The Optical Internet Wavelength Division Multiplexing (WDM) and Lambda Switching

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Transmission of multiple light signals (wavelengths) on the same strand of fiber

- DWDM Dense WDM
- 密集波分复用
- More sophisticated → more expensive
- CWDM Coarse WDM 料波分复用
 - Lower number of wavelengths → cheaper

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Initial WDM Application

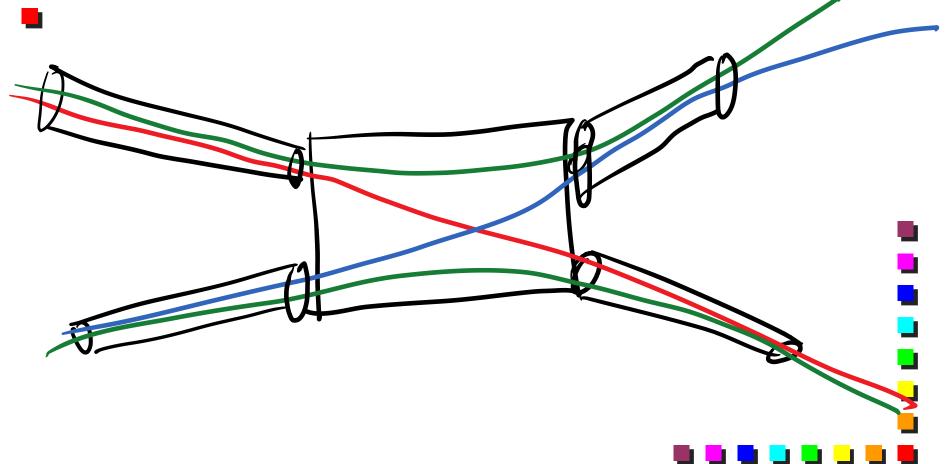
Increase transmission capacity of fiber

增强了光纤的吞叶

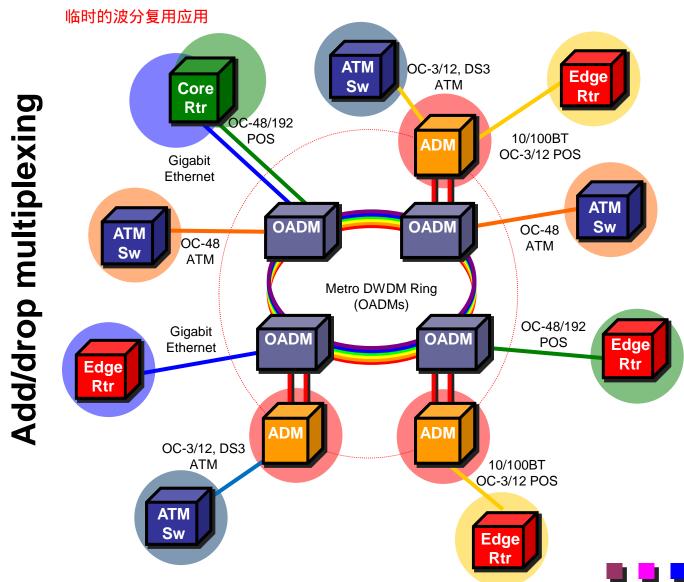
- Trunk bandwidth
- Increase the utilization (ROI: return of investment) of [existing] fiber
- Point to point configurations

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Taking it a step further: Wavelength Switching



"Interim" WDM Application



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"Interim" WDM Application

临时

Add/drop multiplexing

- Ring topologies with WDM add/drop multiplexers
 - Optical Add-Drop Multiplexer (OADM)
 - Inserting wavelengths on the ring
 - Extracting wavelengths from the ring
- Mostly static or semipermanent interconnection configurations
 - Reconfigurable OADM (ROADM)

