Optical Networks: Recent Advances, Trends, and Issues

Raj Jain

Raj Jain is now at
Washington University in Saint Louis
Jain@cse.wustl.edu
http://www.cse.wustl.edu/~jain/

These slides are available at:

http://www.cis.ohio-state.edu/~jain/talks/opnet01.htm

NAYNA Networks

1. Market Developments
2. Hot Issues
3. Technology Developments
4. Research Topics

Past...

Who started optical networking?

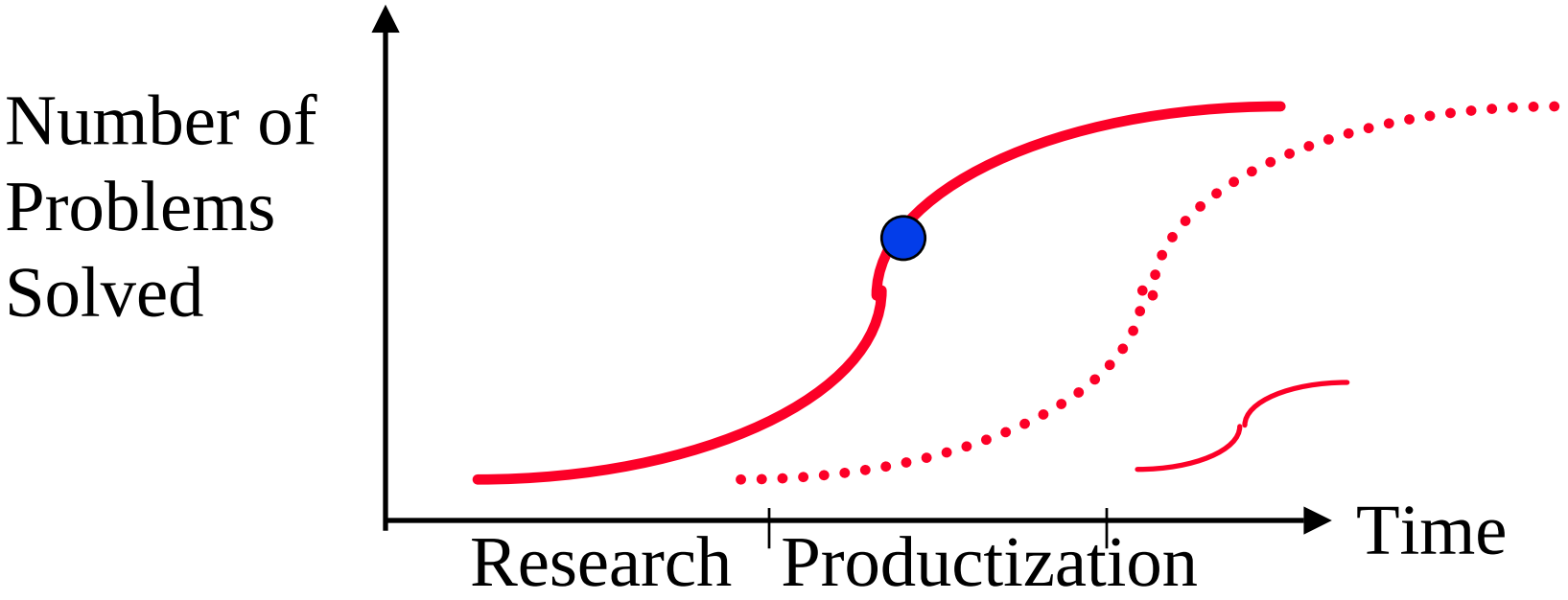
Present

What's happening in telecom?

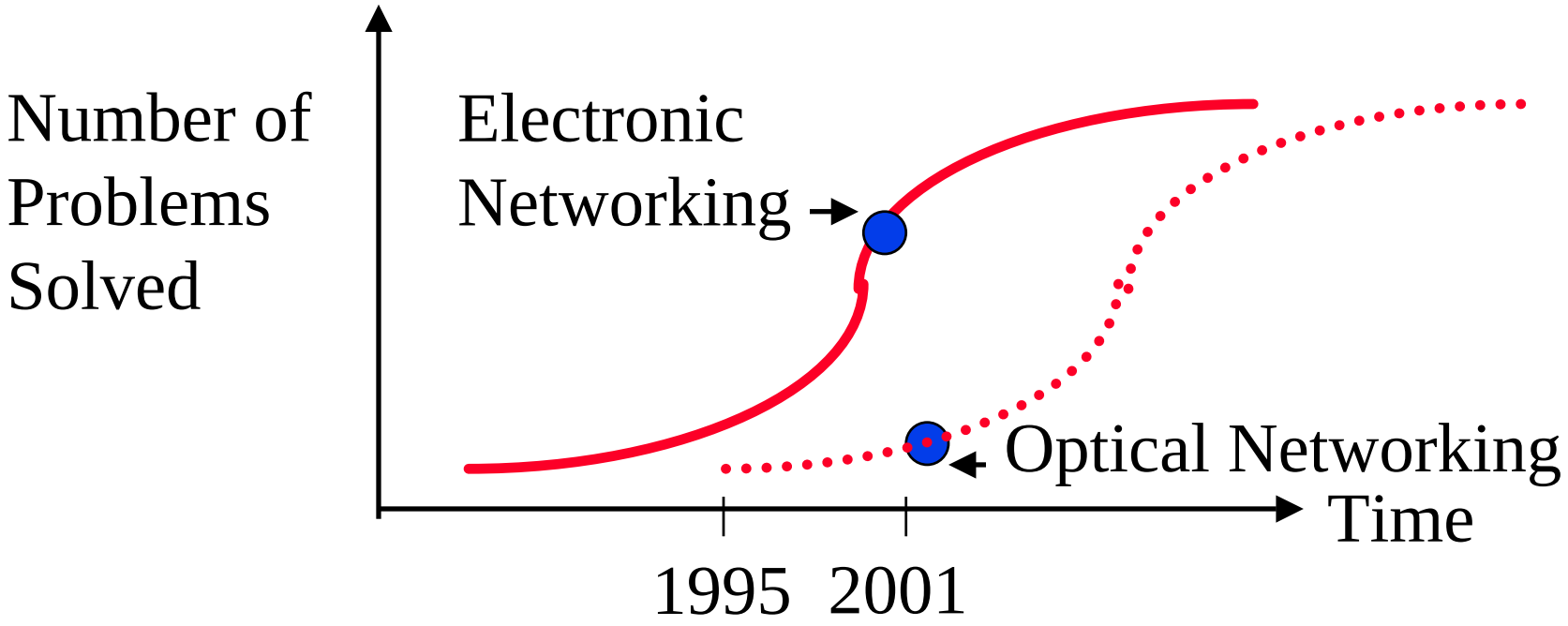
Future

Is there any future in optical networking?

