



The Optical Internet

Wavelength Division Multiplexing (WDM) and Lambda Switching

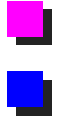
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<http://www.synchrodyne.com/baldi>





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WDM: Wavelength Division Multiplexing

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

- DWDM - Dense WDM

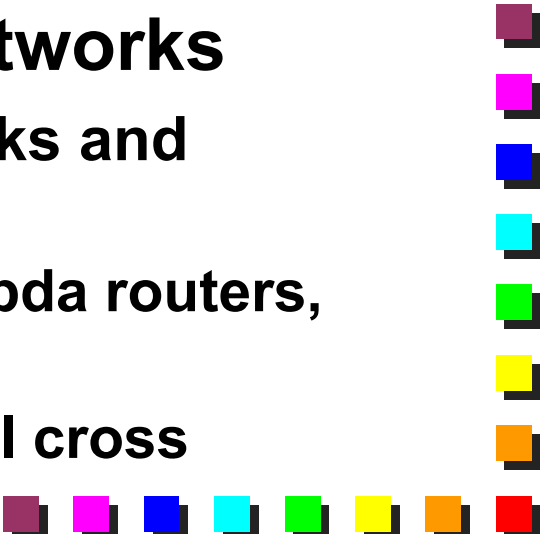
- More sophisticated → more expensive

- CWDM - Coarse WDM

- Lower number of wavelengths → cheaper



WDM Deployment

- **First: increase transmission capacity of fiber**
 - point to point configurations
 - **Interim: add/drop multiplexing**
 - ring topologies with WDM add/drop multiplexers
 - inserting wavelengths on the ring
 - extracting wavelengths from the ring
 - mostly static or semipermanent configurations
 - **Ultimate: wavelength switched networks**
 - arbitrary mesh topologies of WDM links and wavelength switches
 - also called wavelength routers, lambda routers, lambda switches
 - today they are mostly (only?) optical cross connects
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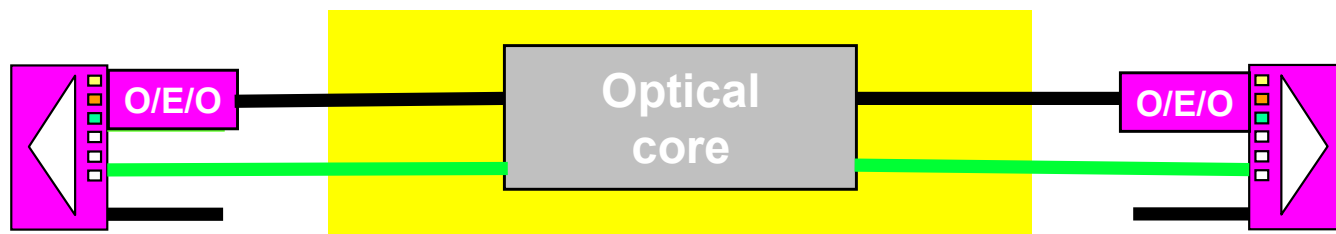
Optical Switching

■ Fiber cross-connect

- the whole signal from an input fiber switched to an output fiber
- Micro-electro-mechanical systems (MEMS)

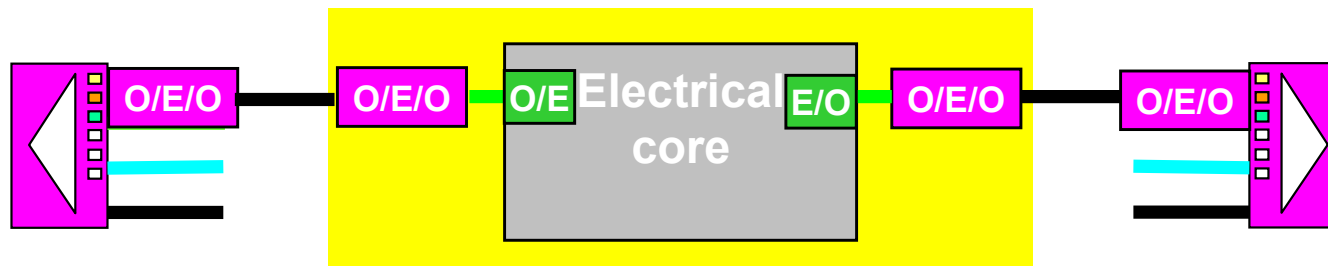
■ Wavelength cross-connect without wavelength conversion

- one (or more) wavelengths from an input fiber to an output fiber
- WDM de-multiplexer+MEMS
- amplification before or/and after switching
 - OEO (optical-electrical-optical) conversion with electrical regeneration
 - optical amplification



Optical Switching

- **Wavelength cross-connect with wavelength conversion**
 - one (or more) wavelengths from an input fiber to other one (or others) on an output fiber
 - **OEO (optical-electrical-optical) conversion with electrical switching**
 - easier signal monitoring
 - forward error correction (FEC) possible to reduce Bit Error Ratio (BER)

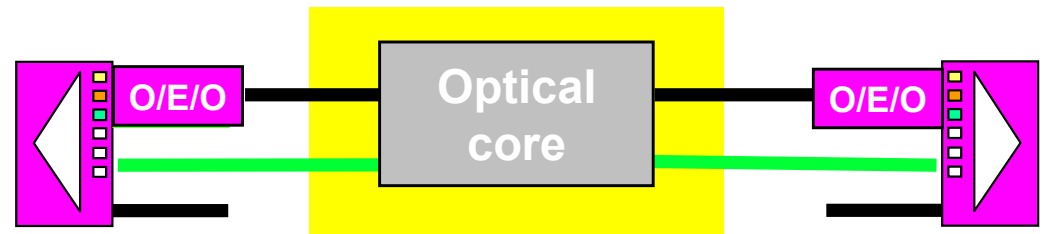


Dynamic Optical Switching

■ Wavelength switch without wavelength conversion

- switch configuration is changed dynamically

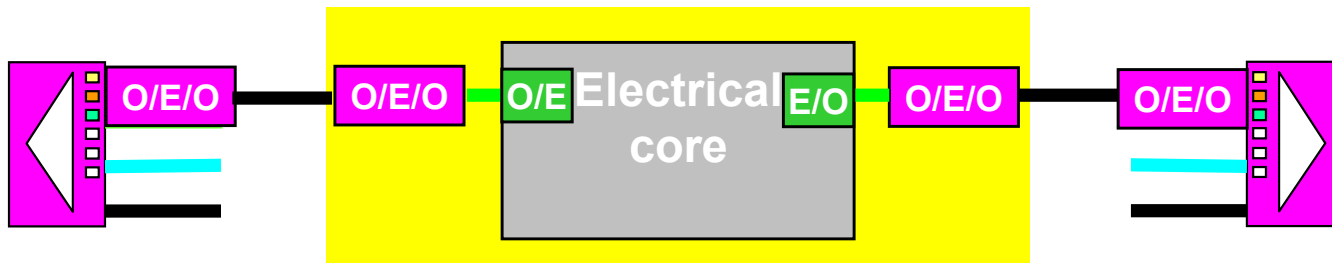
- by management
- by time of day
- every packet!?! ...



