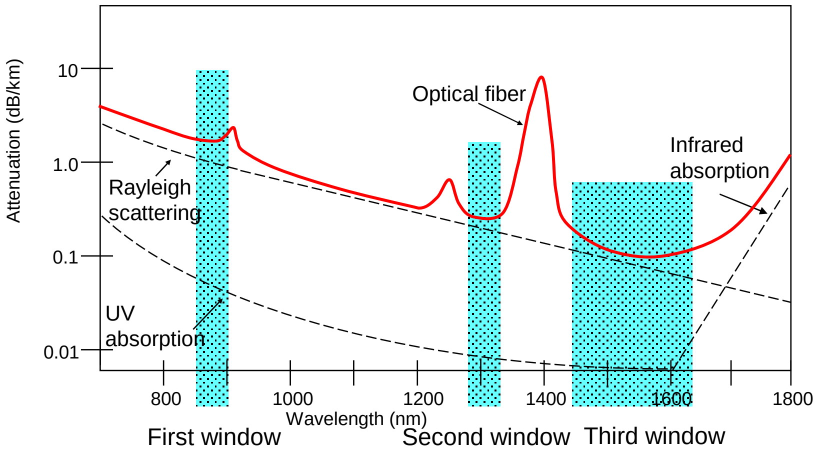
Introduction to optical networking

http://deisnet.deis.unibo.it

Fibers attenuation



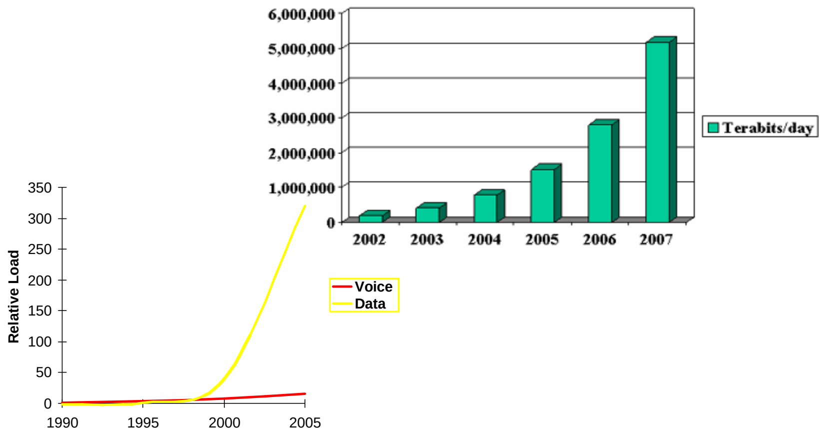
First window
850 nm
a=1.2 dB/Km

Second window
1300 nm
a=0.4 dB/Km

Third window
1550 nm
a=0.2 dB/Km

2

Traffic trends



- "By 2007 Internet users will access, download and share the 10 terabytes information equivalent of the entire Library of Congress more than 64,000 times over every day" (source: IDC/lightreading.com, February 2003)

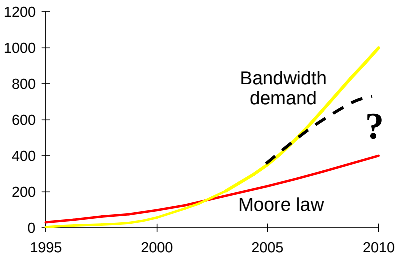
3

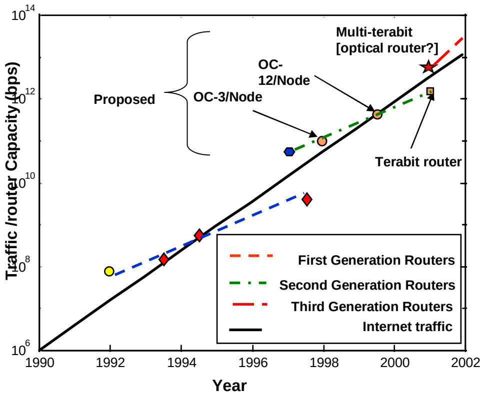
Bandwidth is a limit?

