OPTCOM

PHOTONS TO THE HOME

STATUS OF THE ART IN OPTICAL ACCESS NETWORKS AND FORECASTED OPTOELECTRONIC COMPONENT REQUIREMENTS

Presenter: Prof. Roberto Gaudino

Pavia, 2016 February 11st

Politecnico di Torino,
Dipartimento di Elettronica e Telecomunicazioni
OPTCOM group (www.optcom.polito.it)
Corso Duca degli Abruzzi 24, 10129 Torino, Italy,
E-mail: roberto.gaudino@polito.it

Outline of the presentation

- A review of the current status of Access networks
- Optical access networks based on PON architecture
- Challenges in future PON generations: how to handle Wavelength Division Multiplexing (WDM) and low cost?
- Connections to the EU project FABULOUS and to Silicon Photonics technologies

A review of the current status of access networks

Classification of telecommunication networks

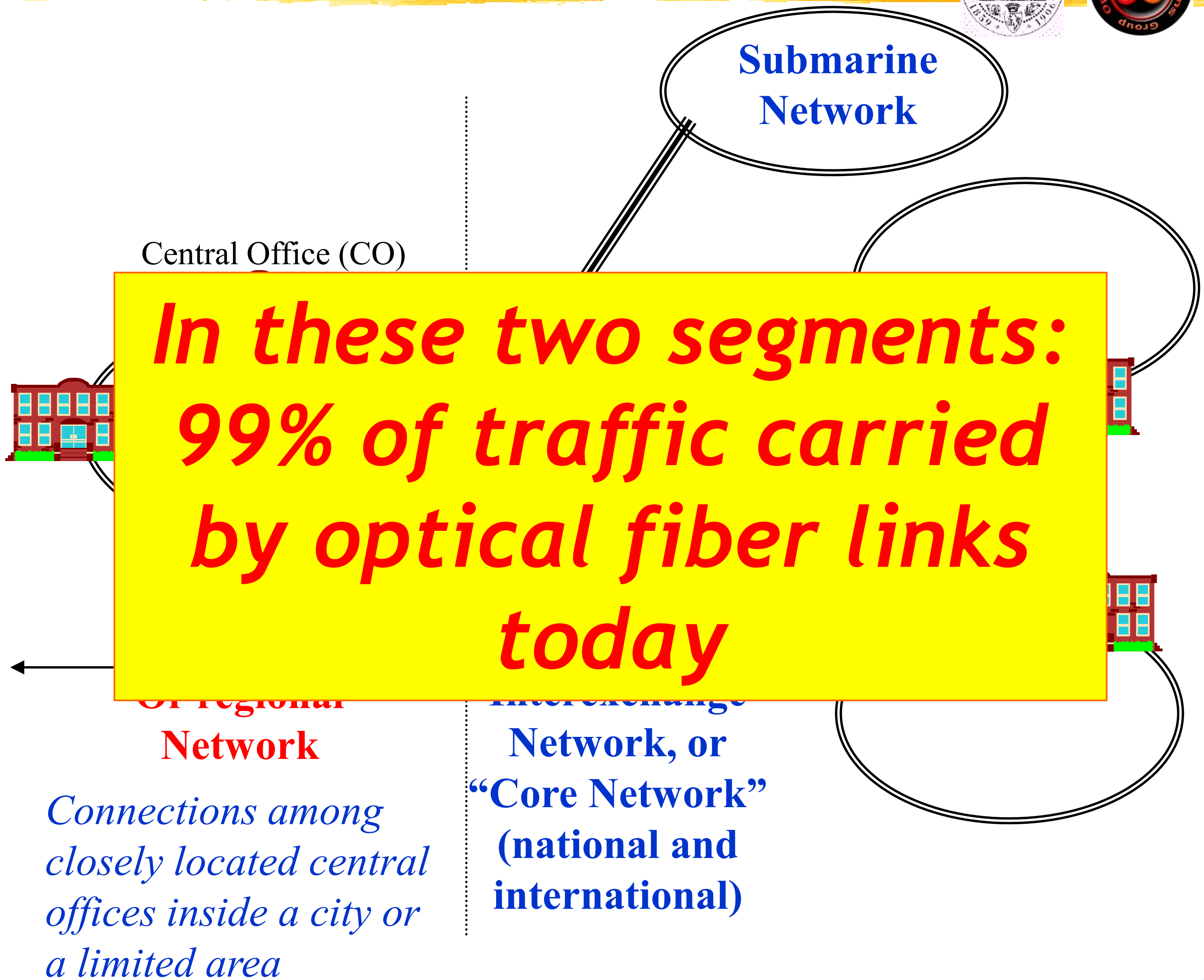
- Telecommunication networks are organized in three segments:
  1. Long-haul networks
     - Very long distance connections among large cities
  2. Metropolitan and regional networks
     - Medium distance connections inside large cities or among smaller cities
  3. Access networks
     - Toward final residential users

Long-haul networks

- Up to thousands of km
  - Trans-pacific links are 9000 km long
- Extremely high bit rates
  - Terabit/s per link
- Need to be extremely reliable and thus redundant
- Very high cost hardware

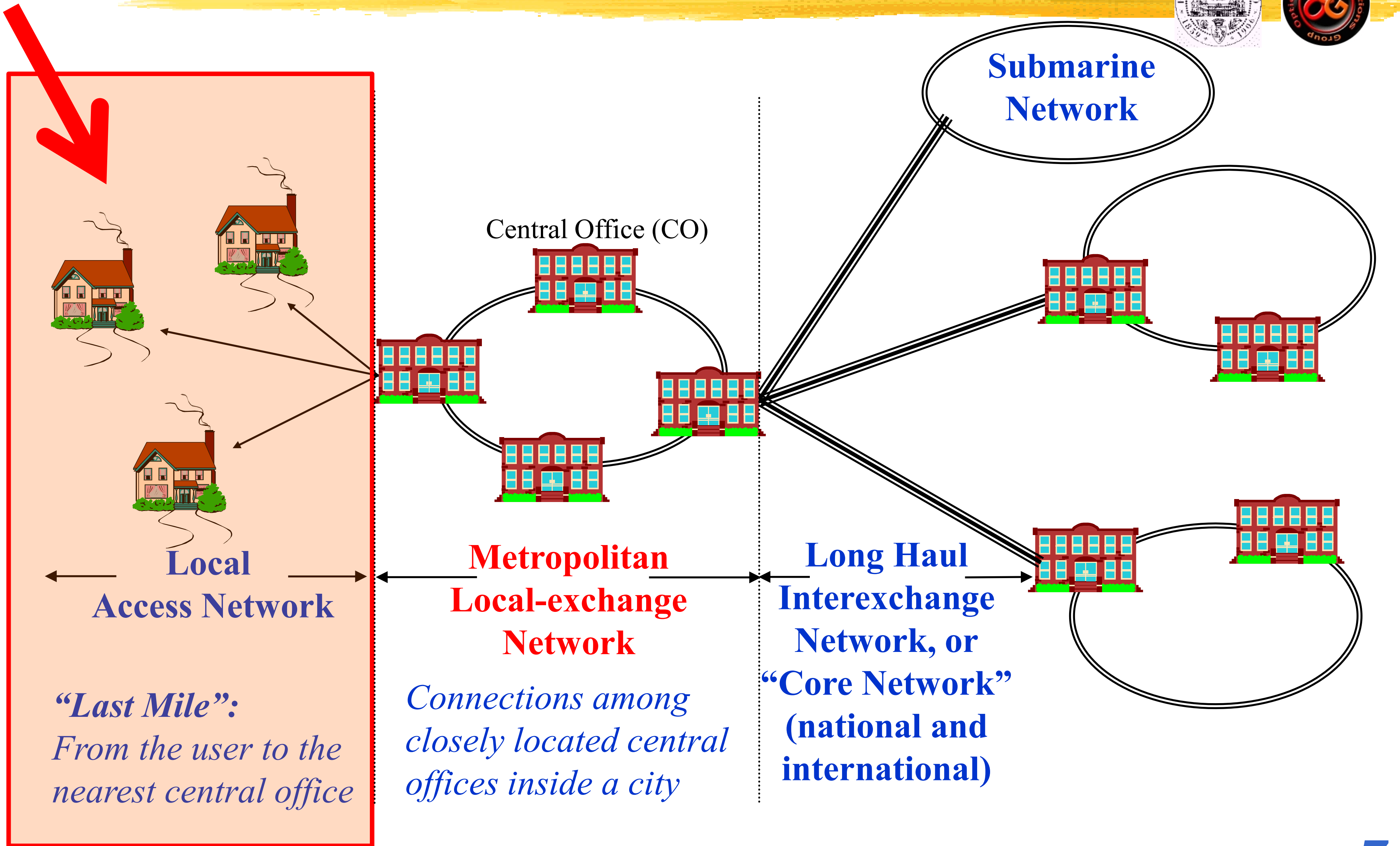
Metropolitan and regional networks

- Up to about 100km
- Very high bit rates
  - 100 Gbit/s per link typical
- Need to be extremely reliable and thus redundant
- High cost hardware



In these two segments: 99% of traffic carried by optical fiber links today

Access netowrks



Access Networks

- For access network we mean the last part of the public network toward the final user, which can be further divided into two very different areas:
  - Mobile
  - Fixed
    - Business
    - Residential
      - Fixed residential area networks typically have to cover a 2-3 km distance from each central office

Target scenario for this talk

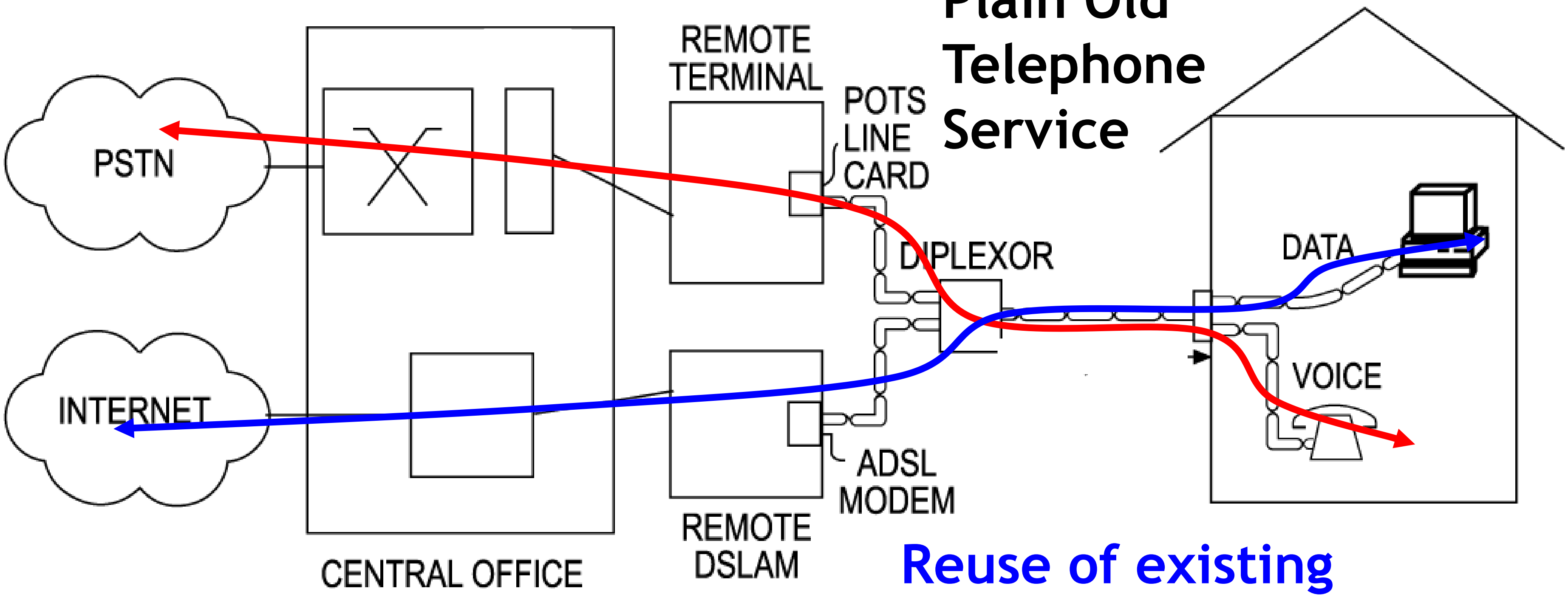
Residential Access Networks today (2016)