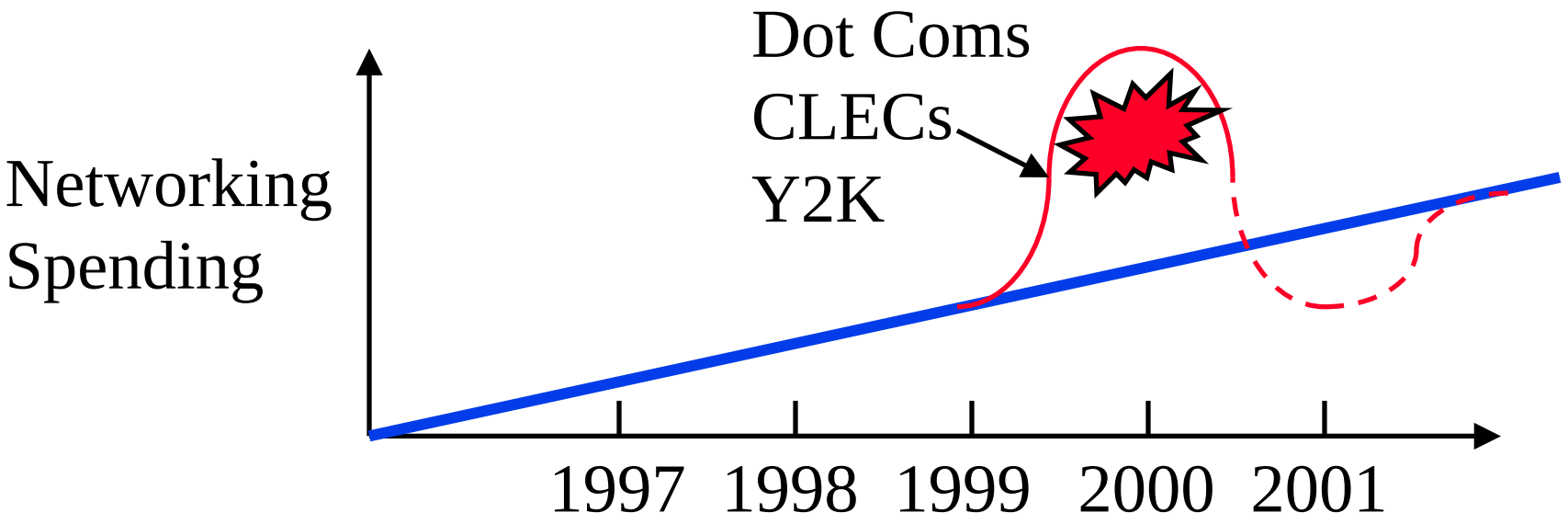
Life Cycles of Technologies



Life Cycles of Technologies



The Bubble

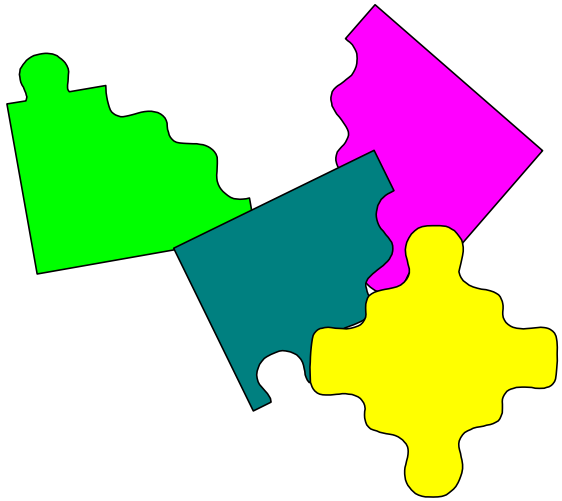


- Sidgmore: Internet Traffic doubling every 40 days, 30 days, …⇒ Over-projection data networking equipment
- Nearly 1/3 of all tech IPOs over the last 21 years happened in 1999 and 2000. Source:Morgan Stanely/Chi at Opticomm

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
   $\Rightarrow$ 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?

