SAPIENZA
UNIVERSITÀ DI ROMA

Network Infrastructures

A.A. 2024-2025

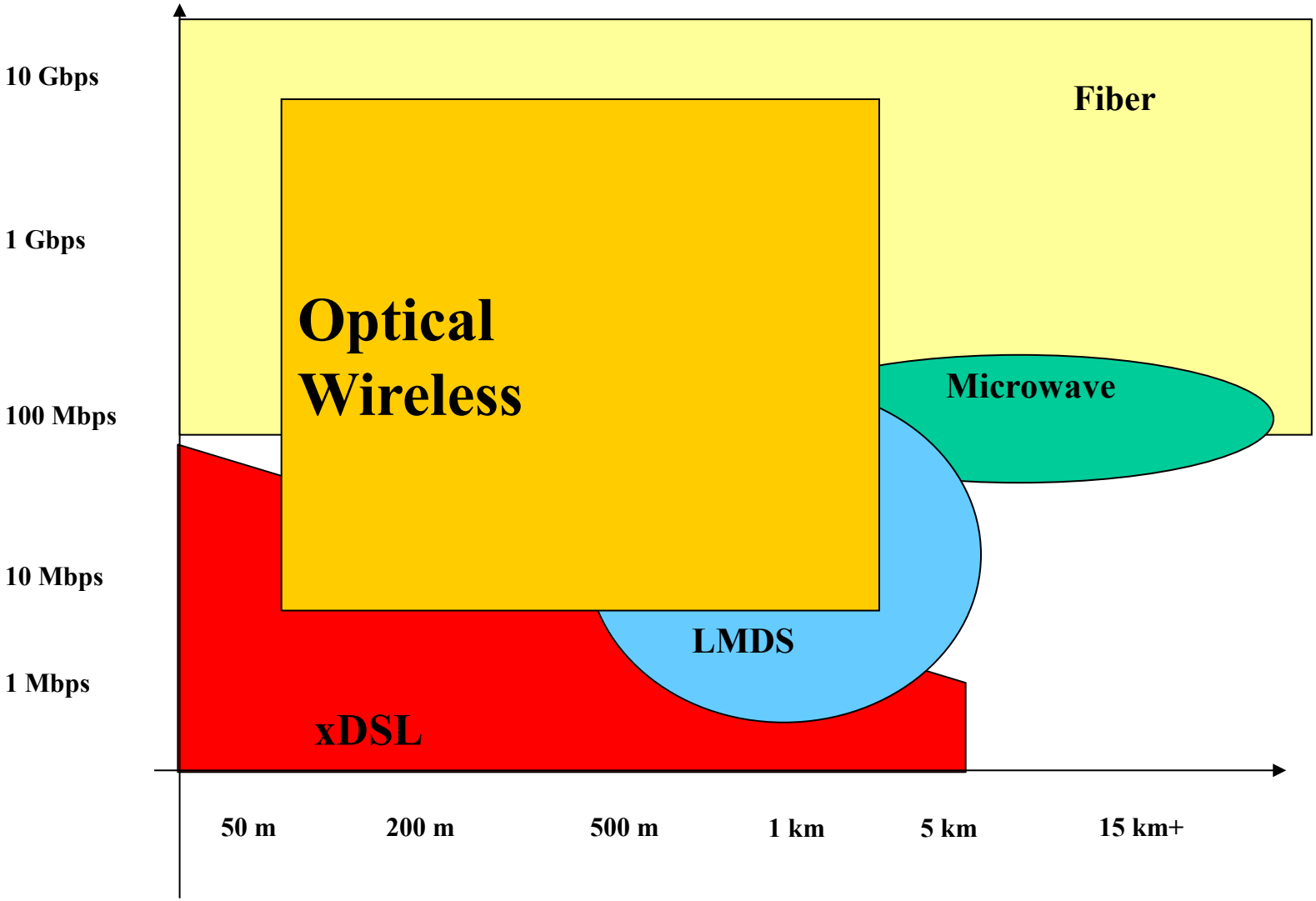
Prof. Francesca Cuomo

Outline

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

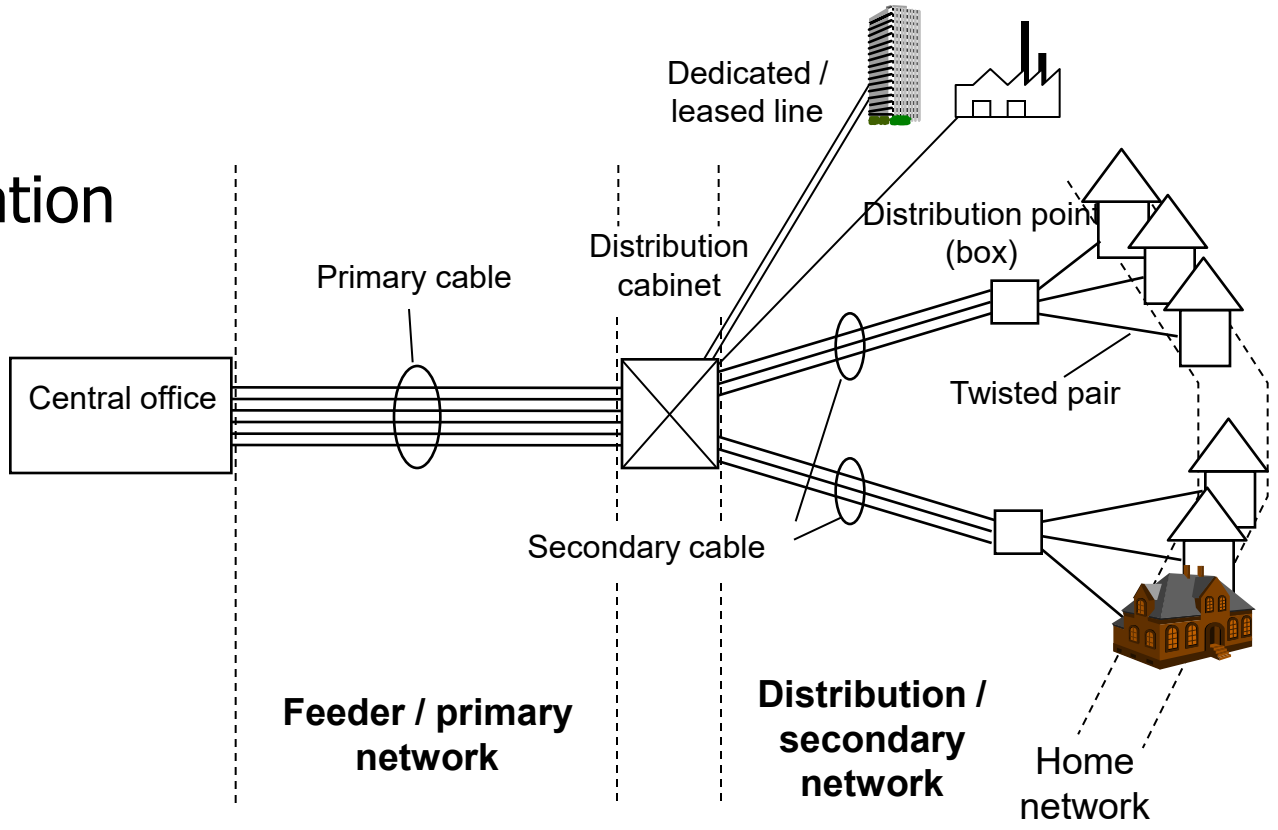
Part of these slides are taken from:
Towards Fiber to the X (FTTX): Passive Optical Networks,
Francesco Matera Responsabile Area Tecnologie Reti di Nuova Generazione
mat@fub.it
Main source: Project EU E-Photon/One+, Lessons from Prof. A. Pattavina, G. Maier, Politecnico di Milano

Access/backhoul



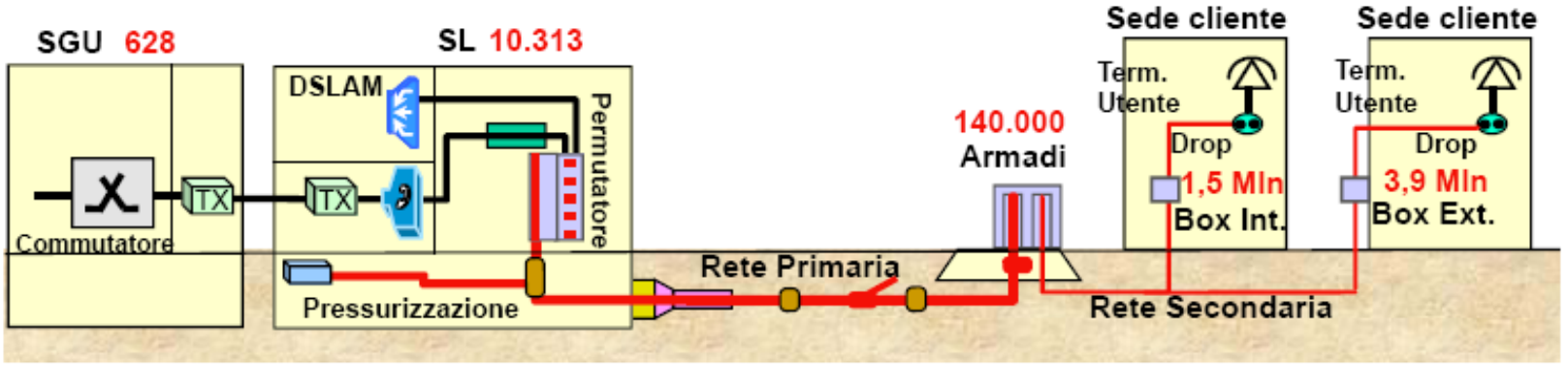
PSTN access-network Physical architecture

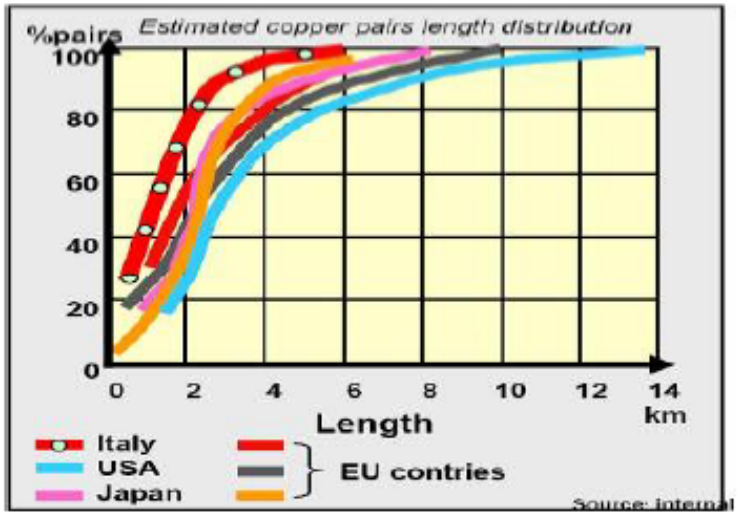
- Primary network
  - High sharing
  - Cost minimization
- Secondary network
  - Flexibility
  - Branching
- Cables
  - Primary
    - 2400-2000 pairs
    - In duct or pipe
  - Secondary
    - 100-10 pairs
    - Trenched or aerial
- Cascading more stages of cabinets is possible but rare



Telecom access networks

La rete accesso in rame oggi

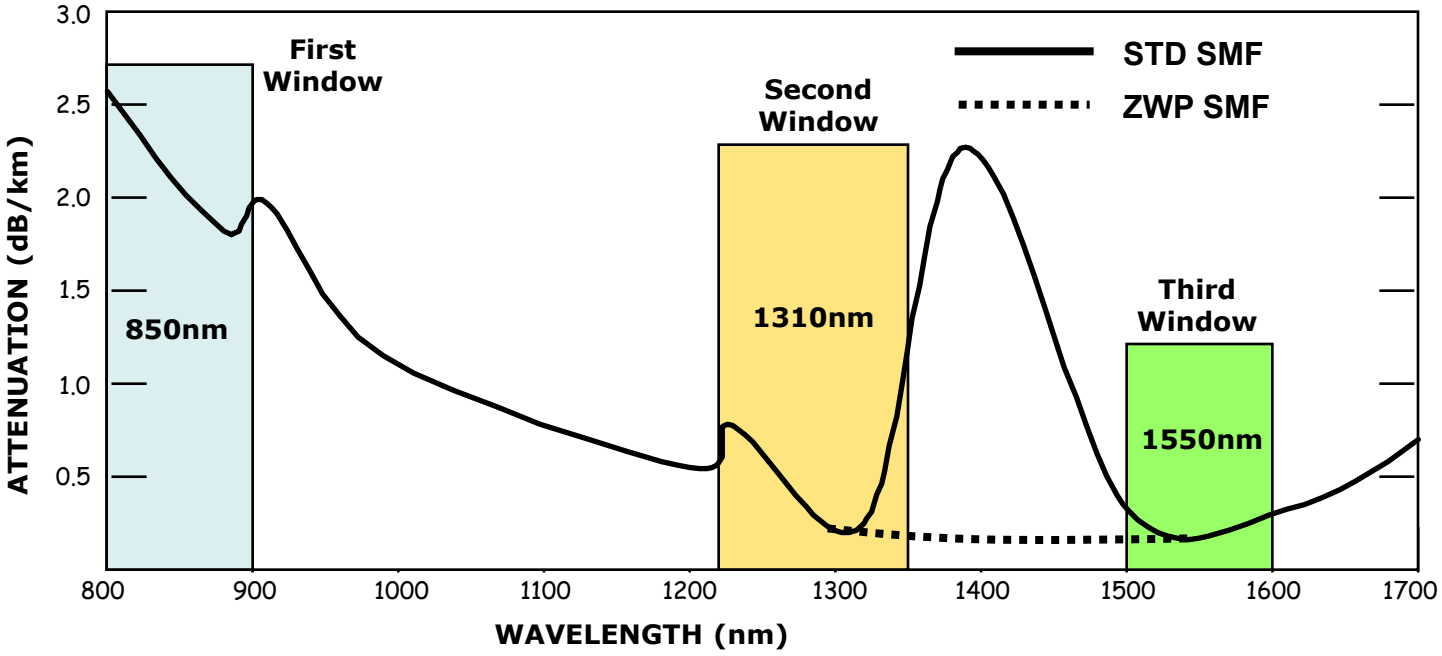




- ~ 530.000 km cavo
- ~ 110.000.000 km coppia
- ~ 140.000 armadi
- ~ 5.500.000 distributori/terminazioni