- In Europe, the majority of the residential customers use some forms of ADSL (or xDSL) carried over the traditional copper "twisted pair"

- But new solutions based on optical fibers are very quickly gaining momentum
  - Ultra-broadband new access solutions
  - The situation is very different from country to country in the world

ADSL: Asymmetric Digital Subscriber Loop

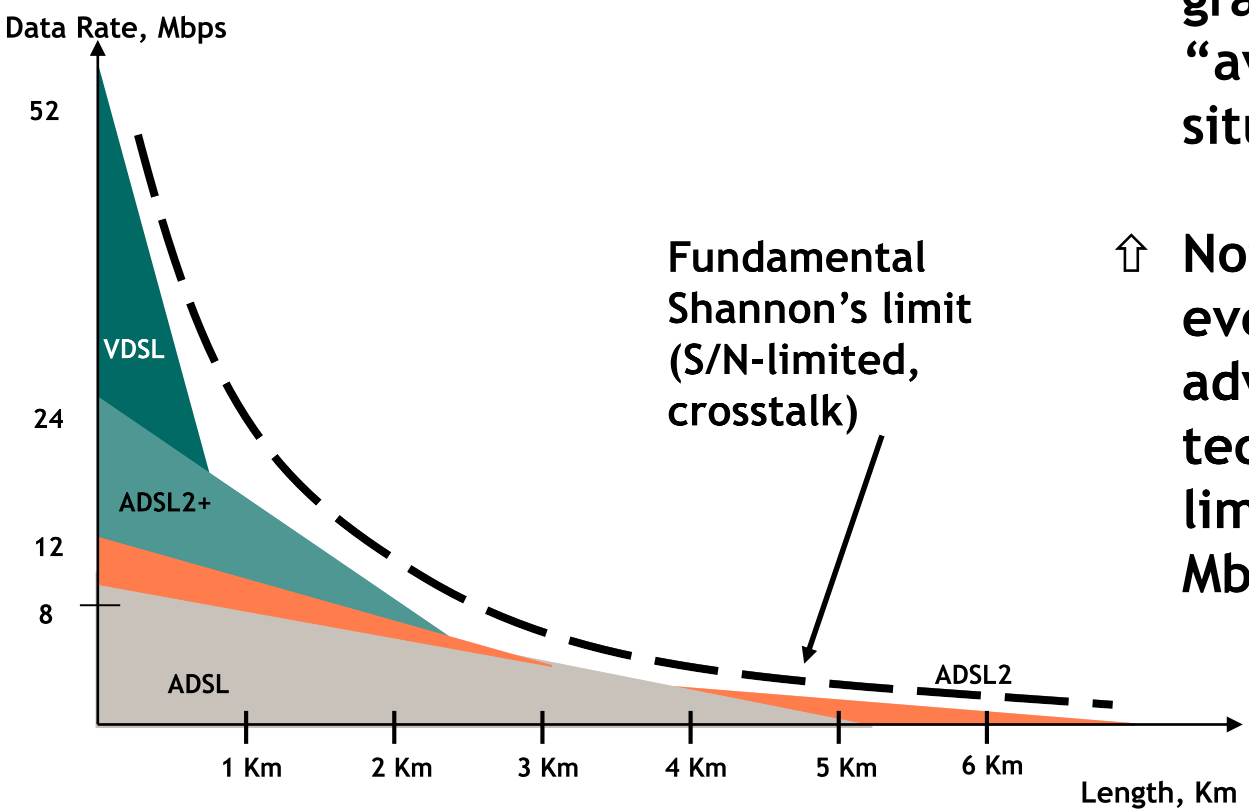
POTS
Plain Old Telephone Service



Reuse of existing copper twisted pairs
NO re-cabling needed

Picture taken from: *http://www.emeraldinsight.com/content_images/fig/2720060202006.png*

xDSL ultimate capacity limits

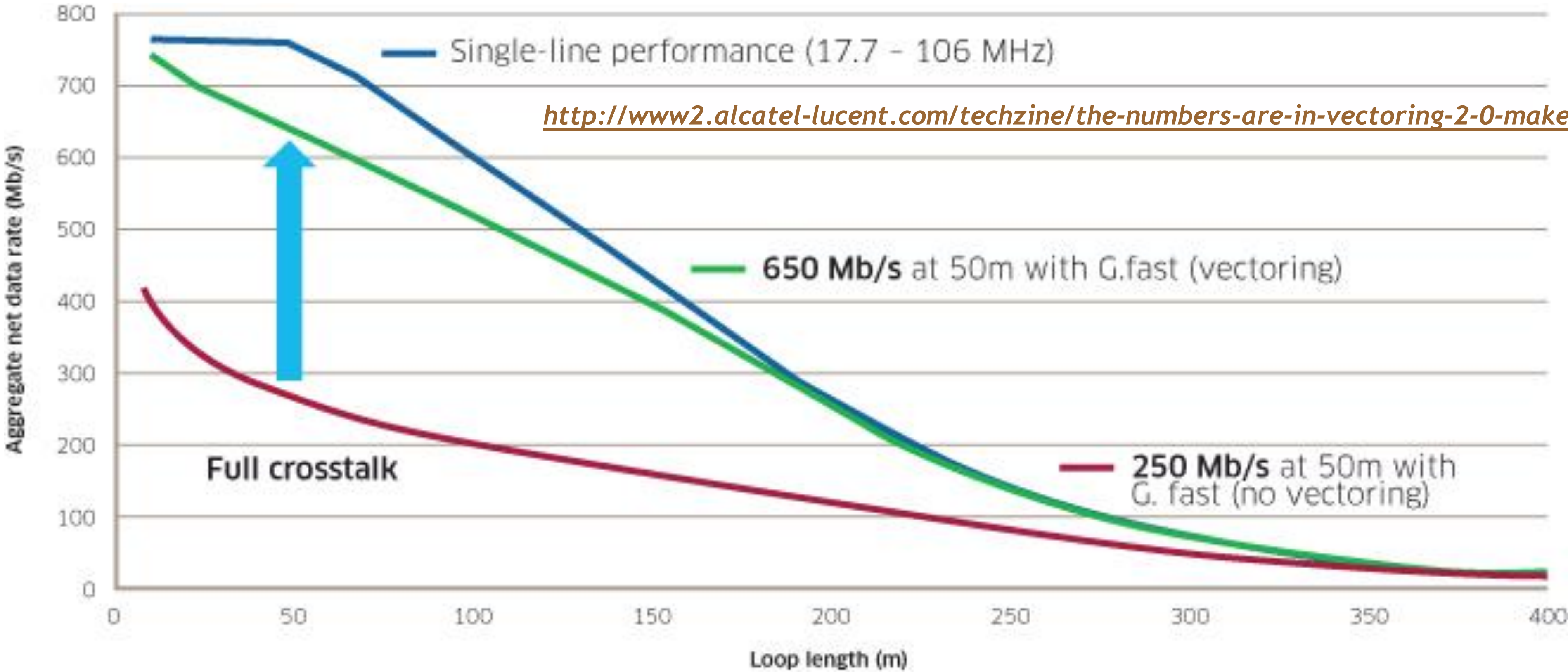


Source: Ericsson

- This is a reference graph considering an "average" crosstalk situation
- Note that above 2km even the most advanced xDSL technologies are limited to less than 4 Mbit/s

xDSL most recent evolutions: G.FAST

- Most recent evolution of xDSL (such as the soon to be released G.FAST) promises to go up to 1 Gbps but only on very short distances (100 meters or less)



EU Digital Agenda for 2020

- In 2010 the EU "Digital Agenda for Europe" (DAE) set the EU official objectives for Next Generation Access Network (NGAN)
  - By 2020, all European citizens should access the Internet at bit-rates greater than 30 Mbit/s
  - By 2020, not less than 50 percent of European households should be able to subscribe contracts at speeds over 100 Mbit/s

- European Commission: "A Digital Agenda for Europe", COM(2010)245, available at: http://ec.europa.eu/europe2020/pdf/digital-agenda-communication-en.pdf

COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS

A Digital Agenda for Europe

Brussels, 19.05.2010
COM(2010) 245

The future economy will be a network-based knowledge economy with the internet at its centre. Europe needs widely available and competitively-priced fast and ultra fast internet access. The Europe 2020 Strategy has underlined the importance of broadband deployment to promote social inclusion and competitiveness in the EU. It restated the objective to bring basic broadband to all Europeans by 2013 and seeks to ensure that, by 2020, (i) all Europeans have access to much higher internet speeds of above 30 Mbps and (ii) 50% or more of European households subscribe to internet connections above 100 Mbps.

To reach these ambitious targets it is necessary to develop a comprehensive policy, based on a mix of technologies, focusing on two parallel goals: on the one hand, to guarantee universal broadband coverage (combining fixed and wireless) with internet speeds gradually increasing up to 30 Mbps and above and over time to foster the deployment and take-up of next generation access networks (NGA) in a large part of the EU territory, allowing ultra fast internet connections above 100 Mbps.

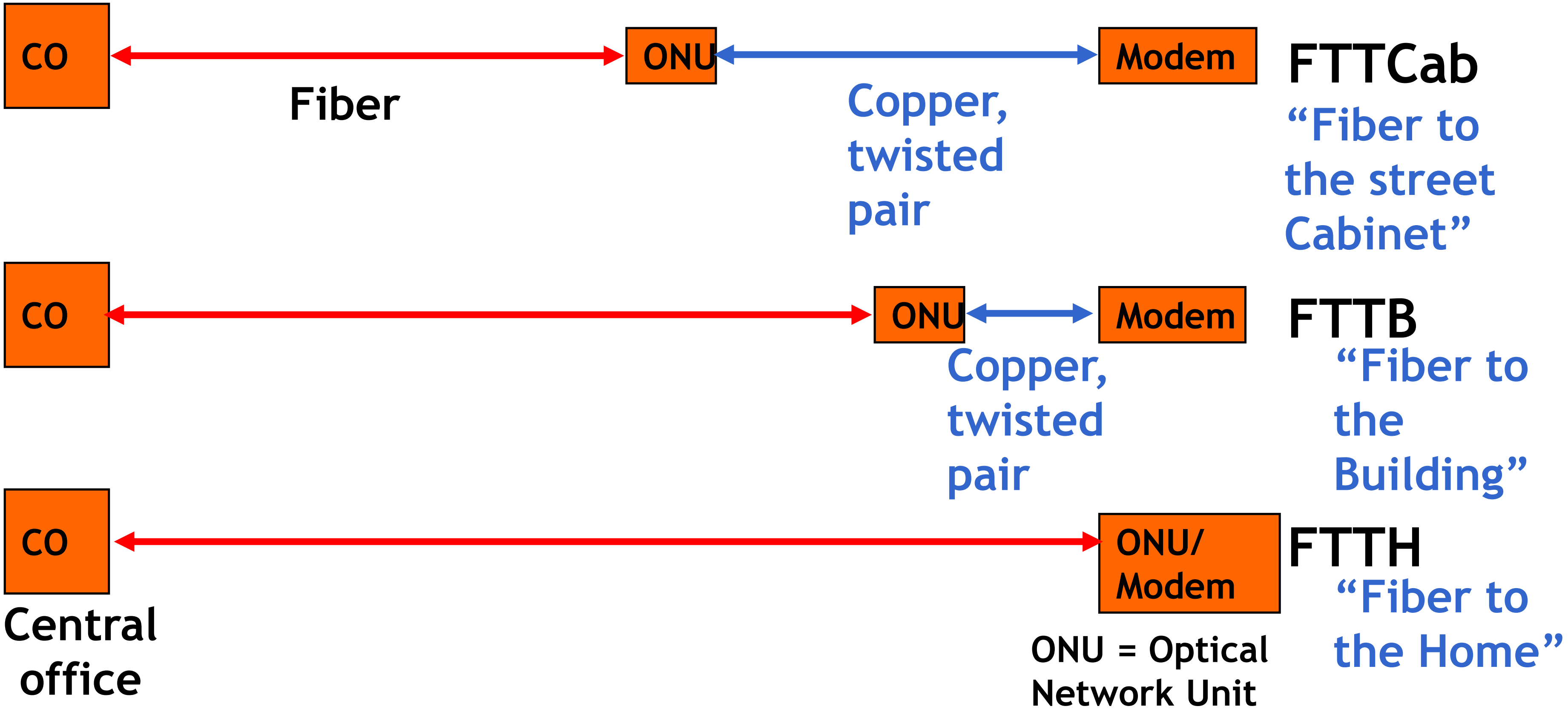
Optical Access Networks

Fiber to the X (FTTX) solutions:

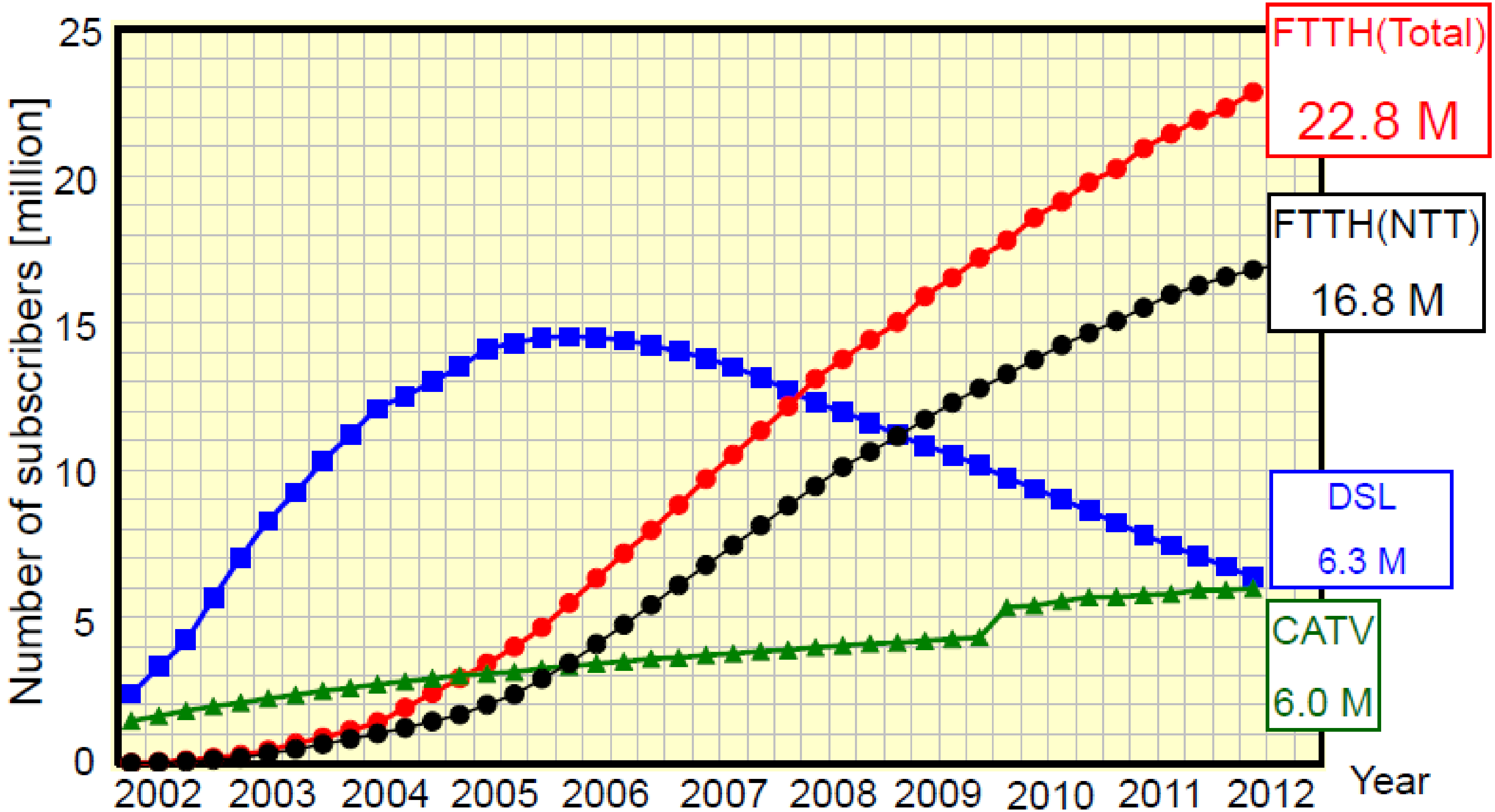
a “must” to deliver ultra-broadband connection as requested by the EU directive

Fiber To The…

- The key idea: use a fiber going as close as possible to the final user

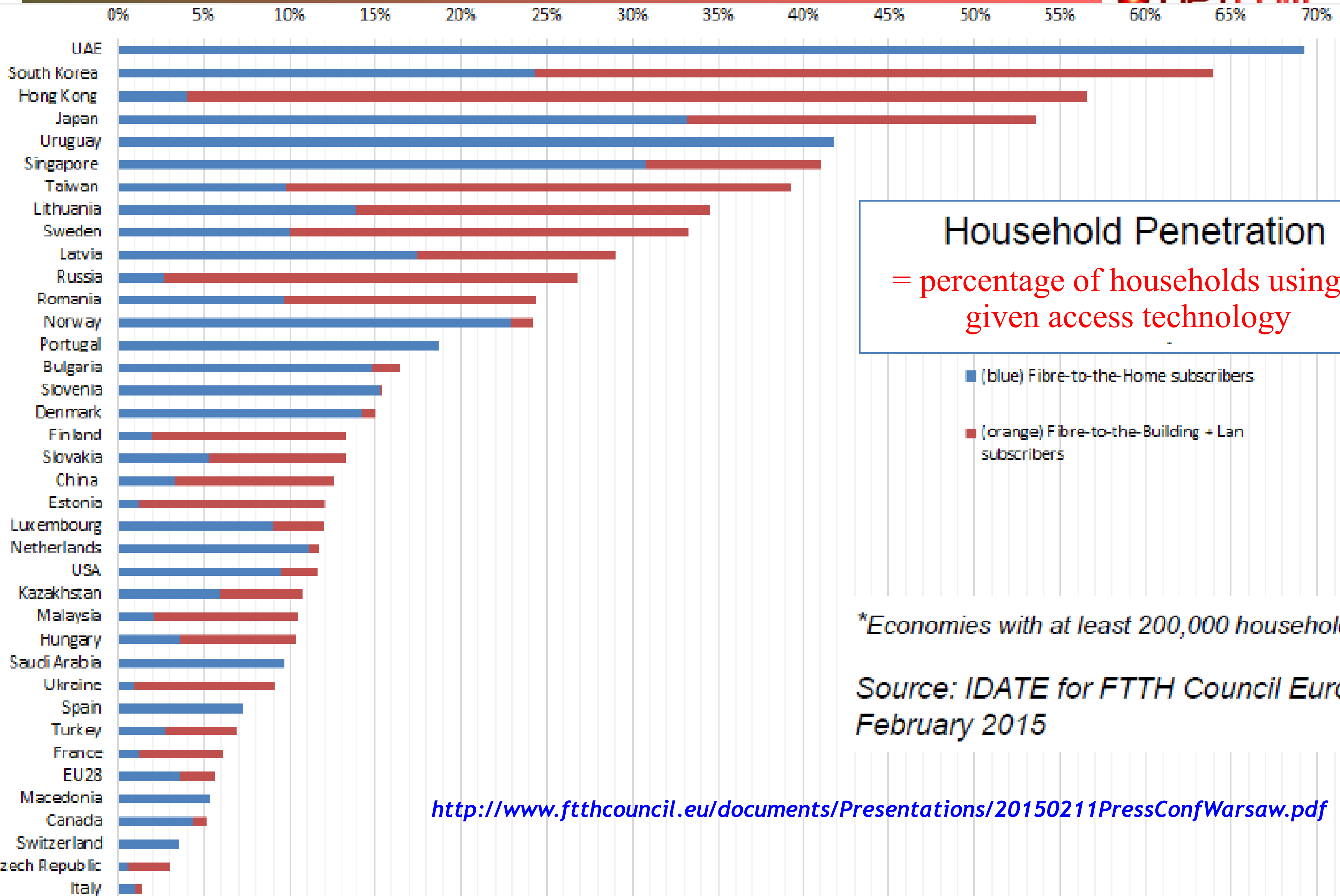


Situation in Japan, 2012



NTT presentation at: ***OFC/NFOEC2013 NTh4F.5 21 Mar., 2013***

FTTx: today penetration rate (2015)



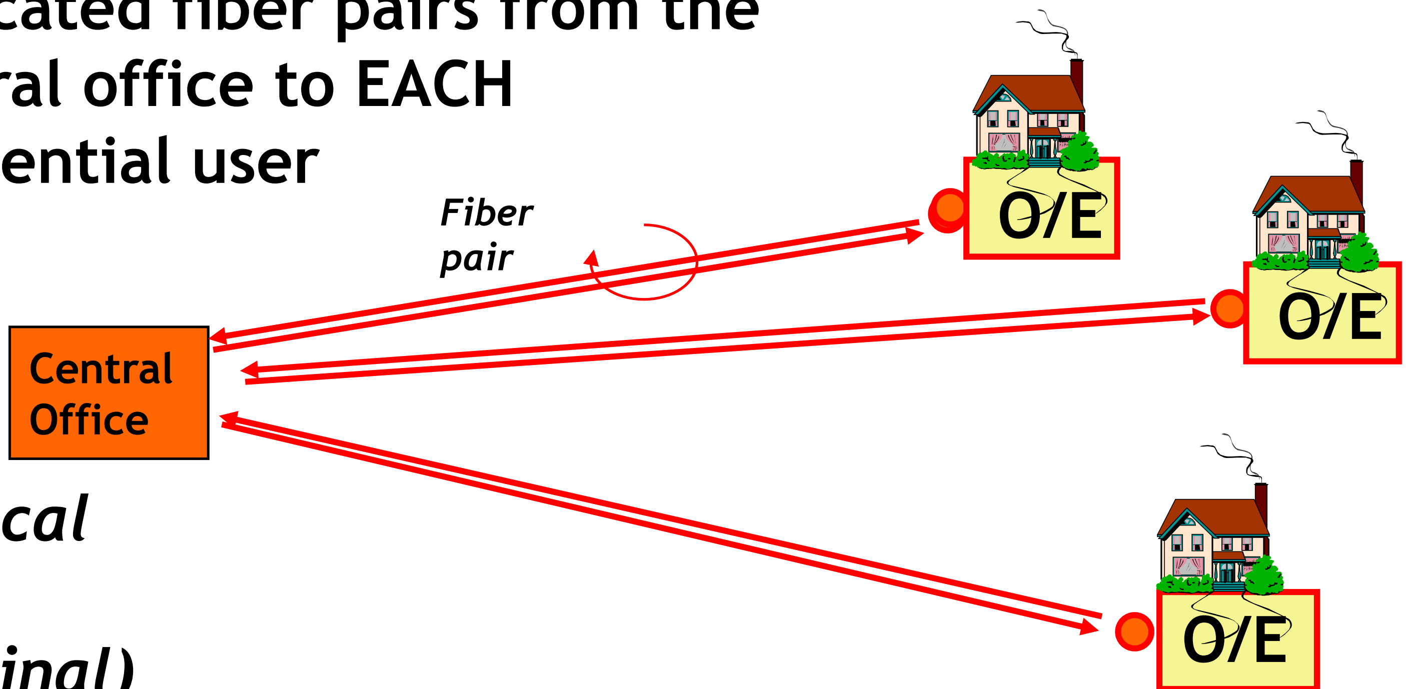
Two different options for FTTx

1. A dedicated fiber for each optical end-point
   - It is sometimes indicated as "Peer-to-Peer" o "Point-to-Point" (P2P)
     - Typical for FTTCab or FTTB
     - It is used anyway also in some countries for FTTH

