IP over SONET and Optical Networks

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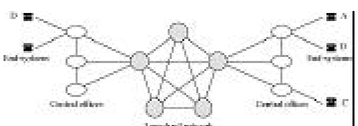
Based in part on slides of Nick McKeown (Stanford)

- Internet Core Transport Evolution & Trends
- SONET
- Optical Networking: Components
- Control plane:
  - Overlay model, peer model
  - Issues: provisioning, restoration, routing, traffic engineering

Telephony: Multiplexing

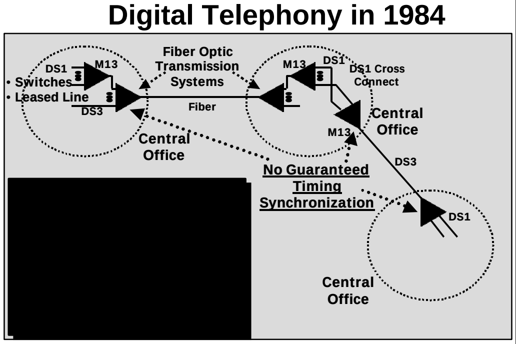


- ***Telephone Trunks*** **between central offices carry hundreds of conversations: Can't run thick bundles!**
- **Send many calls on the same wire: *multiplexing***
- **Analog multiplexing**
  - **bandlimit call to 3.4 KHz and frequency shift onto higher bandwidth trunk**
- **Digital multiplexing: convert voice to *samples***
  - **8000 samples/sec => call = 64 Kbps**

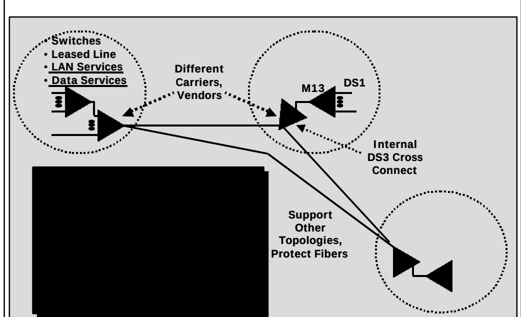
Telephony: Multiplexing Hierarchy

- **Pre-SONET:**
  - **Telephone call: 64 kbps**
  - **T1 line: 1.544 Mbps = 24 calls (aka DS1)**
  - **T3 line: 45 Mbps = 28 T1 lines (aka DS3)**
- **Multiplexing and de-multiplexing based upon strict timing (synchronous)**
  - **At higher rates, jitter is a problem**
  - **Have to resort to bit-stuffing and complex extraction => costly "plesiochronous" hierarchy**
- **SONET developed for *higher multiplexing aggregates***
  - **Use of "pointers" like C to avoid bit-stuffing**

Digital Telephony in 1984



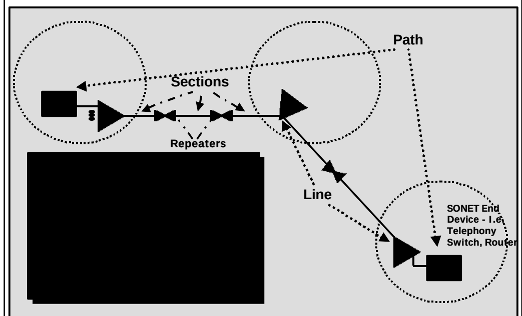
Post-AT&T Divestiture Dilemmas



SONET

- Synchronous Optical Network
- Layer 1 Standards For Communication over Fiber Optic (and Electrical) Links
- Facilitates:
  - Fiber Optic Link Speed Increases
  - Variety Of Topologies and Grooming Functions
  - Operations, Administration, Maintenance, and Provisioning (OAM&P)
- Used As Telephony Carrier Equipment And CPE Interconnect

Equipment Types



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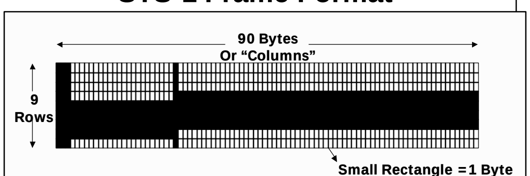
STS-1 Frame Format



