



SAPIENZA  
UNIVERSITÀ DI ROMA

# Network Infrastructures

A.A. 2020-2021  
Prof. Francesca Cuomo

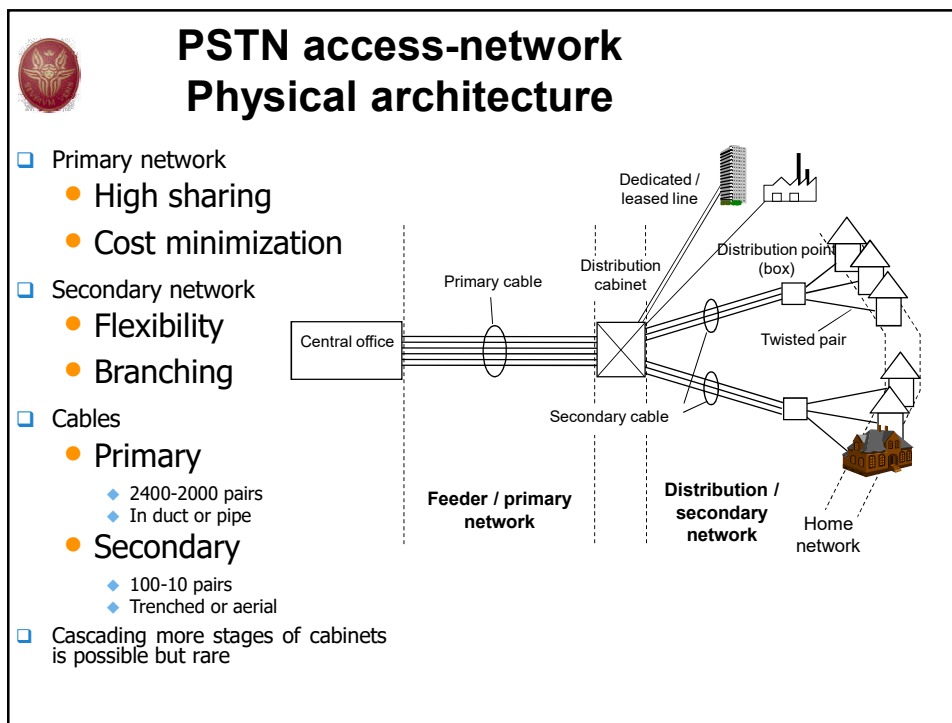
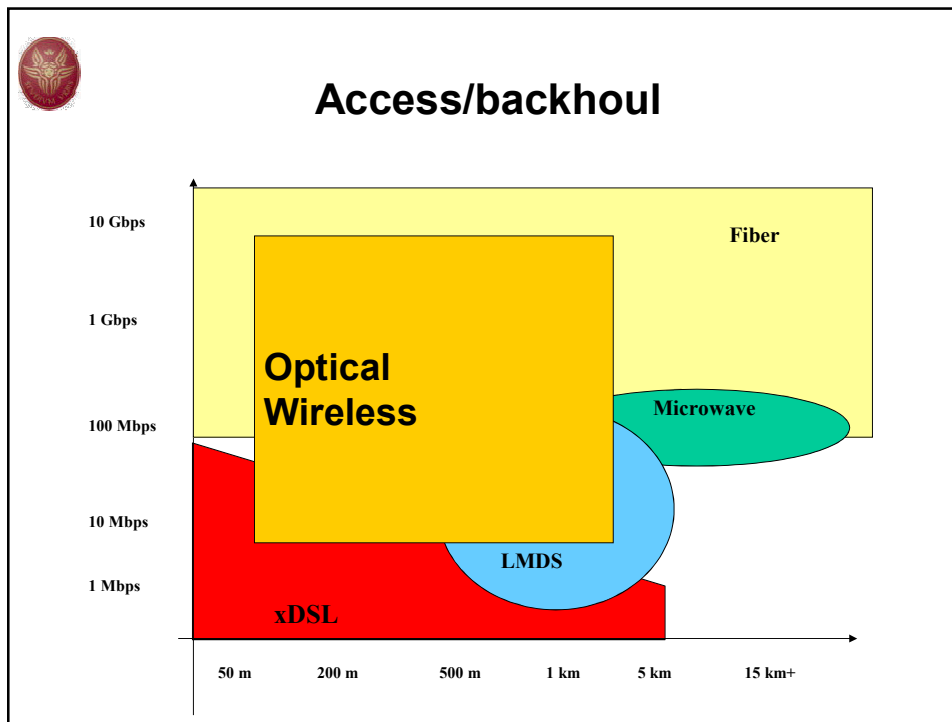


## Outline

- Why FTTx
- How FTTx: PON
- Principles of Optical Fibre Systems
- PON characteristics (APON, BPON, EPON, GPON)
- Future: WDM PON
- Application
- Market (cost, unbundling)

Part of these slides are taken from:  
Towards Fiber to the X (FTTx): Passive Optical Networks,  
Francesco Matera Responsabile Area Tecnologie Reti di Nuova Generazione  
[mat@fub.it](mailto:mat@fub.it) ; +39 06 5480 2215

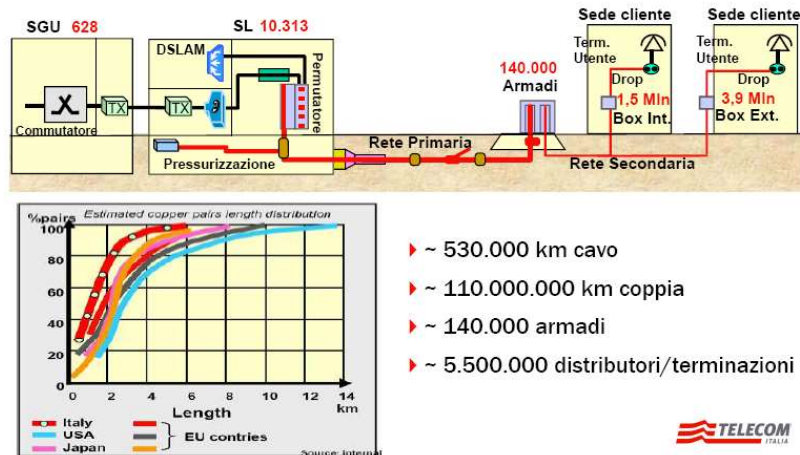
Main source: Project EU E-Photon/One+, Lessons from Prof. A. Pattavina, G. Maier, Politecnico di Milano





## Telecom access networks

### La rete accesso in rame oggi

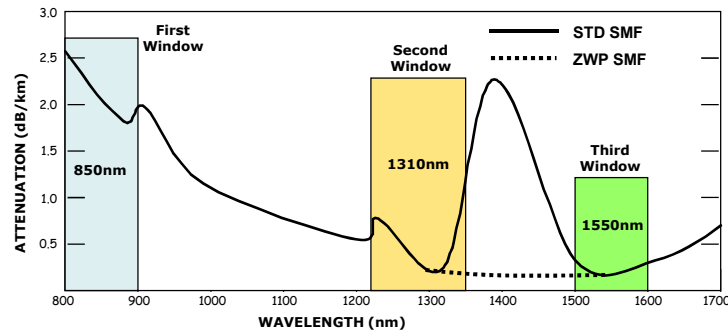


TELECOM ITALIA



## Optical Fiber: Attenuation

- Single Mode Fiber (SMF) to achieve large distances
  - ITU G.652 SMF (STD)**
    - "water peak" attenuation renders the 1360nm–1480nm spectrum unusable for data transmission
  - ITU G652c/d SMF (ZWP)**
    - "zero-water peak"