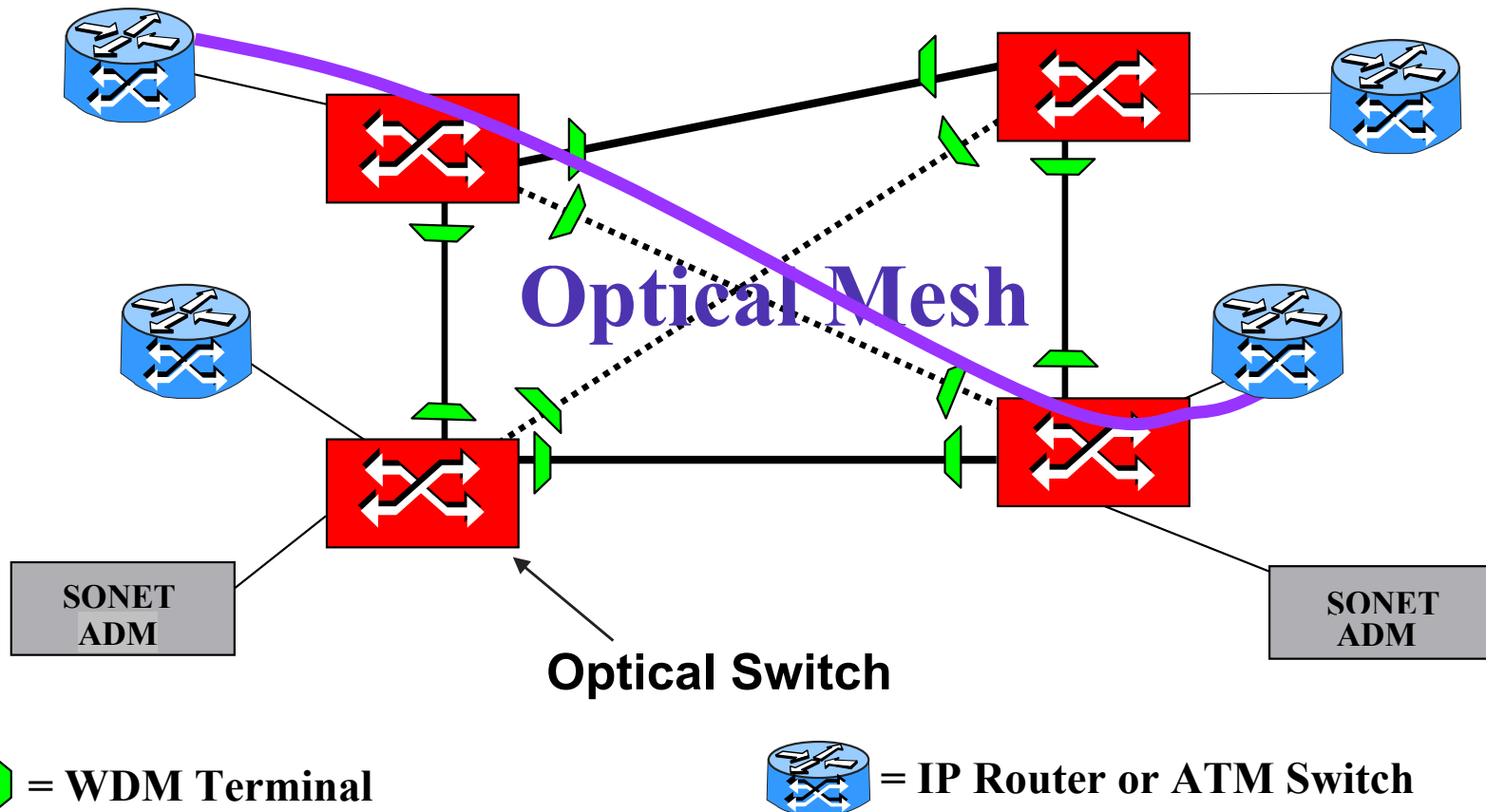
- WDM de-multiplexer+MEMS, electroholography, bubbles

■ Wavelength switch with wavelength conversion

- OEO (optical-electrical-optical) conversion with electrical switching
- circuit switching (SONET/SDH)



What to do with Optical Switches?