4

Motivation for optical networks

- Cost and performance limitations are more and more related to switching and multiplexing rathar then to transmission bandwidth





Economics: the stock market in 2000

Equal weighted index of 16 optical systems and component stocks
Source: Conrad Leifur, U.S. Bancorp Piper Jaffrayinvited presentation at Opticomm 2000

First generation optical networks

- At first the optical fibers replace copper wire in traditional networks (layer 1 OSI)
- Examples:
  - Submarine systems
  - SONET/SDH: synchronous networks as an evolution of traditional TDM plesiochronous network (telephone network)
  - ESCON, FiberChannel, HIPPI: computer and peripherals interconnection in the short range
  - FDDI, Gbit Ethernet: high speed LANs and WANs
  - RPR - Resilient Packet Ring (IEEE 802.17)

7

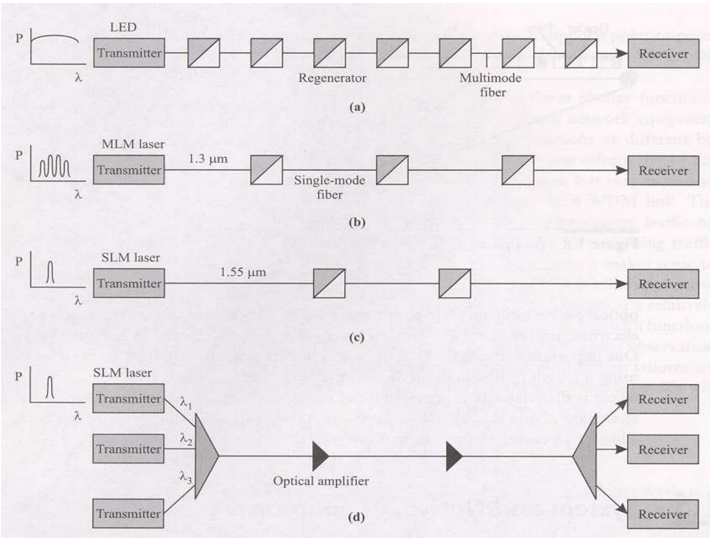
Optical transmission systems evolution

1960

1970

1980

1990



8

Transparent networks

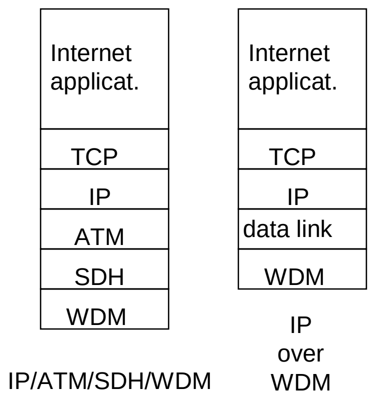
- Opaque networks
  - Transmission in optics
  - Electronics for
    - Signal quality monitoring and regeneration
    - Switching
    - Multipexing
  - O/E/O conversion at the edges of every network span
- Transparent networks
  - Data never leave the optical domain
  - Requires
    - Optical switching
    - All optical 3R regeneration (Reshaping, Reamplification, and Retiming)
    - All optical wavelength conversion