2. A shared optical infrastructure for many users
     - PON: "Passive Optical Networks"
     - Typical for "true" FTTH

P2P Architecture

- ⇧ Dedicated fiber pairs from the central office to EACH residential user

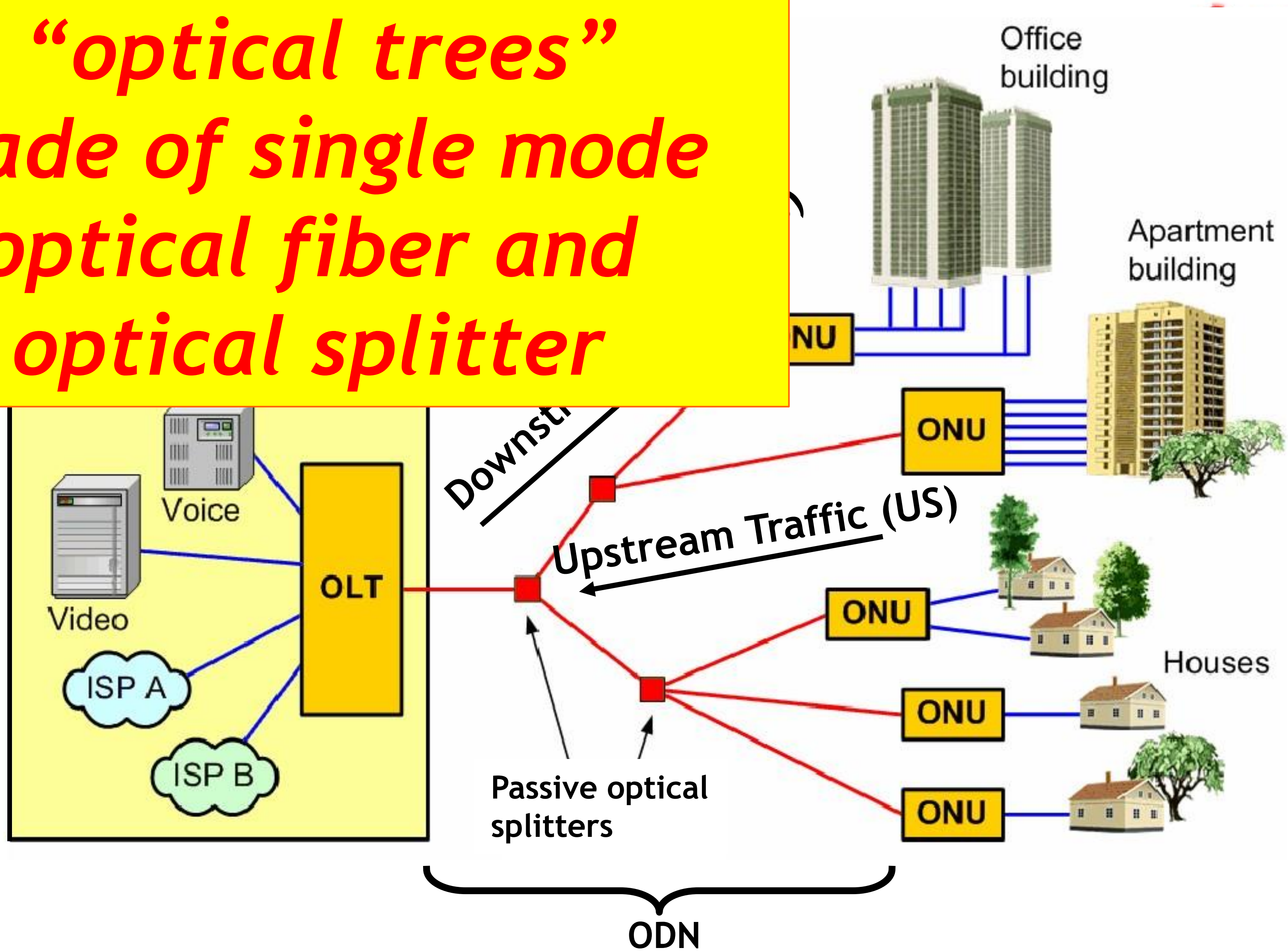


OLT (Optical Line Terminal)

ONU (Optical Network Unit)

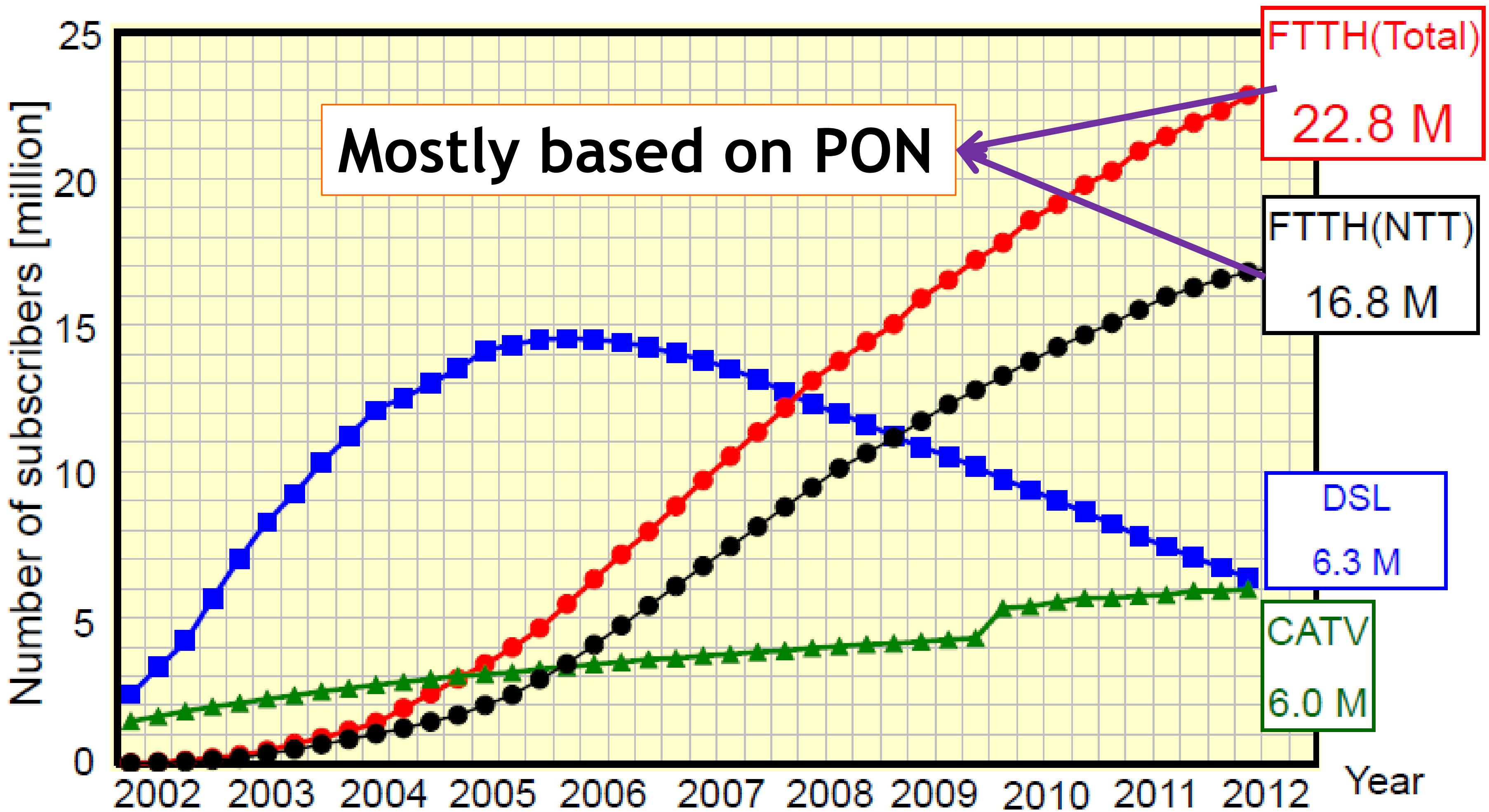
- ⇧ It replicates the architecture of the “traditional” copper twisted pair access network sive Optical Network

PONs are “optical trees” made of single mode optical fiber and optical splitter



ODN: Optical Distribution Network
ONU: Optical Network Unit
OLT: Optical Line Termination

Situation in Japan, 2012



NTT presentation at: ***OFC/NFOEC2013 NTh4F.5 21 Mar., 2013***

PON physical layer: what are the main differences compared to “standard” point-to-point optical transmission?

- Likely the most significant difference to have in mind compared to optical long-haul is COST

- **The "optical modem" at the user side (ONU) should not be much more expensive than an high-end ADSL modem**
  - Order of magnitude: 100€ for the full "optical modem"

PON power budget

- For a typical PON with N=64 users, the attenuation due to the splitter alone is around 19-20 dB (ideally it is $10 \cdot \log_{10}(N)$ dB)
- The system power budget should also take into account:
  - Fiber loss
  - Penalties due to dispersion, reflections, etc.
  - Ageing
  - System margin
- Thus, even though PON are short-distance systems, the power budget is very tight!
- The overall attenuation from TX to RX in the worst case direction is called "ODN-loss"

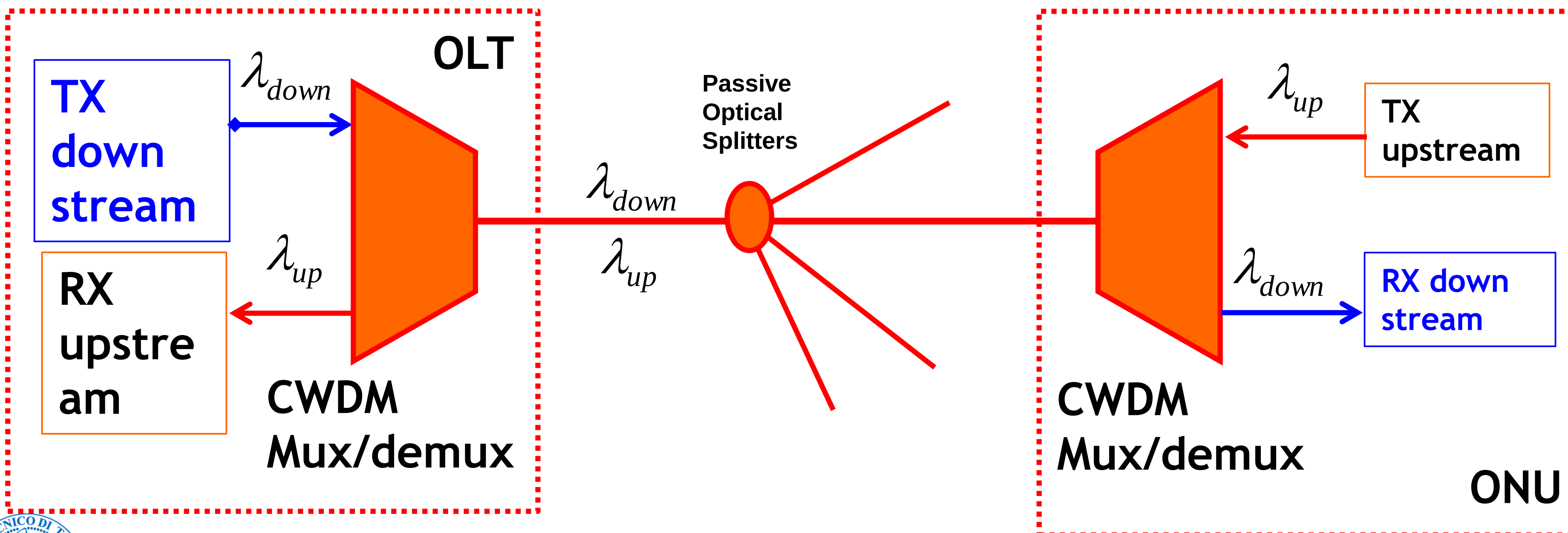
Typically, most PON transceivers should cope with ODN-loss values **greater or equal to 28 dB without any optical amplification along the link**

