IO2654 Optical Networking

Spring semester 2014

W E L C O M E !

Paolo Monti: course responsible

Lena Wosinska: examiner

KTH/ICT

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IO2654 Optical Networking

How to contact us

- KTH Social (https://www.kth.se/social/course/IO2654/)
  - Schedule
  - Information about project work
  - Q&A with the teachers
  - Message board
- Webpage: http://www.ict.kth.se/courses/IO2654/index.html (info will gradually disappear -> KTH social)
- Mail
- Appointment

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IO2654 Optical Networking

Lecture 1

Course introduction
&
Fiber access networks

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OUTLINE

- General information
  - Aim of the course
  - The course at a glance
- Layered network models
  - ISO's OSI model and Internet model (TCP/IP)
  - Optical layer and client layers of the optical layer
- Broadband access networks
  - Overview of broadband access technologies
  - Evolution of fiber access networks
  - Passive Optical Network (PON)
- Summary

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AIM of the course

After the course the students should be able to:

- Define the main limitations and possibilities of the optical network technologies
- Define the main differences between optical networking and "traditional" networking
- Solve simple WDM network design and optimization problems
- Solve static and dynamic WDM provisioning problems
- Explain the benefits of optical layer survivability
- Describe the main issues in management and control of optical networks

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The course at a glance

- Lectures
  - F 1–3, and F 8-9: Lena Wosinska
  - F 4-7 and 10-12: Paolo Monti
- Examination
  - Oral exam (presentation of a technical paper plus discussion)
  - Grade based on both parts

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Lectures

#	Content
L1	Introduction: course overview. Fiber access networks.
L2-L3	WDM network design
L4-L5	WDM static provisioning heuristics
L6-L7	WDM dynamic provisioning heuristics
L8-L9	Photonics in Switching: optical circuit switching (OCS), optical packet switching (OPS) and optical burst switching (OBS)
L10	Survivability
L11	Network control and management
L12	Traffic grooming

Exam May 27, 2014 - oral

Oral exam

- The oral exam consists of two parts for a total of about 45'
- Part 1
  - 20' presentation about one technical papers (among a list of proposed ones)
- Part 2:
  - oral discussion about the technical content of the presented paper with possible questions about the material presented and discussed during the all course
- The final grade will reflect both parts of the discussion, where also the ability to stay in the allocated time for the presentation will be taken into account
- Papers list from which you will be able to choose will be provided after the third class
- By May 13: send an email to Paolo to let him know what is the paper chosen for the oral exam

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Text books and reading advice

Textbook:

Biswanath Mukherjee: *Optical WDM Networks*, First Edition, Springer, 2006

Lectures

- **L1:** Course introduction, layered network models, optical layer. Optical access networks
  - Chapters 1, 5 and lecture notes
- **L2-3:** WDM Network design
  - Chapters 7, 8 and lecture notes
- **L4-5:** WDM static provisioning
  - Chapter 7.2, 7.3, 7.4, 7.5 and lecture notes
- **L6-7:** WDM Dynamic provisioning
  - Chapter 7.3.2, 7.4.3, 7.4.4 and lecture notes
- **L8-9:** Photonics in switching: optical circuit switching (OCS), optical packet switching (OPS) and optical burst switching (OBS)
  - Chapter 2.6, 17.1-3, 17.4-17.4.4, 17.5.1, 17.8, 18.1, 18.5-6 and lecture notes
- **L10:** Survivability in WDM networks
  - Chapter 11 and lecture notes
- **L11:** Control and management in optical networks
  - Chapter 16 and lecture notes
- **L12:** Traffic grooming
  - Chapter 13 and lecture notes

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Course Evaluation

- One volunteer
- Meetings
  - After a few lectures
  - After the end of the course
- Compile results of course evaluation forms

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OPTICAL NETWORK

It is NOT NECESSARILY all optical

Characteristics of an optical network

Transmission: optical

Switching:

all-optical/ all-electronic/ hybrid

circuit/ packet/ burst

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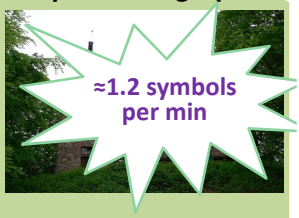
Transmission of optical signals

Ancient time (BC)	18th Century	21st Century ~ Now
Smoke signals	***Optical telegraph***	***Fiber communication***
		
In ancient China, soldiers stationed along the Great Wall were able to *transmit one bit message as far away as 480 km in a few hours* by signaling from tower to tower	The line between Paris and Lille *(230km)* transferred a complete message, consisting of *36 symbols*, *in about 32 minutes*.	09/2009, researchers from the Bell Labs reported transmission of *155 wavelength channels,* each carrying *100 Gigabits of data per second* (in total *15.5 terabit/s*) *over 7000 km*.

Advantages of optics

- Fantastic for transmission
  - Optical amplifier can simultaneously amplify all of the signals on all (~160) wavelength channels on a single fiber
- Huge bandwidth: 50 Tbps on a single fiber
  - Compare it to electronic data rates of few Gbps
- Low signal attenuation
- Low signal distortion
- Low power consumption
- etc

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Development of optical networks

- First-generation optical networks
  - Transmission in the optical domain (to provide capacity)
  - Example: SONET network (Synchronous Optical Network)
- Second-generation optical networks
  - Wavelength routed network (Optical Circuit Switching OCS)
  - More functionality in the optical domain (optical networking)
    - Some of routing, switching and intelligence is moving into the optical layer
- Third-generation optical networks (?)

