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

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

Past...

Who started optical networking?

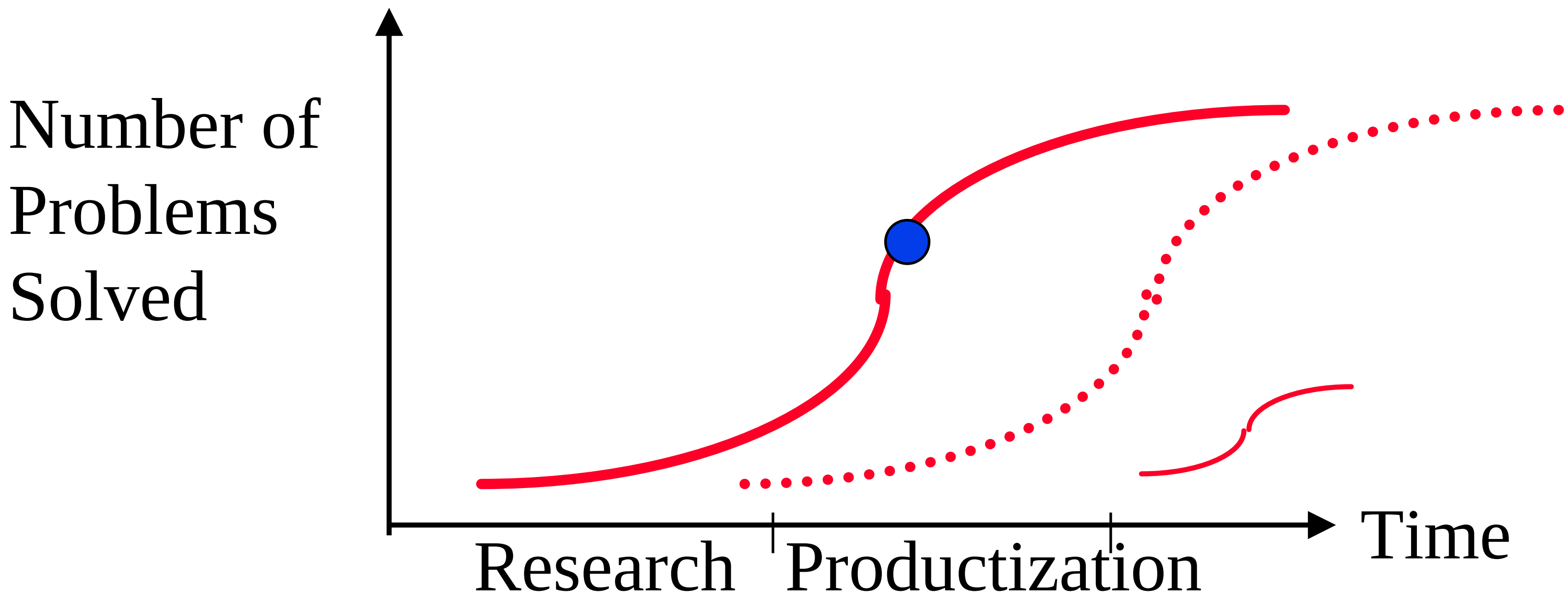
Present

What's happening in telecom?

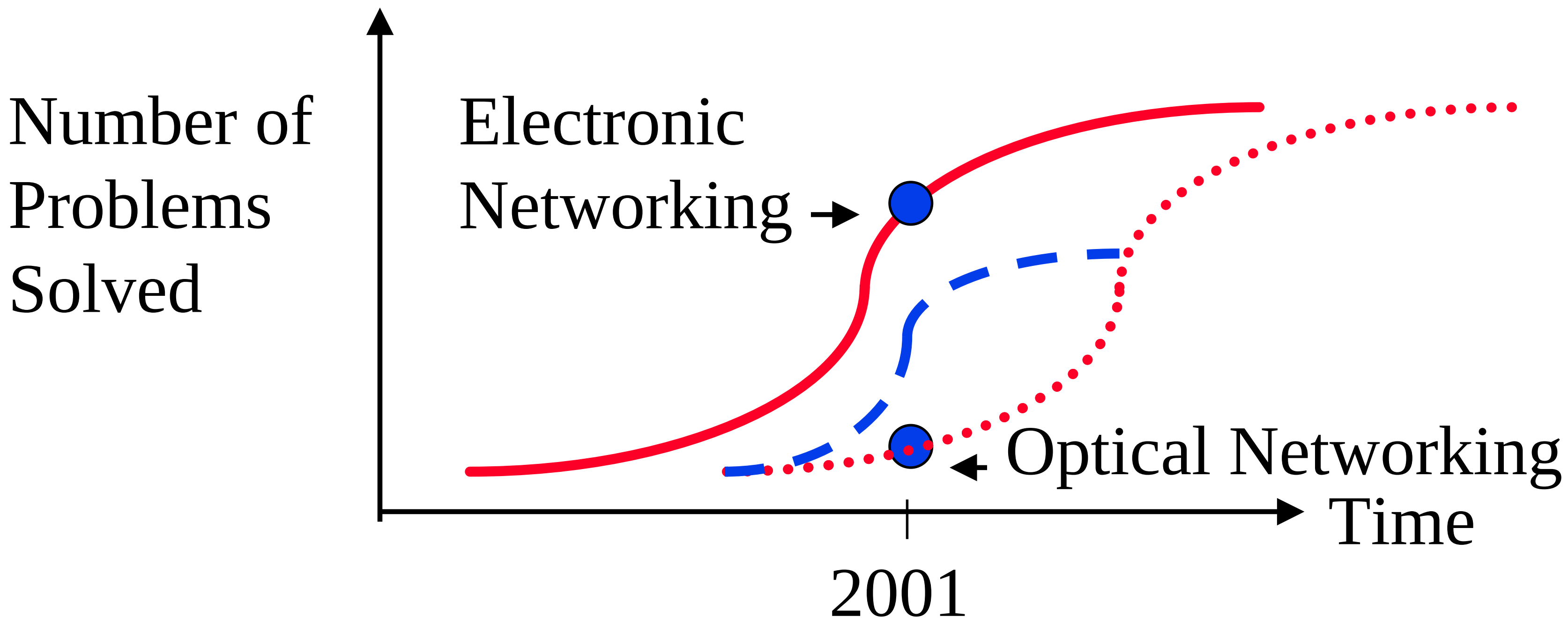
Future

Is there any future in optical networking?