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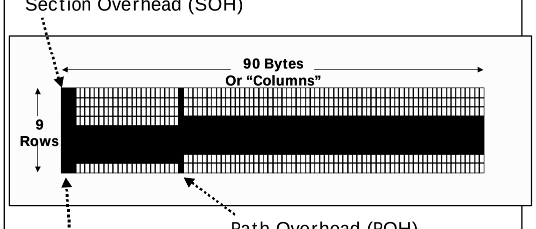
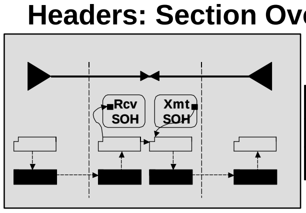
STS = Synchronous Transport Signal

STS-1 Headers



Headers: Section Overhead (SOH)



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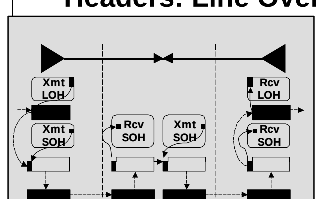
Selected Fields:
- **A1,A2 - Framing Bytes**
- **BIP-8 - Bit Interleaved Parity**
- **F1 User - Proprietary Management**

Headers: Line Overhead (LOH)



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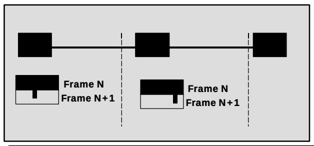
Selected Fields:
- H1-3 - Payload *Pointers*
- K1, K2 - *Automatic Protection Switching*
- D4-D12 - 576 kbps OSI/CMIP

Headers: Path Overhead (POH)



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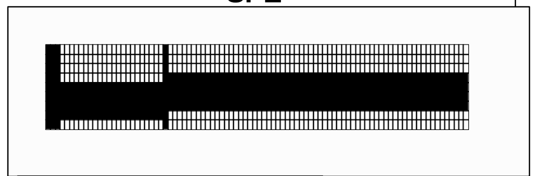
Selected fields:
- **BIP-8 -** ***Parity***
- **C2 - Payload** ***Type*** **Indicator**
- **G1 - End End** ***Path Status***

SPE



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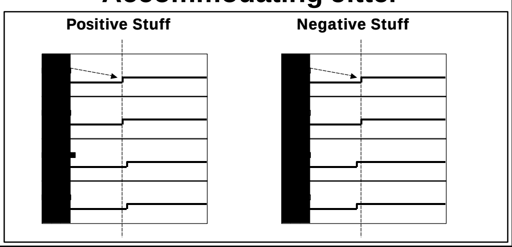
Defined Payloads
- **Virtual Tributaries (For DS1, DS2)**
- **DS3**
- **SMDS**
- **ATM**
- **PPP ...**

Accommodating Jitter



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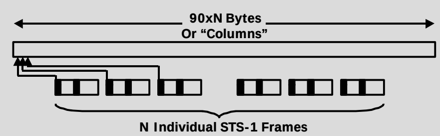
STS-N Frame Format

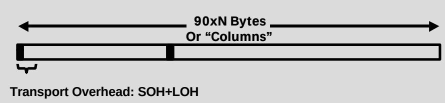


Composite Frames:
- **Byte Interleaved STS-1's**
- **Clock Rate = Nx51.84 Mbps**

Examples	
STS-1	51.84 Mbps
STS-3	155.520 Mbps
STS-12	622.080 Mbps
STS-48	2.48832 Gbps
STS-192	9.95323 Gbps

Complex demultiplexing !!

STS-Nc Frame Format



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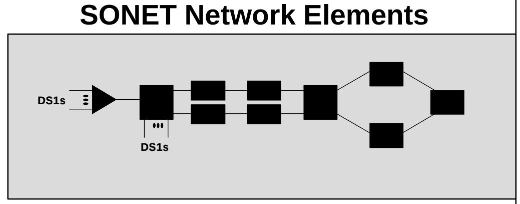
Current IP over SONET technologies use concatenated mode: OC-3c (155 Mbps) to OC-192c (10 Gbps) rates

