IP over DWDM Networks

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These slides are available at

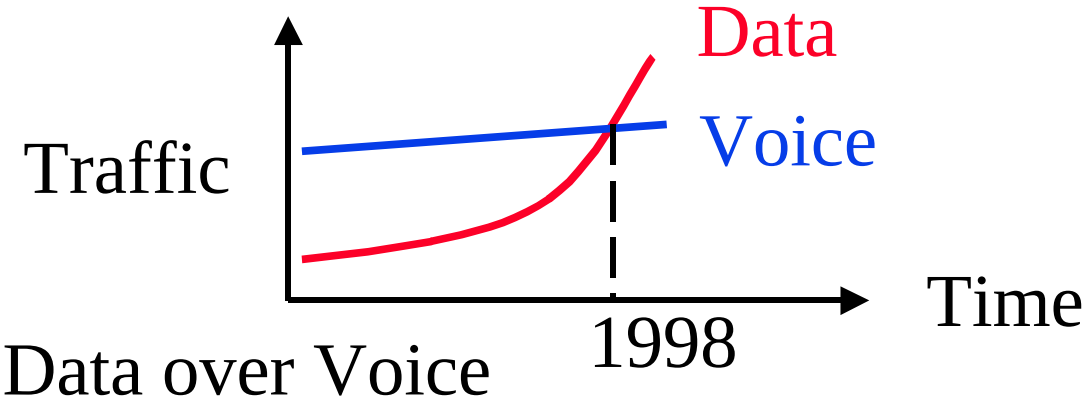
http://www.cis.ohio-state.edu/~jain/talks/opnet00.htm

- **What** factors lead to IP and DWDM?
- **Why** IP directly over DWDM?
- **How** to IP over DWDM?
  - What changes are required in IP?

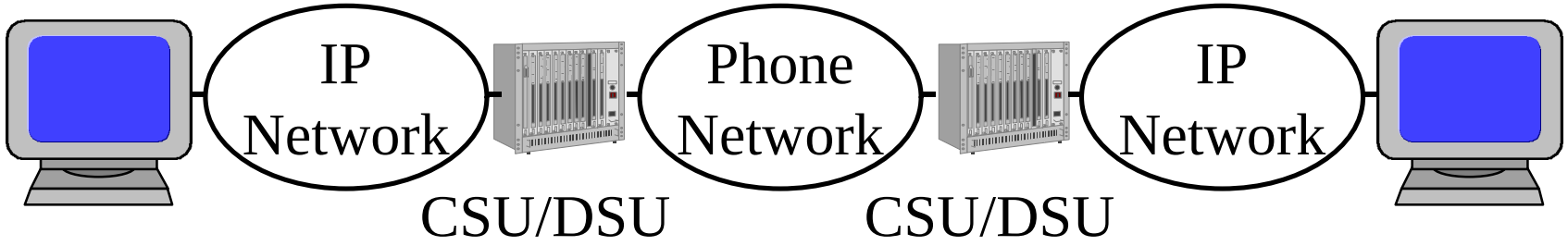
Trend: More Internet Traffic

- Number of Internet hosts is growing super-exponentially.
- Traffic per host is increasing: Cable Modems+ADSL
- UUNet traffic was doubling every 4 months…now every 100 days…
- Traffic growth is faster than processing capacity

