IP over Petabit DWDM Networks: Issues and Challenges

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

Overview

- Recent trends in network traffic and capacity
- QoS approaches: ATM, Inteserv, Diffserv, MPLS
- IP over DWDM: Why?
- IP over DWDM: How?
- Research Topics

Nickel Sale

Long distance anywhere any time
25¢/minute, … 20¢, 10¢, 5¢, …, free

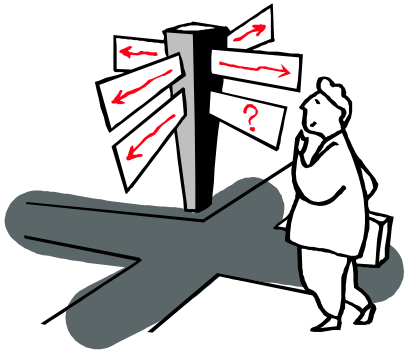
Trend: More Capacity

- Silicon capacity is doubling every 18 months (Moore's Law)
- Storage capacity is doubling every 12 months
- FDDI in 1993: 100 Mbps to 60 km over single mode
- 16 Wavelengths/fiber, 2.5 Gbps/Wavelength
  $\Rightarrow$ 40 Gbps/fiber (1998)
- 1022 Wavelengths/fiber, 40 Gbps/Wavelength
  $\Rightarrow$ 40,000 Gbps/Fiber
  = Growth rate of 1000 in five years
- Networking capacity is doubling every 6-9 months

Trend: More Traffic

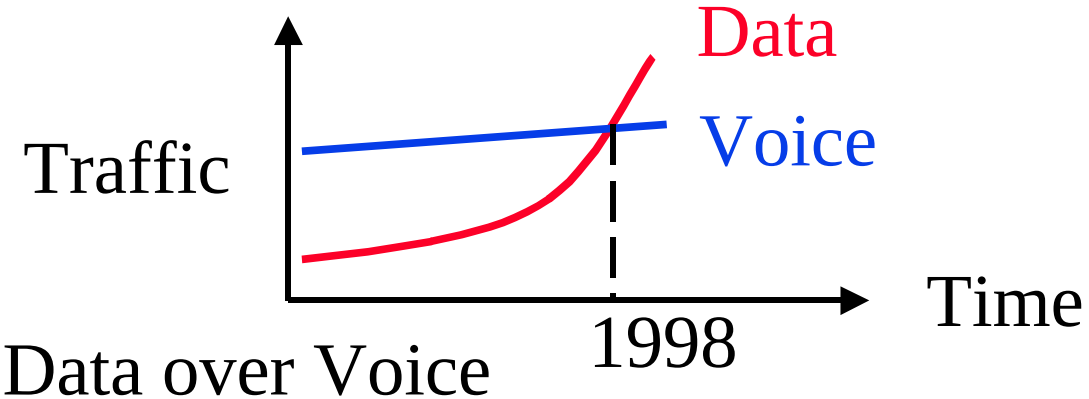
- Number of Internet hosts is growing super-exponentially.
- Traffic per host is increasing: Cable Modems+ADSL
- All projections of network traffic turn out to be lower than actual
- UUNet traffic was doubling every 4 months… 100 days...

Trend: Traffic > Capacity

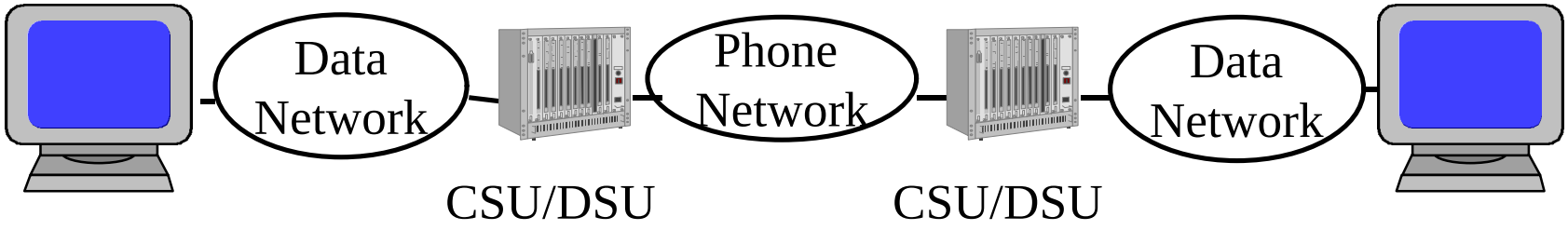


Expensive Bandwidth	Cheap Bandwidth
❑ Sharing	❑ No sharing
❑ Multicast	❑ Unicast
❑ Virtual Private Networks	❑ Private Networks
❑ More efficient use (L3)	❑ Less efficient use
❑ Need QoS	❑ QoS less of an issue
❑ Likely in WANs	❑ Possible in LANs