SONET Network Elements



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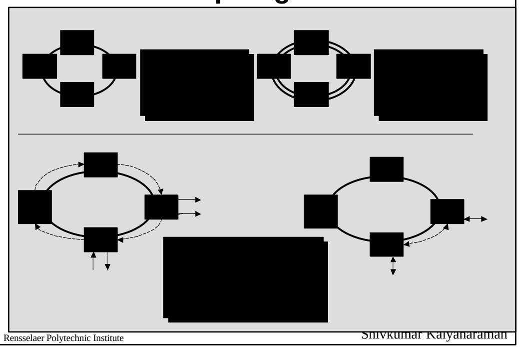
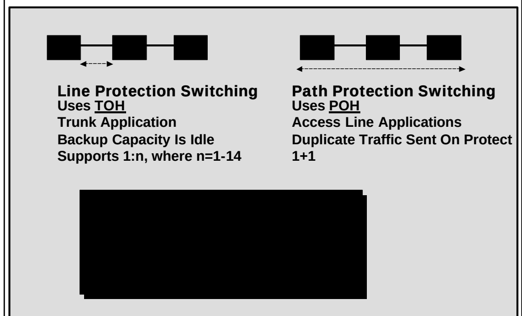
Topologies

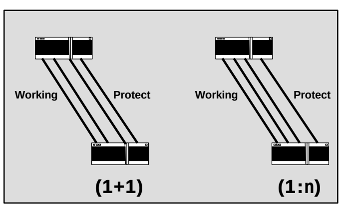


Automatic Protection Switching (APS)



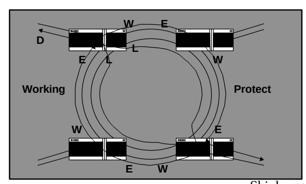
Protection Topologies - *Linear*

- Two nodes connected to each other with two or more sets of links



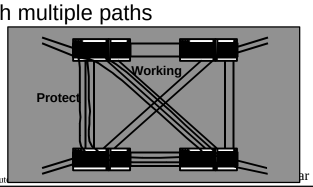
Protection Topologies - *Ring*

- Two or more nodes connected to each other with a ring of links
  - Line vs. Drop interfaces
  - East vs. West interfaces

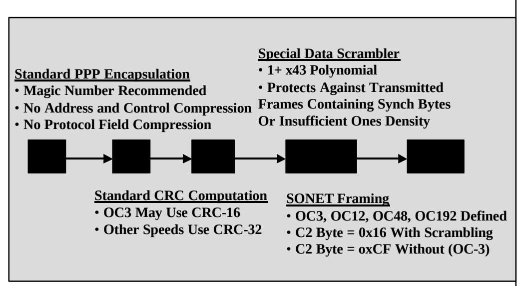


Protection Topologies - *Mesh*

- Three or more nodes connected to each other
  - Can be sparse or complete meshes
  - Spans may be individually protected with linear protection
  - Overall edge-to-edge connectivity is protected through multiple paths



Packet Over SONET (POS)

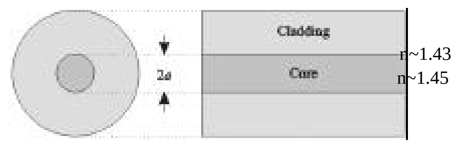


Quick History of Optical Networking

- **1958: Laser discovered**
- **Mid-60s: Guided wave optics demonstrated**
- **1970: Production of low-loss fibers**
  - **Made long-distance optical transmission possible!**
- **1970: invention of semiconductor laser diode**
  - **Made optical transceivers highly refined!**
- **70s-80s: Use of fiber in telephony: SONET**
- **Mid-80s: LANs/MANs: broadcast-and-select architectures**
- **1988: First trans-atlantic optical fiber laid**
- **Late-80s: EDFA (*optical* amplifier) developed**
  - **Greatly alleviated distance limitations!**
- **Mid/late-90s: DWDM systems explode**
- **Late-90s: *Intelligent* Optical networks**

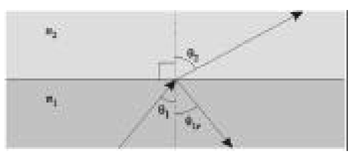
Geometrical Optics

- Fiber Made of Silica: SiO_2 (primarily)
- Refractive Index, $n = c_{vacuum}/c_{material}$
- $n_{core} > n_{cladding}$



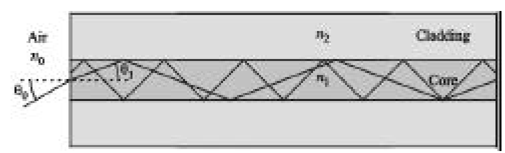
Geometrical Optics (cont.)