Wavelength Conversion

■ Complex

■ OEO conversion

- expensive

- non data transparent → does not scale

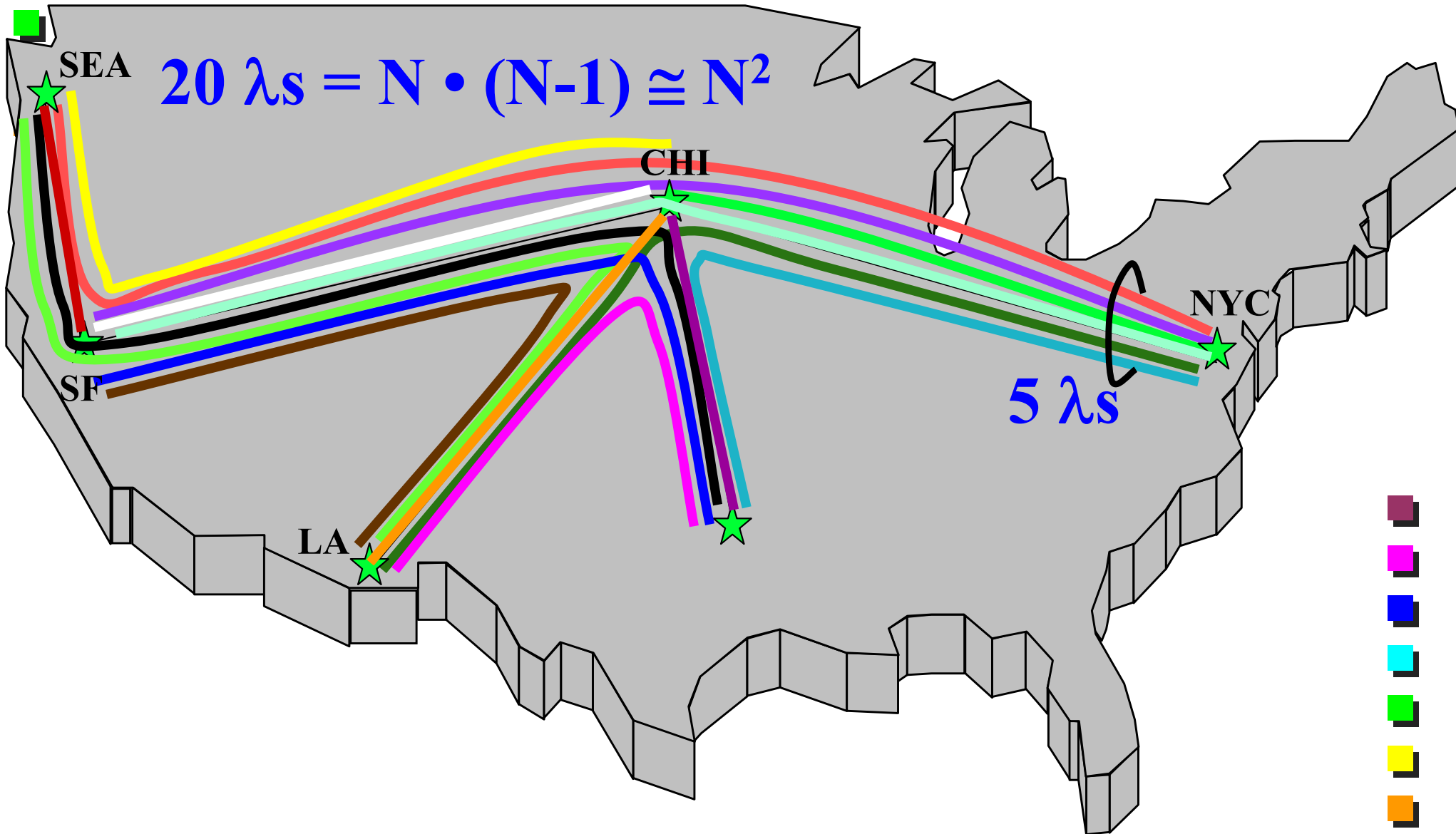
■ Does not require the same wavelength end-to-end