9

Photonics in switching

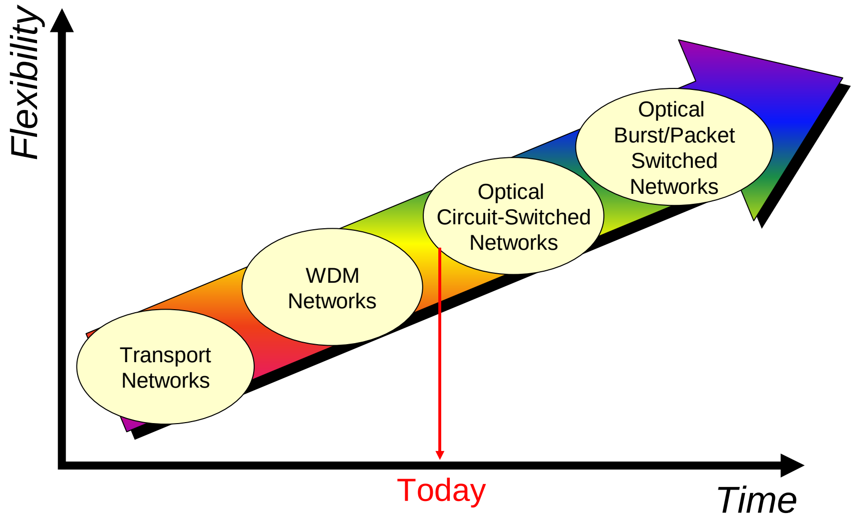
- Optical circuit switching (**OCS**)
  - Relatively mature technology today
  - Providing lightpaths
  - WDM network elements
    - Fiber, Optical line amplifier (OLA)
    - Optical line termination (OLT)
    - Optical add-drop multiplexer (OADM)
    - Optical cross-connect (OXC)
- Optical packet switching **(OPS)**
  - Not available today due to some technological problems
    - Controllable optical memory for optical buffering
    - Control functions in the optical domain
    - Synchronization, etc
- Optical burst switching **(OBS)**
  - Hybrid packet switching: a feasible solution?

- De-layering
  - Reduce operational costs
  - Allow faster provisioning



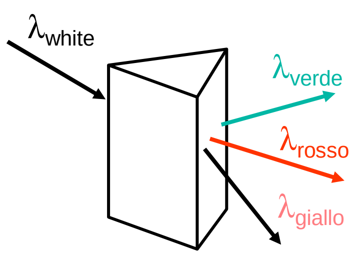
10

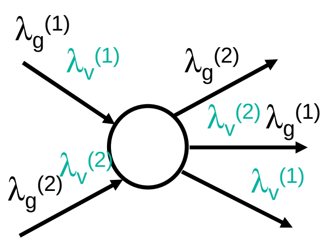
Optical Networking Evolution



Optical circuit switching

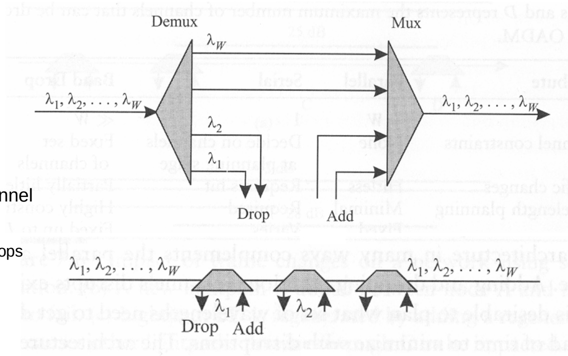
- A lightpath corresponds to a circuit
  - Set-up a lightpath
  - The whole lightpath is available during the connection
  - Disconnect
- The prism: wavelength as a routing tool





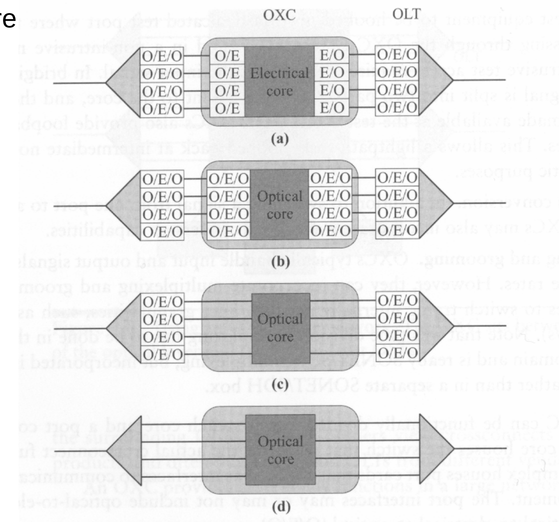
Optical Add-Drop Multiplexer

- Parallel structure
  - Arbitrary channels
  - Fixed loss
  - Demux of all channels
    - Inefficient for small drop
    - Higher loss
    - Many filters
- Serial structure
  - Each OADM drops one channel
  - Modular cost
    - More modules for more drops
    - Disrupts service
    - Loss increases



