IP over DWDM Networks

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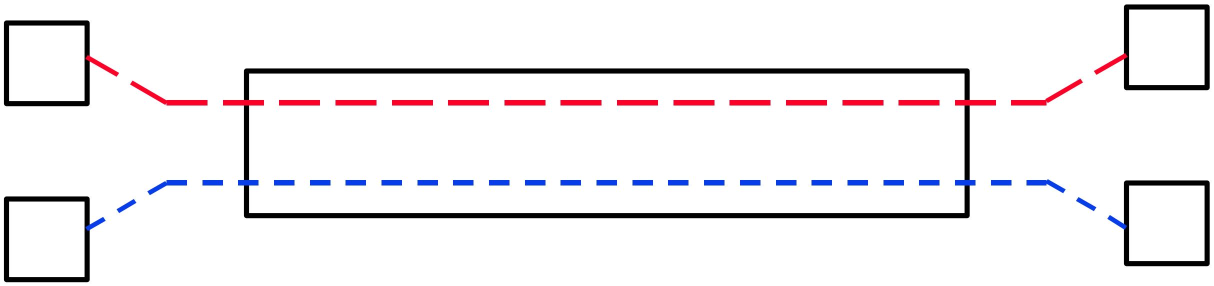
These slides are available at

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

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 WDM Records

- 1×40 G up to 65 km (Alcatel'98). PMD Limited.
- 32× 5 G to 9300 km (1998)
- 64× 5 G to 7200 km (Lucent'97)
- 100×10 G to 400 km (Lucent'97)
- 16×10 G to 6000 km (1998)
- 132×20 G to 120 km (NEC'96)
- 70×20 G to 600 km (NTT'97)
- 1022 Wavelengths on one fiber (Lucent 99)
- Ref: OFC'9x

WDM Applications

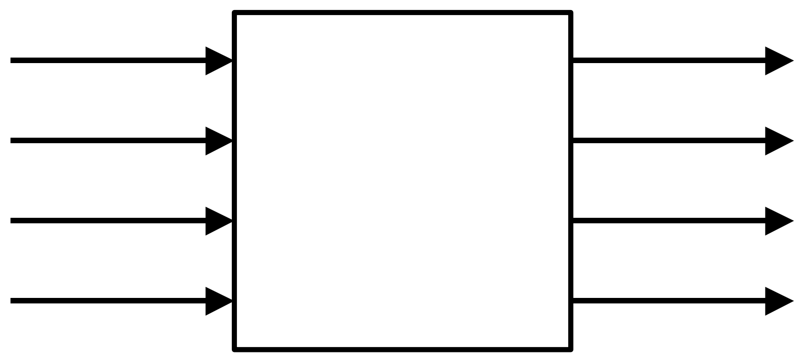
- WANs: Fiber links ⇒ WDM ⇒ DWDM Links
- Undersea Links: Amplifiers ⇒ High maintenance cost ⇒ Can't put too many fibers
- DWDM highly successful in long-haul market.
- Not yet cost-competitive in metro market.
  Bandwidth demand is low and more dynamic.
  Many new lower cost products for metro market.