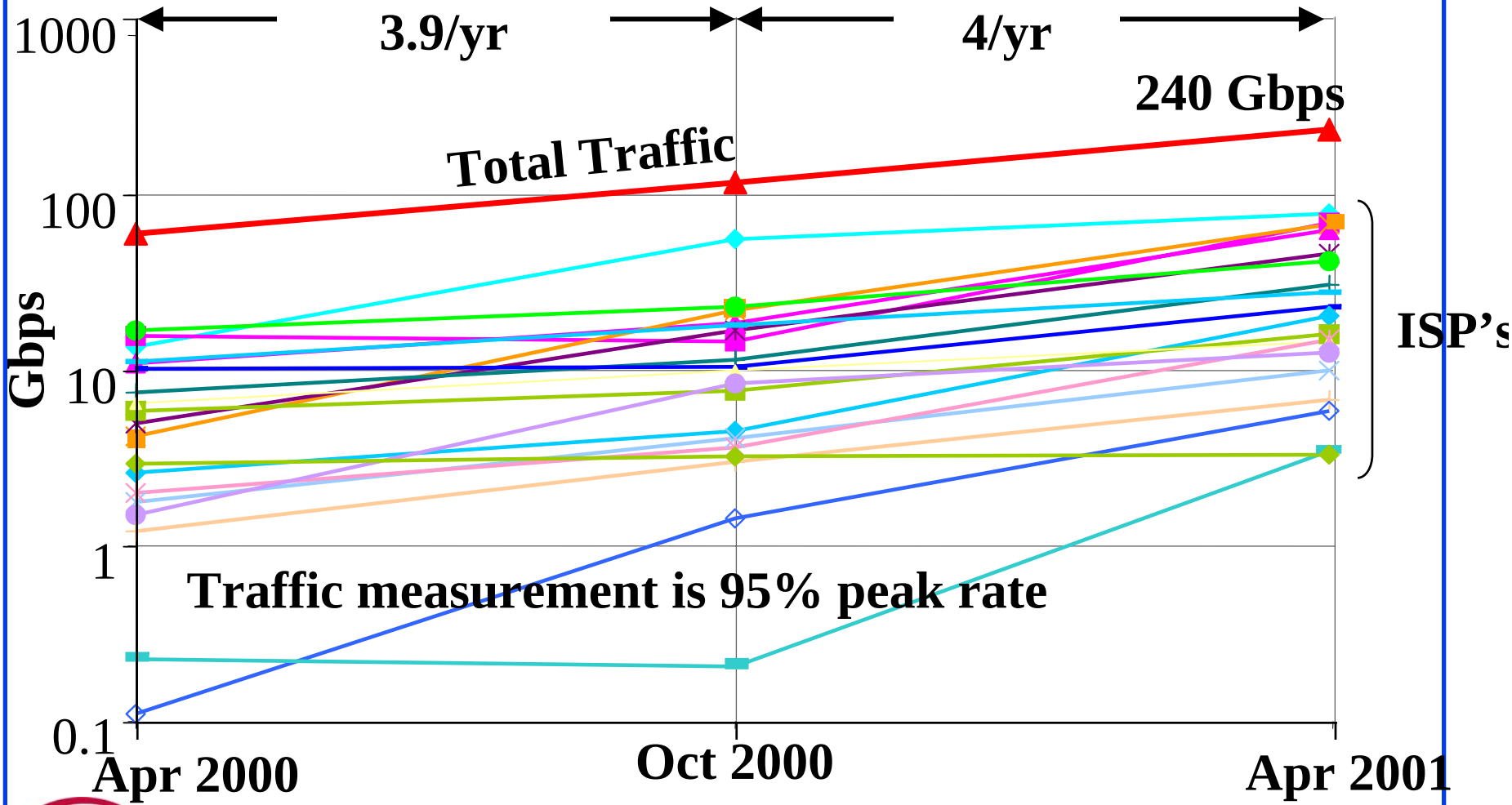
- IP Traffic Growth will slow down from 200-300% per year to 60% by 2005
  - McKinsey & Co and JP Morgan, May 16, 2001
- 98% of fiber is unlit - WSJ, New York Times, Forbes (Fiber is a small fraction of cost. Laying is expensive.)
- Nortel blamed sales decline on falling IP traffic
- Carriers are using 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