Types of OXCs

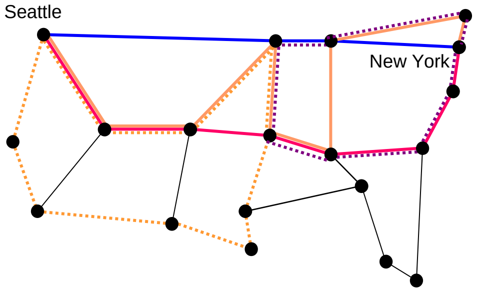
- Electronic or optical core
  - Transparency
  - Cost
  - Size
- Transparent or opaque core
  - Signal converted
  - Electronic signal
    - Signal monitoring
  - Optical signal
    - Transparency



WDM networks design

- WDM network objective is to establish lightpaths to support the client traffic demands
  - Given the fiber (physical) topology and the traffic matrix
  - Determine the lightpath topology (logical network)
    - Lightpath topology design (LTD)
  - According to routing and wavelength availability constraints
    - Routing and Wavelength Assignment (RWA)

Given a traffic matrix (a forecast) and a fiber (physical) topology:
design the network that fits the traffic forecast



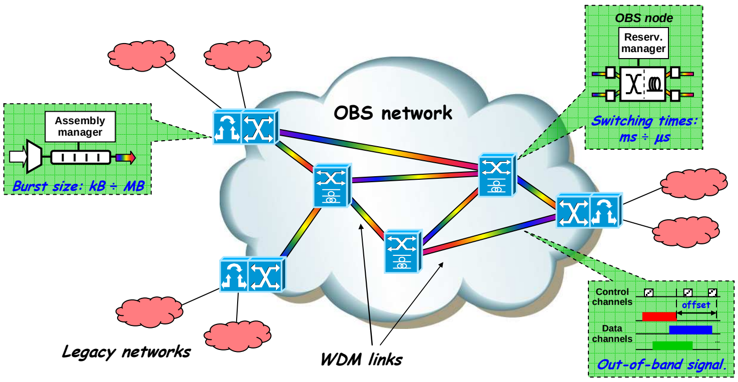
Static WDM network optimization ***Complexity***

- Routing and Wavelength Assignment (RWA) [OzBe03]
  - The capacity of each link is given
  - It has been proven to be a NP-complete problem [ChGaKa92]
  - Two possible approaches
    - Maximal capacity given ⇒ maximize routed traffic (throughput)
    - Offered traffic given ⇒ minimize wavelength requirement

- Routing Fiber and Wavelength Assignment (RFWA)
  - The capacity of each link is a problem variable
  - Further term of complexity ⇒ Capacitated network
  - The problem contains multicommodity flow (routing), graph coloring (wavelength) and localization (fiber) problems
  - It has been proven to be a NP-hard problem (contains RWA)

OBS network

- Control and data information travel **separately** on different channels
- Data coming from legacy networks are aggregated into **a burst unit** in edge node
- **The control packet** is sent first in order to reserve the resources in intermediate nodes
- The burst follows the control packet with some **offset time**, and it crosses the nodes remaining in **the optical domain**