Sample Products

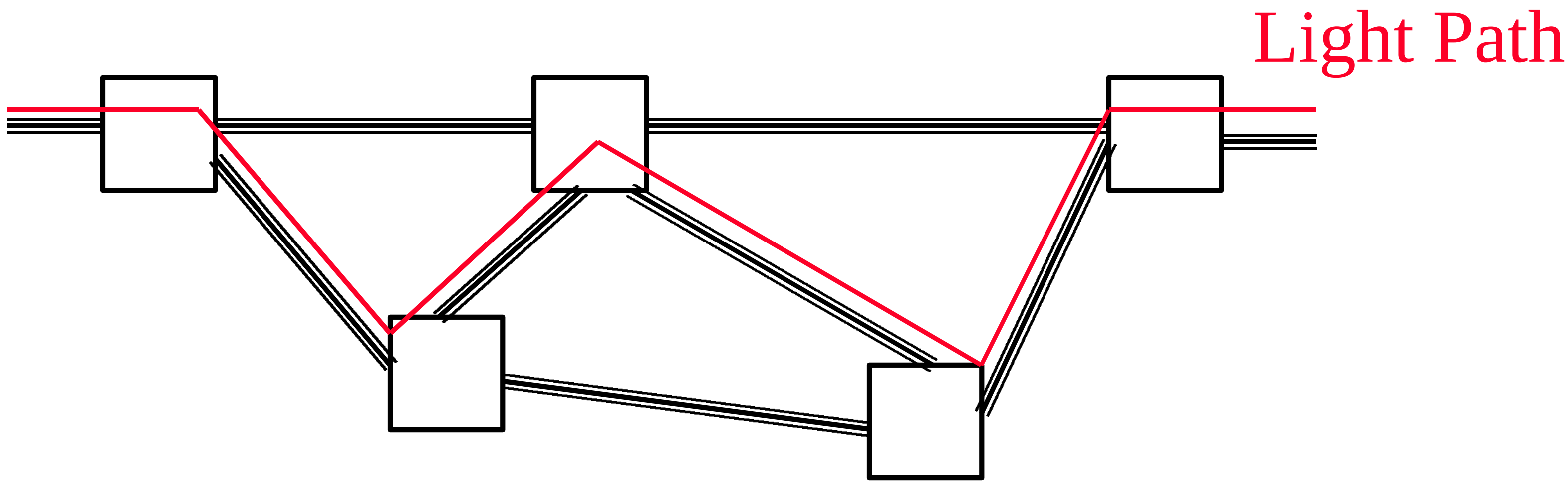
- **Nortel/Cambrian**: Optera Metro: 32 × 2.5G Optera LH: 2560×622Mbps, 1280×1.25Gbps (Gb Ethernet), 640×2.5Gbps, 160×10Gbps
- **Pirelli Optical Systems**: 128×10G TeraMuX WaveMux H-DWDM with Soliton
  OMDS 32λ WDM System
- **Monterey Networks**: Wavelength Router™
  256×256 OC-48 scalable to 160 Tbps
  Non-blocking any to any.
  Fully hot swappable w/o fiber swap
  1+1 or 1:N APS. Straight IP over DWDM.

Optical (Wavelength) Cross Connect

- Slow switching nodes.
- Configuration changed by management.
- May allow any wavelength on any fiber to go to any fiber.
- Programmable.
- Control channel could be electronic or optical.



Wavelength Routed Networks



- Light path through a DWDM network
- Routing ⇒ Wavelength assignment problem
- Two wavelengths from different fibers should not be mixed ⇒ Need wavelength conversion

Stack Debate

1993	1996	1999	2000
IP	IP	IP	IP/MPLS
ATM	PPP	PPP	Sonet Framing
SONET	SONET		
DWDM	DWDM	DWDM	DWDM
Fiber	Fiber	Fiber	Fiber

ATM provides voice+data integration

Ignores Voice

PPP = Point to point protocol in HDLC-like framing

Multi-Layer Stack: Why?

- Speed: λ > SONET > ATM > IP
  ATM < OC-12, IP < OC-3
  Low speed devices ⇒ Not enough to fill a λ
  SONET (1λ) limited to 10 Gbps
- Distance: End-system, Enterprise backbone, Carrier Access, Carrier Backbone, Core
- Some unique function in each layer
  - ATM = Access/Integration/Signaling/QoS/TM
  - SONET = Mux/Transport

Multi-layer Stack: Problems

- Increasing Bandwidth
  $\Rightarrow$ Core technologies move towards the edges
- Gigabit Routers $\Rightarrow$ No need for grooming
  One router port should be able to use all resources.
- Functional overlap:
  - Multiplexing:
    DWDM $\lambda = \Sigma$ STM $= \Sigma$ VC $= \Sigma$ Flows $= \Sigma$ packets
  - Routing: DWDM, SONET, ATM, IP
  - QoS/Integration: ATM, IP
- Static division of bandwidth in SONET good for continuous traffic not for bursty traffic.