■ No wavelength assignment problem

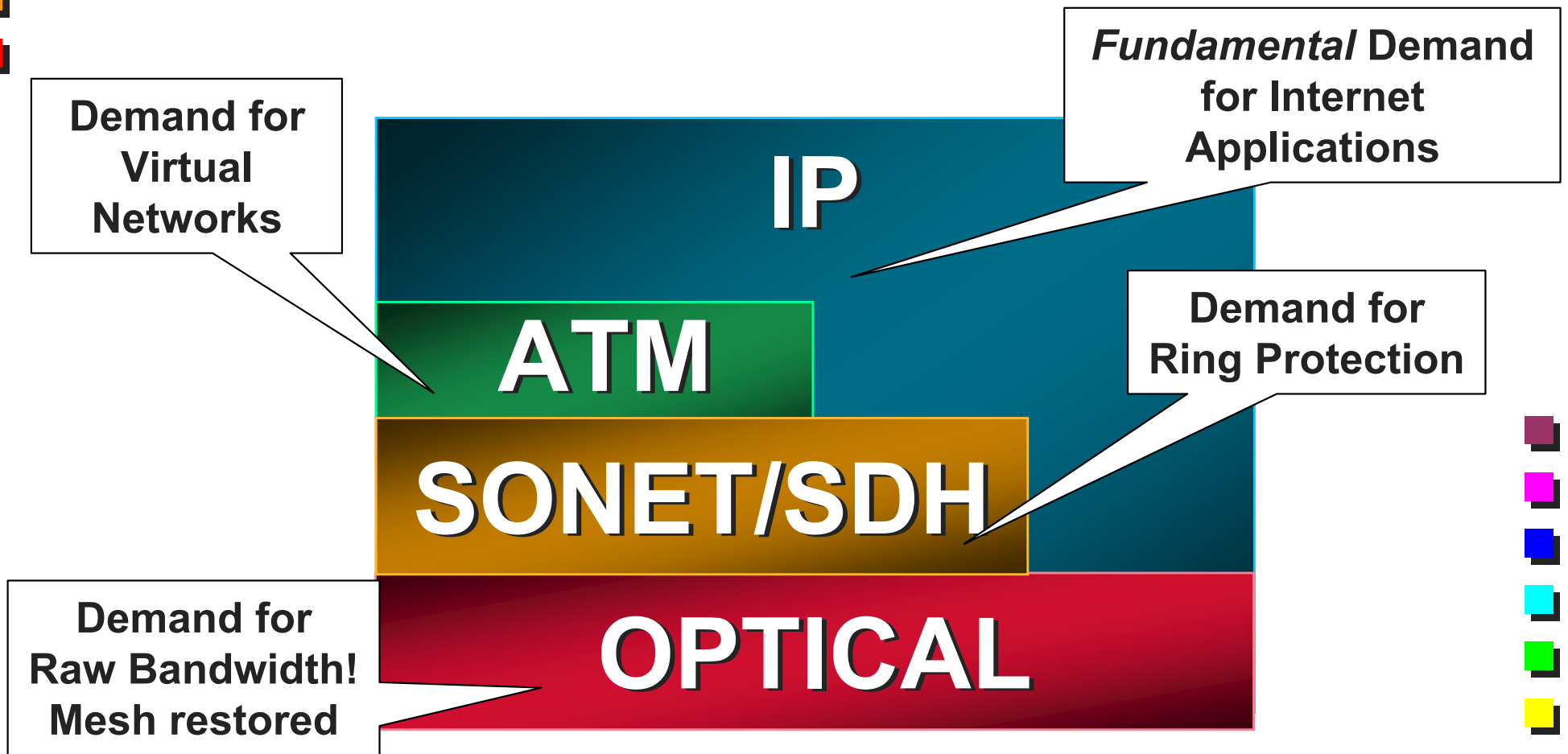
- N^2 problem



λ Switching: the N^2 Problem



IP over Glass? Not Exactly

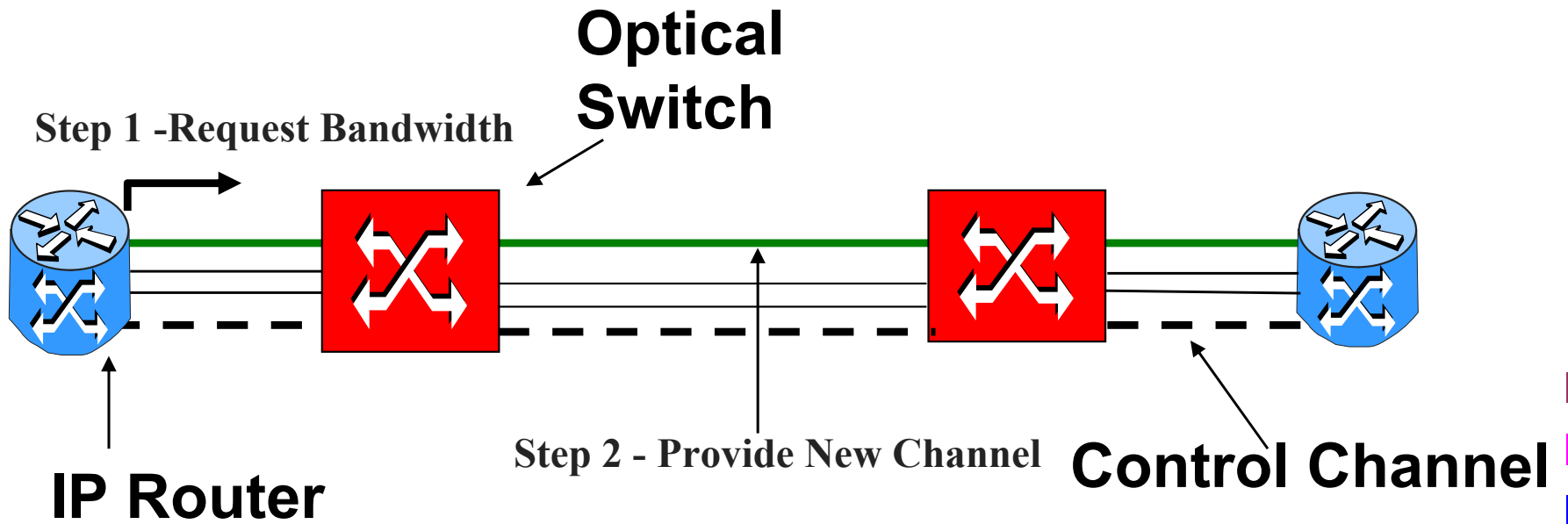




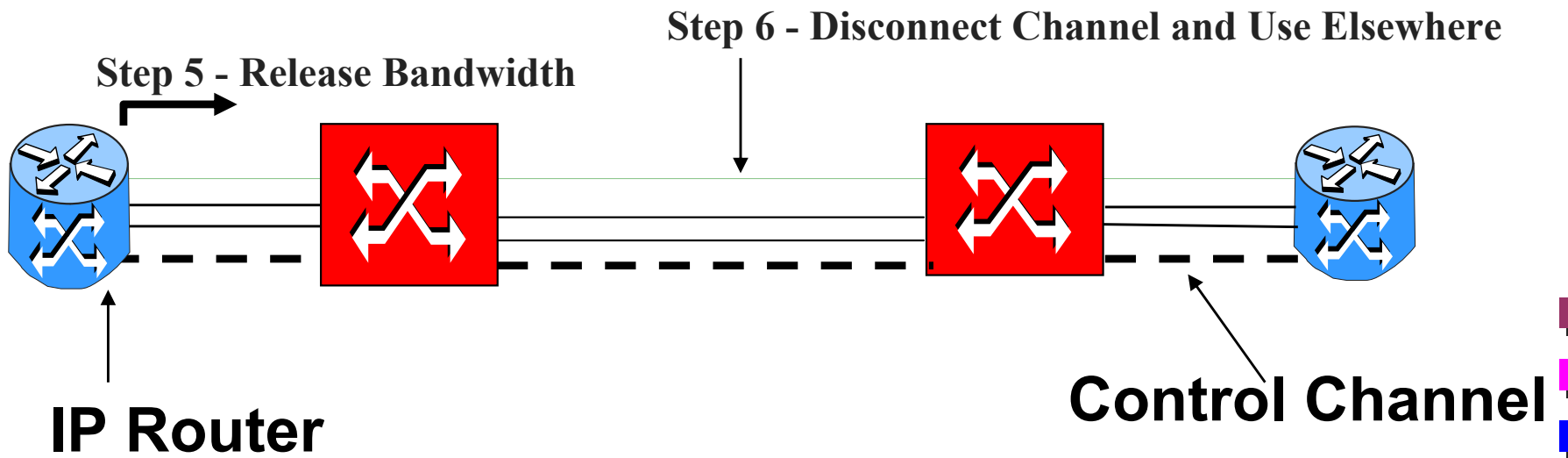
What is Expected from the Optical Network?