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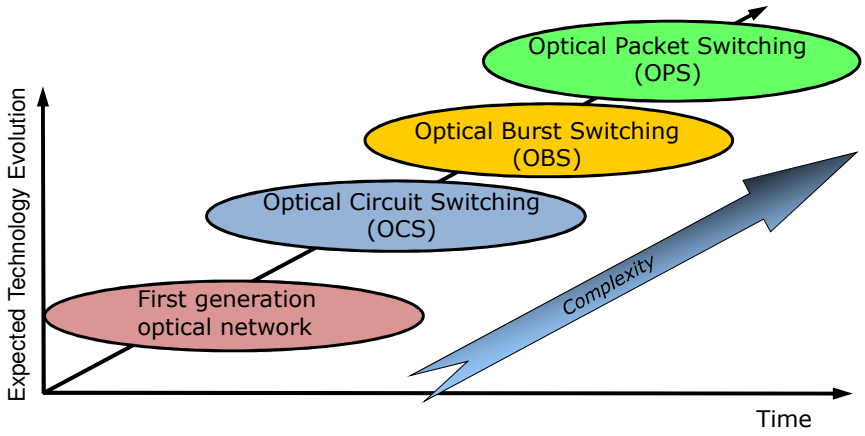
Optical Networks



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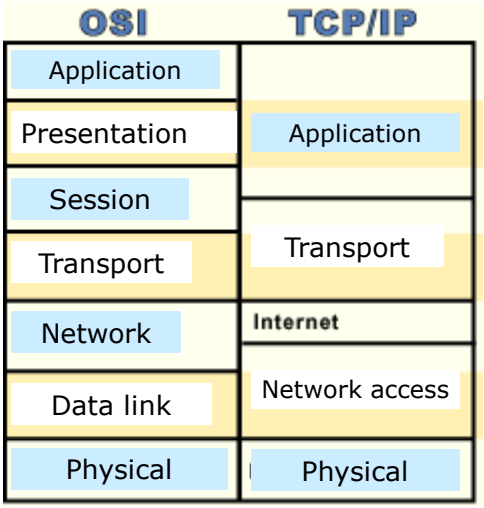
Layered models

Mapping between the layers



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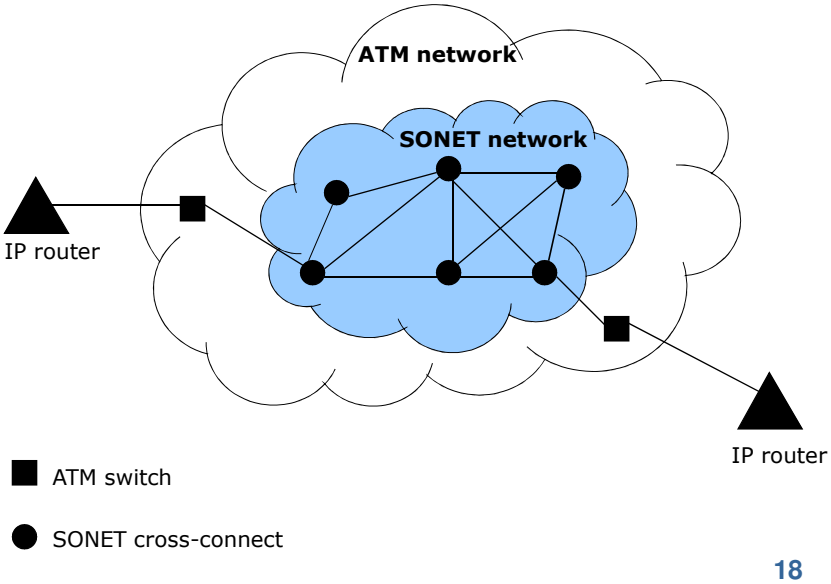
Multiple protocol stacks



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The Optical Layer

The optical layer

- The optical layer provides lightpath service to it's client layers.
- Lightpath: optical connection
  - An optical channel trail between two nodes that carries the entire traffic within a wavelength

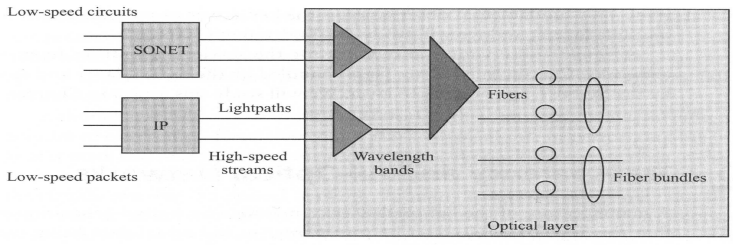

Figure 1.11 Example of a typical multiplexing layered hierarchy.

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Optical layer service: providing lightpaths

- Bandwidth
- Adaptation to and from client layers
- Performance
  - Bit error rate (BER)
    - Optical signal quality (OSNR, CD, PMD, nonlinear impairments)
  - Jitter
  - Maximum delay
- Protection
  - Multiple levels of protection
- Fault management

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Functions of the optical layer

- Multiplexing wavelengths
- Switching and routing wavelengths
- Monitoring network performance at various locations in the network

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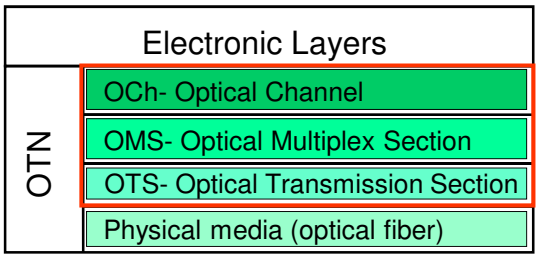
Layers within the optical layer