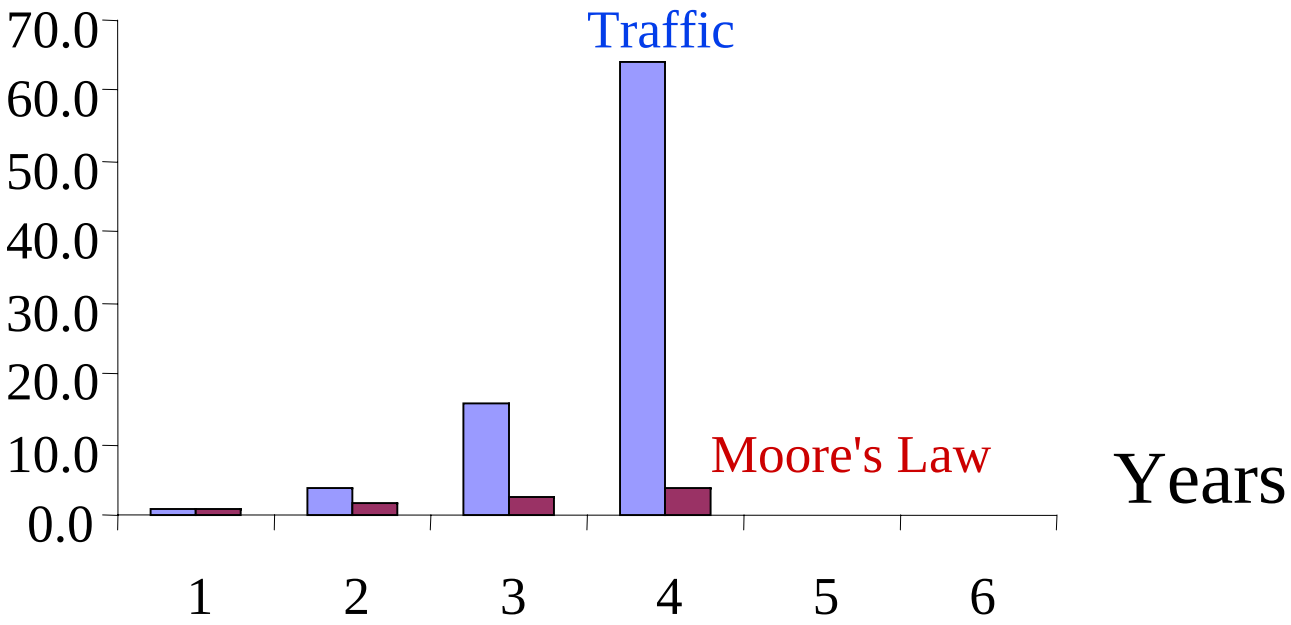
Robert's Traffic Measurements

19 Largest Tier 1 U.S. Internet Service Providers



Source: L. Roberts at Opticomm 2001

Moore's Law is Too Slow

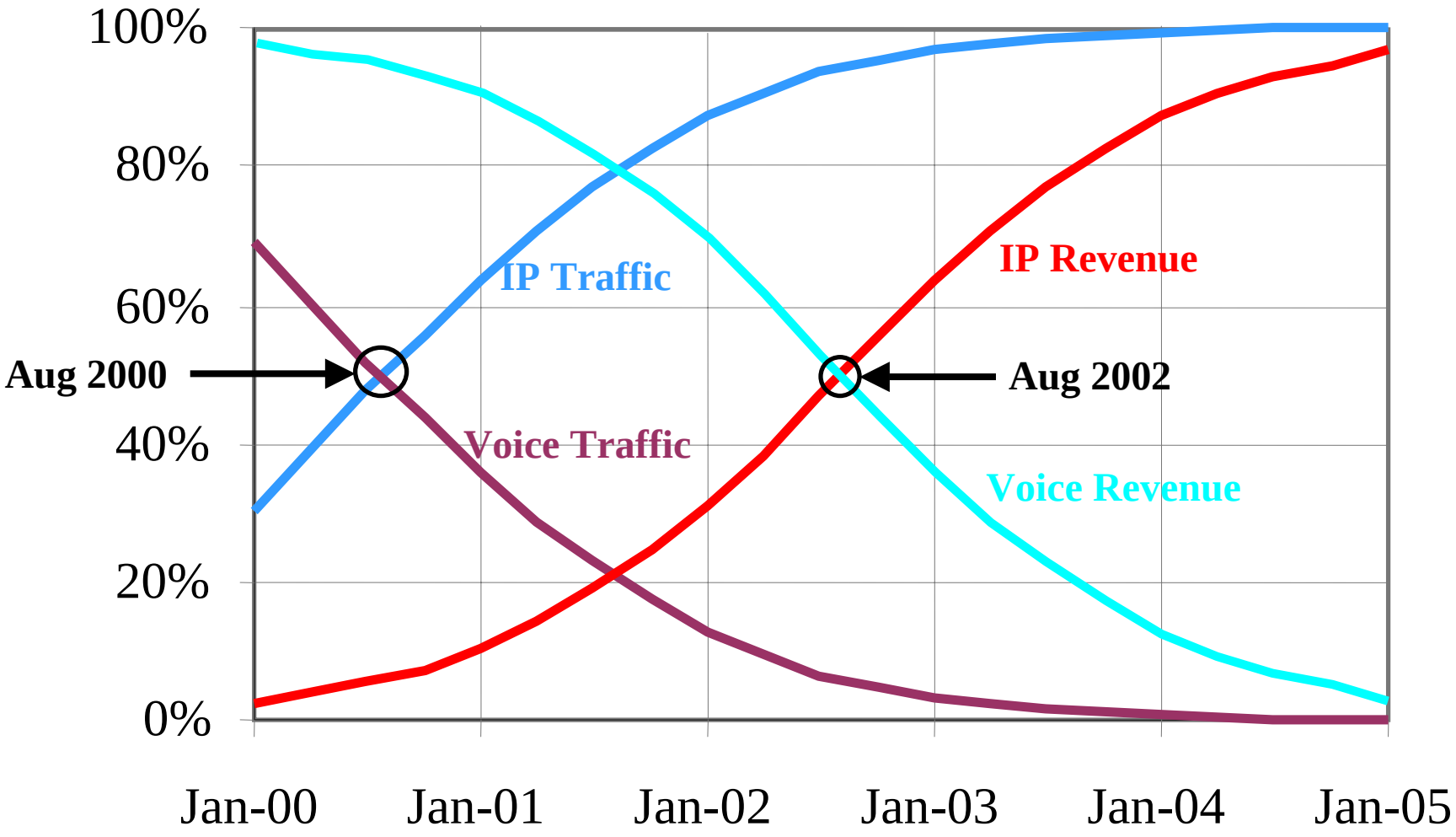


- Moore's Law: Factor of 2 every 1.5 years
  $\Rightarrow$ 60%/year
- Internet Traffic: Factor of 4 per year
  $\Rightarrow$ Need Optical Switching