Optical Fiber: Attenuation

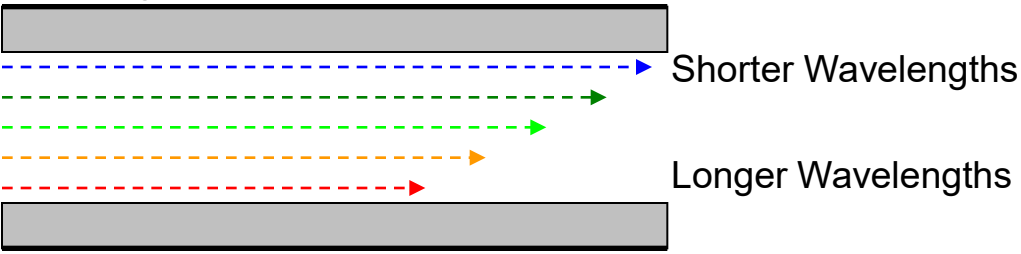
- Single Mode Fiber (SMF) to achieve large distances
  - **ITU G.652 SMF (STD)**
    - "water peak" attenuation renders the 1360nm–1480nm spectrum unusable for data transmission
  - ITU G652c/d SMF (ZWP)
    - "zero-water peak"

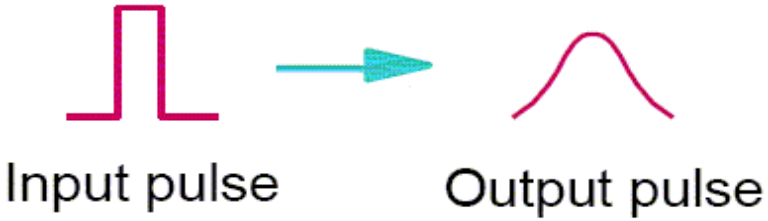


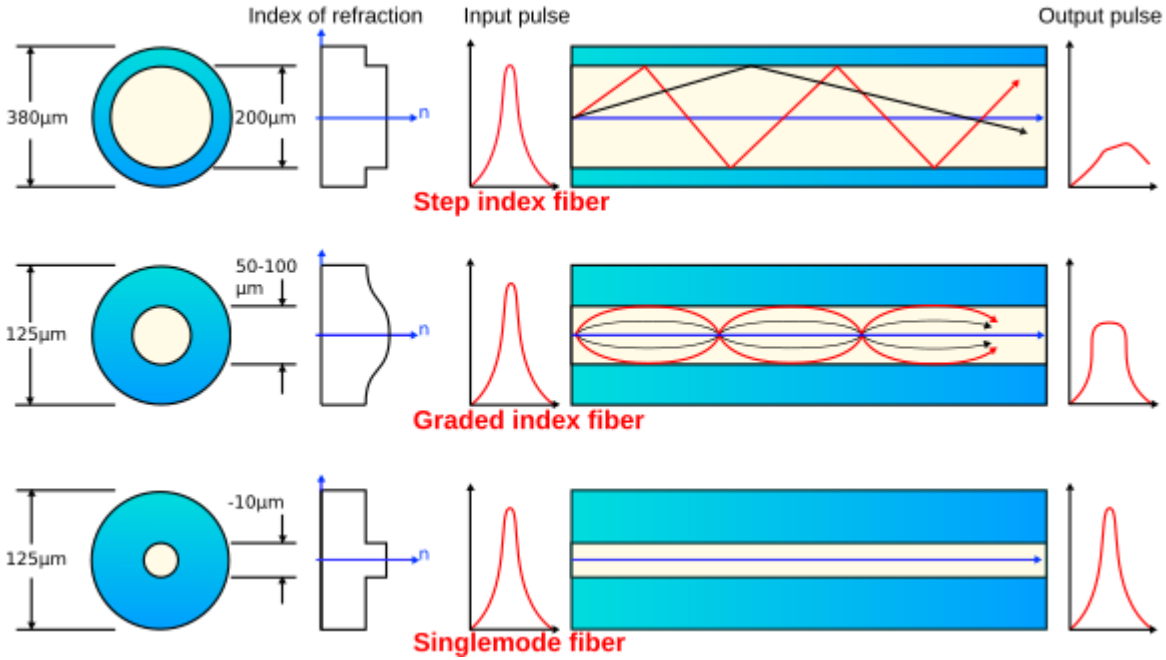
Optical Fiber: Chromatic Dispersion

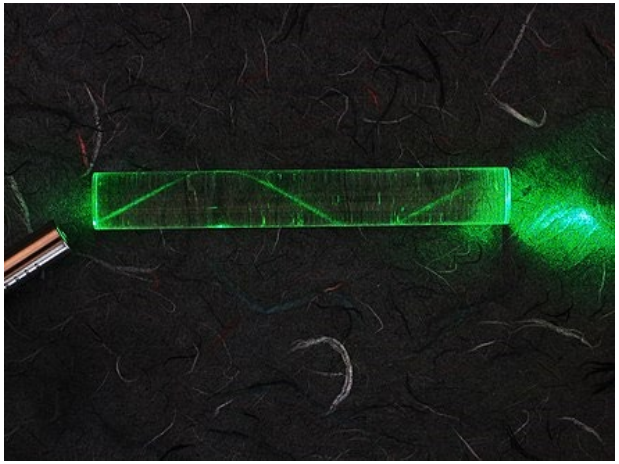
- Causes signal pulse broadening

Single-mode optical fiber





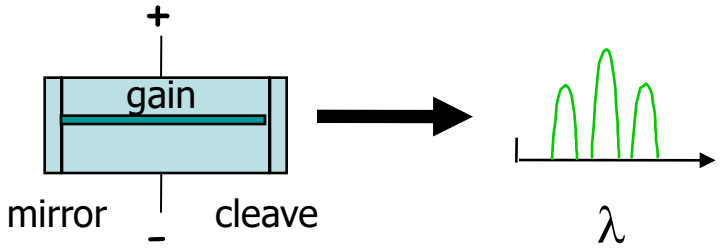




Lasers Diodes (LD)

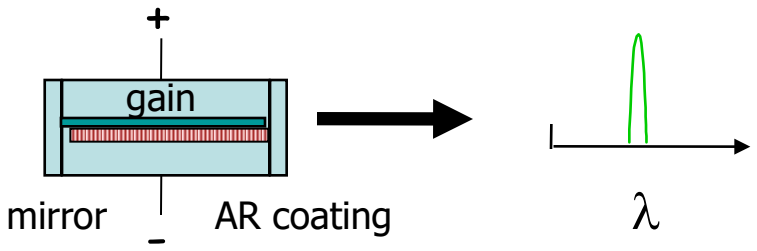
- Fabry-Perot (FP)
  - Cheap
  - Noisy
    - Sensitive to chromatic dispersion
  - Used on 1310 nm

Simple FP



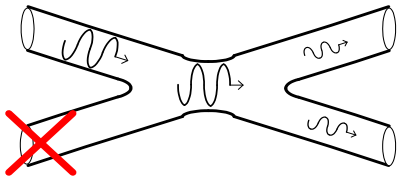
- Distributed Feedback (DFB)
  - More expensive
  - Narrow spectral width
    - Less sensitive to chromatic dispersion
  - Used on 1550 nm (or 1310 nm)

DFB

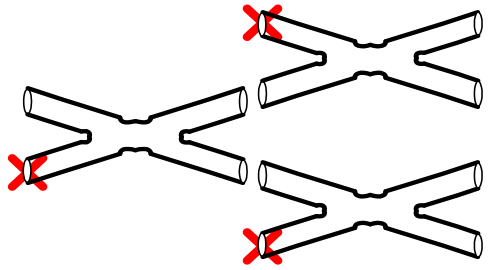


Passive Splitters

- 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 *10log(0.5)=3dB*
  - Loss ~*3dB* x log_2*(#ONUs)*

	Conventional	Low-loss
Splitter 1x2	3.7dB	3.4dB

Photodiodes (PD)

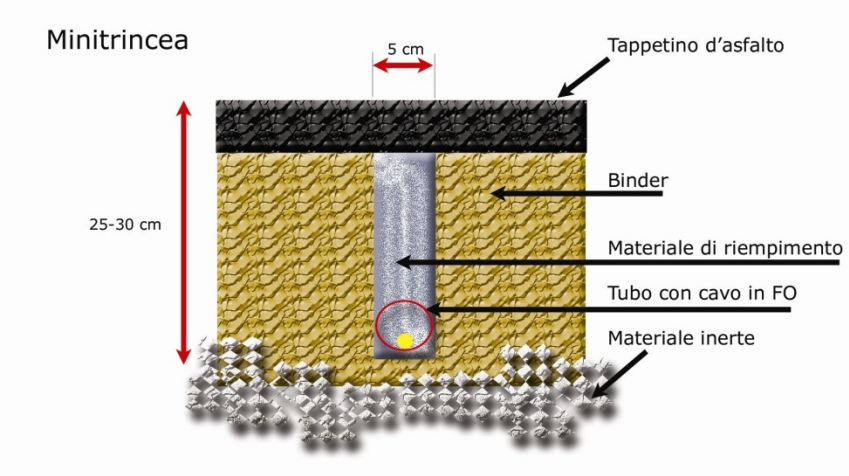
- PIN Photodiodes
  - Good optical sensitivity (~-22 dBm)
  - Silicon for shorter λ's (eg 850nm)
  - InGaAs for longer λ's (eg 1310/1550nm)
- Avalanche Photodiodes (APDs)
  - Higher sensitivity (~-30 dBm)
  - Primarily for extended distances in Gb/s rates
  - Much higher cost than PIN diodes

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**

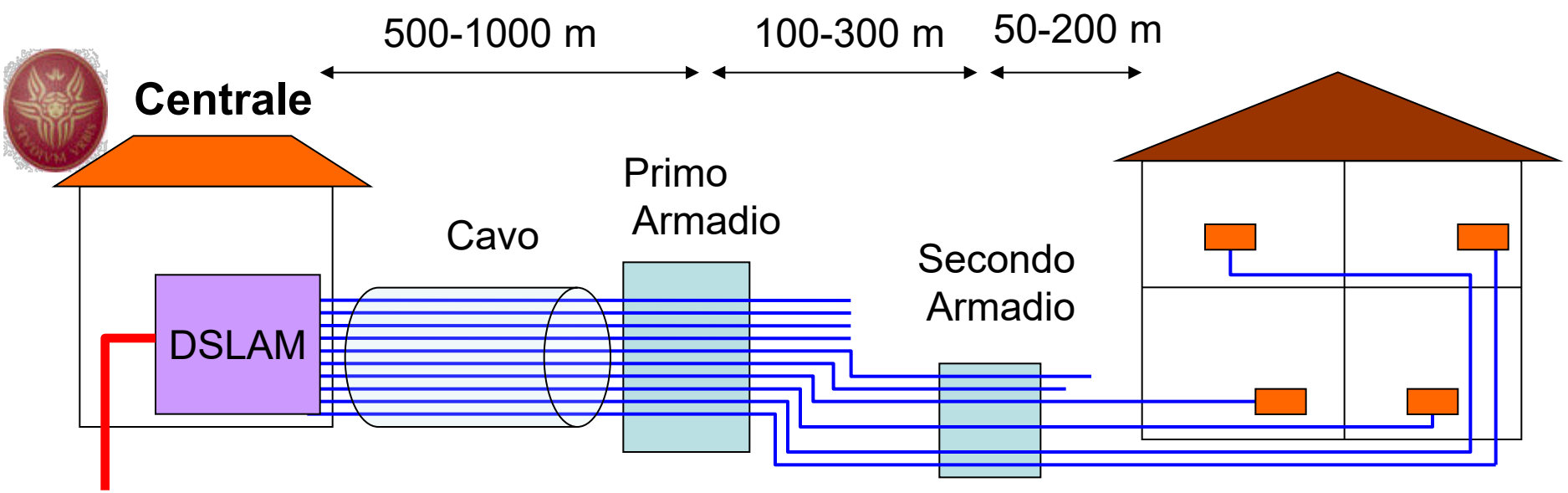
Fiber installation



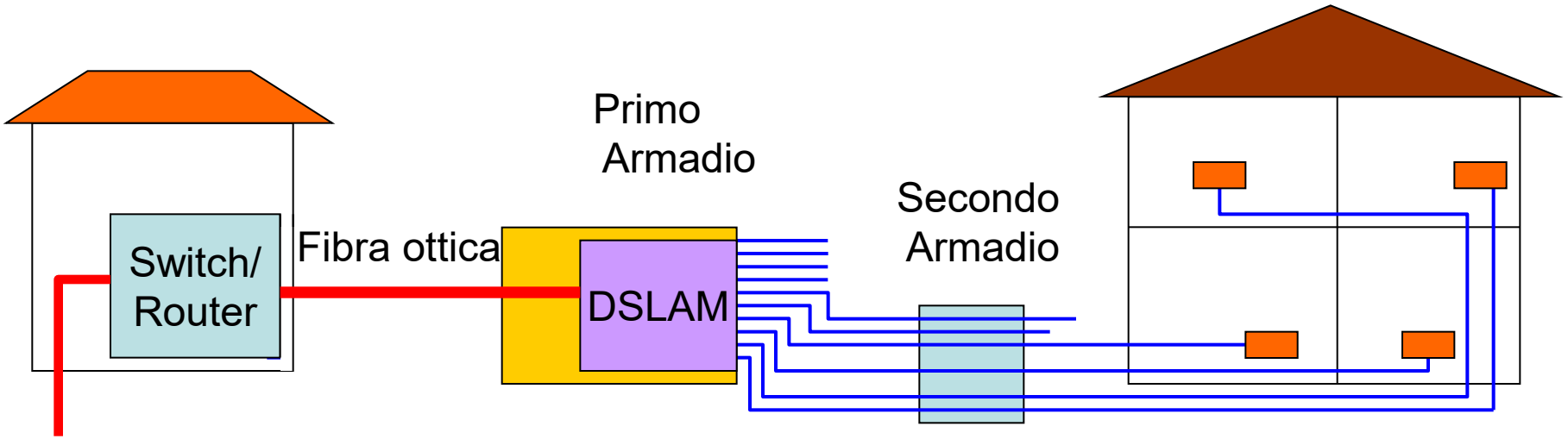
La microtrincea come semplice ed economica soluzione per la diffusione della fibra ottica nella rete di accesso (from HighBand)