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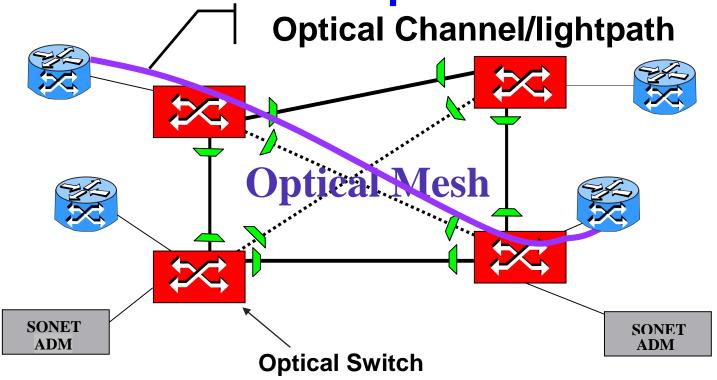
Ultimate WDM Application

Wavelength switched networks

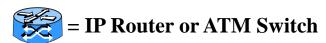
- Arbitrary mesh topologies of WDM links and wavelength switches
 - A.k.a. wavelength routers, lambda routers, lambda switches
 - Mostly ("only") optical cross connects
- Optical Switching Wavelength switching

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= WDM Terminal



Deployed in the network core because of its coarse bandwidth allocation

1 optical channel: 2.4Gb/s or more

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Why Optical Switching?

It has the potential of being simple, hence delivering a (very) low cost per switched bit

它有简单的潜力,因此提供一个(非常)低成本的每交换位

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A look into the historical moment in which optical switching became extremely popular

[problems are still current, expectation on optical switching is lower]

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Telecommunications Industry Analysis

Cross-Connects

Network Management

lephony

mecment

ement

Network Management

DSLAM Muth-Service Access Optical Technologies in Terabit Networks

Dr. John Ryan

Integrated teress Principal & Chief Analyst DSLAM Multi-Service Access

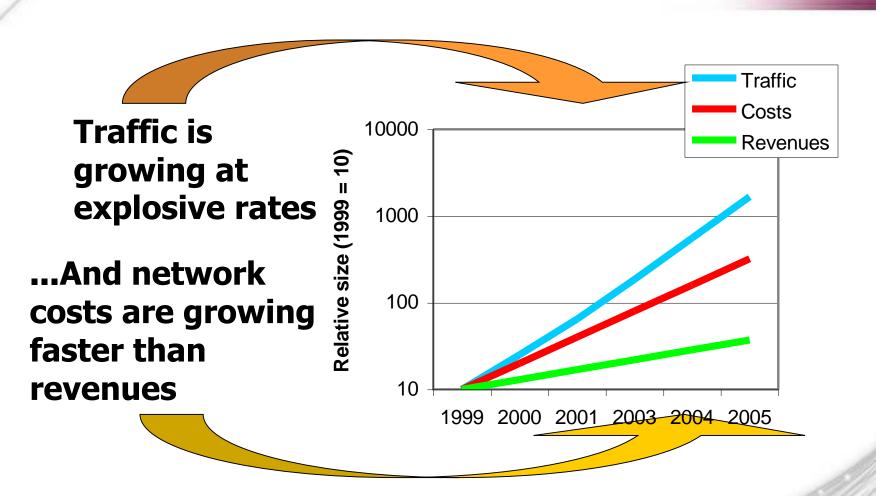
RHK

XDSL/HDSL

Cable Modem:

Optical Internetworking Forum, Atlanta, June 5th, 2000

The Resulting Traffic Dilemma...