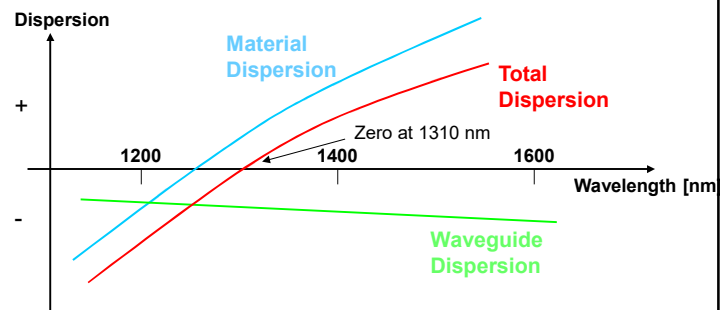
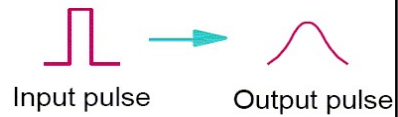
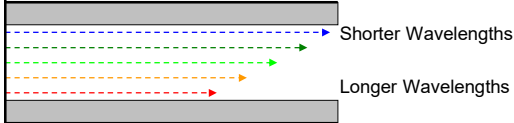




## Optical Fiber: Chromatic Dispersion

- Causes signal pulse broadening

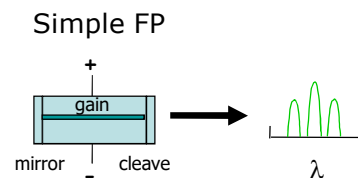
Single-mode optical fiber



## Lasers Diodes (LD)

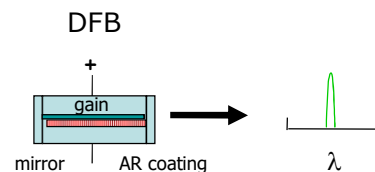
- Fabry-Perot (FP)

- Cheap
- Noisy
  - Sensitive to chromatic dispersion
- Used on 1310 nm



- Distributed Feedback (DFB)

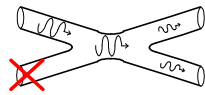
- More expensive
- Narrow spectral width
  - Less sensitive to chromatic dispersion
- Used on 1550 nm (or 1310 nm)



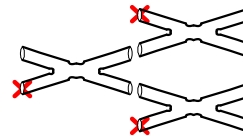


## Passive Splitters

### 1x2 Splitter



### 1xN Splitter



- The basic element consists of two fibers fused together
- Every time the signal is split two ways, the signal is reduced by  $10\log(0.5)=3\text{dB}$ 
  - Loss  $\sim 3\text{dB} \times \log_2(\#\text{ONUs})$

	Conventional	Low-loss
Splitter 1x2	3.7dB	3.4dB



## Photodiodes (PD)

### PIN Photodiodes

- Good optical sensitivity ( $\sim -22\text{ dBm}$ )
- Silicon for shorter  $\lambda$ 's (eg 850nm)
- InGaAs for longer  $\lambda$ 's (eg 1310/1550nm)

### Avalanche Photodiodes (APDs)

- Higher sensitivity ( $\sim -30\text{ dBm}$ )
- Primarily for extended distances in Gb/s rates
- Much higher cost than PIN diodes



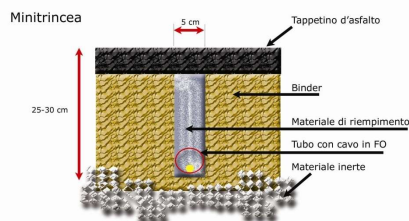
## Transceiver Assumptions

	TX Power	RX Sensitivity
ONU (FP+PIN)	0 dBm	-22 dBm
OLT (DFB+APD)	1 dBm	-30 dBm

- **Upstream (@1310nm) Power Budget = 30 dB**
- **Downstream (@1490nm) Power Budget = 22 dB**



## Fiber installation

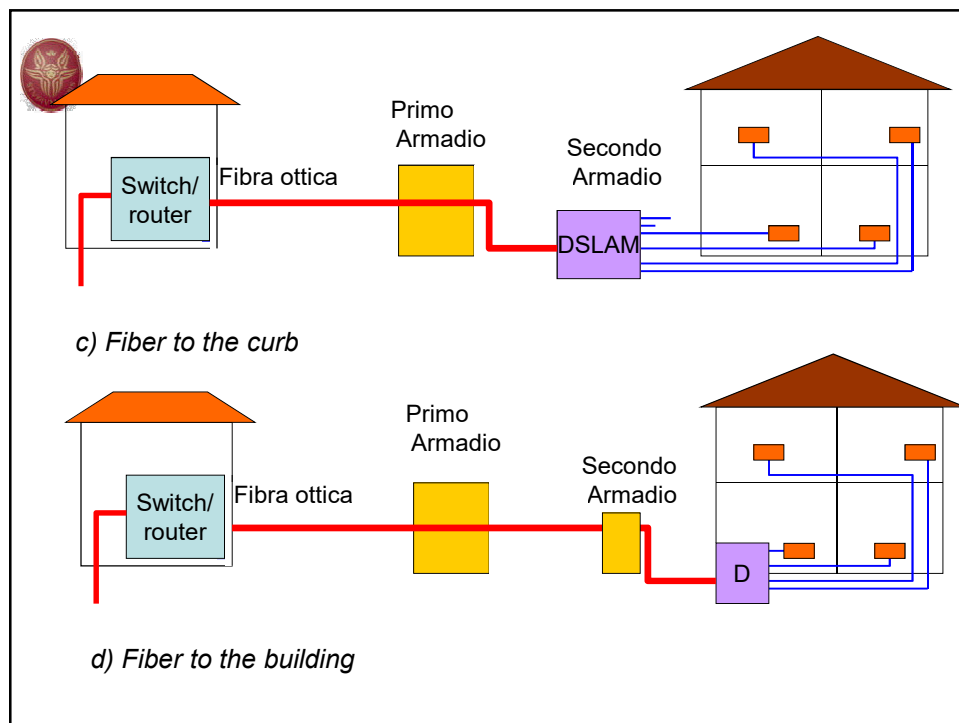
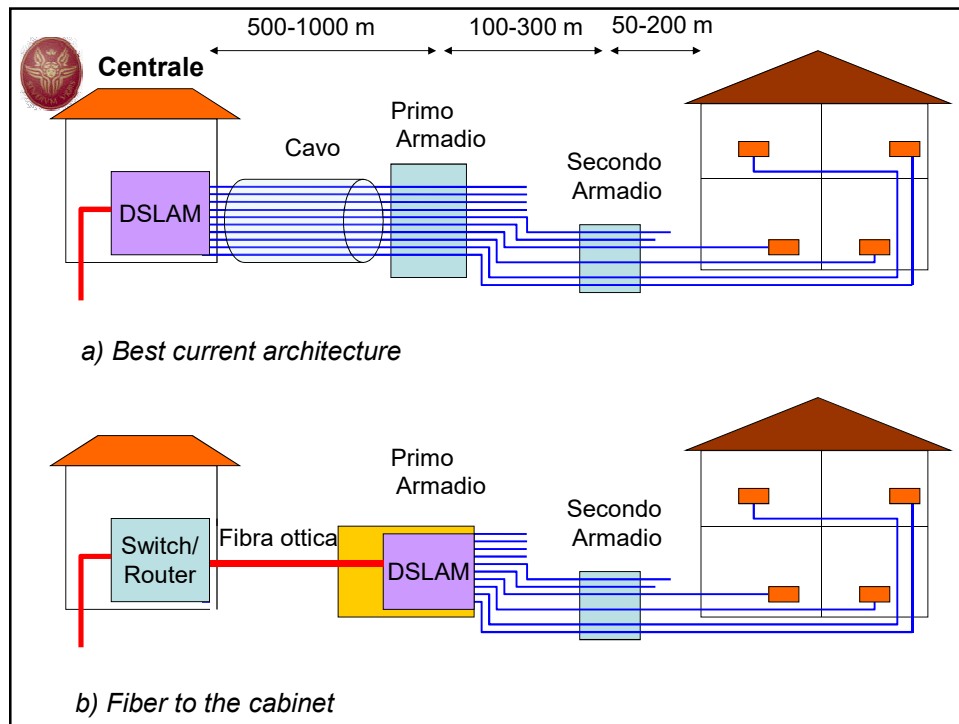