Soffiaggio della fibra (ERICSSON)

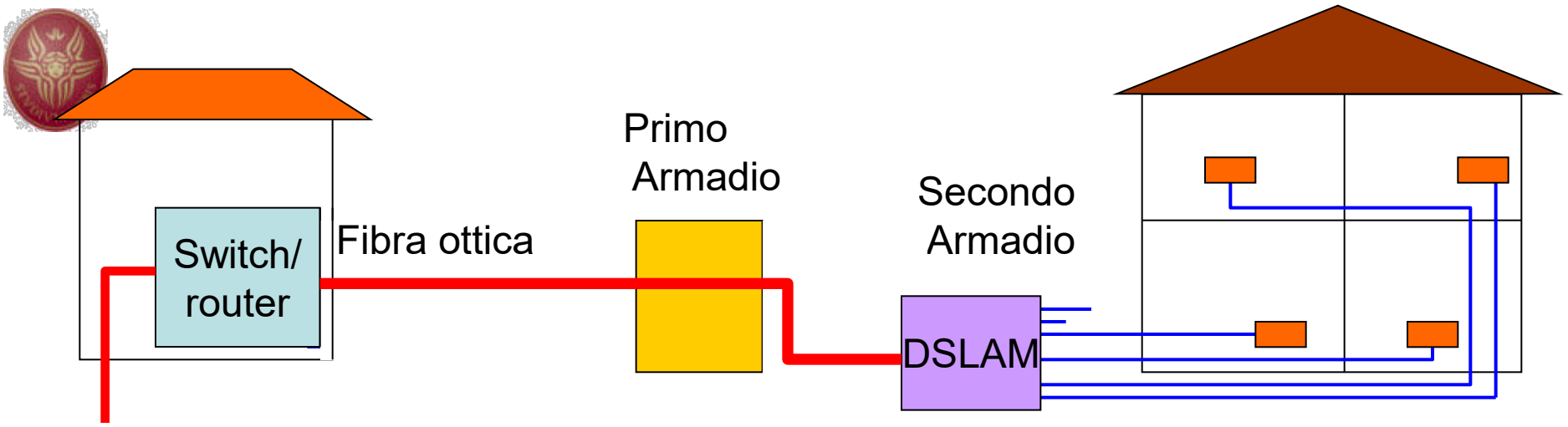
30-40 K €/km per microtrincea



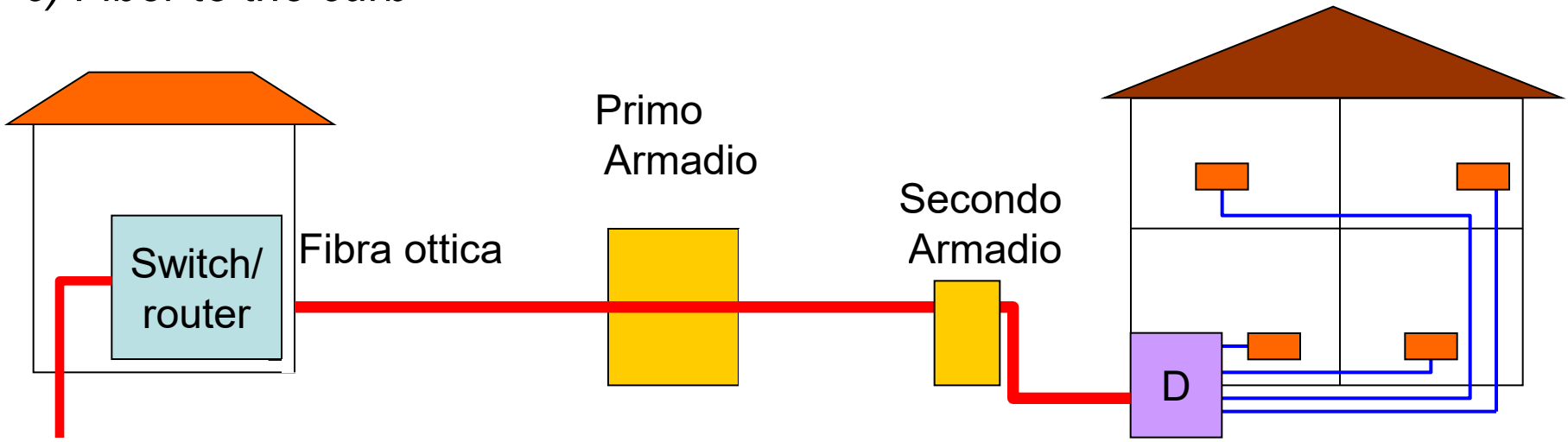
a) Best current architecture



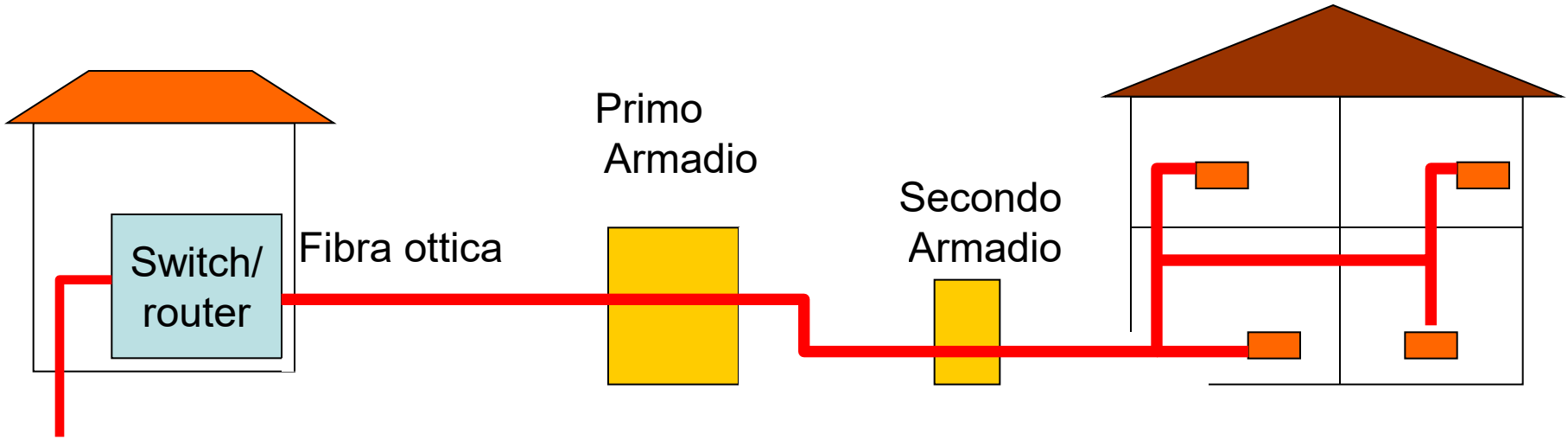
b) Fiber to the cabinet



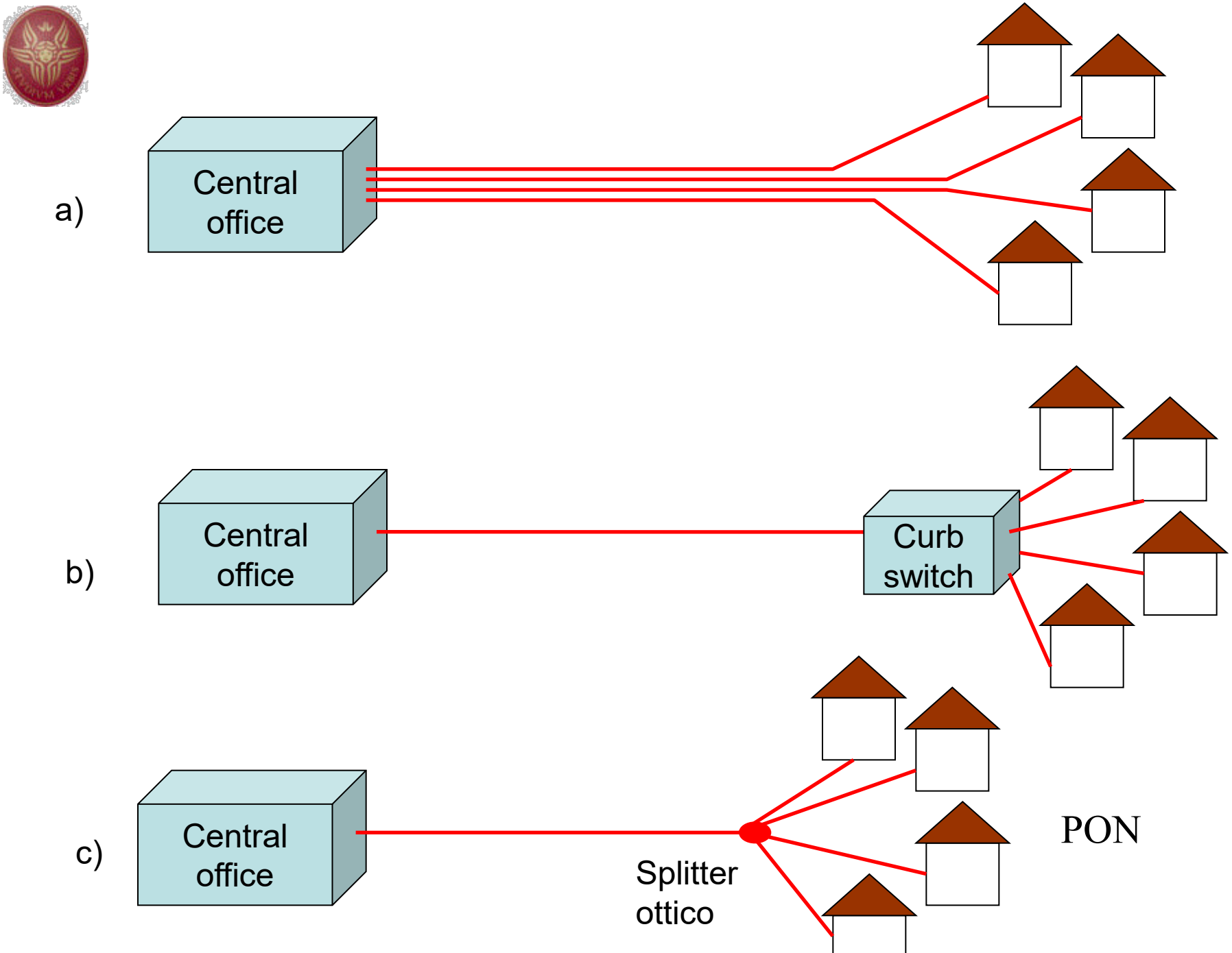
c) Fiber to the curb



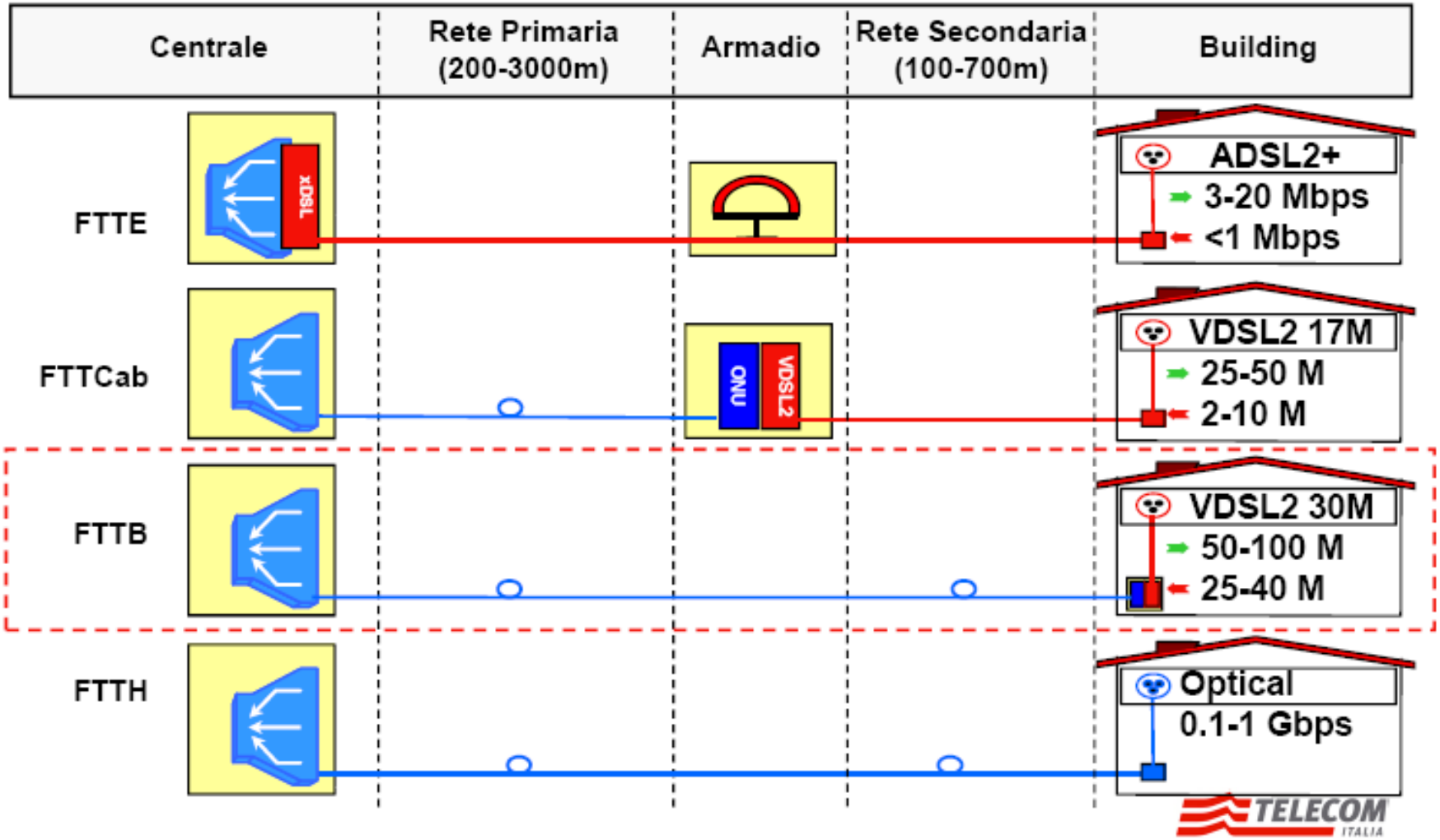
d) Fiber to the building



e) Fiber to the home

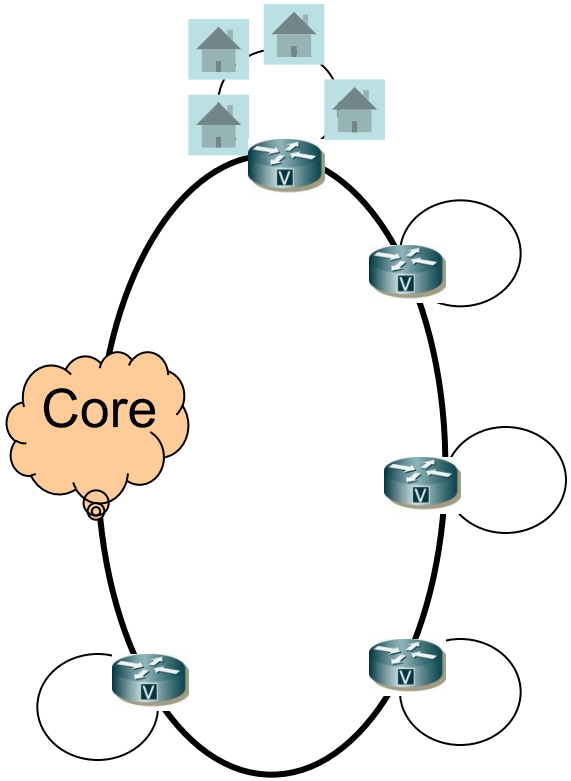

a)
Central office
b)
Central office
Curb switch
c)
Central office
Splitter ottico