Optical Transport Network protocol layers

- Optical channel sublayer (OCh)
- Optical multiplex section (OMS)
- Optical transmission section (OTS)
- Physical media layer
  - Fiber-type specification, developed in other Recommendations



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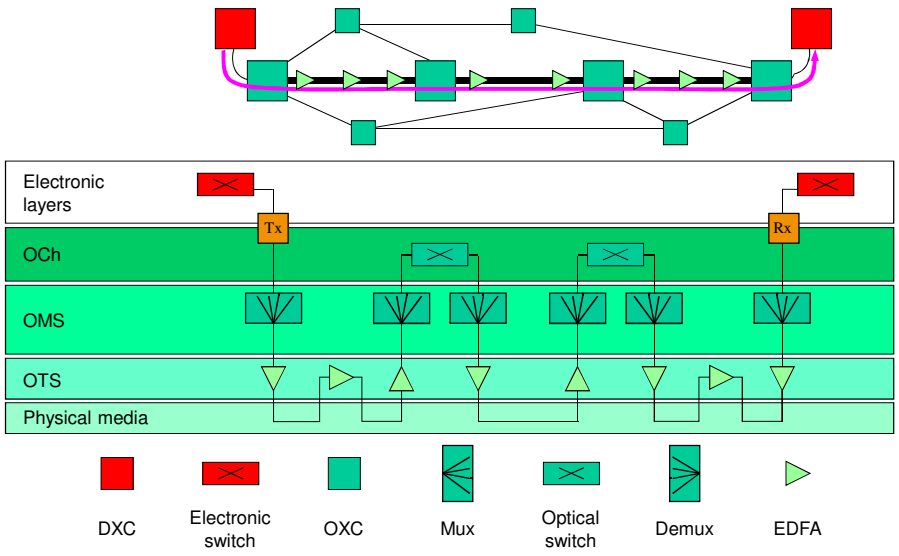
Simplified view of an optical connection



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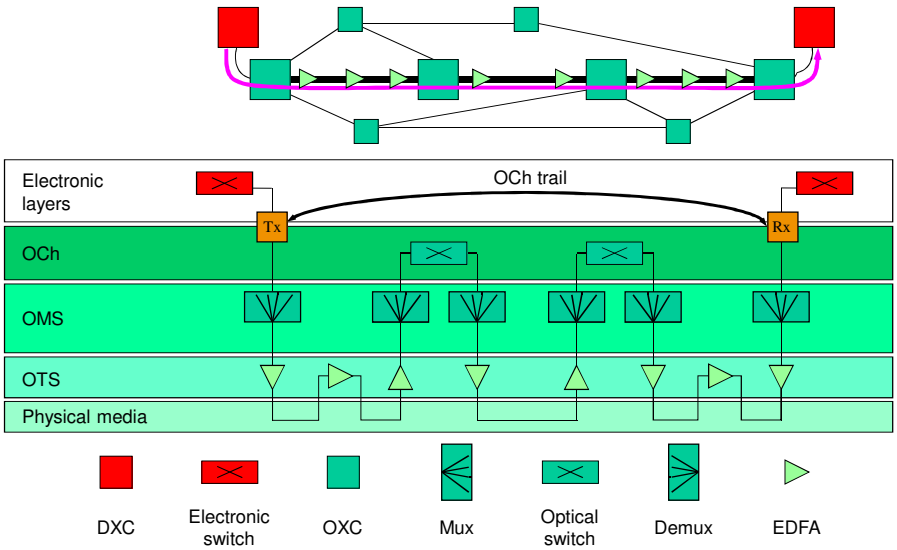
OCh sub-layer



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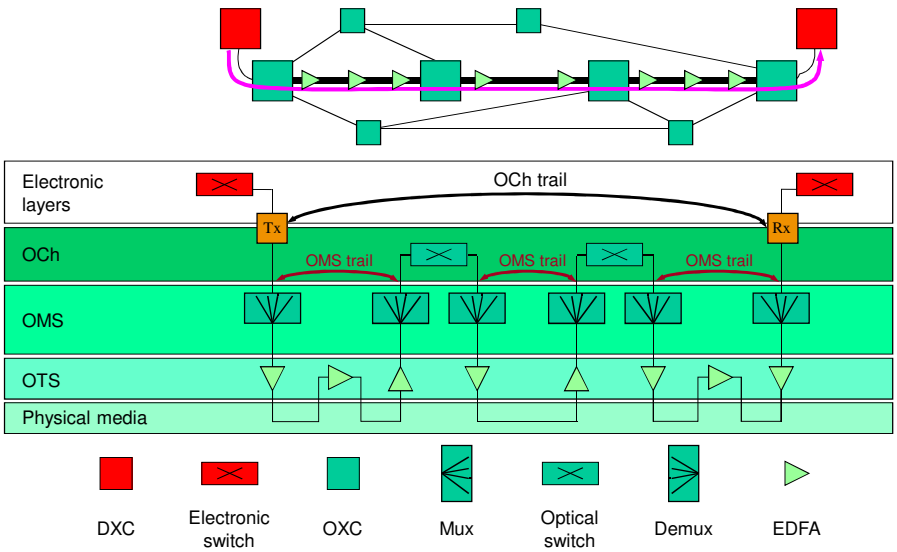
OMS sub-layer