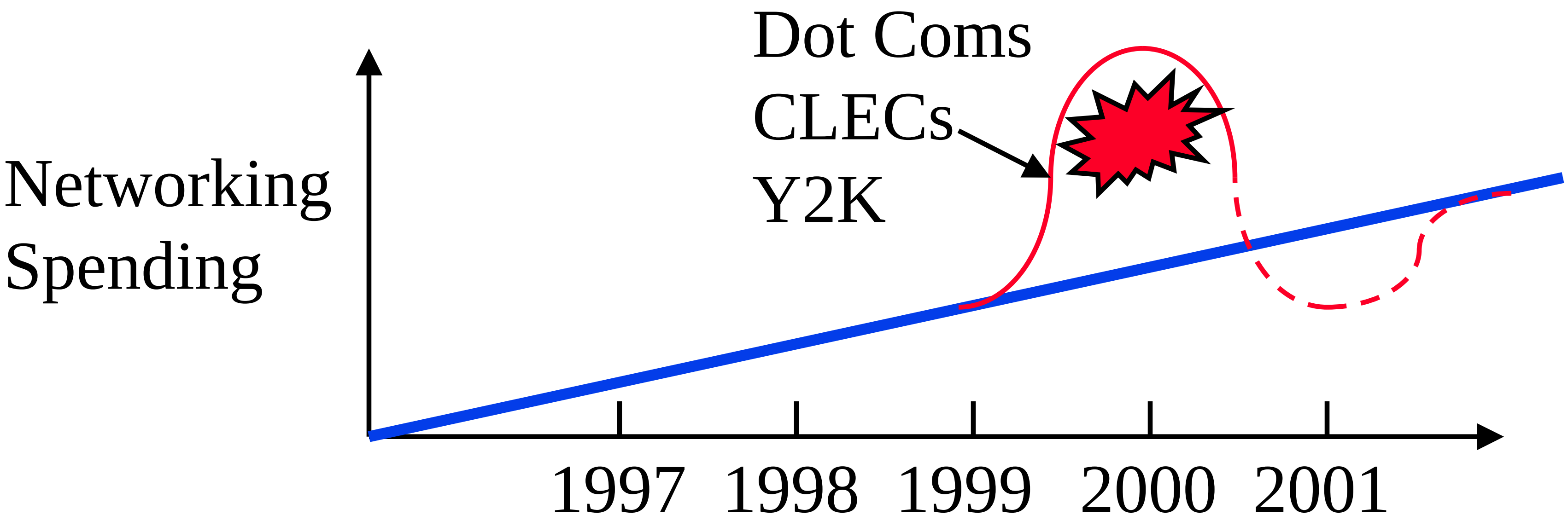
Life Cycles of Technologies



Life Cycles of Technologies



The Bubble

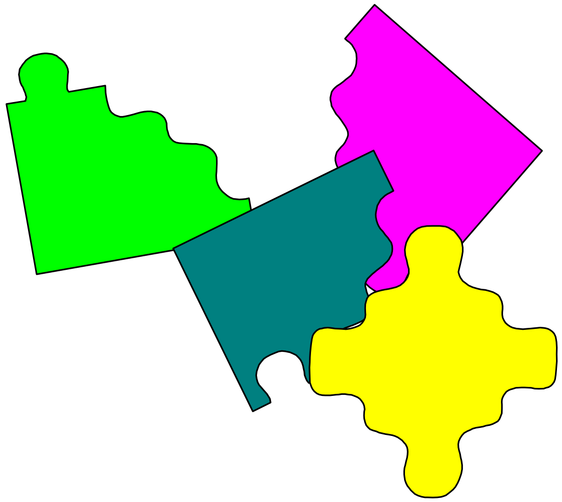


- Sidgmore: Internet Traffic doubling every 40 days, 30 days, …⇒ Over-projection data networking equipment
- Nearly 1/3 of all tech IPOs over the last 21 years happened in 1999 and 2000. Source:Morgan Stanely/Chi at Opticomm

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

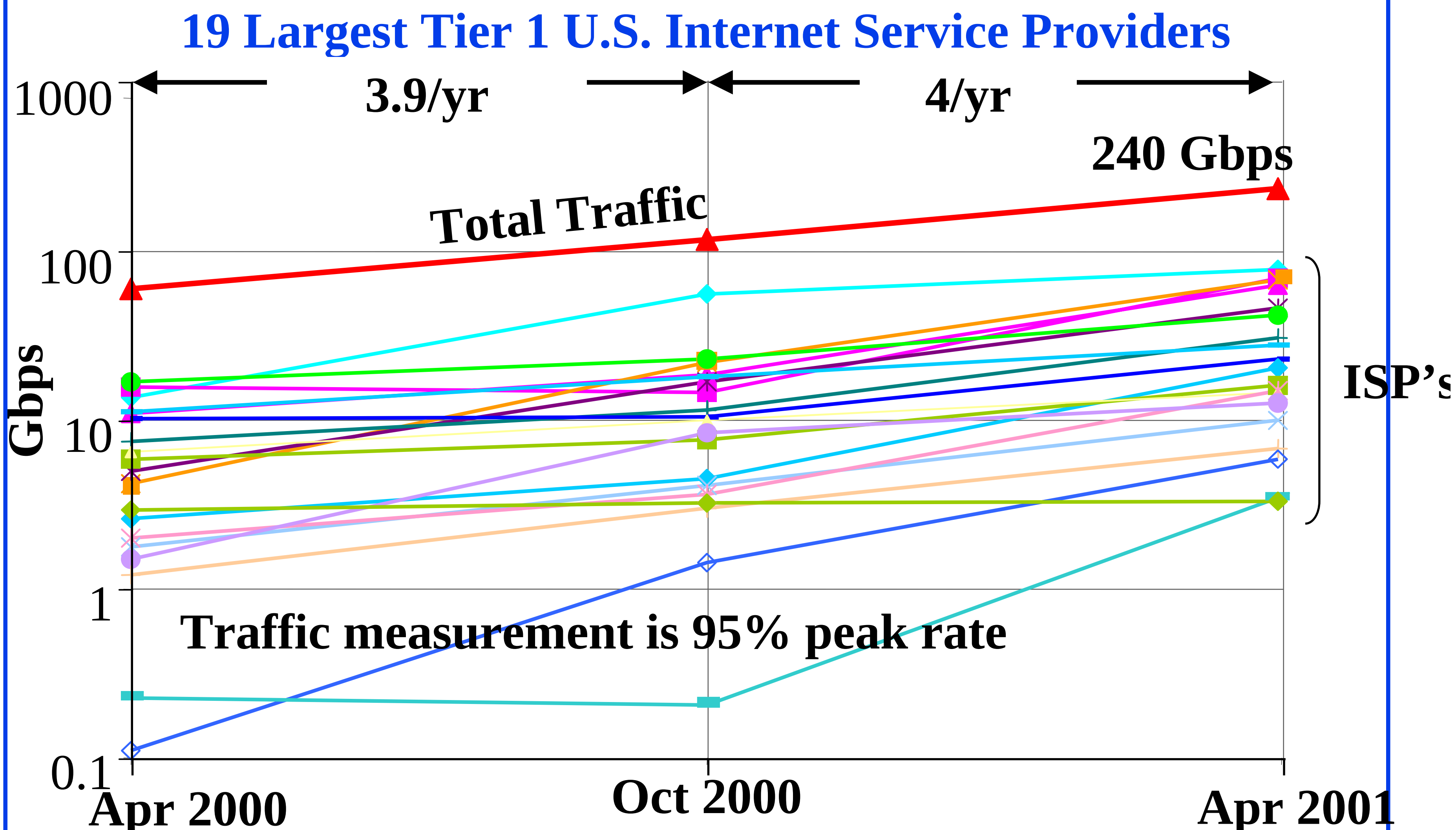
Is Internet Growing?

- 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, Marril Lynch & Co. in Wall Street Journal

Internet Growth (Cont)

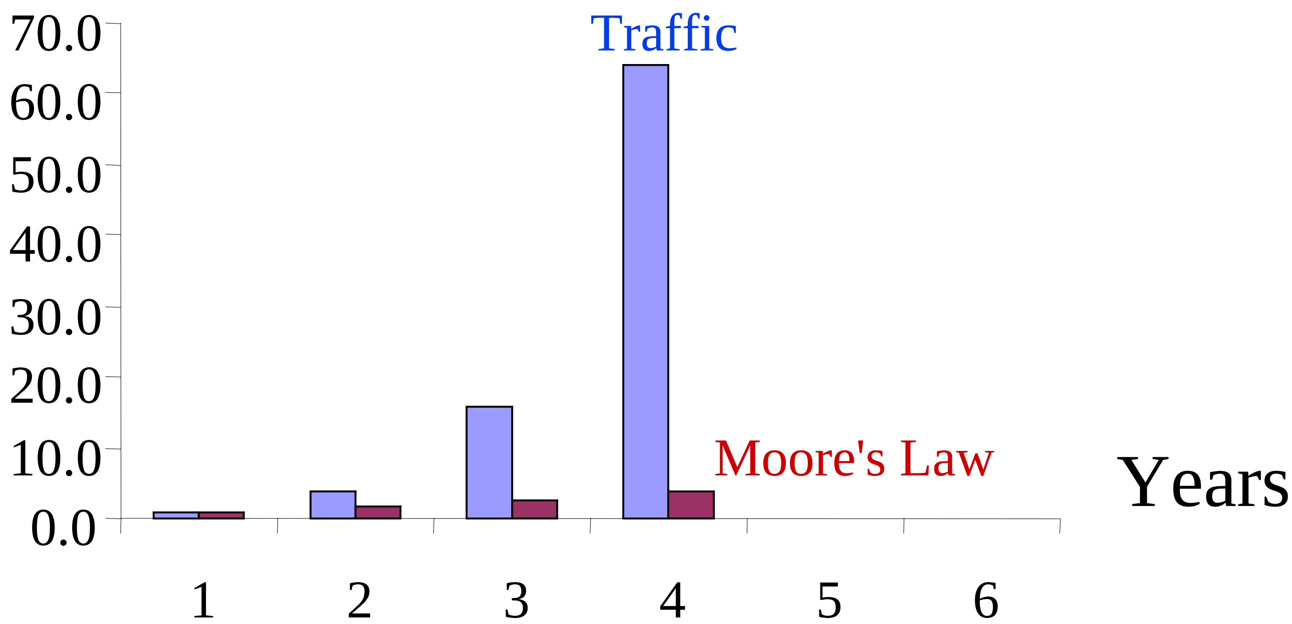
- Demand on 14 of 22 most used routes exceeds 70%
  -Telechoice, July 19, 2001
- Traffic grew by a factor of 4 between April 2000-April 2001
  -Larry Roberts, August 15, 2001