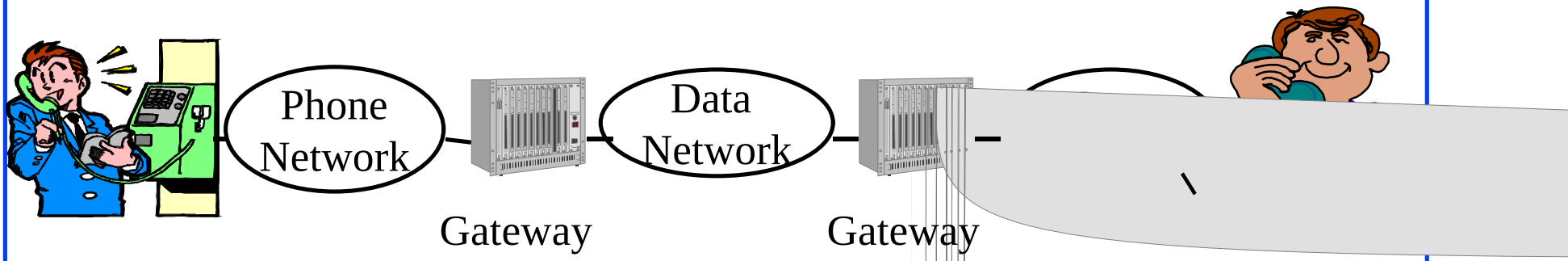
Trend: Data > Voice



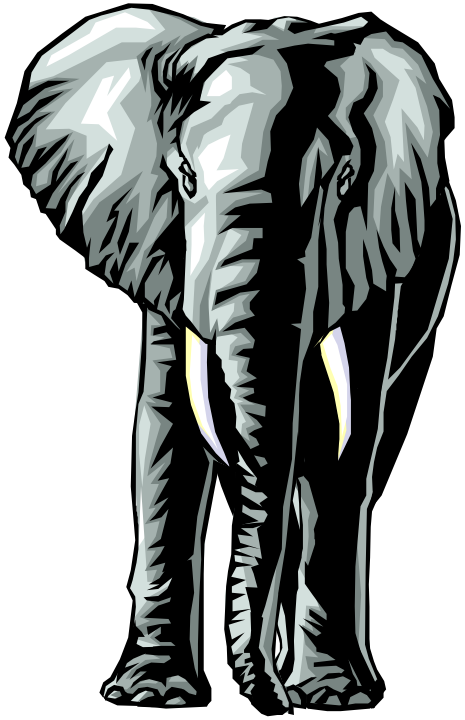
- Past: Data over Voice

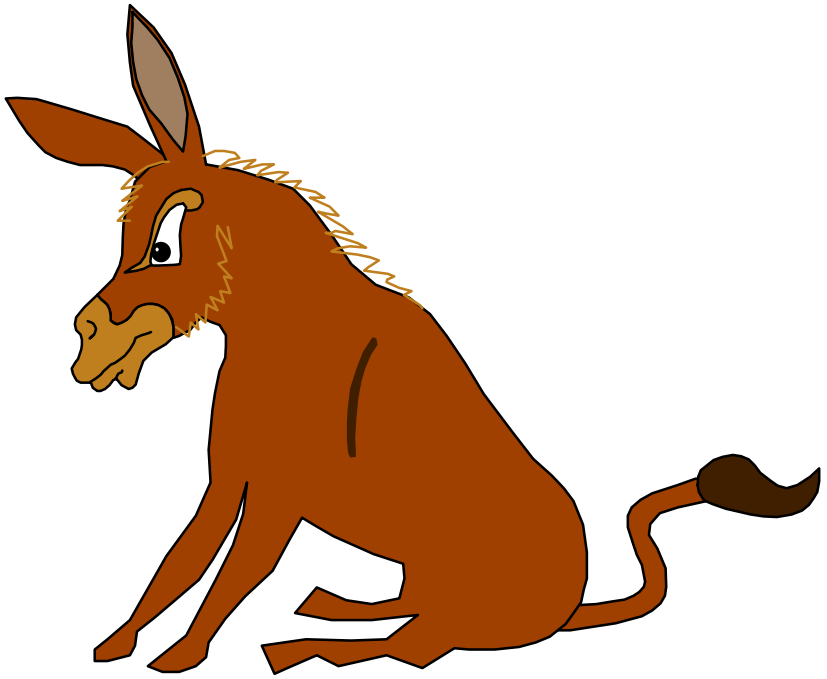


- Future: Voice over Data



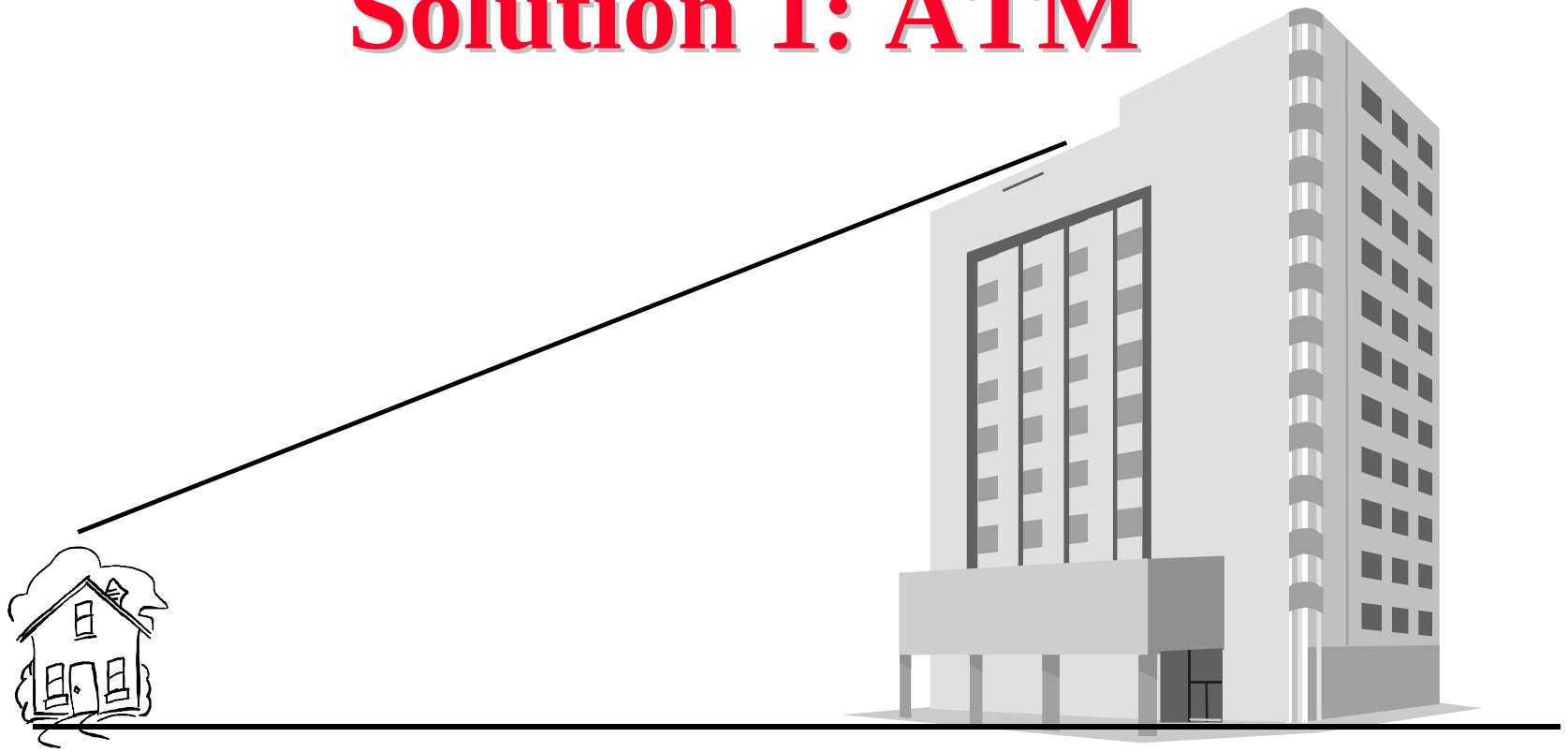
Telco vs Data Networks





Telco Protocols	Data Protocols
QoS	Simplicity
Reliability	
Protection	Need QoS, Protection...

