SAPIENZA
UNIVERSITÀ DI ROMA

Network Infrastructures

A.A. 2019-2020
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
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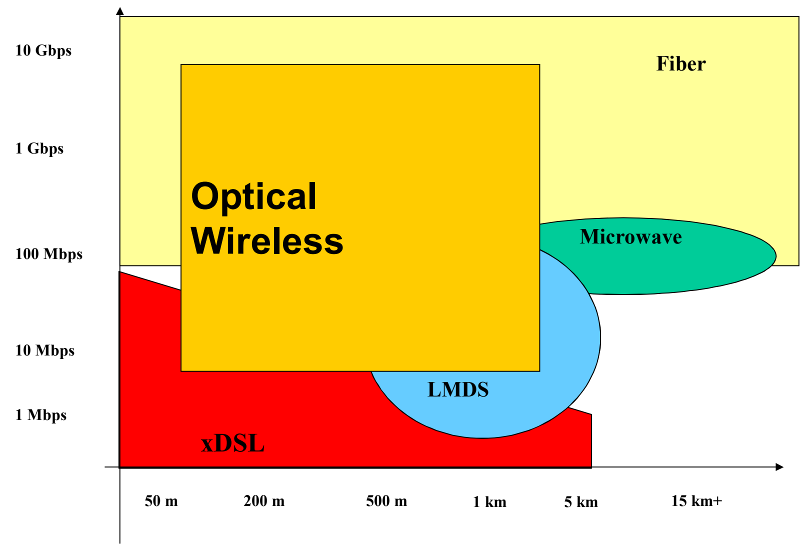
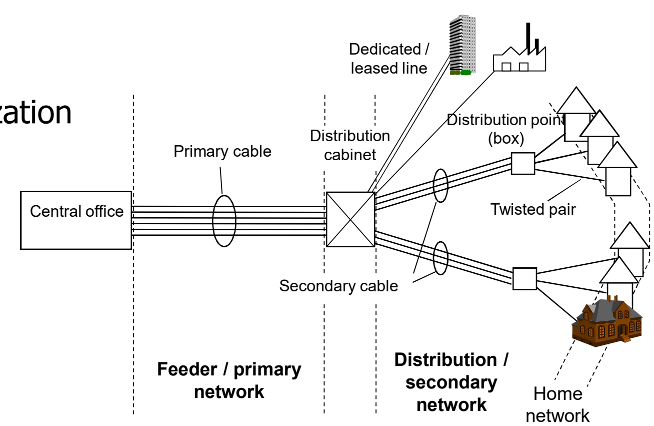
Main source: Project EU E-Photon/One+, Lessons from Prof. A. Pattavina, G. Maier, Politecnico di Milano

Access/backhoul



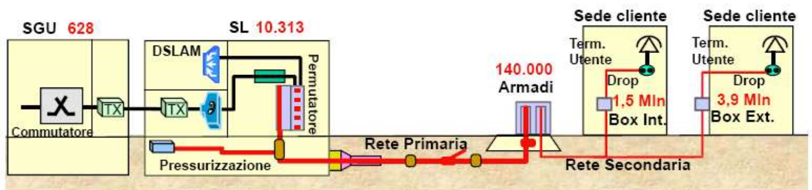
PSTN access-network Physical architecture

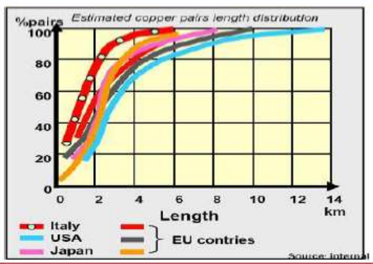
- Primary network
  - High sharing
  - Cost minimization
- Secondary network
  - Flexibility
  - Branching
- Cables
  - Primary
    - 2400-2000 pairs
    - In duct or pipe
  - Secondary
    - 100-10 pairs
    - Trenched or aerial
- Cascading more stages of cabinets is possible but rare



Telecom access networks

La rete accesso in rame oggi

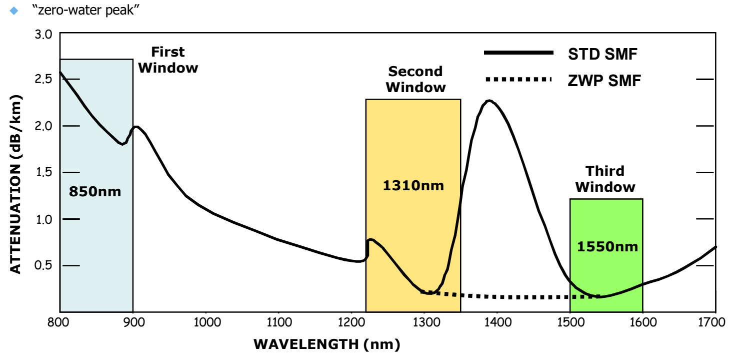




- ~ 530.000 km cavo
- ~ 110.000.000 km coppia
- ~ 140.000 armadi
- ~ 5.500.000 distributori/terminazioni

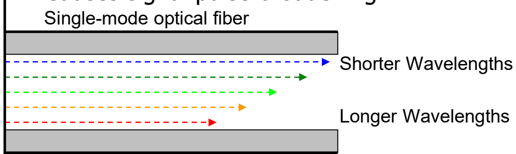
Optical Fiber: Attenuation

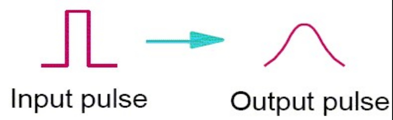
- Single Mode Fiber (SMF) to achieve large distances
  - **<u>ITU G.652 SMF (STD)</u>**
    - "water peak" attenuation renders the 1360nm–1480nm spectrum unusable for data transmission
  - ITU G652c/d SMF (ZWP)
    - "zero-water peak"

