

Elements of the NGAN

- *Optical Line Termination (OLT)*, it is the terminating device of optical cables and it can be positioned both in SLs and in SGUs.
- *Optical Network Unit (ONU)*: the optical device positioned close to the user: it can be connected, on the user side, to a copper network termination (NT) dello stesso. Multiple ONUs are connected to one OLT. In the FTTC case, the ONU is in the street cabinet. In the FTTB case, the ONU is placed close to the building.
- *Optical Network Termination (ONT)*: it is the user's optical termination, in the FTTH architecture
- *Optical Distribution Frame (ODF)*: it is the optical permutator, in the exchange, which substitutes the electric wire permutator (MDF). Peripheral devices placed in street cabinets or underground are the SDFs, while, if they are placed inside buildings, they are called DFs.

Elements of the NGAN

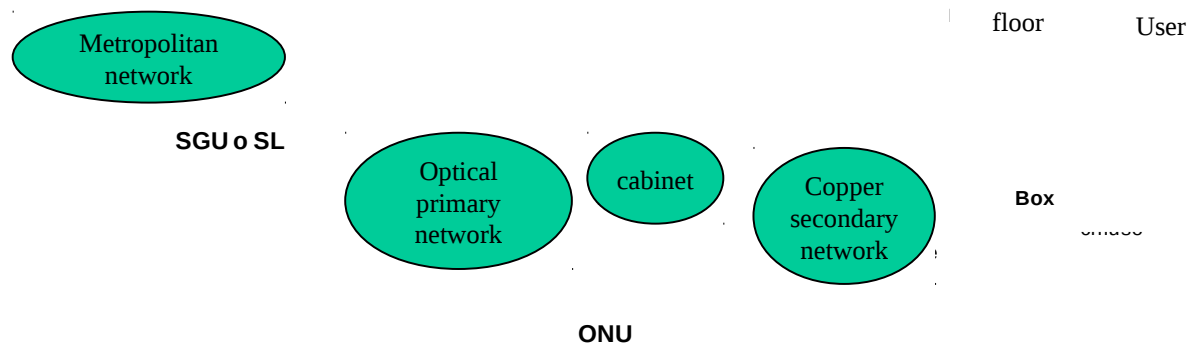
- In some cases optical connections among OLT, ONU and ONT are single-fiber, thus bidirectional transmission is obtained by wavelength division.
- OLT-ONU connections frequently adopt 2 fibers (no need of wavelength division)
- In other less frequent cases, optical connections are made with two fibers, one active and one spare.

Point-to-Point systems (Point-to-Point, P2P)

- In P2P systems there is a dedicated optical connection from OLT to ONU/ONT, used with Fast Ethernet (100 Mbit/s) or Gigabit Ethernet (1 Gbit/s) technologies
- Generally the access network has a star topology, which is common also in the classic copper access network
- The optical transmission cable is dedicated, thus the transmission capacity is the highest possible
- The P2P architecture has comparatively higher costs
- PON techniques provide an alternative tradeoff trading in performance for cost

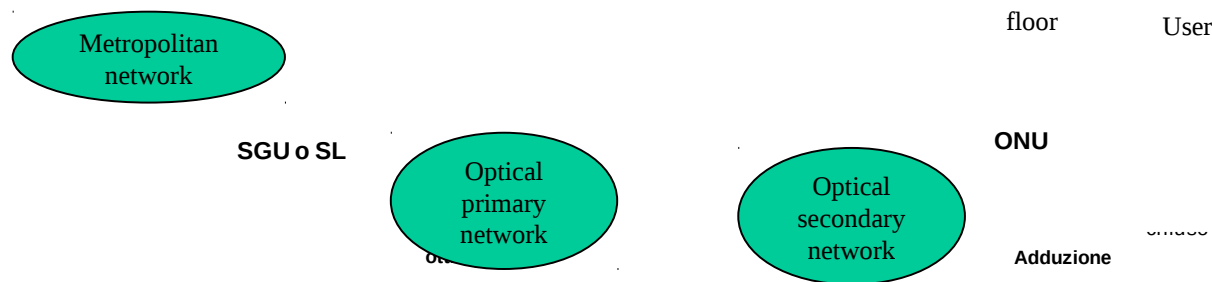
Point-to-Point systems (Point-to-Point, P2P)

- The Figure shows a P2P-FTTC system
- The connection between the SGU/SL to the street cabinet (*armadio*) is optical
- The street cabinet accommodates the ONU to terminate and connect optical fibers and copper lines
- On the copper network, transmission is frequently done through VDSL2