Solution 1: ATM



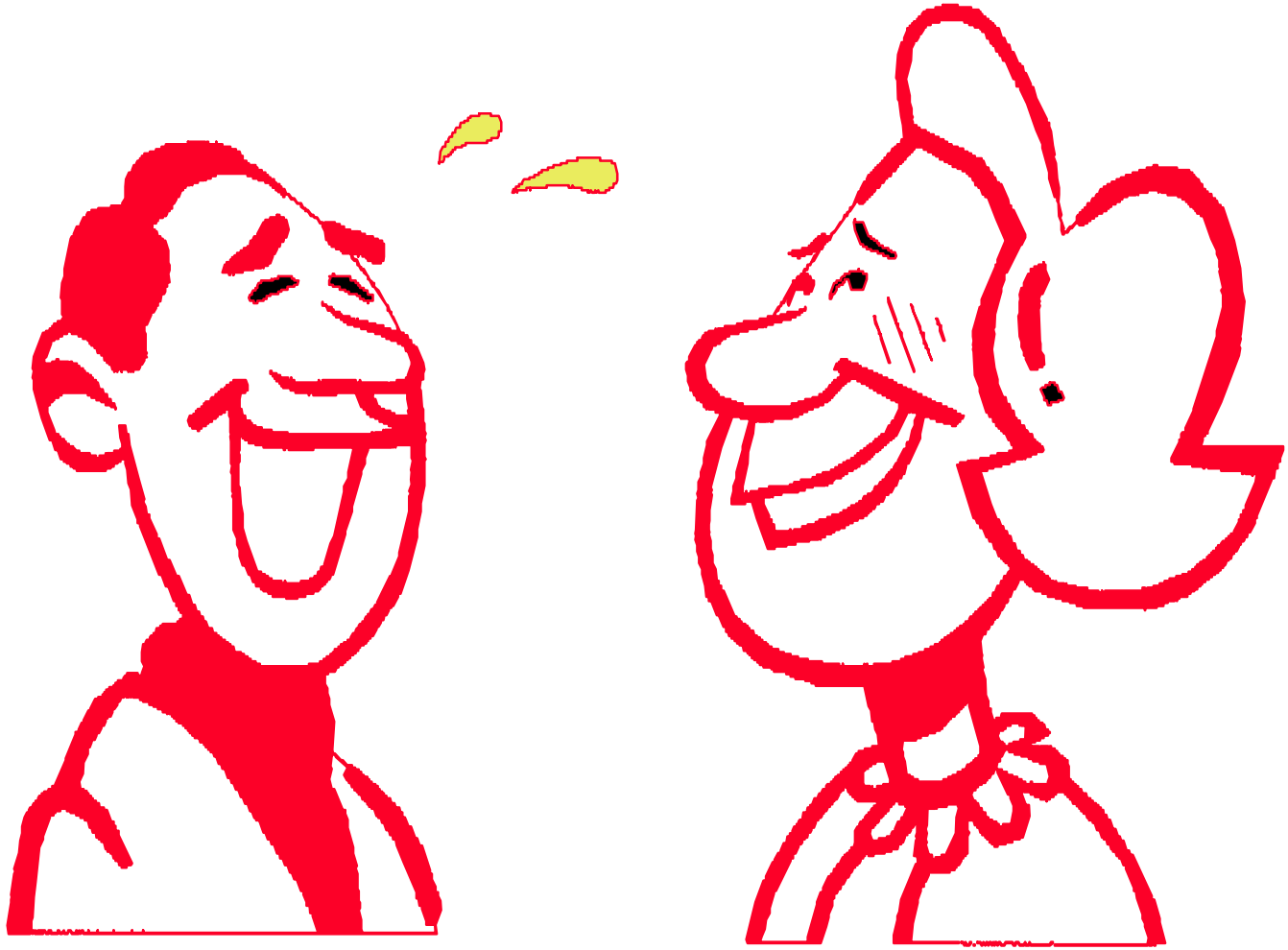
Today ATM

- Most carriers including AT&T, MCI, Sprint, UUNET, switched to ATM backbone
- ATM can't reach desktop: Designed by carriers.

Solution 2: Integrated Services

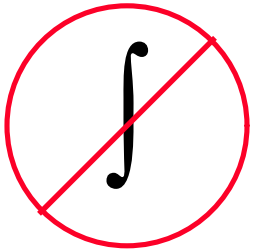
- 1996-1998
- Controlled Service and Guaranteed Service (VBR and CBR)
- Per-Flow guarantee
- Requires signaling (RSVP)