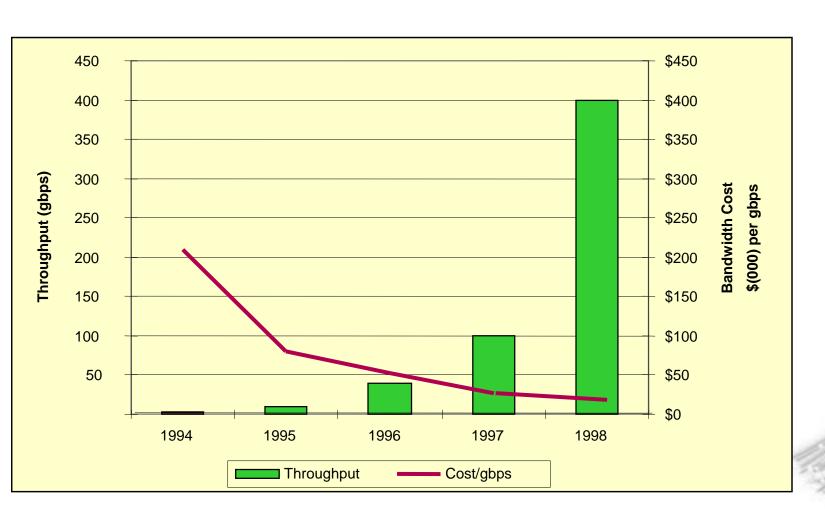
Optical networks help solve this dilemma -- on a large scale.

RHK

13

Optics Reshape the Cost Curve

DWDM driving down the cost of trunk bandwidth





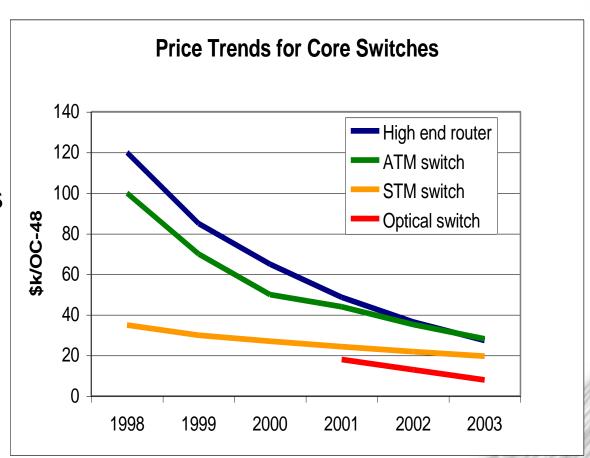
Pricing & The Technologies

Prices/OC-48

 (2.5Gbps)
 dropping rapidly
 in favor of

 10Gbps+ systems

 By 2002, optical switches could offer the most bandwidth per dollar







And to technology, leaving hype behind

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- Optical vs Electronic core
- Cross Connect vs Switch
- Wavelength Conversion

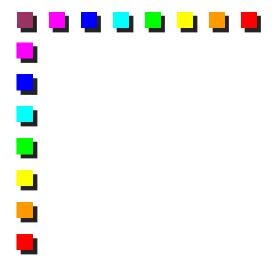
Different levels of complexity

不同等级的复杂度

不同等级的弹性

Different levels of *flexibility*

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Switching Core

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Deploy physical properties of materials to deflect light from incoming fiber to outgoing fiber

- Tilting mirrors 倾斜的镜子
 - Micro-electro-mechanical systems (MEMS)
 - Voltage operated
- Holographic reflecting surfaces 全息反射表面
 - Voltage operated
- Materials changing properties with
 - Heat
 - Pressure
 - Voltage/current

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- **♦ [Potentially] inexpensive (low CAPEX)**
 - Low cost material
 - Low cost process [once technology is mature]
- **Bit rate and signal independent** 比特率和信号无关
 - Unlimited scalability
 - Multi standard
- **Low power consumption**

更少的能量消耗

- Low operation costs (OPEX)
- High production costs

高昂的造价

- Immature technology
- High attenuation (and no regeneration)

高衰凋

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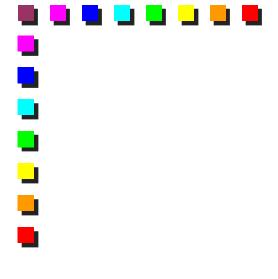
Convert optical signal into an electric one and use a circuit interconnection network

- Optical-electrical conversion 光电转换
- Receive the bits and switch them
- It loses all the nice properties of an optical core
 - Bit rate independence
 - Low power consumption
 - Low cost

