

The Optical Internet

Wavelength Division Multiplexing (WDM) and Lambda Switching

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WDM: Wavelength Division Multiplexing

nel mio cavo trasmetto più segnali a diverse lunghezze d'onda

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

- DWDM - Dense WDM
 - More sophisticated → more expensive
- CWDM - Coarse WDM
 - Lower number of wavelengths → cheaper

è un segnale laser, come posso trasmetterlo? Quale lunghezza d'onda prendere affinchè riesca a trasmetterlo.





sul cavo riesco a trasmettere diversi pacchetti su diverse lunghezze d'onda contemporaneamente

--> uso più efficiente delle risorse



Initial WDM Application

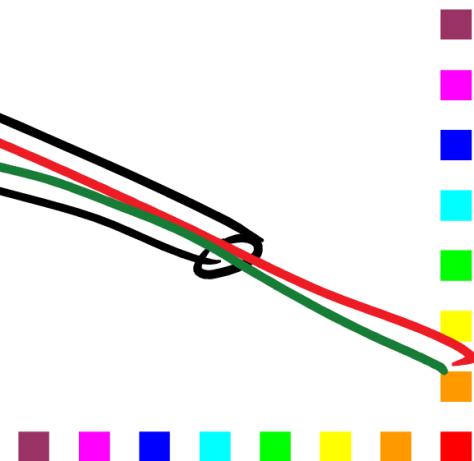
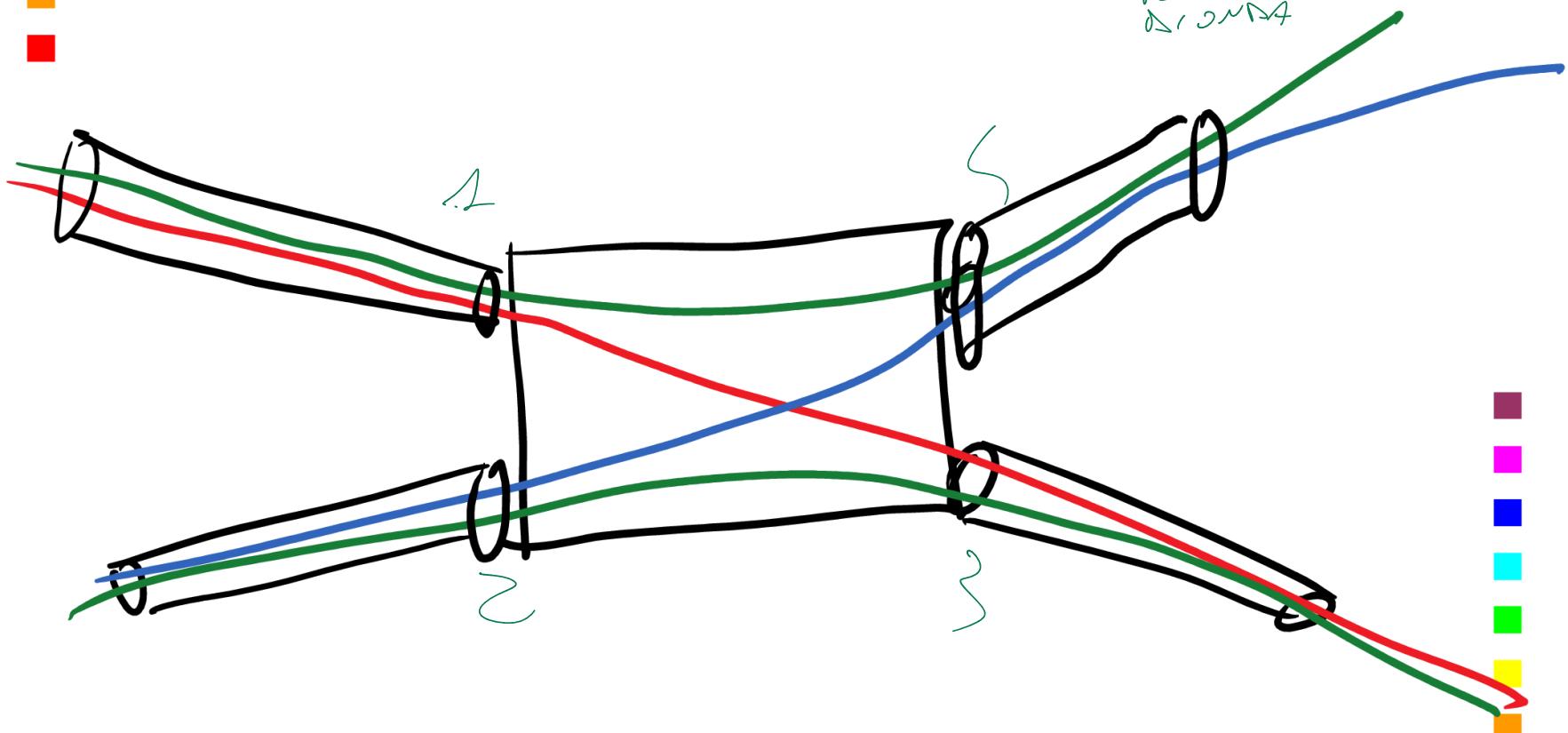
Increase transmission capacity of fiber

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





Taking it a step further: Wavelength Switching



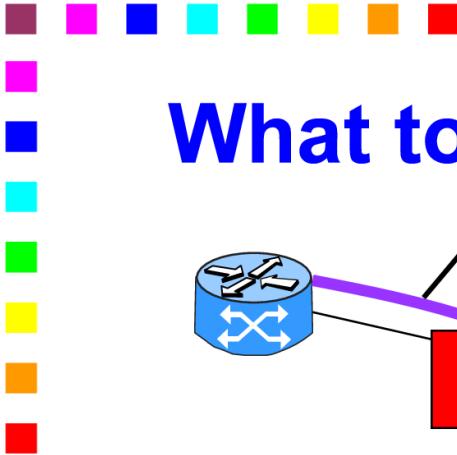


Ultimate WDM Application

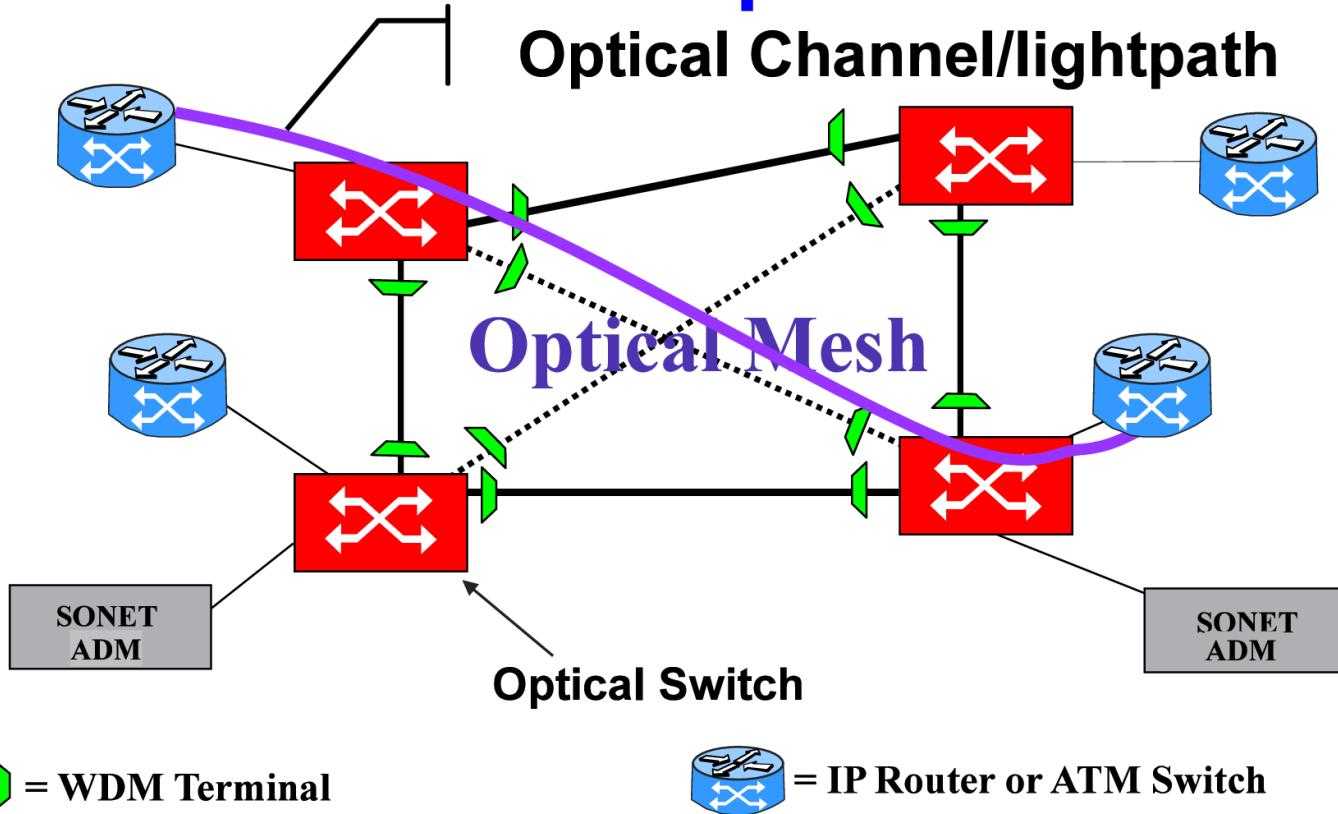
Wavelength switched networks

- **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**





What to do with Optical Switches?



