

IO2654 Optical Networking

Spring semester 2013

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 10-11: Paolo Monti
 - F 12-13: guest lecturers from Ericsson
- Examination
 - Project (info on the web)
 - Written exam
 - Grade based on project and exam

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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-L13	Guest lectures from Ericsson

Project/homework. Deadline May 17th

Project info

- Project based on the material presented in lectures L4-L7
 - Performance evaluation/comparison of a simple provisioning scenario
 - Groups of 2 students (no exceptions)
 - Basic programming skills are required
 - Any programming language is OK (e.g., Matlab, Java, C++, etc.)
 - Project will be posted online on April 18
 - Questions session on April 30, after class?
 - Deadline for reporting on the group composition: April 12
 - Deadline: May 17

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-L13:** Guest lectures

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Course Evaluation Committee

- Three volunteers
- 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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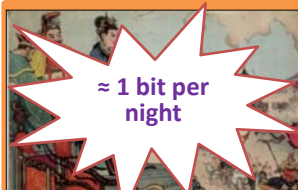
Transmission of optical signals

Ancient time (BC)

18th Century

21st Century ~ Now

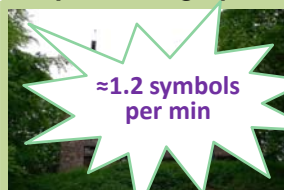
Smoke signals



≈ 1 bit per night

▸ 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

Optical telegraph



≈ 1.2 symbols per min

▸ The line between Paris and Lille (230km) transferred a complete message, consisting of 36 symbols, in about 32 minutes.

Fiber communication



>>1 terabit/s

▸ 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

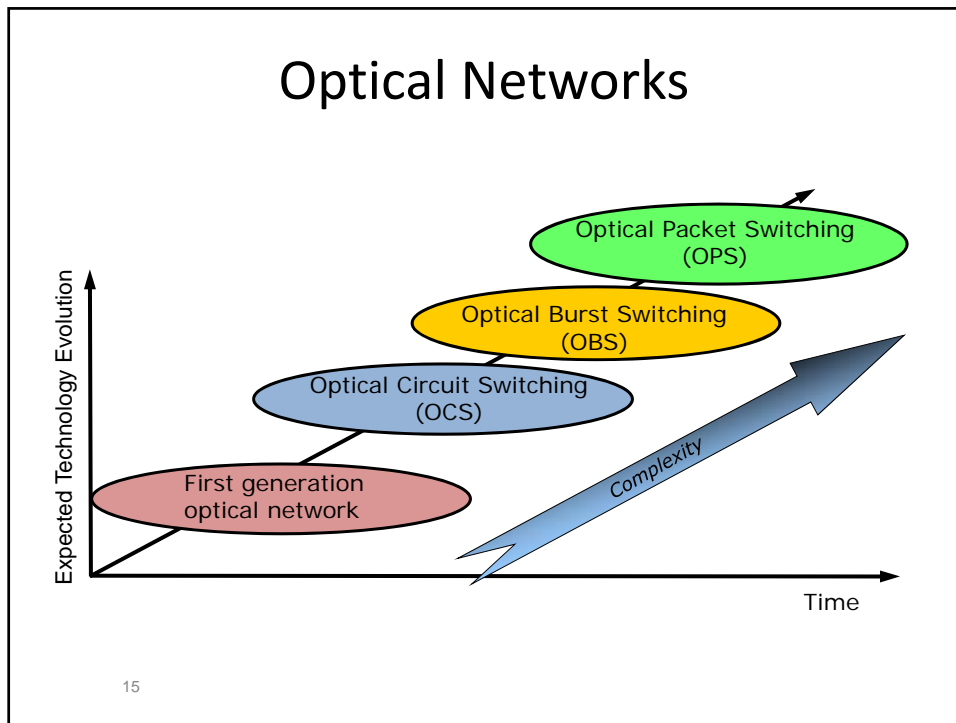
- Fantastic for transmission
 - Optical amplifier can simultaneously amplify all of the signals on all (~160) wavelength channels on a single fiber
- Huge bandwidth: 50 Tbps on a single fiber
 - Compare it to electronic data rates of few Gbps
- Low signal attenuation
- Low signal distortion
- Low power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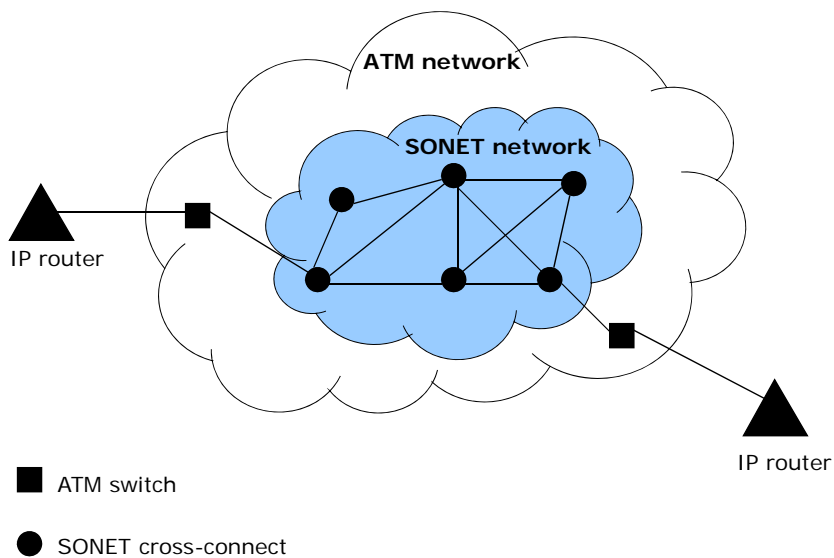
Layered models