Robert's Traffic Measurements



Source: L. Roberts at Opticomm 2001

Moore's Law is Too Slow



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

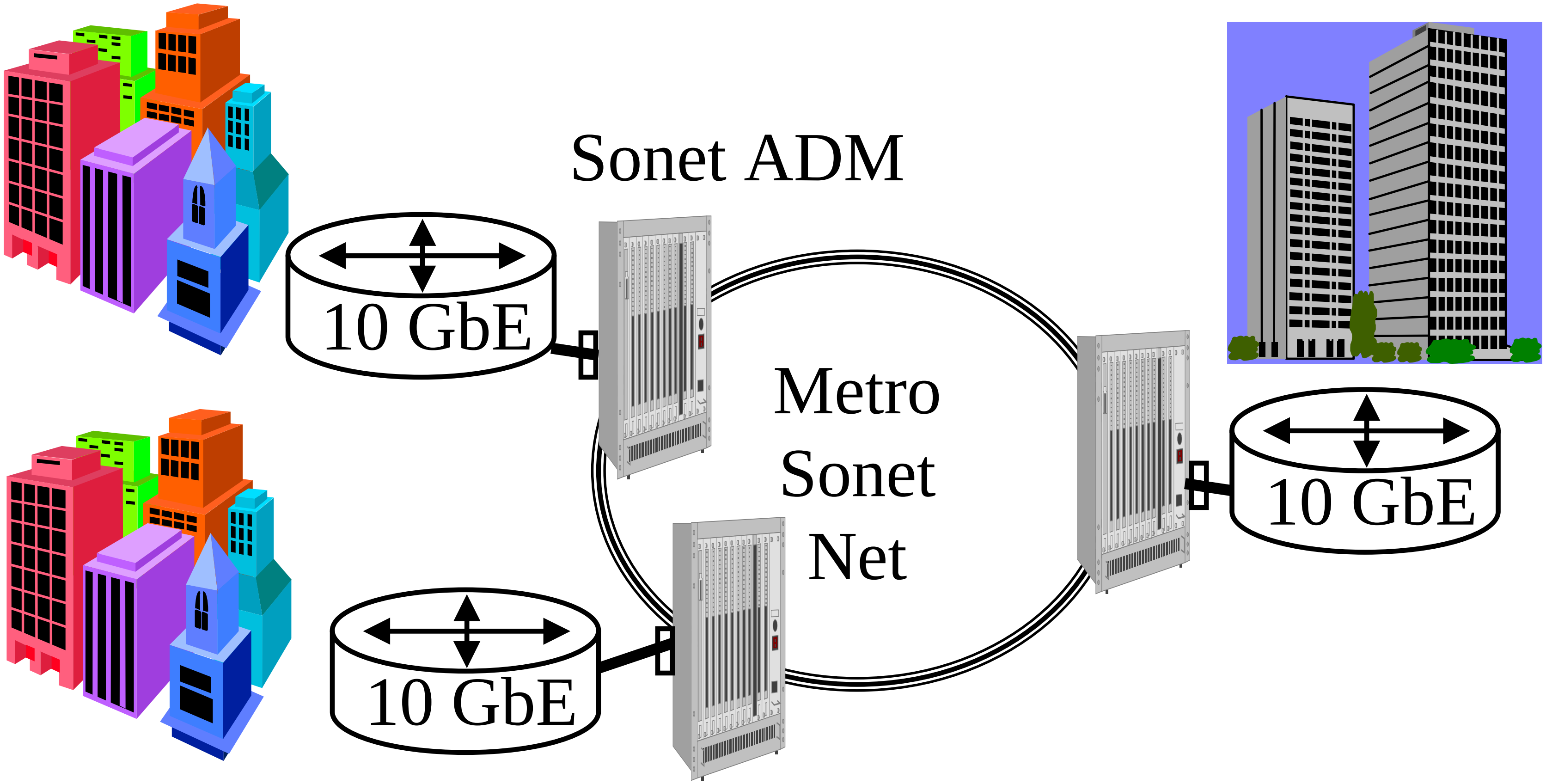
OEO vs OOO

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

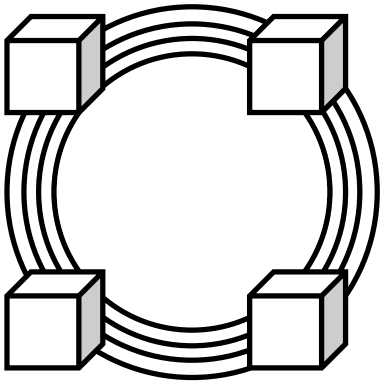
Ethernet vs Sonet

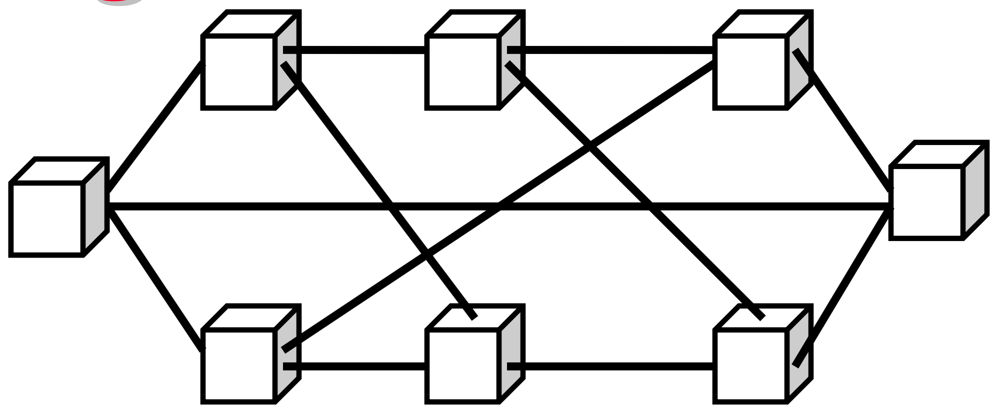
Feature	**SONET**	**Ethernet**
Bit Rate (bps)	155 M, 622 M, 2.5 G, 10 G, 40 G, …	1M, 10 M, 100 M, 1 G, 10 G, …
Timing	Isochronous (Periodic 125μs)	Plesio-Isochronous
Multiplexing	Bit	Packet
Clocks	Common	Independent
Clock jitter	*4.6 to 20* ppm	100 ppm (May change)
Usage	Telecom	Enterprise
Volume	Millions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