PON

Access capacities



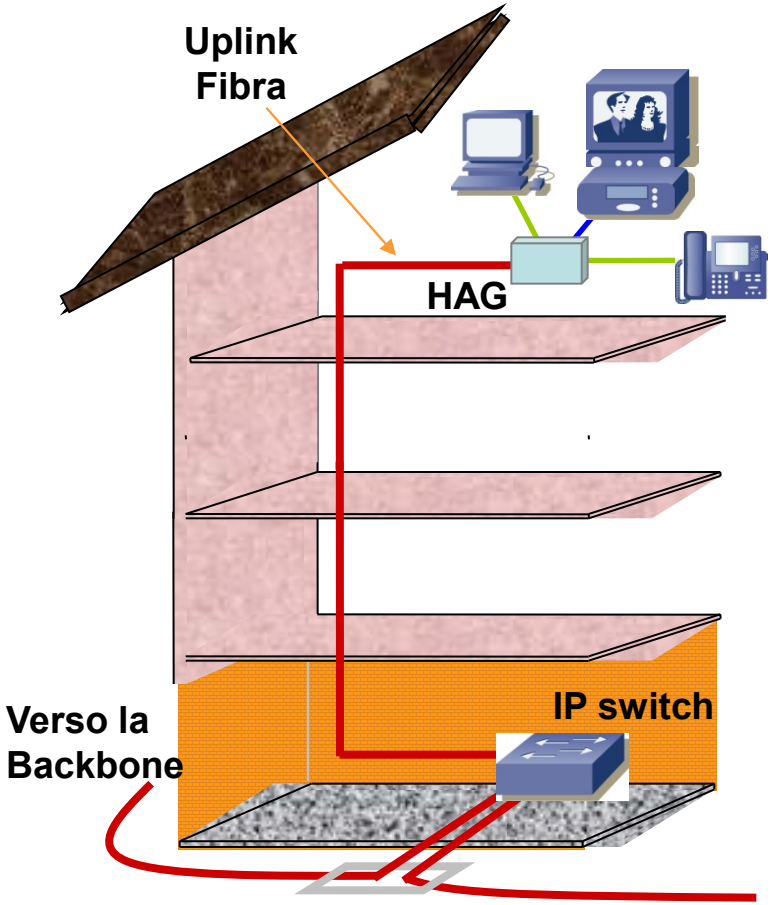
GbE based: FASTWEB

Daisy chain architecture

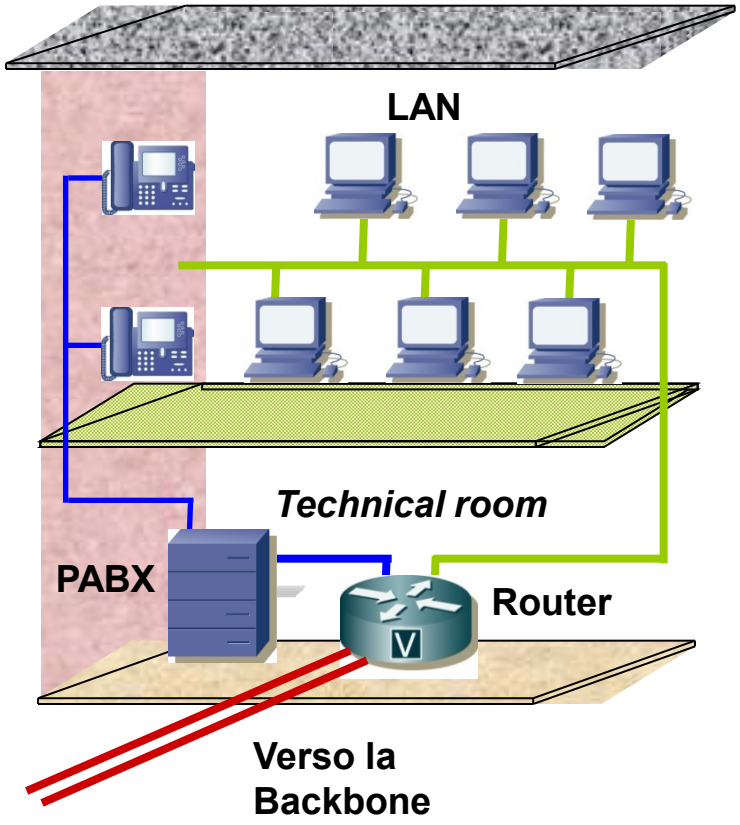


First case in Europe:Fastweb 2000

FTTH: Accesso Residenziale



FTTB: Accesso Business



FTTx = Fiber-to-the-x

- FTTH - Home
- FTTC - Curb
- FTTN - Node or Neighborhood
- FTTP - Premise
- FTTB - Building or Business
- FTTU - 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.

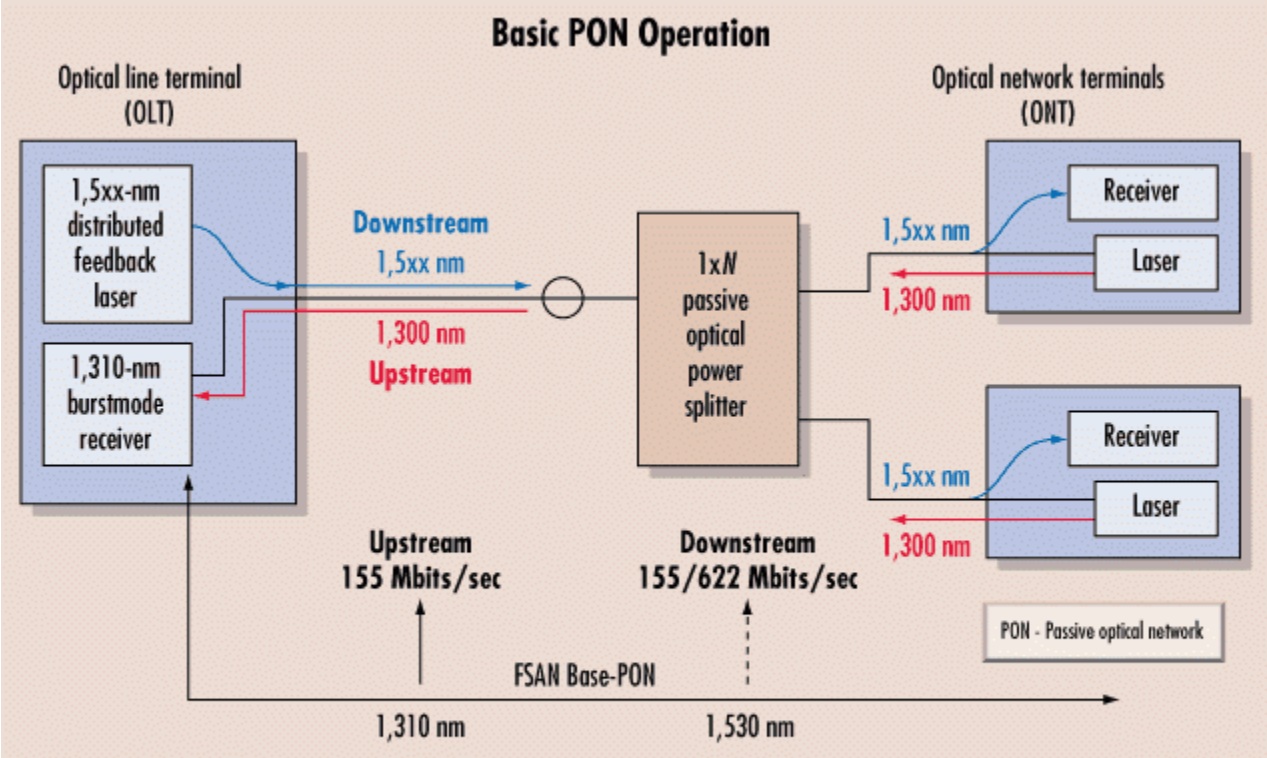
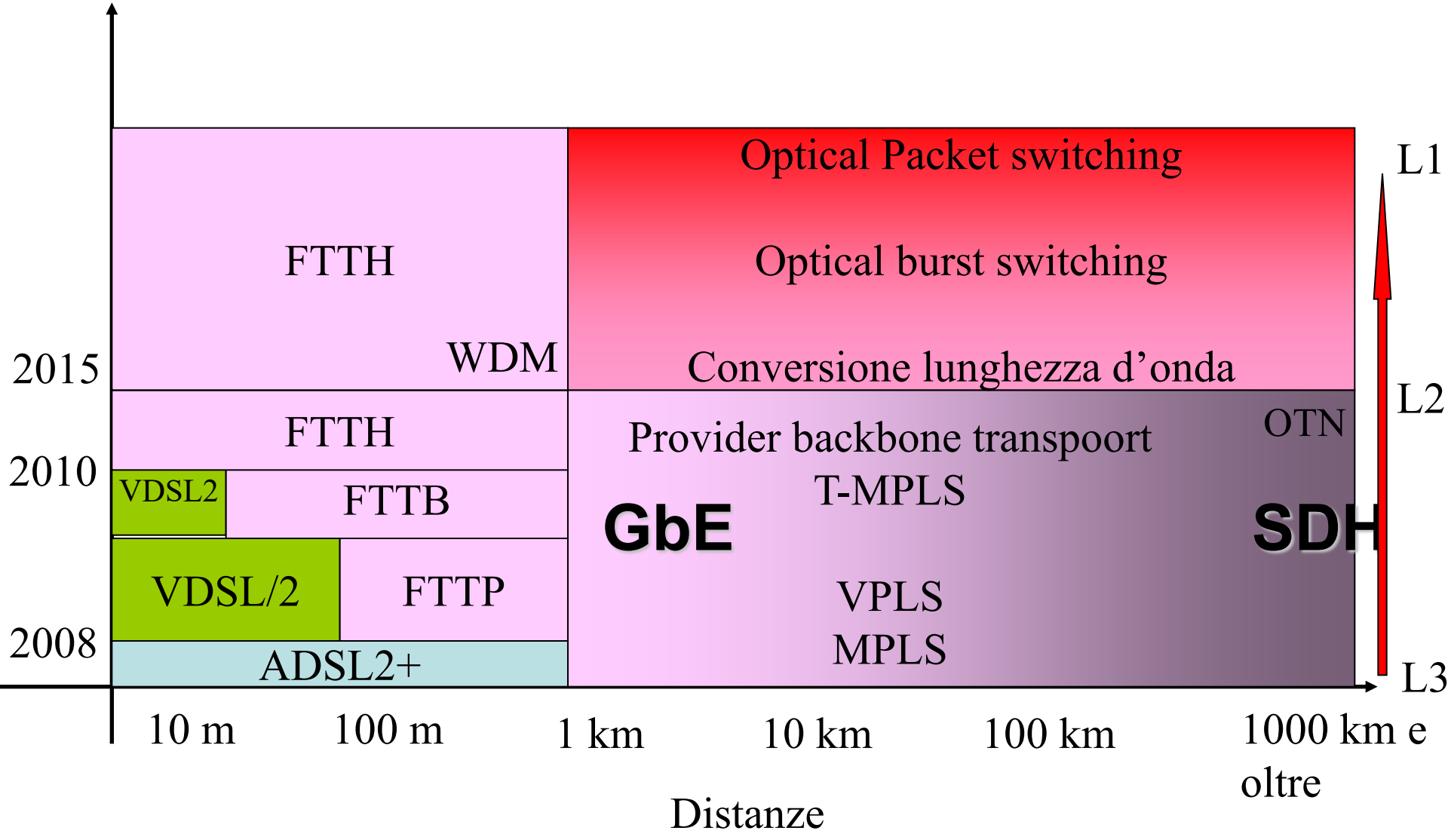