Mapping between the layers

OSI	TCP/IP
Application	
Presentation	Application
Session	
Transport	Transport
Network	Internet
Data link	Network access
Physical	Physical

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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

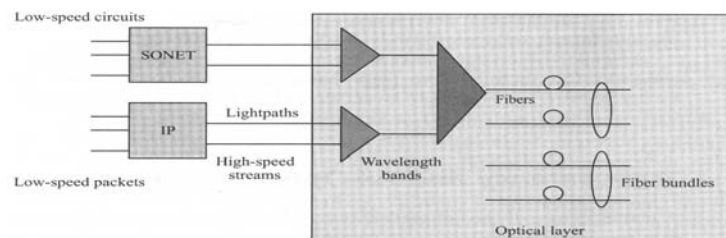


Figure 1.11 Example of a typical multiplexing layered hierarchy.

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

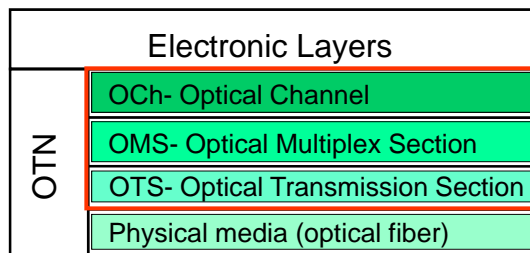
- Multiplexing wavelengths
- Switching and routing wavelengths
- Monitoring network performance at various locations in the network

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Layers within the optical layer

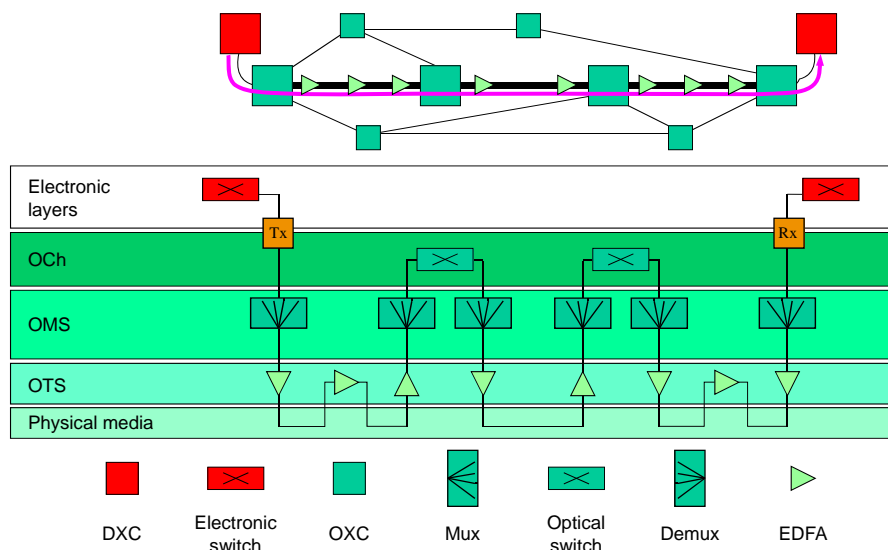
Optical Transport Network protocol layers