- Basics "Laws": Refraction and Reflection



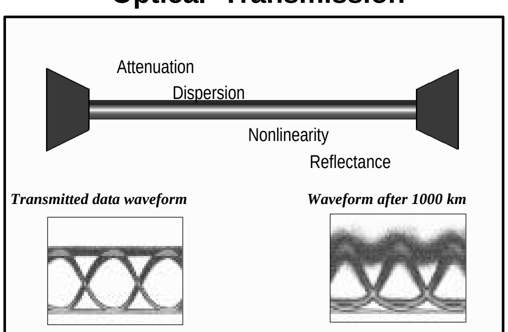
- Reflection: $\theta_{1r} = \theta_1$
- Refraction: $n_1 \sin\theta_1 = n_2 \sin\theta_2$ (*Snell's Law*)
- If $\theta_2 = \pi/2$: Total Internal Reflection
- then $\theta_1 = \sin^{-1}(n_2/n_1)$, "Critical Angle"

Geometrical Optics (cont.)

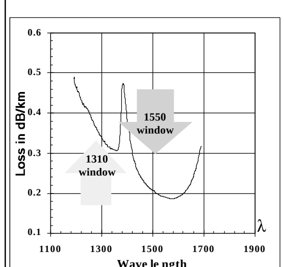


- Light propagates by total internal reflection
- Modal Dispersion: Different path lengths cause energy in narrow pulse to spread out
- δT = time difference between fastest and slowest ray

Optical Transmission

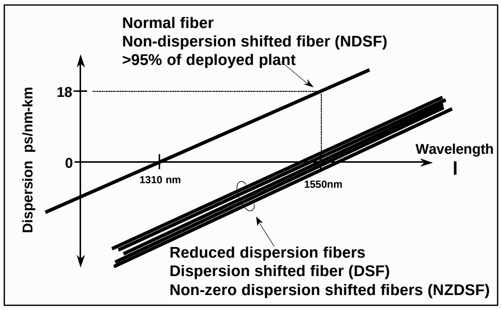


Fiber Attenuation

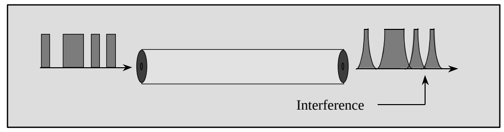


- **Two windows:**
  - **1310 & 1550 nm**
- **1550 window is preferred for long-haul applications**
  - **Less attenuation**
  - **Wider window**
  - **Optical amplifiers**

Fiber *Dispersion*



Dispersion

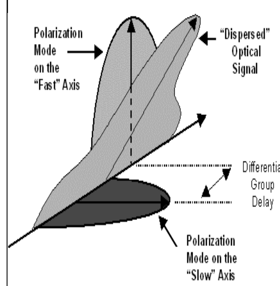


- **Dispersion causes the pulse to spread as it travels along the fiber**
- **Chromatic dispersion is important for singlemode fiber**
  - **Depends on fiber type and laser used**
  - **Degradation scales as (data-rate)^2**
- **Modal dispersion limits use of multimode fiber to short distances**

Single vs. Multimode Fiber

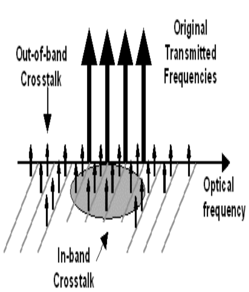
- Silica-Based Fiber Supports 3 Low-Loss "Windows": 0.8, 1.3 , 1.55 μm wavelength
- Multimode Fibers Propagate Multiple Modes of Light
  - core diameters from 50 to 85 μm
  - modal dispersion limitations
- Single-mode Fibers Propagate One Mode Only
  - core diameters from 50 to 85 μm
  - chromatic dispersion limitations (pulse spreading)

Polarization Mode Dispersion (PMD)



- **Most severe in older fiber**
- **Caused by several sources**
  - **Core shape**
  - **External stress**
  - **Material properties**
- **Becomes an issue at OC-192**

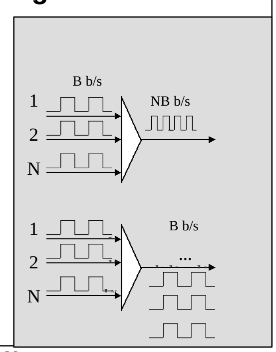
Four-Wave Mixing (FWM)