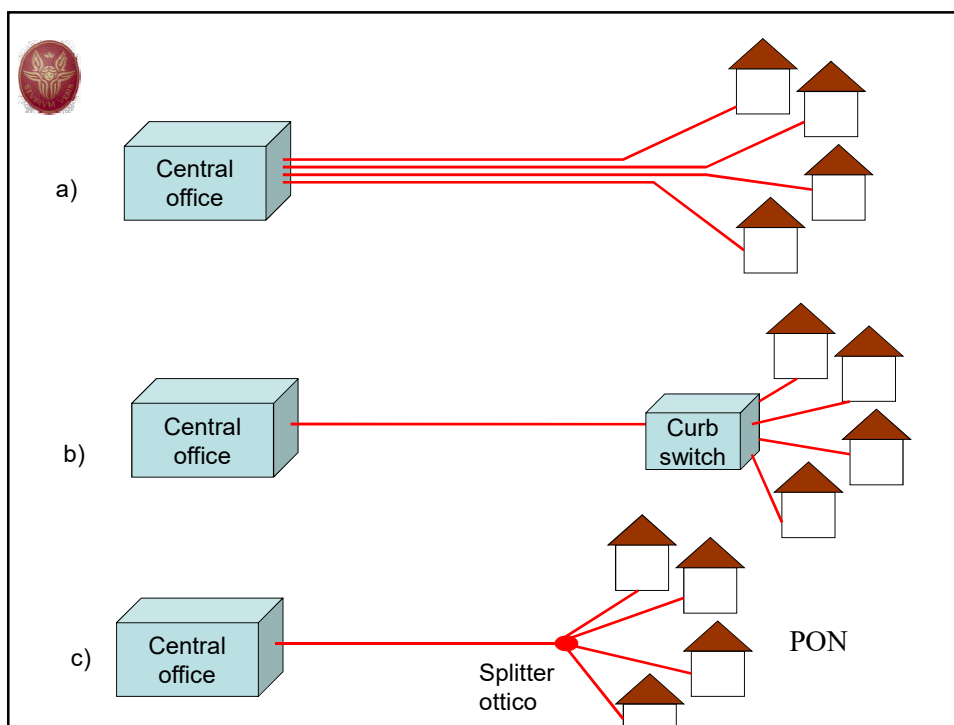
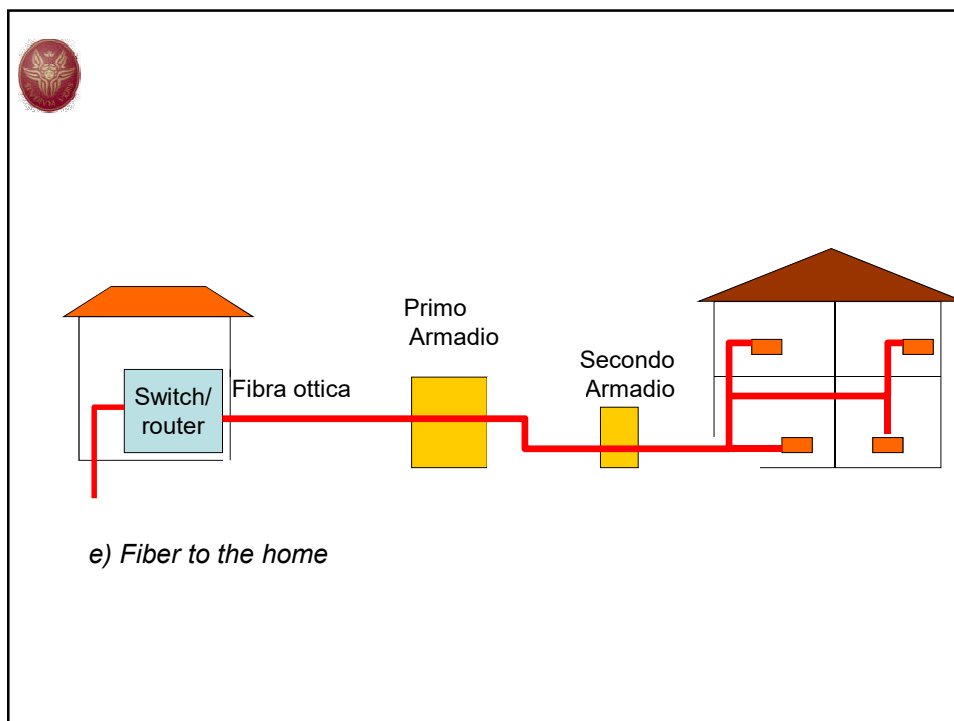
La microtrincea come semplice ed economica soluzione per la diffusione della fibra ottica nella rete di accesso (from HighBand)



Soffiaggio della fibra (ERICSSON)

30-40 K €/km per microtrincea

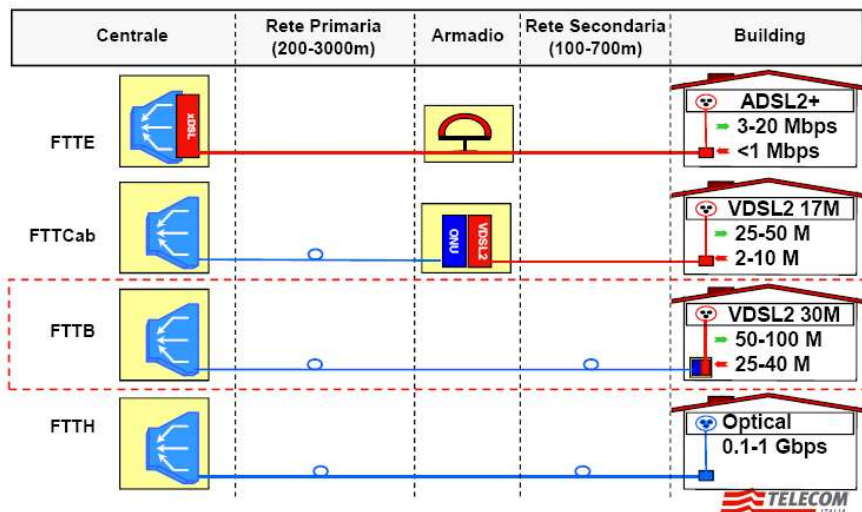






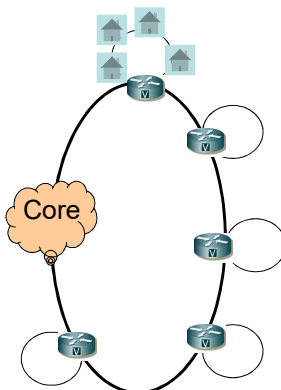


## Access capacities



## GbE based: FASTWEB

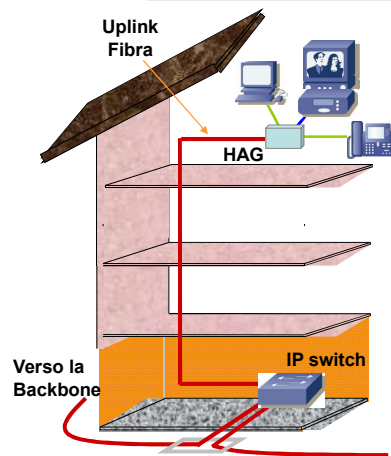
Daisy chain architecture



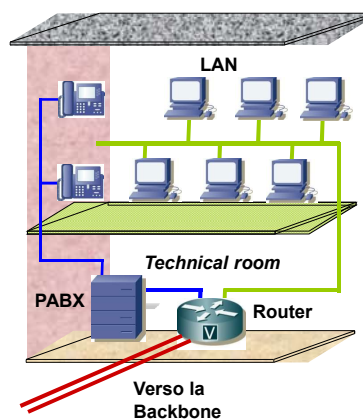


## First case in Europe: Fastweb 2000

### FTTH: Accesso Residenziale



### FTTB: Accesso Business



**FASTWEB**



## FTTx = Fiber-to-the-x

- ☐ FTTH - Home
- ☐ FTTC - Curb
- ☐ FTTN - Node or Neighborhood
- ☐ FTTP - Premise
- ☐ FTTB - Building or Business
- ☐ FTТУ - User
- ☐ FTTZ - Zone
- ☐ FTTO - Office
- ☐ FTTD - Desk



## Basic PON operations

- The optical line terminal (OLT) broadcasts data downstream on 1,510 nm and the ONTs burst data back upstream on 1,310 nm in their assigned time slots.