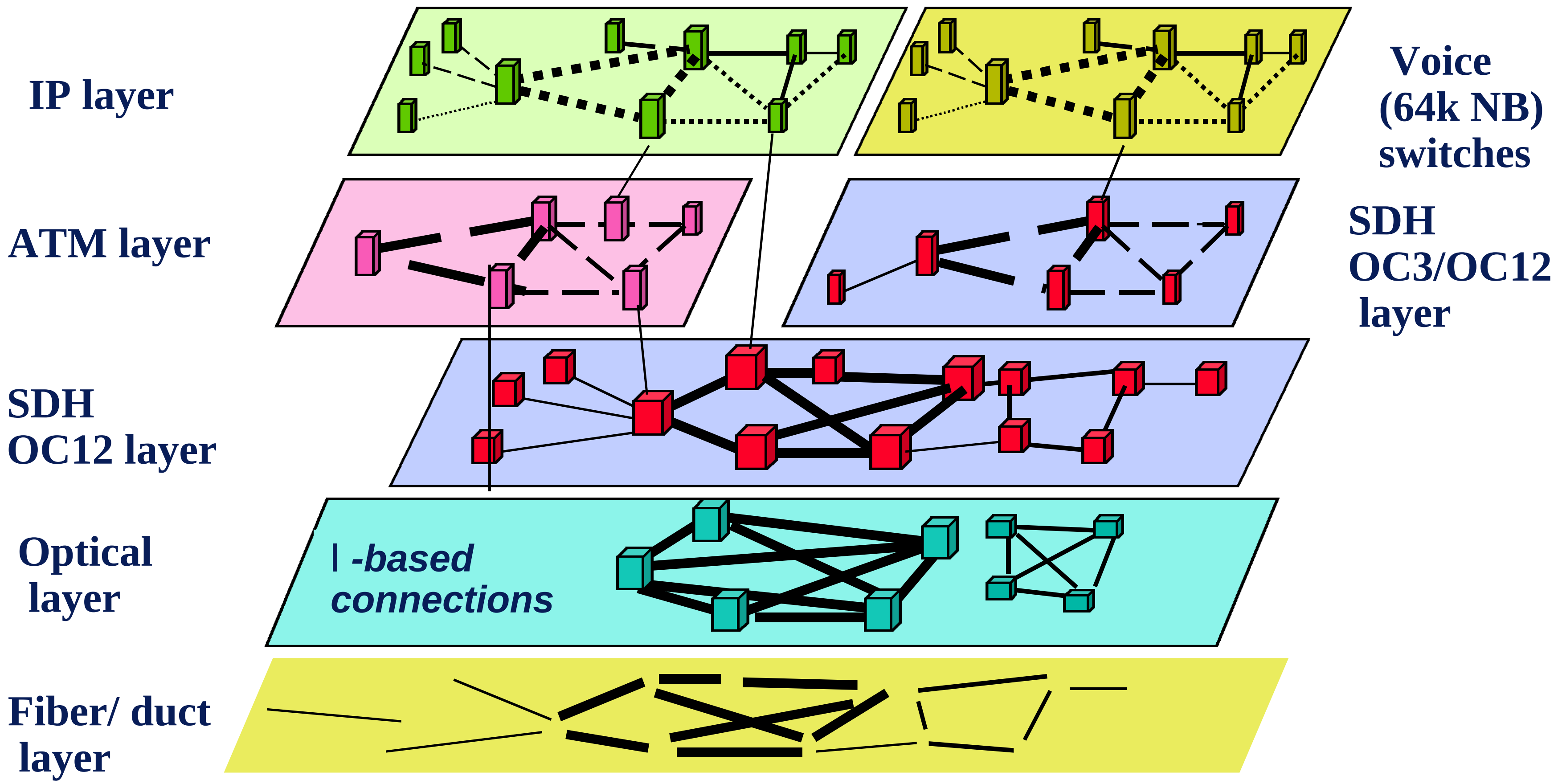
Multilayer Stack Problems (Cont)

- Failure affects multiple layers:
  1 Fiber $\Rightarrow$ 64 λ $\Rightarrow$ 160Gbps = 1000 OC-3 $\Rightarrow$ 10^5 VCs
  $\Rightarrow$ 10^8 Flows
- Restoration at multiple layers:
  DWDM $\Rightarrow$ SONET $\Rightarrow$ ATM $\Rightarrow$ IP
- SONET $\Rightarrow$ 50% lost = Inefficient Protection
- SONET $\Rightarrow$ Manual (jumpers) $\Rightarrow$ Slow provisioning
  Need Bandwidth on all rings $\Rightarrow$ months/connection
  Bandwidth reserved during setup
- Any layer can bottleneck
  $\Rightarrow$ Intersection of Features + Union of Problems

IP Directly over DWDM: Why?