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

Voice vs Data: Traffic vs Revenue

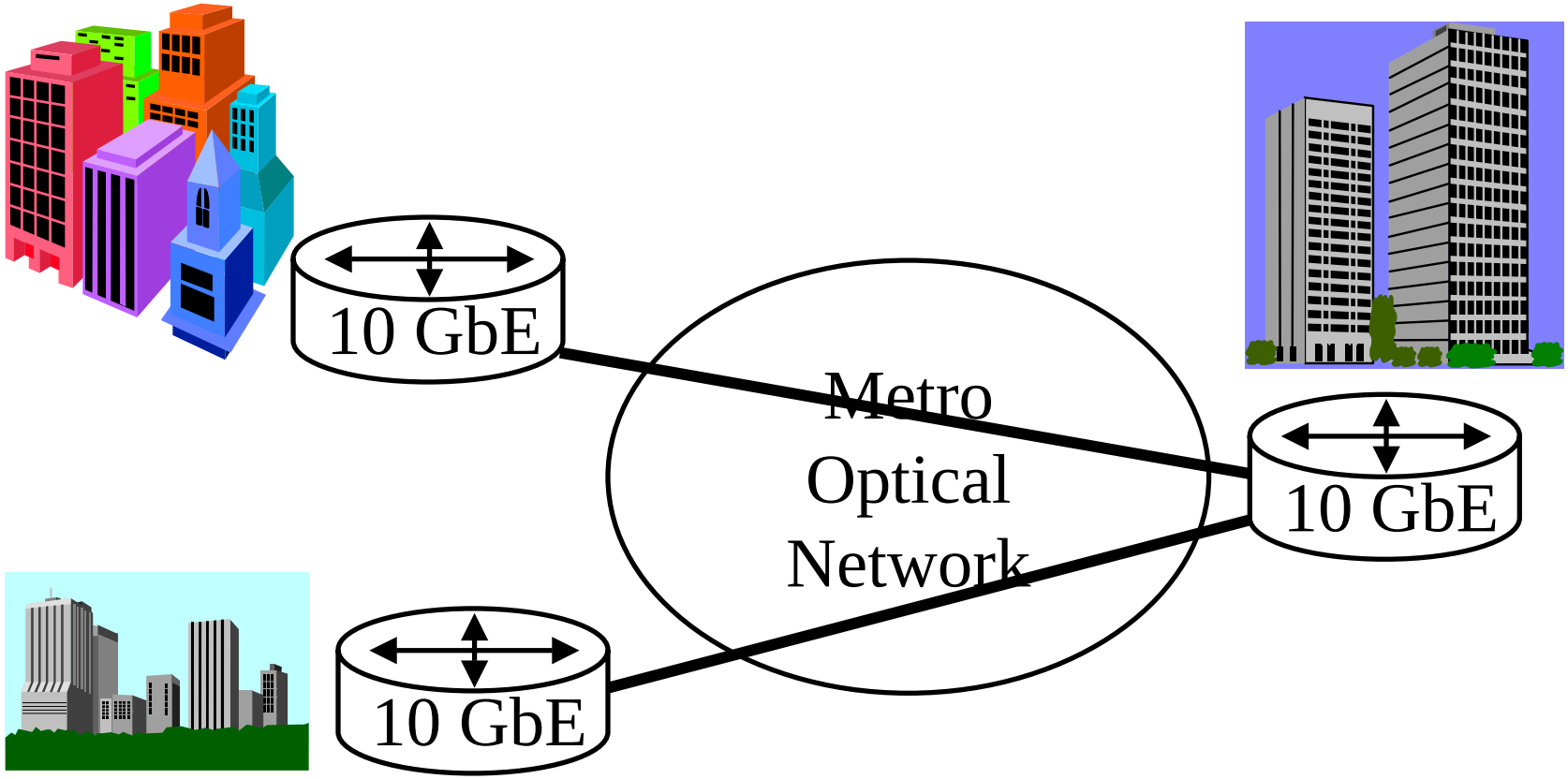


Source: L. Roberts at Opticomm 2001

10 G Ethernet

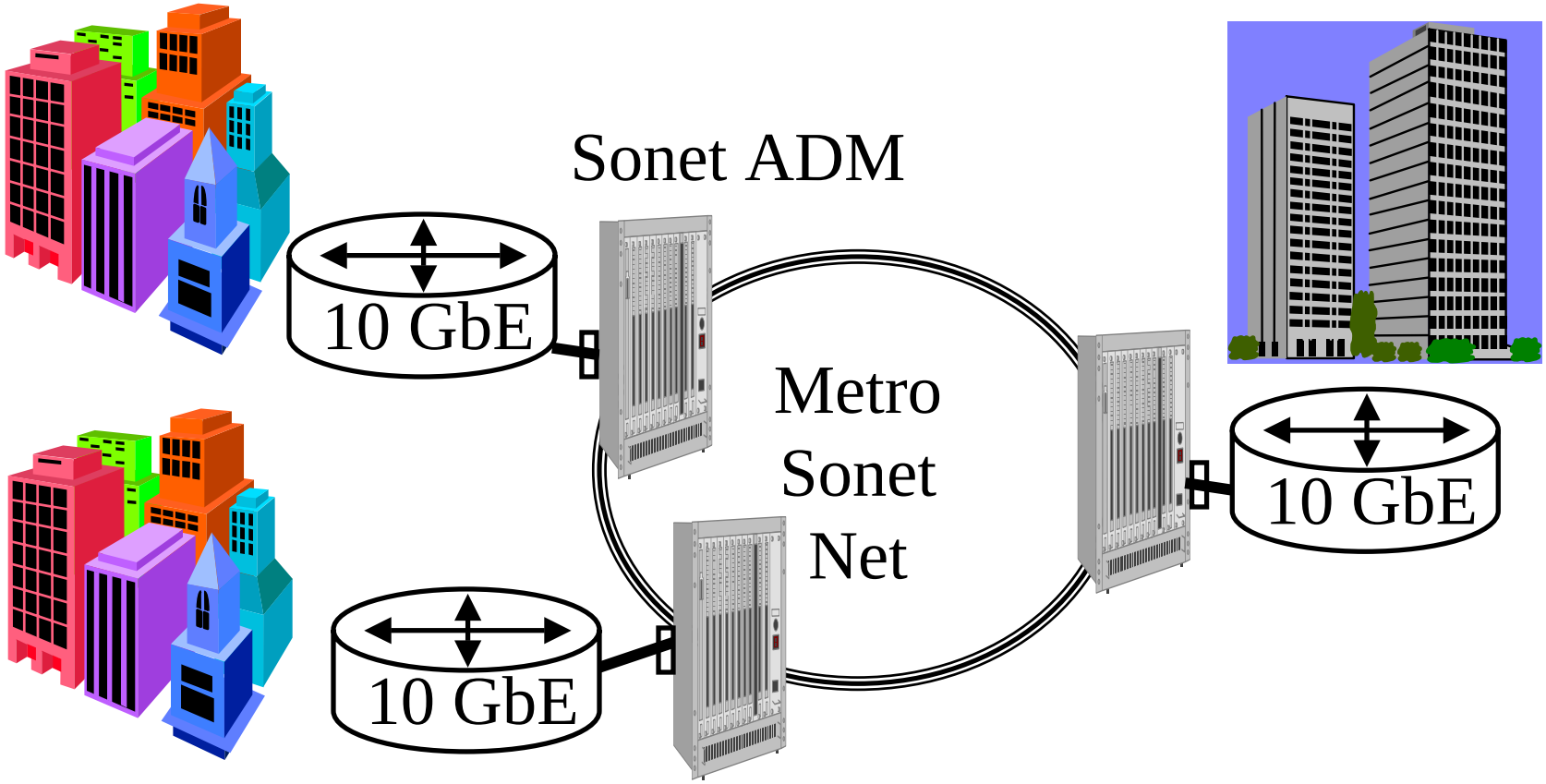
- Two versions: LAN (10 Gbps), WAN (9.5 Gbps)
- Point-to-point full duplex only
- Several different physical layer designs for different distances
- 9.5 Gbps WAN version compatible with SONET in data rate but incompatible in clock jitter
- Forty companies formed Metro Ethernet Forum formed to accelerate Ethernet in Metro. www.metroethernetforum.org

10 GbE over Dark Fiber



- Need only LAN PHY up to 40 km.
  No Sonet overhead. No protection.