Before

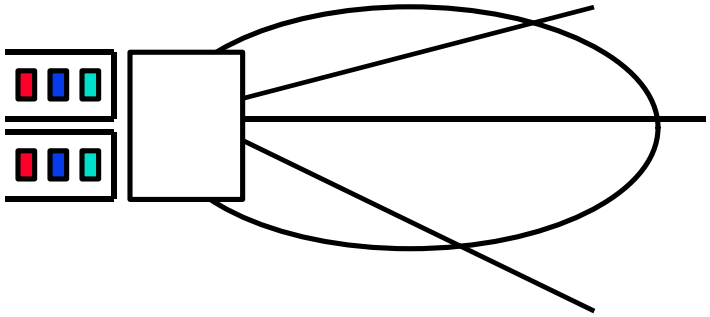


After

Solution 3: Differentiated Services

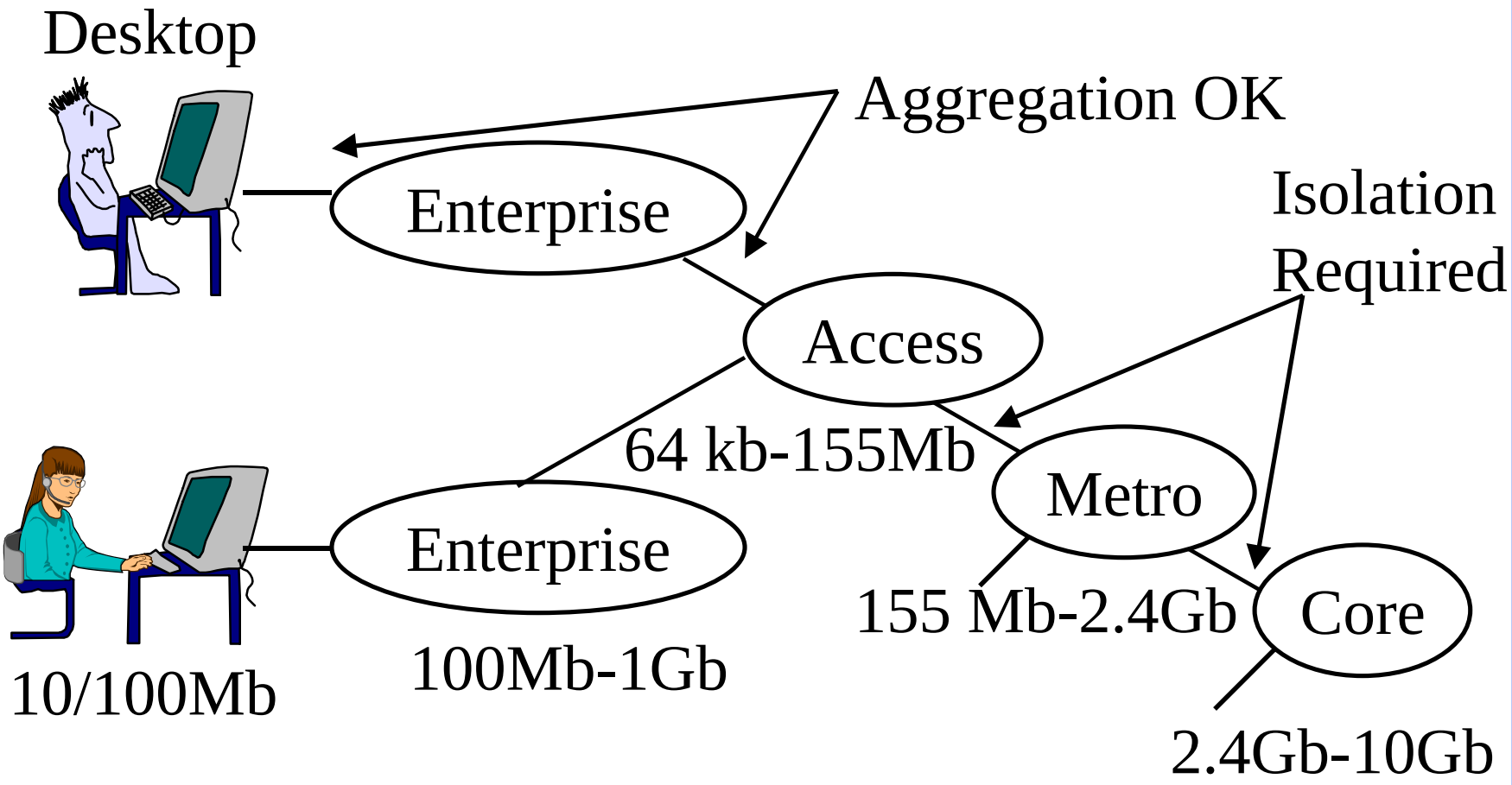


$\Rightarrow$ d/dx

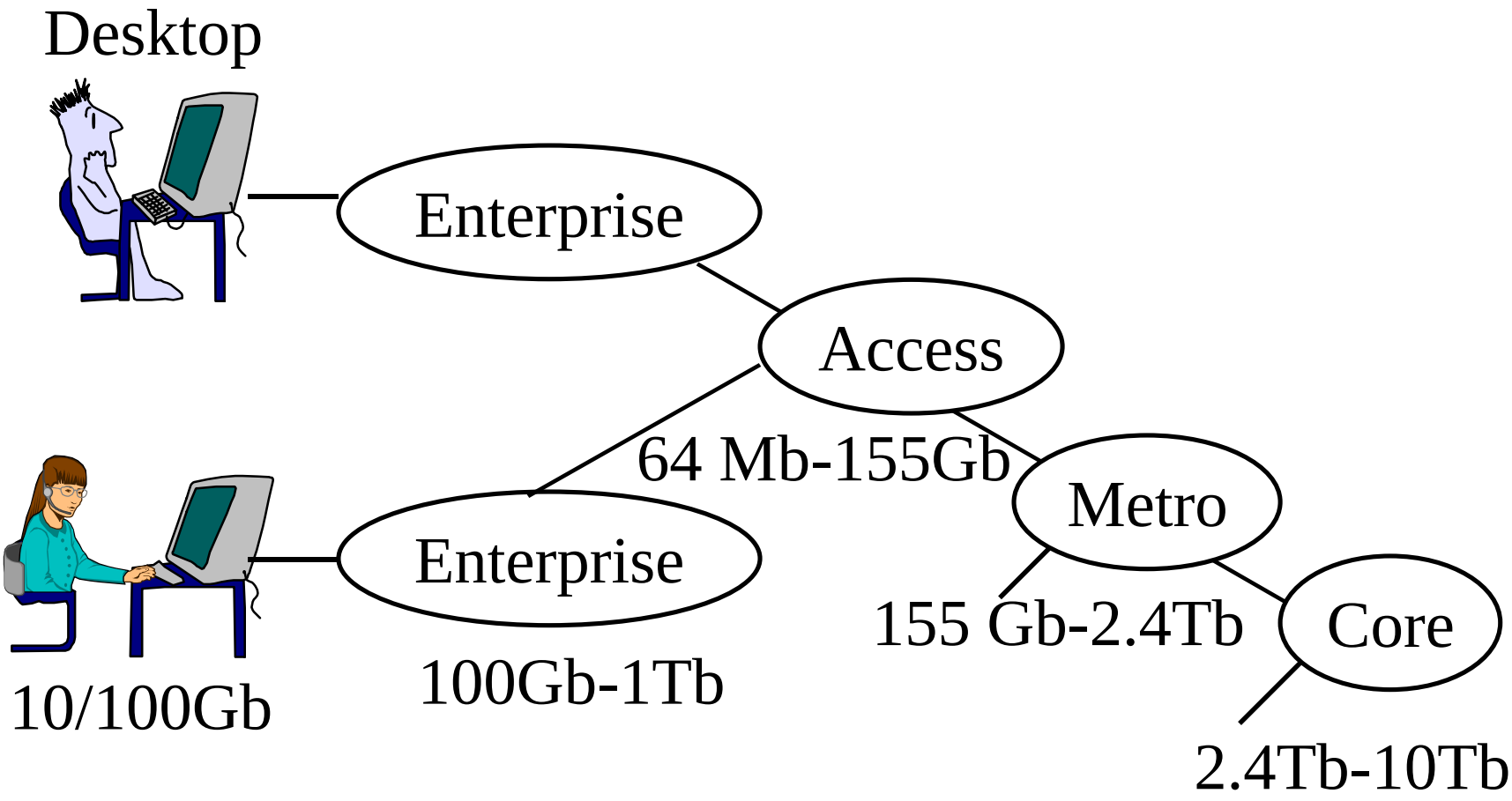


- 1998-1999
- Standardize IPv4 ToS byte's first six bits
- Packets gets marked at network ingress
  Marking $\Rightarrow$ treatment (behavior) in rest of the net
  Six bits $\Rightarrow$ 64 different per-hop behaviors (PHB)
- No per-Flow guarantees. Only aggregate
- Controlled at the ingress. Access based. No signaling