Deployed in the network core because of its coarse bandwidth allocation

■ 1 optical channel: 2.4Gb/s or more

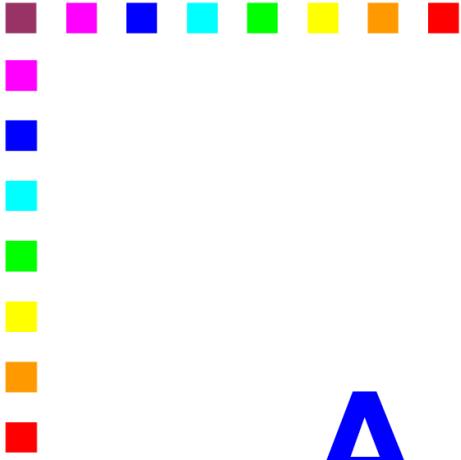




Why Optical Switching?

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





A bit of context

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

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



RHK

Telecommunications Industry Analysis

Optical Technologies in Terabit Networks

Dr. John Ryan
Principal & Chief Analyst

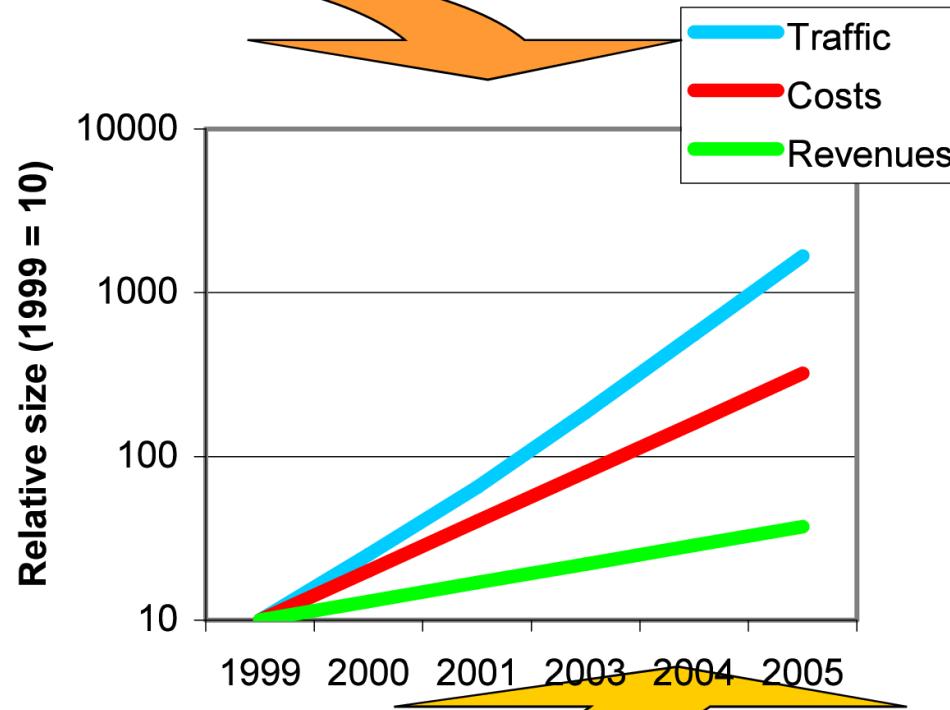
RHK

Optical Internetworking Forum, Atlanta, June 5th, 2000

The Resulting Traffic Dilemma...

Traffic is growing at explosive rates

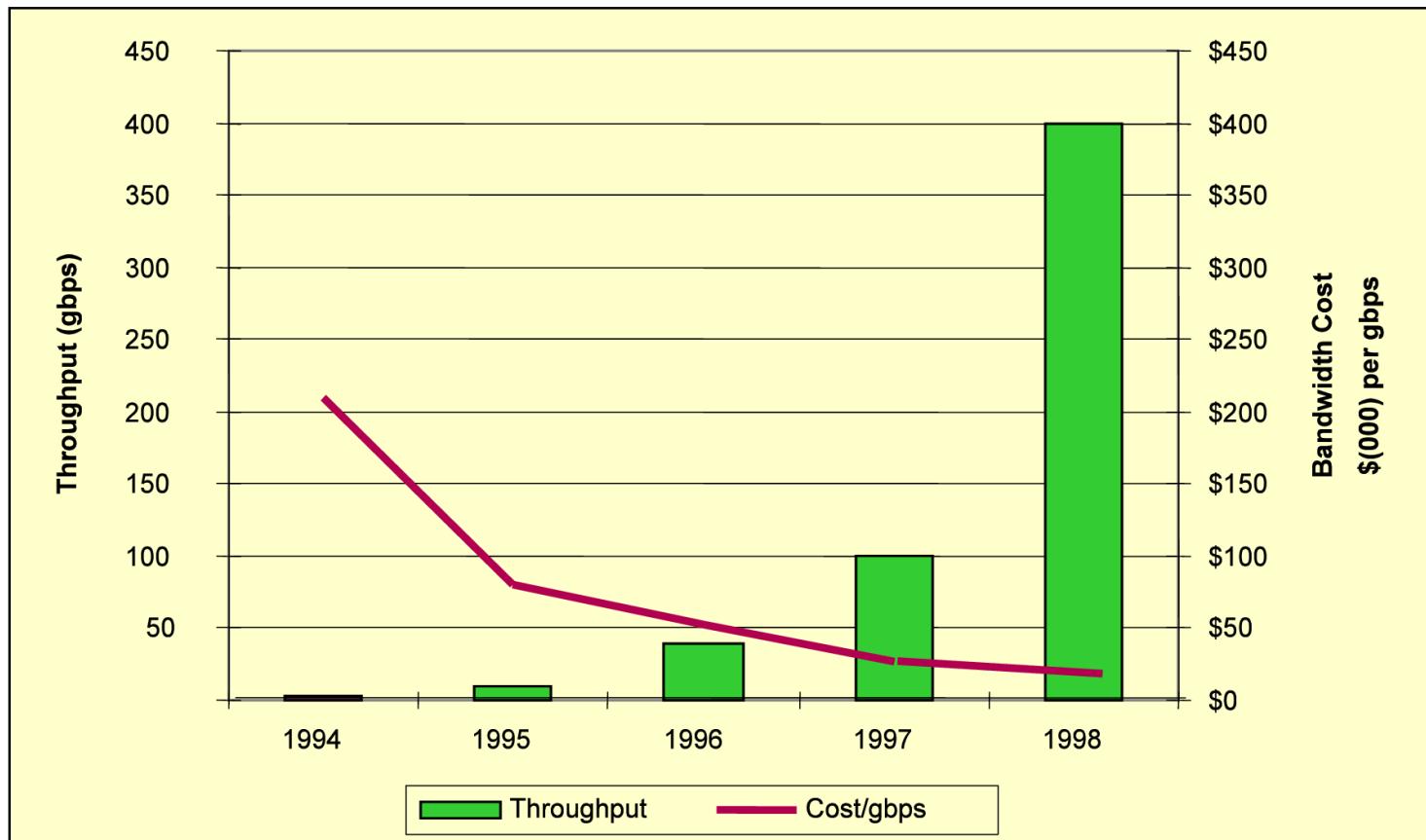
...And network costs are growing faster than revenues