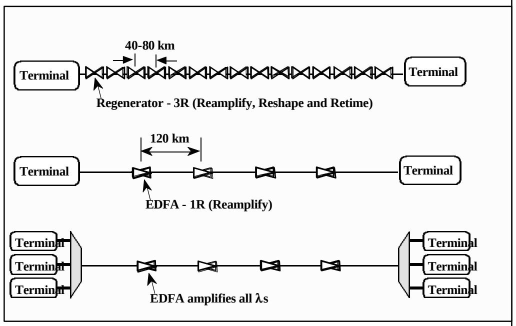
- **Creates in-band crosstalk that can not be filtered**
- **Problem increases geometrically with**
  - **Number of λs**
  - **Spacing between λs**
  - **Optical power level**
- **Chromatic dispersion minimizes FWM**

Multiplexing: WDM

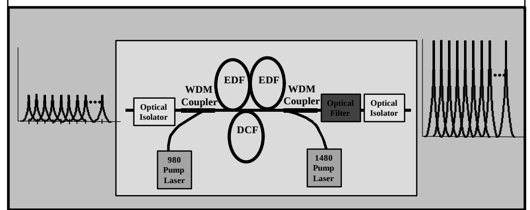
- TDM: Time Division Multiplexing
  - 10Gb/s upper limit
- WDM: Wavelength Division Multiplexing
  - Use multiple carrier frequencies to transmit data simultaneously



Erbium-Doped Fiber Amplifier (EDFA)

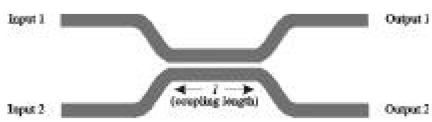


EDFA Enables DWDM!



- **EDFAs <u>amplify all λs</u> in 1550 window simultaneously**
- **Key performance parameters include**
  - **Saturation output power, noise figure, gain flatness/passband**

Optical Couplers

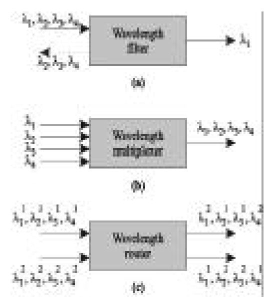


- Combines & splits signals
- Wavelength independent or dependent

- Power(Output1) = α Power(Input1)
- Power(Output2) = (1- α) Power(Input1)
  - Power splitter if α=1/2: 3-dB coupler
- Used to construct simple optical switches

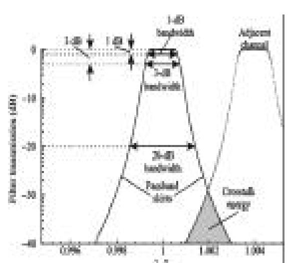
Multiplexers, Filters, Routers

- **Filter selects one wavelength and rejects all others**
- **Multiplexor combines different wavelengths**
- **Router exchanges wavelengths from one input to a different output**



Characteristics of Filters

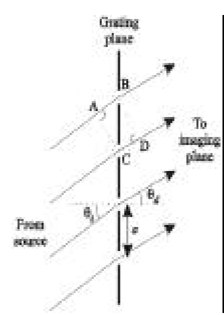
- Low insertion loss
- Loss independent of SOP
- Filter passband independent of temperature
- Flat passbands
- Sharp "skirts" on the passband



Gratings

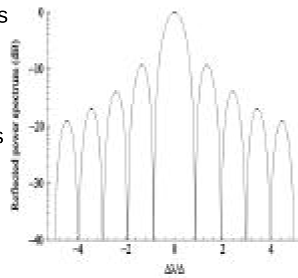
- Constructive interference at wavelength λ and grating pitch, a, if

  $a[\sin(\theta_i) - \sin(\theta_d)] = m \lambda$
- m = order of the grating



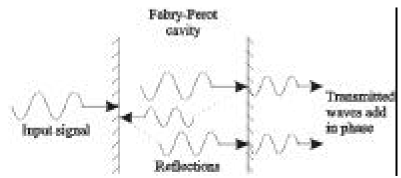
Bragg Gratings

- Bragg wavelength is
  $\lambda_0 = 2\, n_{eff}\Lambda$
  where Λ is period of grating
- If incident wave has wavelength λ_0, it is reflected by Bragg grating