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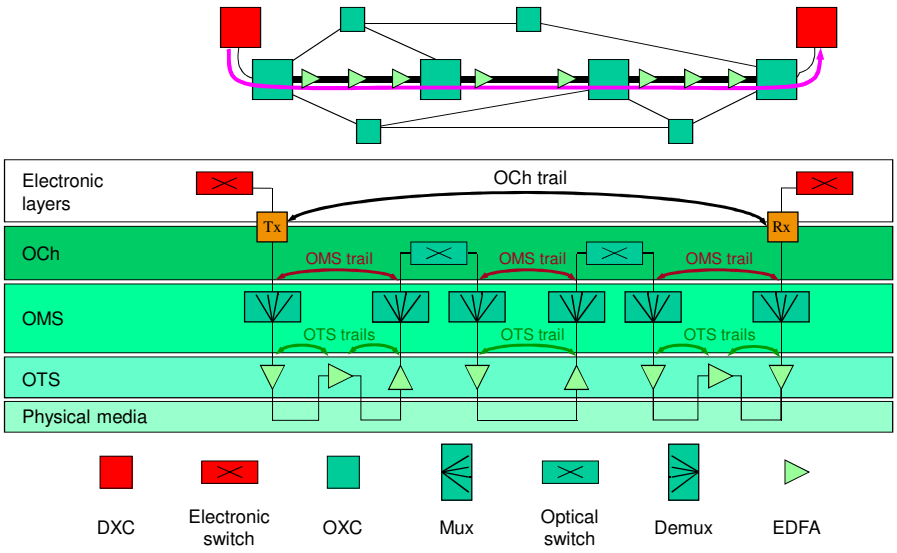
OTS sub-layer



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Client layers of the optical layer

- SONET/SDH
- ATM (Asynchronous Transfer Mode)
- IP

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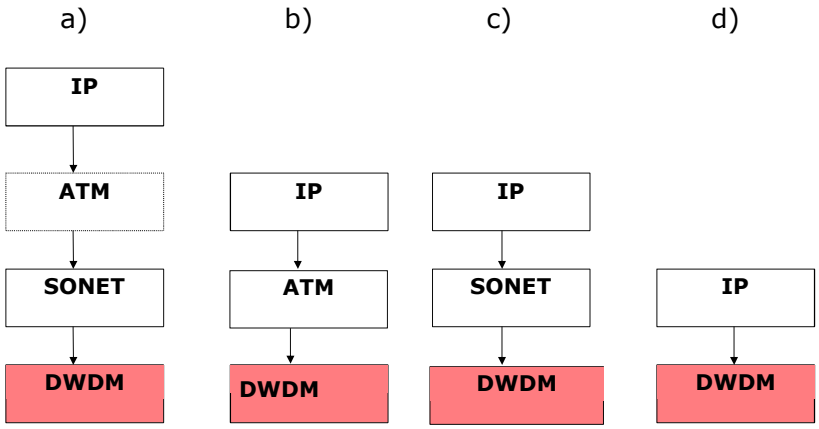
IP over WDM mappings

Towards a two layer network architecture



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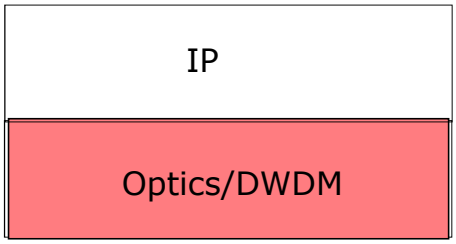
A perfect combination



flexibility

capacity

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Broadband access networks

Introduction

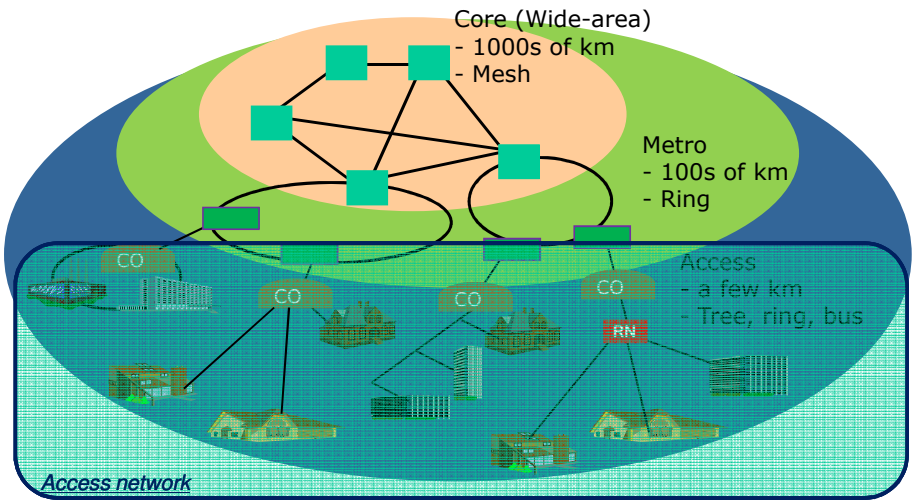
Overview of broadband access technologies

Evolution of fiber access networks

Fiber access network architectures

Passive Optical Network (PON)

Telecom Network Hierarchy



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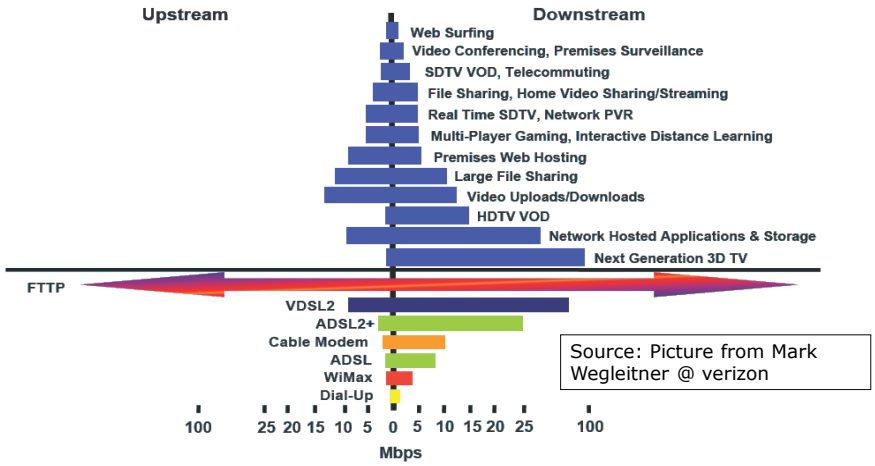
Trend