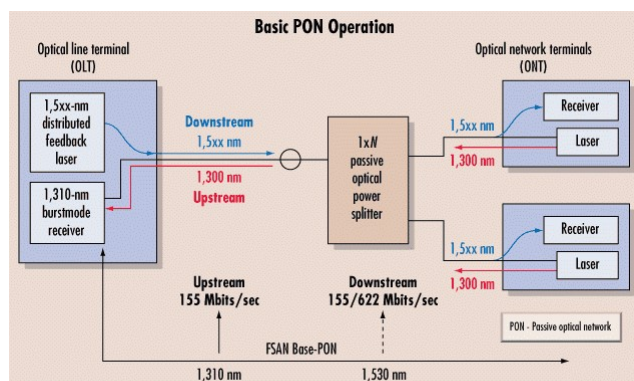
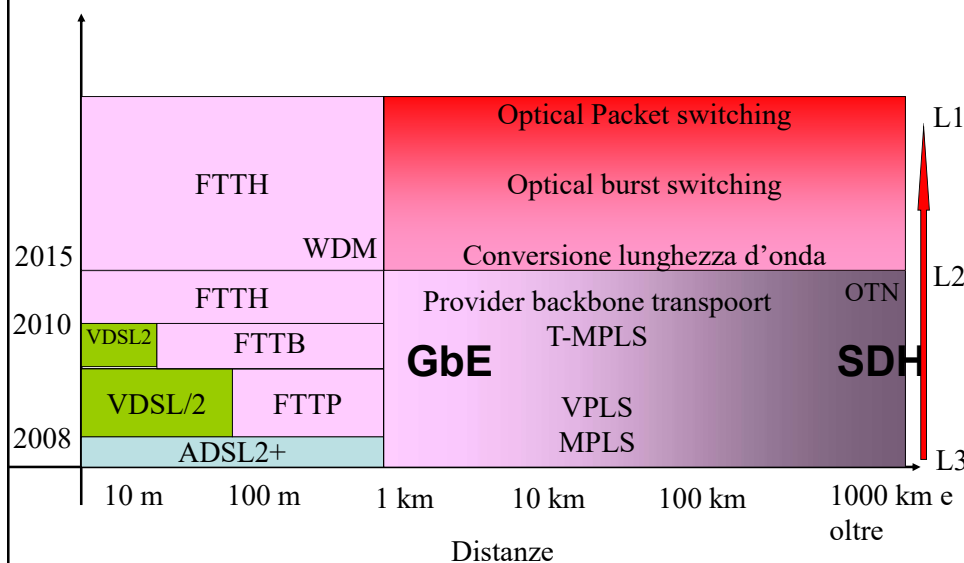


Figure 1. A basic passive-optical-network operation enables service to as many as 32 optical-network terminals (ONTs). Each ONT, in turn, can be connected to multiple subscribers, making fiber more affordable for access networks.



## Photonics Evolution

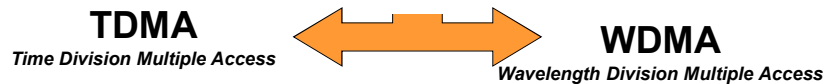




## Time vs. Spectrum Sharing

- 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
  - Data transmitted by ONUs may collide

Need of a channel separation mechanism to fairly share bandwidth resources



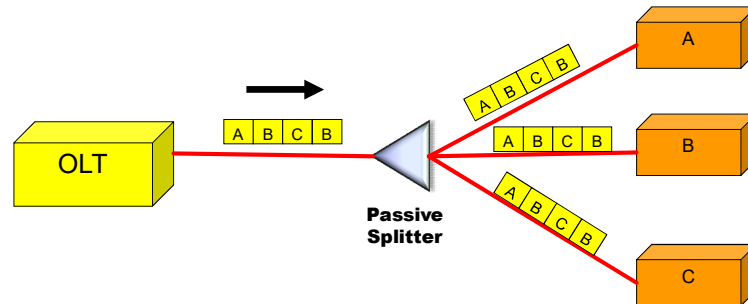
## PON Overview

- **TDM-PONs**
  - Standardized
  - Use few wavelengths (typically 2 or 3)
  - Low cost and mature devices (splitters, lasers, etc.)
  - Limited power budget
    - ◆ Maximum distances  $\leq 20\text{km}$ , Split ratios  $\leq 64$
  - Traffic distribution
    - ◆ Broadcast scheme in downstream
    - ◆ TDMA techniques in upstream
  - Examples: APON/BPON, EPON & GPON
- **WDM-PONs**
  - Proposed in literature and/or demonstrated
  - Introduce WDM techniques and devices (AWG)
  - Long-reach and bandwidth
  - Examples: CPON, LARNET, RITENET, Success-DWA...



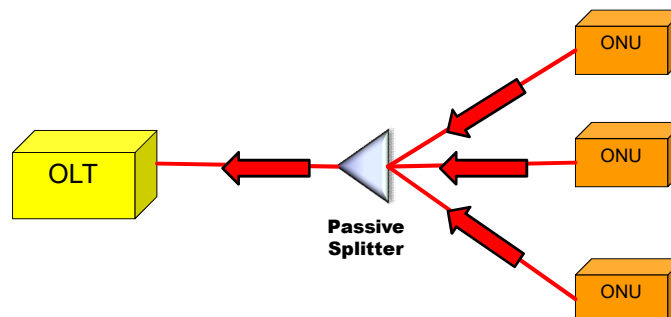
## Downstream Traffic Scheduling

- OLT schedules traffic inside timeslots
  - Time Division Multiplexing (TDM) scheme
- Time slots can vary from  $\sim\mu\text{s}$  to  $\sim\text{ms}$



## Upstream Traffic

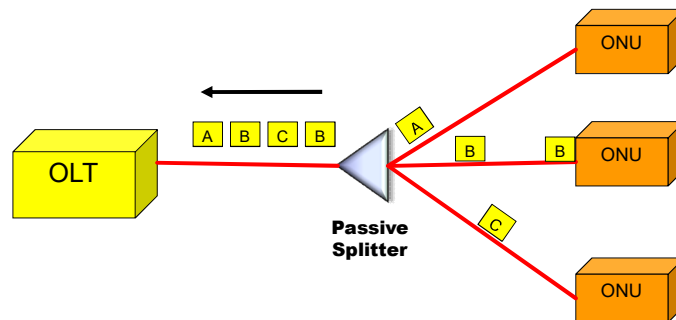
- All ONUs share the same upstream channel
  - ONUs cannot exchange data directly
  - Collisions may occur at the splitter/combiner





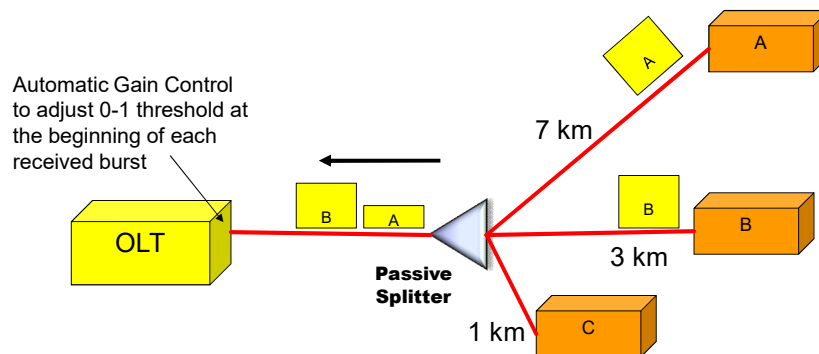
## Upstream Traffic Scheduling 2/4

- In general, PON standards propose Time Division Multiplexing Access (TDMA) schemes
  - Upstream time slicing and assignment