Fabry-Perot Filters

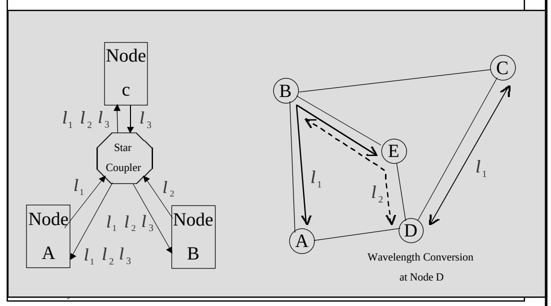
- Fabry-Perot filter also called F-P interferometer or etalon
- Cavity formed by parallel highly reflective mirrors
- **Tunable** filter



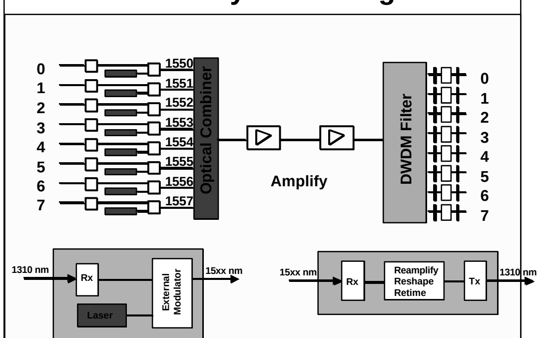
Pre-DWDM: Second Gen. Optical Nets

- Broadcast and Select
  - Passive broadcast to all receivers
  - Number of nodes limited by finite number of wavelengths and power splitting
- Wavelength Routing
  - Allows simultaneous lightpaths using same wavelengths
  - Power not broadcast to unwanted receivers

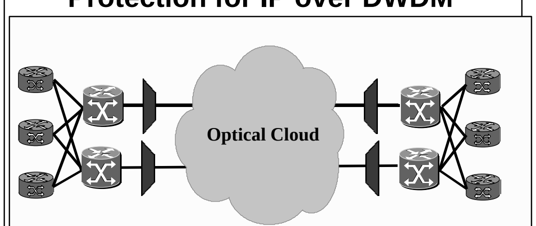
Second Generation Optical Nets



DWDM System Design

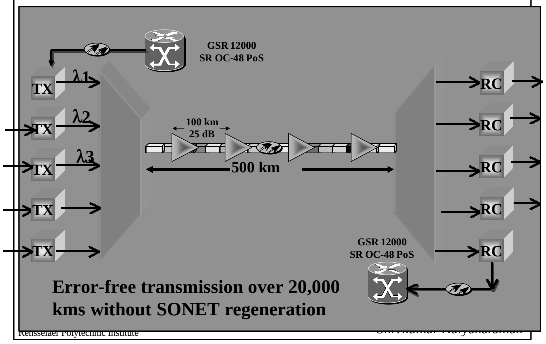


Protection for IP over DWDM

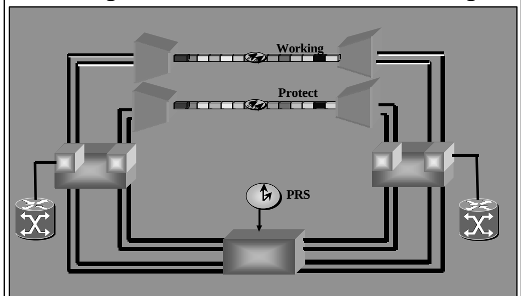


- **Optical protection is not sufficient**
  - **Only protects transmission infrastructure**
- **Layer 3 must provide path restoration**
  - **Opportunity for differentiation at the service level**

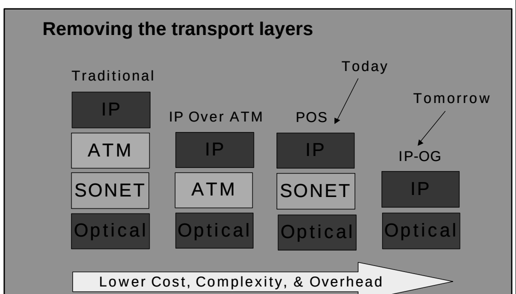
Eg: 40λ DWDM



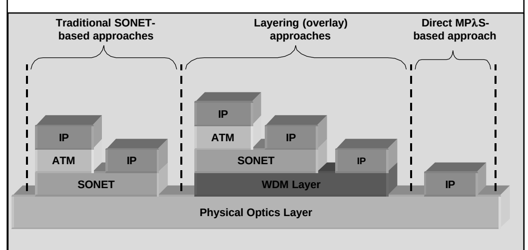
Eg: 16λ DWDM and OC-192 Ring



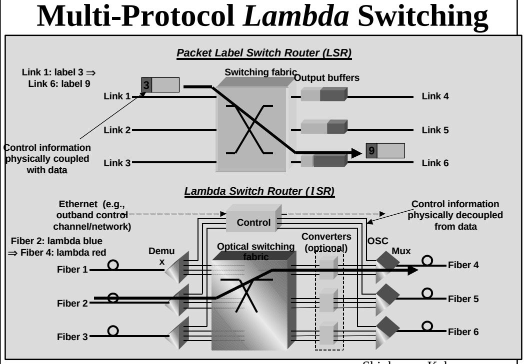
IP over Optical Networks (IPO)



