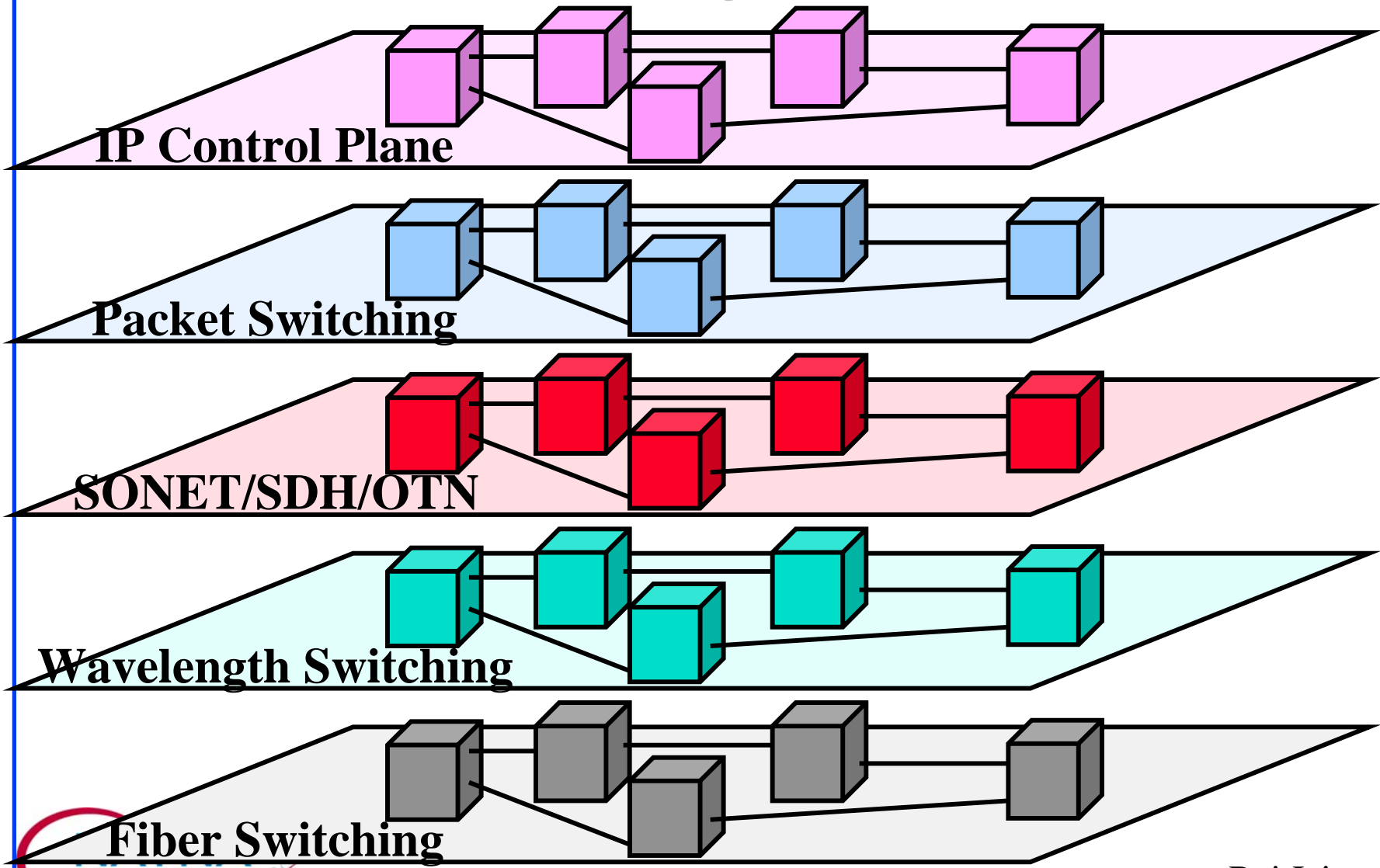


IP-Based Control Plane

- Control is by IP packets (electronic).
Data can be any kind of packets (IPX, ATM cells).
⇒ MPLS

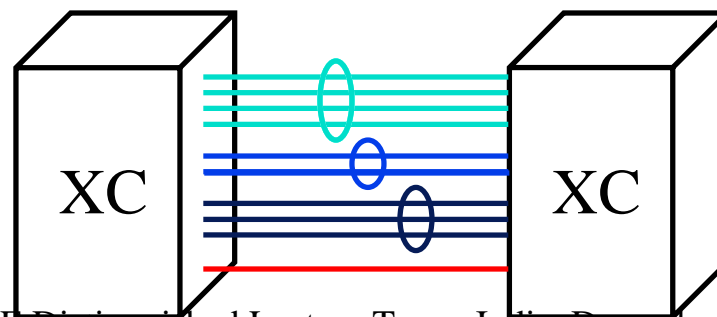


GMPLS: Layered View



MPLS vs GMPLS

Issue	MPLS	GMPLS
Data & Control Plane	Same channel	Separate
Types of Nodes and labels	Packet Switching	PSC, TDM, LSC, FSC, ...
Bandwidth	Continuous	Discrete: OC-n, λ 's, ..
# of Parallel Links	Small	100-1000's
Port IP Address	One per port	Unnumbered
Fault Detection	In-band	Out-of-band or In-Band