Ethernet: Future Possibilities

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

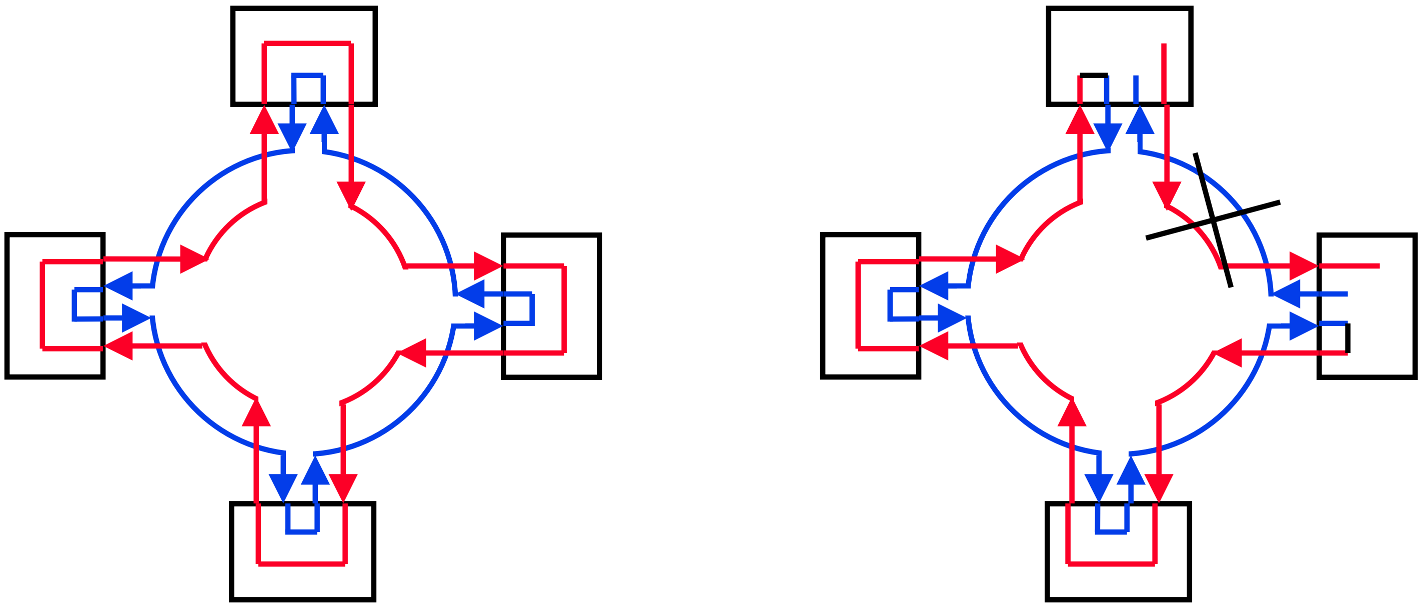
Ring vs Mesh





- On rings: All links same capacity ⇒ 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

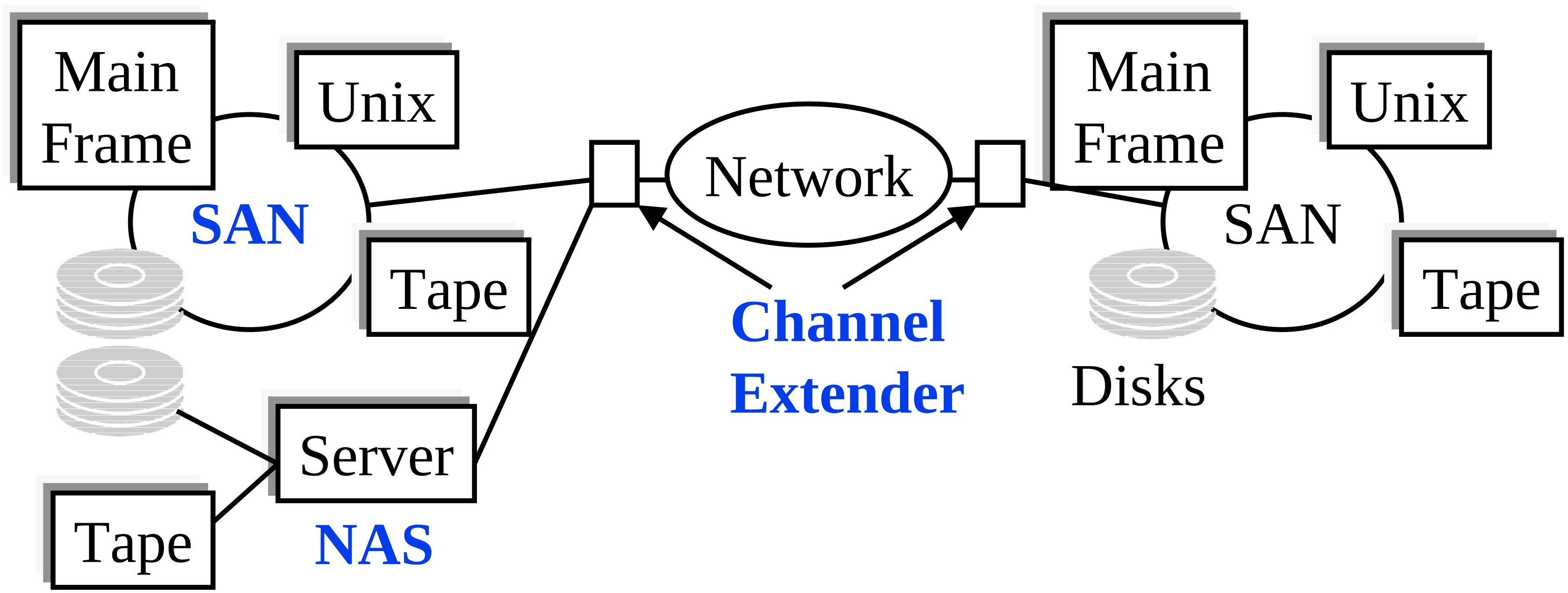


- Dual Counter-rotating rings help protect against failure
- Used in SONET and FDDI
- Need to bring these concepts to Ethernet and IP

New Developments

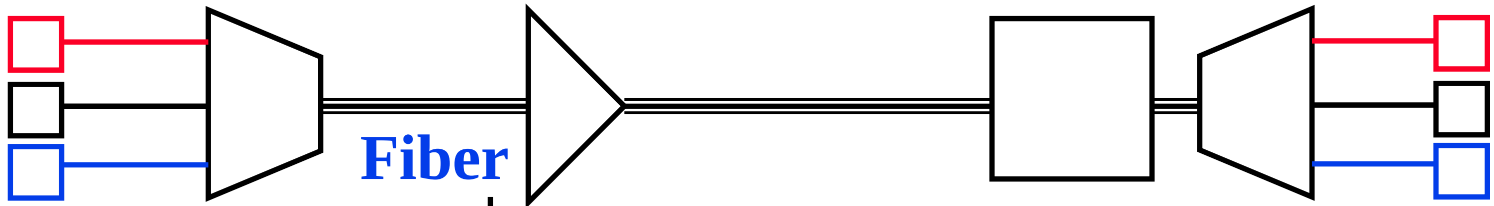
1. New Applications: Storage, VPN, LAN extension, Data hosting
2. Higher Speed: 40 Gbps
3. More Wavelengths per fiber
4. Longer Distances
5. Larger Crossconnects
6. Newer places to install fibers

Storage: New Traffic Demands



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

40 Gbps



Transmitter Sources, Modulators, Wavelockers

Mux/Demux Filters, Interleavers

Amplifier Gain Equalizers, Performance Monitors

Dispersion compensators
PMD compensators

Switching ADM

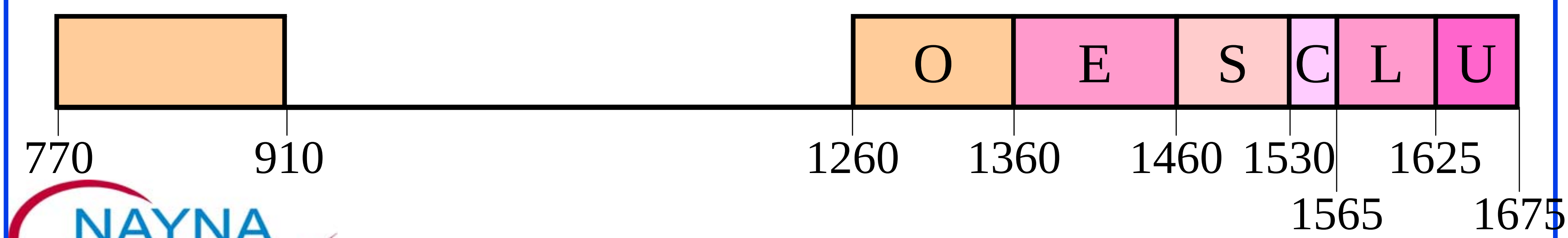
Receivers Detectors

- 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) ⇒ 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)

