



# The Optical Internet

## Wavelength Division Multiplexing (WDM) and Lambda Switching

**Mario BALDI**


baldi@synchrodyne.com

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




OpticalInternet - 1

Copyright: si veda nota a pag. 2



## 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
- 

OpticalInternet - 2

Copyright: si veda nota a pag. 2



## WDM Deployment

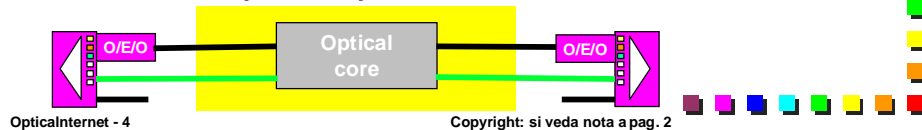
- **First: increase transmission capacity of fiber**
  - point to point configurations
- **Interim: add/drop multiplexing**
  - ring topologies with WDM add/drop multiplexers
    - inserting wavelengths on the ring
    - extracting wavelengths from the ring
  - mostly static or semipermanent configurations
- **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

OpticalInternet - 3

Copyright: si veda nota a pag. 2

## 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



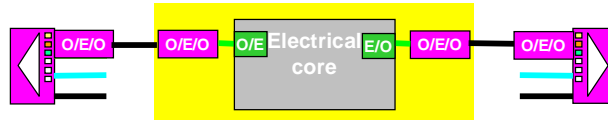
OpticalInternet - 4

Copyright: si veda nota a pag. 2

## 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)



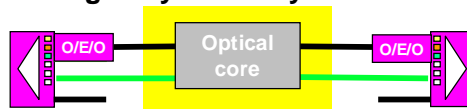
OpticalInternet - 5

Copyright: si veda nota a pag. 2

## Dynamic Optical Switching

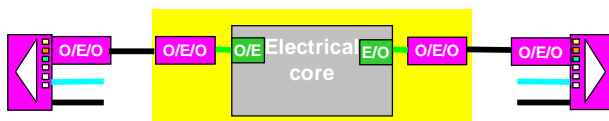
### ■ Wavelength switch without wavelength conversion

- switch configuration is changed dynamically
  - by management
  - by time of day
  - every packet!?! ...
- WDM de-multiplexer+MEMS, electroholography, bubbles



### ■ Wavelength switch with wavelength conversion

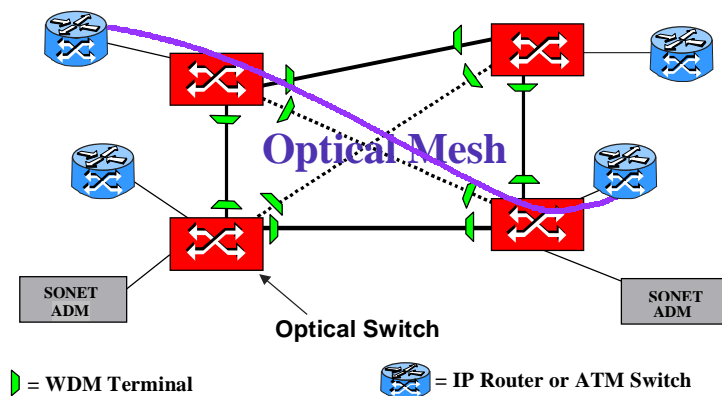
- OEO (optical-electrical-optical) conversion with electrical switching
- circuit switching (SONET/SDH)