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

Optics Reshape the Cost Curve

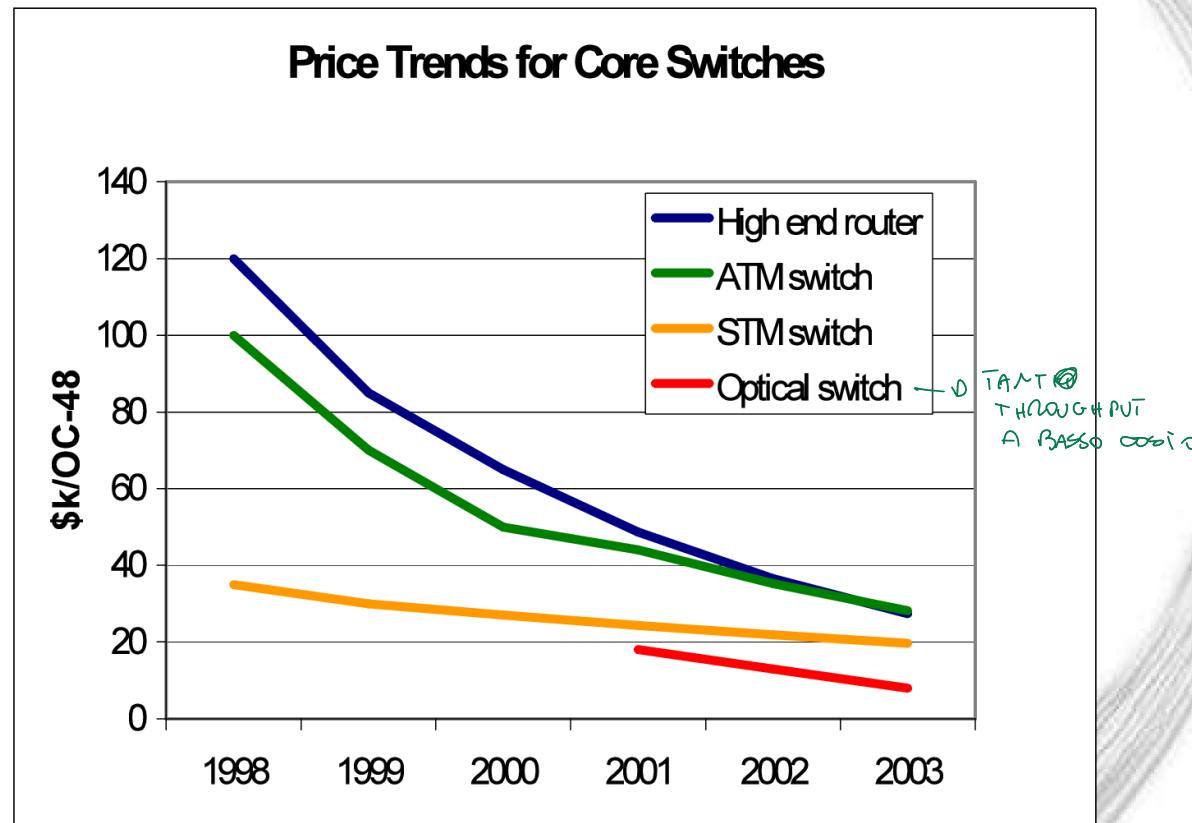
- DWDM driving down the cost of trunk bandwidth

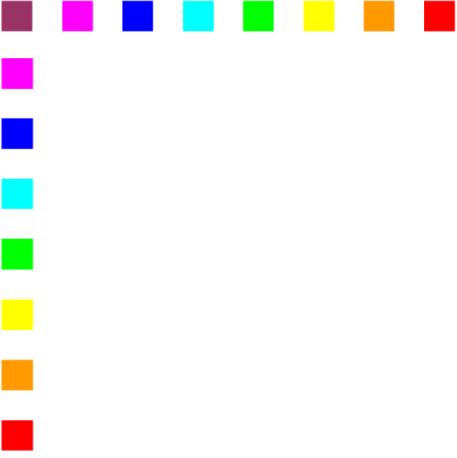


RHK

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





Back to the future

And to technology, leaving hype behind





1. come decidere dove mandarlo
2. come indirizzarlo a lvl fisico



Many Flavors of Optical Switches

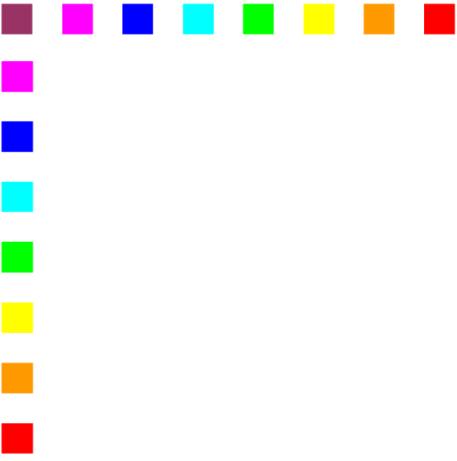
- **Optical vs Electronic core**
- **Cross Connect vs Switch**
- **Wavelength Conversion**

ottico: bello ma complesso
elettronico: ricevo il mio segnale ottico, converto in segnale elettronico e poi ritrasmette in ottico
-->perdo throughput ma ottima flessibilità

Different levels of *complexity*

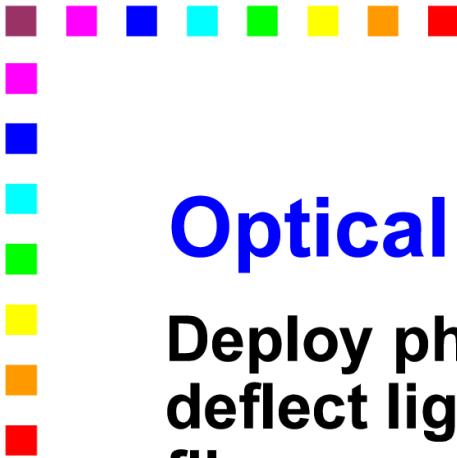
Different levels of *flexibility*





Switching Core



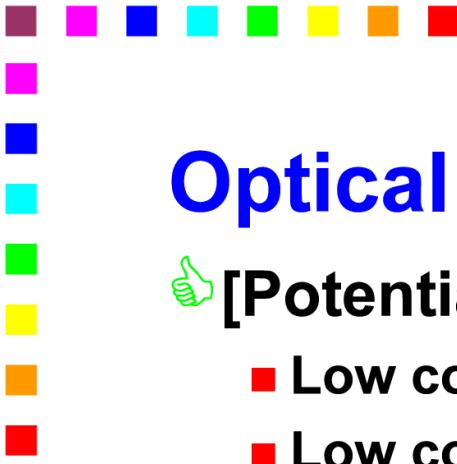


Optical Core

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

- **Tilting mirrors** MEMS: switch al suo interno crea degli specchi fatti di silicio. Inclina gli specchi elettronicamente, regolando l'angolatura in base al percorso che il segnale ottico deve fare.
 - **Micro-electro-mechanical systems (MEMS)**
 - **Voltage operated**
- **Holographic reflecting surfaces**
 - **Voltage operated** oleografico: basato sui cristalli: rifrazione del segnale --> molto resistente ma molto costoso
- **Materials changing properties with**
 - **Heat**
 - **Pressure**
 - **Voltage/current**





Optical Core Properties

👍 [Potentially] inexpensive (low CAPEX)

- Low cost material
- Low cost process [once technology is mature]

👍 Bit rate and signal independent

- Unlimited scalability
- Multi standard

👍 Low power consumption

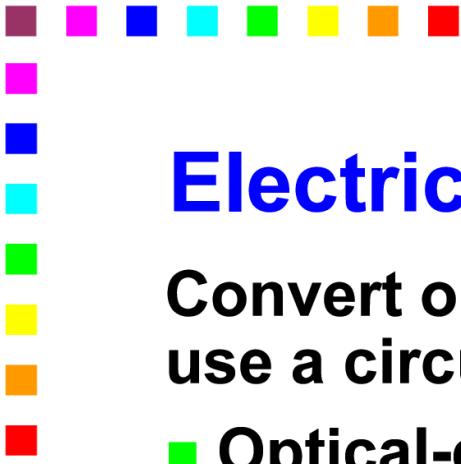
- Low operation costs (OPEX)

👎 High production costs

- Immature technology

👎 High attenuation (and no regeneration)