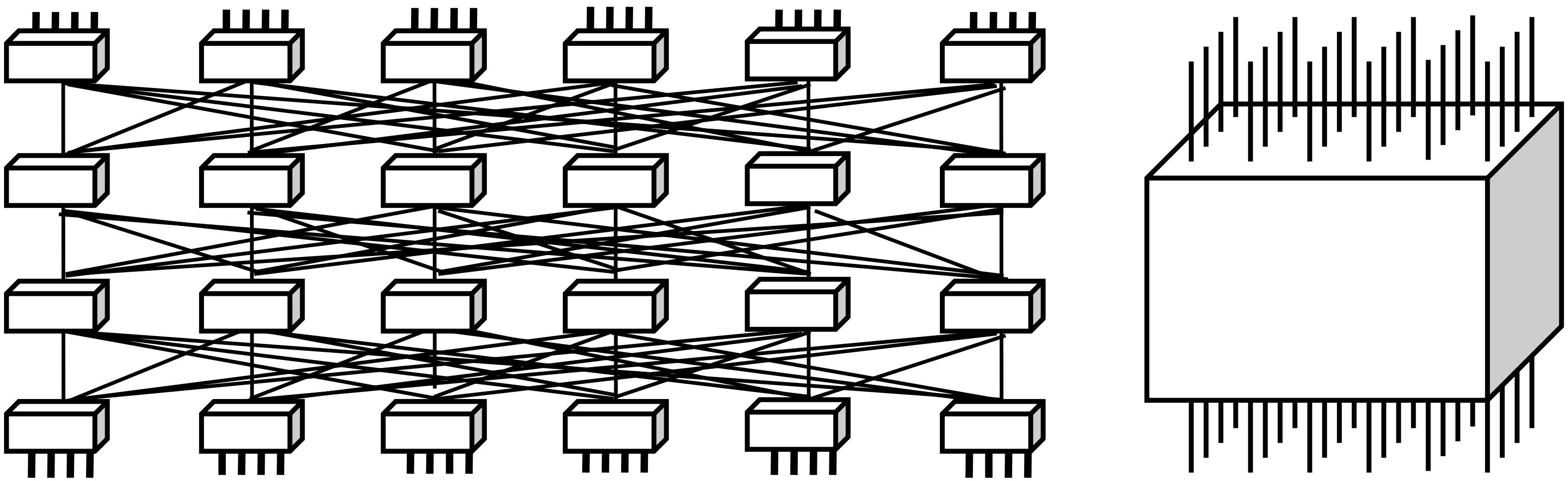
Ultra-Long Haul Transmission

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
  $\Rightarrow$ 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)
  $\Rightarrow$ Larger number of ports per router
  E.g., Avici
- Also, larger # of wavelengths per fiber

Trend: Larger Crossconnects

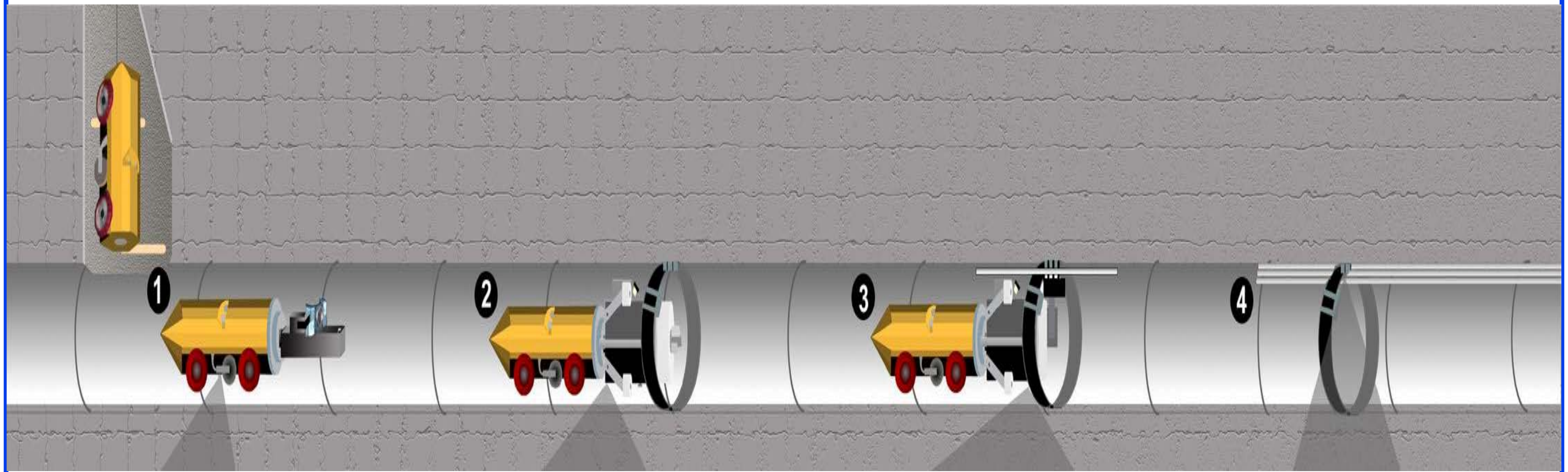


- Example: 24×24 using 4×4 switches ⇒ 24 switches ⇒ 48 External ports, 8×24=192 total ports ⇒ 25% port efficiency
- Crossconnect or routers with large number of ports are more cost effective

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

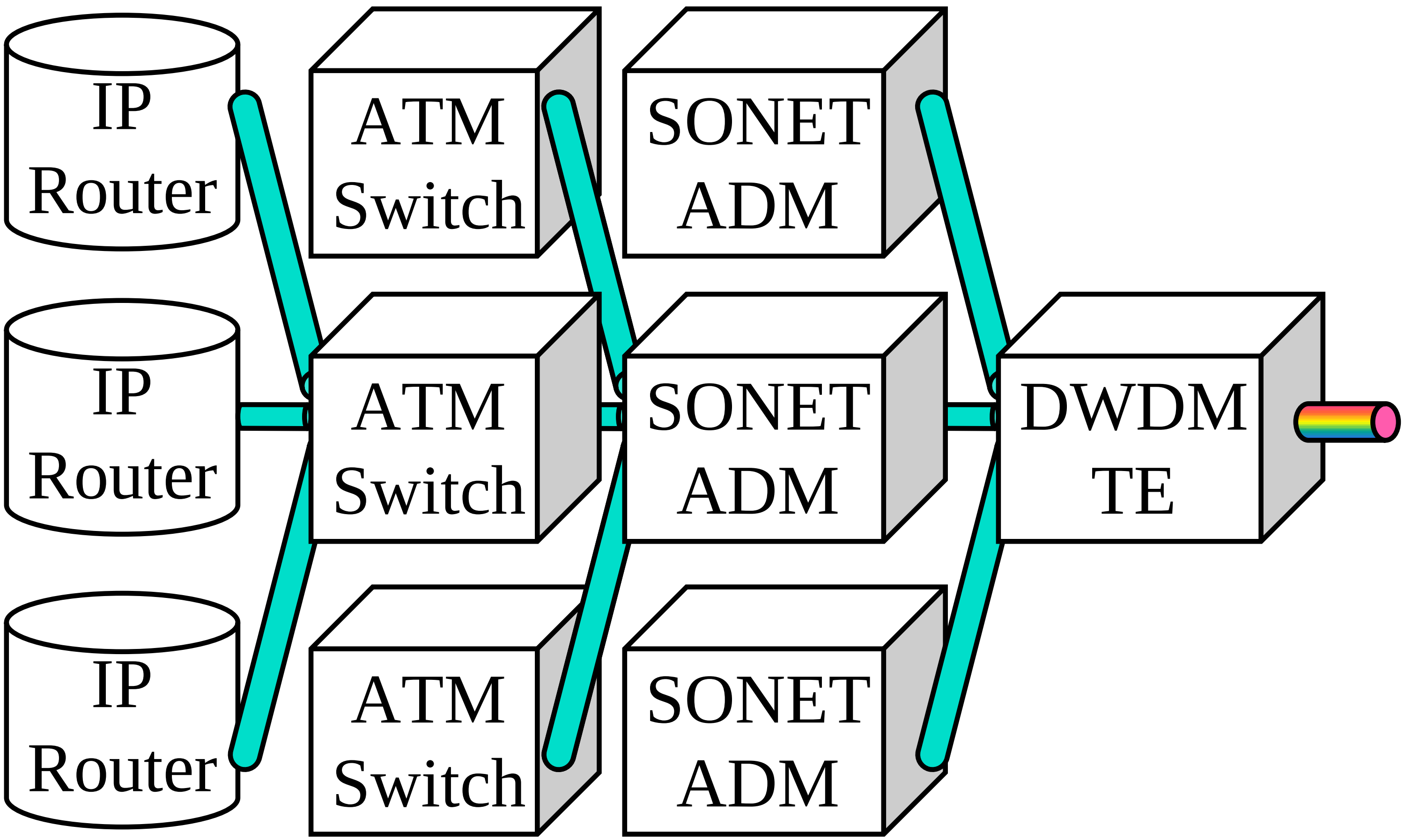
FAST Installation



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)