However

- At current state of technology, cheaper
- Less complex/costly than packet switching

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Switching Dynamics

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交叉连接

Cross Connect

- Fixed/static configuration
 - Changed seldom

通过一个管理系统

静态配置

很少改变

- Through a management system/interface
- Usually optical core

通常是光学核心

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Fiber Cross Connect

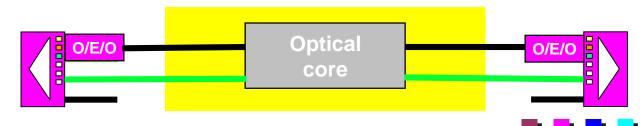
- The whole signal from an input fiber switched to an output fiber 整个信号从输入光纤口转换到输出光纤口
- Micro-electro-mechanical systems (MEMS)
 - 微电子系统 Long re-configuration time
- Optical amplification might be used before and after switching

可在交换前后使用光放大

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- One (or more) wavelengths from an input fiber to an output fiber 从输入光纤到输出光纤的一个或多个波长
- WDM de-multiplexer+MEMS
 - Separates different wavelengths in space
 - "Prism"
- Regeneration may be used before or/and after switching
 - OEO (optical-electrical-optical) conversion with electrical regeneration
 - Requires "receiving" the bits -> bit rate dependent



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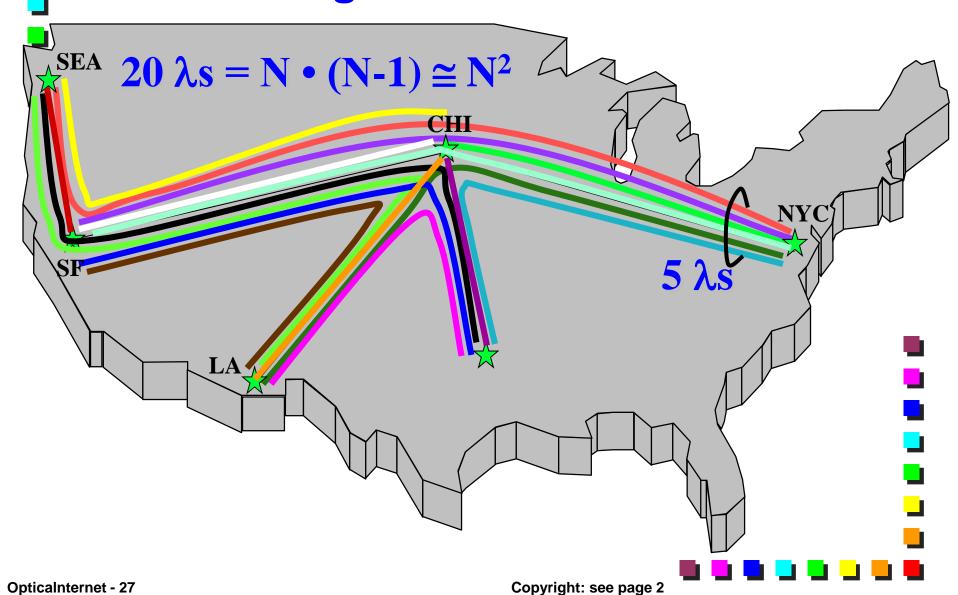


Wavelength Conversion

波长转换

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λ Switching: the N² Problem

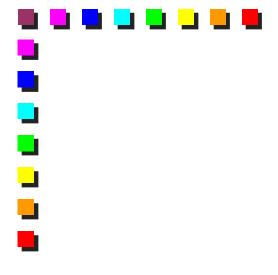


Wavelength Conversion

- Complex 复杂
 - OEO conversion OEO 昂贵且扩展性不好
 - Expensive
 - Non data transparent → does not scale
 - Physical properties
 - E.g., resonance chamber
 - Immature technology -> expensive
- Does not require the same wavelength endto-end 并不要求相同的波长在端对端传输过程中
- No wavelength assignment problem
 - N² problem