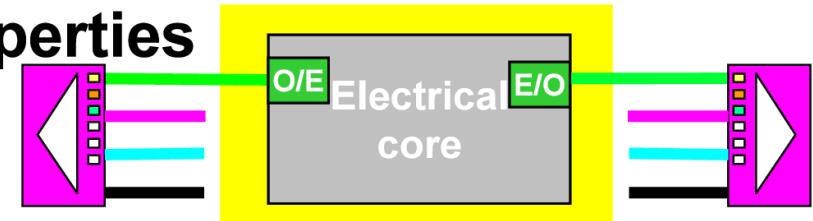




Electrical Core

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

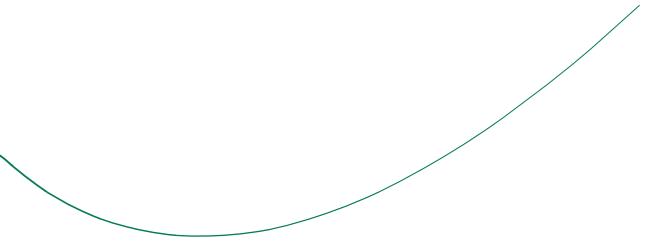
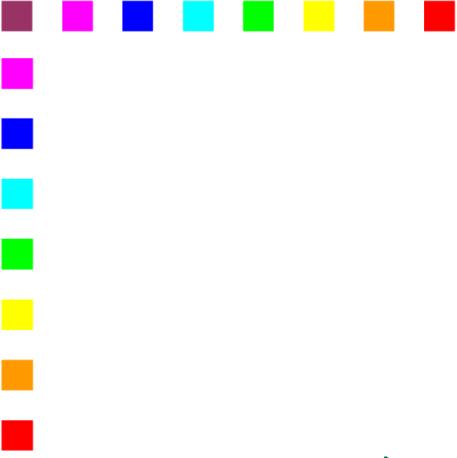
- Optical-electrical conversion
- Receive the bits and switch them
- It loses all the nice properties of an optical core
 - Bit rate independence
 - Low power consumption
 - Low cost



However

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





Switching Dynamics

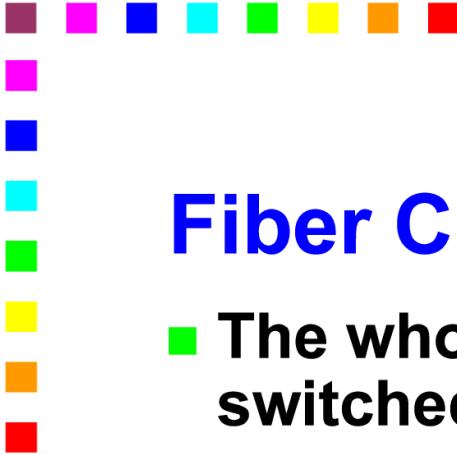




Cross Connect

- Fixed/static configuration
 - Changed seldom
 - Through a management system/interface
- Usually optical core

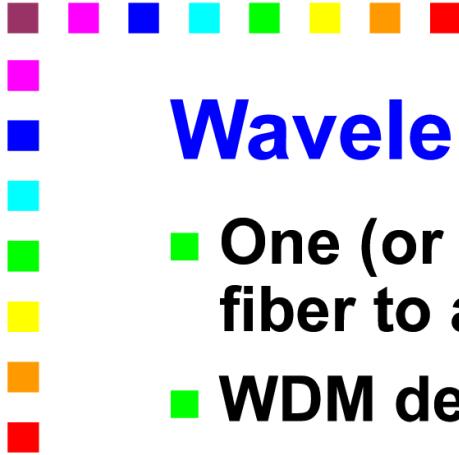




Fiber Cross Connect

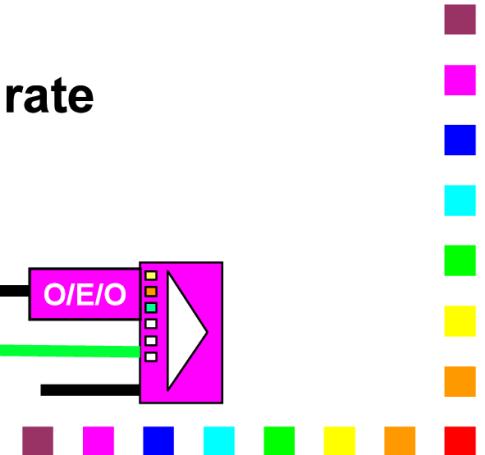
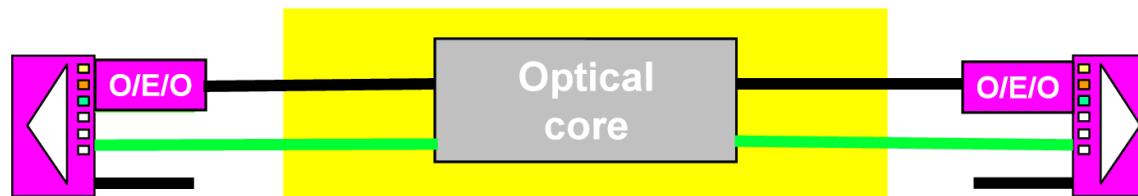
- The whole signal from an input fiber switched to an output fiber
- Micro-electro-mechanical systems (MEMS)
 - Long re-configuration time
- Optical amplification might be used before and after switching

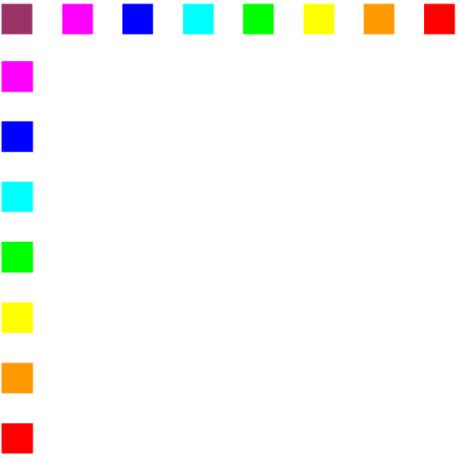




Wavelength Cross Connects

- One (or more) wavelengths from an input fiber to an output fiber
- 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



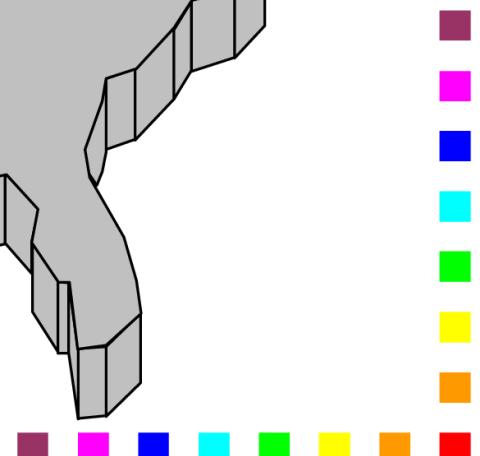
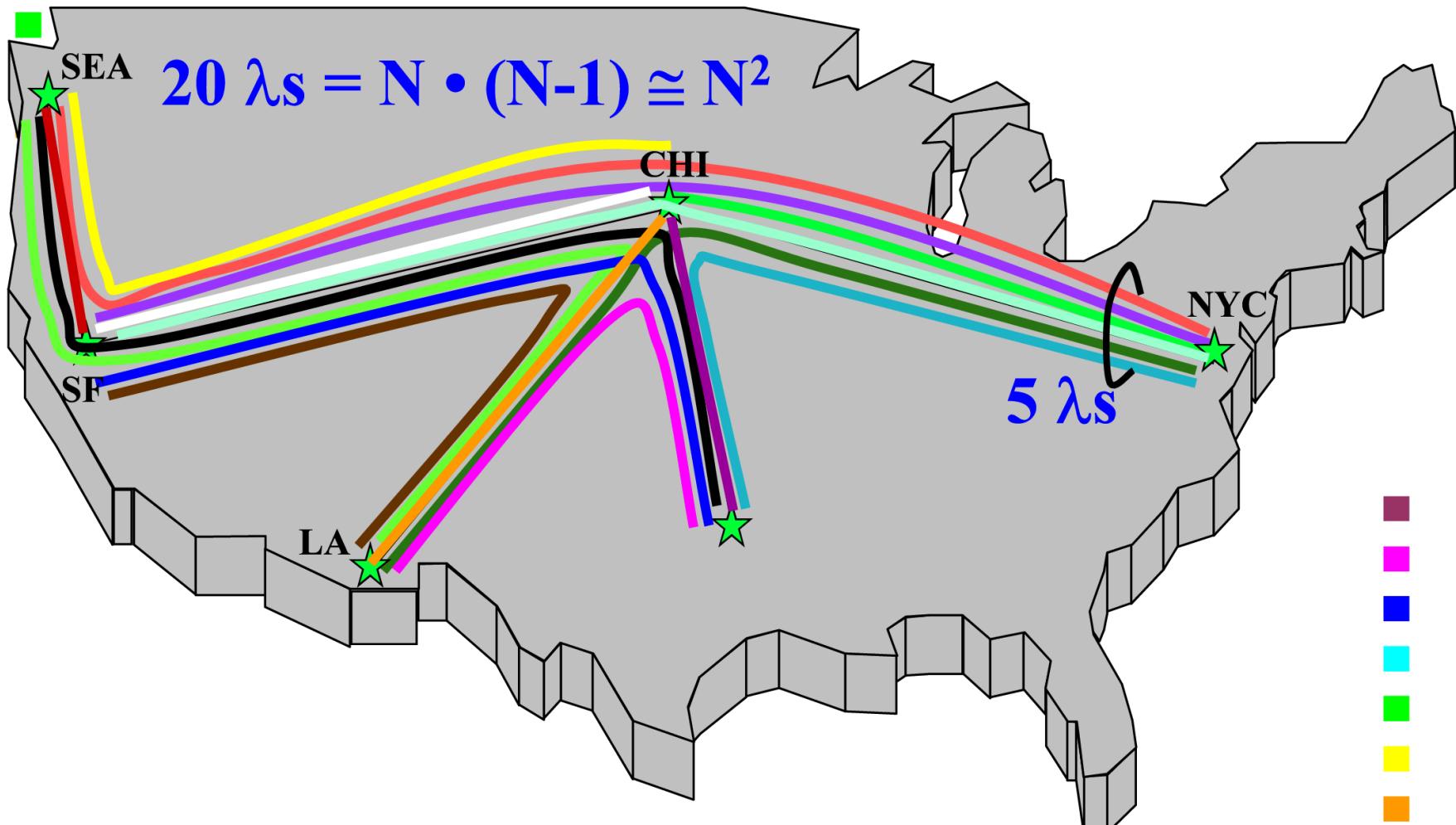