Reduced asymmetry between Upstream and Downstream



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Traffic demand drivers

- User behavior
  - Always on (reachability, upgrades and downloads)
  - File sharing
- Services
  - High-Speed Internet
  - VoIP
  - IPTV

  } "Triple play"
  - Gaming
  - Telemedicine
  - E-Goverment
  - etc

Traffic increases very rapidly

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Triple play capacity requirements

3P	Telephony	TV		Internet access	
	Basic 3P and extended 3P	Basic 3P	Extended 3P	Basic 3P	Extended 3P
Number of channels	**1**	**2**	**4**	**1**	
Capacity	80 kb/s symmetric	2 x 9 Mb/s asymmetric	4 x 15 Mb/s asymmetric	10 Mb/s symmetric	30 Mb/s symmetric

- Basic: design for basic triple play today
- Extended: design for five years from now

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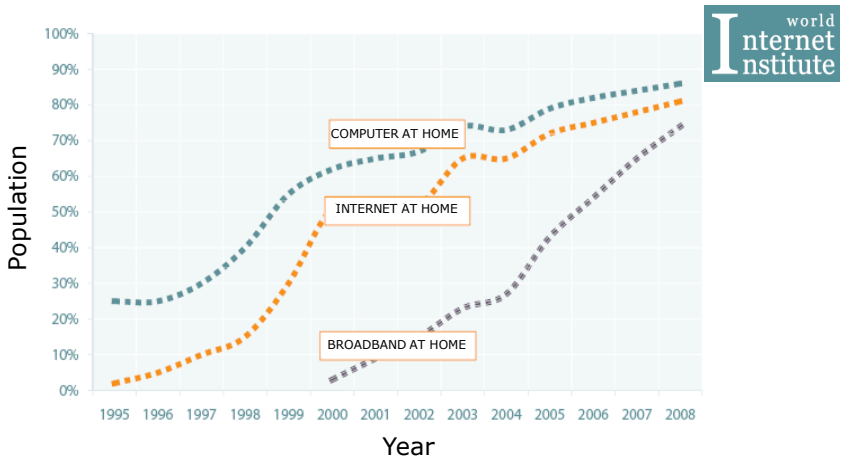
Development in Sweden



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Broadband access technologies

- Digital subscriber loop DSL (from telcos)
  - High-speed digital access to the Internet
  - Based on existing twisted pair
- Cable (from cable TV companies)
- Wireless access: WIMAX, WIFI, 3G, …
- Fiber access
  - Fiber to the cabinet (FTTCab)
  - Fiber to the curb (FTTC) or Fiber to the Building (FTTB)
  - Fiber to the home(FTTH)

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Broadband access technologies: limitations

Access based on:	Capacity/user	Max Reach
ADSL	2 Mb/s (typical)	5.5 km
VDSL	20 Mb/s (typical)	1 km
Coax	2 Mb/s *	0.5 km
Wi-Fi	54 Mb/s (max)	0.1 km
WiMax	28 Mb/s (max)	15 km
EPON	60 Mb/s *	20 km
GPON	40 Mb/s *	20 km

} FTTx

* Bandwidth depends on the number of users

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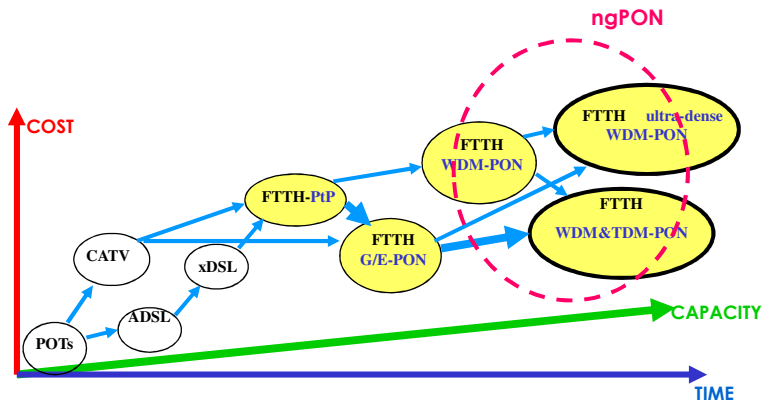
Access network evolution



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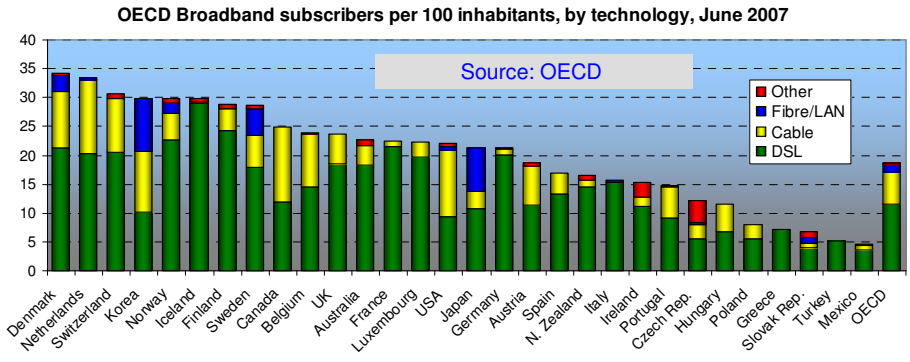
OECD broadband statistics

www.oecd.org/sti/ict/broadband



"Other" are mostly fixed wireless access (3G or WIMAX)