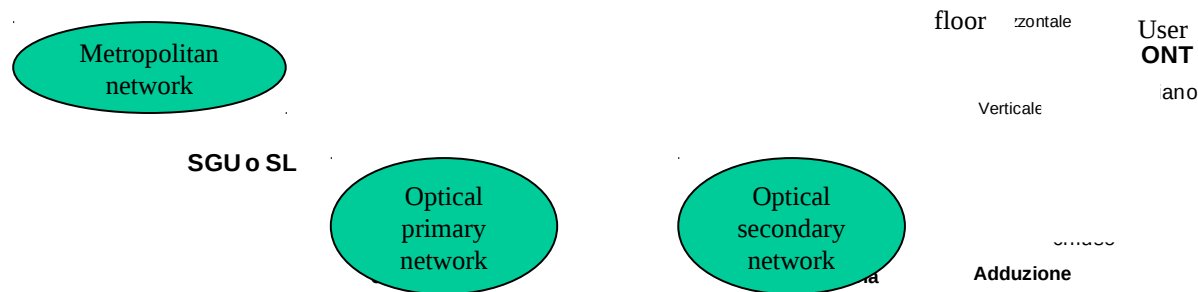
Point-to-Point systems (Point-to-Point, P2P)

- The Figure shows a P2P-FTTB system
- The optical connection reaches the building, then the vertical copper cabling connects the user
- The ONU is placed at the basement of the building, and it is where optical/electrical conversion occurs



Point-to-Point systems (Point-to-Point, P2P)

- The Figure shows a P2P-FTTH system
- Both horizontal and vertical cabling inside the building are made with optical fibers
- Optical terminations in DFs are placed both at the building basement and at each floor
- For a transmission speed of 100 Mbit/s a single fiber is used;
- For 1 to 10 Gbit/s and long distance from building to SGU/SL, two fibers are used, one for uplink and one for downlink



Passive Optical Network, PON

- A PON network used only passive devices between OLT and ONU/ONT
- The capacity of optical fibers is shared among groups of users
- Passive devices can be splitters; a splitter divides the capacity of one optical fibers among a number n of optical fibers at its output
- Conversely, it multiplexes the signal from multiple fibers onto a single fiber, in the opposite direction

Passive Optical Network, PON

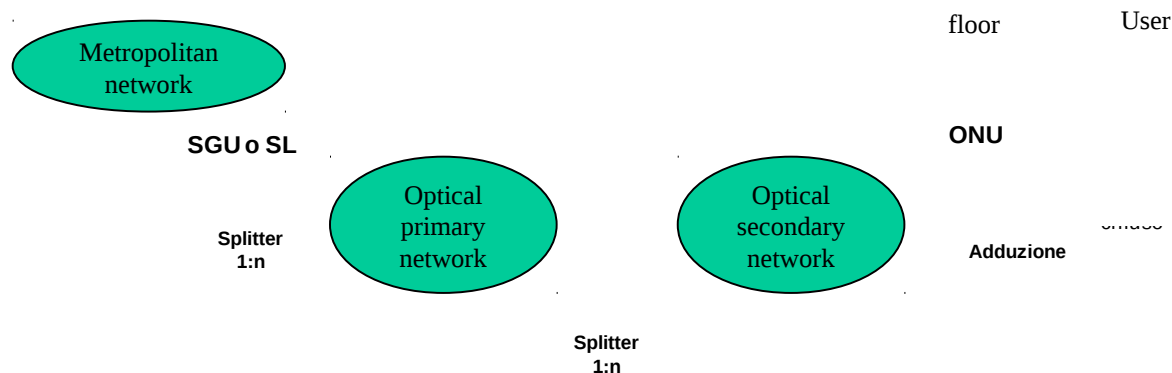
- A splitter is characterized by its split ratio ($1:n$), or split ratio, where n is the number of optical fibers at its output (in the downlink direction)
- n can vary, typical values are 32, 64, and 128
- The signal at the input of the splitter (in the downlink direction) is broadcasted on the n output optical fibers
- Privacy is thus an issue and it can be coped with through encryption
- In the upstream direction, n signals converge into one optical fiber, thus a multiple access method to share the capacity of this single physical resource is needed

Passive Optical Network, PON

- PON systems require comparatively less optical fibers to reach a given number of users, thus, costs are smaller than with P2P systems
- However, sharing the capacity of one fiber among n users degrades