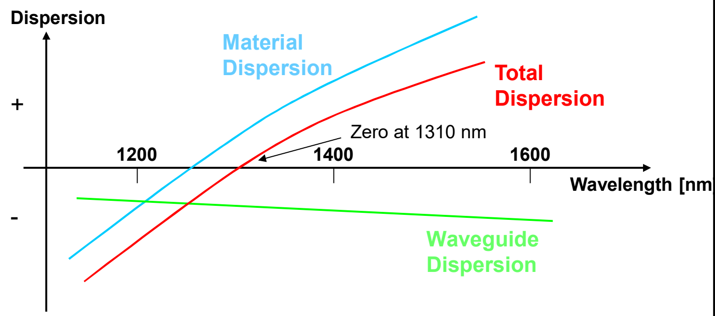


Optical Fiber: Chromatic Dispersion

- Causes signal pulse broadening



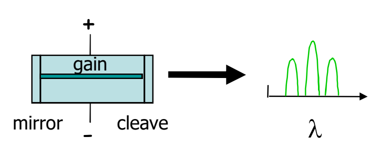




Lasers Diodes (LD)

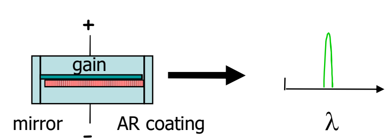
- Fabry-Perot (FP)
  - Cheap
  - Noisy
    - Sensitive to chromatic dispersion
  - Used on 1310 nm

Simple FP



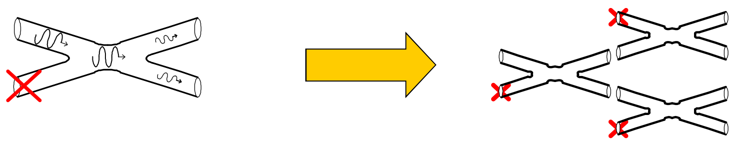
- Distributed Feedback (DFB)
  - More expensive
  - Narrow spectral width
    - Less sensitive to chromatic dispersion
  - Used on 1550 nm (or 1310 nm)

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)

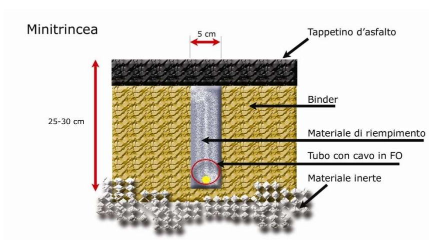
- PIN Photodiodes
  - Good optical sensitivity (~-22 dBm)
  - Silicon for shorter λ's (eg 850nm)
  - InGaAs for longer λ's (eg 1310/1550nm)
- Avalanche Photodiodes (APDs)
  - Higher sensitivity (~-30 dBm)
  - Primarily for extended distances in Gb/s rates
  - Much higher cost than PIN diodes

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**

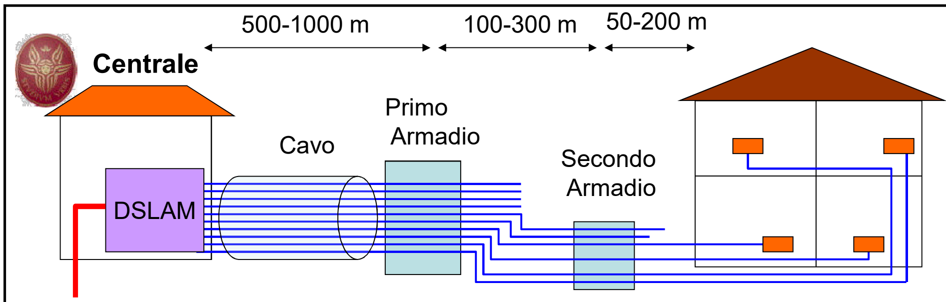
Fiber installation



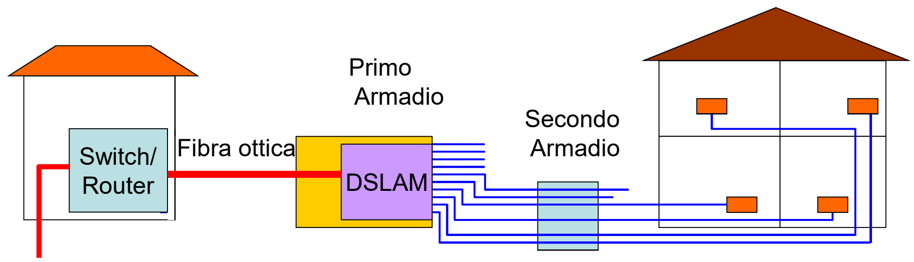
La microtrincea come semplice ed economica soluzione per la diffusione della fibra ottica nella rete di accesso (from HighBand)

30-40 K €/km per microtrincea

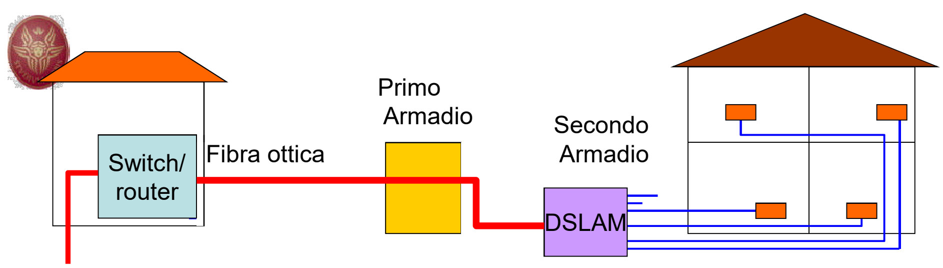
Soffiaggio della fibra (ERICSSON)