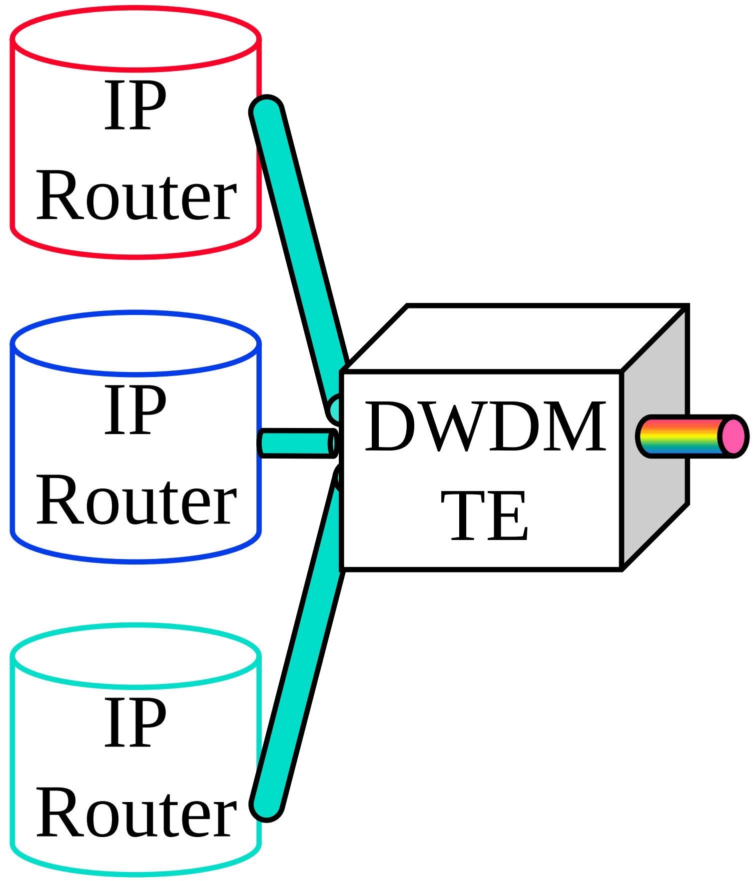


IP over DWDM: Protocol Layers

1993	1996	1999	2001	2003
IP	IP	IP/MPλS	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

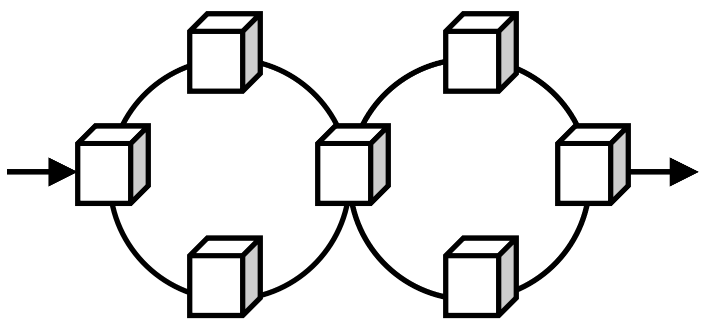
- IP is good for routing, traffic aggregation, resiliency
- ATM for multi-service integration, QoS/signaling
- SONET for traffic grooming, monitoring, protection
- DWDM for capacity
- Problem: Restoration in multiple layers, Sonet Manual
  $\Rightarrow$ Intersection of features and union of problems

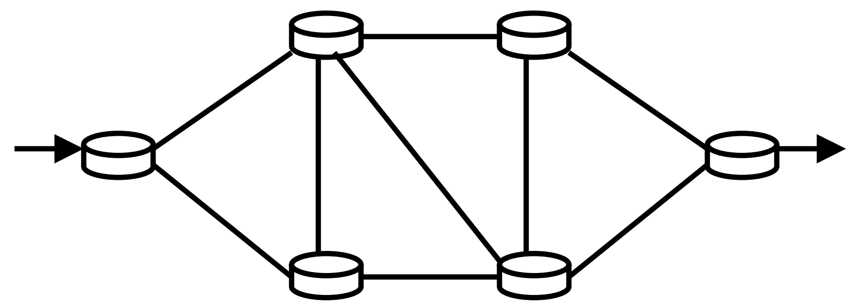
IP over DWDM (Future)



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

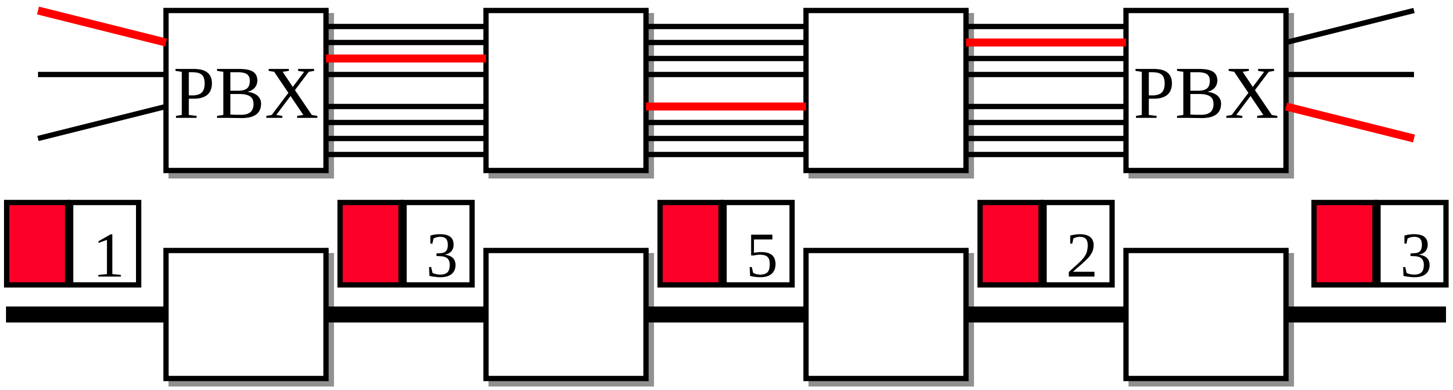




IP over DWDM Issues

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

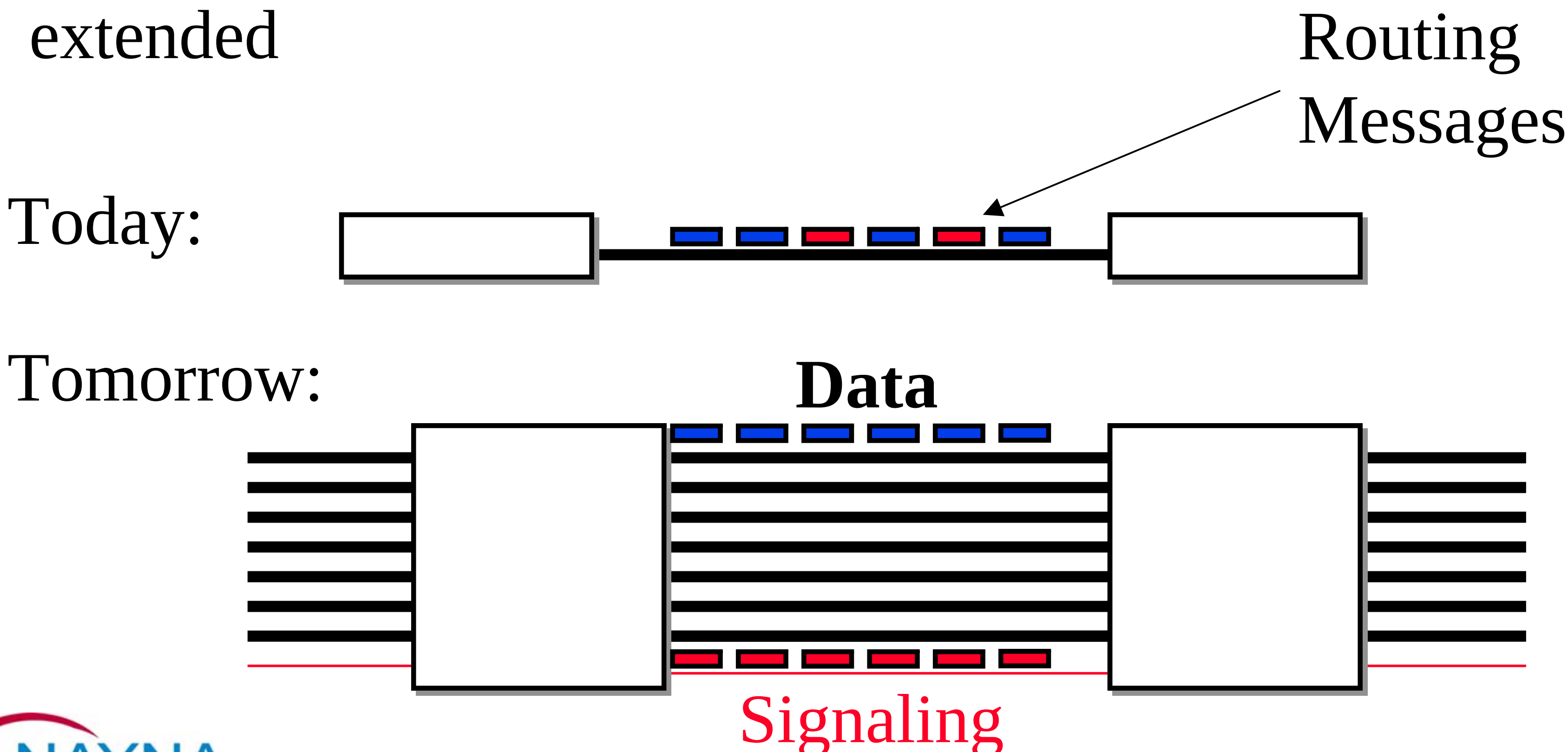
Multiprotocol Label Switching (MPLS)