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

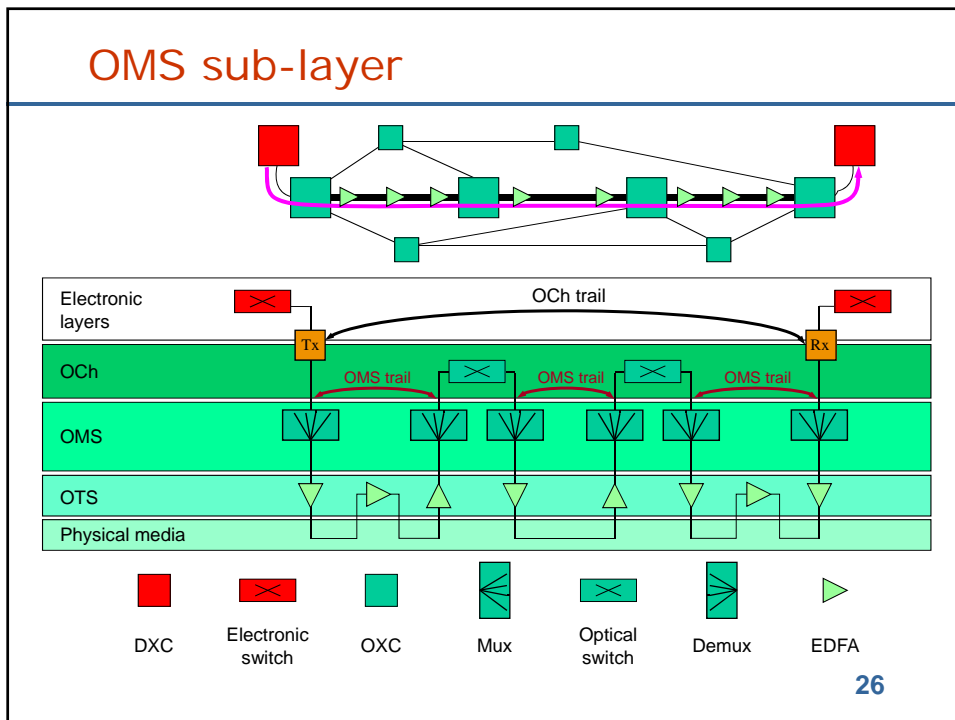
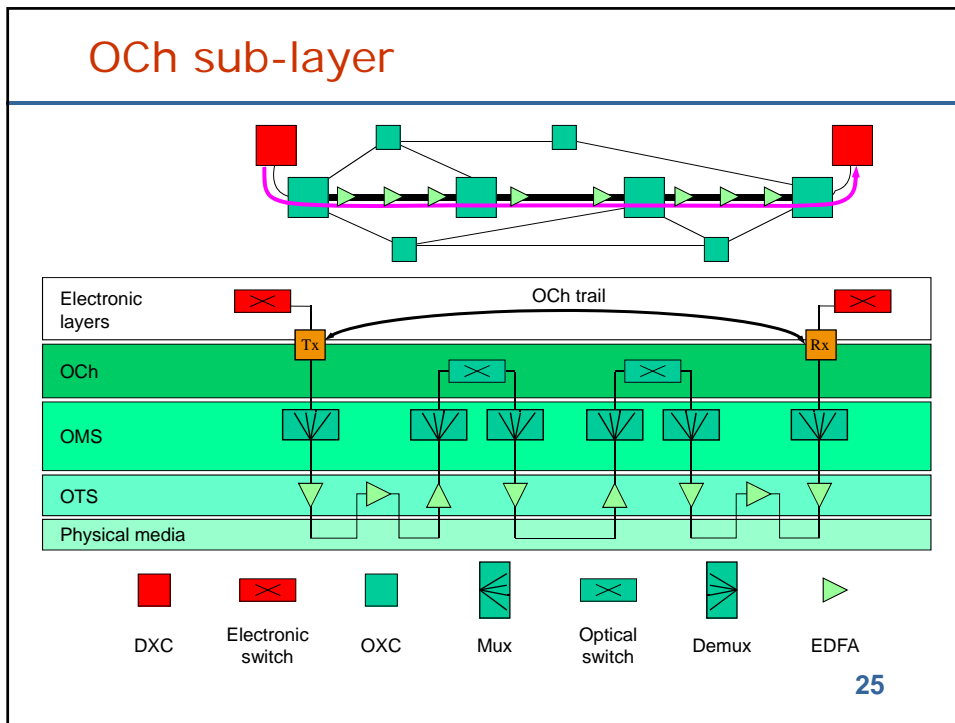