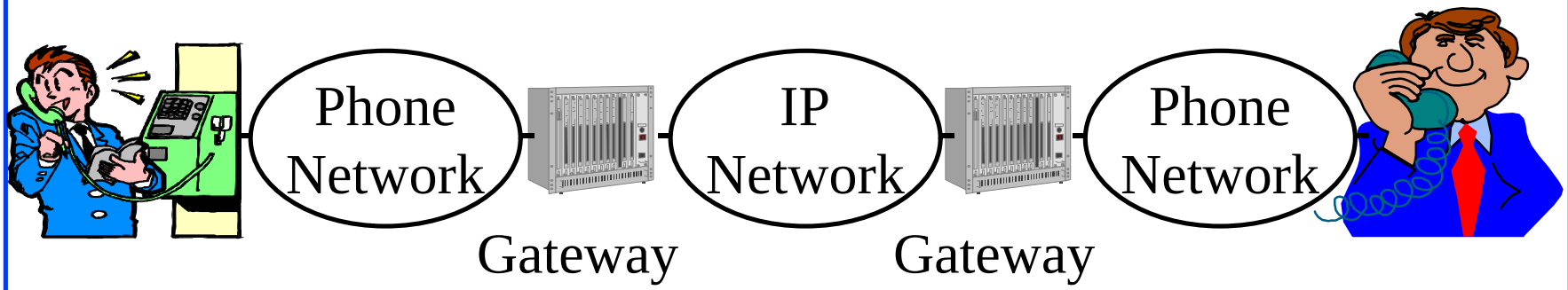
Trend: Data > Voice



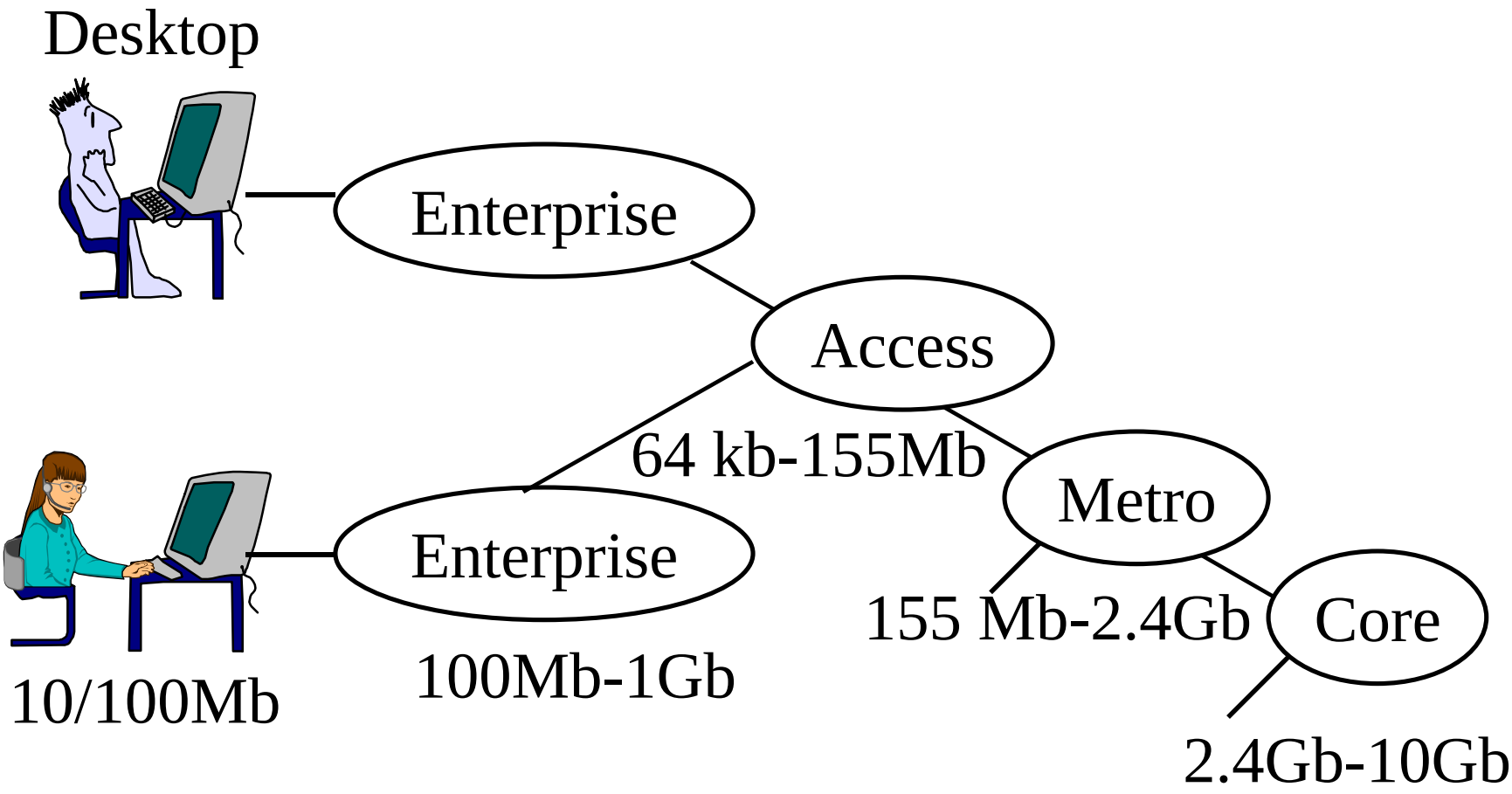
- Past: Data over Voice



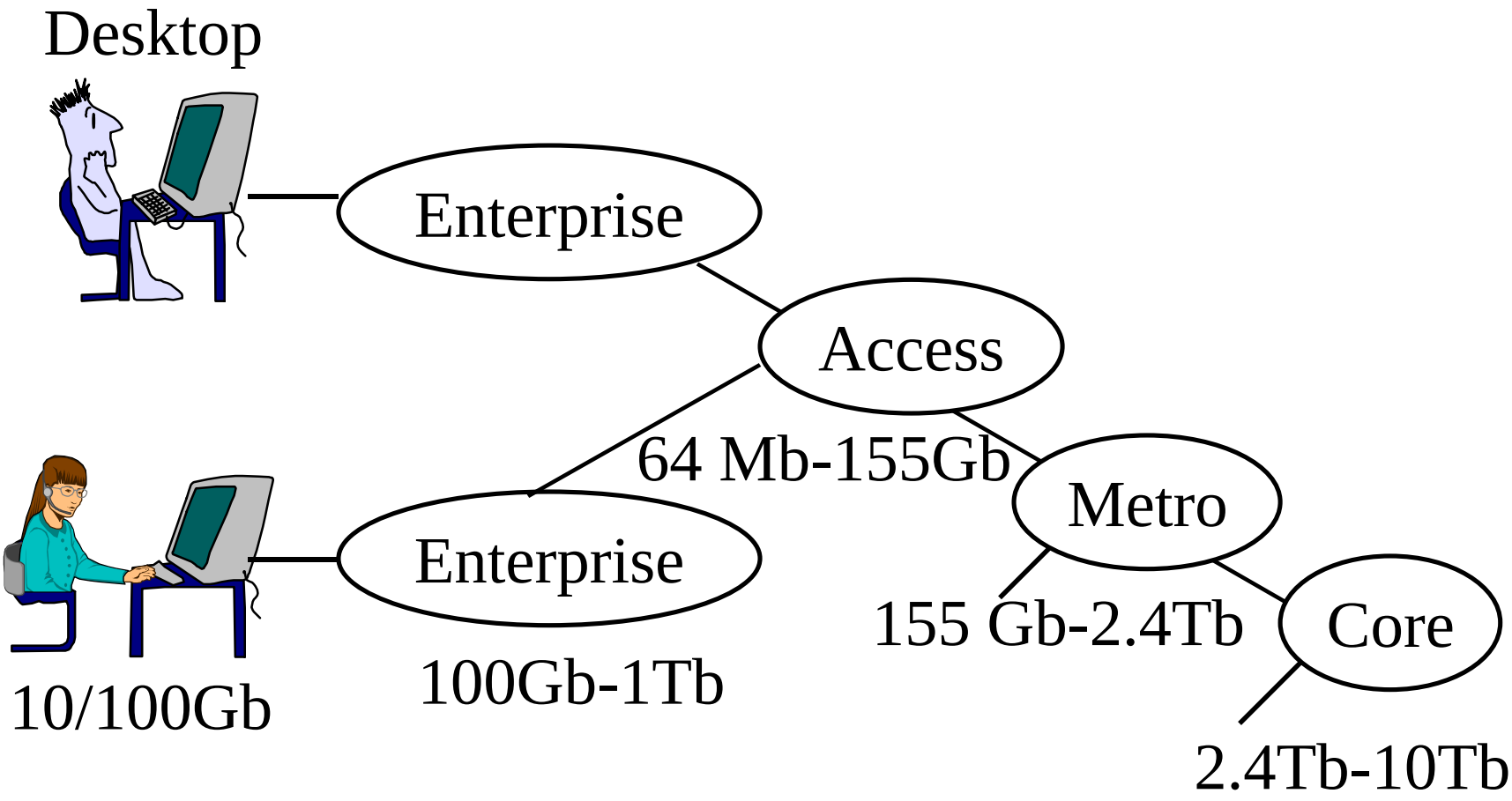
- Future: Voice over Data



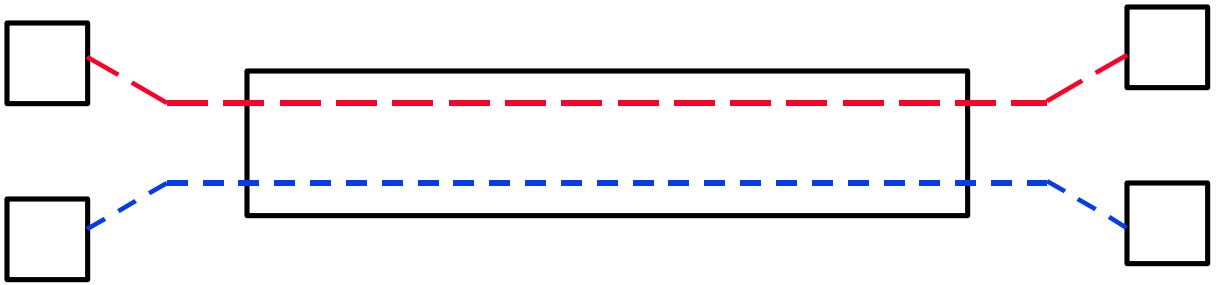
Bandwidth 2000



Bandwidth 2005