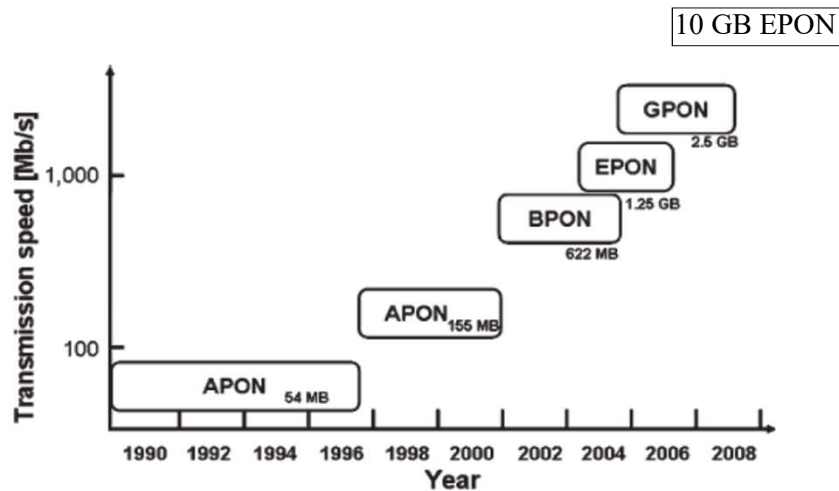
## Upstream Frame Reception

- The OLT receives frames with different powers
  - Much difficult to recover synchronism (clock and data recovery)
  - Burst Mode Receiver (complex) @ OLT
    - Sets 0-1 threshold on a burst basis





## Evolution of the standards



## Fiber in the loop PON standardization: a brief history

- ATM PON (A-PON)
  - Traffic is carried using ATM raw-cell format and framing
  - 1982: idea of PON (British Telecom)
  - 1987 – 1999: PON testbeds by BT, Deutsche Telekom (Eastern Germany), NTT (Japan), BellSouth (Atlanta, USA)
  - 1995: 622 Mbit/s APON testbed (RACE BAF project)
  - 1996: beginning of Full Service Access Network (FSAN) works
  - 1997-'98: ACTS BONAPARTE and EXPERT/VIKING projects
- Broadband PON (B-PON)
  - APON system is standardized by ITU-T with a new name to indicate that the PON can offer full broadband service and not just ATM
  - Line rates: 155 Mbit/s symmetrical or 622/155 Mbit/s down/upstream; ONU/OLT max distance: 20 km; max. # ONUs: 64
  - 1998-'00: ITU-T G.983.1 (physical aspects) and G.983.2 (ONT management and control)
  - 2001-'02: other ITU-T G.983.x and Q.834.x, e.g.
    - ◆ G.983.4/7: Dynamic Bandwidth Assignment (DBA), providing statistical multiplexing (⇒ more users per ONU) and Quality of Service (QoS) enforcement
    - ◆ G.983.3: adoption of WDM to increase capacity or to carry video signals



## Fiber in the loop

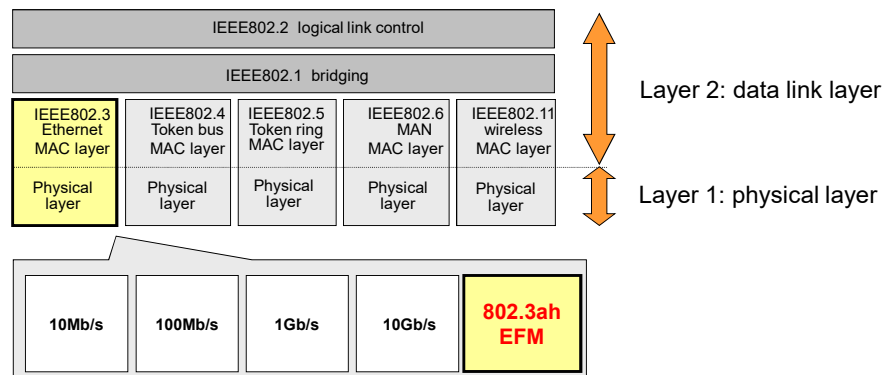
### PON standardization: a brief history

- Ethernet PON (EPON)
  - Traffic is carried using Ethernet framing
    - ◆ Cheaper user equipment than BPON
    - ◆ Ethernet much more widespread than ATM
  - Higher subscriber rates (up to 1.25 GbE symmetrical), **16 ONU** (power budget)
  - 2001: IEEE 802.3ah Study Group "Ethernet in the First Mile (EFM)"
  - First documents in Sept. 2003)
  - 2004: final approval of **Standard IEEE 802.3ah**
- Gigabit-capable PON (G-PON)
  - Traffic is carried by using different possible framings: ATM (G.983 base) or via G-PON Encapsulation Method (GEM), which can interface SDH (G.707 base) or Ethernet (IEEE802.3 base).
  - Various line rates, up to 2.4 Gbit/s symmetrical, ONU/OLT max distance: 20 km; max. # ONUs: **64-128**
  - 2001: activity initiated by the FSAN group
  - 2003: ITU-T G.984.x



## Ethernet Standards in EPONs

- EPON started to be standardized by IEEE 802.3ah EFM since 2001, it was ratified in 2004





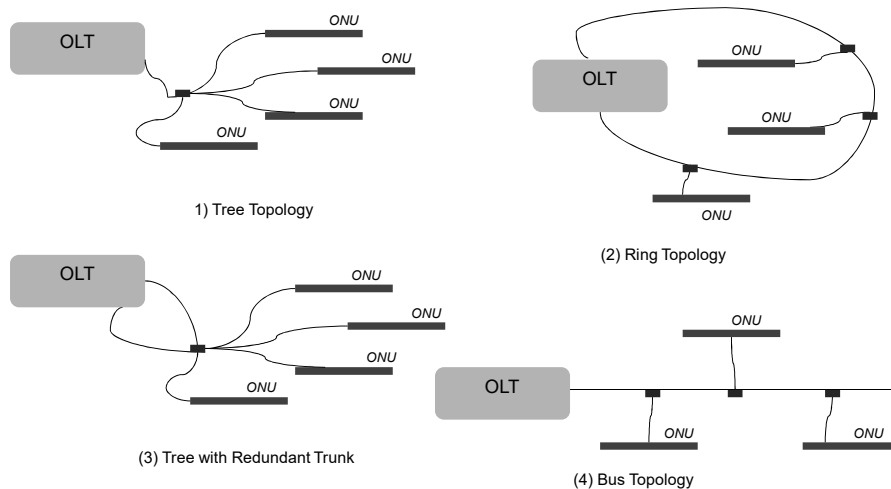


## Ethernet PONs (EPONs)

- ❑ All packets carried in EPON are encapsulated in Ethernet frames
  - Support for variable size packets
- ❑ Similar wavelength plan to BPON
- ❑ Maximum bit rate is 1Gbps MAC-MAC (1.25 Gbps at the physical layer with 8b/10b line coding)
- ❑ Minimum number of splits is 16
- ❑ Maximum reach is
  - 10 km (FP-LD @ ONUs, limited by dispersion in downstream for G.652)
  - 20 km (DFB-LD @ ONUs)
- ❑ Different configurations are allowed