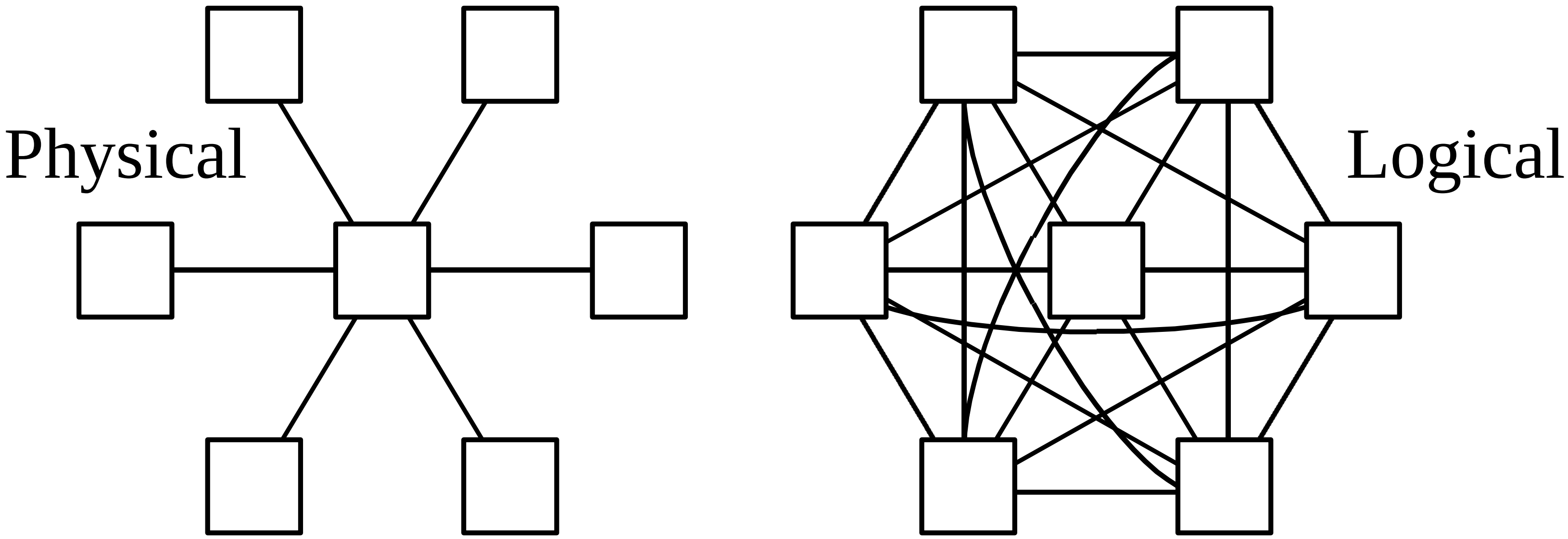
- IP $\Rightarrow$ revenue
  DWDM $\Rightarrow$ Cheap bandwidth
  IP and DWDM $\Rightarrow$ Winning combination
  Avoid the cost of SONET/ATM equipment
- IP routers at OC-192 (10 Gb/s)
  $\Rightarrow$ Don't need SONET multiplexing
- Coordinated restoration at optical/IP level
- Coordinated path determination at optical/IP level
- SONET Framing can remain for error monitoring
  Two parts of a layer: Framing + Protocols