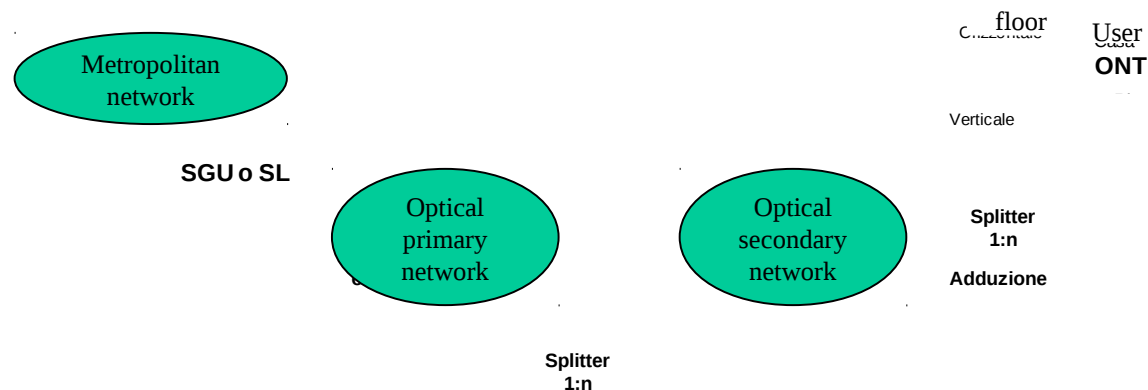
Passive Optical Network, PON

- The Figure shows a FTTB-PON system
- Splitters are frequently placed in small underground cabinets
- Splitting can be performed multiple times, as shown in the figure
- The purpose of the splitter in the SGU/SL is to divide the bandwidth of the PON network among a set of branches departing from the ODF
- The Figure shows one of these n branches
- The purpose of the second splitter is to reduce the number of optical fibers in the secondary access network and thus reduce costs
- If the SGU splitter has ratio 2 and the other splitter has ratio 4, a PON rooted at the OLT reaches 8 ONUs at the building



Passive Optical Network, PON

- The Figure shows a PON-FTTH system
- Usually splitters are placed in small street underground cabinets and inside the building
- The ratio of the street splitter is frequently 1:2 - 1:4, and for the in-building splitter the ratio is 1:8 - 1:32
- This adds up to a total split ratio ranging from 1:16 to 1:128 (typical values in practice)



TDM-PON

- Time Division Multiplexing PONs use two different wavelengths for uplink and downlink communications
- The OLT applies the procedures for the coordinated access to the broadcast optical channel
- In TDM PONs the OLT uses time division: time is divided into slots and each branch ONU-ONT has a dedicated time slot
- In order to avoid collisions, a synchronization signal must be distributed to ONTs, in order to compensate the different round trip delays due to different total length of optical fiber branches
- Two important standards defining how TDM-PONs operate are
 - ITU G.984 Gigabit-capable-PON (GPON)
 - 802.3ah Ethernet-PON (EPON)

TDM-PON

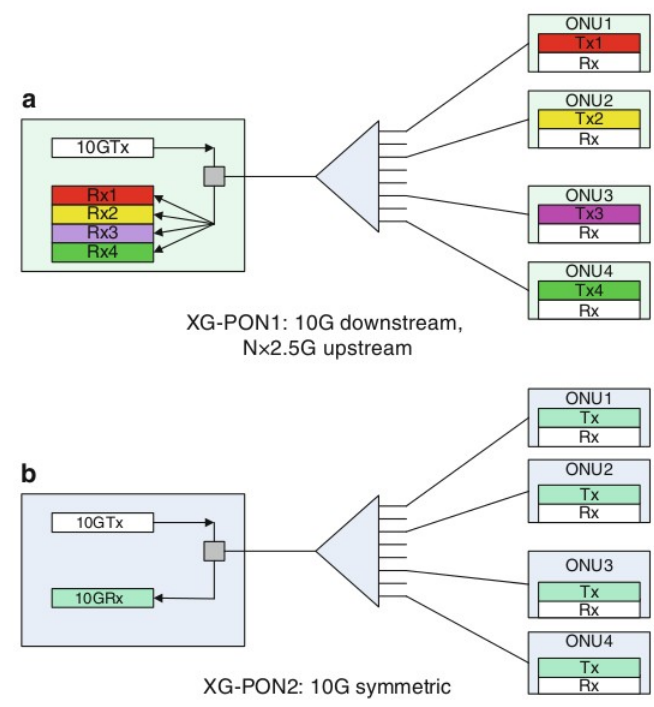
- GPON uses a set of wavelength “windows”: 1480 nm -1500 nm for the downlink channel and 1260 nm -1360 nm for the uplink
- GPON can operate at a speed of about 2,5 Gbit/s (precisely 2,48832 Gbit/s) in downstream and about 1,25 Gbit/s (precisely 1,24416 Gbit/s) in upstream
- The maximum admitted split ratio is 1:128
- The maximum length of the connection can exceed 20 km
- GPON can transport natively both ATM frames and Ethernet frames through encapsulation

NG-PON (ITU-T G.987)

Next-Generation PON (NG-PON) offers a higher bandwidth provisioning. The evolution of NG-PON is divided into two phases: NG-PON1 and NG-PON2. NG-PON1 focuses on PON technologies that are compatible with GPON standards (ITU-T G.984 series) as well as the current optical distribution network (ODN). NG-PON1 is backwardly compatible with existing fiber installations, and tries to facilitate high bandwidth provision, large split ratio, and extended network reach. The objective of NG-PON2 is to provision an independent PON system, without being constrained by the GPON standards and the currently deployed outside plant. As being standardized in ITU-T G.987, NG-PON1 specifies both asymmetric and symmetric 10G-PONs. Asymmetric 10G-PON, also referred to as XG-PON1, provides the downstream data rate of 9.95328 Gbit/s and the upstream data rate of 2.48832 Gbit/s.