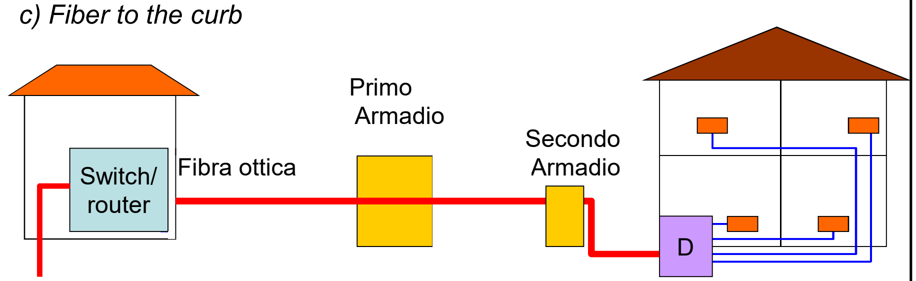
a) Best current architecture



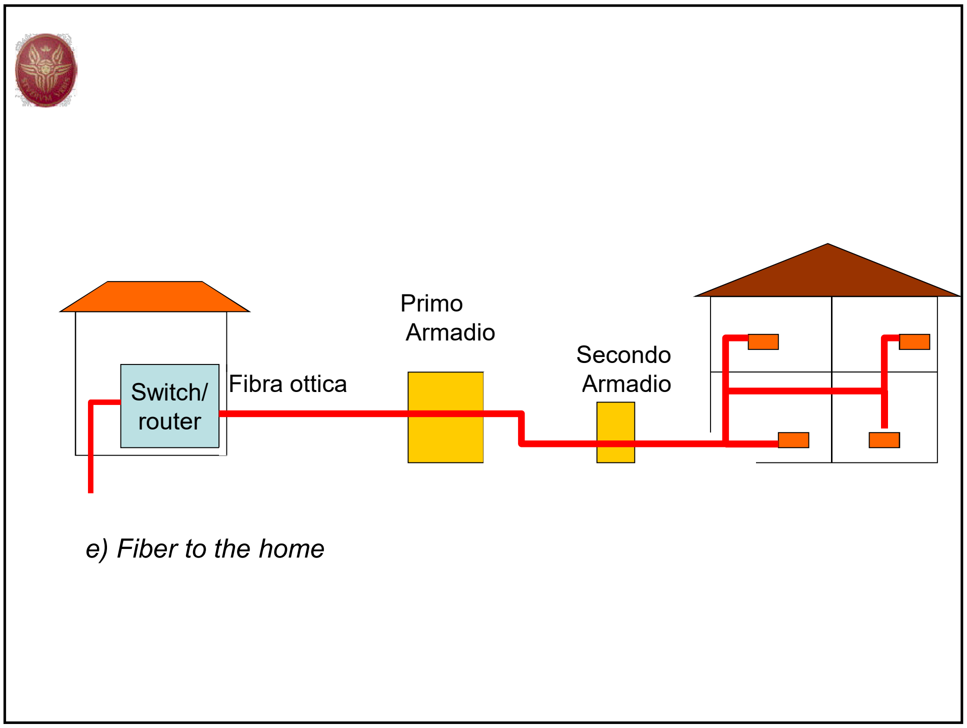
b) Fiber to the cabinet



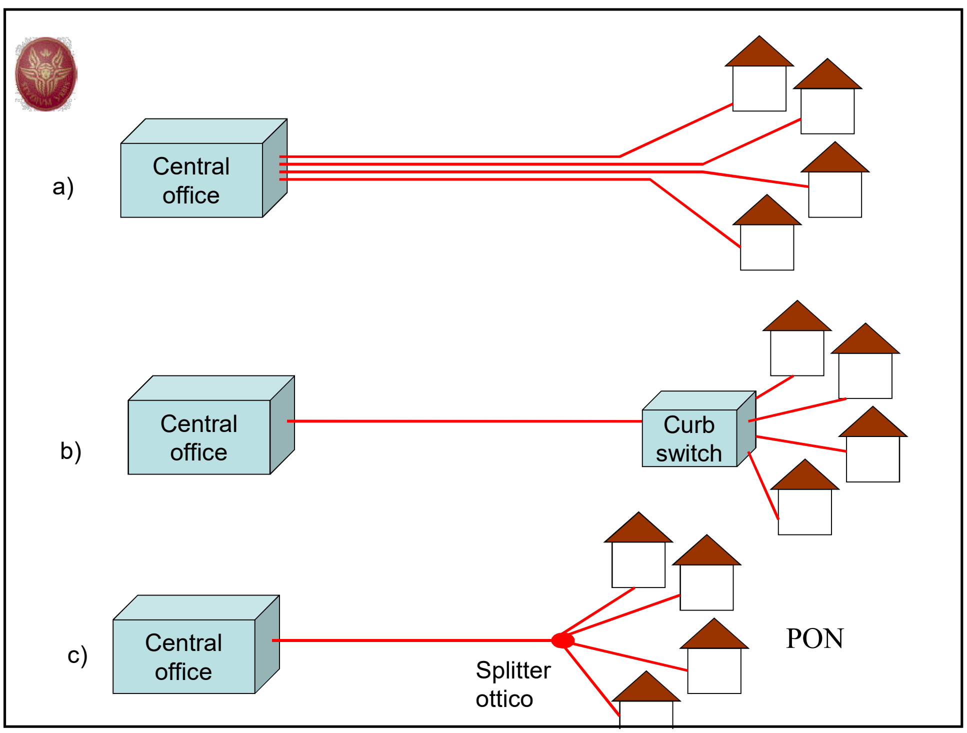
c) Fiber to the curb



d) Fiber to the building

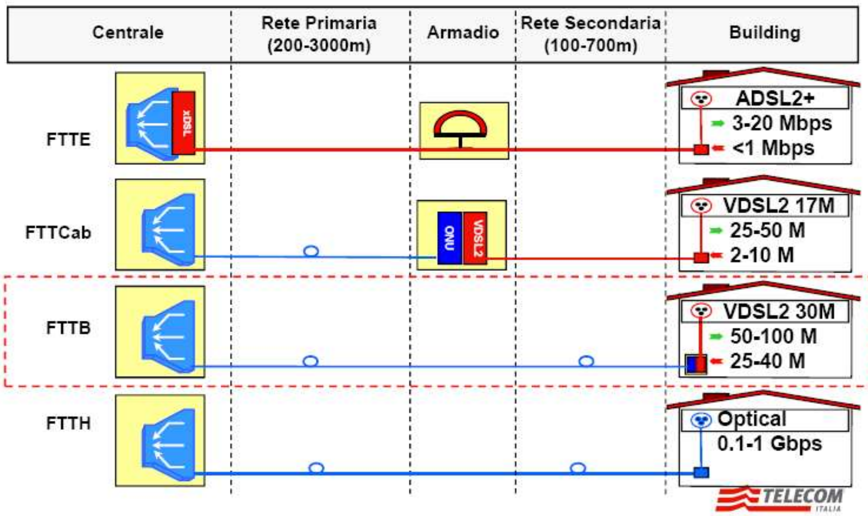


Switch/
router
Fibra ottica
Primo
Armadio
Secondo
Armadio
e) Fiber to the home



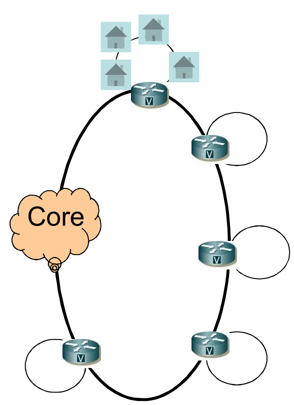
a)
Central
office
b)
Central
office
Curb
switch
c)
Central
office
Splitter
ottico
PON