Figure 1. A basic passive-optical-network operation enables service to as many as 32 optical-network terminals (ONTs). Each ONT, in turn, can be connected to multiple subscribers, making fiber more affordable for access networks.

Photonics Evolution

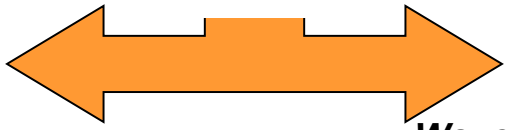


Time vs. Spectrum Sharing

- 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

TDMA
Time Division Multiple Access



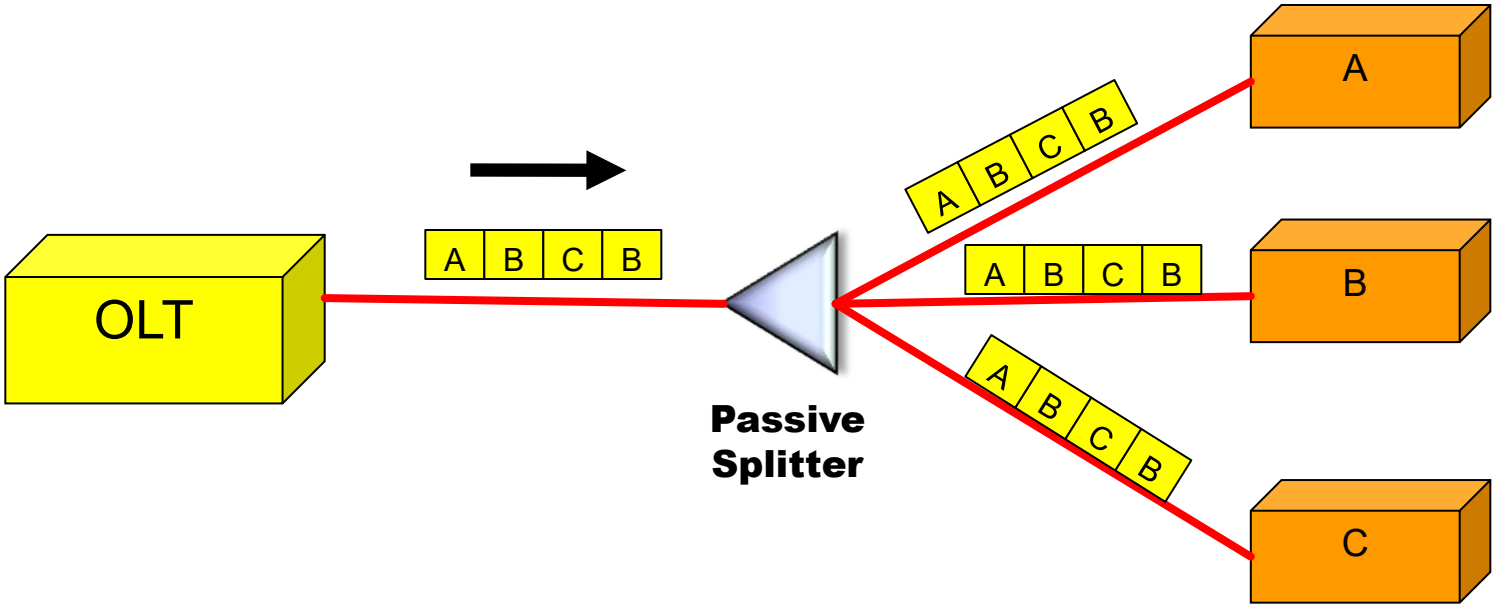
WDMA
Wavelength Division Multiple Access

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 ≤ 20km, Split ratios ≤ 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…

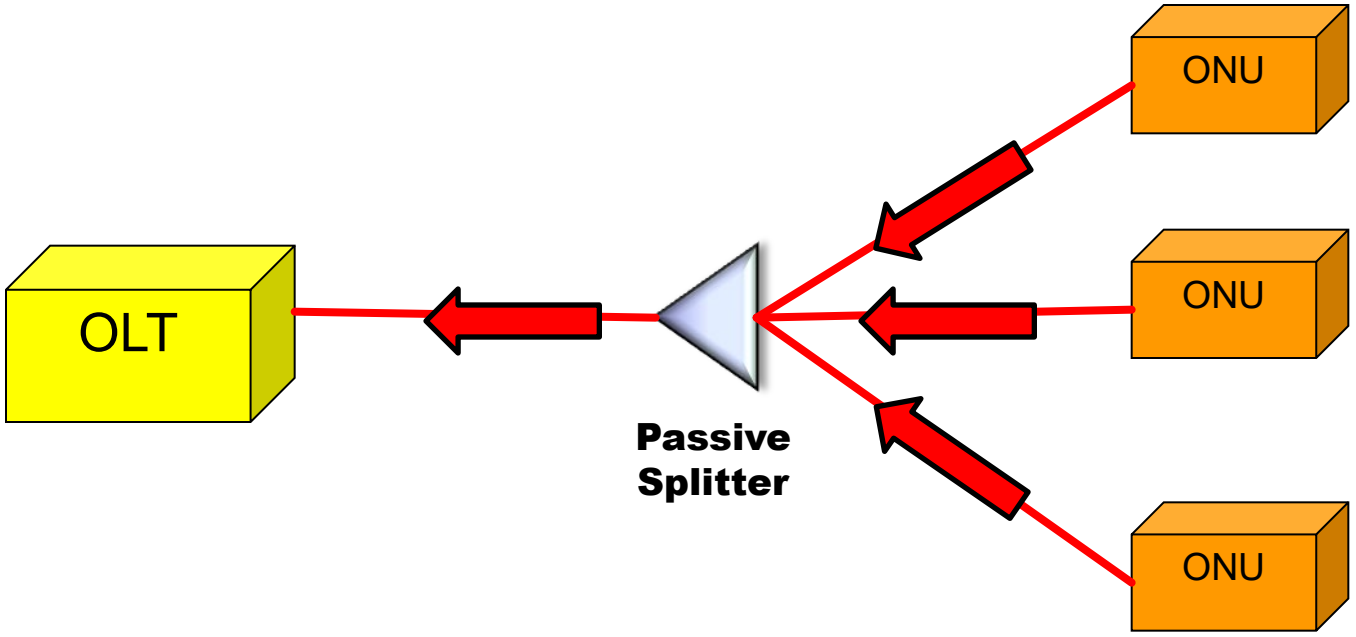
Downstream Traffic Scheduling

- OLT schedules traffic inside timeslots
  - -Time Division Multiplexing (TDM) scheme
- Time slots can vary from ~μs to ~ms