In Japan and Korea the DSL penetration decreases because of swap to FTTH

FTTx completely dominated by a few national operators in Japan and Korea

China not an OECD member and therefore not included here

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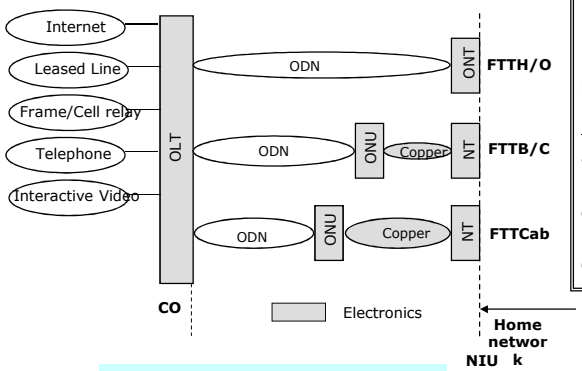
www.oecd.org/sti/ict/broadband

Fiber To The X (FTTx)



Why fiber access?

- Fiber is a "future proof" infrastructure
- Low attenuation → long distances
- High capacity → many broadband users

But

- Too expensive to roll out overnight
- Other access technologies will complement (especially wireless)
- In some areas FTTH is not economically viable

OLT	Optical line terminal
ONT	Optical network termination
ONU	Optical network unit
NT	Network termination

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Fiber access network architectures

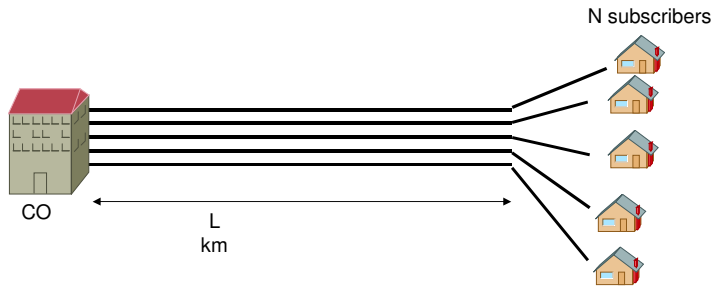
Point-to-Point

Active Optical Networks (AONs)

Passive Optical Networks (PONs)

Point-to-Point links

- Simple, standardized and mature technology



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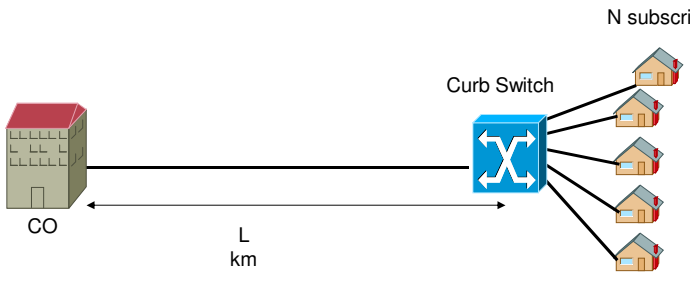
Active Optical Network (AON)

- Simple, standardized and mature technology



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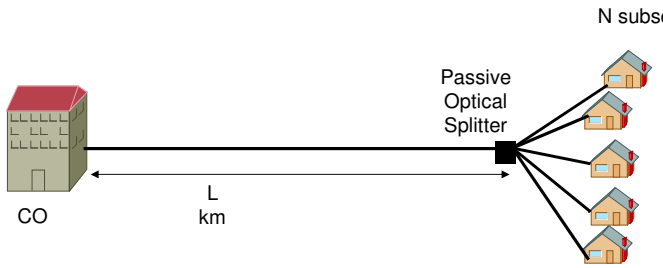
Passive Optical Network (PON)

- Simple, standardized technology
- Passive devices (splitters). No active elements in the signal's path from source to destination



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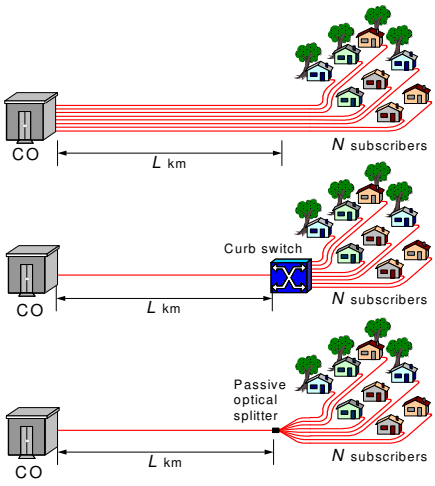
Comparison

P2P links
- *N* fiber lines
- 2*N* transceivers

Concentration switch in the neighborhood
- *1* fiber line
- *Extended reach*
- Power in the field
- 2*N* + 2 transceivers

PON – a distributed switch
- *1* fiber line
- *N* + 1 transceivers
- Path transparency