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

Provisioning

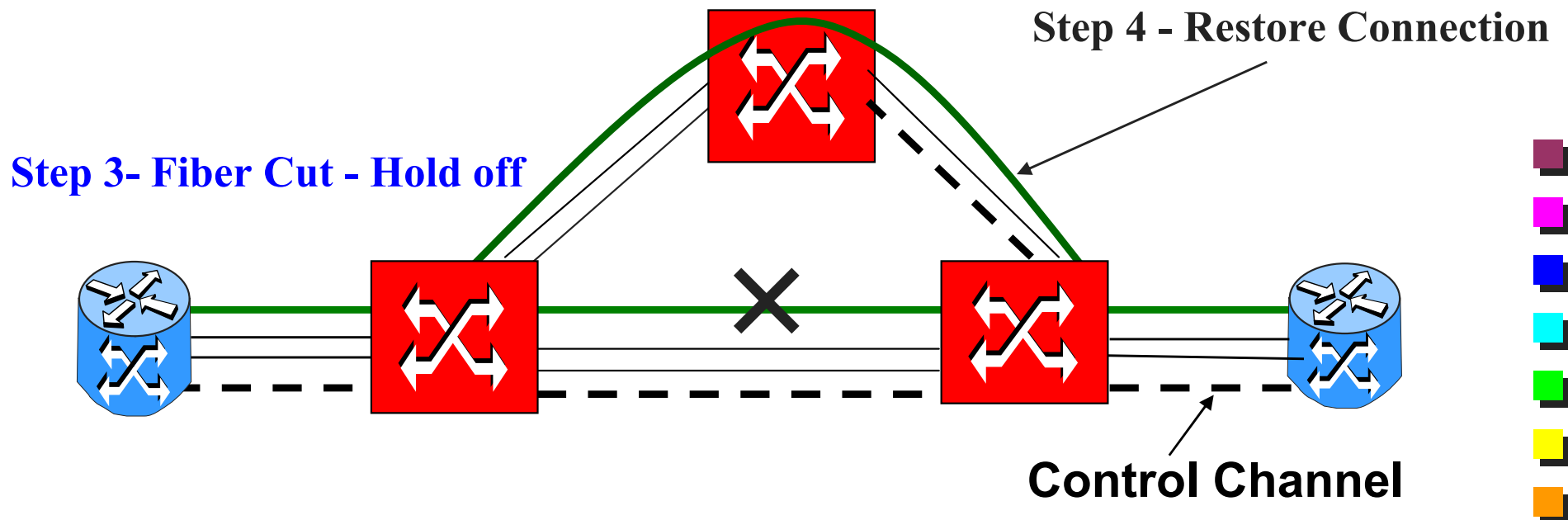


Provisioning




Protection/Restoration

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






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
 - **Can trigger multiple layers of restoration**
 - each has different timescales for detection and repair
 - **Must avoid:**
 - unnecessary traffic shifting
 - packet loss, reordering, control plane churn
 - pathological feedback
 - non self-stabilizing
- 



Signaling: What Optical Switches Need

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



Signaling: What Optical 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**

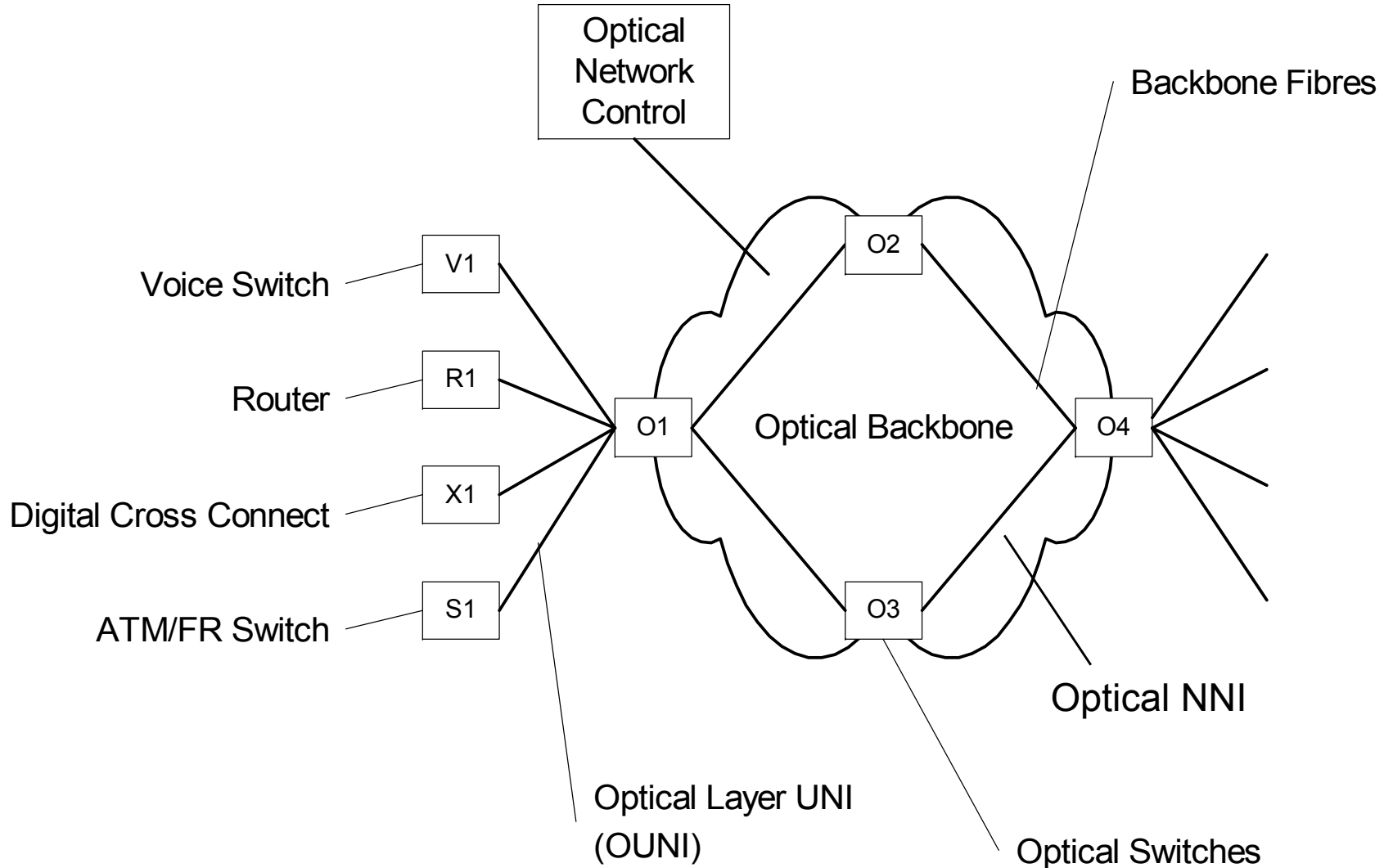




Signaling: How to Do It

- How is the optical layer 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
- 

Network Model





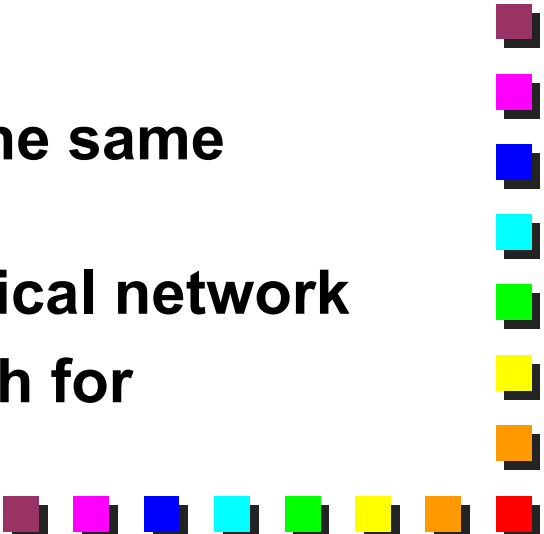
Routing

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
- 



Players in the Optical Arena

- **ITU-T - International Telecommunication Union - Telecommunication Sector**
 - **OTN - Optical Transport Network**
 - **Draft Recommendation G.872**
 - **ASON - Automatic Switched Optical Channel Networks**
 - **IETF - Internet Engineering Task Force**
 - **MPLambdaS - Multi-Protocol Lambda Switching**
 - **MPLS signaling**
 - **Proposal for IPO - IP over Optics Working Group**
- 