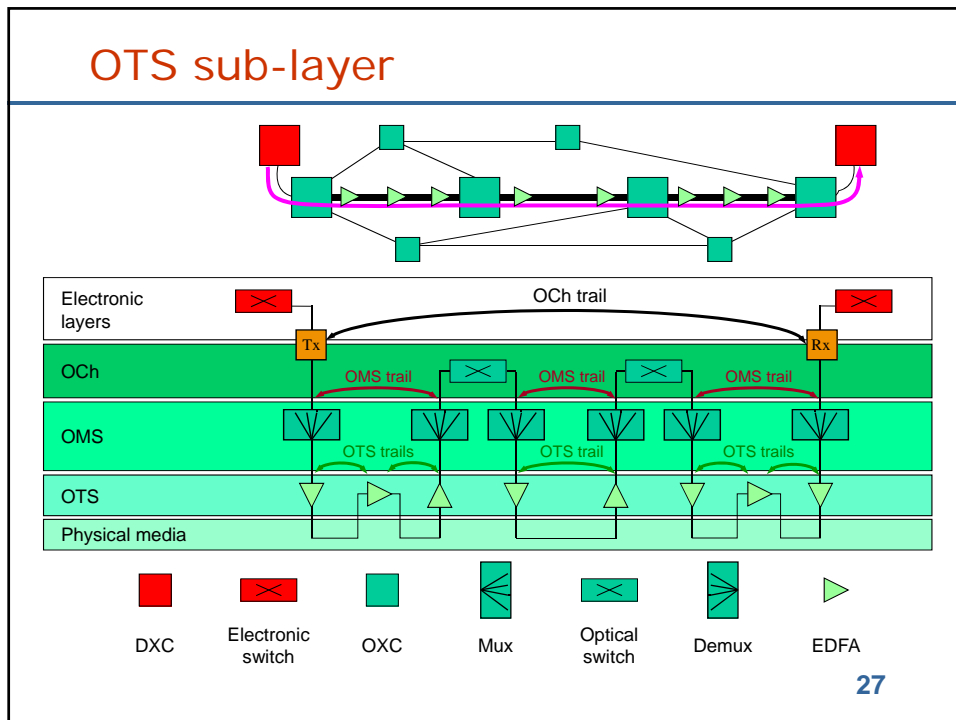
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Simplified view of an optical connection



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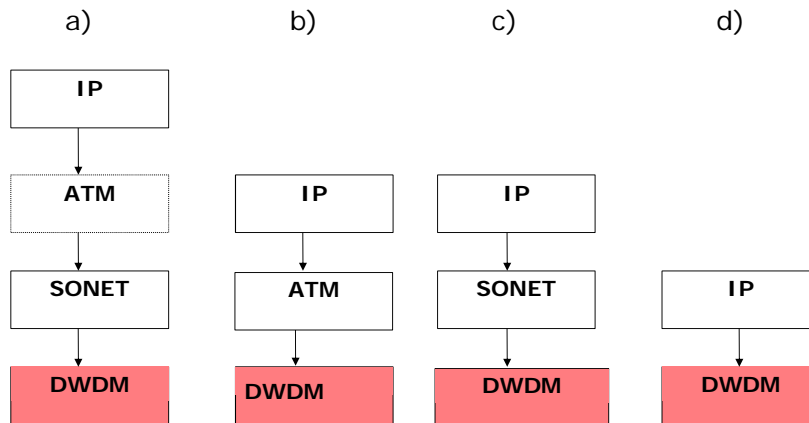




- ### Client layers of the optical layer
- SONET/SDH
 - ATM (Asynchronous Transfer Mode)
 - IP
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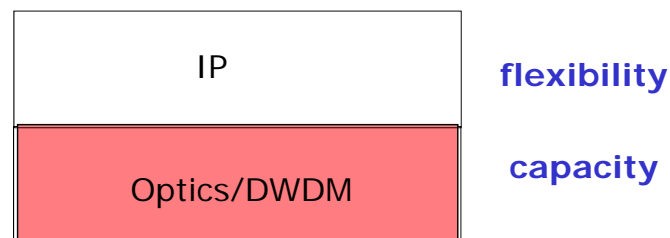
IP over WDM mappings

Towards a two layer network architecture



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A perfect combination

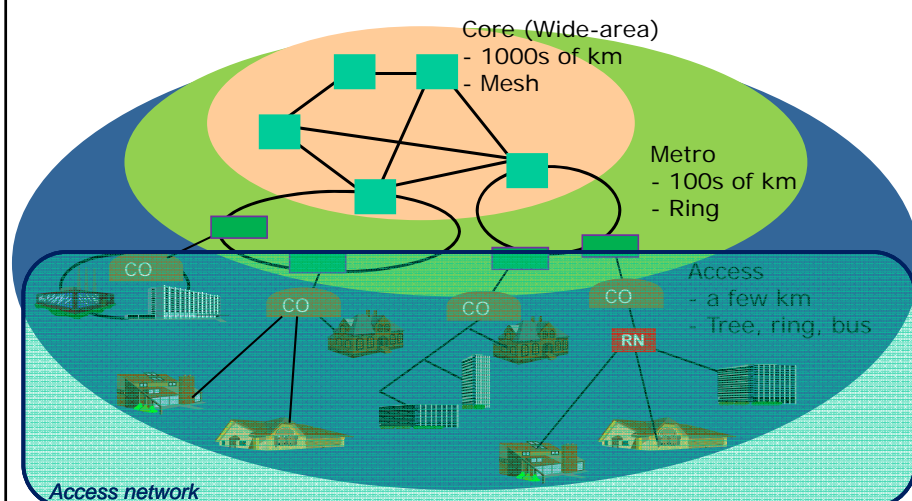


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Broadband access networks

- Introduction
- Overview of broadband access technologies
- Evolution of fiber access networks
- Fiber access network architectures
- Passive Optical Network (PON)