没有波长分配的问题

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Common Combinations

组合

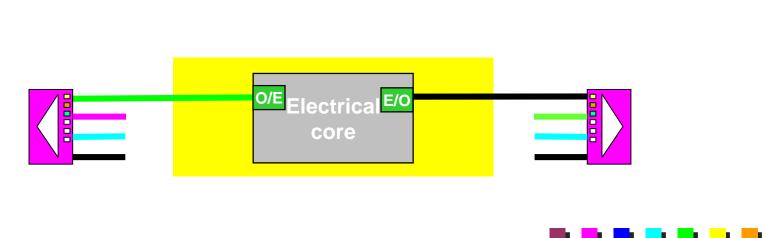
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Wavelength cross-connect with Wavelength Conversion

One (or more) wavelengths from an input fiber to other one (or others) on an output fiber

- Electrical core might be used
- 电子核心可以用来,信号监管,识别纠正错误

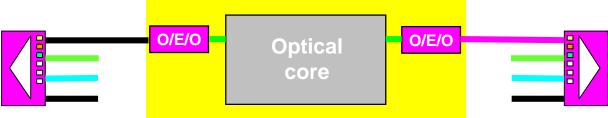
- Easier signal monitoring
- Forward error correction (FEC) possible to reduce Bit Error Ratio (BER)



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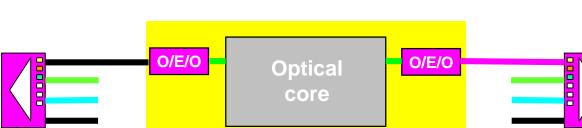
Wavelength cross-connect with **Wavelength Conversion**

- Optical core with OEO (optical-electricaloptical) conversion
 - Also providing signal regeneration



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Dynamic Optical Switching

- Wavelength switch with or without wavelength conversion 波长交換和波长转换
- Switch configuration is changed dynamically
 - By management
 - By time of day
 - By end system signaling
 - Every packet!?! ...
 - Optical packet switching
 - Optical burst switching

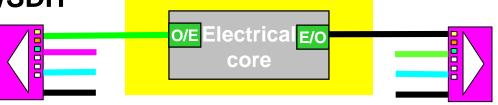
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Dynamic Optical Switching

用于再生和波长转换

O/E/O

- Optical core
 - Electroholography, bubbles
 - OEO for regeneration and wavelength conversion
- Electrical core
 - Possibly SONET/SDH

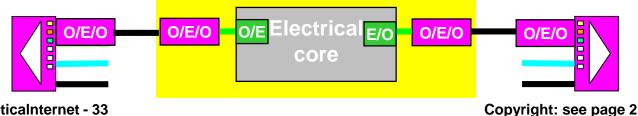


Optical

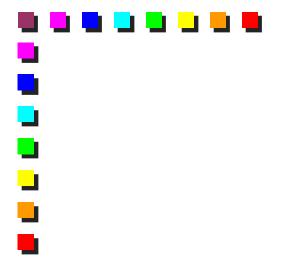
core

O/E/O

Possibly multiple OEO for regeneration



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Deployment



端到端的光路供应和保护

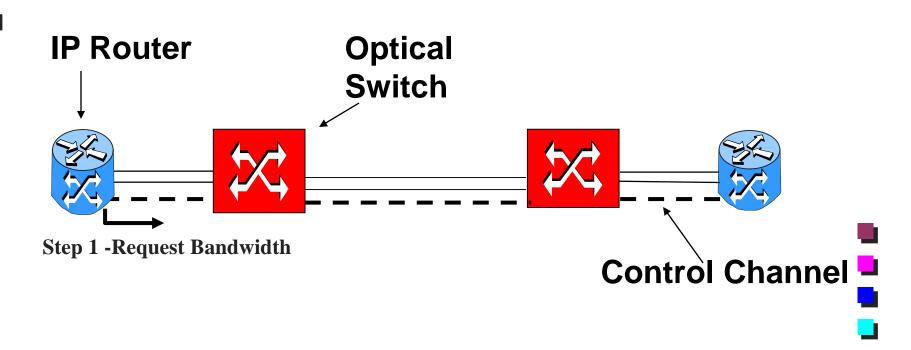
- Provisioning and protection of lightpaths end-to-end
- Client equipment (e.g. routers) to control provisioning of optical layer lightpaths
 - Signaling