Sparse and Dense WDM

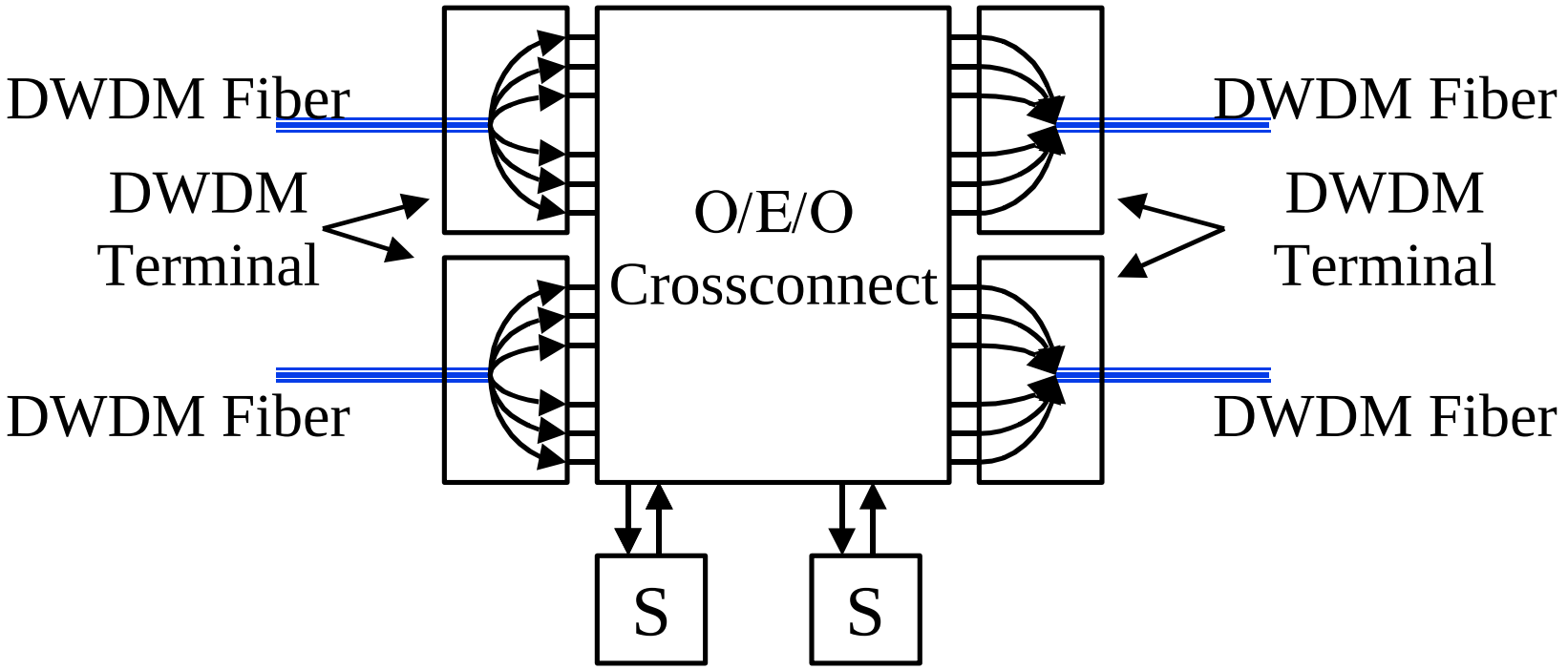


- 10Mbps Ethernet (10Base-F) uses 850 nm
- 100 Mbps Ethernet (100Base-FX) + FDDI use 1310 nm
- Some telecommunication lines use 1550 nm
- WDM: 850nm + 1310nm or 1310nm + 1550nm
- Dense ⇒ Closely spaced ≈ 1nm separation