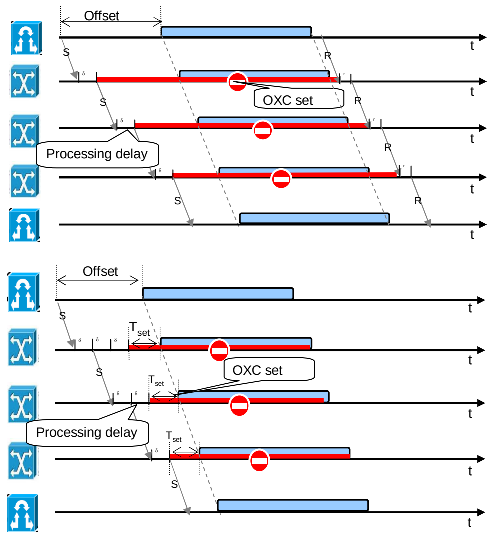


OBS principles

- Variable-length packets, named bursts
- Asynchronous node operation
- A strong separation between the control and data planes
  - Control burst (with control information) transmitted on dedicated control channel and processed electronically
  - Data burst transmitted and switched all-optically
- Burst Signaling Protocols
  - Burst transmission is preceded by a setup message to reserve resources
  - Signaling packets undergo E/O conversion at every hop while burst data travel transparently
  - Two different types of protocols
    - Tell-and-Wait (TAW): two-way reservation schemes
    - Tell-and-Go (TAG): one-way reservation schemes

TAG state-of-art OBS signaling

- JIT (Just in Time) protocol: explicit setup and explicit or implicit release
- Horizon and Just Enough Time protocols: employ estimated setup and estimated release
  - Horizon doesn't support void filling
  - JET supports void filling



OBS Networks Nodes

- Edge node
  - Electronic router and OBS interface
  - Functions
    - Electronic data buffering and processing
    - Burst Aggregation (BA), responsible for collecting data from legacy networks and building the burst unit
    - Setting up the pre-transmission offset time
    - Sending the control packet
    - Sending the burst
- Core node
  - Processing of incoming control packets (electronically) and sending it to the next node that lays on the routing path
  - Reservation of optical resources for transferring the burst
    - Just-In-Time (JIT)
    - Horizon Reservation Mechanism (HRM)
    - Just-Enough-Time (JET) – the most efficient but of high complexity

Optical packet switching

- Conventional routers architecture
  - Routing component
    - Exchange of routing information
    - Build the routing table
  - Forwarding component
    - Forwarding algorithm
      - Packet header processing
      - Routing table look-up
  - Switching
    - Transfer packet from input to output port
  - Transmission

Optics applicable to switching and transmission

21

OPS main open issues

- Header processing
  - Electronics or optics
- Congestion resolution
  - No optical RAMs
  - Time multiplexing with delay lines
  - Wavelength and space multiplexing as alternatives
    - Tuneable wavelength conversion
- Switching time
  - Complexity and cost increase with decreasing switching time
- Synchronization
  - Packet alignment, header rewriting

22

Optical routers

- De-couple routing and forwarding from switching and transmission

☺ Use electronics for processing

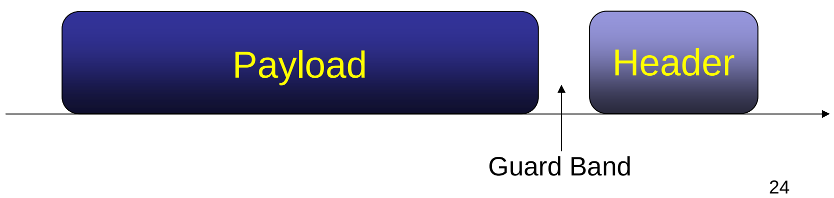
☺ Use optics for high speed data transfer

- Packet payload and header treated differently
  - O/E/O conversion of header at any node
  - Transparent switching of packet payload
- Alternatives
  - In band header
    - Packet header travelling with the payload
  - Out of band header
    - Packet header carried on a separate wavelength

23

Optical packet

- Header and payload bit rates may be different
- Guard band between header and payload to cope with optical devices switching speed
  - Payload must be larger than guard bands
    - Overhead must be limited in the order of 10%
  - Payload longer than average time needed for header processing
    - Limit guard bands between packets
  - Payload must be the shortest possible
    - Limit the packetization delay
  - Payload should fit with carried traffic
    - Any padding needed is an additional overhead