控制光层光路供应的客户端设备(例如路由器)

Cost-effective deployment of flexible networks

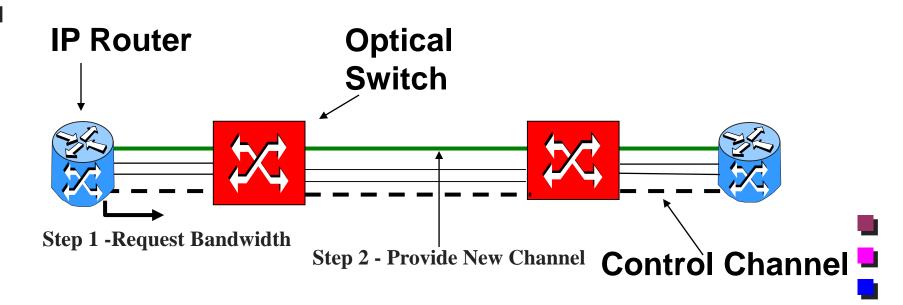
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Provisioning



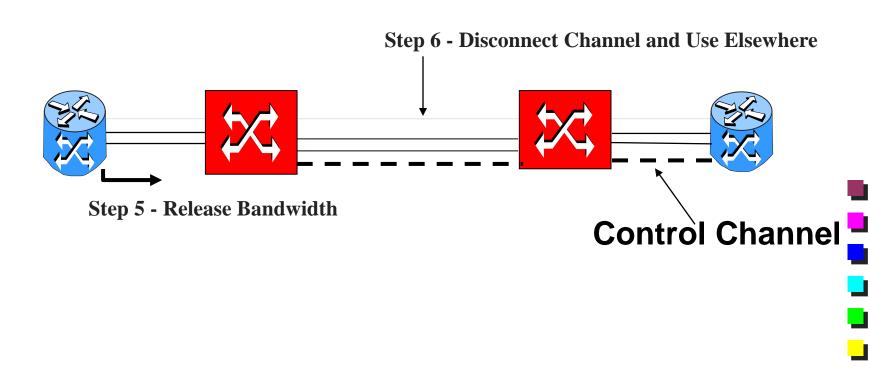
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Provisioning



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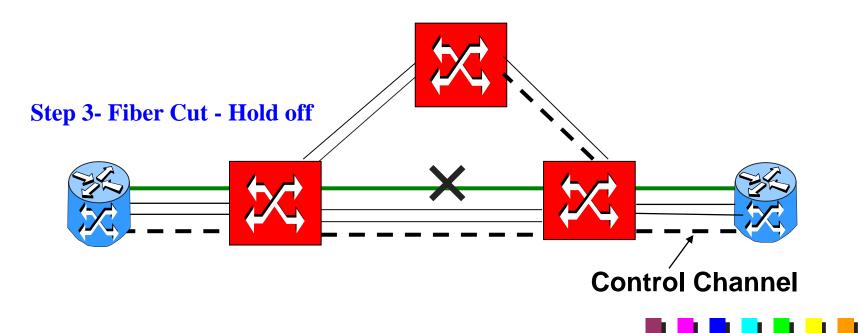
Provisioning