Wavelength Conversion





λ Switching: the N² Problem

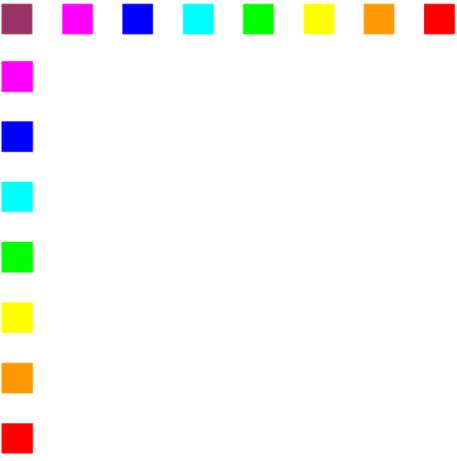




Wavelength Conversion

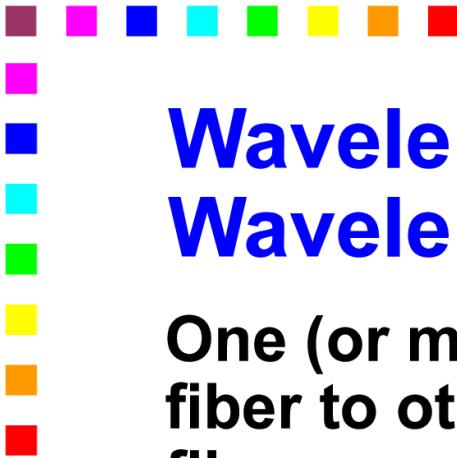
- **Complex**
 - **OEO conversion**
 - Expensive
 - Non data transparent → does not scale
 - **Physical properties**
 - E.g., resonance chamber
 - Immature technology -> expensive
- **Does not require the same wavelength end-to-end**
- **No wavelength assignment problem**
 - **N^2 problem**





Common Combinations

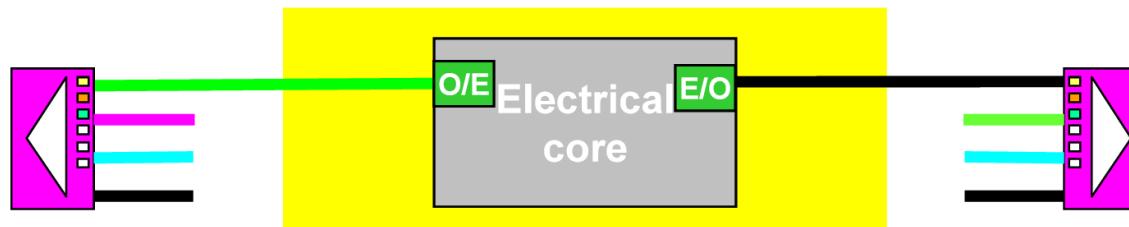


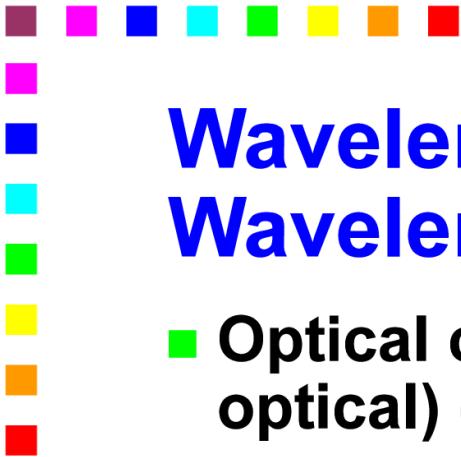


Wavelength cross-connect with Wavelength Conversion

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

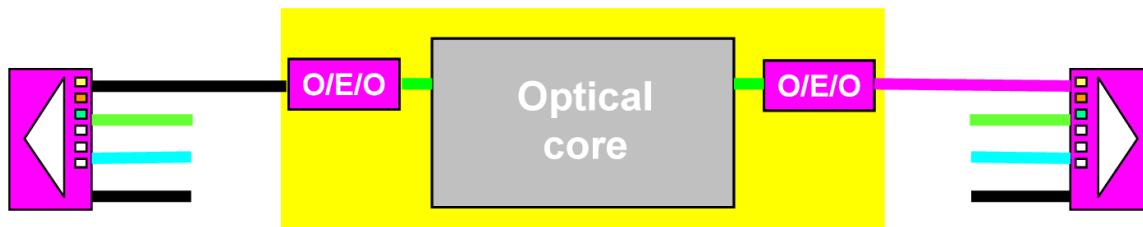
- Electrical core might be used
 - Easier signal monitoring
 - Forward error correction (FEC) possible to reduce Bit Error Ratio (BER)





Wavelength cross-connect with Wavelength Conversion

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

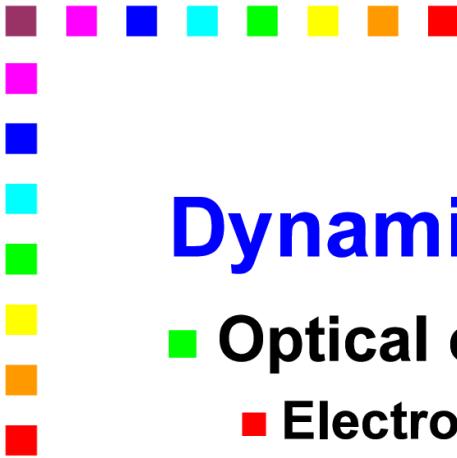




Dynamic Optical Switching

- **Wavelength switch with or without wavelength conversion**
- **Switch configuration is changed dynamically**
 - By management
 - By time of day
 - By end system signaling
 - Every packet!?! ...
 - Optical packet switching
 - Optical burst switching