- Key Issue: How to provision?
  Need Isolation at high speed or cost

Bandwidth 2000



Bandwidth 2005



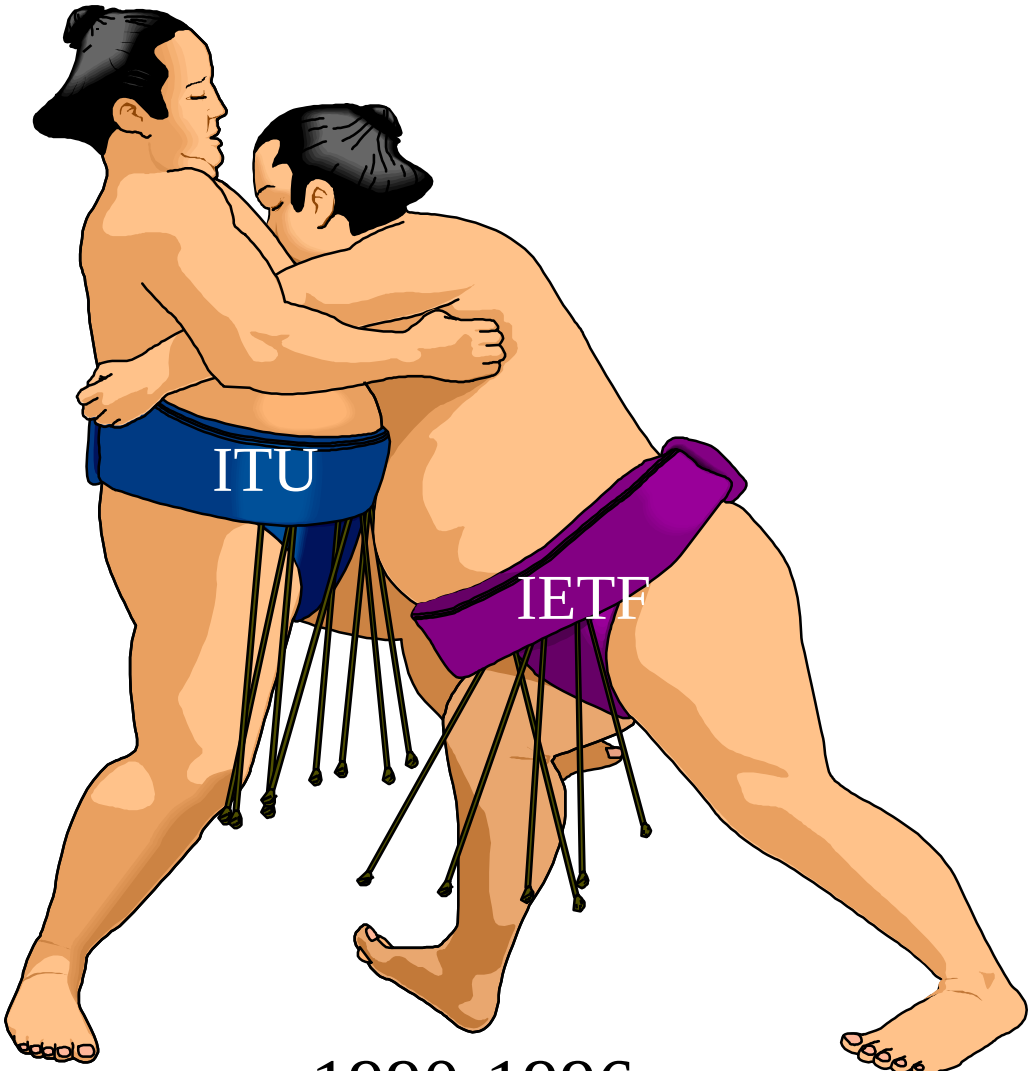
Recent WDM Records

- 1λ×40 G up to 65 km (Alcatel'98)
- 32λ× 5 G to 9300 km (1998)
- 64λ× 5 G to 7200 km (Lucent'97)
- 100λ×10 G to 400 km (Lucent'97)
- 16λ×10 G to 6000 km (1998)
- 132λ×20 G to 120 km (NEC'96)
- 70λ×20 G to 600 km (NTT'97)
- 80λ×40 G to 60 km (Siemens'00)
- 1022 Wavelengths on one fiber (Lucent 99)
- Ref: Optical Fiber Conference 1996-2000