Current PON standards: common features

- Bidirectional transmission using two (or more) different wavelengths
  - Downstream: around 1500 nm
  - Upstream: around 1300 nm (apart from the most recent TWDM-PON)
    - Interestingly, PON is the ONLY massively utilized application where a single fiber is used bi-directionally!
- The ODN should be splitter-based, thus completely “flat” over the used wavelength range
  - No wavelength selective devices inside the ODN

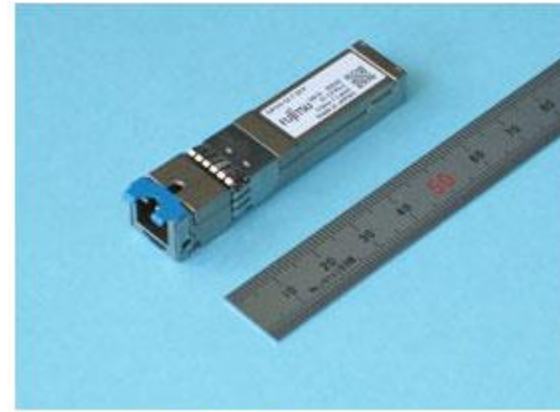
Bidirectionality: required devices

- The upstream and downstream signals should be divided at the terminals by proper optical demultiplexing filters
- In today PON standards, this is obtained by using two different wavelengths, and very coarse wavelength demultiplexer



The current most common ITU version: GPON

- GPON (Gigabit PON, ITU-T)
  - DOWNSTREAM: **2.5 Gbit/s, 1490 nm**
  - UPSTREAM: **1 Gbit/s, 1310 nm**
  - Up to 64 users for each PON tree



GPON Transceivers

- Together with the IEEE Ethernet version called GEPON, it is today massively deployed worldwide (tens of millions devices installed worldwide)
  - It is today a mature technology
- It is to be considered as the current "state-of-the-art" at the deployment level

XG-PON and 10G-EPON

- ITU-T released in January 2011 its Recommendations G.987.1 (and following) for the so-called "XG-PON". Main features:
  - 10 Gbit/s downstream
  - 2.5 Gbit/s upstream
  - Up to 40 km reach
  - Up to 35 dB power budget
- Basically, it was standardized in order to obtain a <u>4x increase in downstream bit rate</u>
  - But still uses one wavelength per direction

Next generation PON (NG-PON2)

Introducing Wavelength Division Multiplexing (WDM)

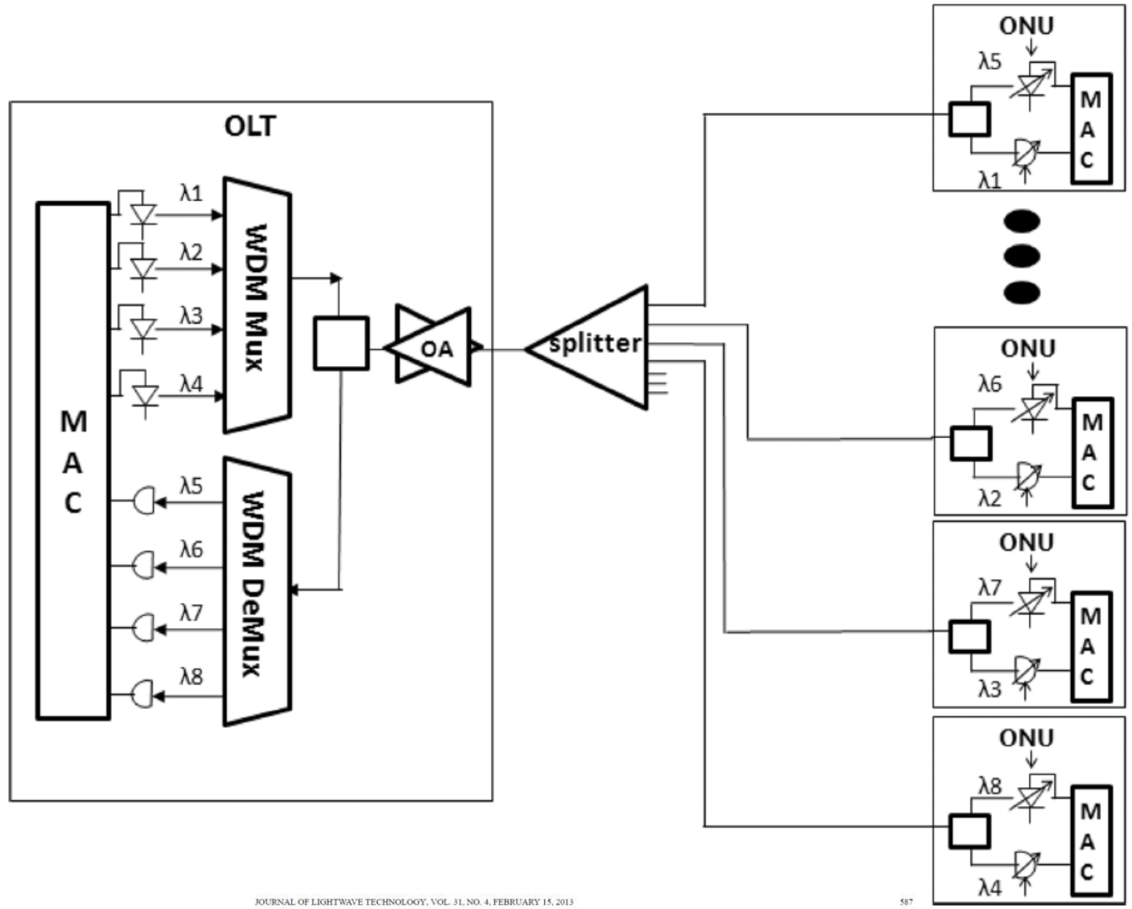
ITU-T G.989.1 TWDM-PON
"40-Gigabit-capable passive optical networks (NG-PON2)"

How to further increase bit rate?

- Four wavelengths per direction (at least)
  - 10 Gbps each in DS
  - 2.5 Gbps each in US

Very recent standard, first version released in Spring 2015

No product yet, but several prototypes available in telecom operator field trials



Picture taken from:


JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 31, NO. 4, FEBRUARY 15, 2013 587

Time- and Wavelength-Division Multiplexed Passive Optical Network (TWDM-PON) for Next-Generation PON Stage 2 (NG-PON2)

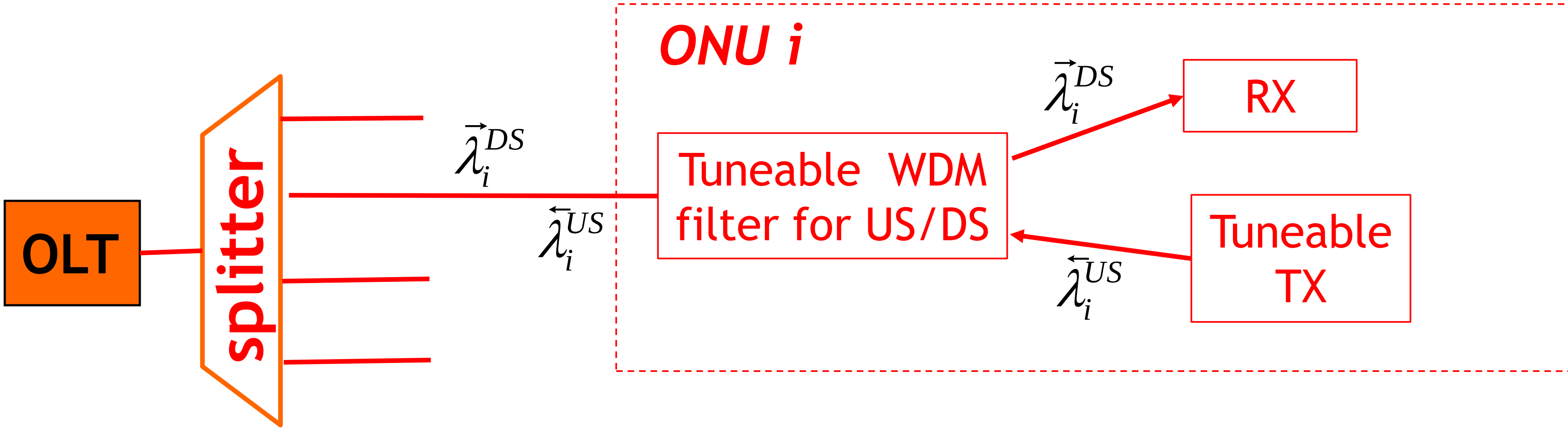
Yuanqiu Luo, *Senior Member, IEEE*, Xiaoping Zhou, Frank Effenberger, *Senior Member, IEEE*, Xuejin Yan, *Senior Member, IEEE*, Guikai Peng, Yinbo Qian, and Yiran Ma

Wavelength allocation

Same spacing used today for long-haul WDM systems: but cost should be two orders of magnitude less!!

- TWDM-PON signals:
  - Wavelength spacing: 100 GHz
  - Number of wavelengths: 4, upgradable to 16
  - Downstream
    - 1595-1600 nm for the first four wavelengths
      - 1597.19, 1598.04, 1598.89, 1599.75 nm, for the first 4 ch
    - 1600-1605 nm for the next four wavelengths
      - 1600.60, 1601.46, 1602.31, 1603.17 nm for the additional 4 Ch
  - Upstream
    - Similar, around the 1535 nm window

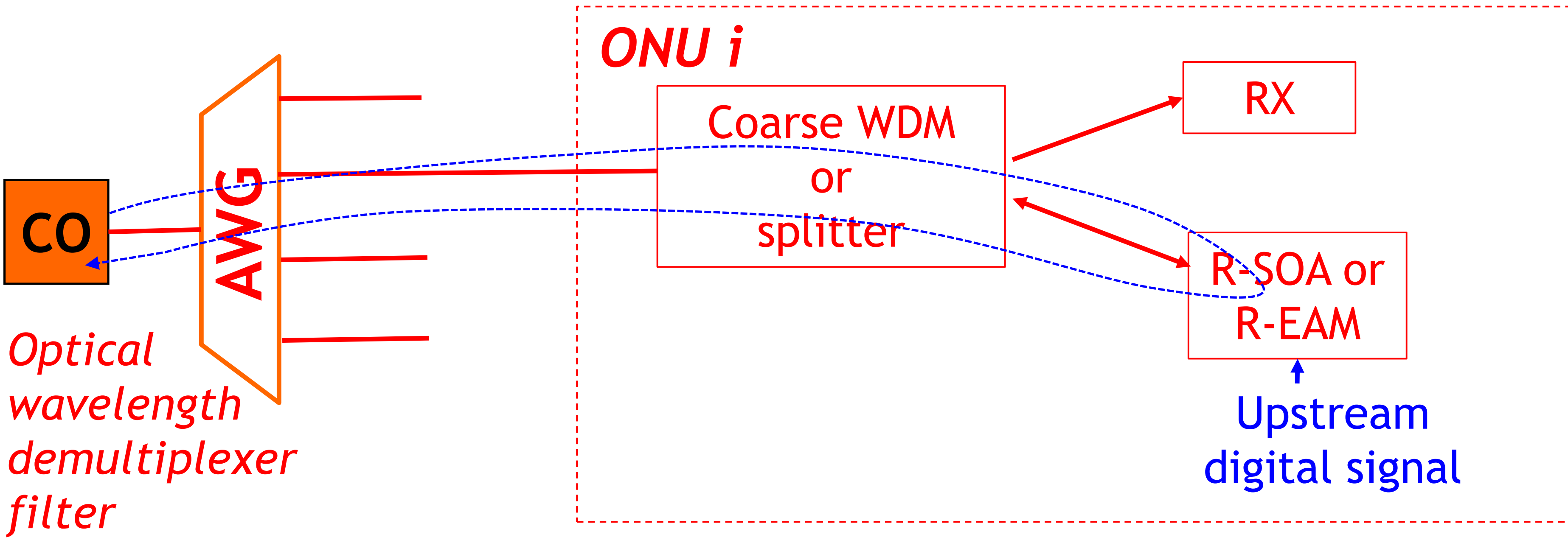
WDM-PON and tunable laser-based ONU



- At the ONU side, a tunable laser and a tunable filter required for US and DS wavelengths for a colorless ONU
- Very flexible solution
- Cost is still too high today for wide wavelength tunability (particularly for a full-fledged 16 wavelengths per direction solution)