Access capacities

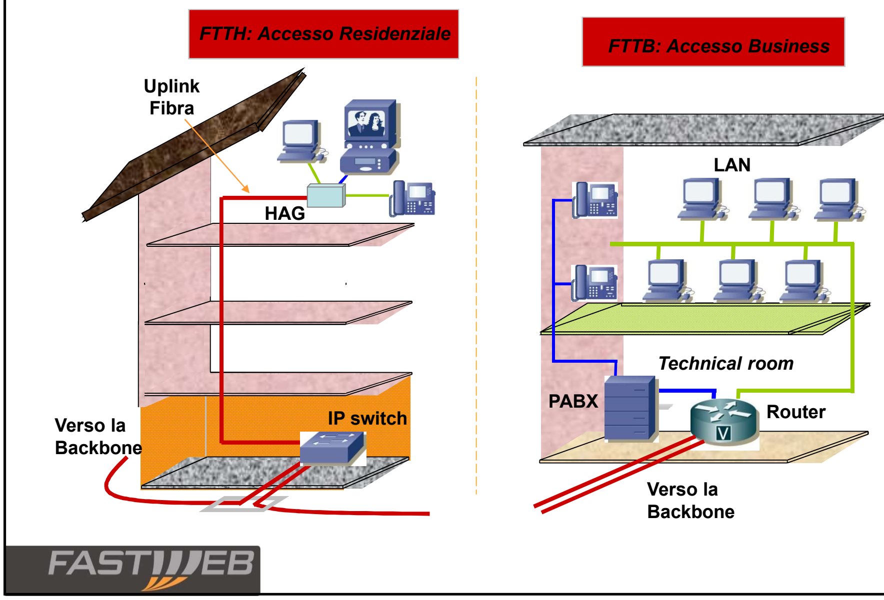


GbE based: FASTWEB

Daisy chain architecture



First case in Europe:Fastweb 2000



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.

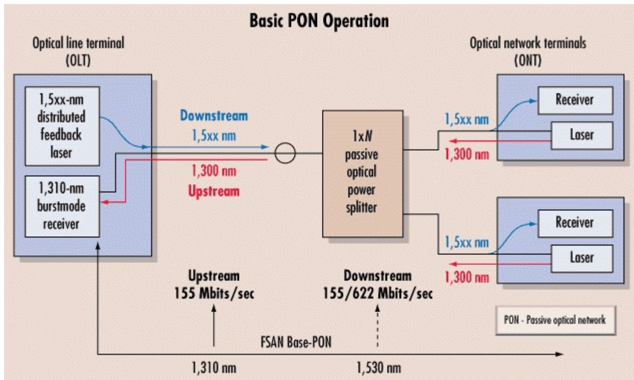
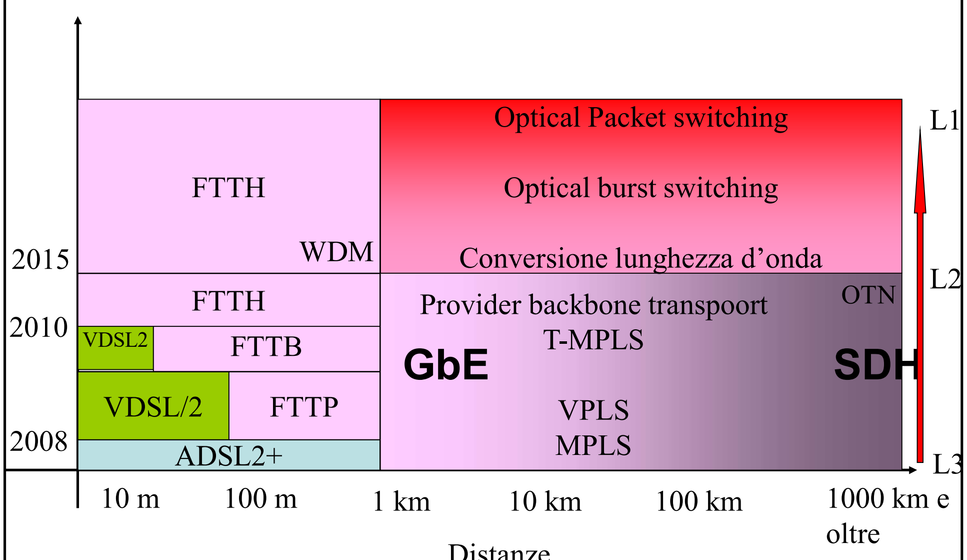


Figure 1. A basic passive-optical-network operation enables service to as many as 32 optical-network terminals (ONTs). Each ONT, in turn, can be connected to multiple subscribers, making fiber more affordable for access networks.

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

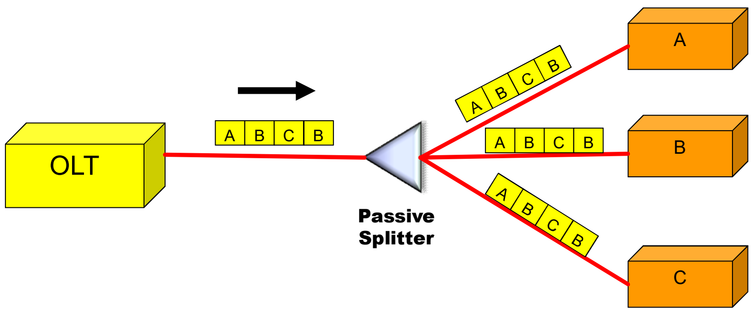
WDMA
Wavelength Division Multiple Access