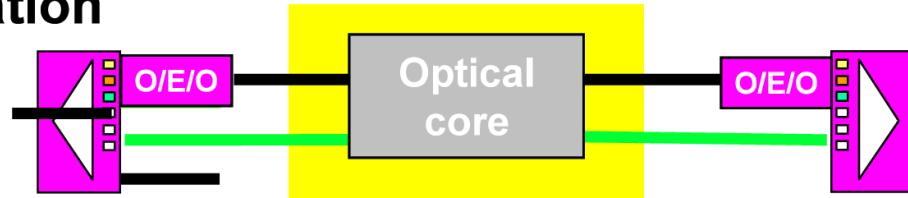




Dynamic Optical Switching

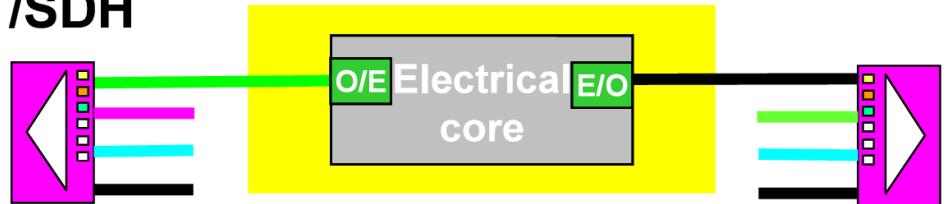
■ Optical core

- Electroholography, bubbles
- OEO for regeneration and wavelength conversion

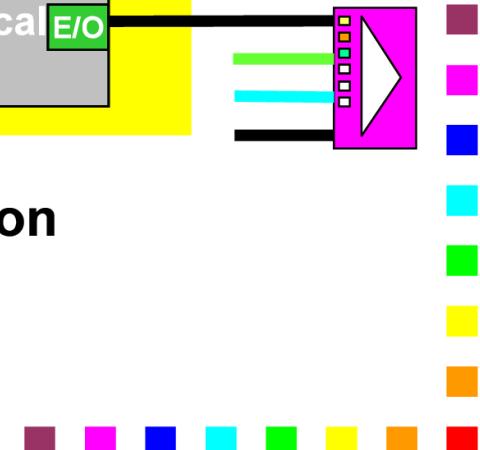
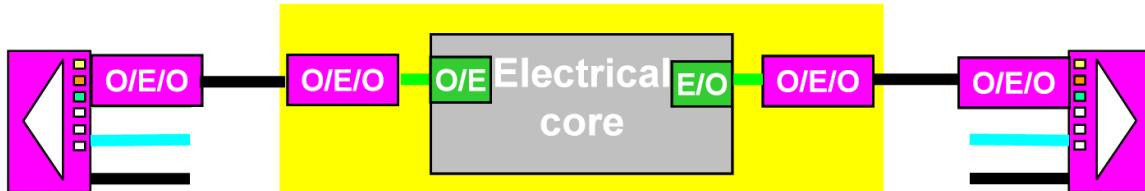


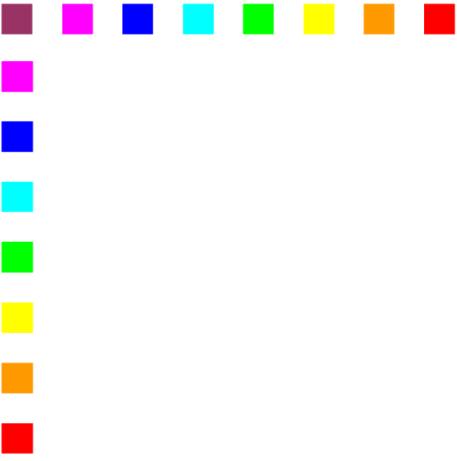
■ Electrical core

- Possibly SONET/SDH



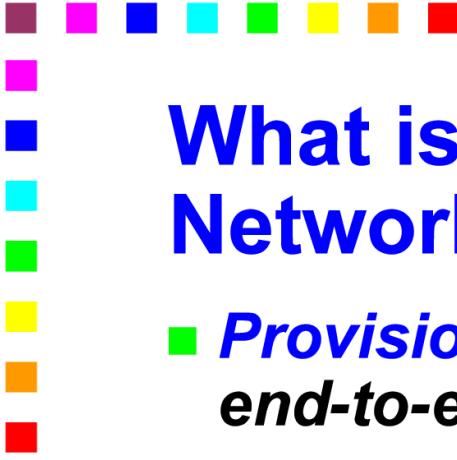
- Possibly multiple OEO for regeneration





Deployment

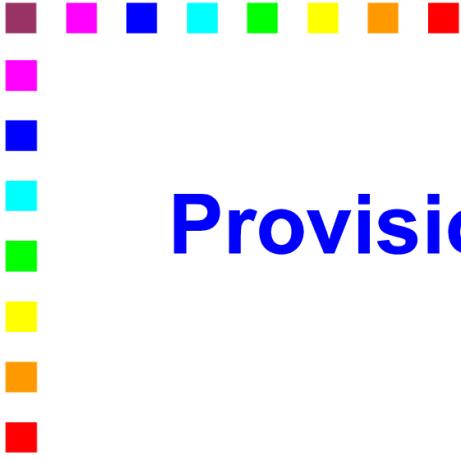




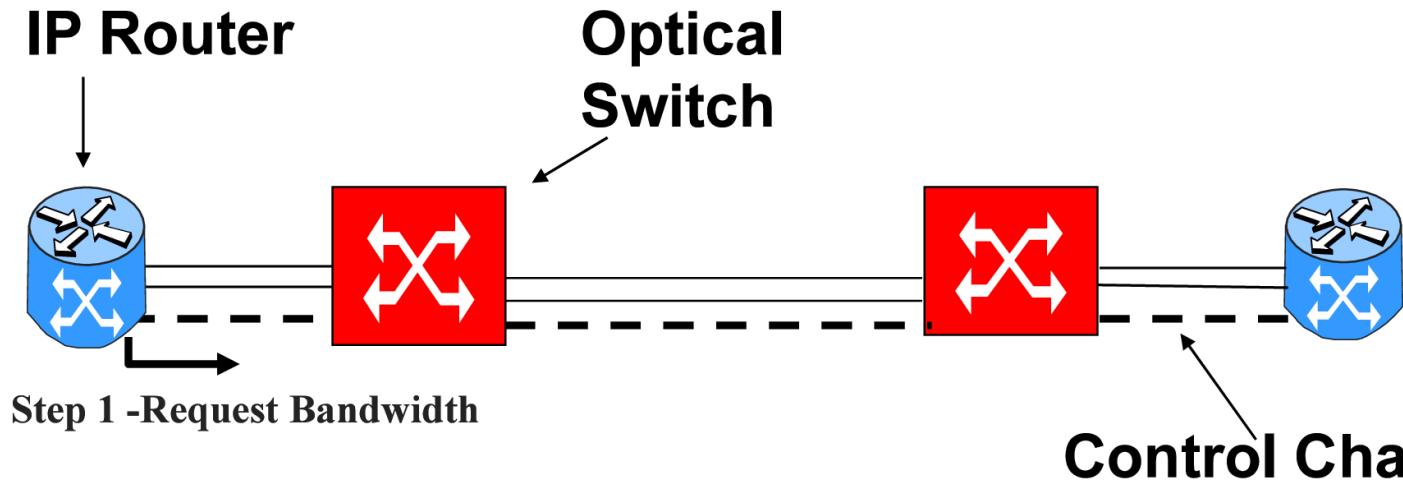
What is Expected from the Optical Network?

- ***Provisioning* and *protection* of lightpaths *end-to-end***
- Client equipment (e.g. routers) to control provisioning of optical layer *lightpaths*
 - Signaling
- Cost-effective deployment of flexible networks



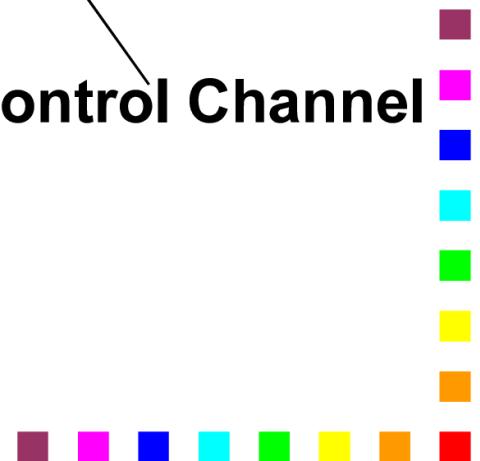
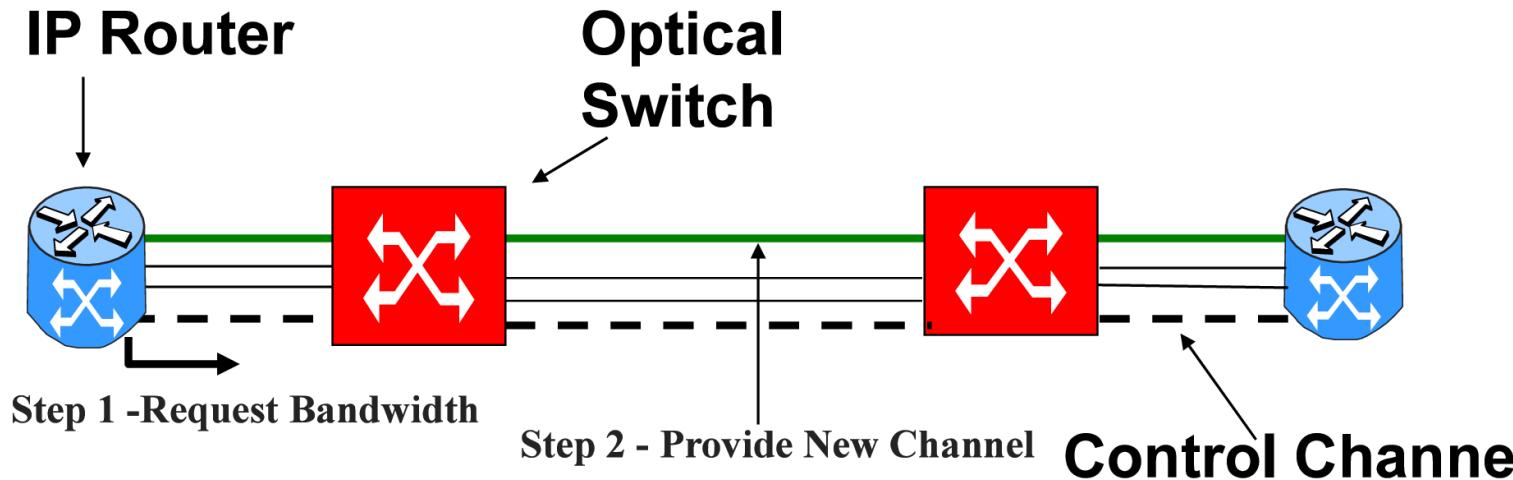