Players in the Optical Arena


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





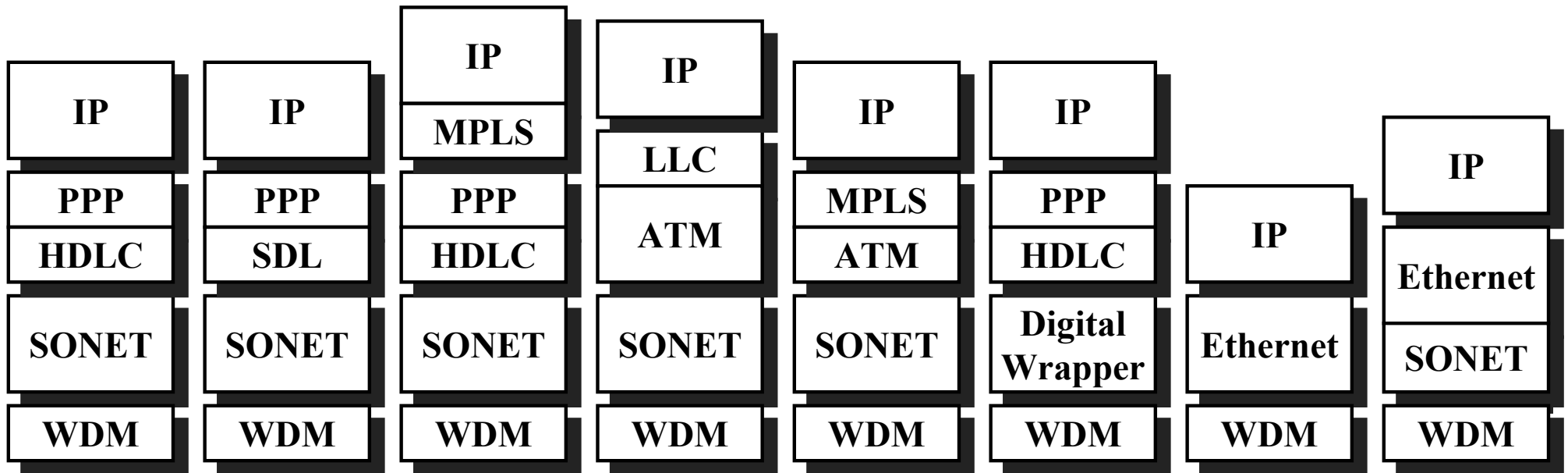
Data Transport

- Physical Layer
 - SONET
 - Ethernet
 - Digital Wrapper
- Data link layer
 - PPP with HDLC framing
 - PPP with SDL framing
 - Ethernet
 - ATM
- MPLS?
- Network layer: IP



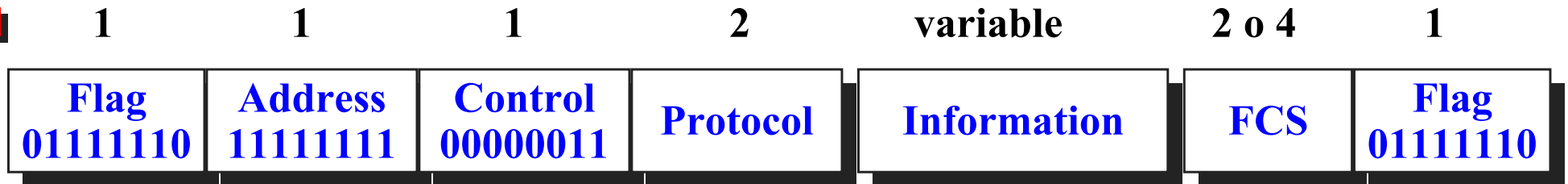
PPP - Point-to-Point Protocol
HDLC - High-level Data Link Control
SDL - Simple Data Link
ATM - Asynchronous Transfer Mode

Some Deployed Configurations

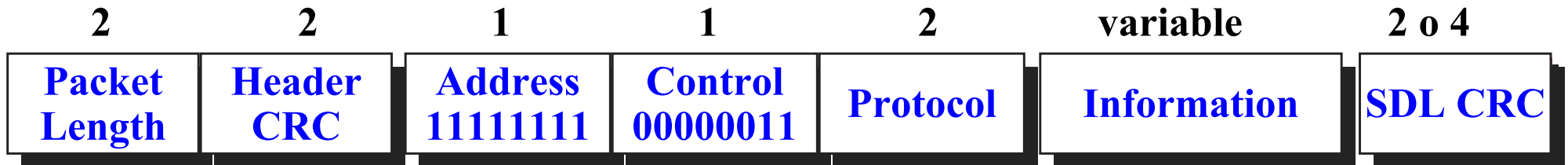


Point-to-Point Protocol (PPP)