10 GbE over Sonet/SDH



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

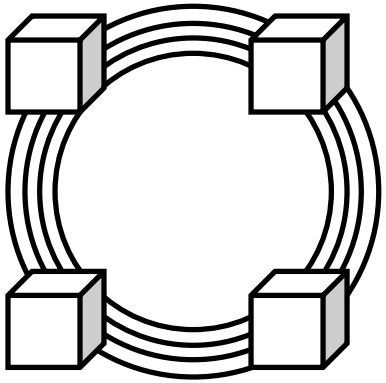
Ethernet vs Sonet

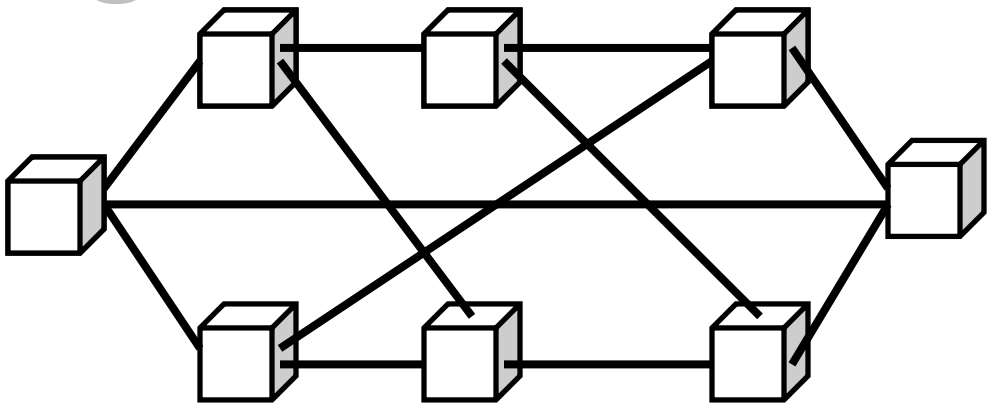
Feature	SONET	Ethernet
Bit Rate (bps)	155 M, 622 M, 2.5 G, 10 G, 40 G, …	1M, 10 M, 100 M, 1 G, 10 G, …
Timing	Isochronous (Periodic 125μs)	Plesio-Isochronous
Multiplexing	Bit	Packet
Clocks	Common	Independent
Clock jitter	*4.6 to 20* ppm	100 ppm (May change)
Usage	Telecom	Enterprise
Volume	Millions	100's 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