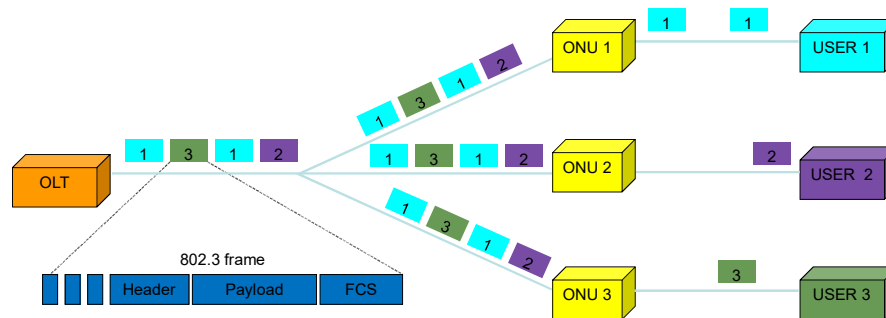
## EPON Configurations





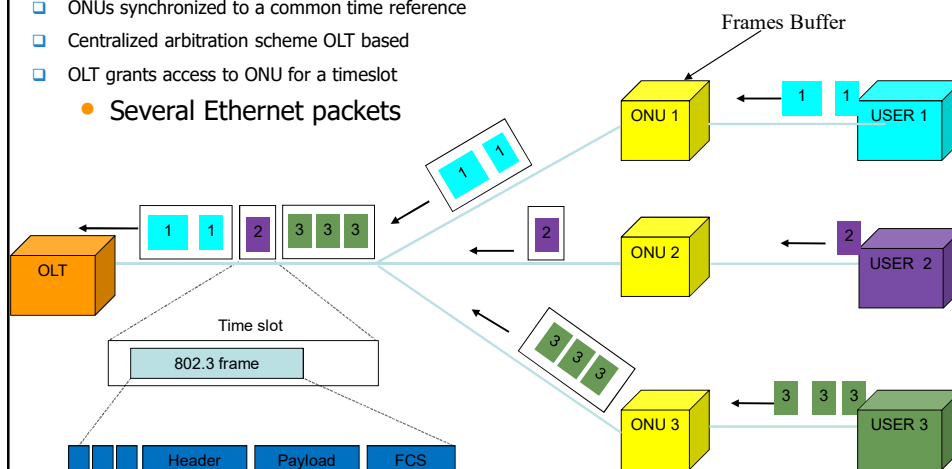
## EPON Downstream Traffic

- Similar to a shared medium network
- Packets are broadcasted by the OLT and selected by their destination ONU



## EPON Upstream Traffic

- ONUs synchronized to a common time reference
- Centralized arbitration scheme OLT based
- OLT grants access to ONU for a timeslot
  - Several Ethernet packets





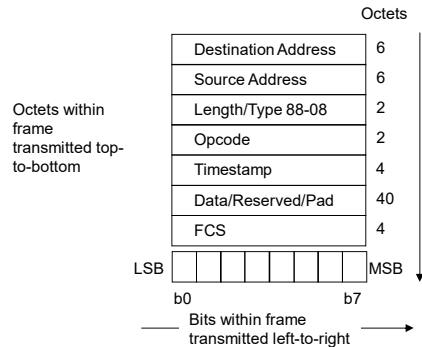
## The Multi-Point Control Protocol (MPCP)

- ❑ Original Ethernet MAC protocol cannot operate properly in the upstream channel (no collision detection) since each ONU cannot hear other ONUs
- ❑ MPCP (Multi-Point Control Protocol) is a new function of the MAC control sublayer. It is developed to support dynamic capacity allocation but the algorithms are an equipment vendors choice (Dynamic Bandwidth Allocation - DBA)

- In-band signalling

- Messages (64 bytes)

- ◆ GATE
- ◆ REGISTER
- ◆ REGISTER\_REQUEST
- ◆ REGISTER\_ACK
- ◆ REPORT



## Autodiscovery mode

- ❑ 3 control messages:
  - **Register, start message sent by OLT;**
  - **Register\_Request, answer message from ONU not registered yet;**
  - **Register\_Ack, message by OLT that allows ONU registration.**



## GPON Standardization

ITU-T	Outline	Adoption
G.984.1	G-PON service requirements (General characteristics)	Mar. 2003
G.984.2	G-PON Physical Layer spec. (Physical Media Dependent (PMD) layer specification)	Mar. 2003
G.984.3	G-PON TC layer spec. (Transmission convergence layer specification)	Feb. 2004



## G.984.1 Service Requirements

Item	Target	
Bit rates	1.25Gbit/s symmetric or higher (2.4 Gbit/s). Asymmetric with 155/622Mb/s upstream	
Physical reach	Max. 20 km or max. 10 km	
Logical reach	Max. 60 km	
Branches	Max. 64 in physical layer	
Wavelength allocation	Downstream: 1480 – 1500nm Upstream: 1260 – 1360nm	Downstream video wavelength (1550 – 1560nm) may be overlaid



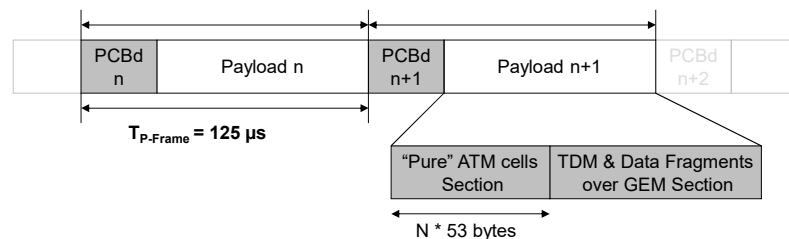
## GPON Encapsulation Mode (GEM)

- GEM provides a *Generic Frame* where to carry both TDM and packet traffic over fixed data-rate channels
  - Similar Generic Framing Procedure (GFP) used in SDH/SONET
- A *Generic Frame* consists of:
  - a core header
  - a payload header
  - an optional extension header
  - a payload
  - an optional frame check sequence (FCS).



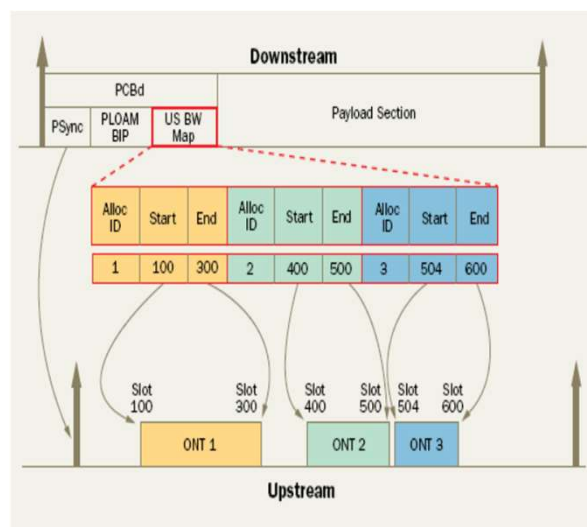
## Downstream Frame Structure 1/3

- It consists of
  - a Physical Control Block Downstream (PCBD)
  - the ATM partition ( $N \times 53$  bytes)
  - the GEM partition