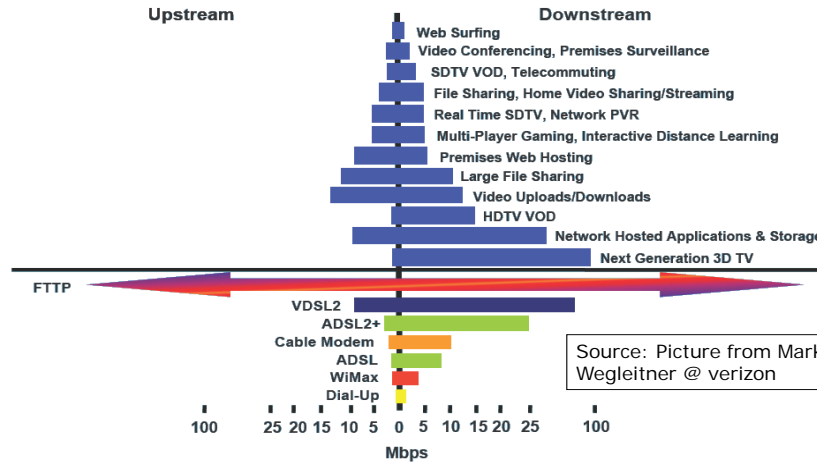
Telecom Network Hierarchy



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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
 - Gaming
 - Telemedicine
 - E-Government
 - etc

} "Triple play"

Traffic increases very rapidly

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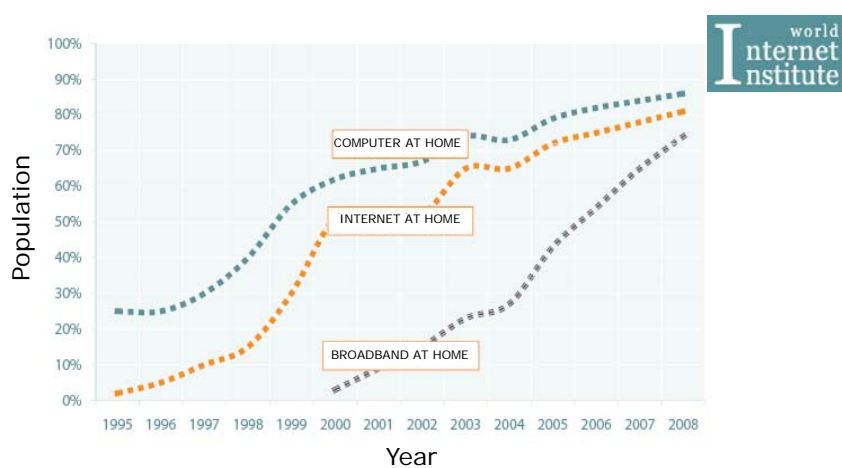
Triple play capacity requirements

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

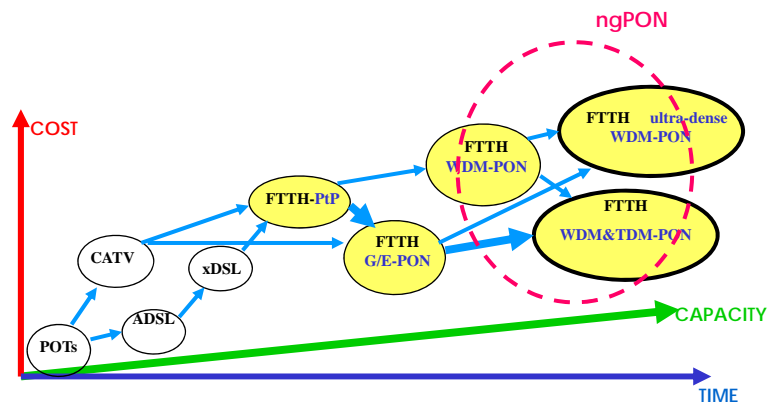
Access based on:	Capacity/user	Max Reach
ADSL	2 Mb/s (typical)	5.5 km
VDSL	20 Mb/s (typical)	1 km
Coax	2 Mb/s *	0.5 km
Wi-Fi	54 Mb/s (max)	0.1 km
WiMax	28 Mb/s (max)	15 km
EPON	60 Mb/s *	20 km
GPON	40 Mb/s *	20 km