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Protection/Restoration

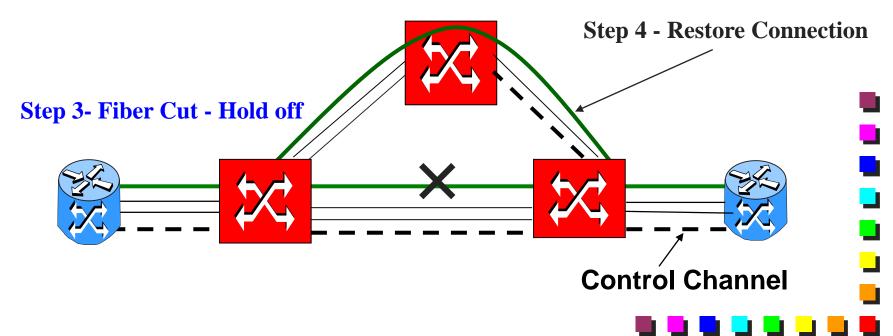
- Protection: pre-determined action
 - non-optimal resource utilization
- Restoration: dynamically determined action
 - optimization of resource utilization



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Protection/Restoration

- Protection: pre-determined action
 - non-optimal resource utilization
- Restoration: dynamically determined action
 - optimization of resource utilization

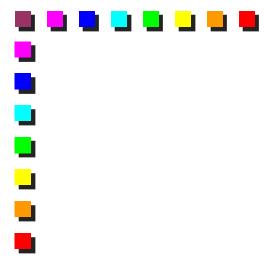


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Protection/Restoration

- Multiple levels of protection:
 - Layer 1 optical, e.g. SONET-like
 - Layer 2 data link bundle
 - Layer 2.5 protected MPLS LSPs
 - Layer 3 routing
- Multiple layers of restoration can be triggered
 - Each different timescales for detection and repair
- Must avoid:
 - Unnecessary traffic shifting
 - Packet loss, reordering, control plane churn
 - Pathological feedback
 - Non self-stabilizing

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Control Plane

What Optical Switches Need

- Resource discovery
 - Topology
 - Access points and node identification
 - **■** Resource usage
- Connection management/signaling
 - Lightpath setup
 - Lightpath take down
 - Lightpath modification
- Distributed routing
- Mesh/ring network protection and recovery
- Establishment of protection service classes

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- Resource discovery
 - Address of users reachable through the optical network
- Manage lightpaths
 - Lightpath setup
 - Lightpath take down
 - Lightpath modification
- Negotiate protection service classes
 - Protected, unprotected, best effort lightpaths

Does all this sound familiar? ATM

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In the Optical Internet network users are routers

- Overlay Model
 - The optical network provides connectivity between routers
 - Routers see the optical network as a black box
 - Routers might be provided with reachability information
- Peer Model
 - Routers and switches participate to the same routing protocols
 - Routers know the topology of the optical network
 - Routers can choose the preferred path for lightpaths between them
 - To reach specific destinations

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How to Do It

- How is the optical network controlled?
 - Layer 3 control plane?
 - MPLS/LDP?
 - LSPs mapped over wavelengths
 - OSPF, BGP4?
 - New signaling and routing standards?
 - Proprietary vendor specific?
- Out of band or in-band
 - Ethernet control channel

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OSPF, IS-IS, BGP for resource discovery

RSVP/LDP for signaling

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Players in the Optical Arena



- ITU-T International Telecommunication Union - Telecommunication Sector
 - OTN Optical Transport Network
 - Recommendation G.872
 - ASON Automatic Switched Optical Channel Networks
- IETF Internet Engineering Task Force
 - MPLambdaS Multi-Protocol Lambda Switching
 - MPLS signaling