## GPON Header

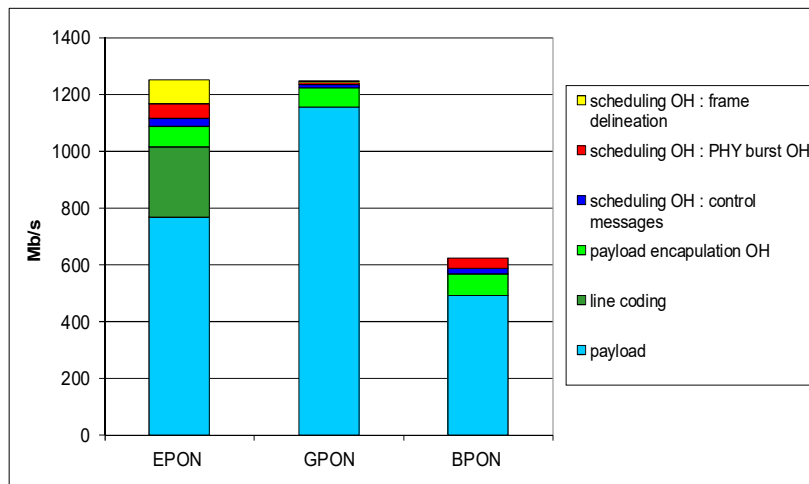


## Technical Standards Comparison

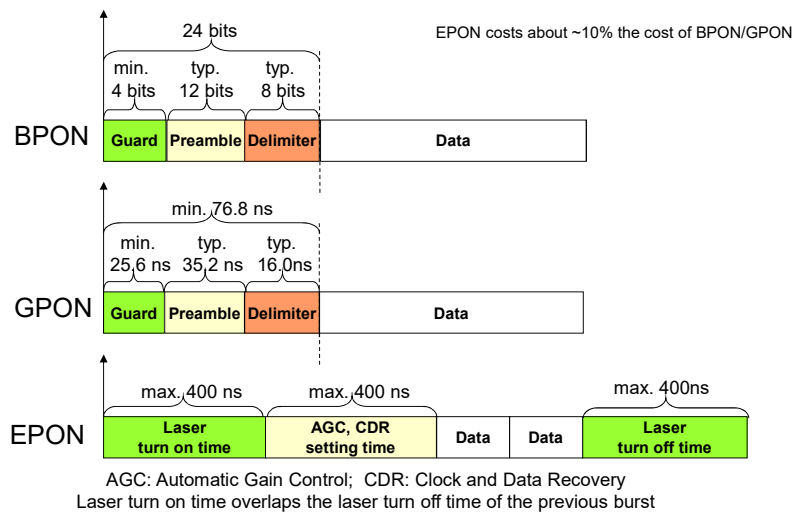
Technology	Standard	Downstream/ Upstream Bandwidth	# ONT served	Lambda	Framing/ Protocol	Distance
<b>APON/BPON</b> (ATM PON/ Broadband PON)	ITU-T G.983.x	155, 622 or 1244 Mbit/s down 155 or 622 Mbit/s up	Limited by power budget and ONU addressing limits: 16 to 32 splitter	1490 nm Down 1310 nm Up (1550 nm Down for RF video)	ATM	20 km
<b>GPON</b> (Gigabit PON)	ITU-T G.984	1.2 or 2.4 Gbit/s down 155, 622, 1.2 or 2.4 Gbit/s up	Up to 64(physical) Up to 128 (logical)	1490 nm Down 1310 nm Up (1550 nm Down for RF video)	GEM: G-PON Encapsulation Method (supports Ethernet), ATM	10/20 km (up to 60 km)
<b>EPON</b> (Ethernet PON)*	IEEE 802.3ah	Symmetric 1.25 Gbit/s	Up to 16	1550 nm Down 1310 nm Up	Ethernet	10/20 km
<b>10GEPON</b> (10 Gigabit Ethernet PON)	IEEE 802.3av (Working Task Force)	10 Gbit/s down 1 Gbit/s up (symmetric 10 Gbit/s in the future?)	32 (maybe more?)	1480-1500 nm Down ? 1260-1360 nm Up ? 1550-1560 Video overlay ?	Ethernet	20 km



## Transmission Efficiency



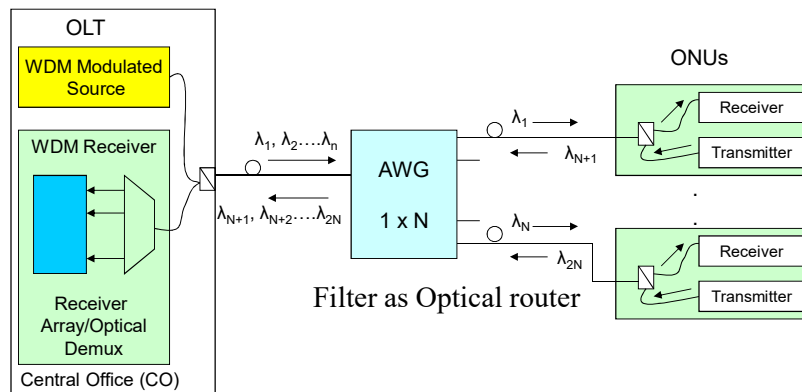
## Header's Comparison



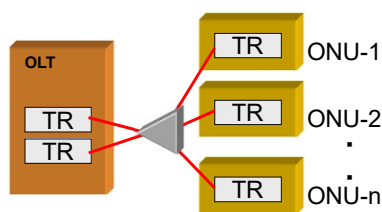


## Simple WDM-PON

- Number of ONUs limited by wavelengths
- Point-to-point topology
- Long-reach (almost point-to-point reach)

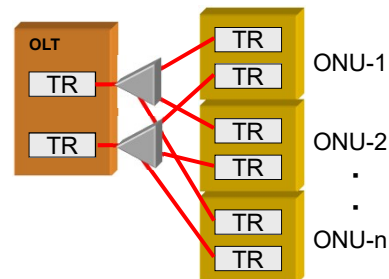


## Protection Mechanisms



**B type**  
**1+1 protection of OLT**

- Cost-effective
- Redundant feeder
- Redundant OLT transceivers



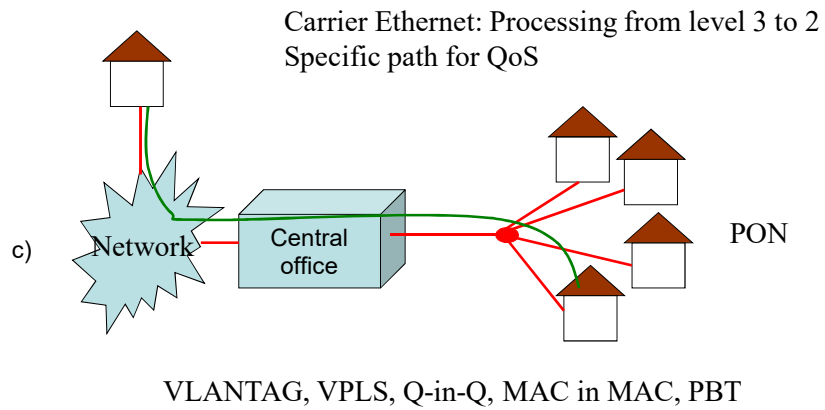
**C type**  
**1+1 protection of PON**

- Most secure and expensive
- Redundant feeder and drops
- Redundant transceivers

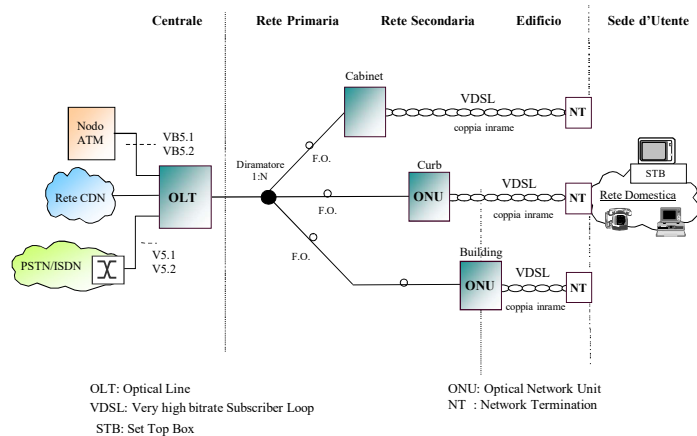




## Carrier Ethernet for PON (EPON)



## Elements of a PON





## International development overview

### □ China

- GPON and EPON are being tested in China : future PON growth mainly depends on Chinese market evolution
- Beijing, Wuhan, Shanghai e Guangzhou are the cities with the greatest FTTX deployment

### □ Japan

- The number of xDSL users has decreased for the first time at the end of 2006, while FTTH users have grown by 10% in 2006 last trimester.
- At the end of 2006, out of 26 million Broadband lines, FTTH accounted for 30% of the total amount.

### □ South Korea

- In July 2007, 500.000 FTTH users
- Almost 4 million FTTB "apartment LANs"



## International development overview

### □ USA

- Large average cable-length
- Large investments form cable operators, that account for a relevant share of the broadband market
- No unbundling required for new fiber infrastructures.