Source: PON Architectures (Springer); SpringerBriefs in Applied Sciences and Technology 2013, pp 11-22

NG-PON (ITU-T G.987)



Source: PON Architectures (Springer); SpringerBriefs in Applied Sciences and Technology 2013, pp 11-22

TDM-PON (IEEE 802.3ah)

- EPON transports natively Ethernet frames and it used the wavelength 1490 nm downstream and 1310 nm upstream
- The transmission capacity is symmetric equal to 1,25 Gbit/s
- A single EPON can reach 32 users, with maximum distance equal to about 20 km

TDM-PON (IEEE 802.3av)

The IEEE 802.3av 10G-EPON task force was charged to increase the downstream bandwidth to 10 Gb/s, and to support two upstream data rates: 10 and 1 Gb/s.
10G-

EPON supports both symmetric 10 Gb/s downstream and upstream, and asymmetric 10 Gb/s downstream and 1 Gb/s upstream data rates.

Owing to the mandatory FEC mechanism and increased line rate, the electronic circuit has to enable more functions and process faster than that in 1G-EPON, thus consequently incurring higher power consumption and possibly larger heat dissipation. Therefore, to accommodate 10 Gb/s in the physical layer, the power consumption of the OLT and the ONU may increase significantly.

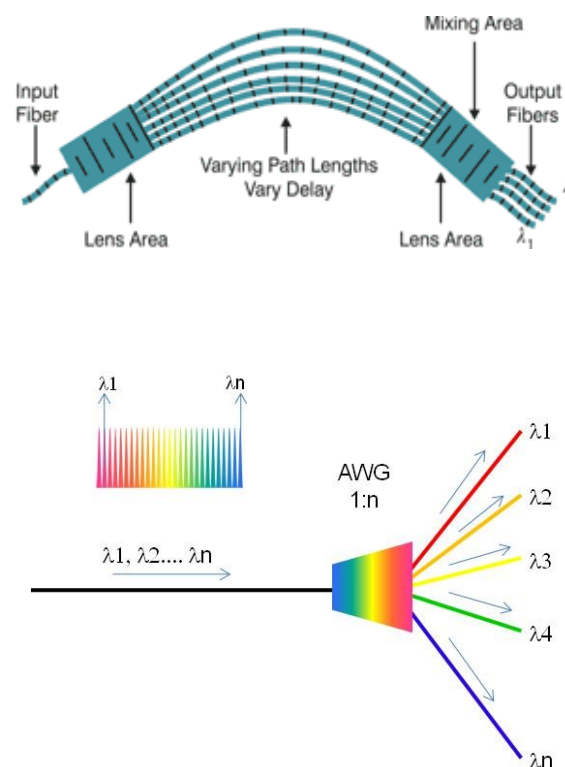
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WDM-PON

In order to increase the transmission capacity of optical access networks, Wavelength Division Multiplexing can be used effectively

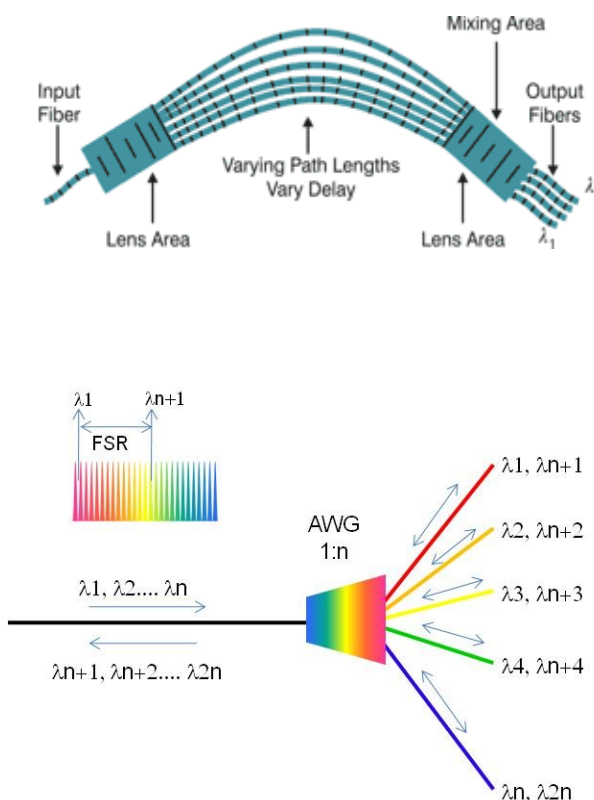
Coarse WDM (CWDM) allows 18 wavelengths, Dense WDM (DWDM) allows 162 wavelengths
The basic device to build a WDM PON is the Arrayed Waveguide Grating (AWG)