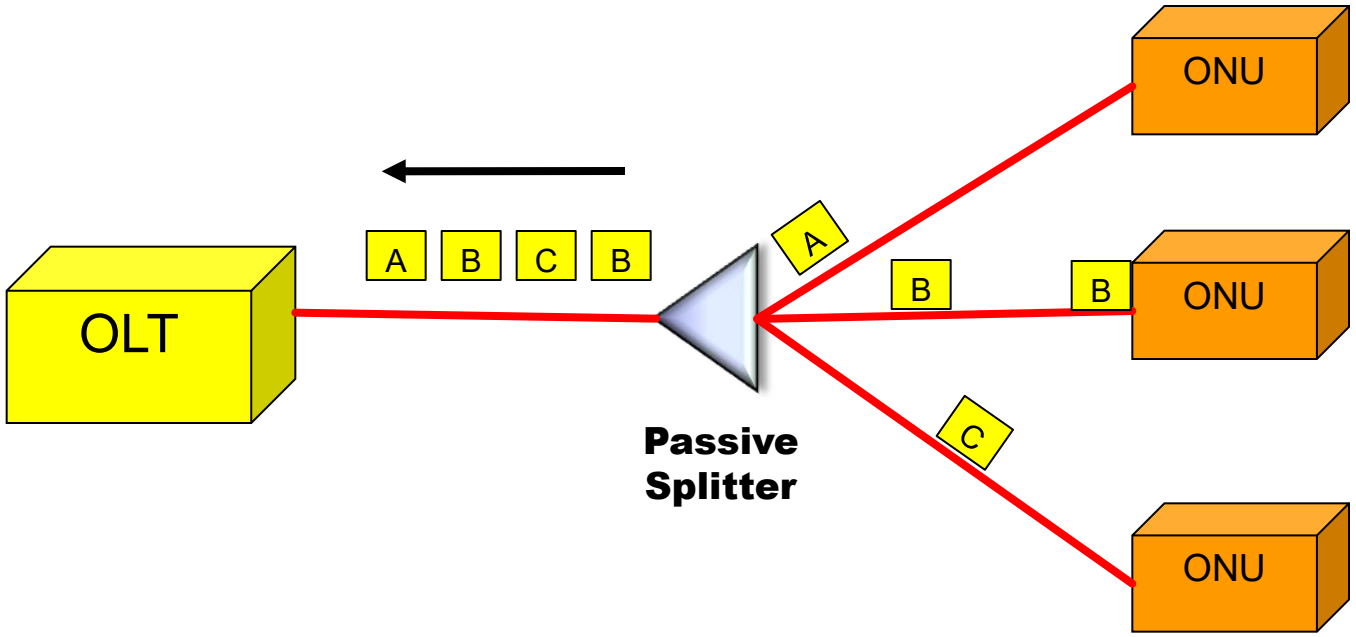
Upstream Traffic

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



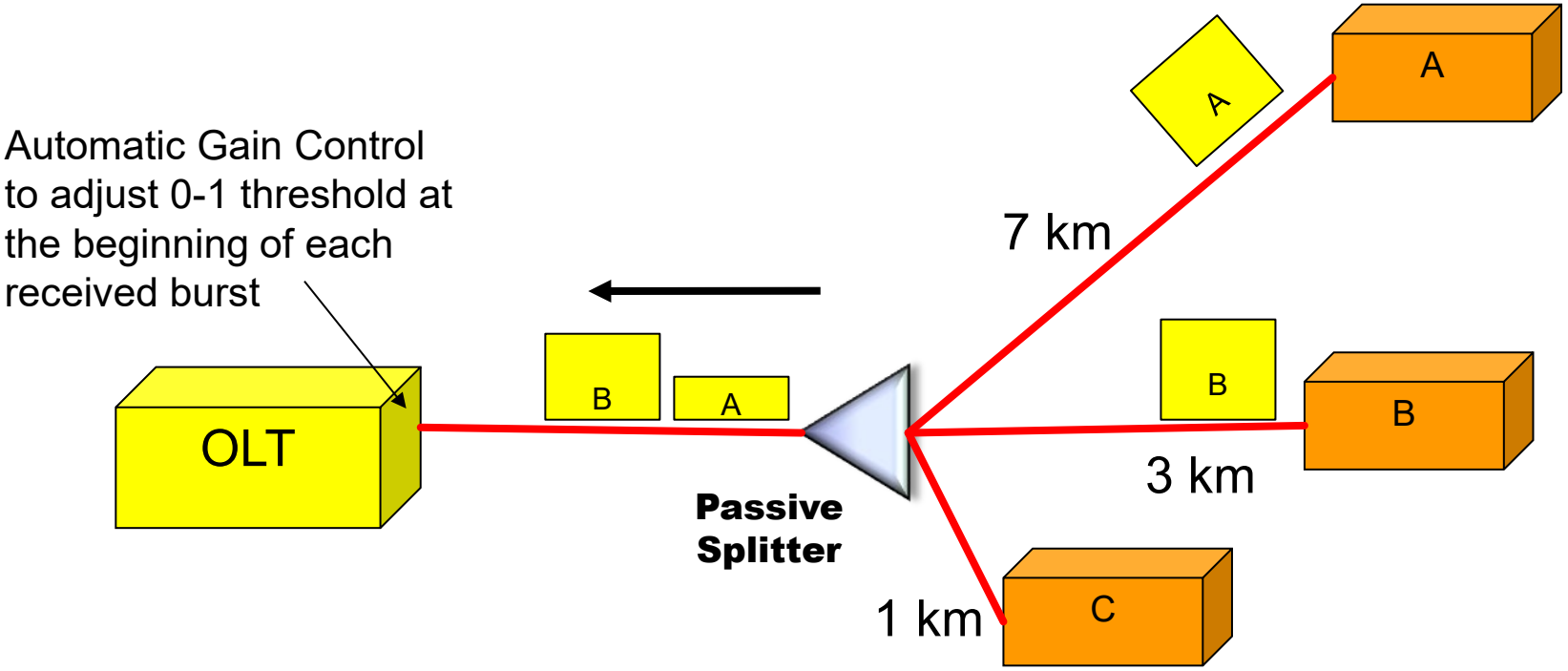
Upstream Traffic Scheduling 2/4

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



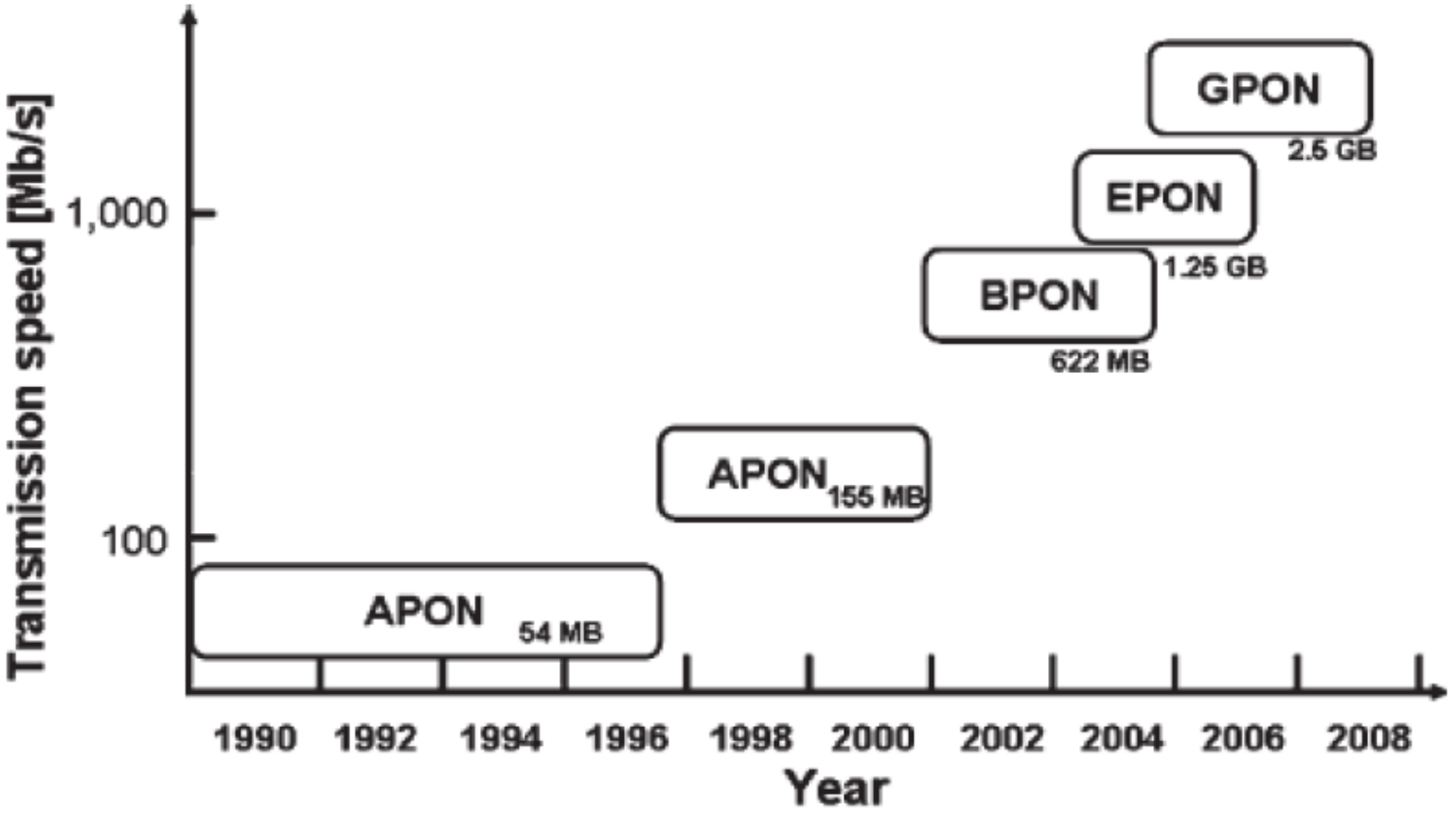
Upstream Frame Reception

- 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



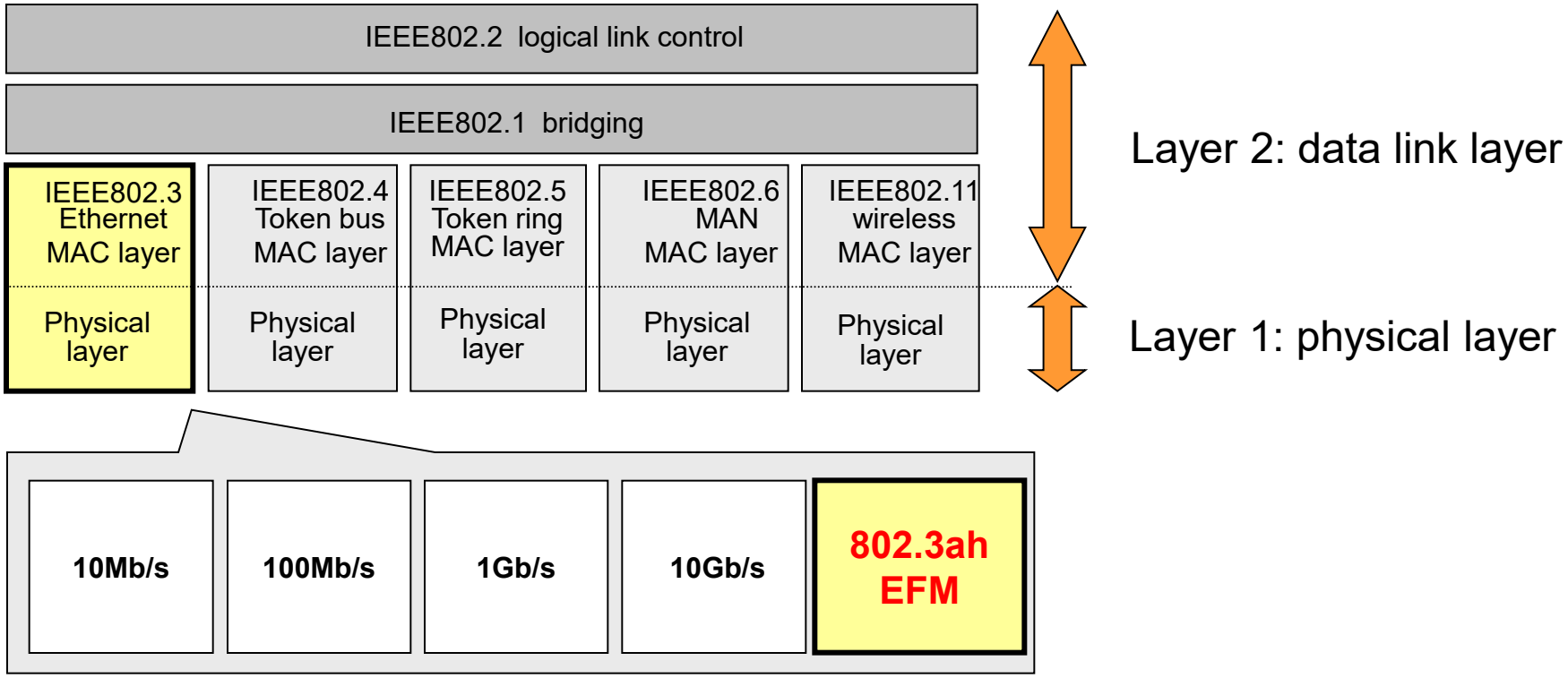
Evolution of the standards

10 GB EPON



Ethernet Standards in EPONs

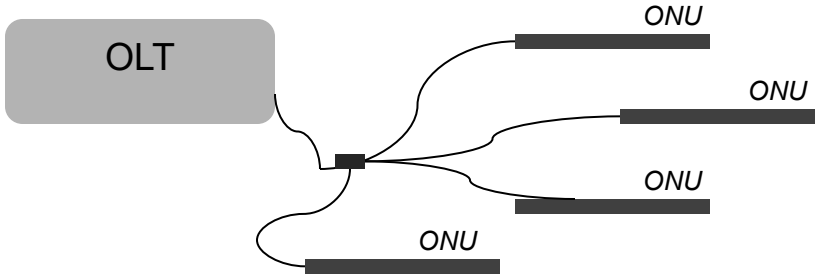
- EPON started to be standardized by IEEE 802.3ah EFM since 2001, it was ratified in 2004



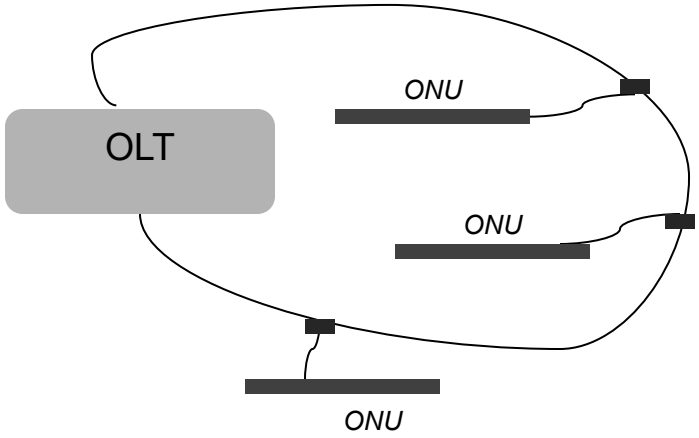
Ethernet PONs (EPONs)

- 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 downstrea for G.652)
  - 20 km (DFB-LD @ ONUs)
- Different configurations are allowed