Recent DWDM Records

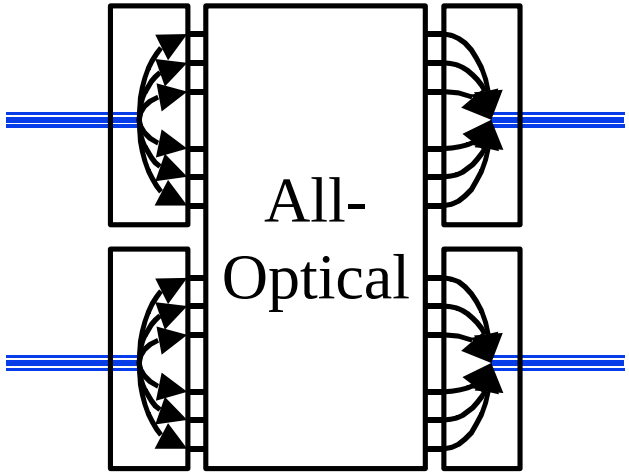
- 1λ×40 Gbps to 65 km (Alcatel'98)
- 32λ× 5 Gbps to 9300 km (1998)
- 64λ× 5 Gbps to 7200 km (Lucent'97)
- 100λ×10 Gbps to 400 km (Lucent'97)
- 16λ×10 Gbps to 6000 km (1998)
- 132λ×20 Gbps to 120 km (NEC'96)
- 70λ×20 Gbps to 600 km (NTT'97)
- 80λ×40 Gbps to 60 km (Siemens'00)
- 1022 Wavelengths on one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

Sample Products



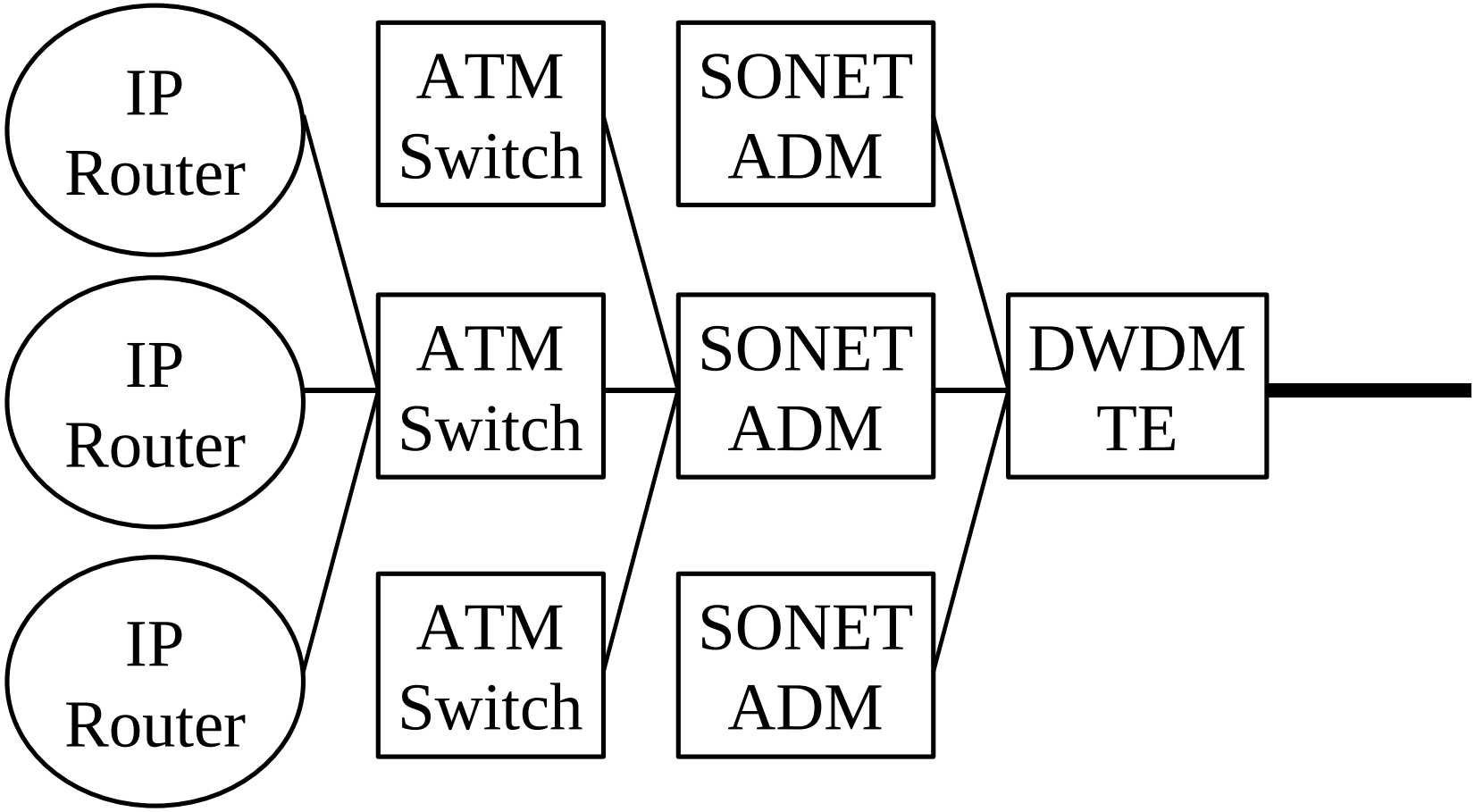
- **DWDM Terminals**: Sycamore SN6000
- **O/E/O Crossconnects**: Cienna Core Director, Tellium Aurora 32, ...