24

Optical packet format

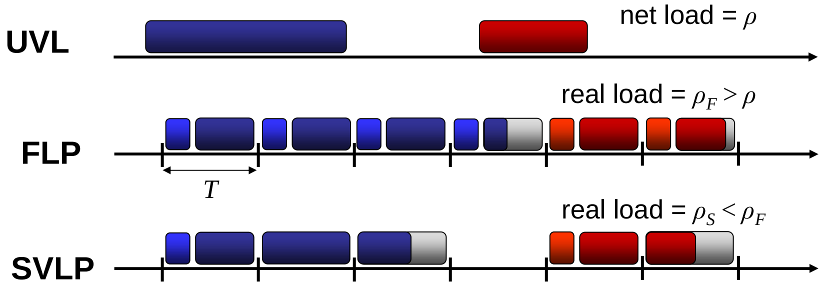
- Use existing packet format?
  - IP datagram
  - ATM cell
- The duration of small packets at high speed is comparable with
  - Guard times
  - Forwarding table look up
- The network is inefficient

A specific packet format is necessary

25

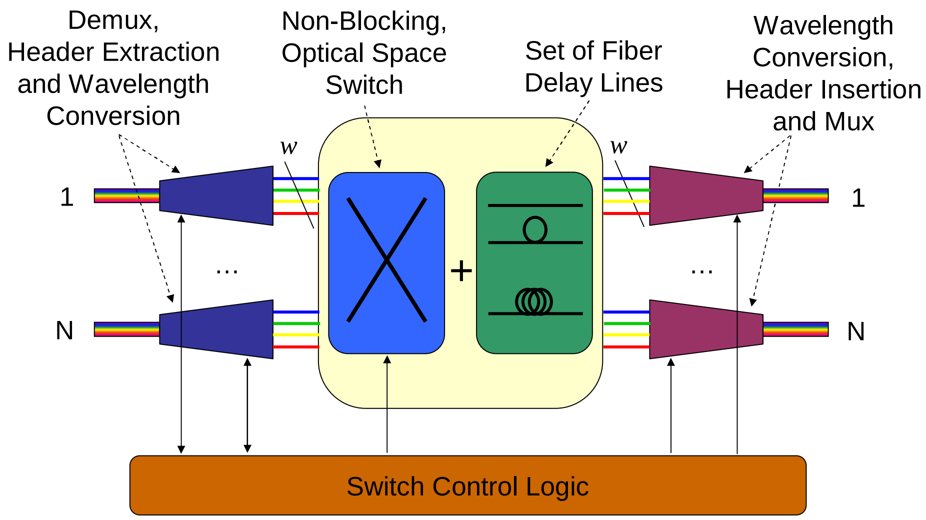
Packet format: time structure

- Unslotted variable length (UVL)
- Slotted – fixed length (FLP)
- Slotted – variable length (SVLP)