} FTTx

* Bandwidth depends on the number of users

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Access network evolution

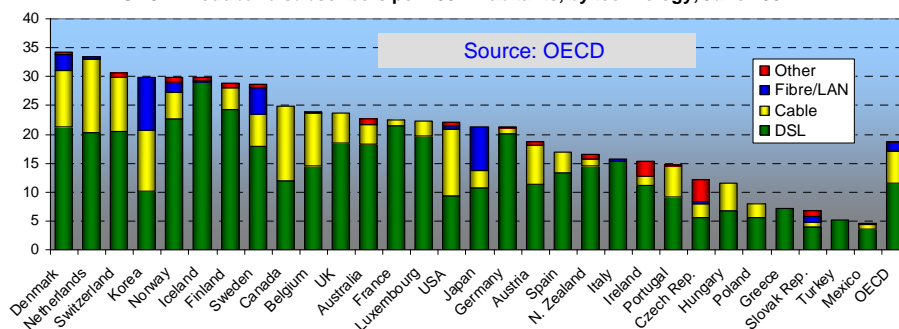


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OECD broadband statistics

www.oecd.org/sti/ict/broadband

OECD Broadband subscribers per 100 inhabitants, by technology, June 2007



Source: OECD

"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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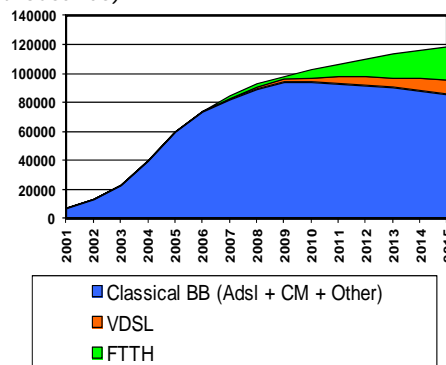
www.oecd.org/sti/ict/broadband

FTTH growth prediction

- IDATE predicts a drop in active ADSL in Europe from 2010 (in Japan happened in 2006)
- In 2016 FTTH users are estimated to grow to 30% of the total broadband lines.

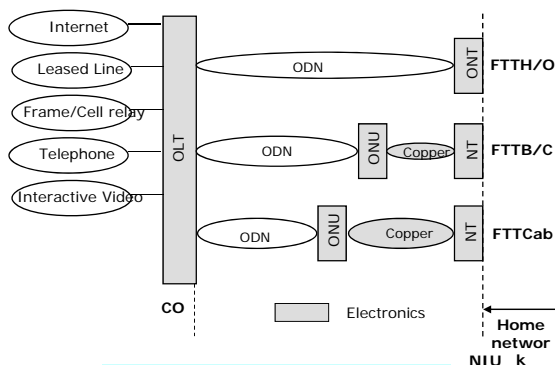
(Ref: IDATE February 2007)

Forecasts for Europe (subscribers in thousands)



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Fiber To The X (FTTx)



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

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

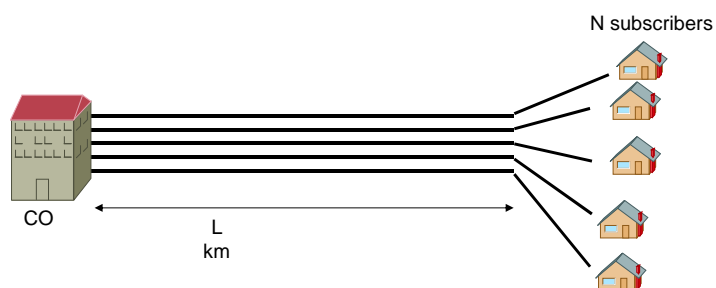
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Fiber access network architectures

Point-to-Point
Active Optical Networks (AONs)
Passive Optical Networks (PONs)

Point-to-Point links

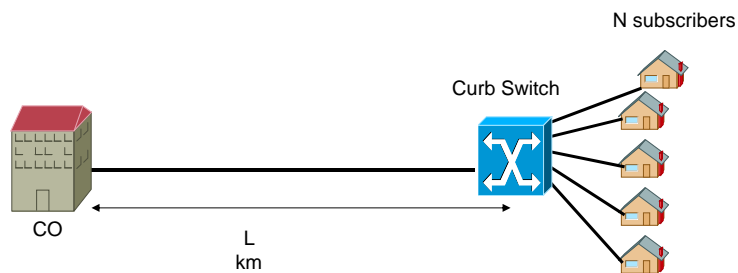
- Simple, standardized and mature technology