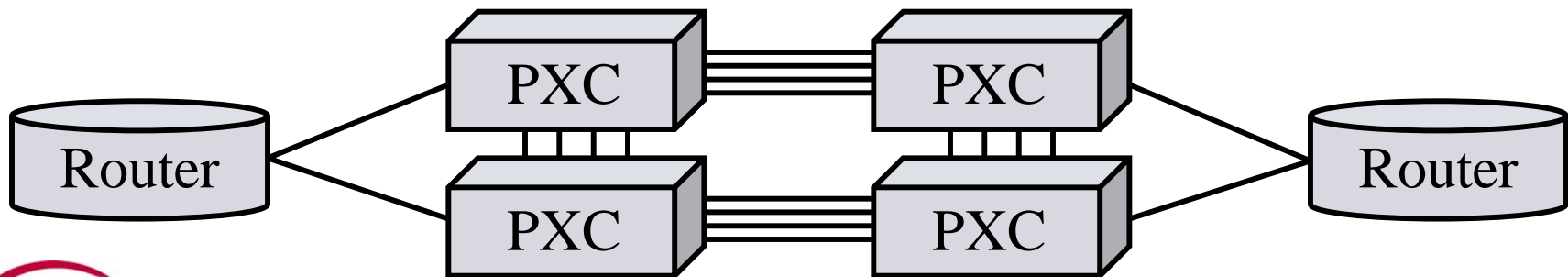


Current Issues

- ❑ Protection and Restoration
- ❑ Fault detection and isolation
- ❑ Network-network Interface
- ❑ All-Optical networks

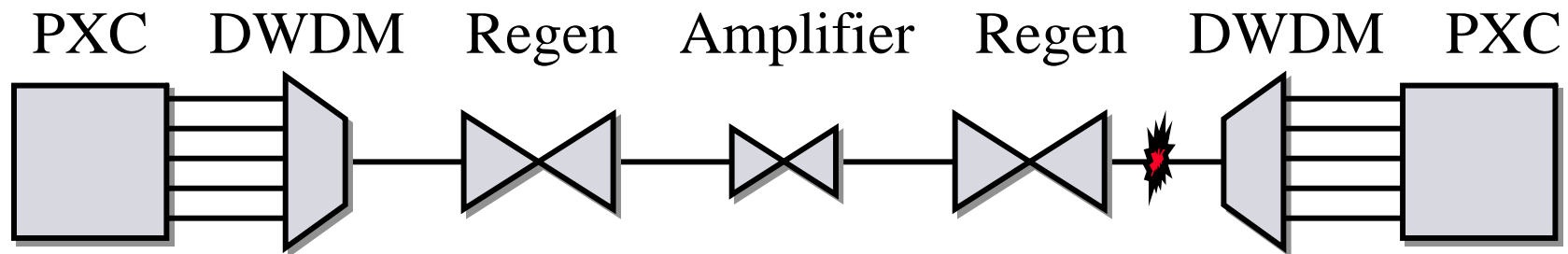
Protection and Restoration

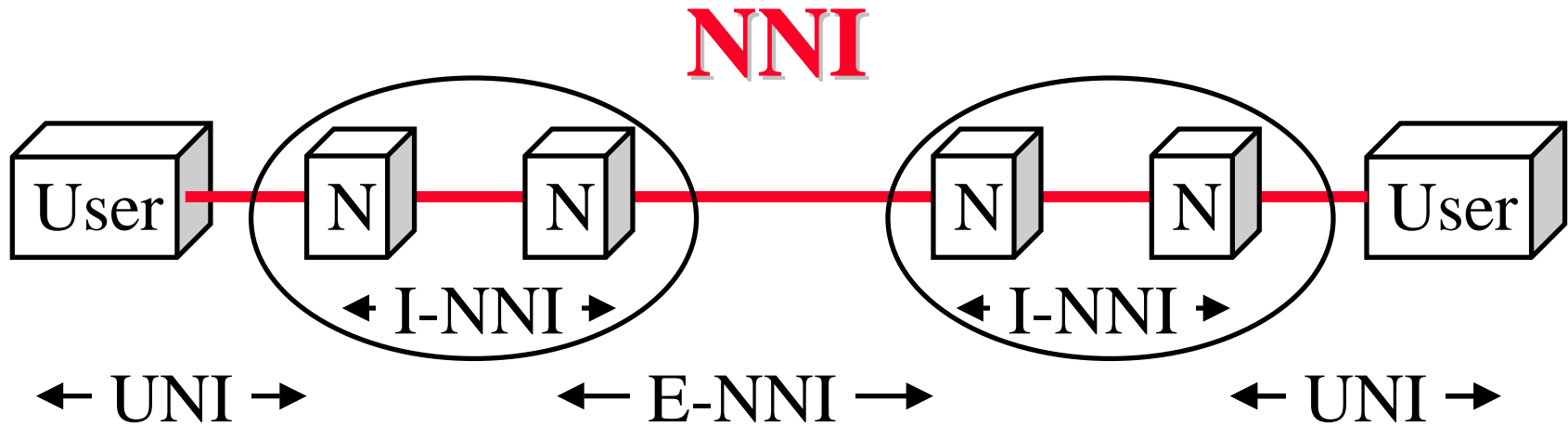
- ❑ Extent: SPAN vs PATH
- ❑ Topology: Ring vs Mesh
- ❑ Redundancy: 1+1, 1:1
- ❑ Finding Paths that do not share the same risk
Each link has to be assigned a risk group
Shared Risk Group (**SRG**) = All paths sharing a risk