B. Mukherjee: Optical Communication Networks

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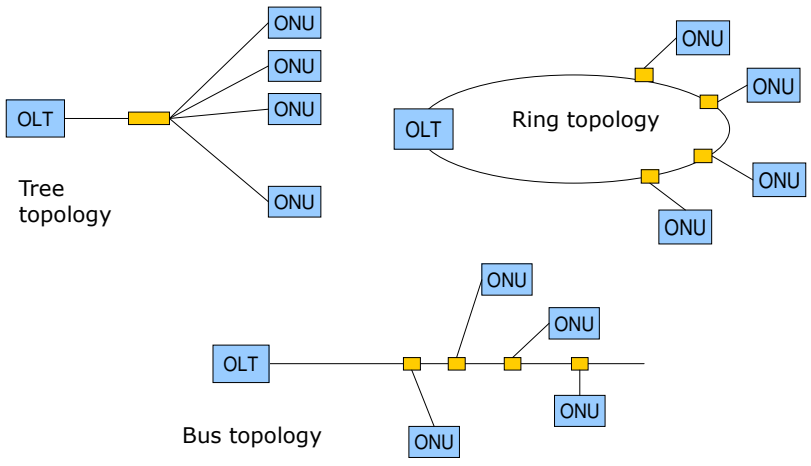
Passive Optical Networks

Basic topologies

Passive architectures

Passive Optical Networks (PONs)

Basic PON topologies



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Passive architectures

- Advantages
  - Simple
  - Easy to operate
  - Do not have any active devices in the outside plant
  - Do not need to be powered
- PON architectures
  - Time Division Multiplex PON (TDM PON)
    - Ethernet PON (EPON)
    - Gigabit PON (GPON)
  - A broadcast-and-selected WDM PON (WPON)
  - A wavelength-routing PON (WRPON)

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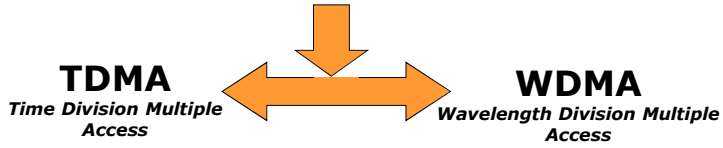
Time vs. Spectrum Sharing

- Downstream → *point-to-multipoint* network
  - The OLT manages the whole bandwidth
- Upstream → *multipoint-to-point* network
  - ONUs transmit only towards the OLT
  - ONUs cannot detect other ONUs transmissions
  - Collisions may occur ➔ Need for a channel separation mechanism in order to share resources



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Time vs. Spectrum Sharing

- **TDM-PONs: Current generation PON**
  - Standardized
  - Use few wavelengths (typically 2 or 3)
  - Low cost and mature devices (splitters, lasers, etc.)
  - Limited power budget
    - Maximum distances ≤ 20km, Split ratios ≤ 64
  - Traffic distribution
    - Broadcast scheme downstream
    - TDMA techniques upstream
  - Examples: APON/BPON, EPON & GPON
- **WDM-PONs: Next generation PON (long term)**
  - Proposed in literature and/or demonstrated
  - Introduce WDM technology and devices (AWG)
  - Long-reach and high bandwidth
  - Examples: CPON, LARNET, RITENET, Success-DWA…
- **Hybrid WDM/TDM-PONs: Next generation PON (short term)**

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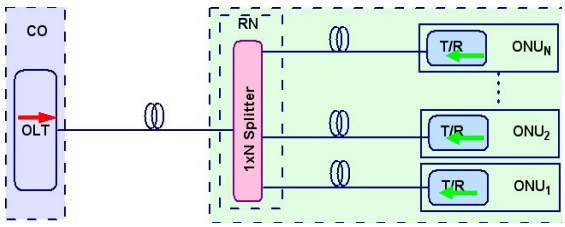
TDM PON

- **Downstream traffic** is broadcasted to all ONUs
  - Low security
  - ONUs filter data (frames) by destination address
- **Upstream traffic** is time division multiplexed at the RN
- **Upstream and downstream traffic** is sent at different wavelengths to share one fiber between OLT and RN



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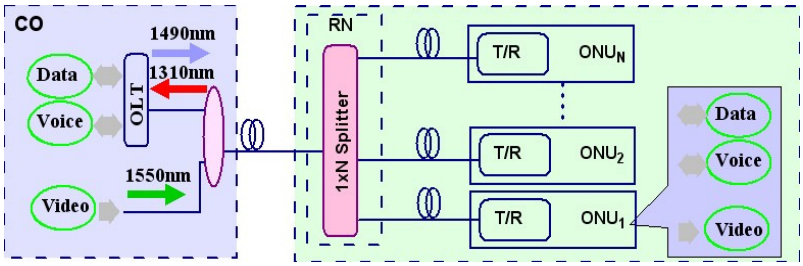
PON with analogue video overlay



- Data and voice in both directions
- Video in only one direction
- Video on dedicated wavelength all the way to ONU
- Analogue video overlay commonly used in the US in FTTx installations (temporary solution)

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Ethernet PON (EPON)

- EPON preserves 802.3 frame format
- EPON uses existing MAC
- EPON uses existing 8B/10B encoding
- EPON uses standard 802.3 line rate (1 Gbps)
- 320 million Ethernet ports deployed worldwide (~95% of all switch ports)