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Active Optical Network (AON)

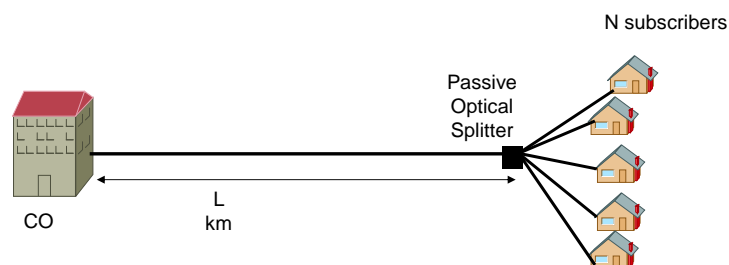
- Simple, standardized and mature technology



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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

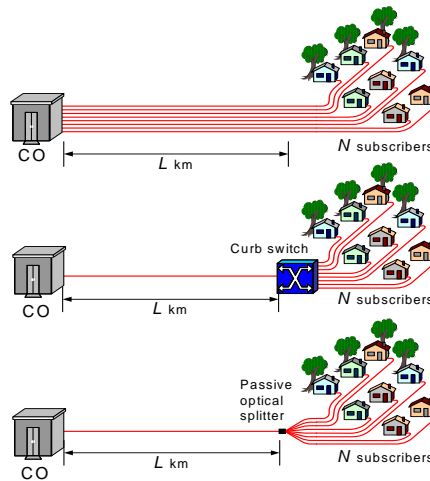
- ☞ N fiber lines
- ☞ $2N$ transceivers

Concentration switch in the neighborhood

- ☞ 1 fiber line
- ☞ *Extended reach*
- ☞ Power in the field
- ☞ $2N + 2$ transceivers

PON – a distributed switch

- ☞ 1 fiber line
- ☞ $N + 1$ transceivers
- ☞ Path transparency



B. Mukherjee: Optical Communication Networks

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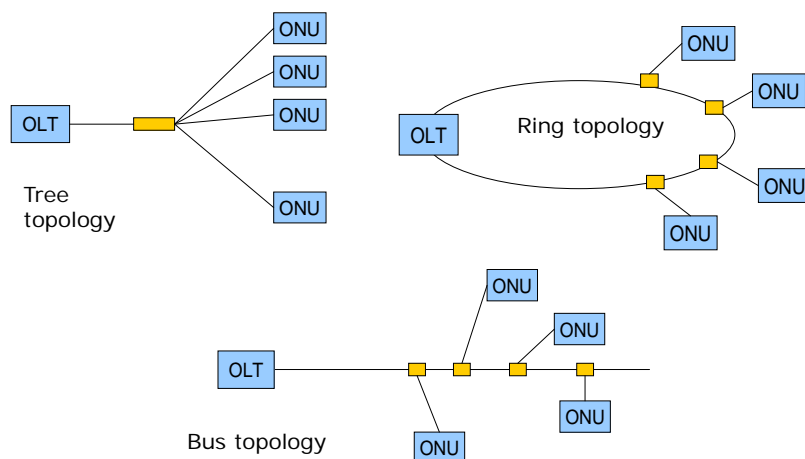
Passive Optical Networks

Basic topologies

Passive architectures

Passive Optical Networks (PONs)

Basic PON topologies



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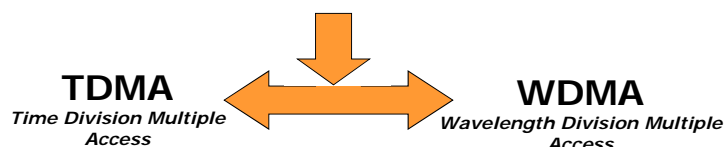
Passive architectures

- 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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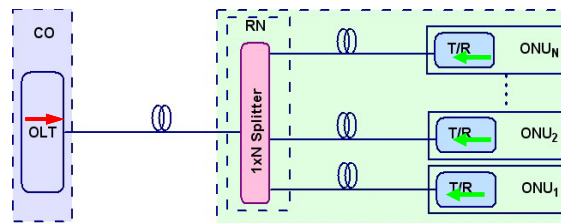
Time vs. Spectrum Sharing

- **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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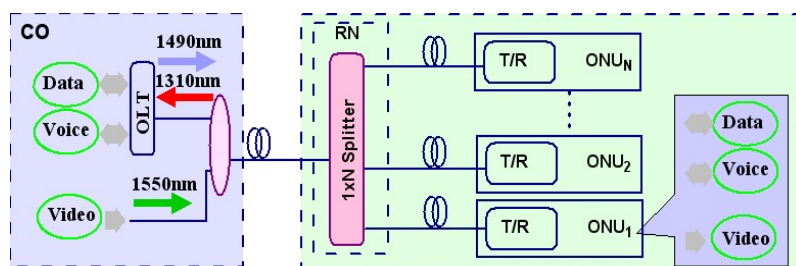
TDM PON