### □ Brazil, Colombia, Argentina, Chile

- Less than 300.000 FTTH users

### □ Australia, New Zeeland, Kuwait, Russia, United Arab Emirates, Pakistan

- Less than 2 million FTTH users

*Ref: EXFO, may 2007*

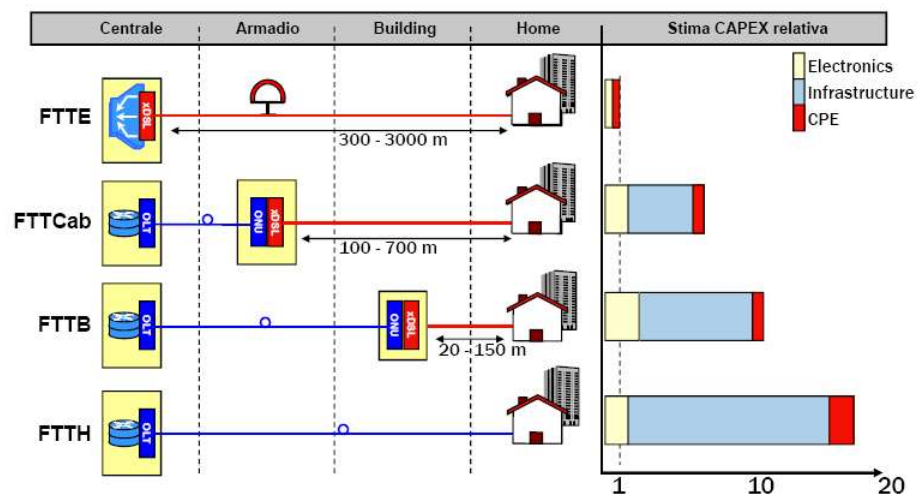


## International development overview

- Mostly in Northern Europe, local administrations are building the infrastructure, with equal access conditions for service providers
- The leading incumbents are deploying extended FTTCab/VDSL infrastructure plans.
- Sweden: more than 500.000 FTTH users
- France, UK: more than 600.000 FTTH users
- Italy : more than 250.000 FTTH users
- Denmark: more than 400.000 FTTH users
- Holland : more than 500.000 FTTH users



## FTTx costs



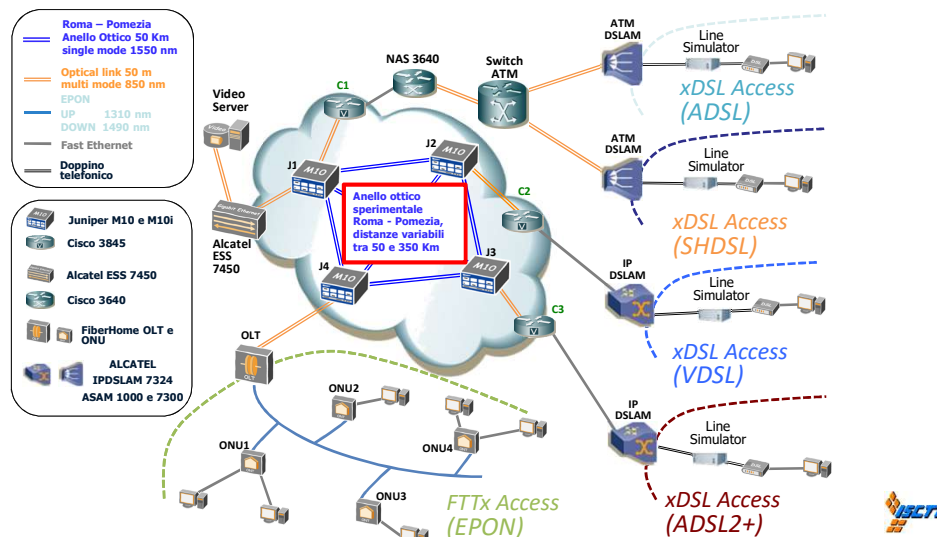


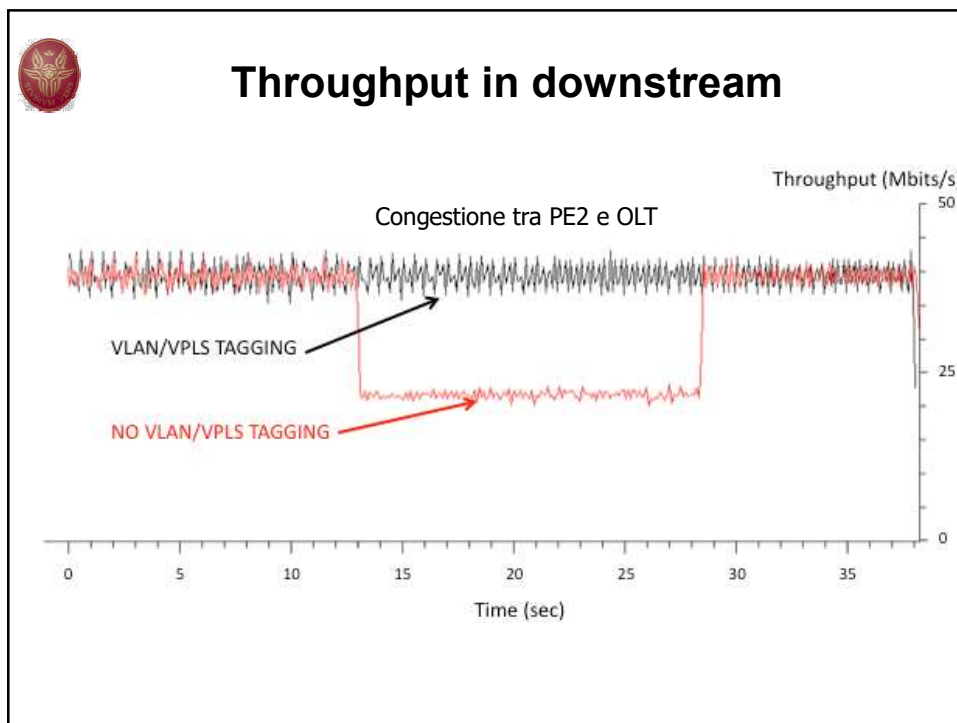
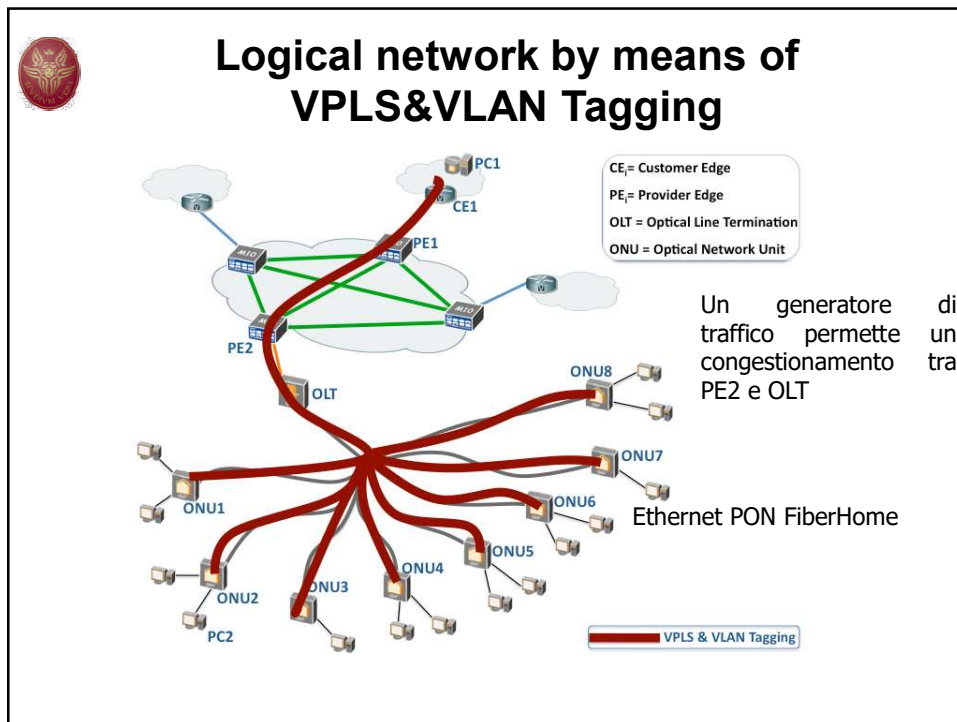
## FUB study on NGN economics

- 1400 Mega Euro for digital Divide end (connection of central office to backbone)
- FTTC/B/H for all? No 2 Mb/s for all but 20 Mb/s for almost all and >50 Mb/s for many
- 10 million of users based on FTTB: total cost 15000 Mega Euro!
- Unbundling problems:
  - For OLO no PON, yes Point-to-point
  - We say yes PON since:
    - » with logical unbundling now and WDM later!
    - » Too cost to include devices in central office and fibres in current ducts
    - » With PON we can shift OLO location from central office to



## FUB Experiments on EPON







## Conclusions

- FTTx necessary for NGN
- PON is the best current solution
- Problems for investments and network properties