High-Level Data Link Control (HDLC) framing



Simple Data Link (SDL) framing

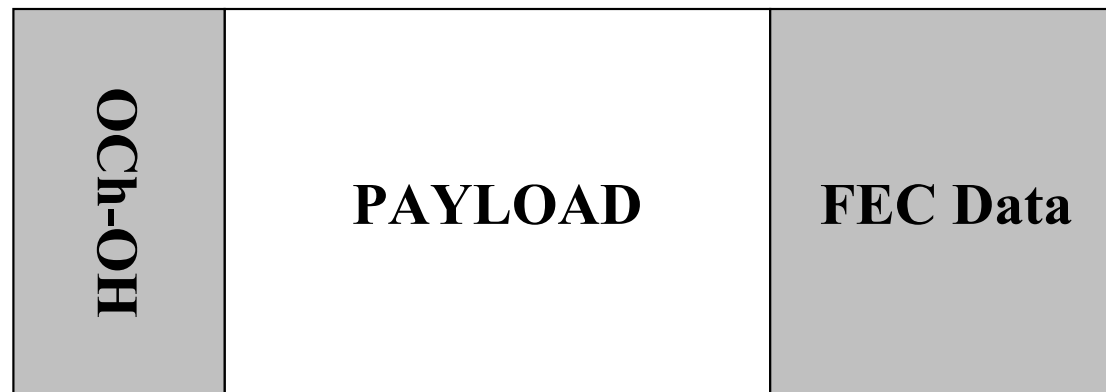


CRC hunting



Digital Wrapper

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



OCh - Optical Channel


OH - Overhead

FEC - Forward Error Correction

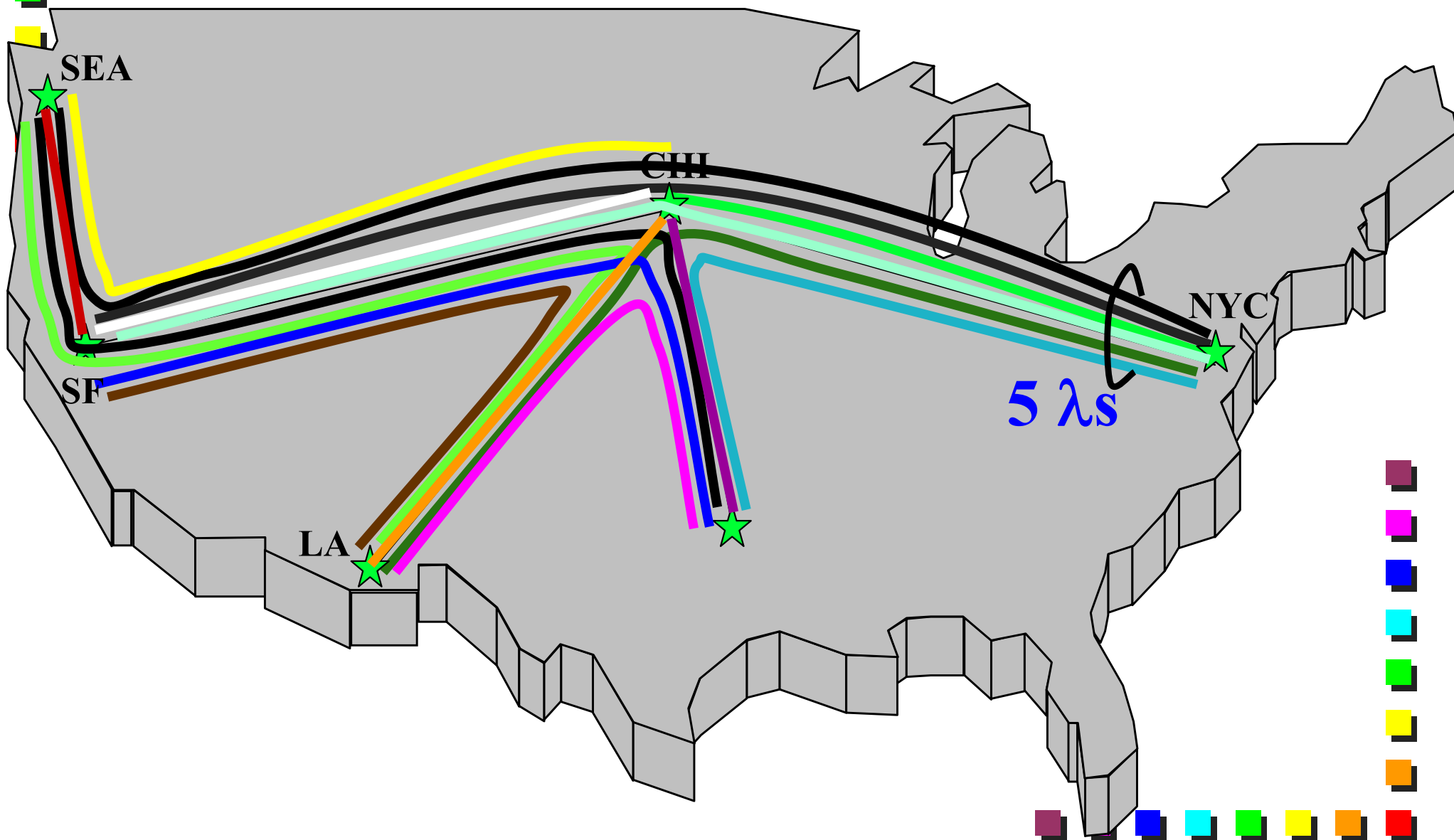




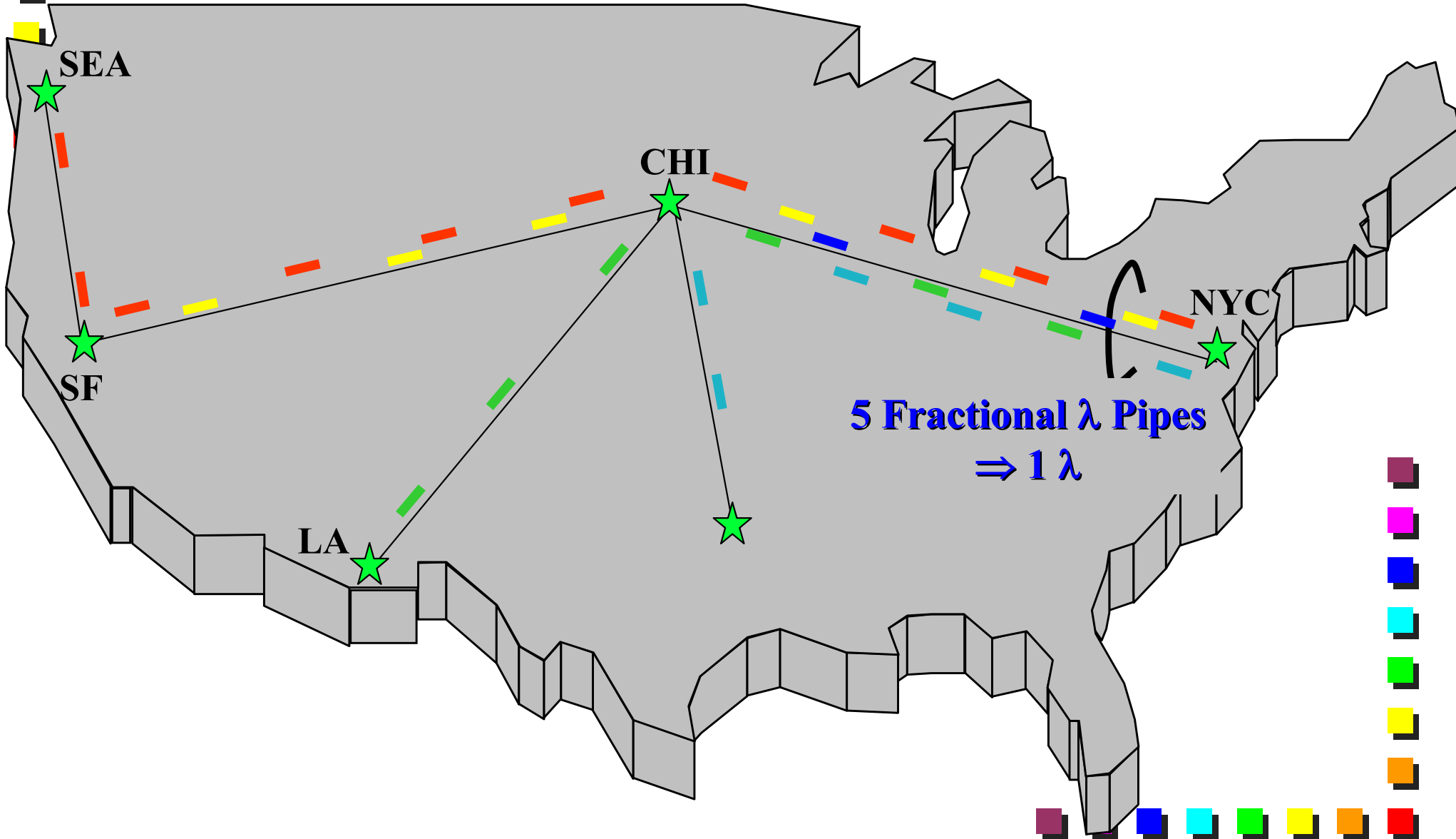
How about the SONET Comeback?