Sample Products

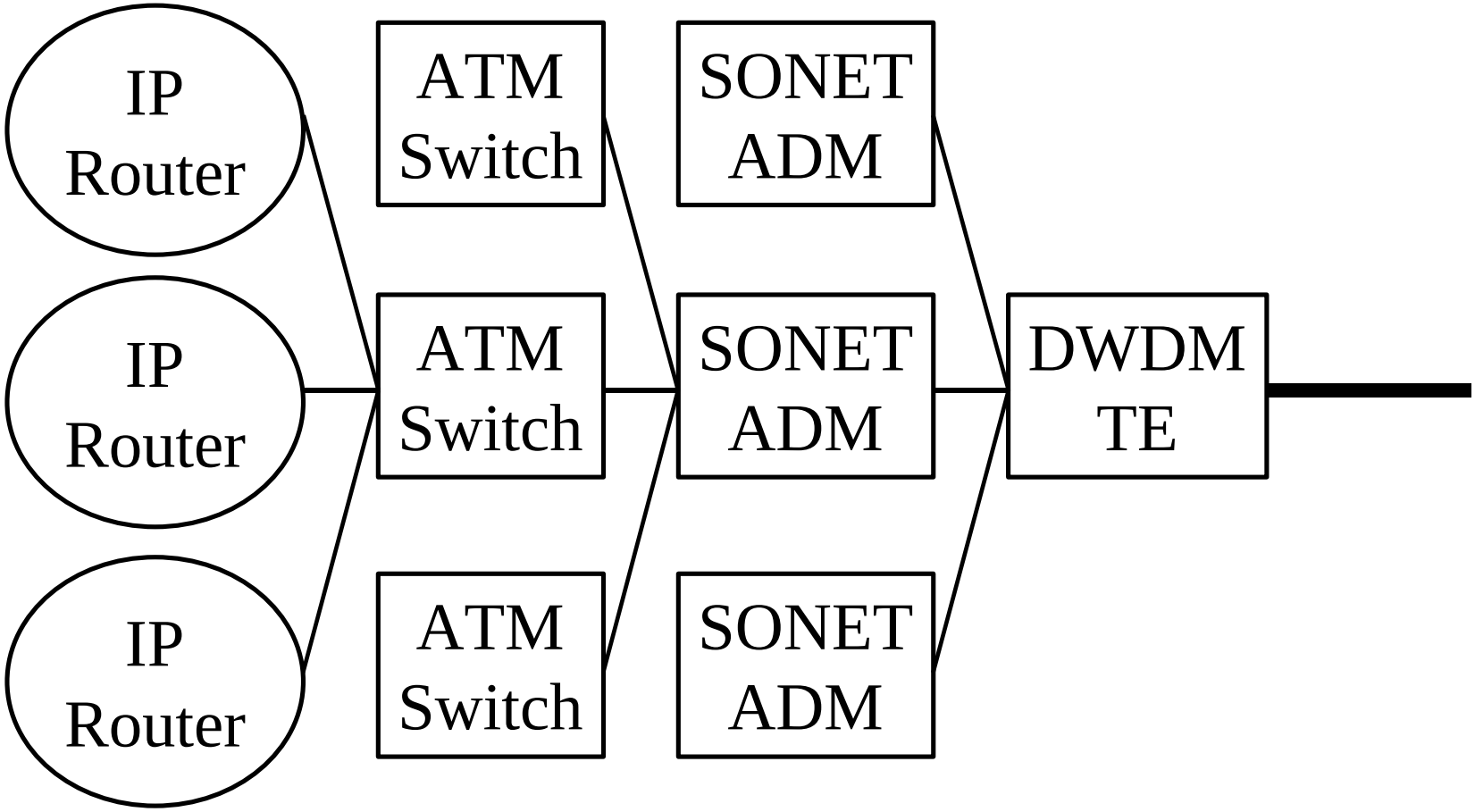
- **Lucent WaveStar Family**:
  - OLS 400G/80G/40G/10G/2.5G: 80×OC-48 or 40×OC-192 (point-to-point)
- **Ciena CoreDirector:** 256 × OC-48 or 64 × OC192 (640G total) Switch, Optical signaling and routing protocol
- **Corvis Optical Switch:** Up to 6 ports, 800 Gbps each
- **Sycamore SN 16000:** 512 × OC-48
- Coming soon: 4096 × OC-768 = 160 Tbps
- Future: 4096 × OC-3072 = 0.6 Pbps