- **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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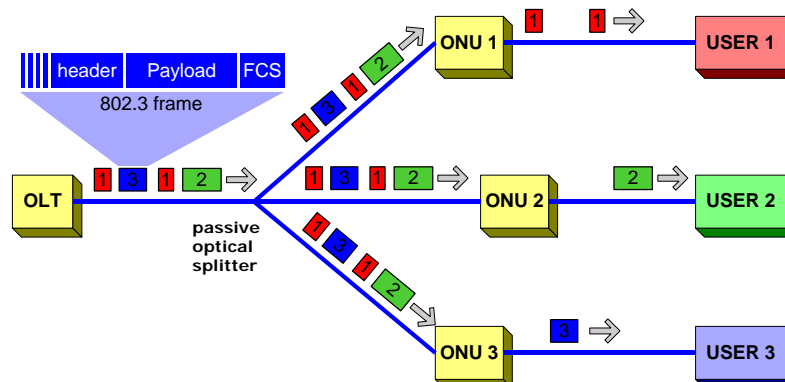
Ethernet PON (EPON)

- 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

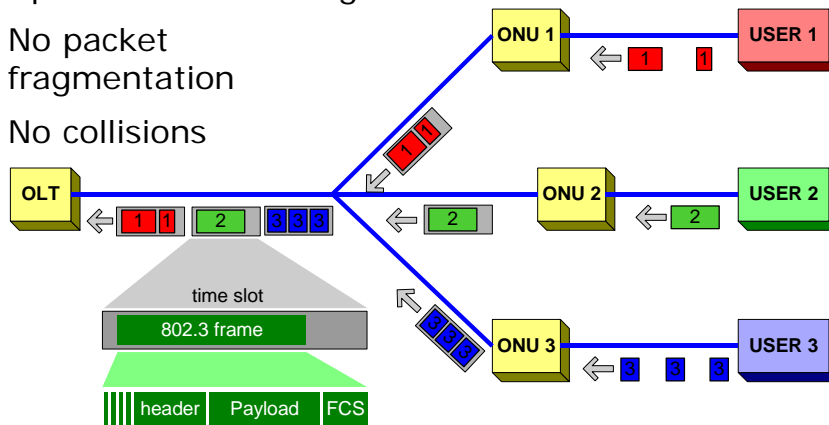
Downstream Transmission



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

Upstream Transmission

- Upstream time slicing
- No packet fragmentation
- No collisions



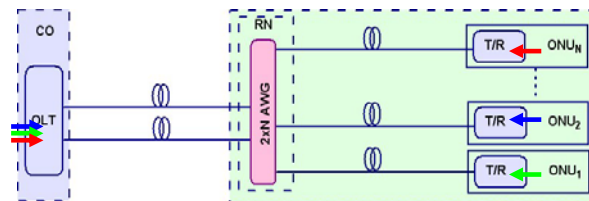
How to schedule ONUs?: static vs. dynamic bandwidth allocation

B. Mukherjee: Optical Communication Networks

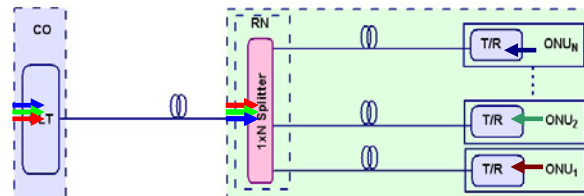
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WDM PON

WRPON: Wavelength Routed PONs (incl. AWG)

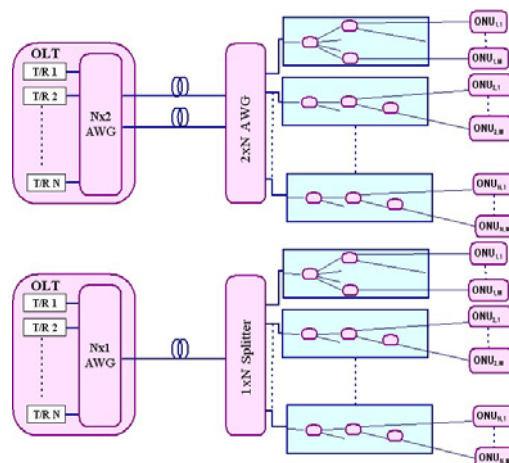


WPON: WDM broadcast and select PONs



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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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