An alternative to avoid tunable lasers

WDM-PON and reflective solutions



- It requires devices that modulates light in reflection
  - Reflective Semiconductor Optical Amplifier (R-SOA)
  - Reflective Electro Absorption Modulators (R-EAM)

The EU-project FABULOUS

an alternative for NG-PON3

Roberto Gaudino, POLITO

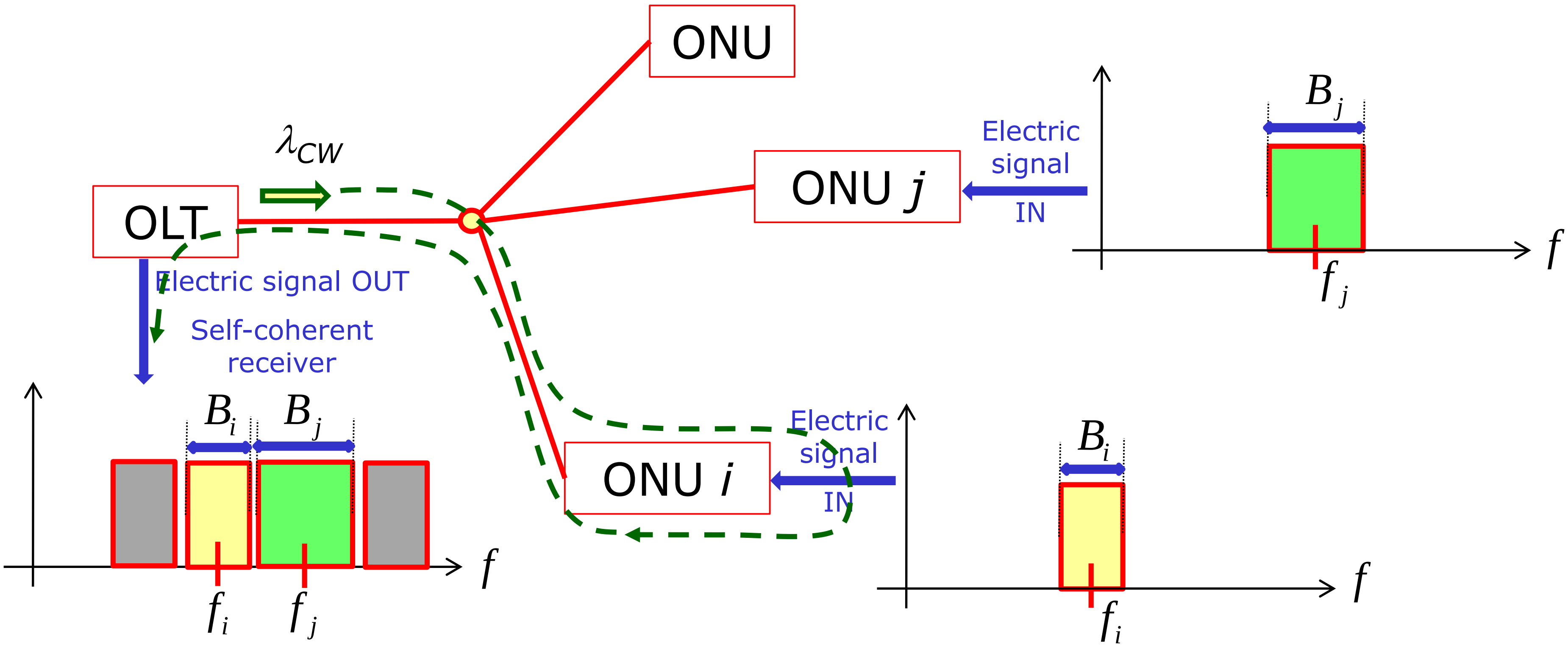
Let's focus on FABULOUS upstream

- We propose an optical reflective architecture at the user side
  - No need for tunable lasers at ONU
  - Only tunable filters

- Multiplexing is achieved by electrical frequency division multiplexing (FDMA-PON) and advanced modulation formats (16-QAM)

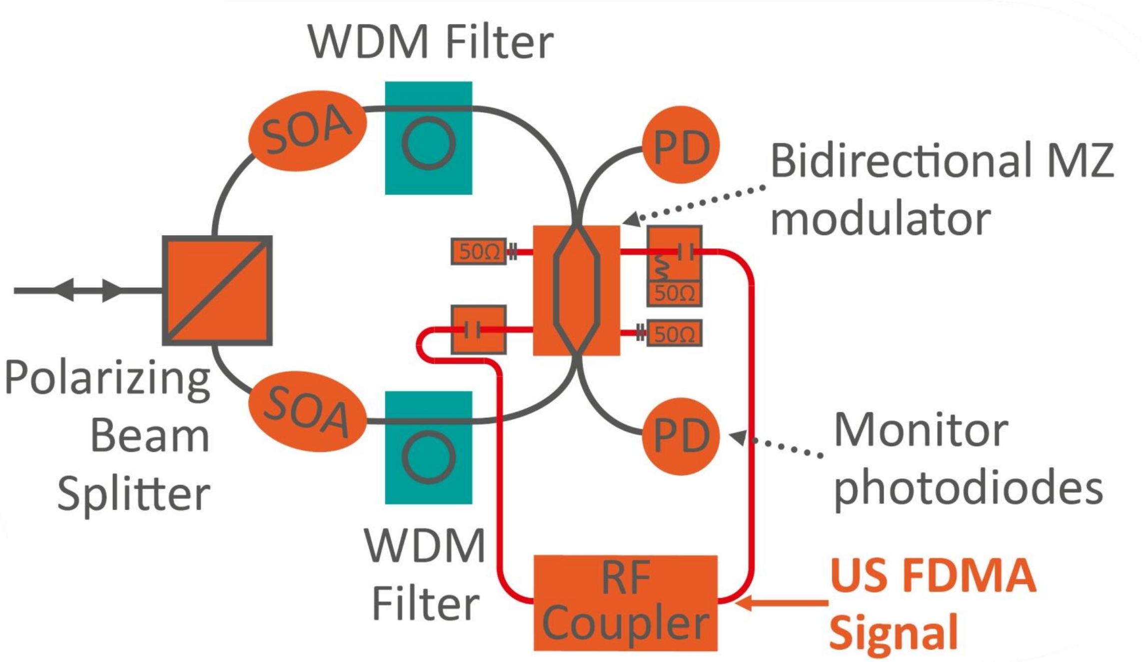
Frequency division multiplexed (FDMA) PON

- PON based on electrical subcarrier FDM/FDMA in both directions
- Project focus on upstream



Detail on the ONU

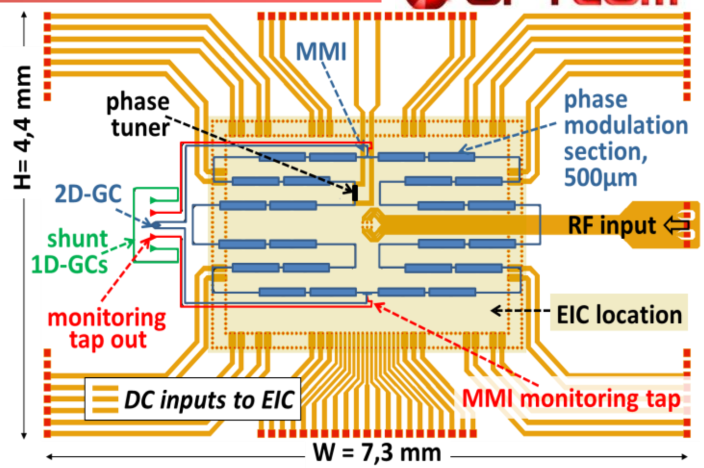
One of the main purposes of the project is to integrate the required reflective modulator on a **Silicon Photonics platform**



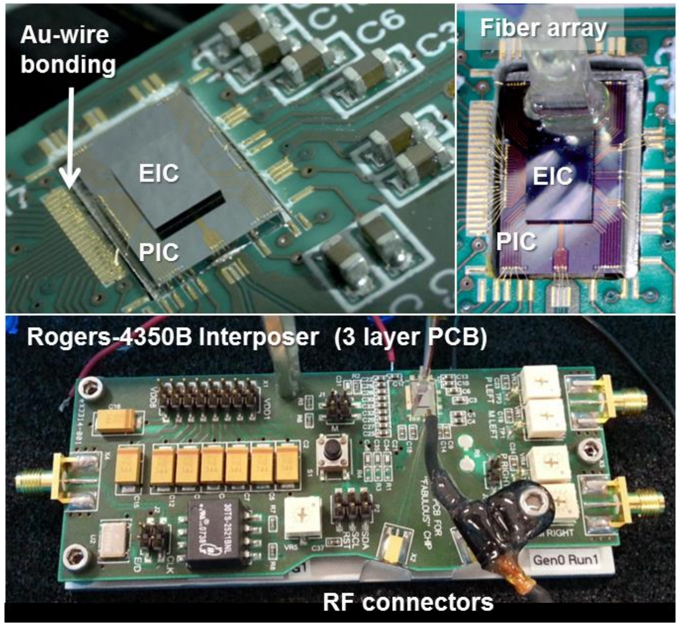
PROs compared to TWDM-PON

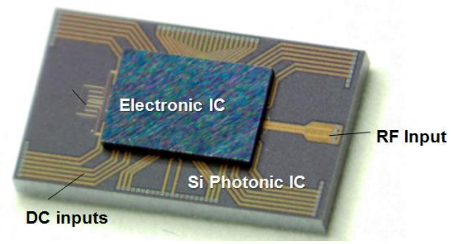
FABULOUS potential advantages:

- We demonstrated that on each wavelength 40 Gbps downstream and 20 Gbps upstream may be possible



- The key optoelectronic component have been realized in Silicon Photonics to show potential low cost