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…

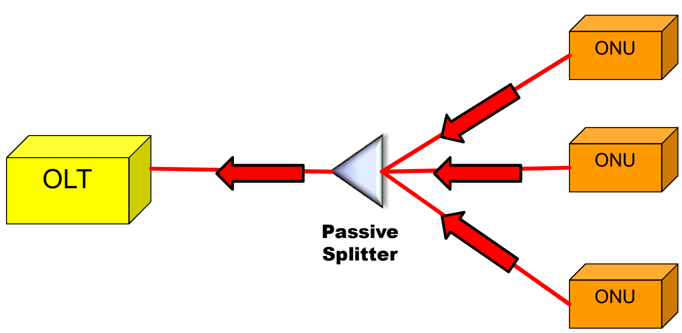
Downstream Traffic Scheduling

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



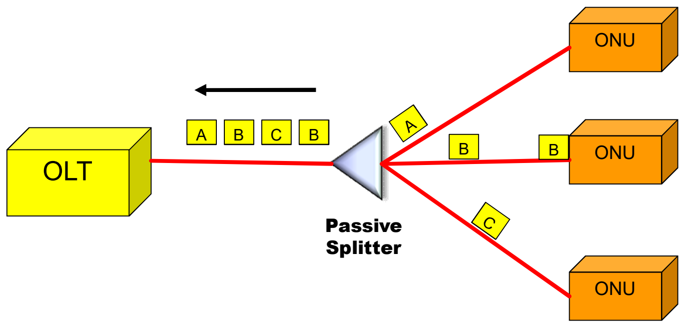
Upstream Traffic

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



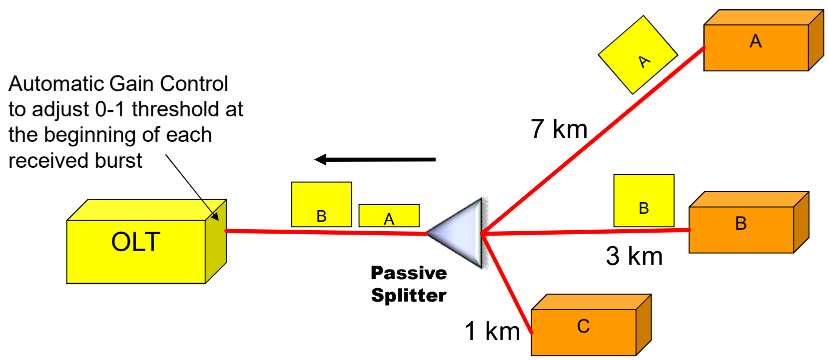
Upstream Traffic Scheduling 2/4

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

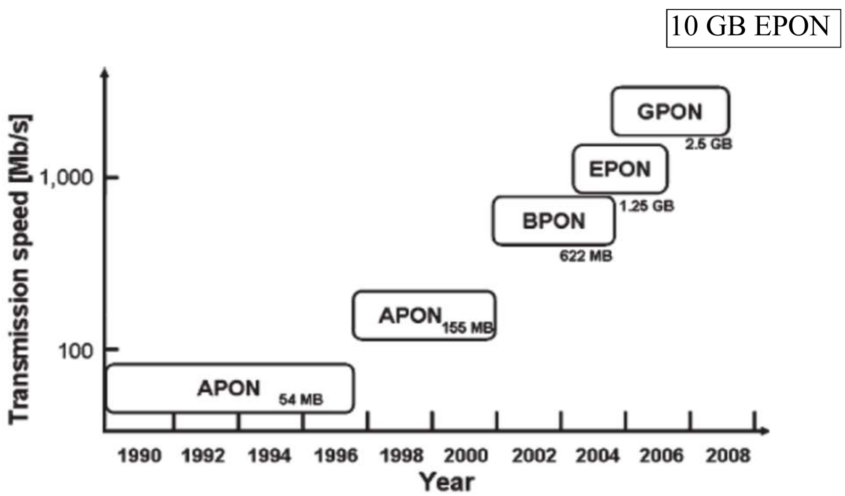


Upstream Frame Reception

- 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



Fiber in the loop
PON standardization: a brief history

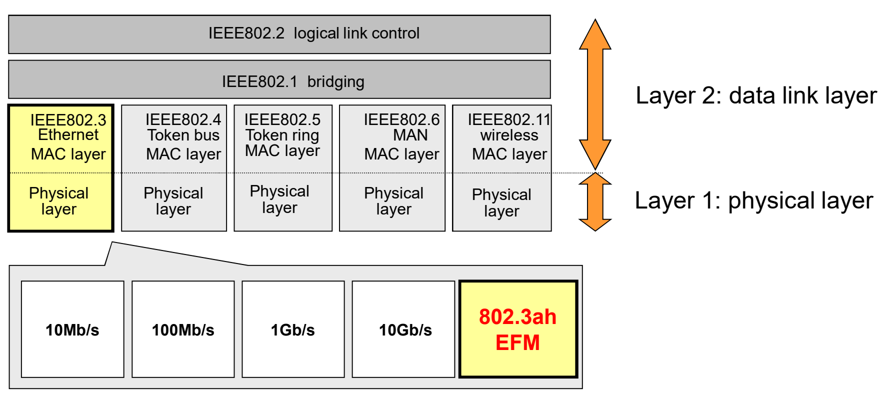
- ATM PON (A-PON)
  - Traffic is carried using ATM raw-cell format and framing
  - 1982: idea of PON (British Telecom)
  - 1987 – 1999: PON testbeds by BT, Deutsche Telekom (Eastern Germany), NTT (Japan), BellSouth (Atlanta, USA)
  - 1995: 622 Mbit/s APON testbed (RACE BAF project)
  - 1996: beginning 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 then 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

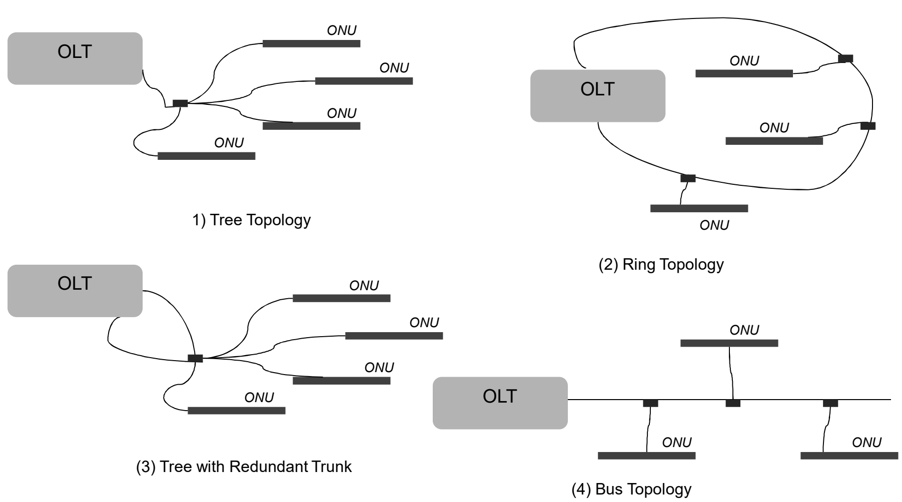
- EPON started to be standardized by IEEE 802.3ah EFM since 2001, it was ratified in 2004