ITU vs IETF

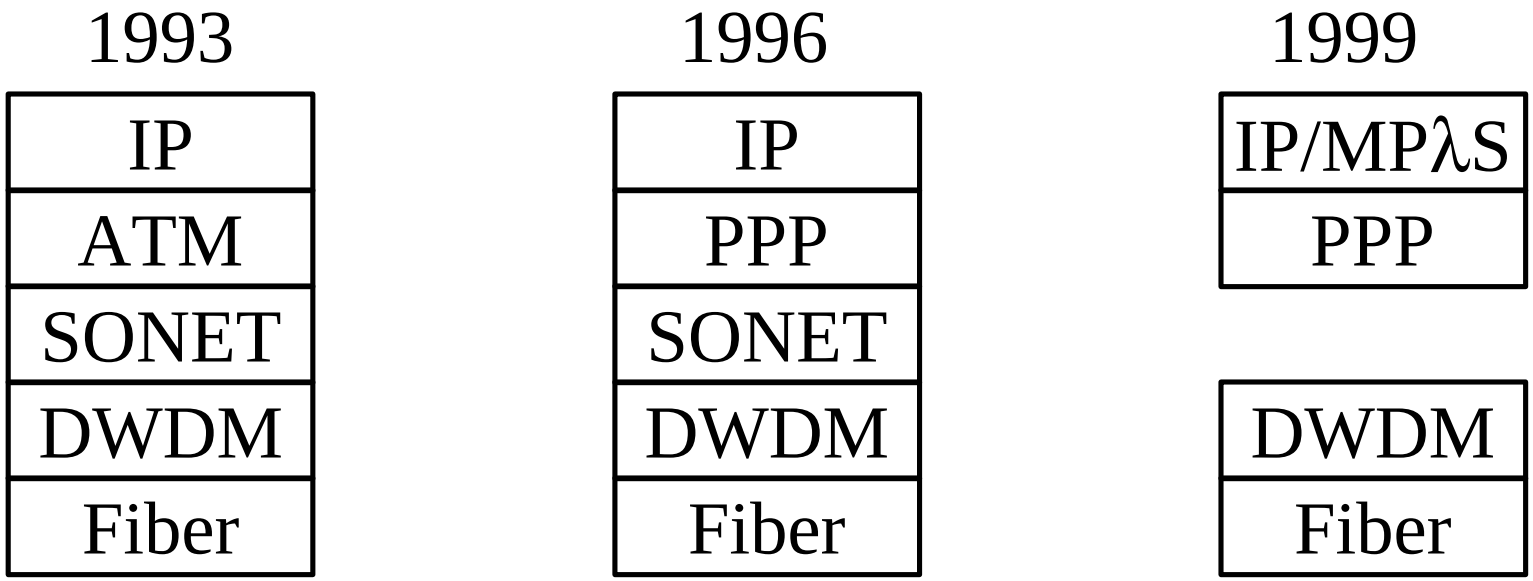


1990-1996

Initial DWDM Deployment



IP over DWDM: Protocol Layers



- IP is good for routing, traffic aggregation, resiliency
- ATM for multi-service integration, QoS/signaling
- SONET for traffic grooming, monitoring, protection
- DWDM for capacity

Multi-layer Stack: Problems

- Functional overlap:
  - Muxing:DWDM λ=ΣSTM=ΣVC=ΣFlows=Σ packets
  - Routing: DWDM, SONET, ATM, IP
  - QoS/Integration: ATM, IP
- Failure affects multiple layers:
  1 Fiber $\Rightarrow$ 64 λ $\Rightarrow$ 1000 OC-3 $\Rightarrow$ 10^5 VCs $\Rightarrow$ 10^8 Flows
- Restoration at multiple layers:
  DWDM $\Rightarrow$ SONET $\Rightarrow$ ATM $\Rightarrow$ IP
- SONET $\Rightarrow$ Manual (jumpers) $\Rightarrow$ months/connection
- Any layer can bottleneck
  $\Rightarrow$ Intersection of Features + Union of Problems

IP over DWDM: Why?

- IP ⇒ Revenue
  DWDM ⇒ Cheap bandwidth
  IP and DWDM ⇒ Winning combination
  Avoid the cost of SONET/ATM equipment
- IP routers at OC-192 (10 Gbps)
  ⇒ Don't need SONET multiplexing
- IP for route calculation, traffic aggregation, protection
- Optical layer for route provisioning, protection, restoration
- Coordinated restoration at optical/IP level
- Coordinated path determination at optical/IP level

Telecom Discovers MPLS

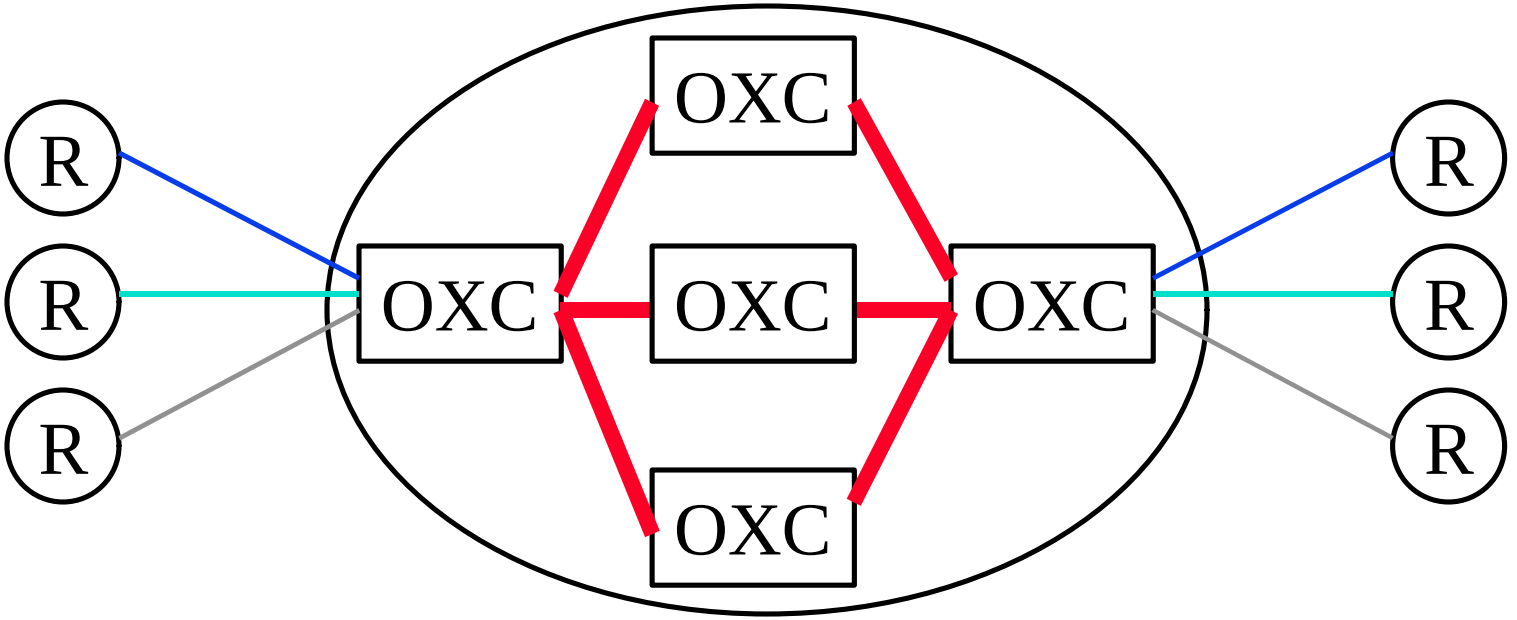
Telecom

MPLS

2000: ATM over MPLS, Sonet over MPLS,
Frame Relay over MPLS, DWDM over MPLS, ...