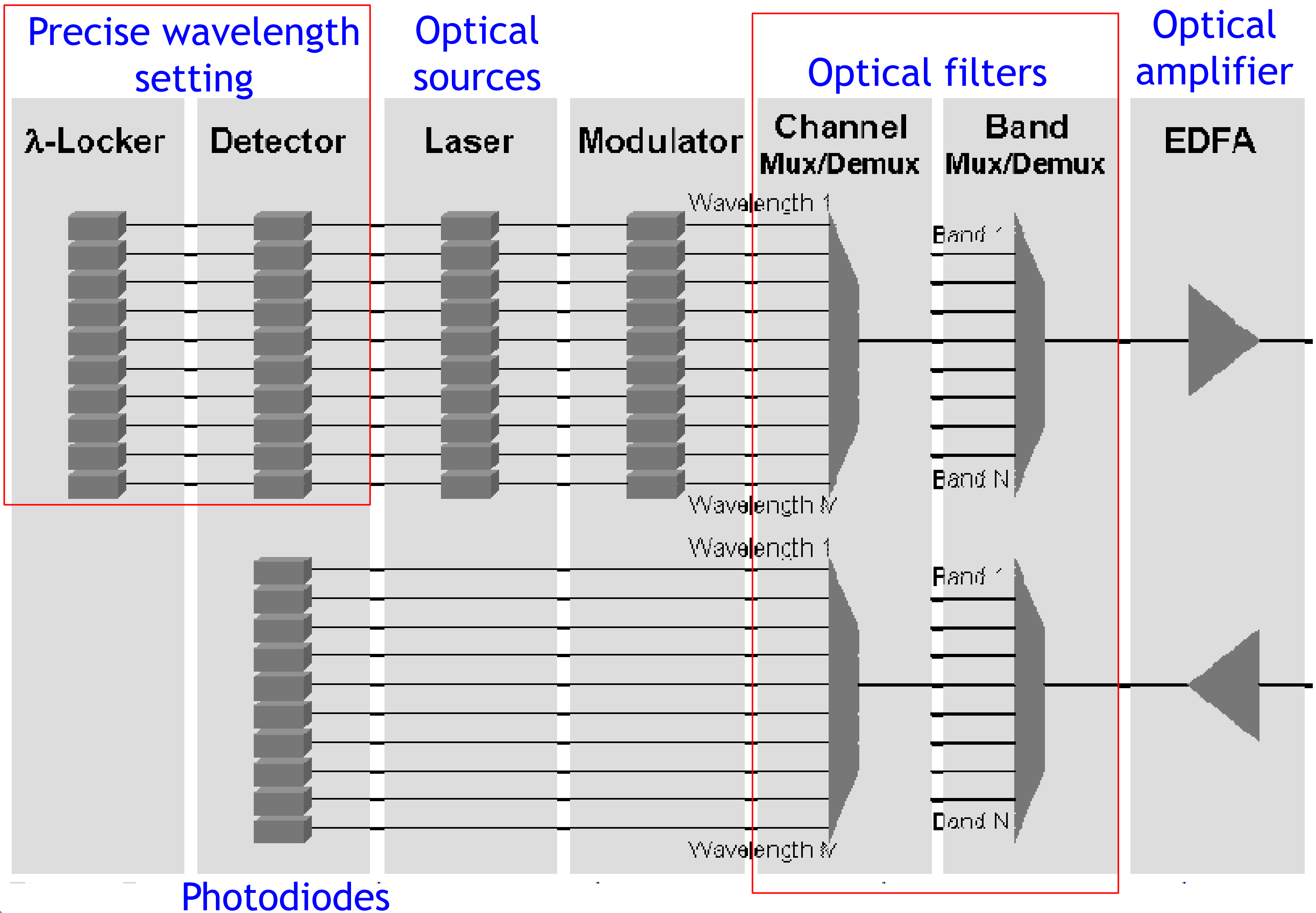




Silicon photonics integration

for optical transmission systems

Main optical components for a WDM system



Components for high-performance optical fiber systems

- Today high performance optical fiber transmission systems requires many different components (such as Lasers, modulators, filters, couplers, optical amplifiers, photodiodes, etc.)
  - Each type of components is highly optimized in term of performance
  - This in turns requires the use of very different basic technologies
    - In-P and in general III-V semiconductors for active optical elements
    - Lithium-Niobate for high performance modulators
    - Different technologies for optical filters
- Components are then discretely assembled
  - In fact, packaging ends up being one of the highest cost

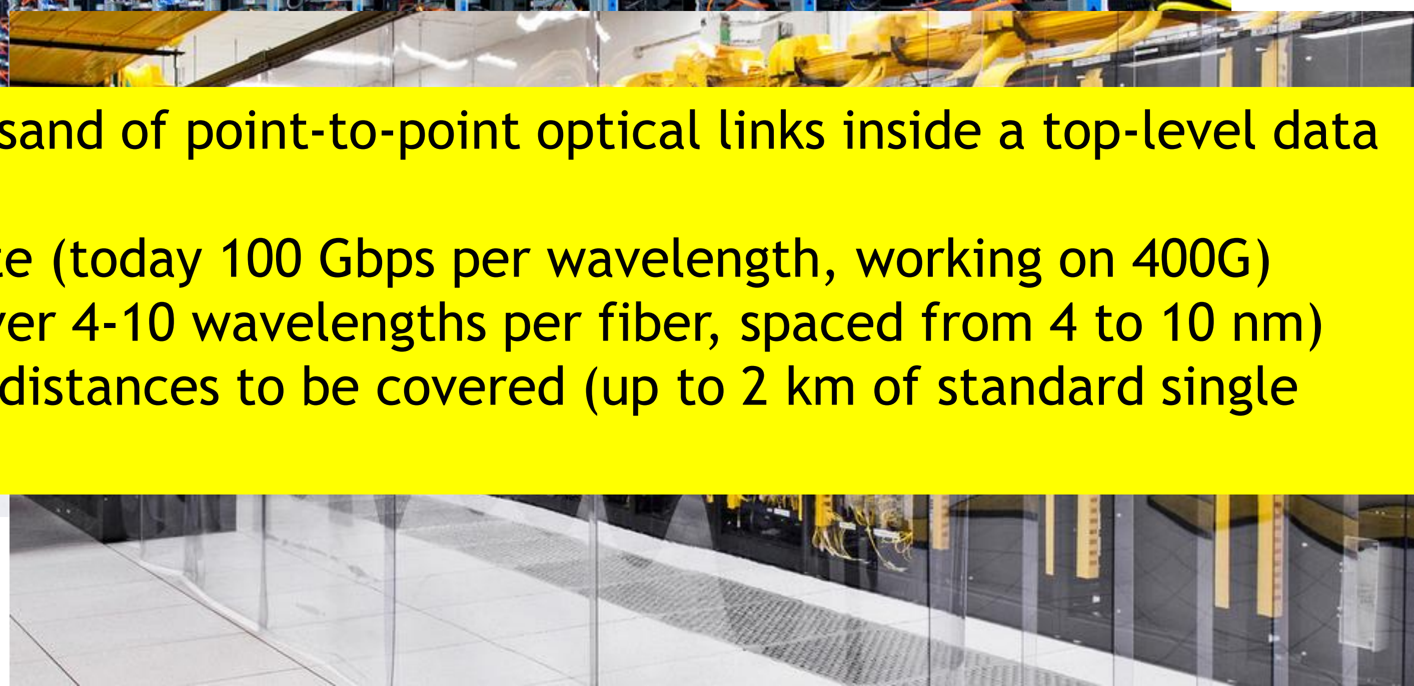
Photonics Integrated Circuits today

OPTCOM

- Integrating different optical functionalities on a single photonic platform is a very hot research topic today, particularly for market segments for which low cost is a must due to high volumes
- The area in which photonic integration is expected to have a near term impact is for high speed optical links for data center
- Optical access can be the other application area as soon as multiple wavelength systems will be massively deployed in PON
  - i.e. when NG-PON2 will reach the market (2-3 years??)

Images from Google's Data Center

http://www.google.com/about/datacenters/gallery/#/tech



Hundreds of thousand of point-to-point optical links inside a top-level data center

- very high bit rate (today 100 Gbps per wavelength, working on 400G)
- CWDM (today over 4-10 wavelengths per fiber, spaced from 4 to 10 nm)
- relatively short distances to be covered (up to 2 km of standard single mode fiber)

OPTCOM

- Indium Phosphide (InP) Photonic Integrated Circuits are today commercial available

- The next goal is Silicon Photonics to further reduce costs

	InP base PIC	Silicon Photonics
Light source	Good light source material	Need InP light source
Process complexity and maturity	Less mature =more expensive	Very mature =less expensive
Scale, wafer size	Smaller size	Large scale

http://www.infinera.com/pdfs/whitepapers/Photonic_Integrated_Circuits.pdf

http://www.ofcconference.org/library/images/ofc/2014/Market%20Watch%20and%20SPS/Norman.pdf