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

EPON Configurations



1) Tree Topology

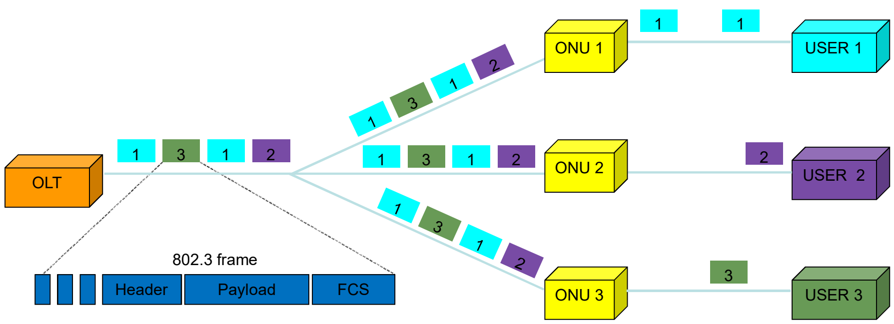
(2) Ring Topology

(3) Tree with Redundant Trunk

(4) Bus Topology

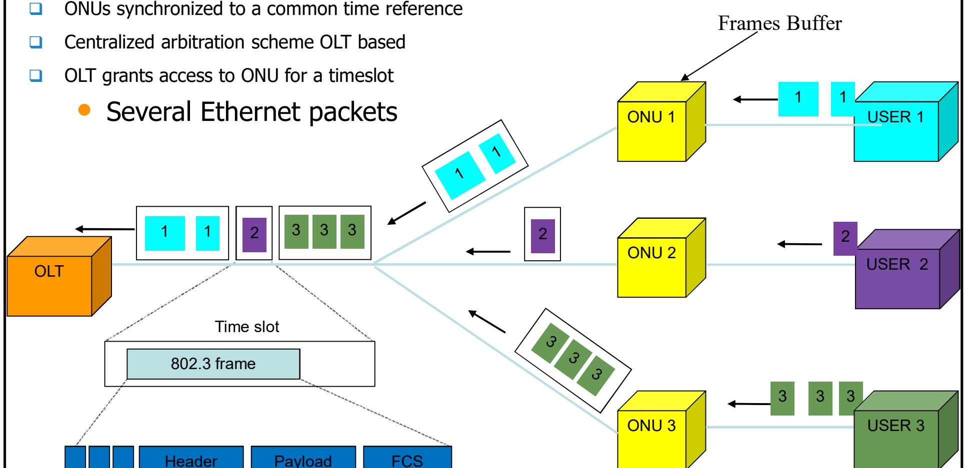
EPON Downstream Traffic

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



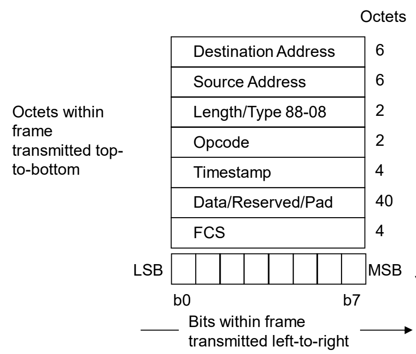
EPON Upstream Traffic

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



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

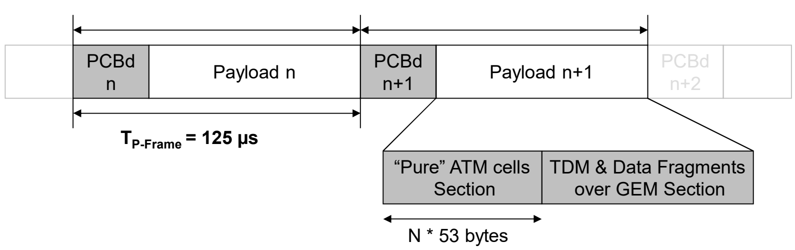
GPON Encapsulation Mode (GEM)

- 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

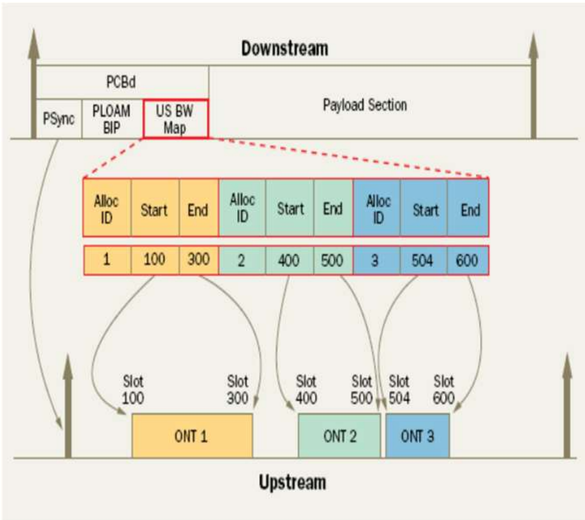
- A *Generic Frame* consists of:
  - a core header
  - a payload header
  - an optional extension header
  - a payload
  - an optional frame check sequence (FCS).