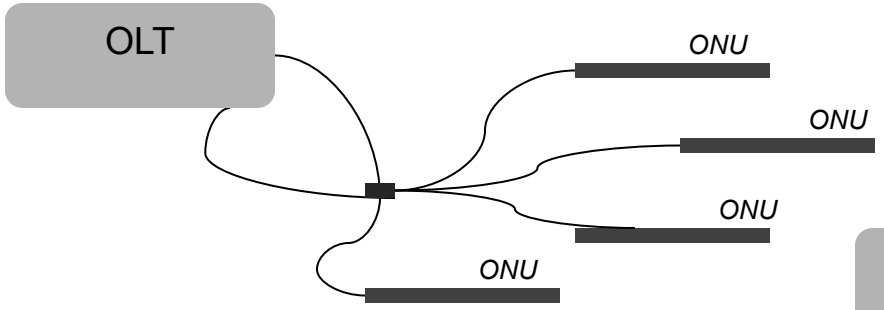
EPON Configurations



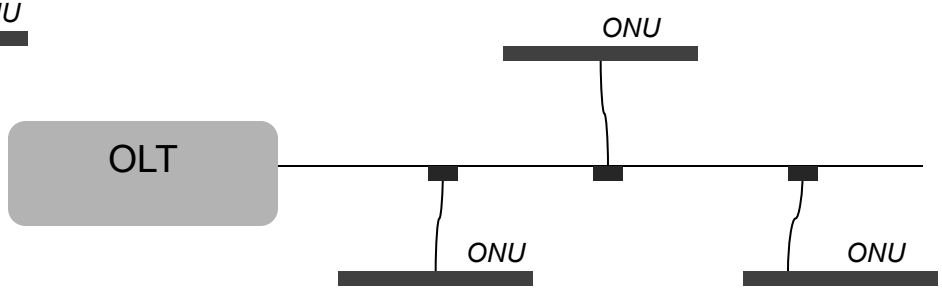
1) Tree Topology



(2) Ring Topology



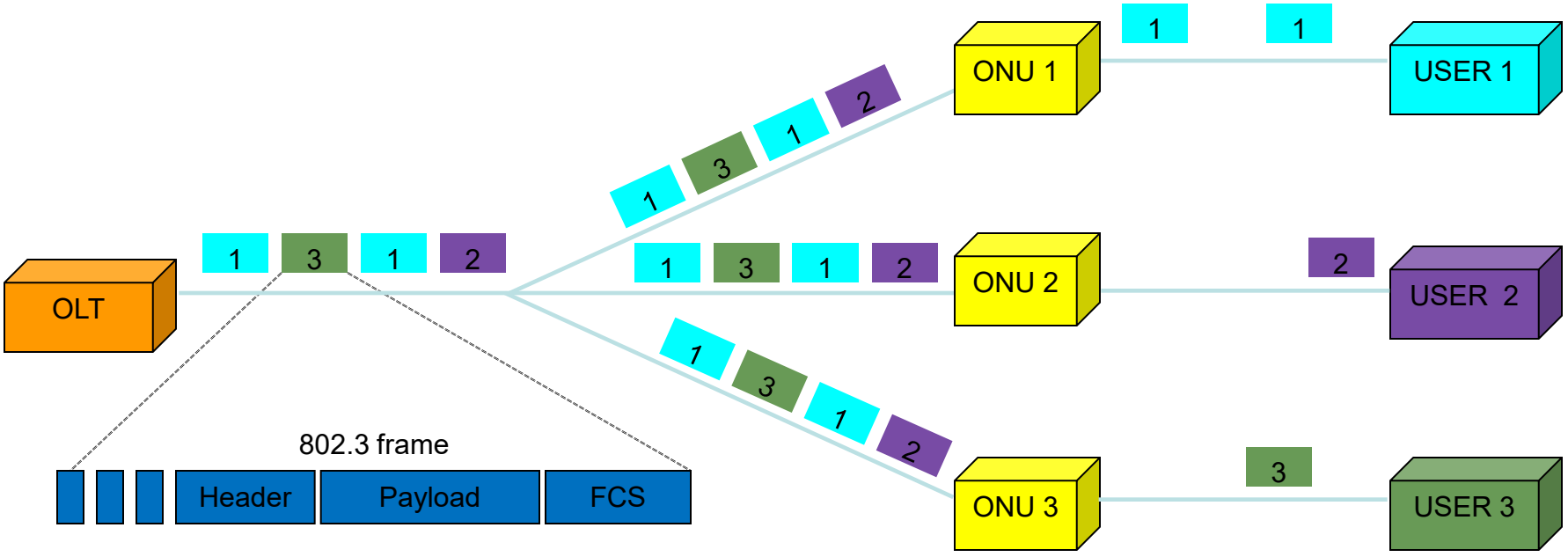
(3) Tree with Redundant Trunk



(4) Bus Topology

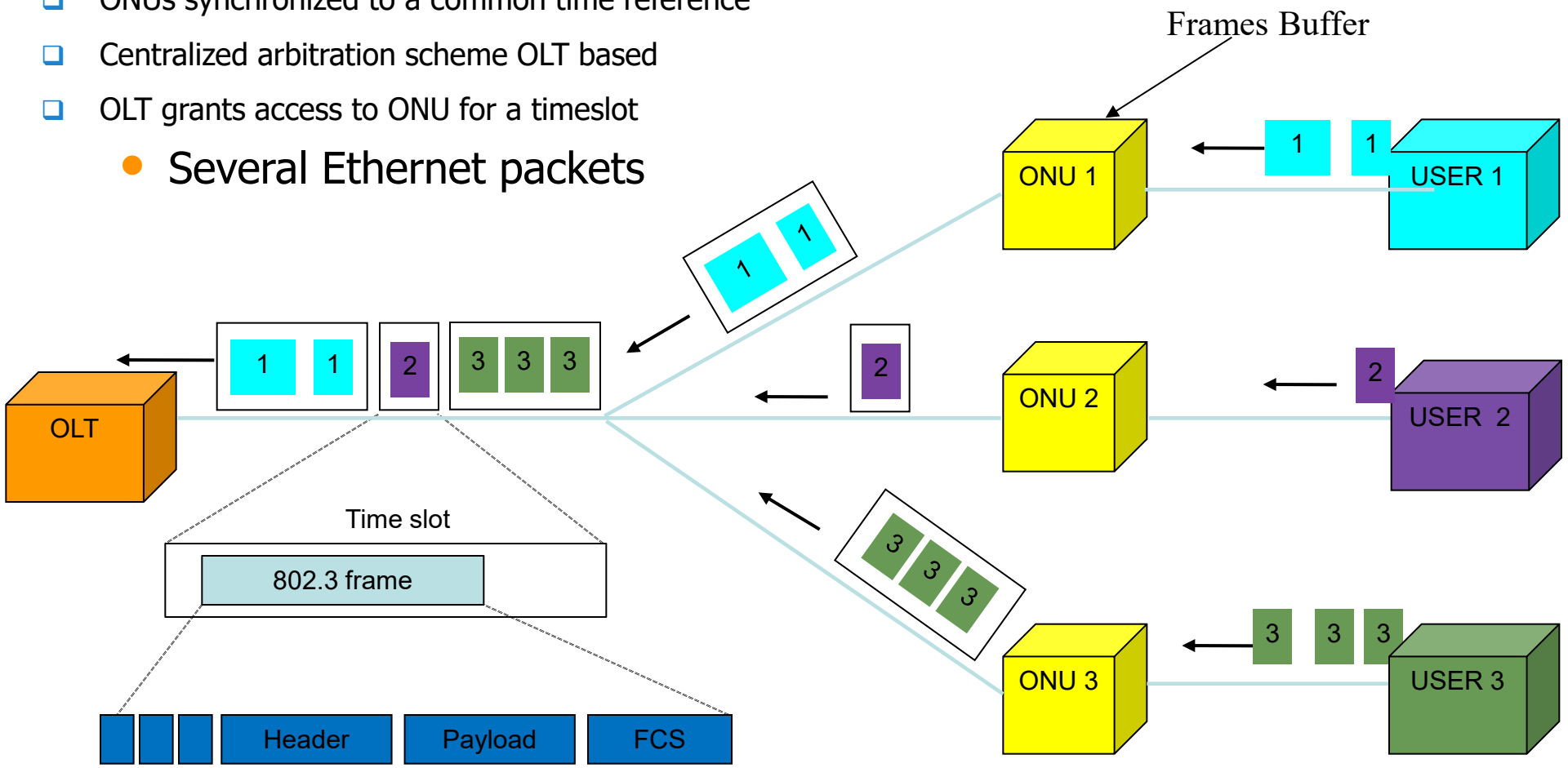
EPON Downstream Traffic

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

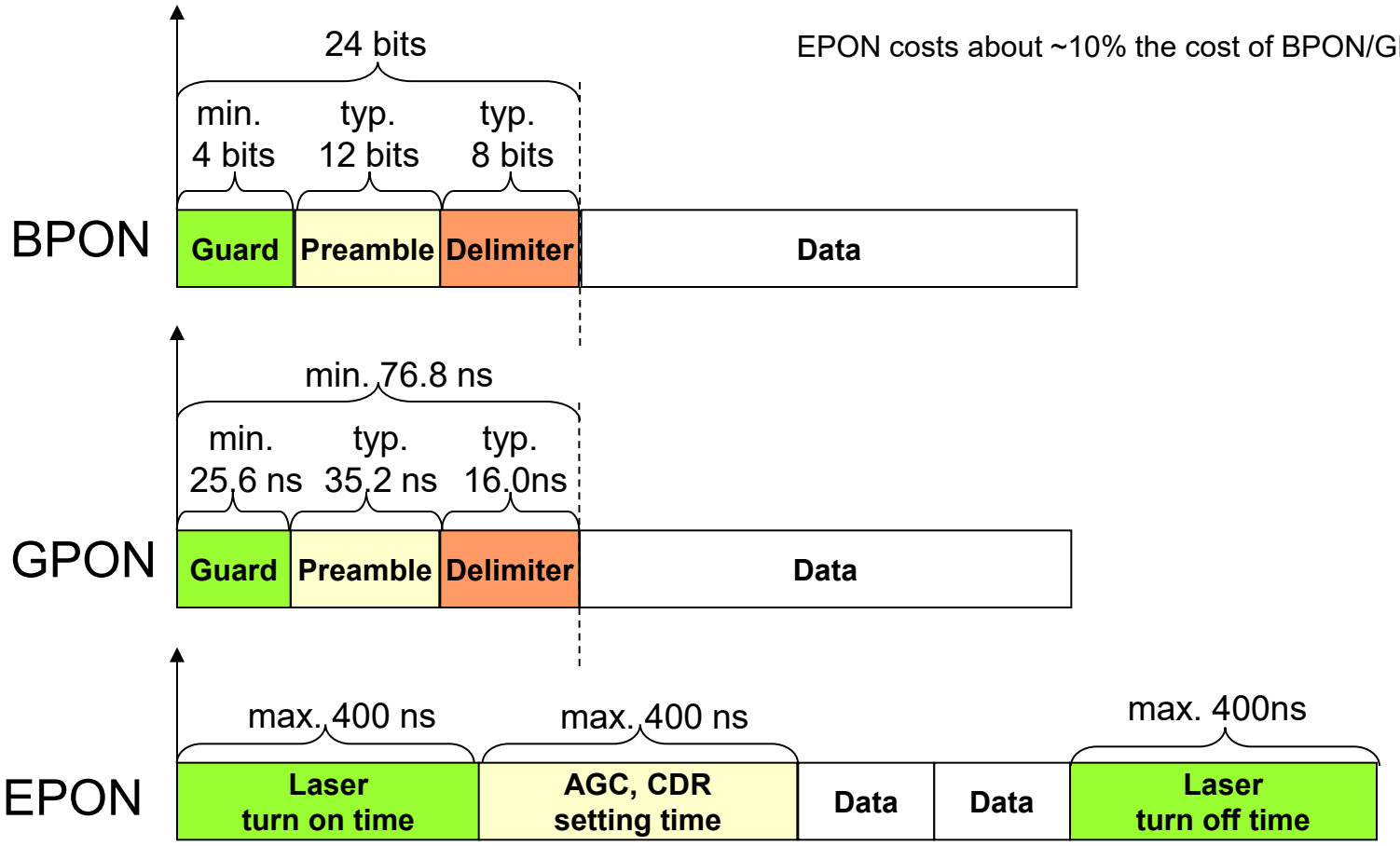


EPON Upstream Traffic

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



Header's Comparison



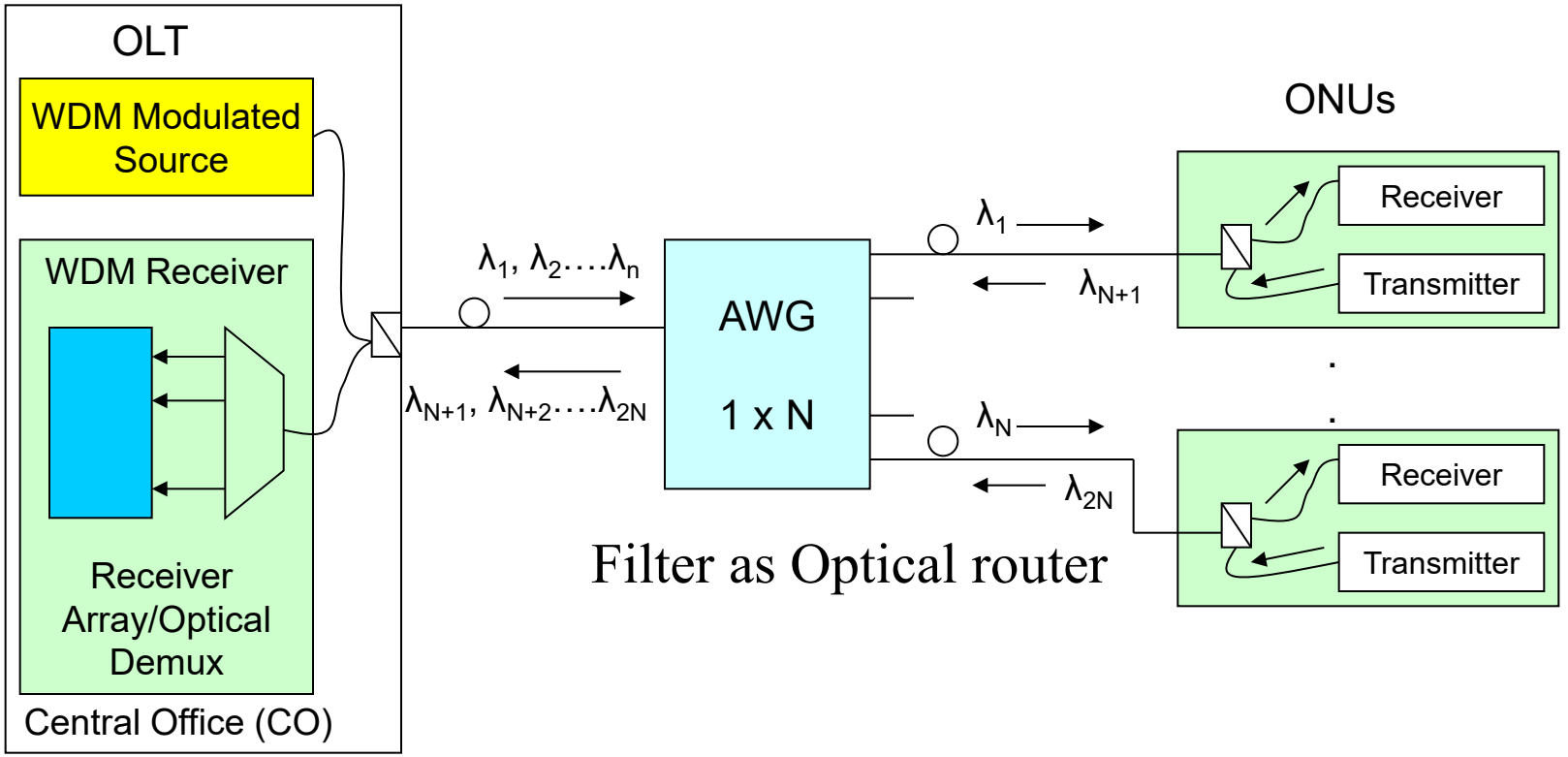
EPON costs about ~10% the cost of BPON/GPON