All-Optical Switch

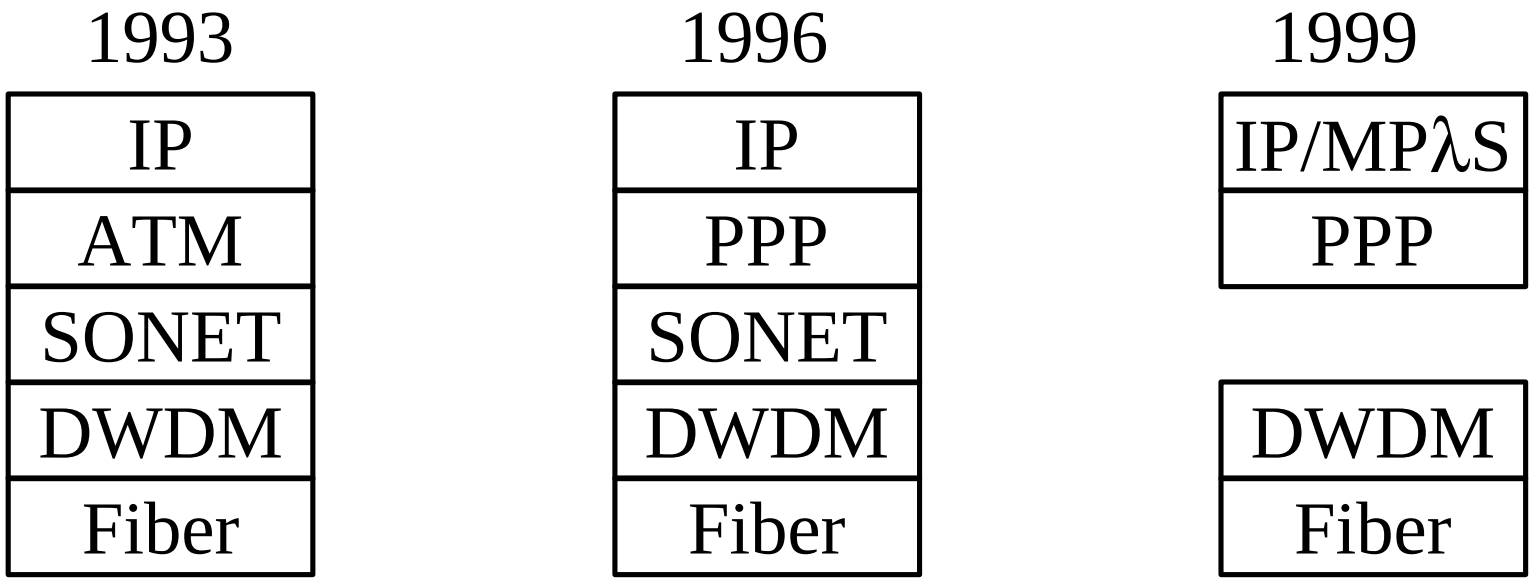


- No Electrical processing ⇒ Lower cost/space/power
  ⇒ Large number of ports
- Data rate independent:
  OC-48, OC-192, OC-768, OC-1536, OC-3072, ...
- Payload independent: ATM, SONET, IP/PPP, ...
- Switch ⇒ Intelligent ⇒ Auto provisioning, routing, ...

IP over DWDM


IP Router
IP Router
IP Router
ATM Switch
ATM Switch
ATM Switch
SONET ADM
SONET ADM
SONET ADM
DWDM TE