OpticalInternet - 6

Copyright: si veda nota a pag. 2

## What to do with Optical Switches?

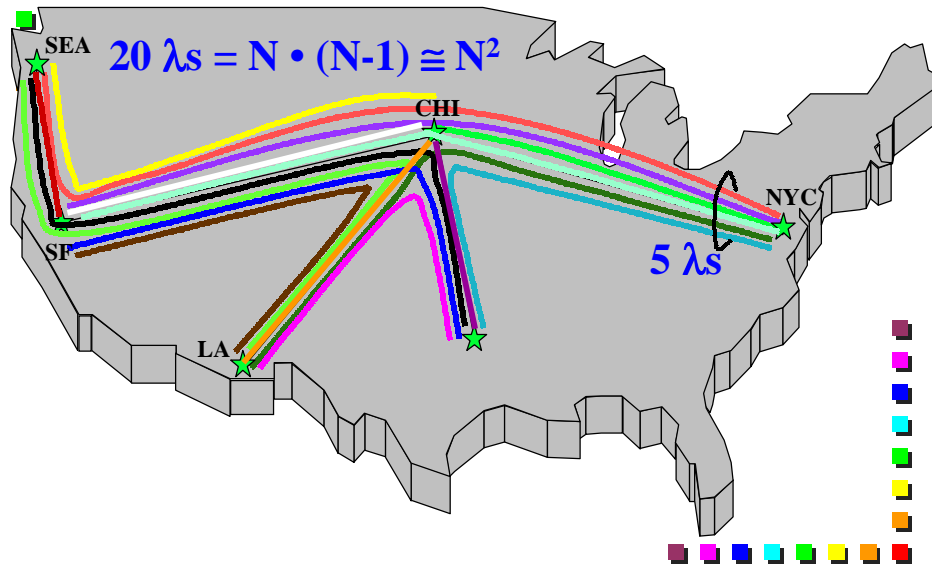


## Wavelength Conversion

- **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



## $\lambda$ Switching: the $N^2$ Problem

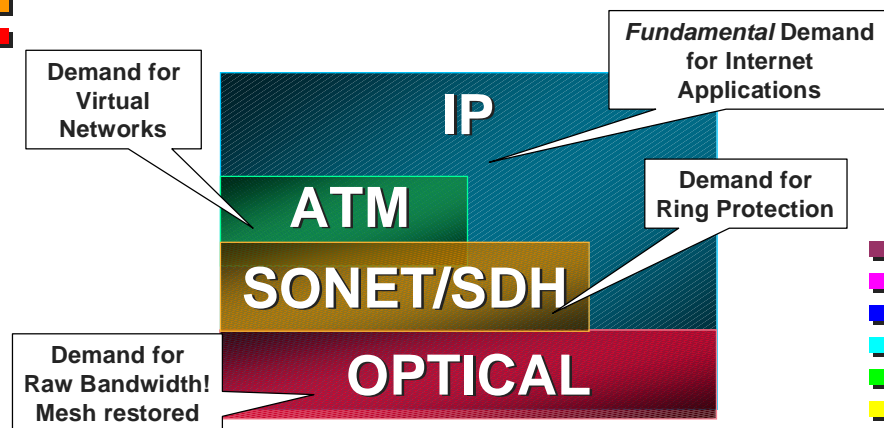


OpticalInternet - 9

Copyright: si veda nota a pag. 2



## IP over Glass? Not Exactly



OpticalInternet - 10

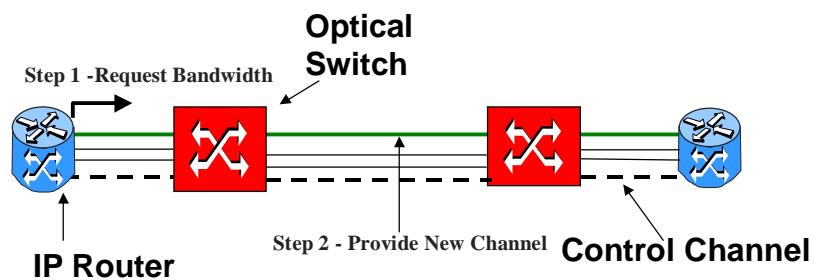
Copyright: si veda nota a pag. 2



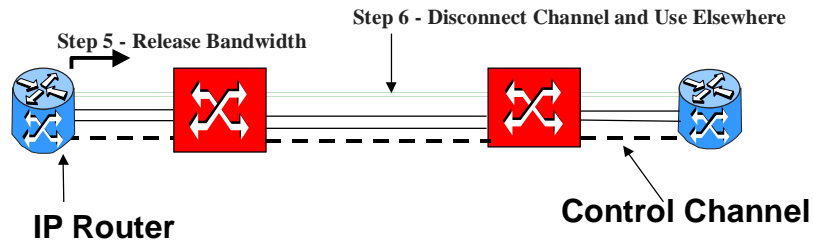
## What is Expected from the Optical Network?