Focus: simplicity and integrity of Ethernet

Work is done by IEEE802.3ah task force

B. Mukherjee: Optical Communication Networks

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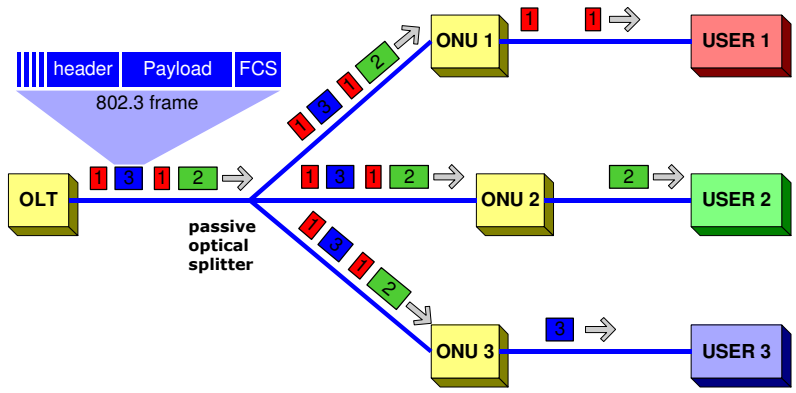
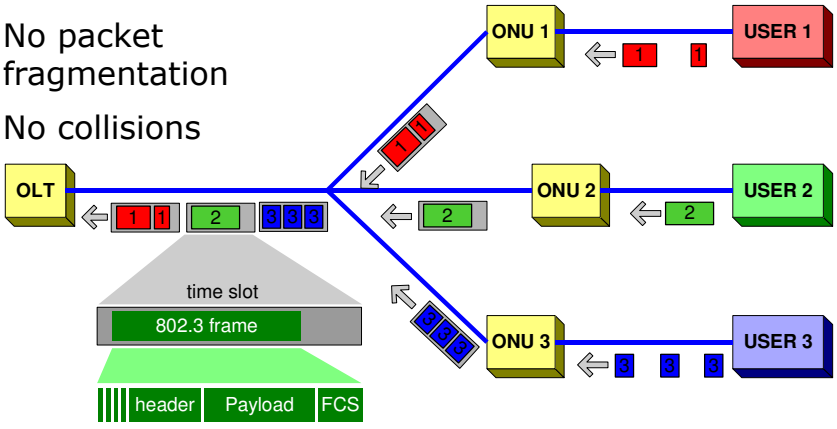
Downstream Transmission



- Downstream channel is broadcast.
- 802.3 Frames extracted by ONUs.

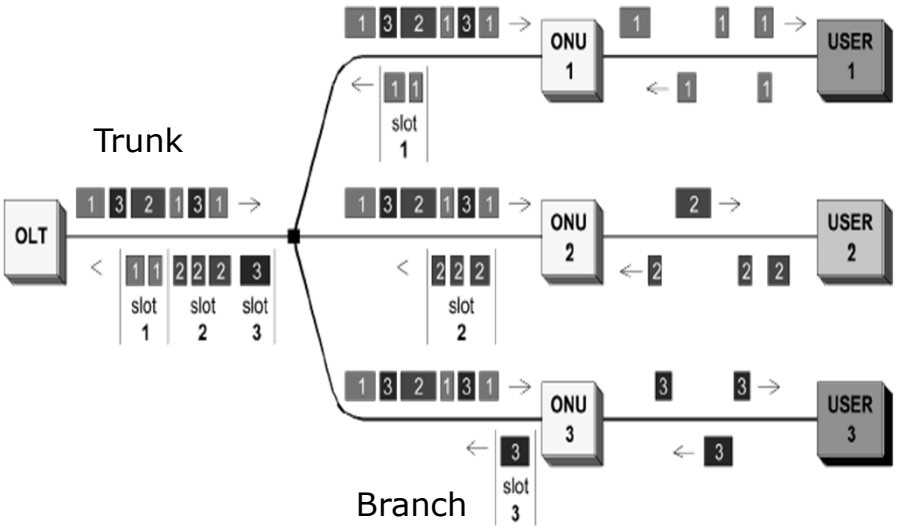
Upstream Transmission

- Upstream time slicing
- No packet fragmentation
- No collisions



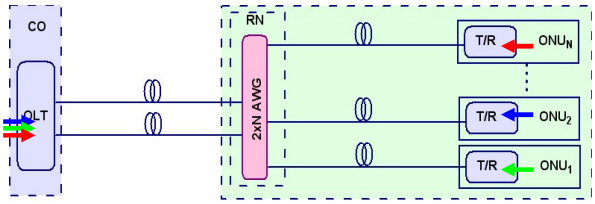
How to schedule ONUs?: static vs. dynamic bandwidth allocation

EPON Downstream and Upstream

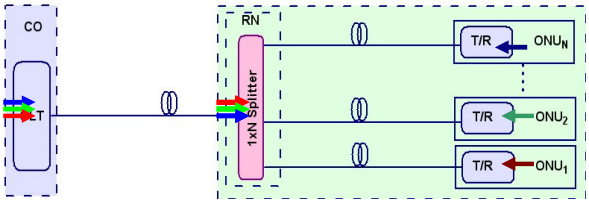


WDM PON

WRPON: Wavelength Routed PONs (incl. AWG)



WPON: WDM broadcast and select PONs



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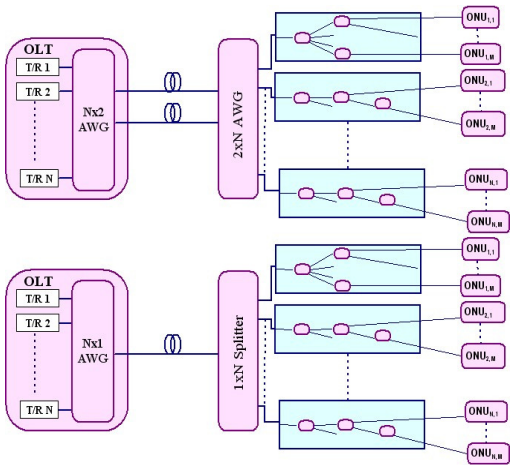
Hybrid WDM/TDM-PON



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Summary

- General information
  - Course at a glance
- Layered communications models
  - OSI and TCP/IP and optical layer
  - Multiple protocol stacks
- Fiber access networks
  - Network architectures
  - Passive Optical Networks
- Next lecture: WDM network design

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