- It is a passive device that passively routes different wavelengths to different optical fibers



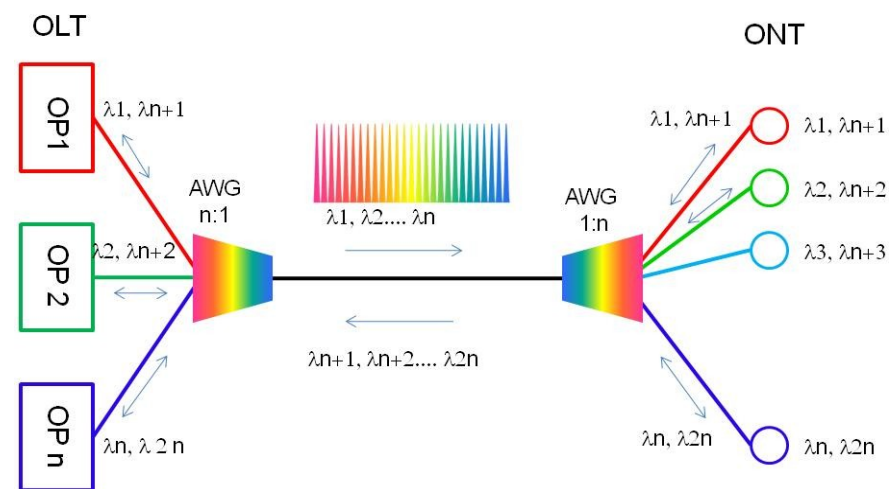
WDM-PON

- The AWG is bidirectional, thus, in the uplink direction, it multiplexes multiple incoming wavelengths into a single optical fiber
- In order to connect n users, $2n$ wavelengths are needed
- For each user, a wavelength is for the downlink channel and another wavelength serves the uplink channel



WDM-PON

- WDM PON allow a simple sharing model of access network resources among operators
- Channels from different operators are multiplexed into a single fiber by a first AWG (downlink)
- Then, the second AWG demultiplexes user specific signals



WDM-PON

Source: PON Architectures (Springer); SpringerBriefs in Applied Sciences and Technology 2013, pp 11-22