Fault Detection and Isolation

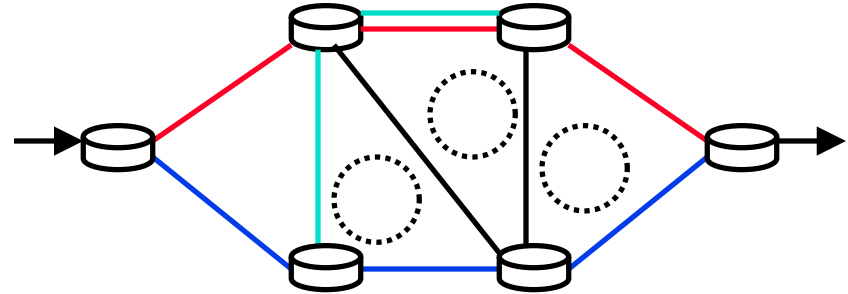
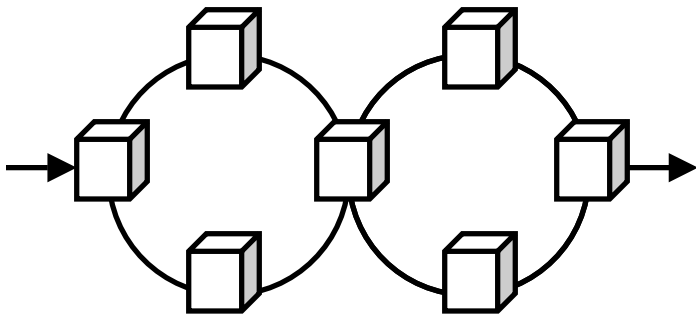
- ❑ SONET: Remote Defect Indicator, Alarm Indication Signal, Bit Interleaved Parity
- ❑ Photonic: Loss of signal, Optical degradation of signal
- ❑ Solution: A protocol for active devices to communicate fault information to Photonic switches
Examples: LMP-DWDM, NTIP



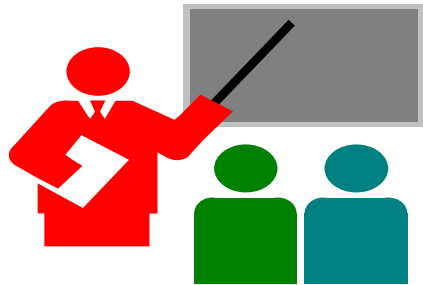


- NNI = Network to Network or
Node-to-Node or
Network-to-Node Interface
- Examples: Open Shortest Path First (OSPF)
Private Network to Node Interface (PNNI)
- OIF is starting a new project on NNI

Research Topics



- ❑ Find path through interconnection of ring networks
- ❑ Find best alternate path for protection
- ❑ Find shared protection paths
- ❑ Identify rings in a mesh networks
- ❑ Routing in all-optical networks: Non-linearity's



Summary

1. CLECs to ILECs: revolution to evolution
⇒ New debates on Ring vs Mesh, Ethernet vs Sonet
2. Traffic growth ⇒ New developments in 40Gbps optics, ultra-long haul, and more wavelengths
3. Routers and crossconnects with larger number of ports are more cost effective.
4. Separation of control and data plane. IP control plane.
Transport Plane = λ , SONET, Packets ⇒ GMPLS
5. Starting on all-optical networks, protection, fault management, and NNI



References

- ❑ Detailed references in http://www.cis.ohio-state.edu/~jain/refs/opt_refs.htm
- ❑ Recommended books on optical networking, http://www.cis.ohio-state.edu/~jain/refs/opt_book.htm
- ❑ Optical Networking and DWDM, <http://www.cis.ohio-state.edu/~jain/cis788-99/dwdm/index.html>
- ❑ IP over Optical: A summary of issues, (internet draft) <http://www.cis.ohio-state.edu/~jain/ietf/issues.html>
- ❑ Lightreading, <http://www.lightreading.com>