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

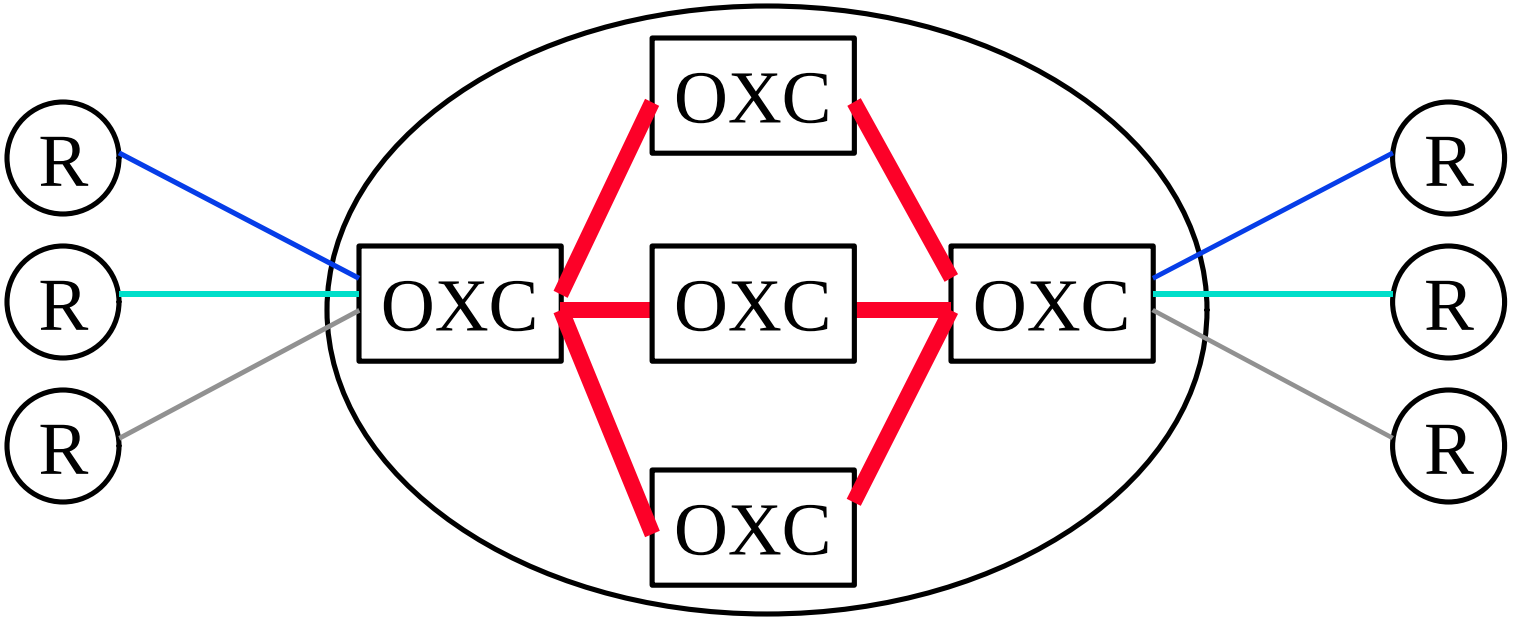
- Functional overlap:
  - Muxing:DWDM λ=ΣSTM=ΣVC=ΣFlows=Σ packets
  - Routing: DWDM, SONET, ATM, IP
  - QoS/Integration: ATM, IP
- Failure affects multiple layers:
  1 Fiber $\Rightarrow$ 64 λ $\Rightarrow$ 1000 OC-3 $\Rightarrow$ 10^5 VCs $\Rightarrow$ 10^8 Flows
- Restoration at multiple layers:
  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

MPλS

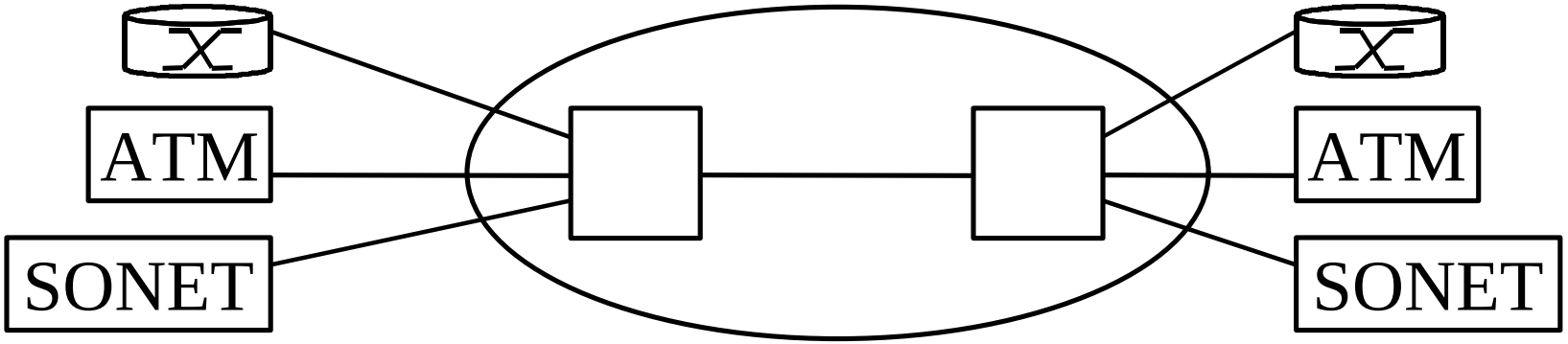
- MPλS = Multi-Protocol Lambda Switching
- All packets with one label are sent on one wavelength
- Next Hop Forwarding Label Entry (NHFLE)
  ⇒ <Input port, λ> to <output port, λ> mapping



IP over DWDM Issues

- Addressing
- Signaling
- Protection
- Routing
- Provisioning/Traffic Engineering

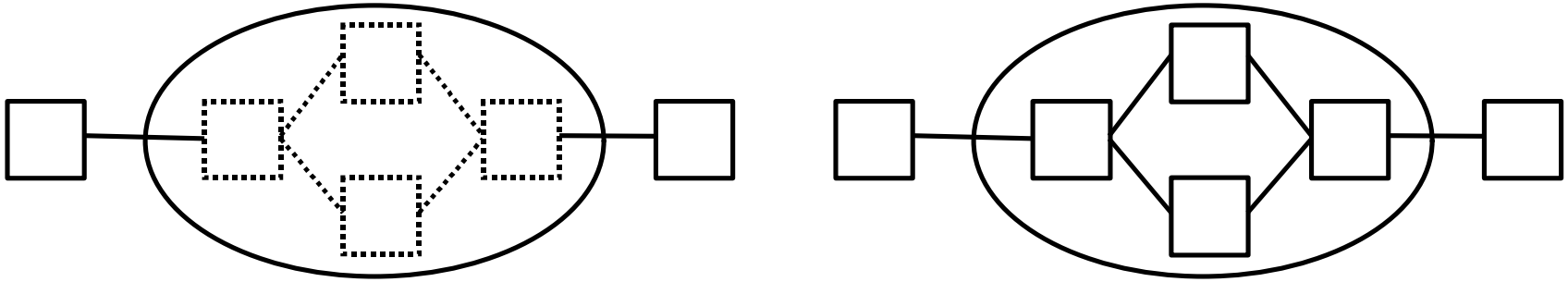
Addressing



- Optical crossconnects will be IP addressable devices
- One IP Address per interface ⇒ Too many addresses
  Solution: One address per crossconnect
  Ports identified by IP Address:port #
- All clients need IP addresses.
  ATM Switches and SONET Muxes need IP addresses.
  Need ATM address to IP address directory servers.