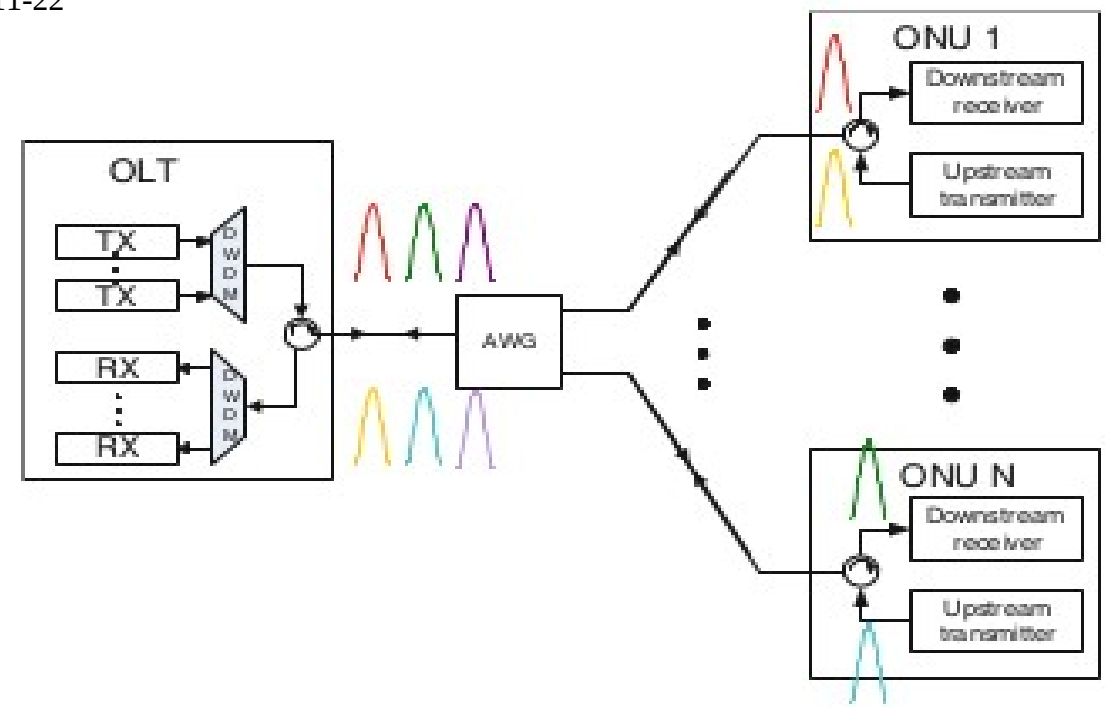


Fig. 2.4 A typical WDM-PON architecture

Source: PON Architectures (Springer); SpringerBriefs in Applied Sciences and Technology 2013, pp 11-22

WDM-PON

WDM PON is a candidate solution for next-generation PON systems in competition with 10G-EPON and NG-PON1 systems. To achieve high bandwidth provisioning, WDM PON supplies each subscriber with a wavelength rather than sharing wavelength among 32 or even more subscribers in TDM PON.

WDM PON architecture enjoys several advantages over conventional TDM PON systems.

- 1) WDM PON allows each user being dedicated with one or more wavelengths, thus allowing each subscriber to access the full bandwidth accommodated by the wavelengths.
- 2) Second, WDM PON networks typically provide better security and scalability because each home only receives its own wavelength.
- 3) the MAC layer control in WDM PON is more simplified as compared to TDM PON because WDM PON provides P2P connections between the OLT and the ONU
- 4) Finally, each wavelength in a WDM PON network is effectively a P2P link, thus allowing each link to run at a different speed and with a different protocol for maximum flexibility and pay-as-you-grow upgrades.

WDM-PON

Despite these attractive features, WDM PON is cost inhibitive because of the wavelength specific feature of ONUs. Since each subscriber is dedicated with some wavelengths, the OLT in WDM PON that supports 32 ONUs must transmit on no less than 32 different wavelengths, and each ONU should operate at their own wavelengths. The wavelength-specific feature of ONUs imposes higher requirements on lasers as compared to TDM PONs if the same kind of wavelength fixed lasers for all ONUs is employed. One solution is to use tunable lasers with which each ONU can be tuned to its desired wavelength. However, tunable lasers are costly. Another solution is to equip each subscriber with a wavelength-specific fixed tuned laser. Individual wavelength-specified sources cannot be readily employed in the OLT of WDM PON because they require a number of optical sources with different wavelengths. These cost-prohibitive devices constitute a major hurdle in early design of WDM PON systems.

Source: PON Architectures (Springer); SpringerBriefs in Applied Sciences and Technology 2013, pp 11-22

OFDM PON

Orthogonal frequency division multiplexing (OFDM) PON, employs OFDM as the modulation scheme and exploits its superior transmission capability to improve the bandwidth provisioning of optical access

networks.

OFDM uses a large number of closely-spaced orthogonal subcarriers to carry data traffic. Each subcarrier is modulated by a conventional modulation scheme (such as quadrature amplitude modulation or phase-shift keying) at a low symbol rate, thus achieving the sum of the rates provided by all subcarriers compatible to those of

Source: PON Architectures (Springer), SpringerBriefs in Applied Sciences and Technology 2013, pp 11-22

OFDM PON

Advantages of OFDM PONs:

Enhanced spectral efficiency

Avoiding costly optical devices and
using cheaper electronic devices

Dynamic allocation of subcarriers

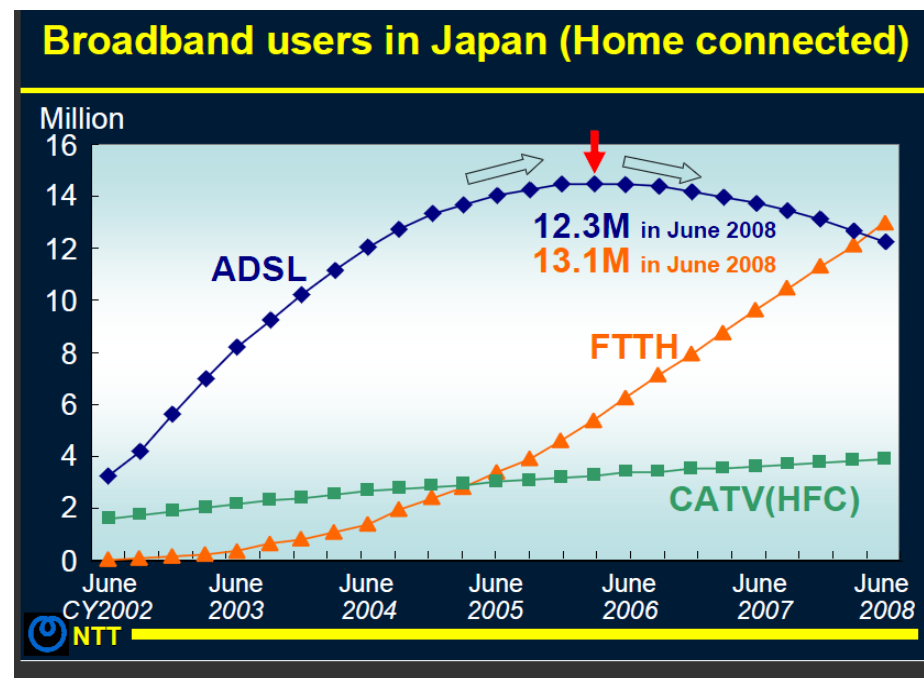
Source: PON Architectures (Springer); SpringerBriefs in Applied
Sciences and Technology 2013, pp 11-22