- **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

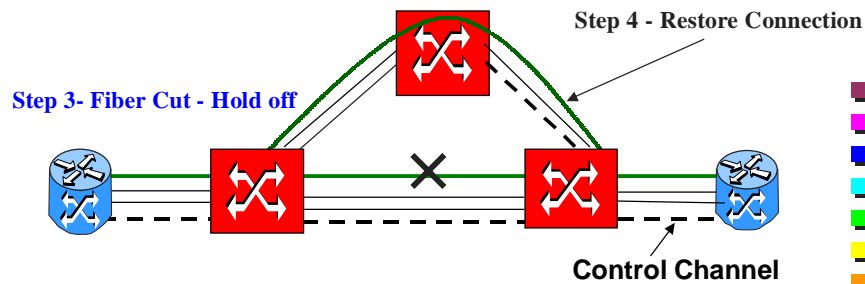


OpticalInternet - 13

Copyright: si veda nota a pag. 2

## Protection/Restoration

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



OpticalInternet - 14

Copyright: si veda nota a pag. 2

## 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

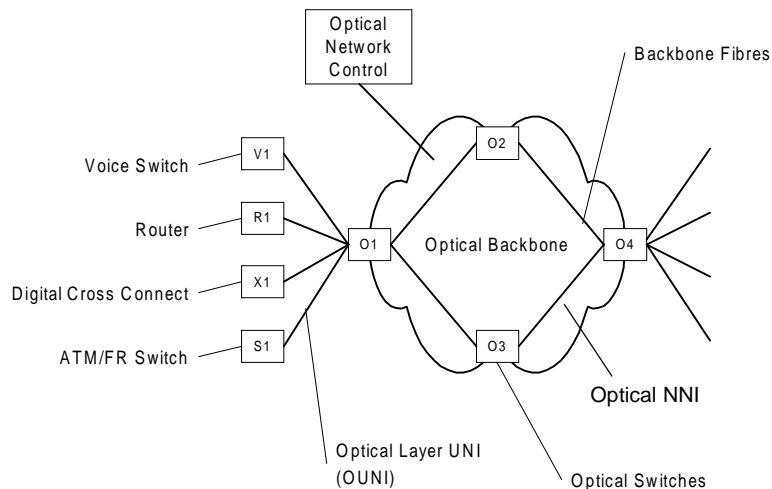
- Resource discovery
  - Address of users reachable through the optical network
- Manage lightpaths
  - Lightpath setup
  - Lightpath take down
  - Lightpath modification
- Negotiate protection service classes
  - Protected, unprotected, best effort lightpaths

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

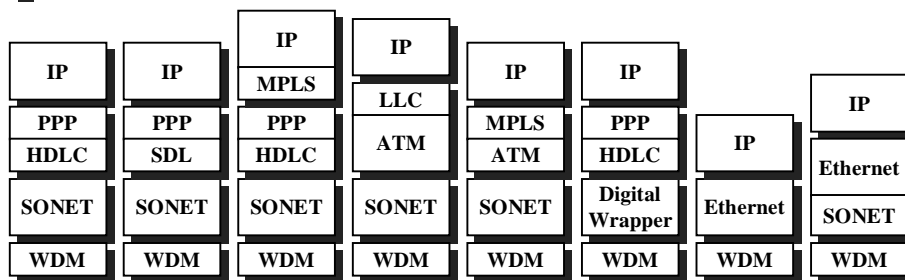
- PPP with HDLC framing
- PPP with SDL framing
- Ethernet
- ATM

### MPLS?

### Network layer: IP

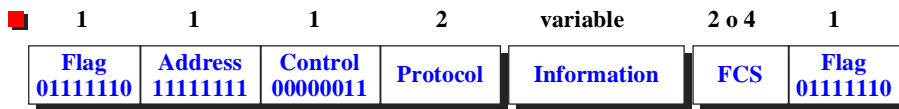
PPP - Point-to-Point Protocol  
 HDLC - High-level Data Link Control  
 SDL - Simple Data Link  
 ATM - Asynchronous Transfer Mode