Virtual Topology Issue



Ref: Dixit

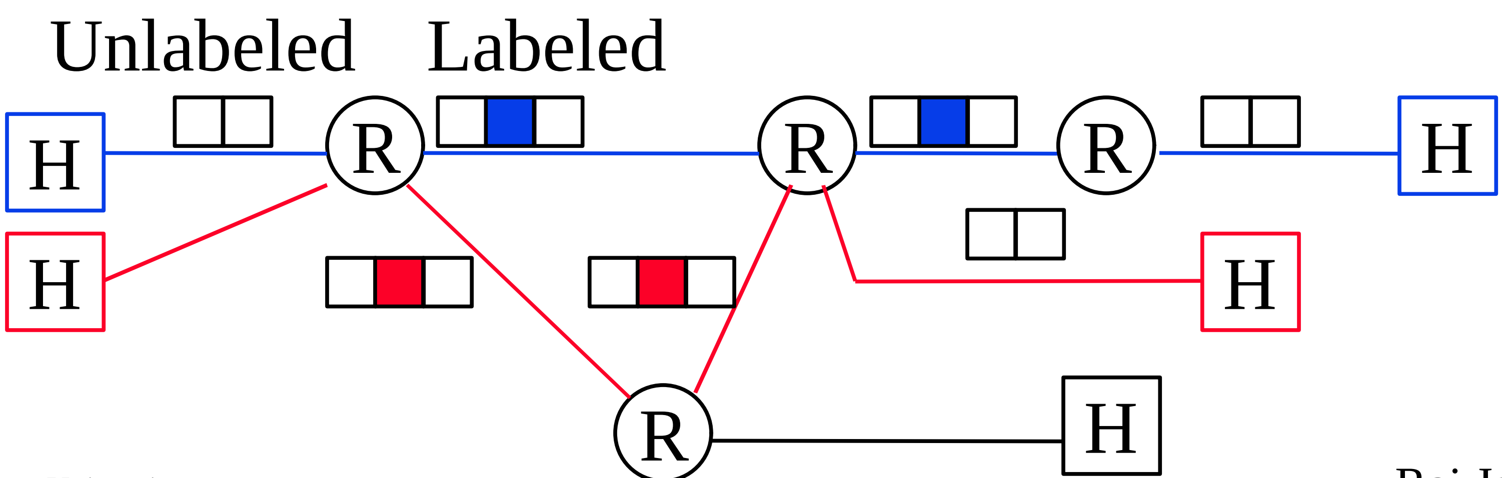
IP over ATM: Lessons



- Duplication between PNNI and OSPF
- Virtual topology ⇒ n^2 scaling problem
- Solutions:
  - IP Switching ⇒ Make every switch a router
  - MPLS ⇒ Make every switch an LSR

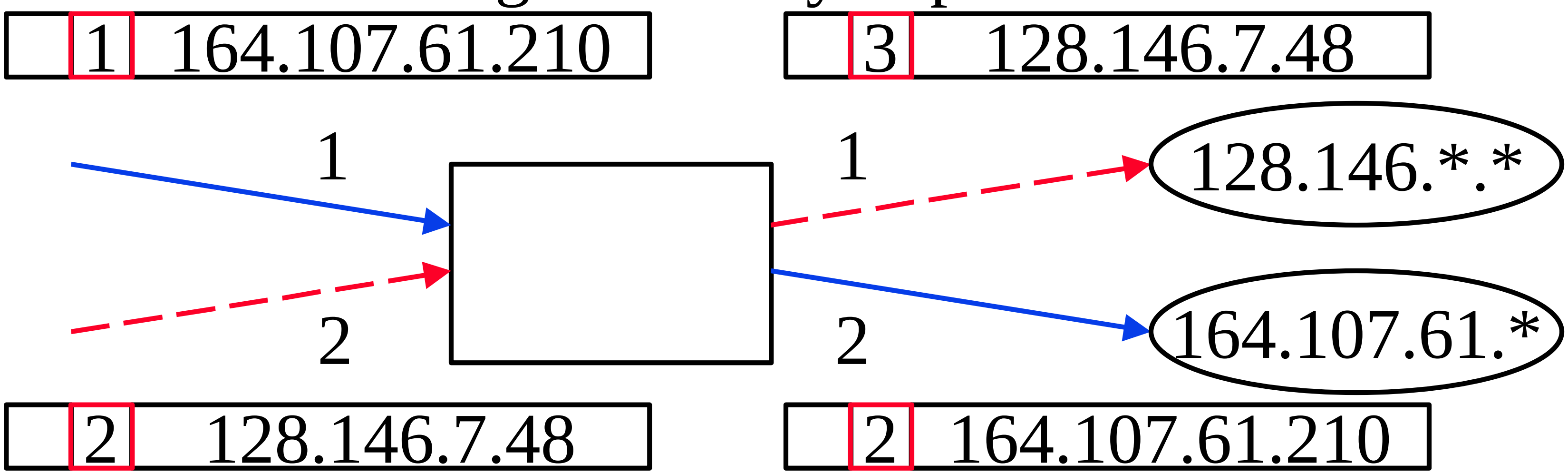
Label Switching

- Label = Circuit number = VC Id
- Ingress router/host puts a label. Exit router strips it off.
- Switches switch packets based on labels.
  Do not need to look inside ⇒ Fast.