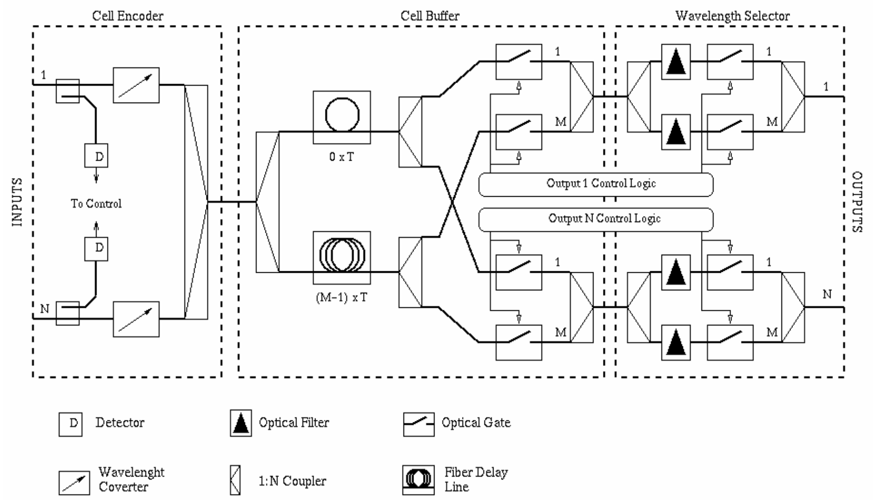
26

Optical Packet Switch Architecture



27

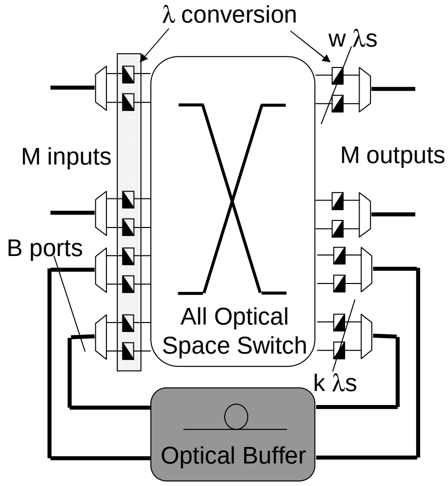
The KEOPS broadcast and select



28

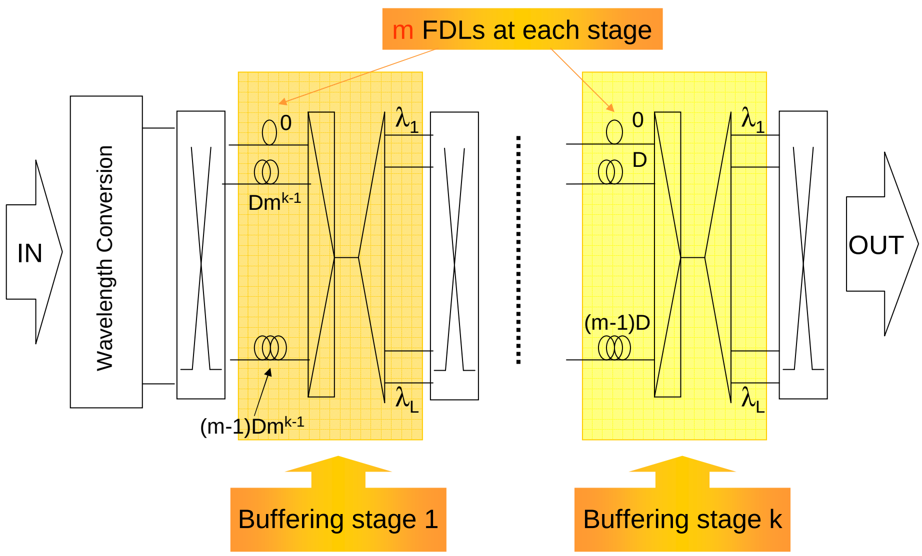
David Optical Packet Router

- All optical space switch
- WDM inlets/outlets
- Contention resolution:
  - Wavelength multiplexing
  - Time multiplexing
- Target
  - 256 x 256 matrix
  - Link speed 10 Gbit/s
  - Throughput 2.56 Tbit/s