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

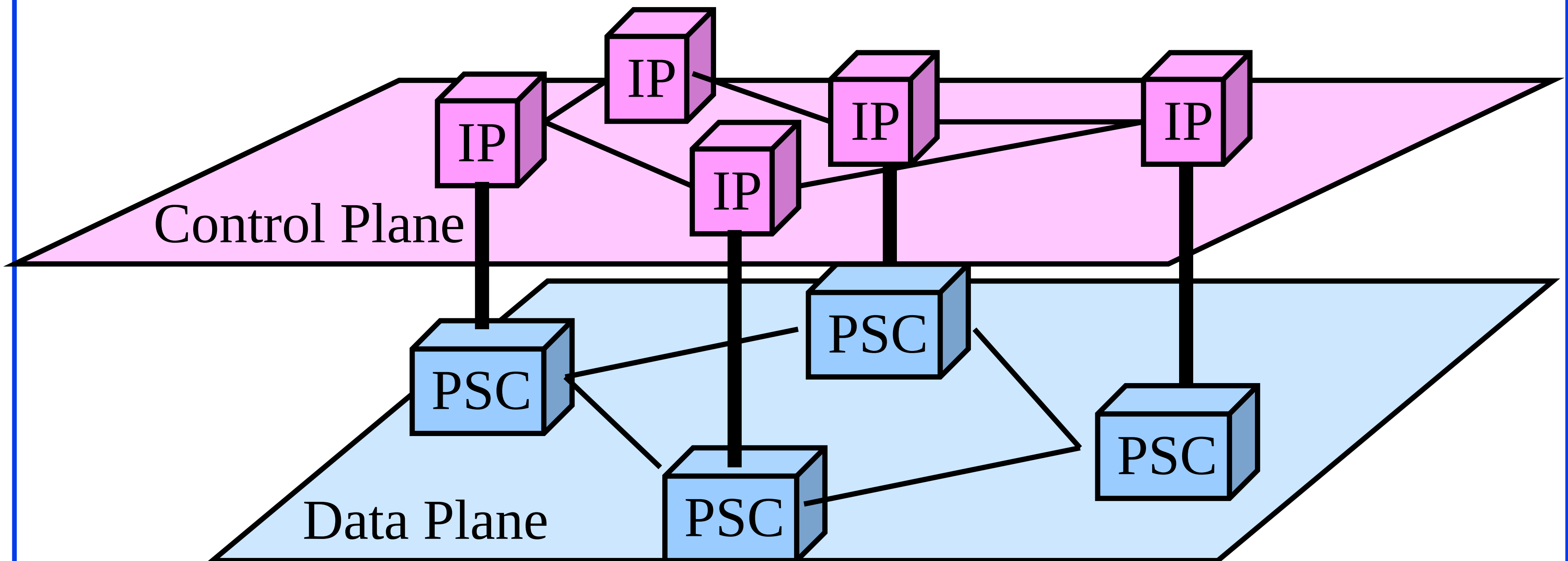
Issue: Control and Data Plane Separation

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



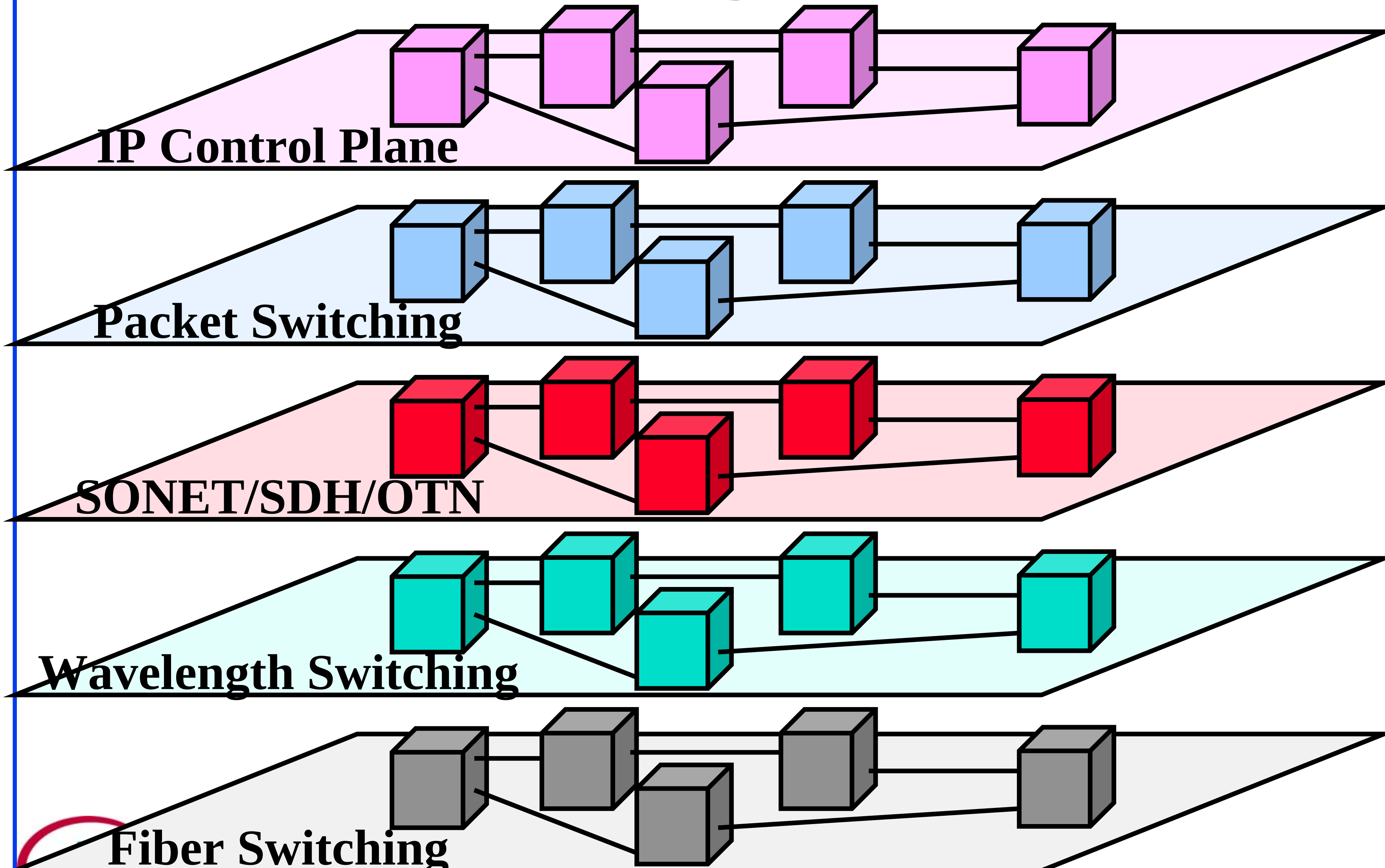
IP-Based Control Plane

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



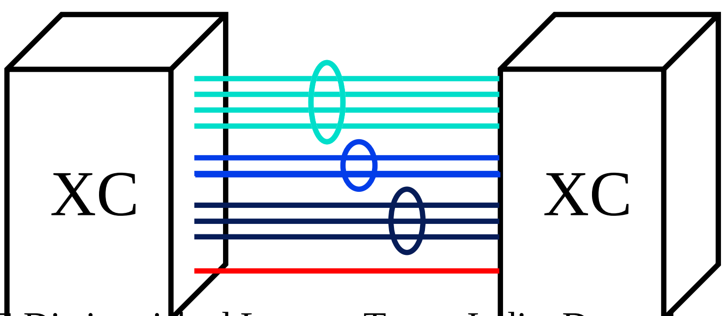
PSC = Packet Switch Capable Nodes

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	Unnumberred
Fault Detection	In-band	Out-of-band or In-Band