Label Switching (Cont)

- Labels have local significance
- Labels are changed at every hop



Input Port	Input Label	Adr Prefix	Output Port	Output Label
1	1	164.107.61.*	2	2
2	2	128.146.*.*	1	3

IP over MPLS over DWDM

- MPLS = Multi-Protocol Lambda Switching
- DWDM network ≈ ATM network with Limitations
- Optical Channel Trail = VC = LSPs = Traffic Trunk
- Fiber = Link
- Limited # of channels
- Global significance, if no λ conversion
- Local significance with λ conversion (still complex)
- Granularity = $\lambda \Rightarrow$ Fixed datarate
- No aggregation yet $\Rightarrow$ No label merging

MPLS over DWDM (Cont)

- No hierarchy yet ⇒ No label stacks
- No TDM yet ⇒ No cells or packets
- No queueing ⇒ No scheduling, No Priority, No burstiness, No policing
- Need Shaping/grooming at entry
- Faster restoration via redundancy (rings/mesh)
- Vendor specific management
  ⇒ Interoperability issues

MPLS Control Plane: Today

- Resource Discovery: IGP (OSPF/PNNI)
- Path Computation: IGP (OSPF/PNNI)
- Connection Management: Label Distribution via IGP(OSPF), LDP, RSVP
- Survivability: Rerouting,...
- Constraint-based routing based on data rate, overbooking, delay, ...

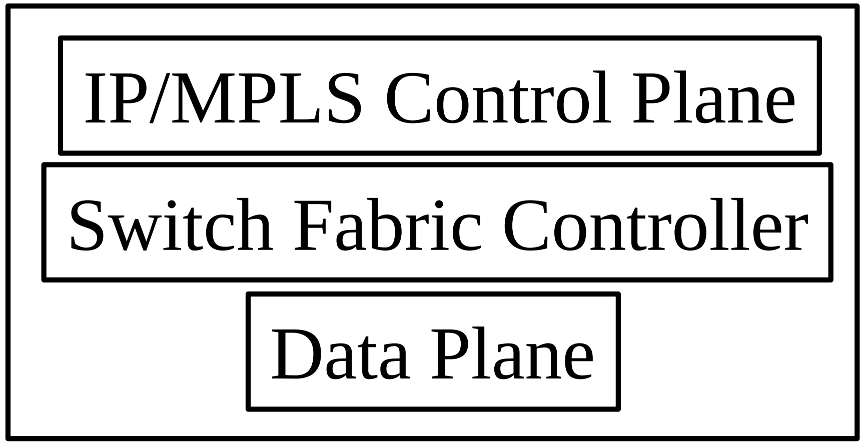
MPLS Control Plane: Tomorrow

- Next Hop Forwarding Label Entry (NHFLE)
  = Preprogrammed λ switching
  = Wavelength Forwarding Information Base matrix
  ⇒ <Input port, λ> to <output port, λ> mapping
- Constraints: Data rate, Attenuation, Dispersion, Length, delay
- Topologies: Linear and rings to partial Mesh
- λ control plane via network management
  ⇒ Permanent ⇒ Static routing
  ⇒ Too slow for restoration

MPLS Control Tomorrow (Cont)

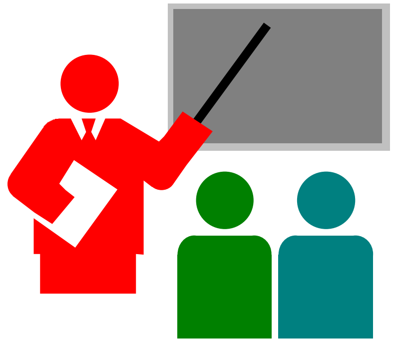
- Can add resilience (survivability) preemption, resource class affinity attributes to trails
- Each OXC will be an IP addressable device
- Control plane can be out-of-band IP channel, dedicated supervisory channel
- Need to build on concept of "Abstract Node" in IP routing $\Rightarrow$ Failures are handled locally
- λ availability will be advertised by optical node/WRouter