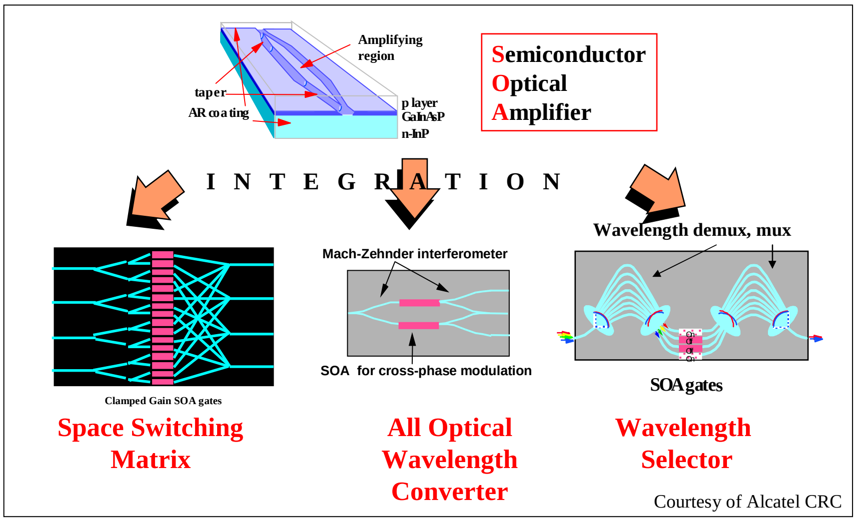
29

Multistage Buffer Switch



30

Technology



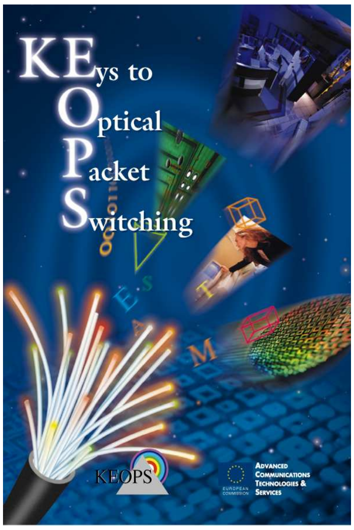
31

Optical networks research at DEIS

- National projects
  - IPPO (PRIN): 2001-2002, € 39000
  - Intrepido (PRIN): 2003-2004, € 50000
  - Grid.IT (FIRB): 2003-2006, € 218000
- International projects
  - ATMOS (RACE II) : 1994-1995
  - KEOPS (ACTS) : 1995-1998, € 327000
  - DAVID (IST VFP) : 2000-2003, € 329000
  - e-Photon/ONe (IST VIFP) : 2004-2005, € 114000
  - e-Photon/ONe+ (IST VIFP) : 2006-2007, …
- Total funding 1995-2005 = € 1077000
- 3 staff members + 1 in 2005

32

The KEOPS Project



Partners:

- Alcatel Alsthom Recherche* (F)
- France Télécom CNET (F)
- Centro Studi E Laboratori Telecomunicazioni (I)
- Technical University of Denmark (DK)
- Alcatel SEL** (D)
- Alcatel CIT*** (F)
- University of Bologna (I)
- Eidgenössische Technische Hochschule Zürich (CH)
- University of Strathclyde (UK)

* now, Alcatel CIT, Etablissement de Marcoussis
** active till Feb.97, *** active till Dec.96

Objective

Analysis and demonstration of bit rate transparent all-optical packet switching within all-optical network architecture including network & system studies, lab. trials based on components developed in the project

33

The DAVID Project

Partners:

- Alcatel CIT (F)
- Alcatel SEL (D)
- Opto+ (F)
- BT (UK)
- IMEC (B)
- COM (DK)
- NTUA (G)
- University of Bologna (I)
- Polytechnic of Torino (I)
- University of Essex (UK)
- UPC (E)
- LRI (F)
- INT (F)

d a v i d

http://david.com.dtu.dk

Goals

- Develop concepts and technologies for future optical networks
- Traffic engineering in packet-over-WDM based networks
- Control systems for optical networks

34

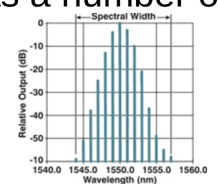
e-Photon/ONe (www.e-photon-one.org)

- 38 partner institutions (from Portugal to Turkey)
  - 32 academic institutions
  - 3 telecom operators (Telenor, France Telecom, TID)
  - 2 manufacturers (Alcatel, Siemens)
- ~400 researchers actively involved in the NoE
- Coordinator: Politecnico di Torino
- Project start date: February 2004
- End of Phase 1: March 2006
  - funded for 2 years with 2.9 M€
- End of Phase 2: March 2008
  - 2 more years with extra 3.75 M€

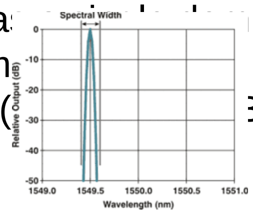
e-Photon ONe

35

- Reshaping, Reamplification, and Retiming (**3R**)
- **Multilongitudinal Mode (MLM) Laser :** An injection laser diode which has a number of longitudinal modes



- **Single-longitudinal Mode Laser (SLM):** An injection laser diode which ha[s] ... inant longitudinal mode. A single-m... a side mode suppression ratio (... 3.



36