Introduction to optical networking

http://deisnet.deis.unibo.it

Fibers attenuation

![Graph showing fibers attenuation with different windows and their respective wavelengths and attenuation values. First window at 850 nm with an attenuation of 1.2 dB/Km, Second window at 1300 nm with an attenuation of 0.4 dB/Km, Third window at 1550 nm with an attenuation of 0.2 dB/Km. UV absorption, Rayleigh scattering, and Infrared absorption are also depicted.](image-url)
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)

Bandwidth is a limit?
Motivation for optical networks

- Cost and performance limitations are more and more related to switching and multiplexing rather than 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 Jaffray invited 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)

Optical transmission systems evolution
**Transparent networks**

- **Opaque networks**
  - Transmission in optics
  - Electronics for
    - Signal quality monitoring and regeneration
    - Switching
    - Multiplexing
  - 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

**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

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Optical Networking Evolution

- Optical Circuit-Switched Networks
- Optical Burst/Packet Switched Networks
- WDM Networks
- Transport Networks

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 doesn’t support void filling
  - JET supports void filling

- Horizon and Just Enough Time protocols: employ estimated setup and estimated release

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

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
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

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
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

Packet format: time structure

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

\[
\text{net load} = \rho \\
\text{real load} = \rho_F > \rho \\
\text{real load} = \rho_S < \rho_F
\]
Optical Packet Switch Architecture

Demux, Header Extraction and Wavelength Conversion

Non-Blocking, Optical Space Switch

Set of Fiber Delay Lines

Wavelength Conversion, Header Insertion and Mux

Switch Control Logic

The KEOPS broadcast and select

Diagram showing the KEOPS broadcast and select mechanism.
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

Multistage Buffer Switch

m FDLs at each stage

Buffering stage 1

Buffering stage k
Technology

Optical networks research at DEIS

- National projects
  - Intrepid (PRIN): 2003-2004, € 50000
  - Grid.IT (FIRB): 2003-2006, € 218000
- International projects
  - 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
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

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)

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

http://david.com.dtu.dk
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€

- 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 has a dominant longitudinal mode. A single-mode laser with a side mode suppression ratio (SMSR) of 25 dB.