MPλS

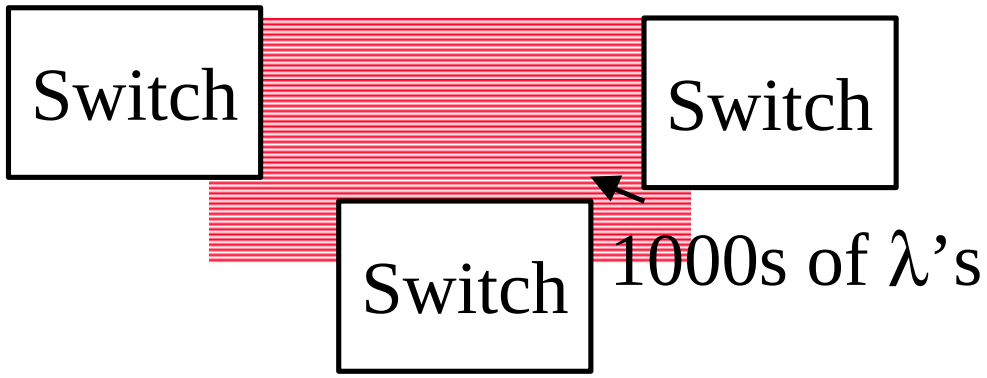
- MPλS = Multi-Protocol Lambda Switching
- All packets with one label are sent on one wavelength
- Optical crossconnects (OXCs) are IP addressable devices and may use OSPF for route calculations



MPλS (Cont)

- Next Hop Forwarding Label Entry (NHFLE)
  ⇒ <Input port, λ> to <output port, λ> mapping
- MPλS = Simplified MPLS
  - No label stacks
  - No per-packet forwarding ⇒ No queuing, No scheduling, No Priority, No burstiness, No policing
- LDP/CR-LDP and RSVP need extensions for:
  - Resource discovery,
  - Provisioning,
  - Protection/restoration

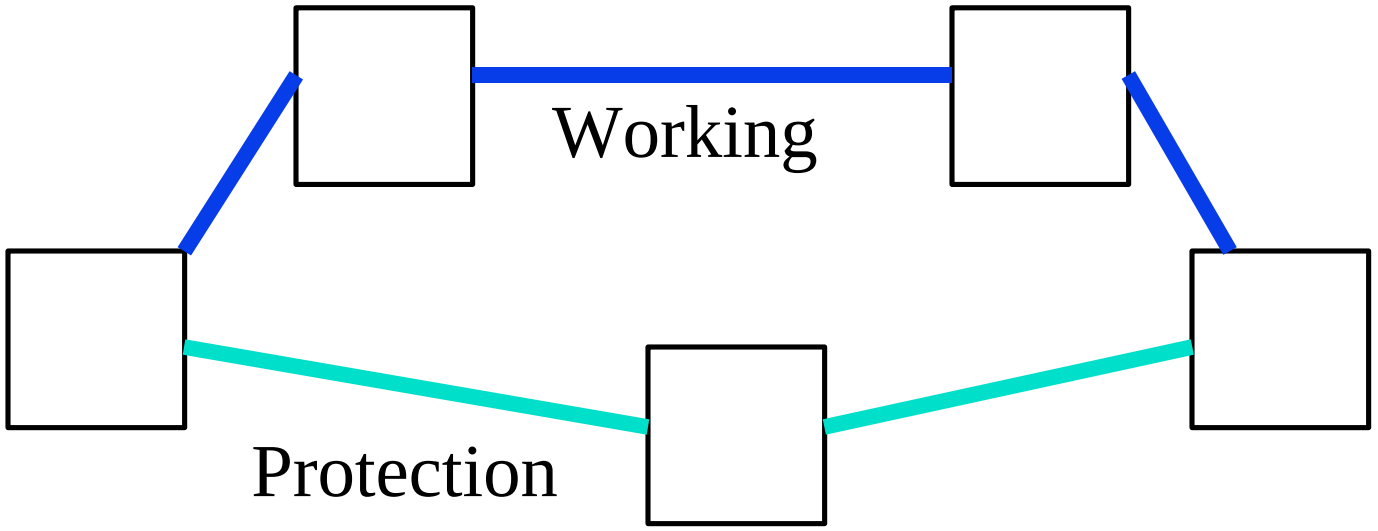
Research Topics: Network Layer



Routing in/with:

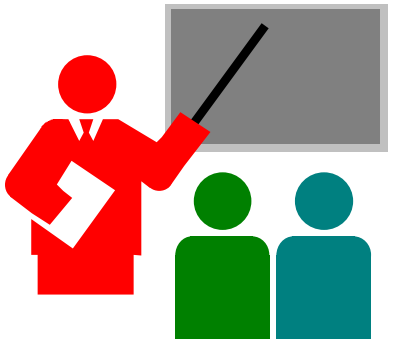
- Highly connected Networks: Countless paths
  ⇒ Link Bundling
- Highly dynamic topology: Wavelength failures
- Adaptive Networks: Automated provisioning
- Risk Avoidance, Protection
- Quality of Service: Packet level vs Circuit level

Risk Avoidance



- Find 2nd path: Not sharing the same fiber, cable, trench, central office
- Each λ is a member of multiple Shared Risk Link Groups (SRLG)

Summary



- DWDM has resulted in an exponential growth in network capacity
- Traffic growth is still more than capacity ⇒ QoS
- High speed routers ⇒ IP directly over DWDM
- IP needs to be extended to provide resource discovery, provisioning, protection and restoration

References:

- Detailed references in http://www.cis.ohio-state.edu/~jain/refs/ipqs_refs.htm and 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
- IP over Optical: A summary of issues, (internet draft) http://www.cis.ohio-state.edu/~jain/ietf/issues.html
- IP over DWDM, (talk) http://www.cis.ohio-state.edu/~jain/talks/ip_dwdm/index.html

Thank You!