Optical Node Architecture



- Pre-configured control wavelength upon initialization
- Need to develop hierarchical/aggregation concepts (label stacks or VPs)
  $\Rightarrow$ λ-Group (Optical channel, optical path, Light path)
- Add light path constraints to MPLS label distribution or explicit path requests
- Ref: draft-awduche-mpls-te-optical-00.txt

Summary



- DWDM allows 32- to 128- channels per fiber
- High IP Routing speeds and volumes
  $\Rightarrow$ Need a full wavelength
  $\Rightarrow$ Many ATM/SONET functions not needed
- Need MPLS to provide QoS, Isolation
- Protection/Restoration/Routing should be coordinated between IP/MPLS and DWDM
- Need hierarchy/aggregation concepts for DWDM

References:

- See 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 DWDM, http://www.cis.ohio-state.edu/~jain/cis788-99/ip_dwdm/index.html
- Newsgroup: sci.optics.fiber

Standards Organization

- ITU:
  - **G.681** Functional characteristics of interoffice and long-haul line systems using optical amplifiers including optical multiplexing
  - **G.692** Optical Interfaces for multichannel systems with optical amplifiers (Oct 98): 50 and 100 GHz spacing centered at 193.1 THz (1553.5 nm)
  - **G.872** Architecture for Optical Transport Networks, 1999
  - Several others in preparation

Standards (Cont)

- ANSI T1X1.5: http://www.t1.org/t1x1/_x1-grid.htm
- IETF: MPLS over DWDM
- Optical Interoperability Forum (OIF): www.oiforum.com
  - Started April 1998 by CISCO, Ciena, ...Now over 128 members
  - Working groups on Architecture, Physical and Link Layer, OAM&P
  - Signaling protocols for rapid provisioning and restoration

Acronyms

- ADM Add-Drop Multiplexer
- PANDA Polarization maintaining AND Absorption reducing
- ANSI American National Standards Institute
- APS Automatic Protection Switching
- ATM Asynchronous Transfer Mode
- CDMA Code Division Multiple Access
- DARPA Defense Advanced Research Project Agency
- DCF Dispersion Compensating Fiber
- DPT Dynamic Packet Transport
- DSF Dispersion Shifted Fiber

- DFF	Dispersion Flattened Fiber
- DSL	Digital Subscriber Lines
- DWDM	Digital Wavelength Division Multiplexing
- EDFAs	Erbium-Doped Fiber Amplifiers
- FCC	Federal Communications Commission
- FWM	Four-Wave Mixing
- GHz	Giga Hertz
- IEEE	Institution of Electrical and Electronic Engineers
- IETF	Internet Engineering Taskforce
- IPS	Intelligent Protection Switching

ITU	International Telecommunications Union
KEOPS	Keys to Optical Packet Switching
LAN	Local Area Network
LED	Light Emitting Diode
MMF	Multimode Fiber
NRZ	Non-return to zero
NTONC	National Transparent Optical Network Consortium
OAM	Operation Administration and Maintenance
OC	Optical Carrier
OCh	Optical Channel Layer

- OFC Optical Fiber Conference
- OIF Optical Interoperability Forum
- OMS Optical Multiplex Section
- OPP Optical Packet Path
- SPP Secondary Packet Paths
- OSC Optical Supervisory Channel
- OSN Optical Service Networks
- OSPF Open Shortest Path First
- OTDM Optical Time Domain Multiplexing
- OTS Optical Tranmission Section
- OXC Opical cross connect
- PMD Polarization Mode Dispersion

- PMF Polarization Maintening Fiber
- PMMA PolyMethylMethyelAcrylate
- RI Refrective Index
- RIP Routing Information Protocol
- SNMP Simple Network Management Protocol
- SNR Signal to Noise Ratio
- SONET Synchronous Optical Network
- SRP Spatial Reuse Protoco
- TDM Time Division Multiplexing
- WAN Wide Area Network
- WC Wavelength converter

- WDM Wavelength Division Multiplexing
- WGR Wavelength Grafting Router
- WIXC Wavelength Interchanging Crossconnect
- WSXC Wavelength Selective Crossconnect
- ZBLAN Zirconium, barium, lanthanum, aluminium, and sodium