Current situation of NGAN

- Definition of Large Bandwidth (LB)
 - The ITU-T I.113 recommendation defines Large Bandwidth (LB) as the “transmission capacity that is faster than primary rate Integrated Services Digital Network (ISDN) at 1.5 or 2.0 Mbit/s”
 - The Federal Communications Commission defines it as “broadband as 200 kbit/s (0.2 Mbit/s) in one direction, and advanced broadband as at least 200 kbit/s in both direction”
 - OECD defines it as “broadband as 256 kbit/s in at least one direction”
 - The European Commission defines it as “broadband capacity as downstream capacity equal to or higher than 144 kbit/s”
- Definition of Ultra Large Bandwidth (ULB)
 - Usually ULB is defined as ranging above 30 Mbit/s in the downstream direction, per user

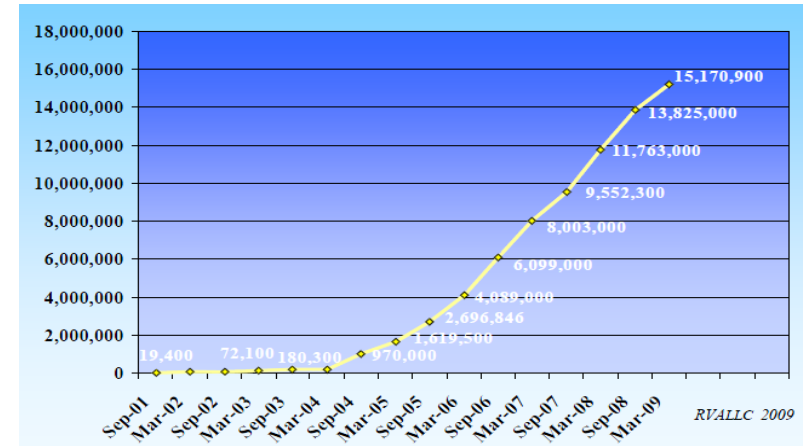
Worldwide NGAN

- In Japan NTT holds about 75% of the FTTH market
- Where operators offer wide spread ULB access, the number of xDSL terminations is decreasing



Worldwide NGAN

- In the USA FTTH is increasing steadily
- The Figure plots the growth of FTTH terminations in North America
- Since the contribution of Canada, Mexico and Caribbeans is about 1,5% of the total, plotted data refer essentially to the USA



Ultra Large Bandwidth

- The 30+ Mbit/s access speed of ULB refers to the peak capacity of the user's downlink
- The actual average capacity available to the individual user can be less than 30 Mbit/s, depending on the traffic concentration policies adopted by operators
- Thus, the definition of ULB is referred to a theoretical maximum capacity, real transmission speed depends on the operator's investments in upgrading its access network and metropolitan network

Ultra Large Bandwidth

- A strategy for the deployment of the NGAN must take into account business issues
 - The required investments for the NGAN will make it really available an upgrade of user's services?
 - If yes, will it be profitable for operators to deploy the NGAN?

Ultra Large Bandwidth

- For residential users, the increased bandwidth will enable services that users will be willing to spend for?
- The figure shows that with a ULB access individual users could benefit of at least two HDTV channels (about 8 Mbit/s each), a number of lower resolution TV channels, high-speed data access (8-10 Mbit/s) and VoIP services
- The issue is the cost of these services

Ultra Large Bandwidth

- Only a subset of user's population will be willing to pay for such services
- However, the high speed data channel will enable fast peer to peer services, and this is likely to increase the size of the user's population interested to ULB access
- In fact, the ranking of users in p2p systems depends mainly on the user's access capacity
- The higher the user's access capacity, the higher the user's rank in the p2p system

Ultra Large Bandwidth

- Thus, it is likely that increased speed of access links will create new service demands, according to the general principle “new streets create more traffic”
- Moreover, Small Office Home Office (SOHO) and Small Medium Enterprise (SME) will be potentially interested in an upgraded network access