Provisioning



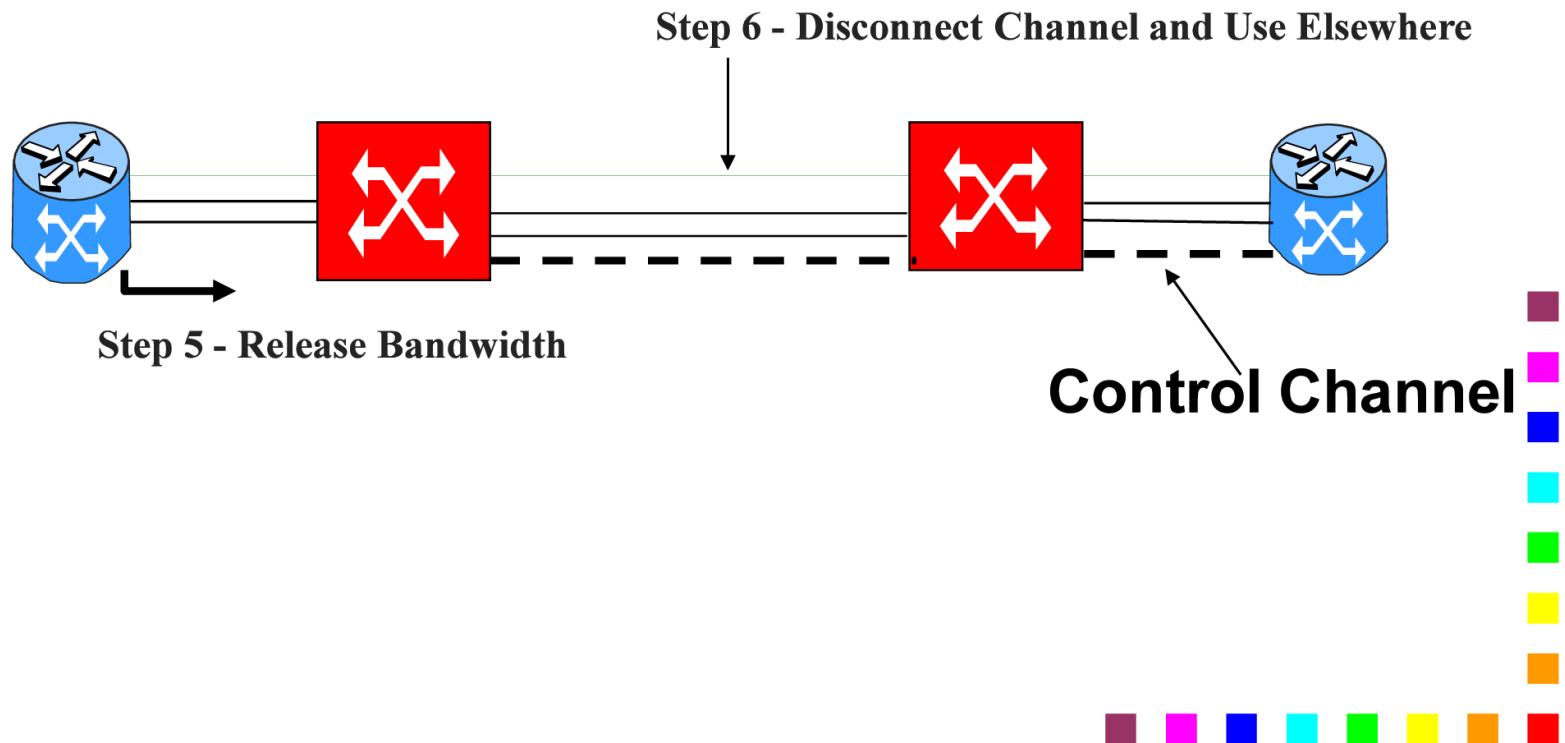


Provisioning





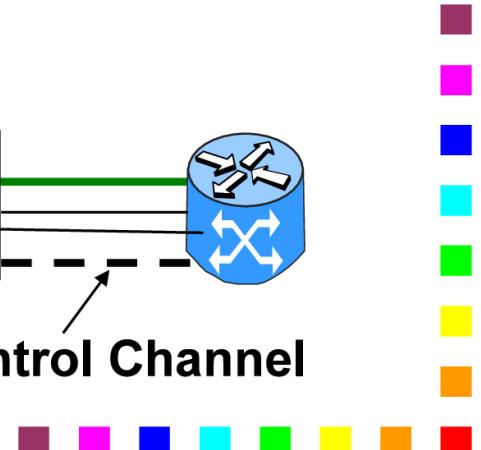
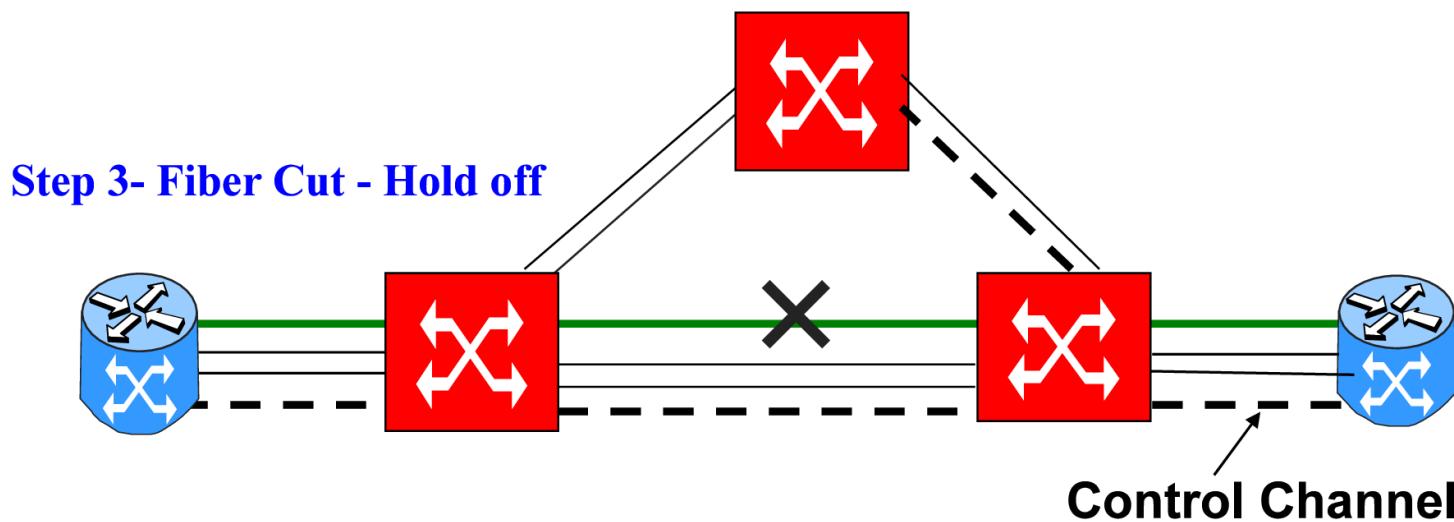
Provisioning