Downstream Frame Structure 1/3

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



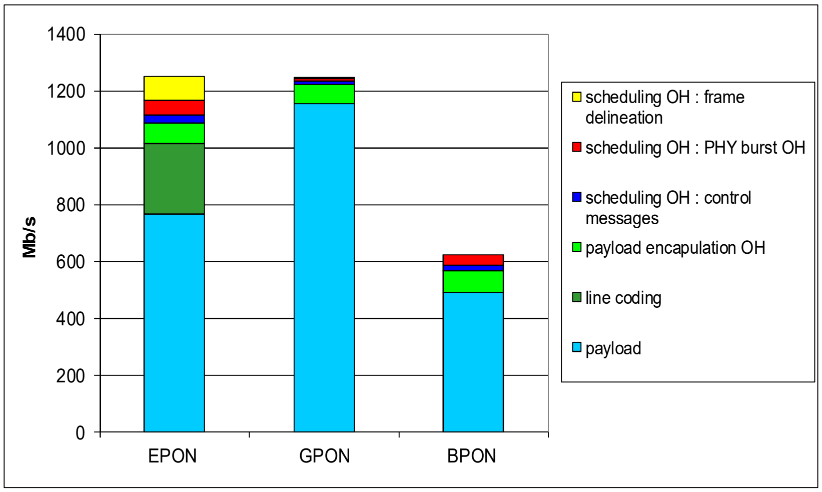
GPON Header



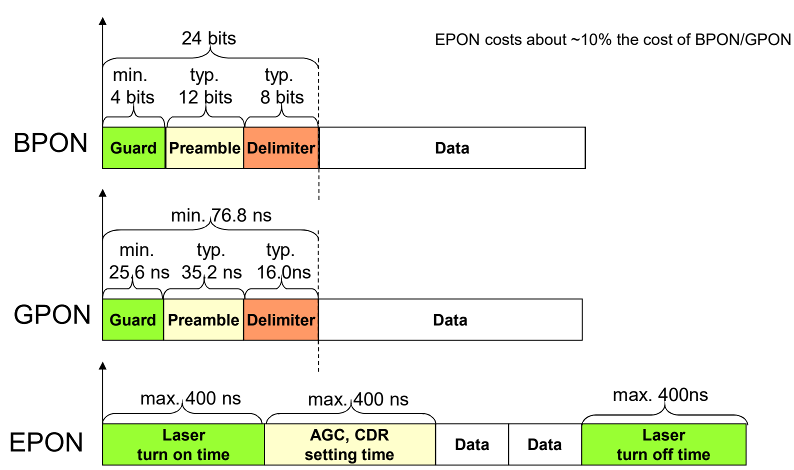
Technical Standards Comparison

Technology	Standard	Downstream/ Upstream Bandwidth	# ONT served	Lambda	Framing/ Protocol	Distance
APON/BPON (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
GPON (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)
EPON (Ethernet PON)*	IEEE 802.3ah	Symmetric 1.25 Gbit/s	Up to 16	1550 nm Down 1310 nm Up	Ethernet	10/20 km
10GEPON (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



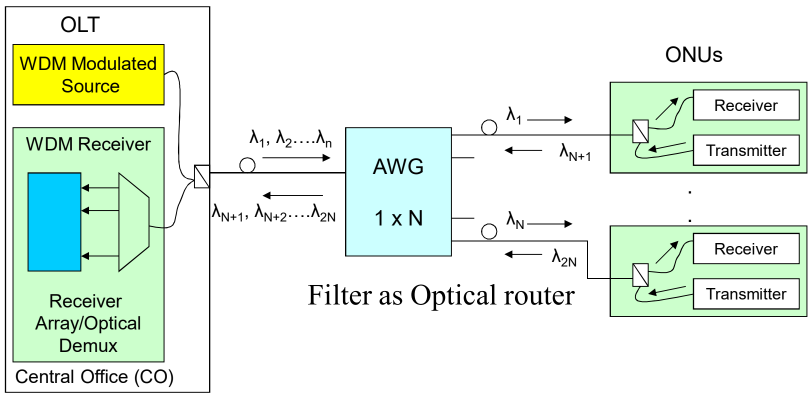
Header’s Comparison



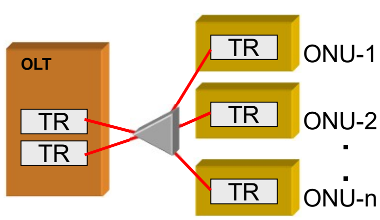
AGC: Automatic Gain Control; CDR: Clock and Data Recovery
Laser turn on time overlaps the laser turn off time of the previous burst

Simple WDM-PON

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

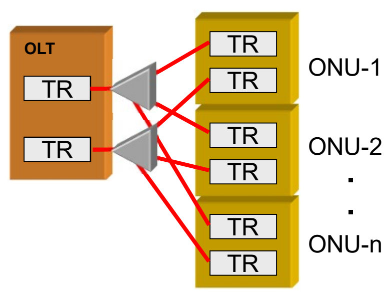


Protection Mechanisms



B type
1+1 protection of OLT

- Cost-effective
- Redundant feeder
- Redundant OLT transceivers



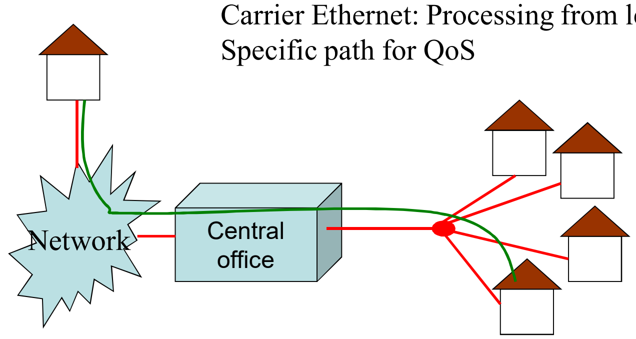
C type
1+1 protection of PON

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

Carrier Ethernet for PON (EPON)

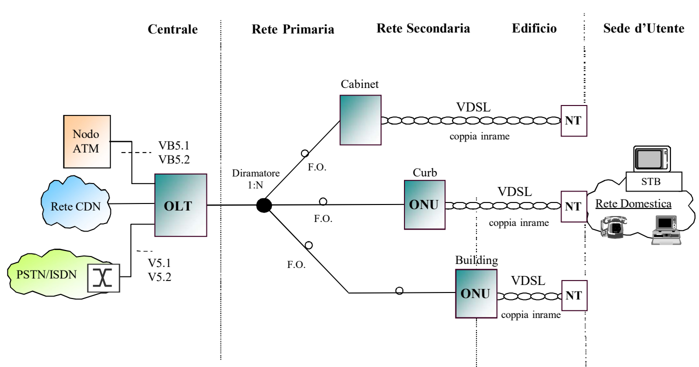
Carrier Ethernet: Processing from level 3 to 2
Specific path for QoS