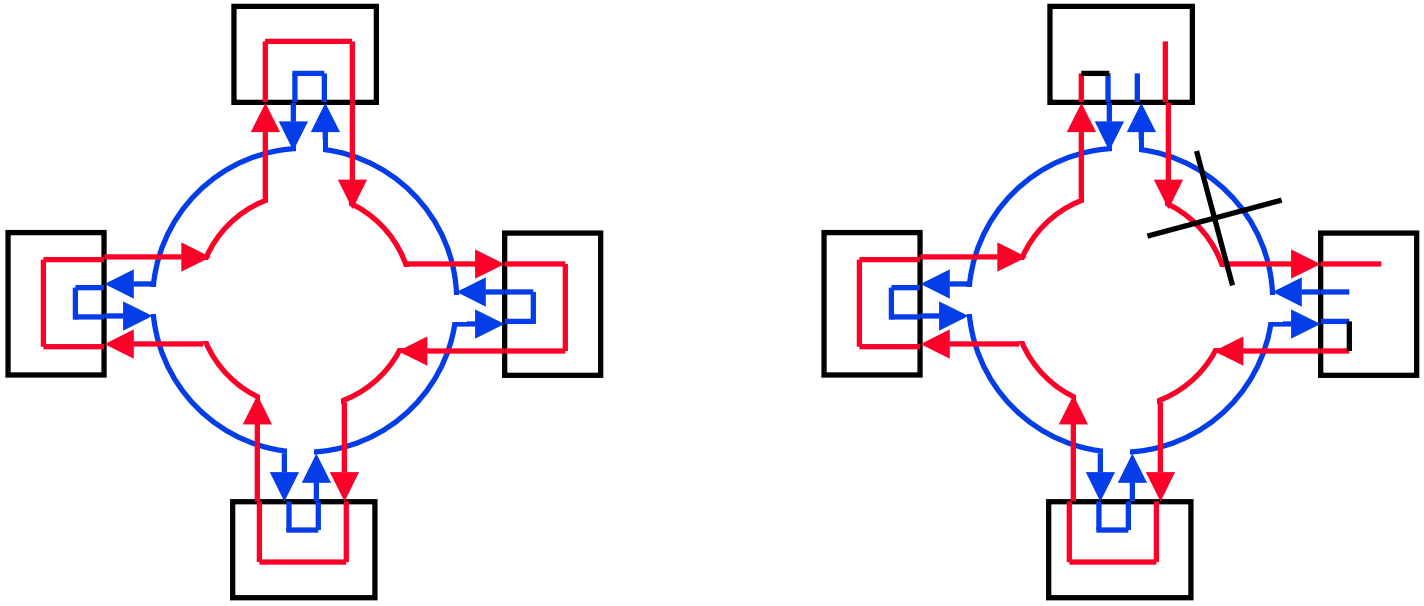
Ring vs Mesh





- 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

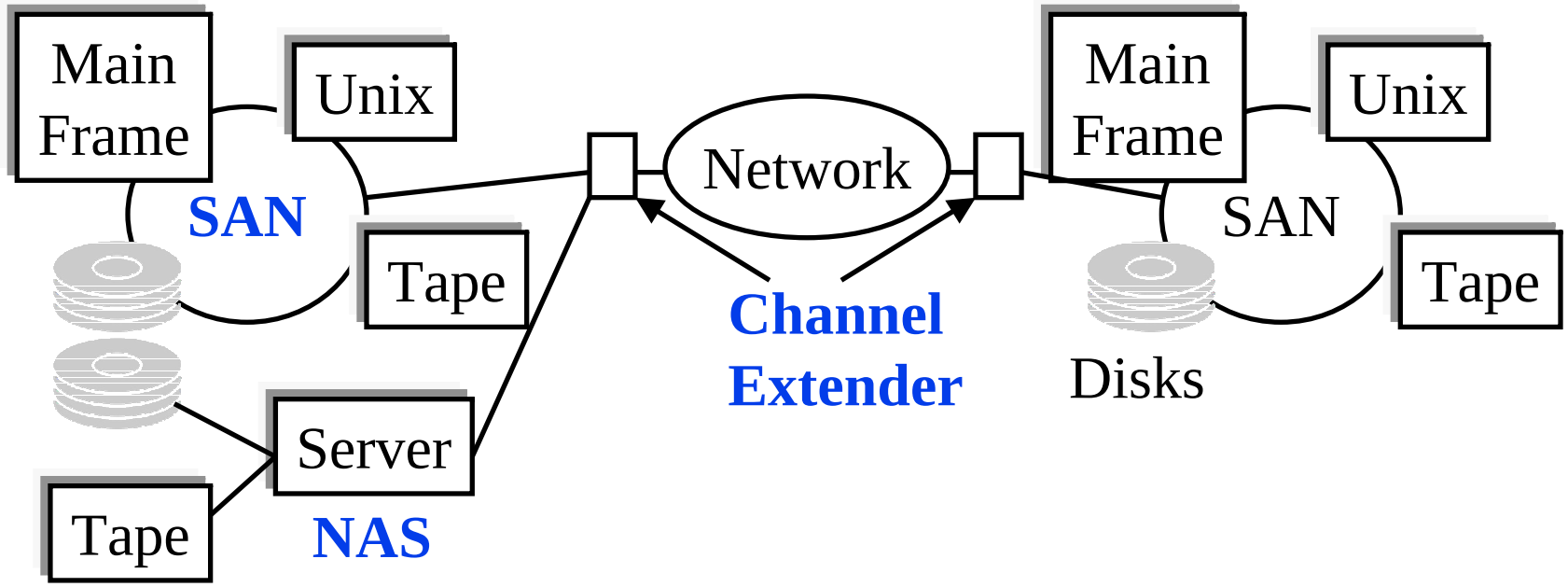


- Dual Counter-rotating rings help protect against failure
- Used in SONET and FDDI
- Need to bring these concepts to Ethernet and IP

New Developments

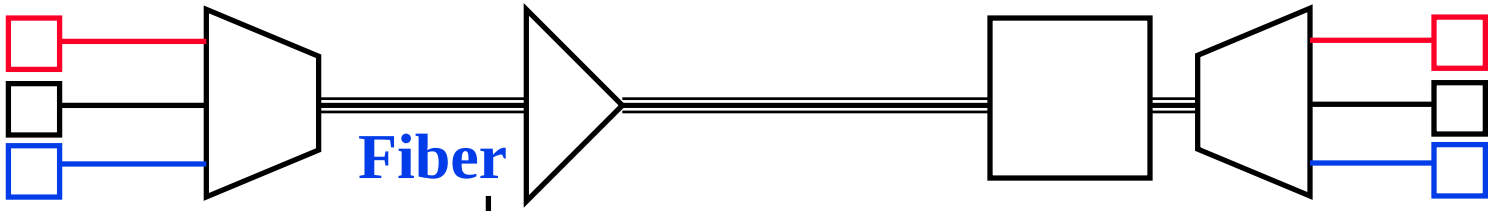
1. New Applications: Storage, VPN, LAN extension, Data hosting
2. Higher Speed: 40 Gbps
3. More Wavelengths per fiber
4. Longer Distances
5. Larger Crossconnects
6. Newer places to install fibers

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



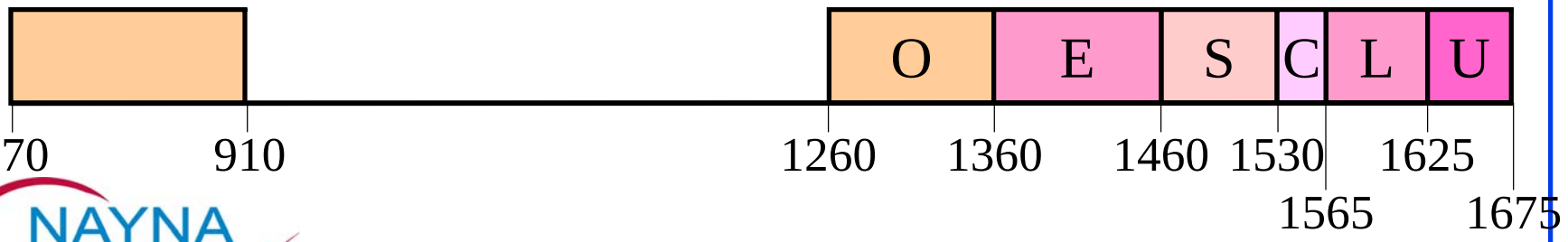
Transmitter	Mux/Demux	Amplifier	Switching	Receivers
Sources	Filters	Gain Equalizers	ADM	Detectors
Modulators	Interleavers	Performance Monitors		
Wavelockers		Dispersion compensators		
		PMD compensators		

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

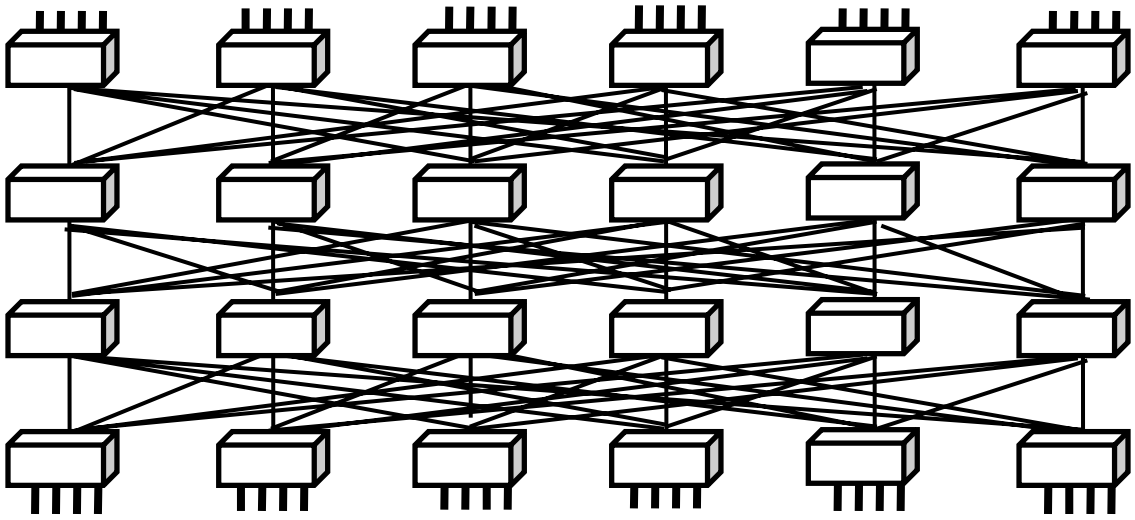
Ultra-Long Haul Transmission

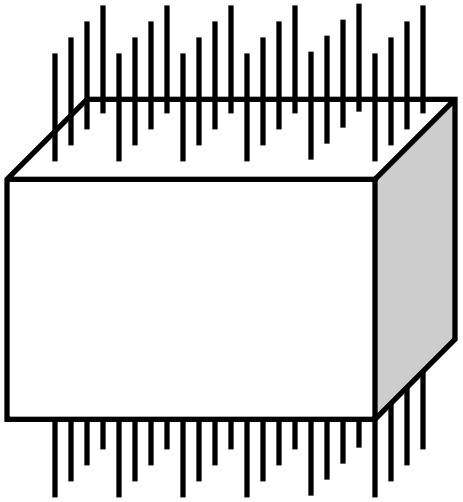
1. Strong out-of-band Forward Error Correction (FEC)
   Changes regeneration interval from 80 km to 300km
   Increases bit rate from 40 to 43 Gbps
2. Dispersion Management: Adaptive compensation
3. More Power: Non-linearity's $\Rightarrow$ RZ coding
   Fiber with large effective area
   Adaptive PMD 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