Signaling

- Two Business Models:
  - Carrier: Overlay or cloud
    - Network is a black-box
    - User-to-network interface (UNI)
  - Enterprise: Peer-to-Peer
    - Complete exchange of information



Signaling (Cont)

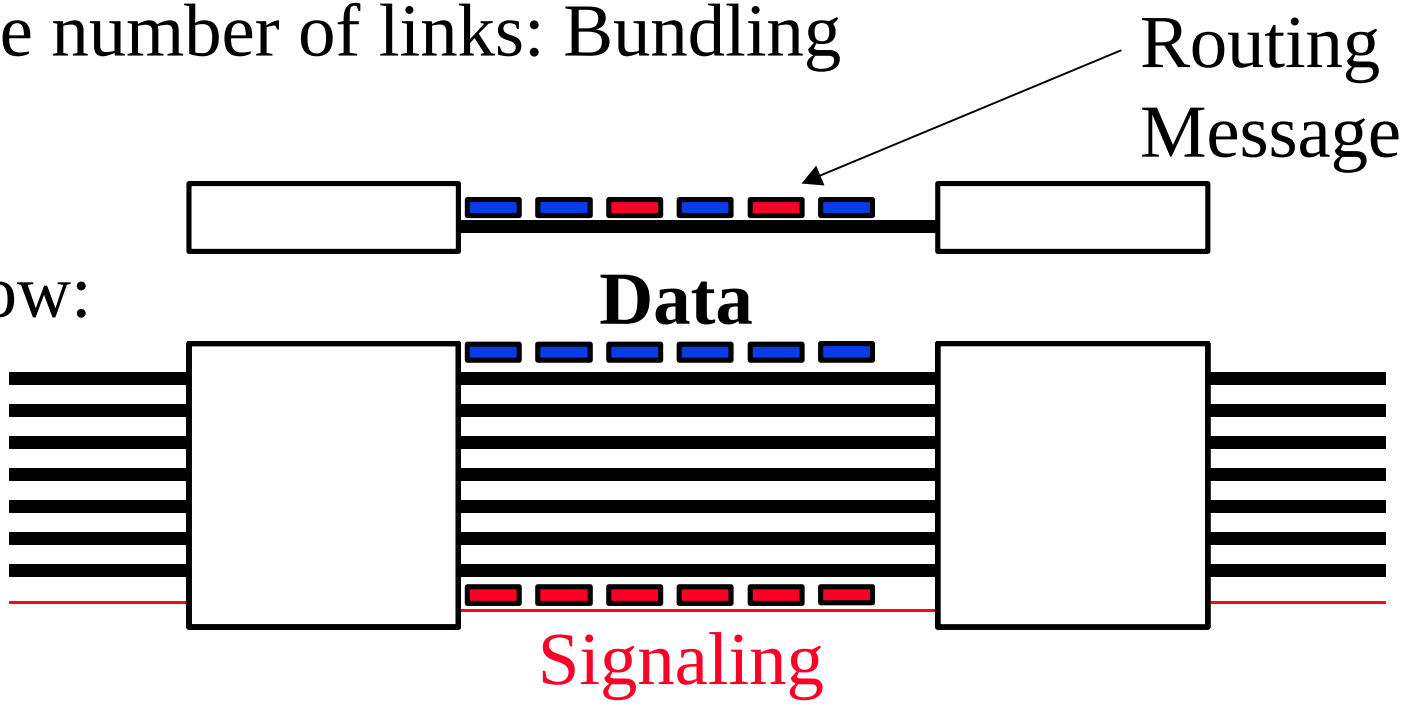
- Optical Internetworking Forum (OIF) is defining UNI signaling: Create, destroy, modify lightpaths
- IP signaling protocols:
  - Constrained-Resource Label Distribution Protocol (CR-LDP)
  - Resource Reservation Protocol (RSVP)
  - Being modified for lightpath creation/modification
    - SONET/PPP
    - OC-48c, OC-192c, …
    - Other attributes