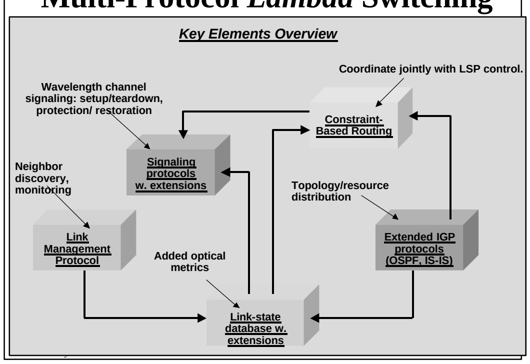
IPO: Control Planes



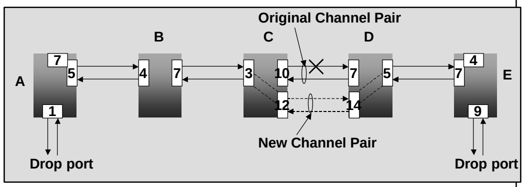
Multi-Protocol *Lambda* Switching



Multi-Protocol *Lambda* Switching

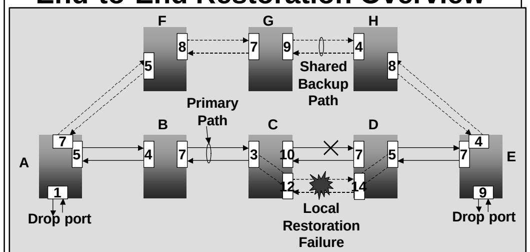


Link-Level Restoration Overview



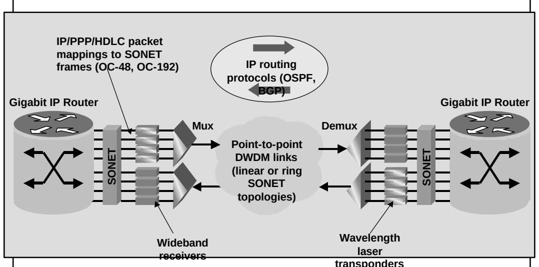
- A lightpaths is locally restored by selecting an available pair of channels within the same link
- If no channel is available then the end-to-end restoration is invoked

End-to-End Restoration Overview

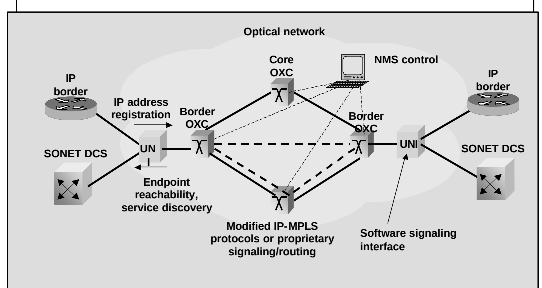


- A shared backup path is "soft-setup" for each restorable primary path
- When local restoration fails, triggers are sent to the end-nodes via signaling

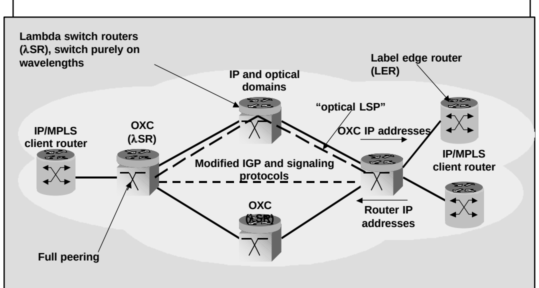
IP-SONET-WDM using POS



IP-Optical using Signaled Overlay



IP-Optical using Peer Model



Summary

- Internet Core Transport Evolution & Trends
- SONET
- Optical Networking: Components
- Control plane:
  - Overlay model, peer model
  - Issues: restoration, routing, traffic engineering