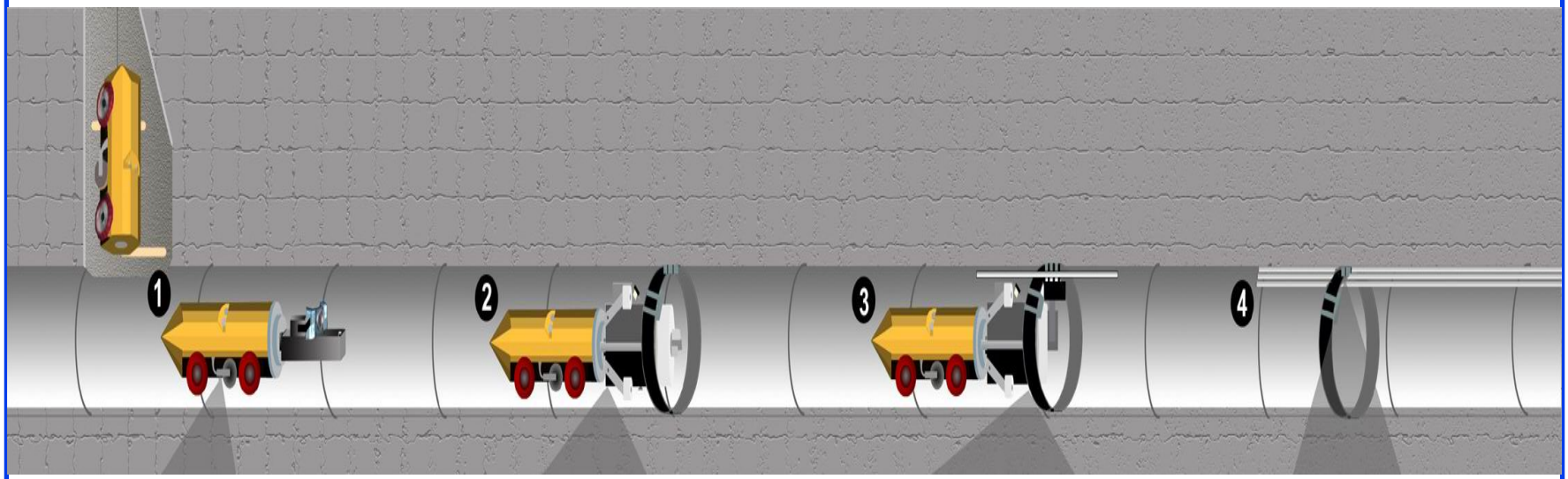


- Example: 24×24 using 4×4 switches ⇒ 24 switches
  ⇒ 48 External ports, 8×24=192 total ports
  ⇒ 25% port efficiency
- Crossconnect or routers with large number of ports are more cost effective

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

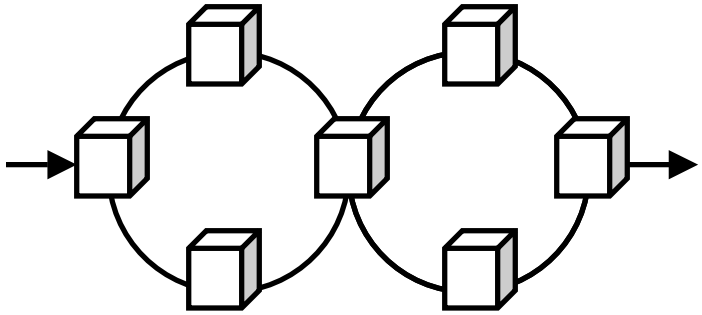
FAST Installation

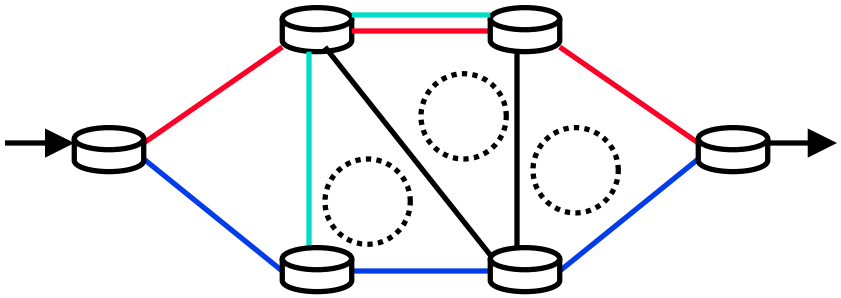


1. Robots map the pipe
2. Install rings
3. Install ducts
4. Thread fibers

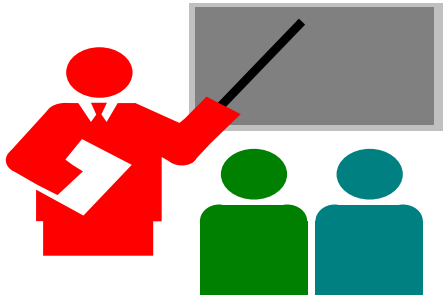
Fast Restoration: Broken sewer pipes replaced with minimal disruption

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. Traffic is increasing faster than Moore's law
   ⇒ Optical Switching
4. Routers and crossconnects with larger number of ports are more cost effective.

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

Standards Organizations

- IETF: www.ietf.org
  - Multiprotocol Label Switching (MPLS)
  - IP over Optical (IPO)
  - Traffic Engineering (TE)
  - Common Control and Management Plane (CCAMP)
- Optical Internetworking Forum (OIF): www.oiforum.com
- ANSI T1X1.5: http://www.t1.org/t1x1/_x15-hm.htm
- ITU, www.itu.ch, Study Group 15 Question 14 and Question 12
- Optical Domain Service Interface (ODSI)
  - Completed December 2000