Routing

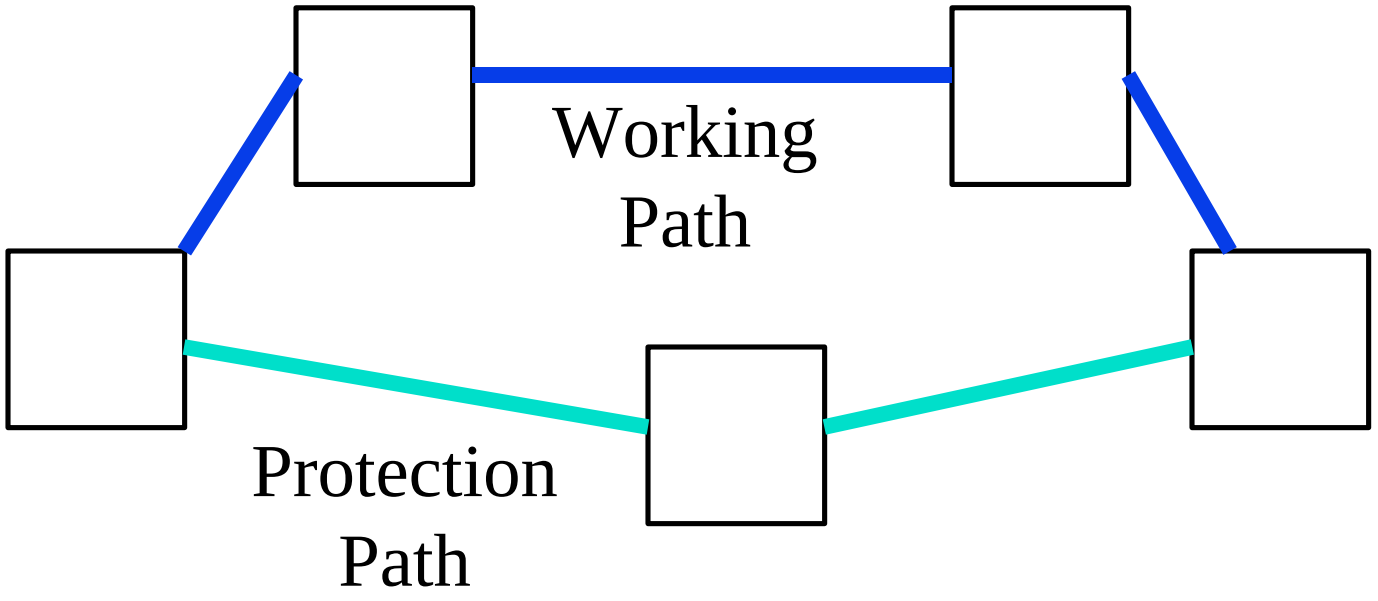
- IP routing (OSPF and IS-IS) extensions for optical networks:
  - Separate control and data channels
  - Large number of links: Bundling

Today:

Tomorrow:



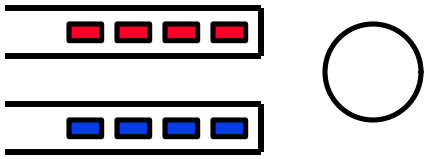
Protection

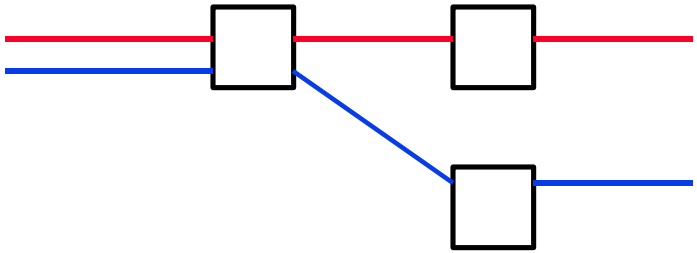


- Find 2nd path: Not sharing the same fiber, cable, trench, central office
- Each λ is a member of multiple Shared Risk Link Groups (SRLG)

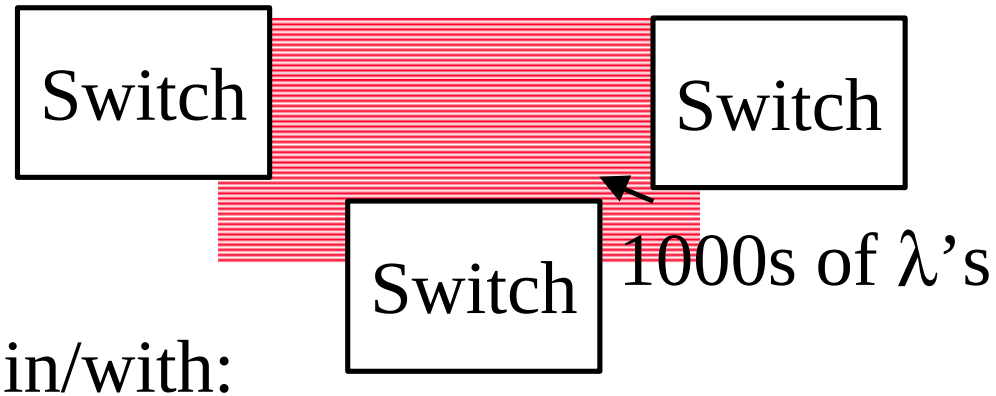
Traffic Engineering

- Quickly create/destroy lightpaths on-demand
- Dynamic topology for dynamic traffic
- Circuit-level priority for setup, holding, and restoration
- No packet-level queuing, marking, scheduling in the core





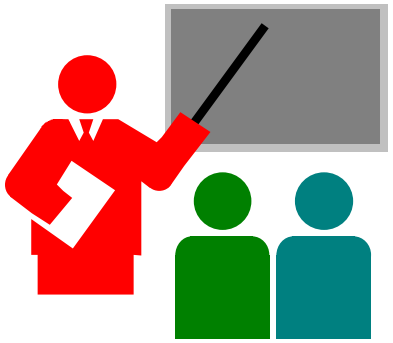
Research Topics: Network Layer



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

Summary



- DWDM has resulted in an exponential growth in network capacity
- High speed routers ⇒ IP directly over DWDM
- Data and control plane separation ⇒ IP Control Plane
- Data will be circuit switched in the core
- IP needs to be extended to provide addressing, signaling, routing, and protection for lightpaths

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

Standards Organizations

- IETF: www.ietf.org
  - Multiprotocol Label Switching (MPLS)
  - IP over Optical (IPO)
  - Traffic Engineering (TE)
- Optical Internetworking Forum (OIF): www.oiforum.com
- Optical Domain Services Interconnect (ODSI) www.odsi-coalition.com
- ANSI T1X1.5: http://www.t1.org/t1x1/_x1-grid.htm
- ITU, www.itu.ch