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

- 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

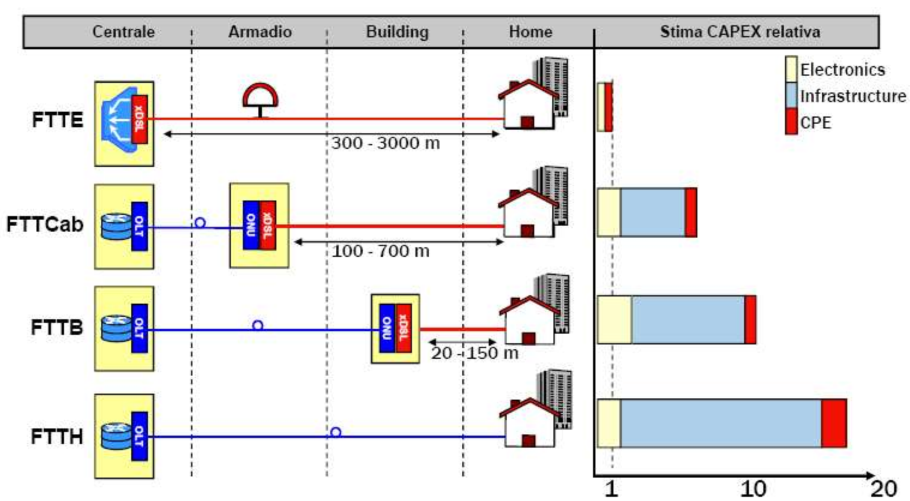
- USA
  - Large average cable-length
  - Large investments form cable operators, that account for a relevant share of the broadband market
  - No unbundling required for new fiber infrastructures.
- Brazil, Colombia, Argentina, Chile
  - Less than 300.000 FTTH users
- Australia, New Zeeland, Kuwait, 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

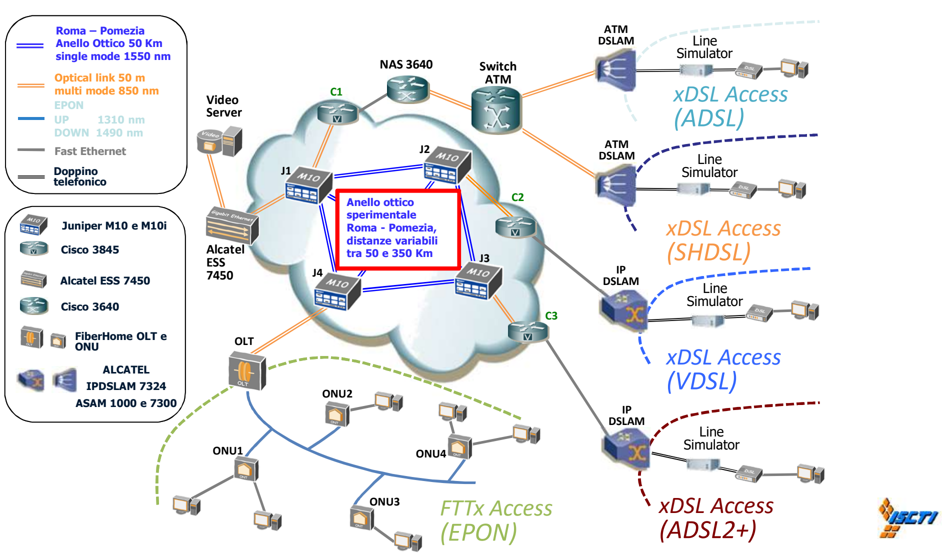
FTTx costs



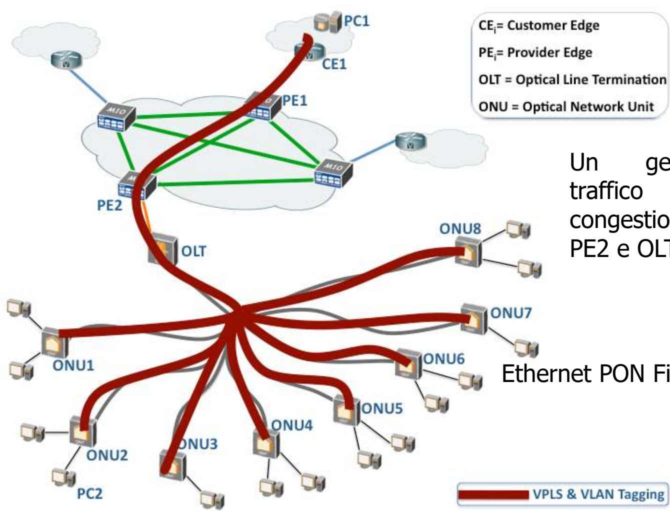
FUB study on NGN economics

- 1400 Mega Euro for digital Divide end (connection of central office to babckbone)
- 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



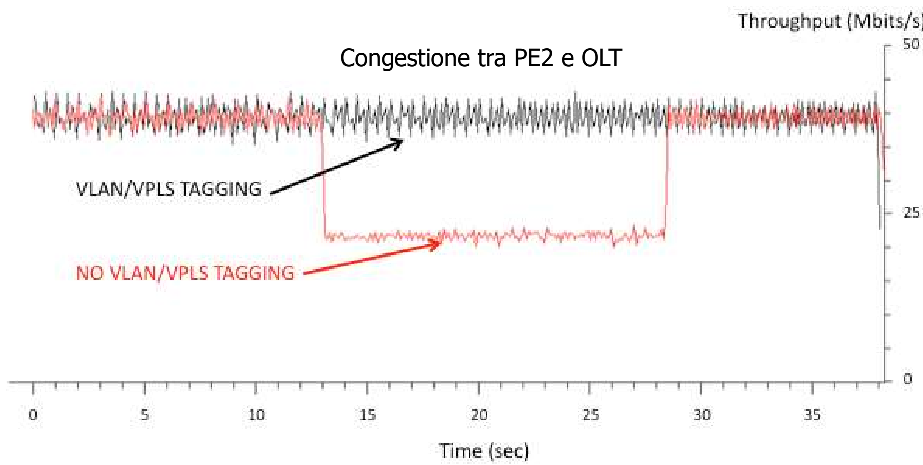
Logical network by means of VPLS&VLAN Tagging



Un generatore di traffico permette un congestionamento tra PE2 e OLT

Ethernet PON FiberHome

Throughput in downstream



Conclusions

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