AGC: Automatic Gain Control; CDR: Clock and Data Recovery

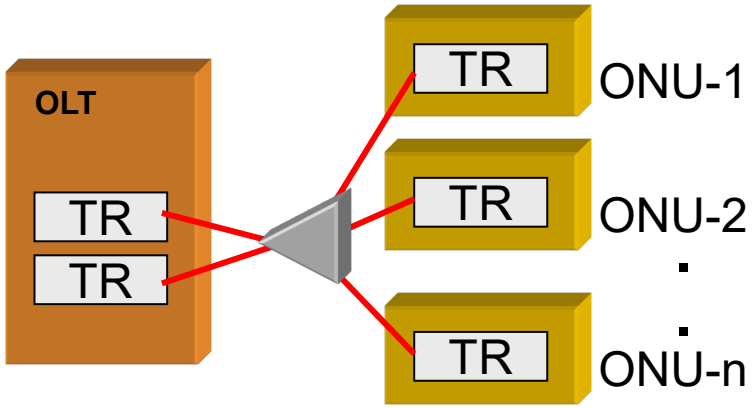
Laser turn on time overlaps the laser turn off time of the previous burst

Simple WDM-PON

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

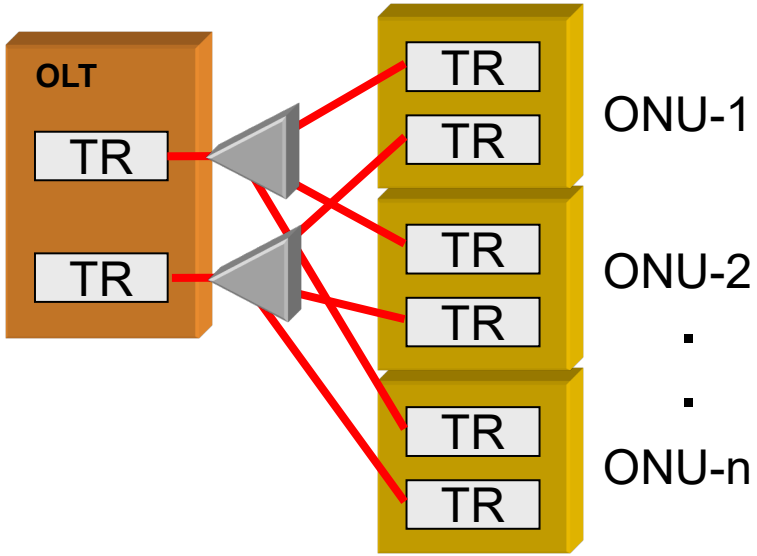


Protection Mechanisms



B type
1+1 protection of OLT

- Cost-effective
- Redundant feeder
- Redundant OLT transceivers



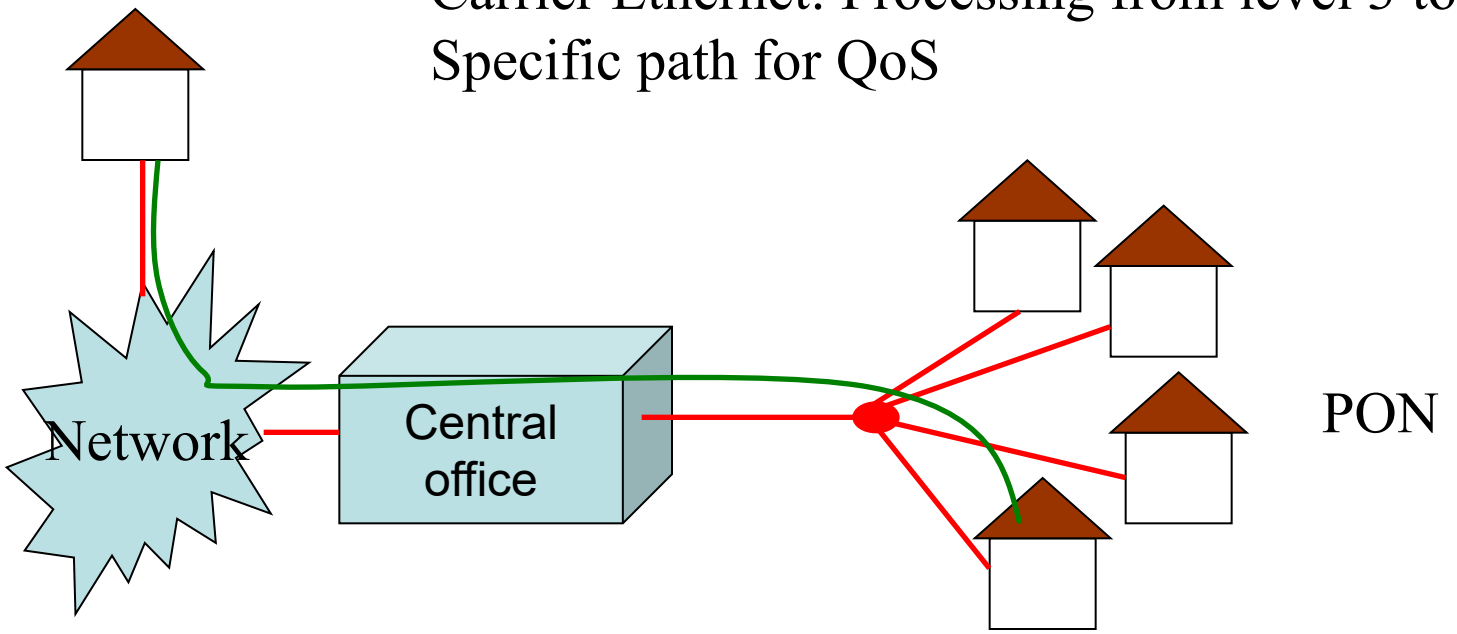
C type
1+1 protection of PON

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

Carrier Ethernet for PON (EPON)

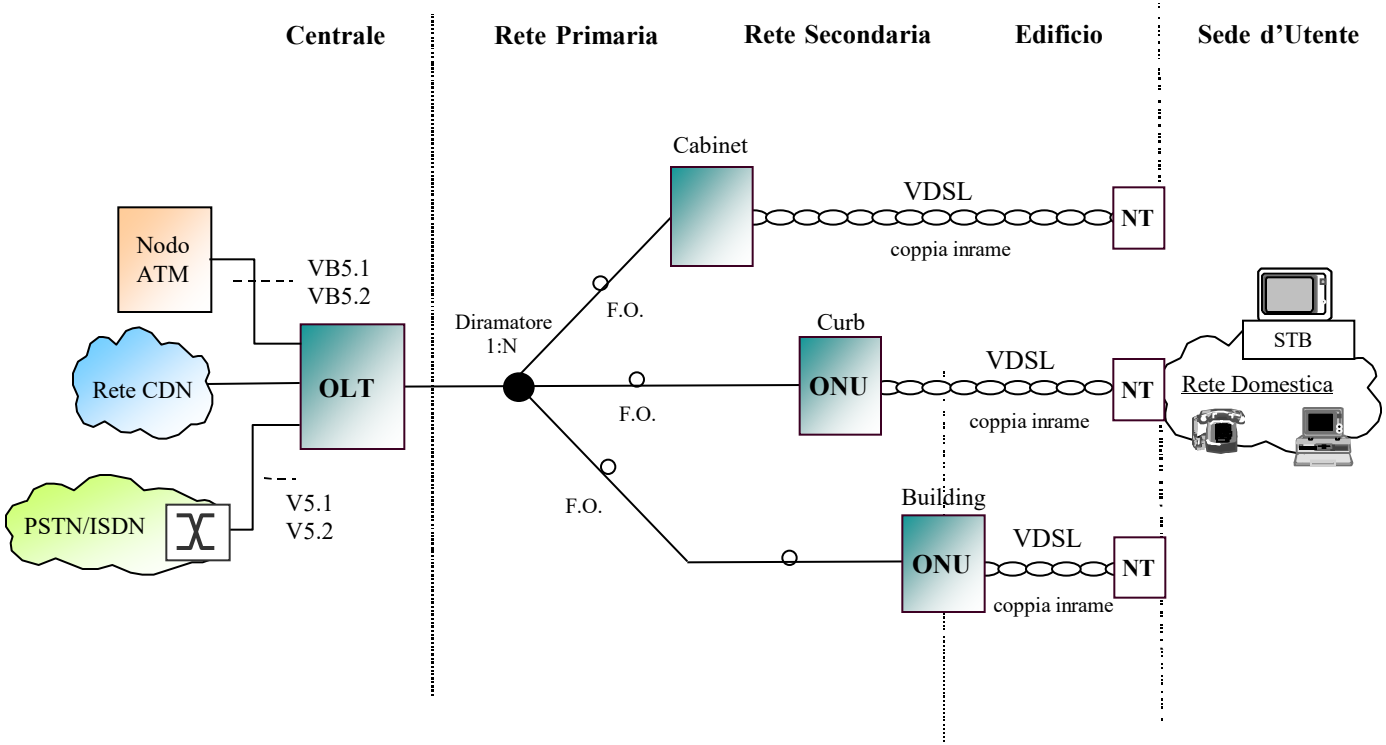
Carrier Ethernet: Processing from level 3 to 2
Specific path for QoS

c)



VLANTAG, VPLS, Q-in-Q, MAC in MAC, PBT

Elements of a PON



OLT: Optical Line
VDSL: Very high bitrate Subscriber Loop
STB: Set Top Box

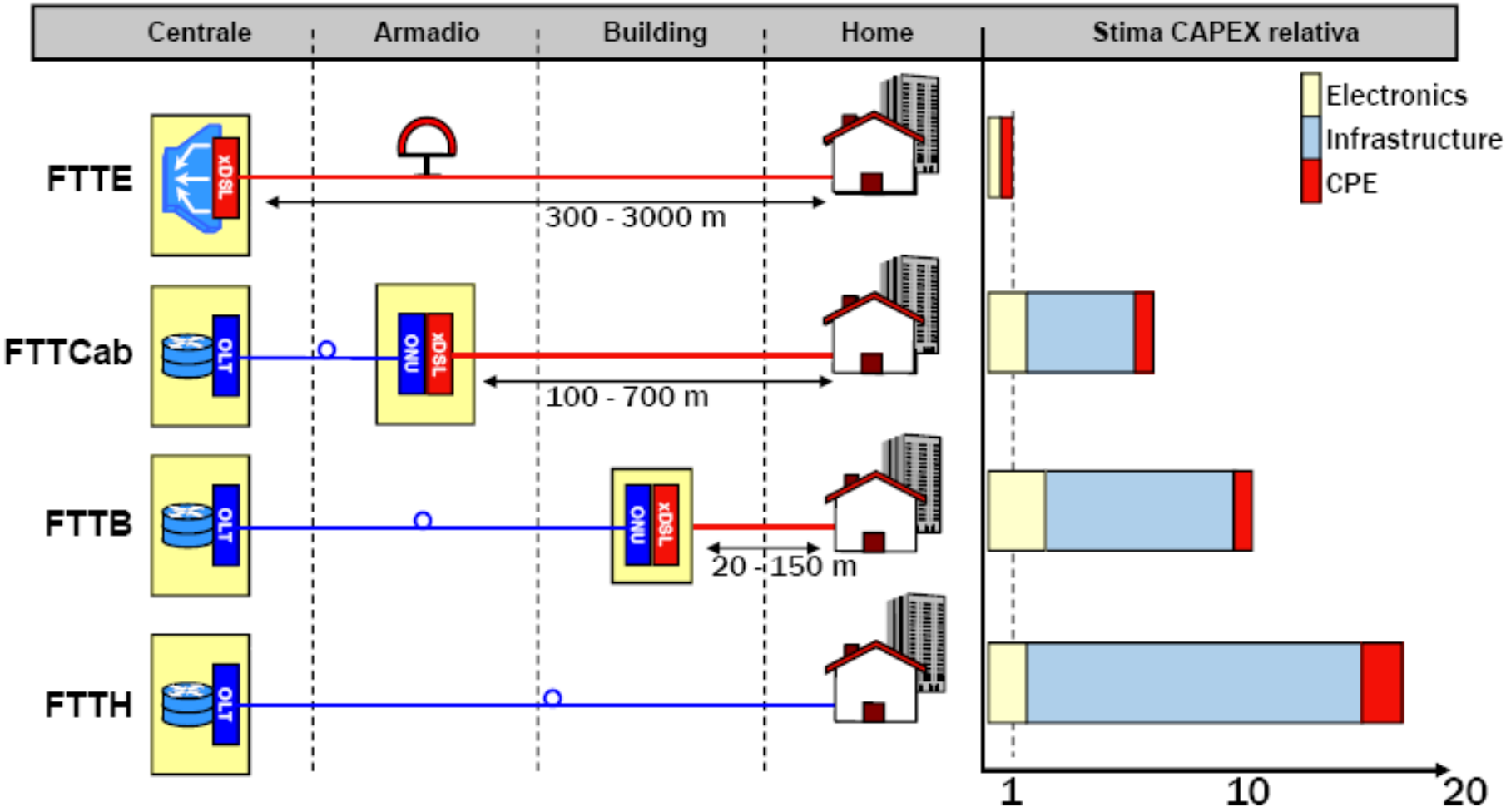
ONU: Optical Network Unit
NT : Network Termination

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

FTTx costs


Centrale
Armadio
Building
Home
Stima CAPEX relativa
FTTE
FTTCab
FTTB
FTTH
OLT
ONU
xDSL
300 - 3000 m
100 - 700 m
20 - 150 m
Electronics
Infrastructure
CPE
1
10
20