## Some Deployed Configurations

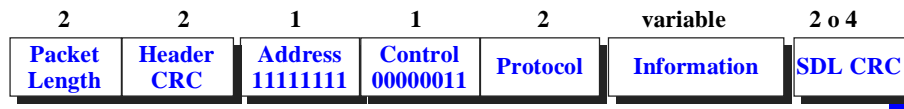


## Point-to-Point Protocol (PPP)

### ■ High-Level Data Link Control (HDLC) framing



### ■ Simple Data Link (SDL) framing

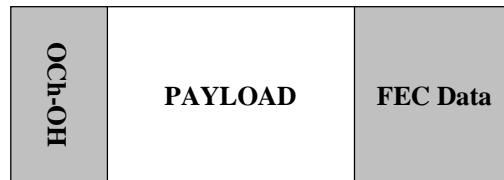


### ■ CRC hunting

## Digital Wrapper

### ■ Improve Bit Error Ratio (BER)

### ■ Provide transparent transport



OCh - Optical Channel

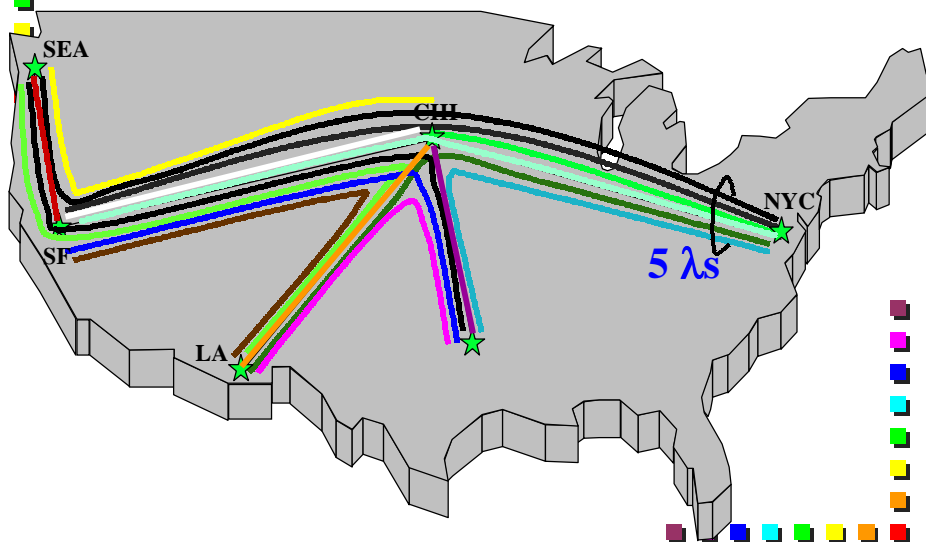
OH - Overhead

FEC - Forward Error Correction

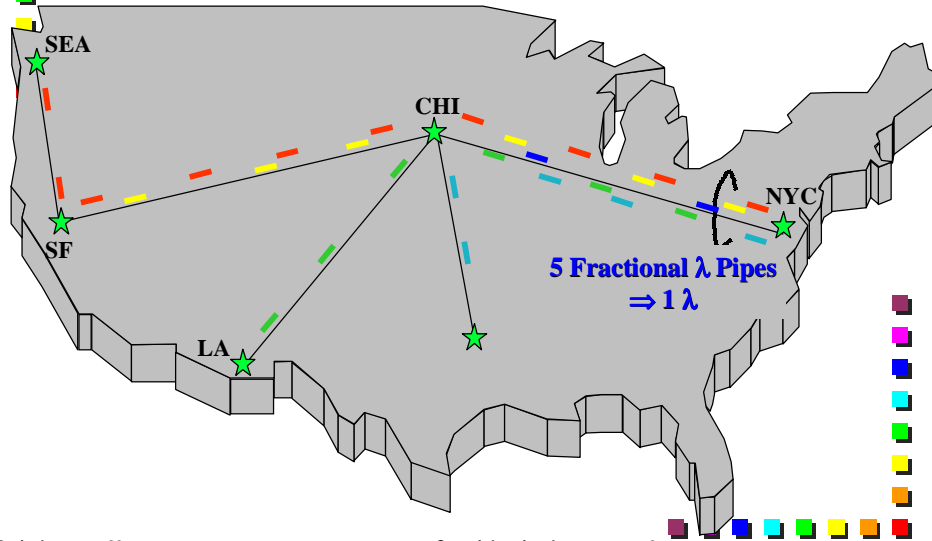
## How about the SONET Comeback?

- A lightpath ( $\lambda$ ) 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**

## $\lambda$ Switching: the $N^2$ Problem



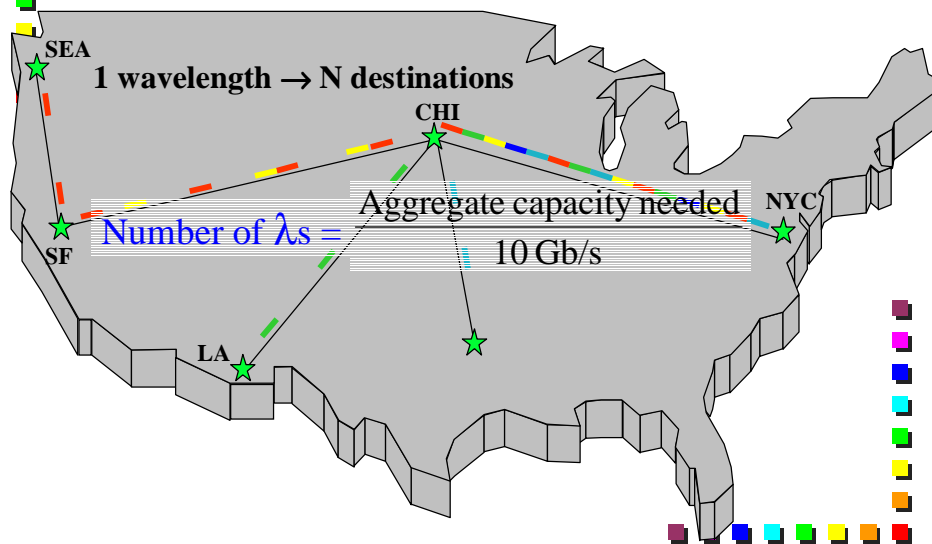
## Fractional Wavelength Switching



OpticalInternet - 29

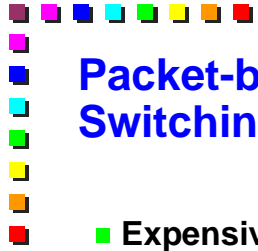
Copyright: si veda nota a pag. 2

## Fractional Wavelength Switching



OpticalInternet - 30

Copyright: si veda nota a pag. 2



## 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**