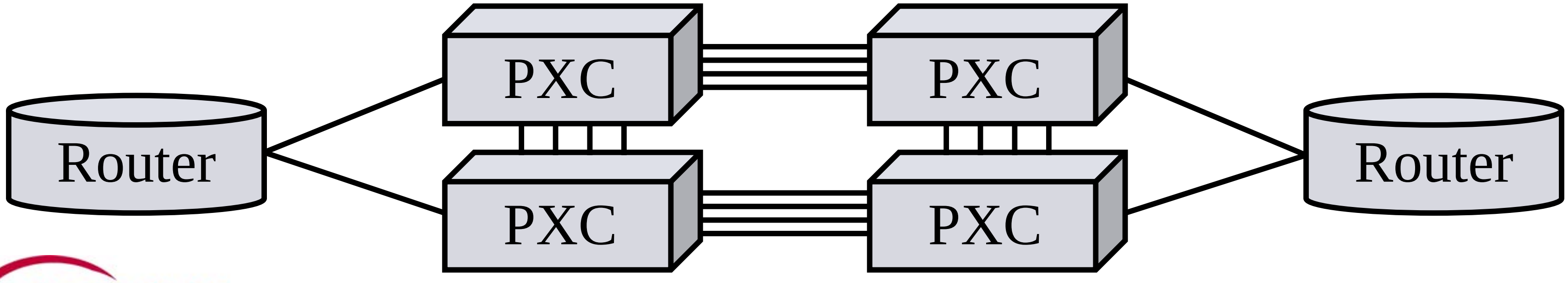


Current Issues

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

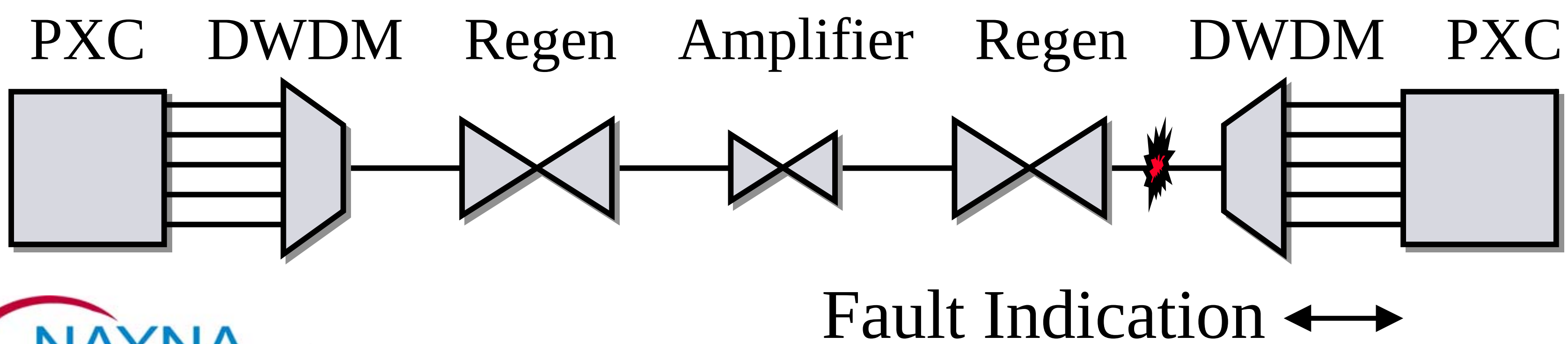
Protection and Restoration

- 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

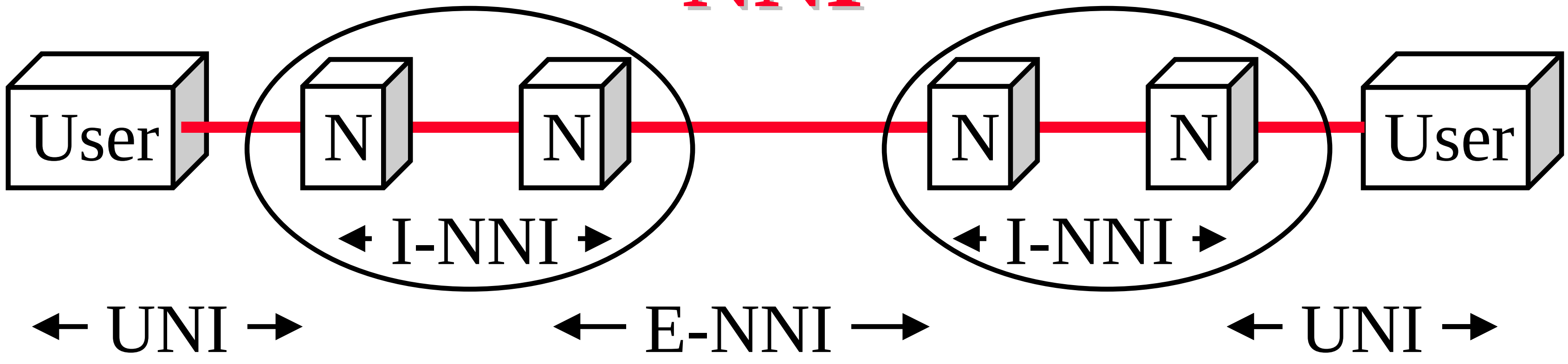


Fault Detection and Isolation

- 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

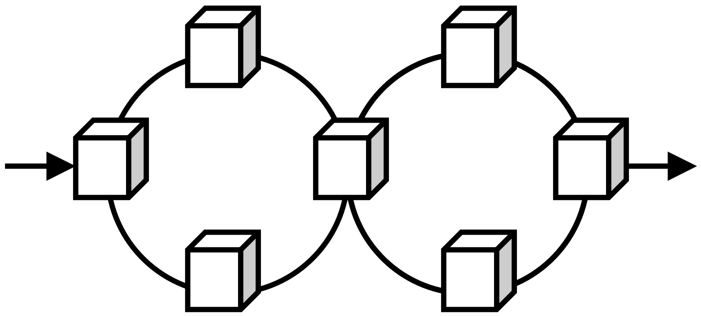


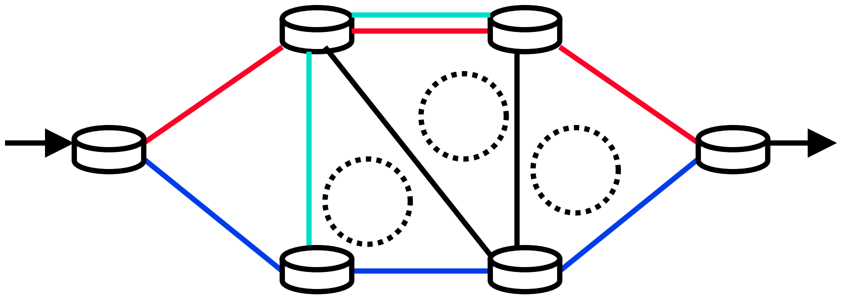
NNI



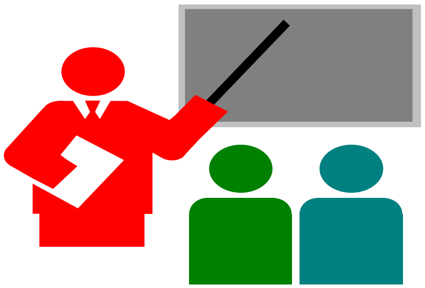
- NNI = Network to Network or
  Node-to-Node or
  Network-to-Node Interface
- Examples: Open Shortest Path First (OSPF)
  Private Network to Node Interface (PNNI)
- OIF is starting a new project on NNI

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