Protection/Restoration

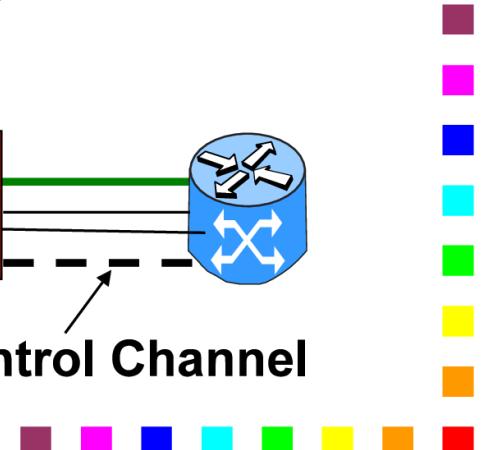
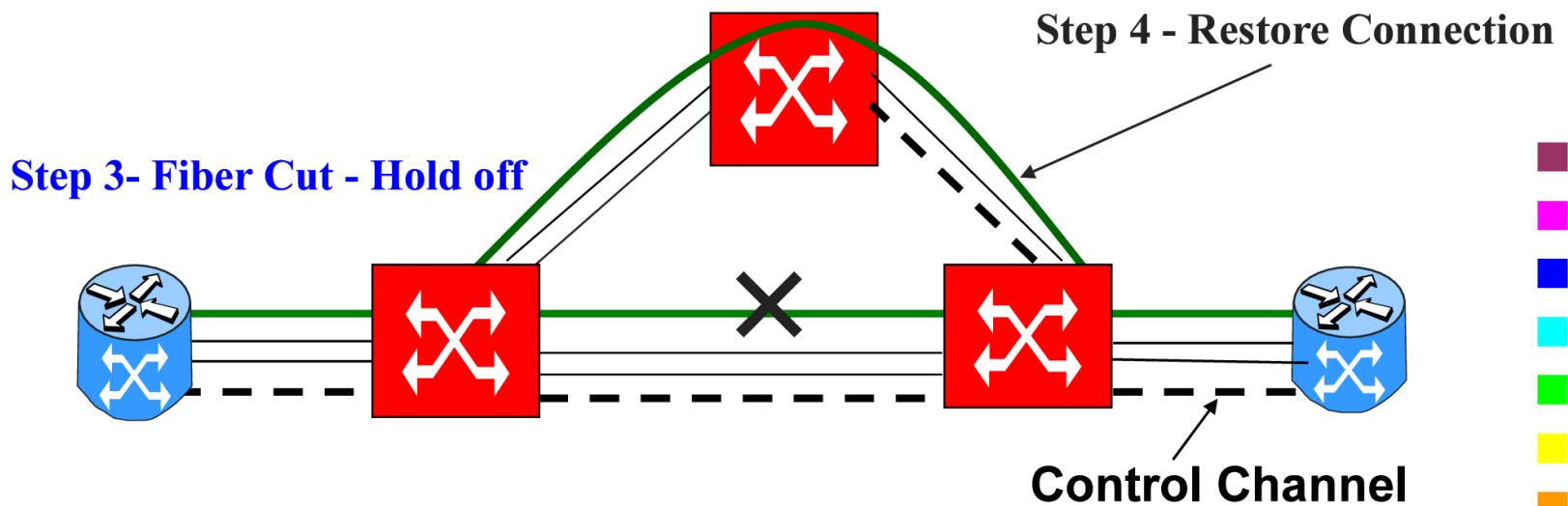
- Protection: pre-determined action
 - non-optimal resource utilization
- Restoration: dynamically determined action
 - optimization of resource utilization





Protection/Restoration

- Protection: pre-determined action
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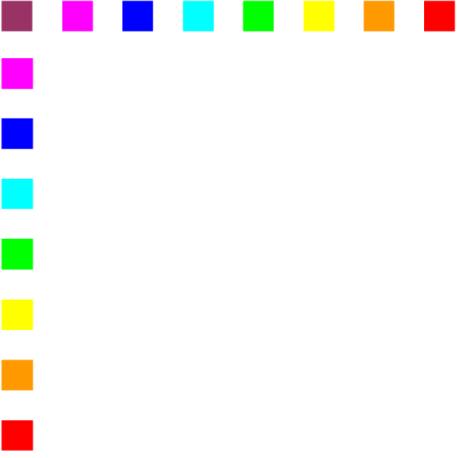




Protection/Restoration

- **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





Control Plane



Copyright: see page 2



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**





What Optical Network Users Need

- **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**





Routing

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





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





MPLS the only sensible choice for the Optical Network Control Plane

MP λ S - Multi-Protocol Lambda Switching

- OSPF, IS-IS, BGP for resource discovery
- RSVP/LDP for signaling





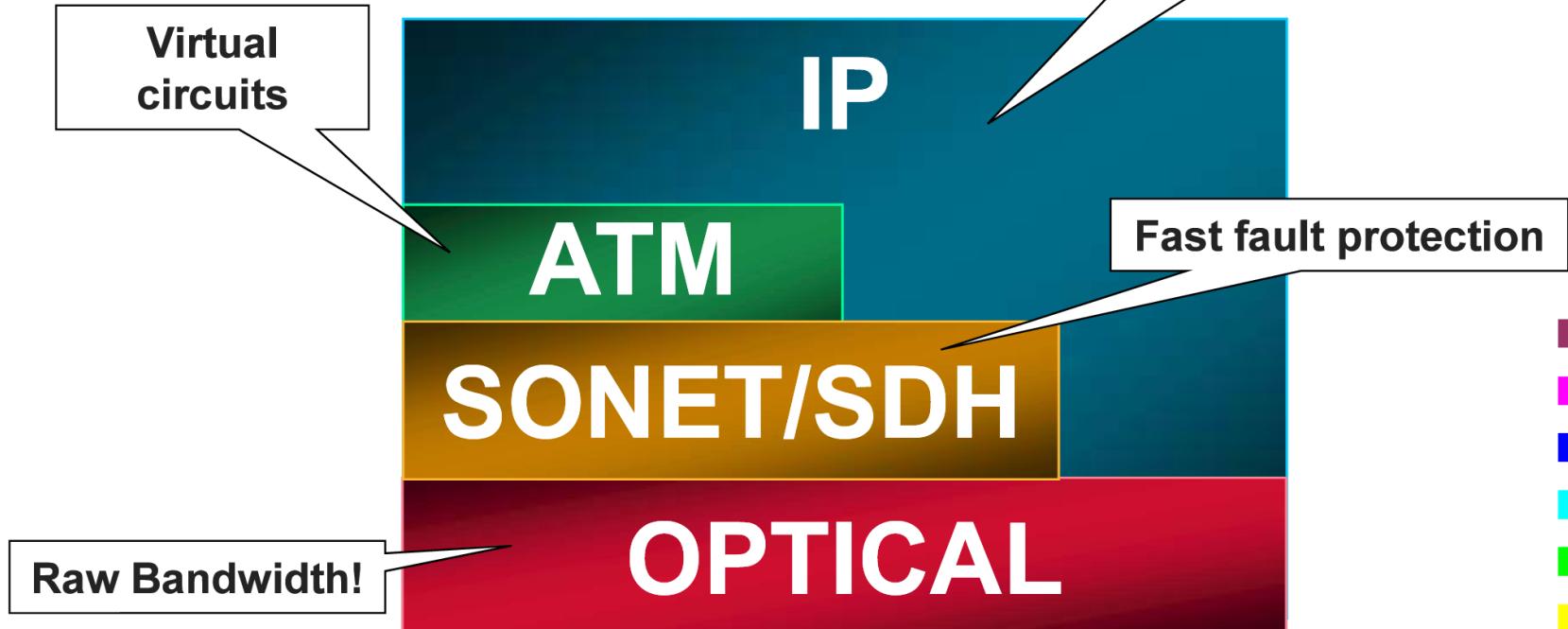
Data Transport and Protocol Stack





IP over Glass ... IP over Photons ... Not Exactly

Fundamental
requirement
for Internet
Applications



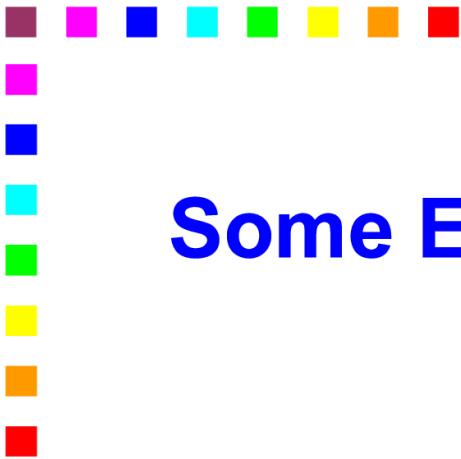


Data Transport

- 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





Some Encapsulation Options