Companies working on Silicon Photonic

LUXTERA
FIBER TO THE CHIP

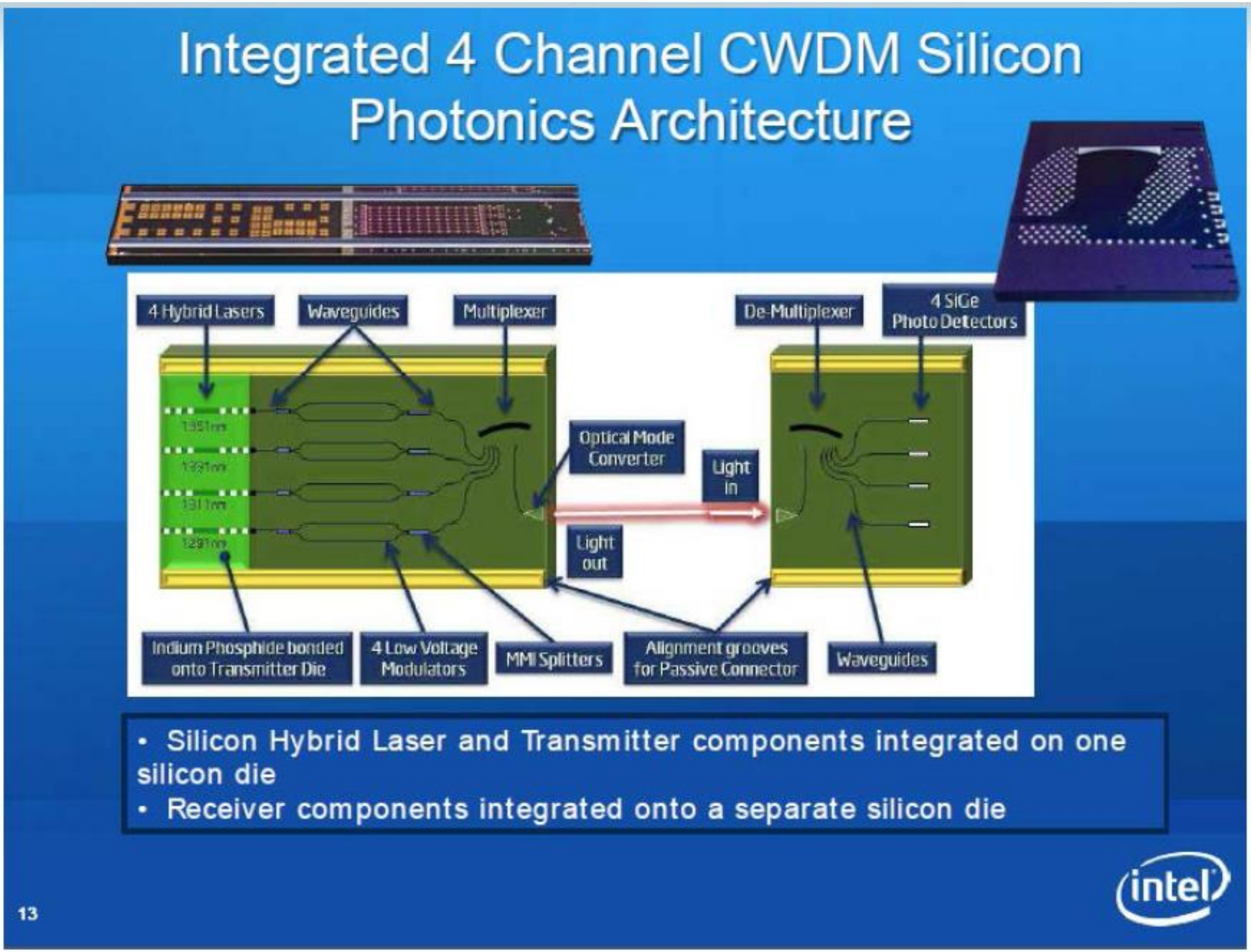
intel

ST life.augmented

Finisar

CISCO

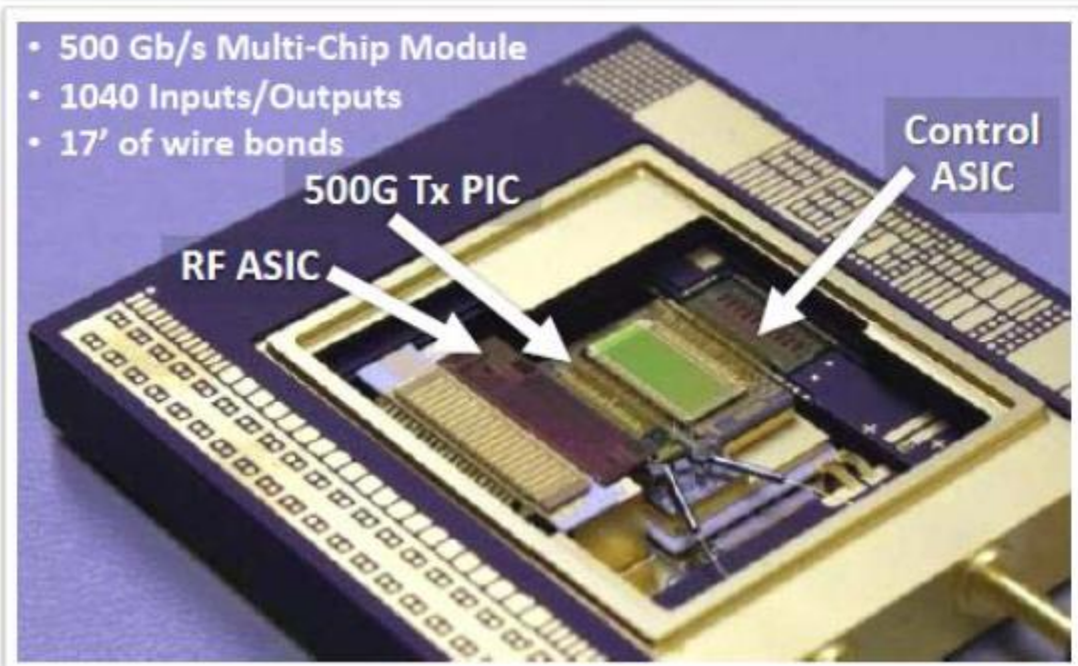
Silicon Photonic solutions



Example of commercial InP transceivers

500G, Large Scale, Monolithic PIC Implementation

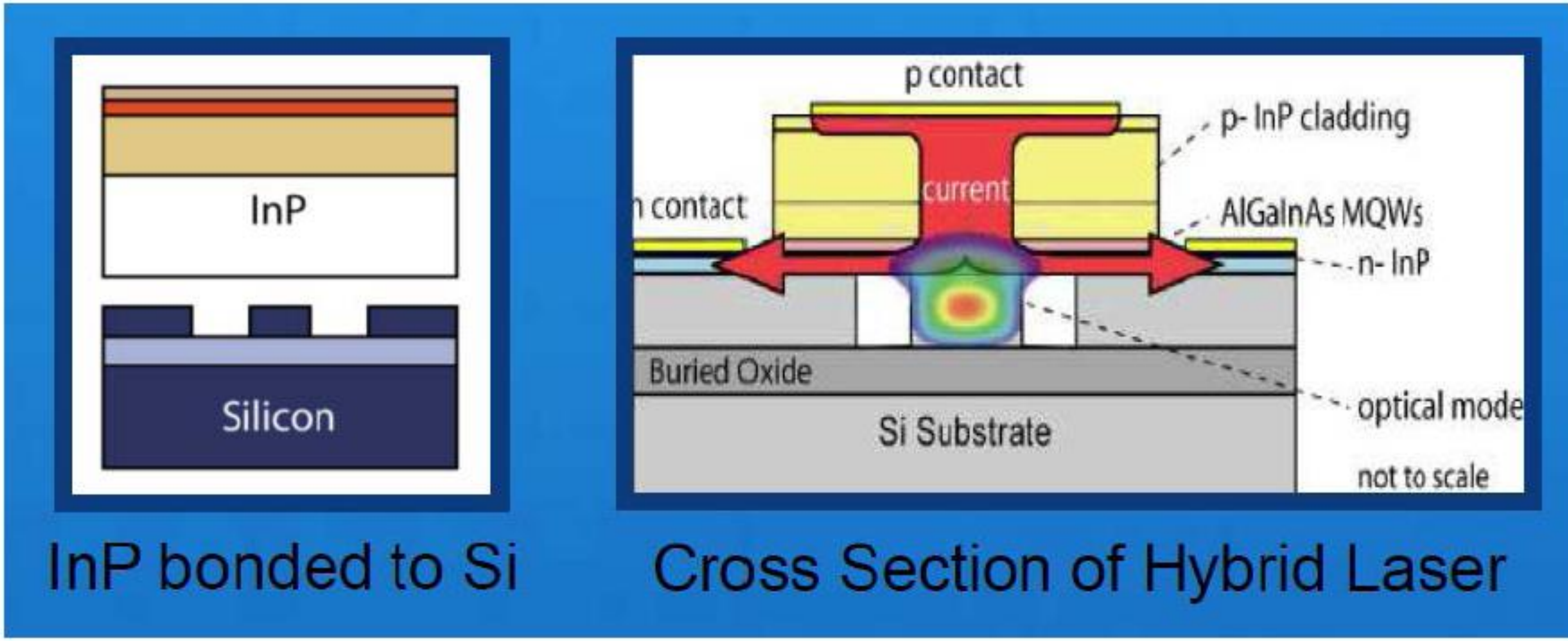
5 x 114Gb/s Transmitter
442 Elements: AWG mux, lasers, modulators, detectors, VOAs, control elements



5 x 114Gb/s Tx PIC Module

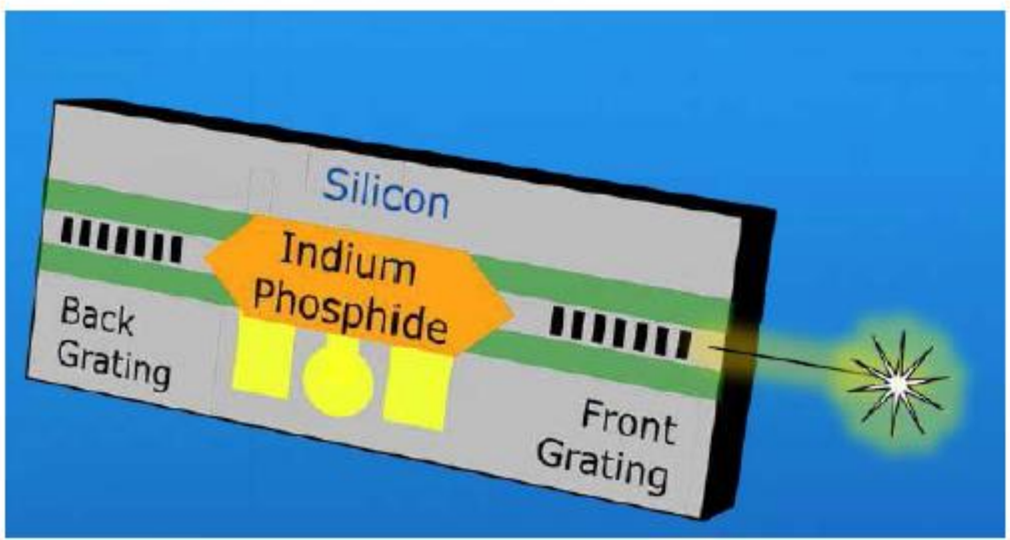
Sourc

The laser problem on silicon photonic platforms



InP bonded to Si

Cross Section of Hybrid Laser



Intel, UCSB

Conclusion

- Fiber Optic Transceivers volumes is reaching today "mass" volumes in the following areas:
  - Short-reach for data center and LAN
  - Optical access

- In both areas:
  - Photonic Integrated Circuits is a must
  - To further reduce cost, Silicon Photonics will surely play a key role
    - But "active" elements (lasers and optical amplifiers) are still an open issue…

Acknowledgments

The research leading to these results has received funding from the European Community's Seventh Framework Programme FP7/2007-2013 under grant agreement n°318704, titled:

FABULOUS: “FDMA Access By Using Low-cost Optical Network Units in Silicon Photonics”

- WEB site:

www.fabulous-project.eu

- To contact the Consortium:

info@fabulous-project.eu

- To contact the author:

Roberto Gaudino

E-mail: gaudino@polito.it

Backup slides

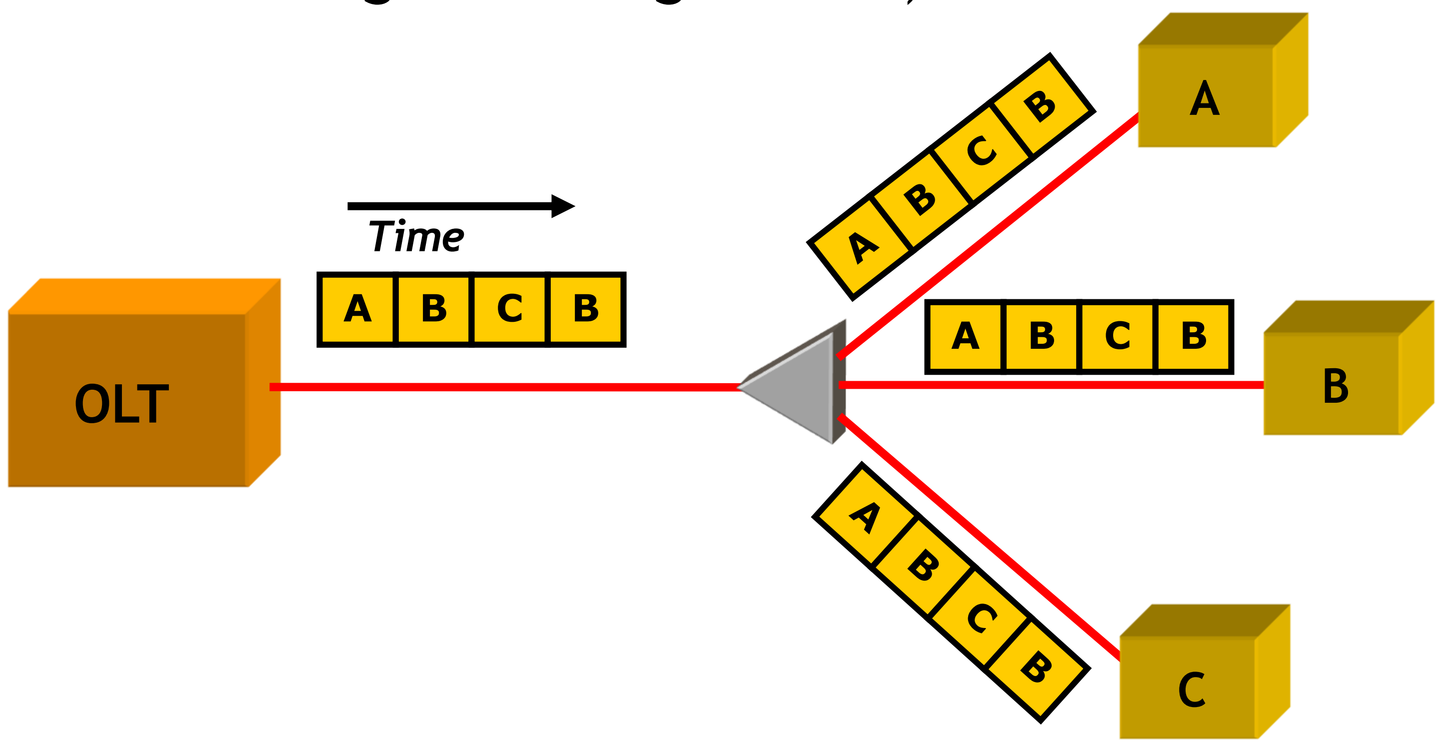
Current PON standards: common features

How to handle multiple access among *N* users?

- Downstream: Time Division Multiplexing (TDM)
- Upstream: Time Division Multiple Access (TDMA)

Downstream Traffic Scheduling

- OLT schedules traffic inside timeslots
  - Time Division Multiplexing (TDM) scheme
- Time slots can vary from ~μs to ~ms
  - Time slots are allocated dynamically (DBA Dynamic Bandwidth Assignment Algorithms)



Upstream Traffic Scheduling

- Current PON standards use
- Time Division Multiplexing Access (TDMA) schemes
  - Burst mode and centrally-synchronized transmitters at ONU
  - Proper upstream time slicing and assignment needed