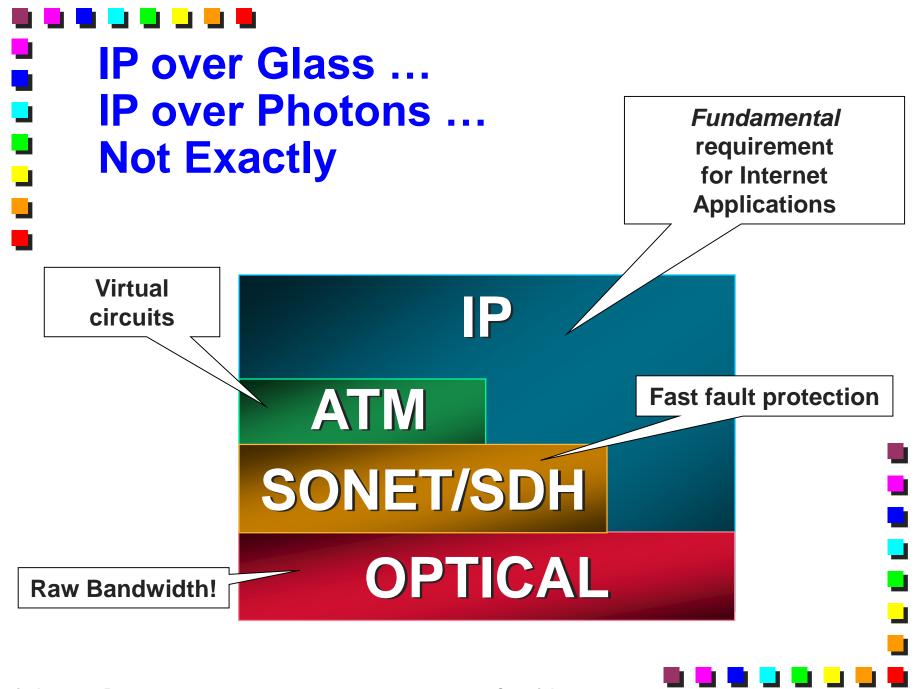
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Fora - Consortia

- OIF Optical Internetworking Forum
 - Focus on SONET
 - Adopting MPLS signaling
- ODSI Optical Domain Service Initiative
 - Service inteface
 - No NNI

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Data Transport and Protocol Stack



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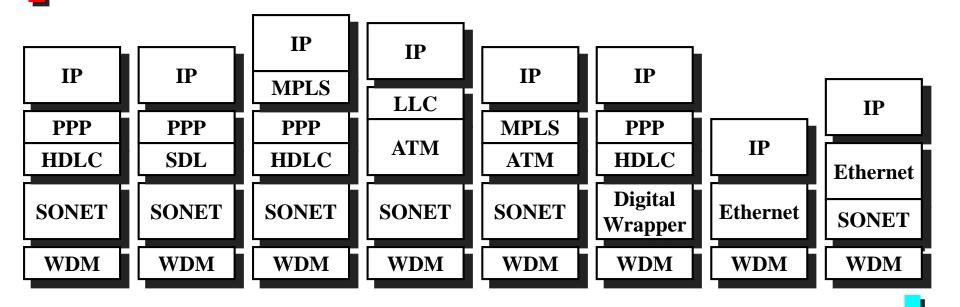
Data Transport

- Physical Layer -> transfer of bits
 - SONET/SDH
 - Ethernet
 - Digital Wrapper
- Data link layer -> framing
 - PPP with HDLC framing
 - PPP with SDL framing
 - Ethernet
 - ATM
- MPLS?
- Network layer: IP

PPP - Point-to-Point Protocol
HDLC - High-level Data Link Control
SDL - Simple Data Link
ATM - Asynchronous Transfer Mode

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Some Encapsulation Options



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High-Level Data Link Control (HDLC) framing

1 1 1 2 variable 2 0 4 1

Flag 01111110		Control 00000011	Protocol	Information	FCS	Flag 01111110
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Simple Data Link (SDL) framing

22112variable2 o 4Packet LengthHeader CRCAddress 11111111Control 00000011Protocol InformationInformationSDL CRC

CRC hunting

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PoS: Packet Over SONET

- Use SONET/SDH physical layer for transmission of bits
 - No SONET switching
 - No SONET (de)grooming
 - No SONET (de)multiplexint
 - Channels
- Way to encapsulate IP packets in SONET frames
 - One SONET channel per link/optical channel
 - PPP deployed

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Digital Wrapper

- Improve Bit Error Ratio (BER)
- Provide transparent transport

PAYLOAD FEC Data

OCh - Optical Channel

OH - Overhead

FEC - Forward Error Correction

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