- A lightpath (λ) is a large pipe
 - 2.5 Gb/s to 40 Gb/s
 - Individual users do not generate such volume of traffic
 - Finer switching granularity is needed
 - N^2 problem
 - Fractional wavelength switching
 - Wavelengths have to be filled up: **grooming**
- 

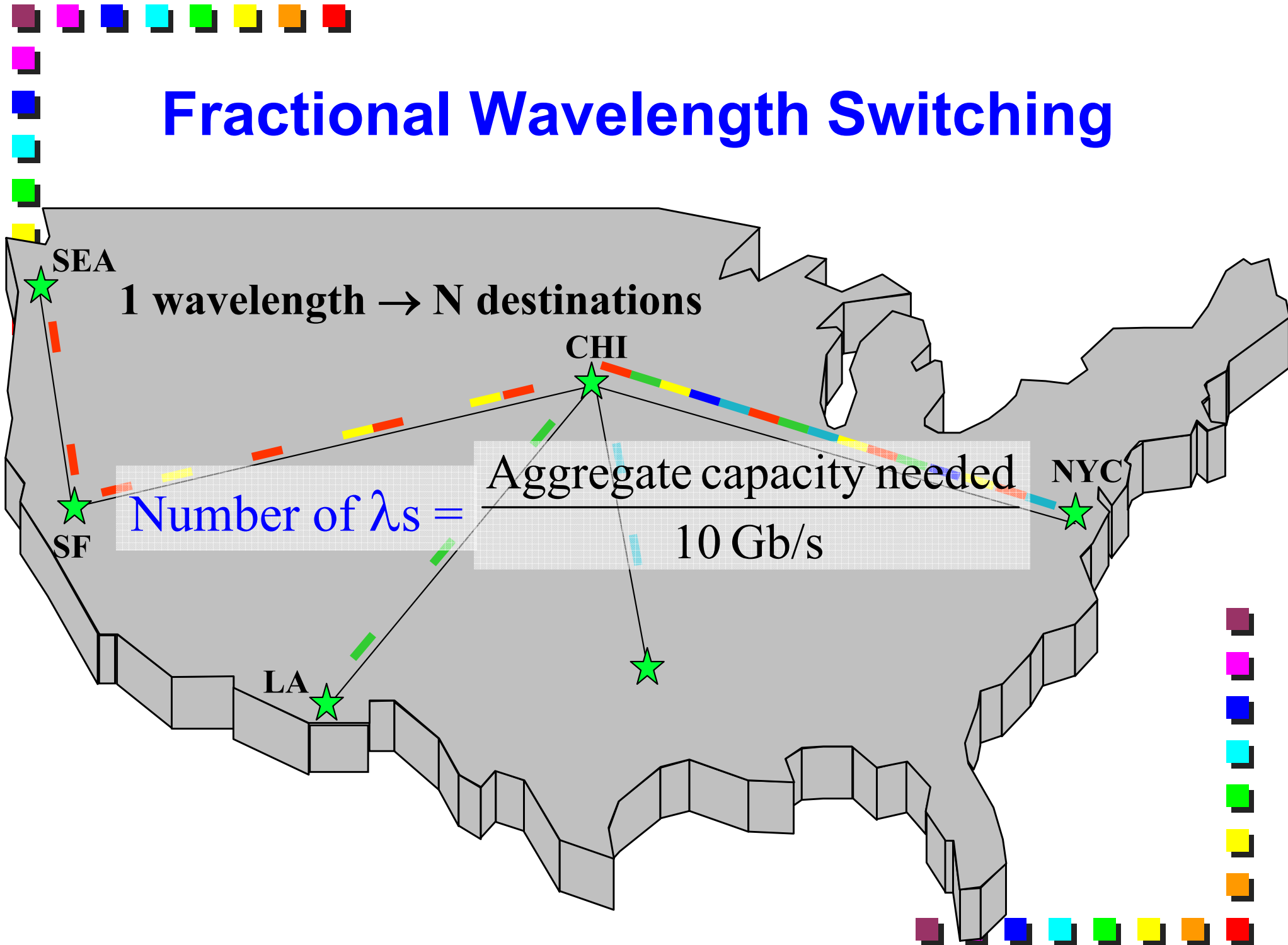
λ Switching: the N^2 Problem

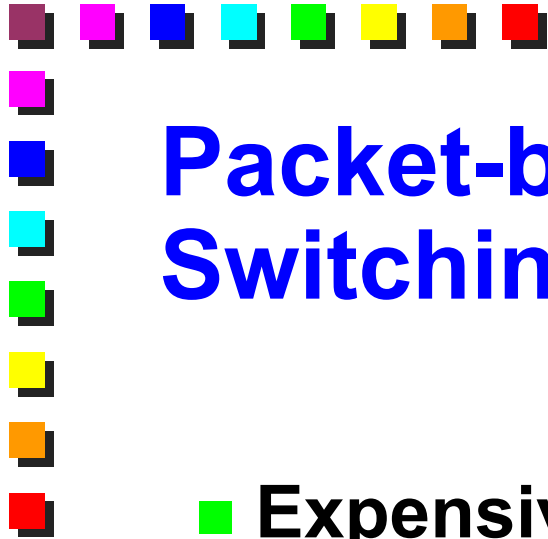


Fractional Wavelength Switching



Fractional Wavelength Switching





Packet-based Fractional Wavelength Switching and Grooming

Terabit Routers

- Expensive header processing
 - complex
 - slow
- Probabilistic service
 - No hard quality of service guarantees
- Long routing-based restoration time

SONET represents today's solution for fractional wavelength switching and grooming