Deployment of NGAN

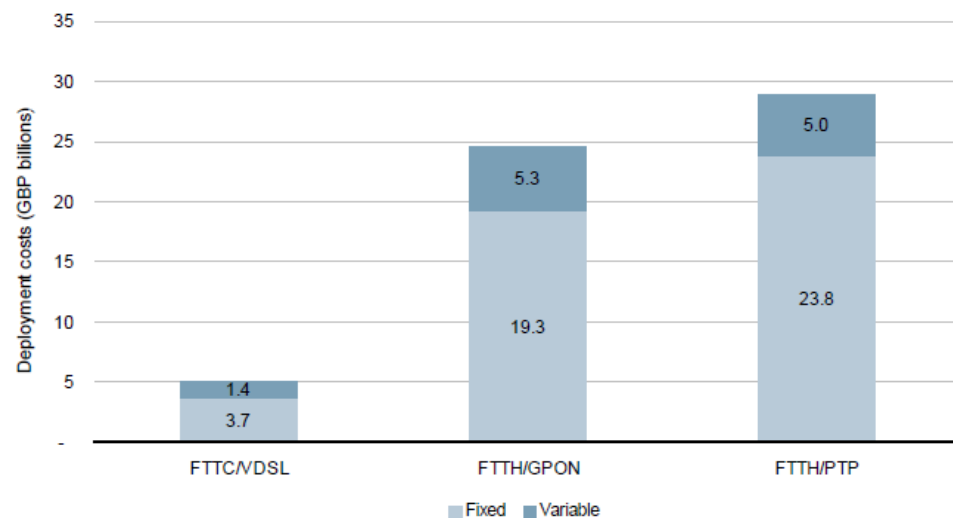
- FTTx access architectures are expensive infrastructures
- The migration towards a 100% FTTH architecture requires higher costs than FTTC/FTTB
- Thus, once again operators must seek a tradeoff between performance and costs
- In Italy, the cost difference between FTTC/FTTB and FTTH is relatively smaller than in other countries
- This depends on the current status of the copper access network, on the distribution of user population and geographical features of the national territory

Deployment of NGAN

- FTTH can require up to 5 times investment costs than FTTC
- FTTH P2P requires about 10% investment costs more than FTTH
- One of the main cost components is constituted by cabling, excavations in streets
- A significant issue is the replication of the infrastructure to allow sharing among operators; this will be advantageous only in densely populated areas

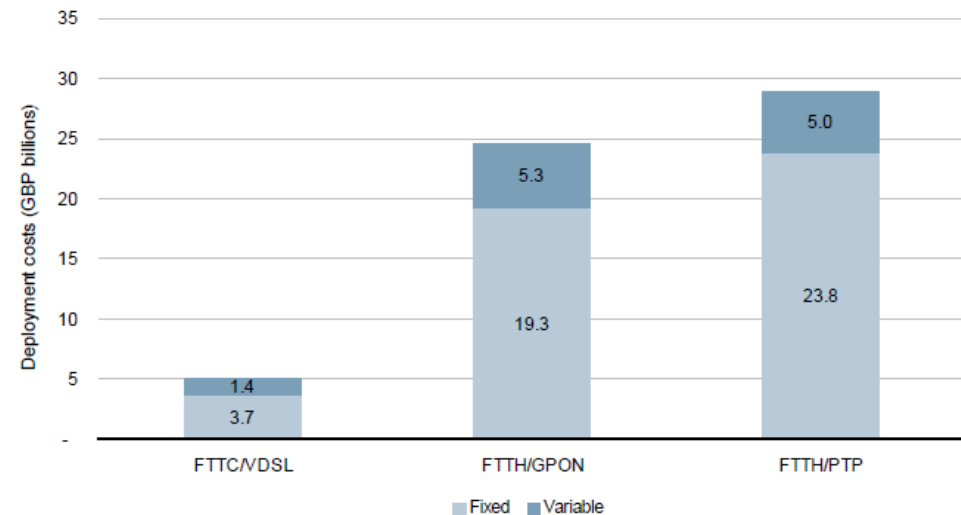
Deployment of NGAN

- The figure plots data relative to the deployment of the NGAN in great britain (comparing FTTC/VDSL, FTTH/GPON and FTTH/P2P), in order to connect 100% of the user population
- FTTH/P2P offers better performance, but higher costs
- FTTH costs 5 times more than FTTC
- FTTH/P2P costs about 15% more than FTTH/GPON



Deployment of NGAN

- In the Figure, fixed costs (to build the infrastructure) are much higher than variable costs (costs to activate user's connection)
- A common strategy of Incumbent Operators is to build a FTTC infrastructure as a transition step towards FTTH

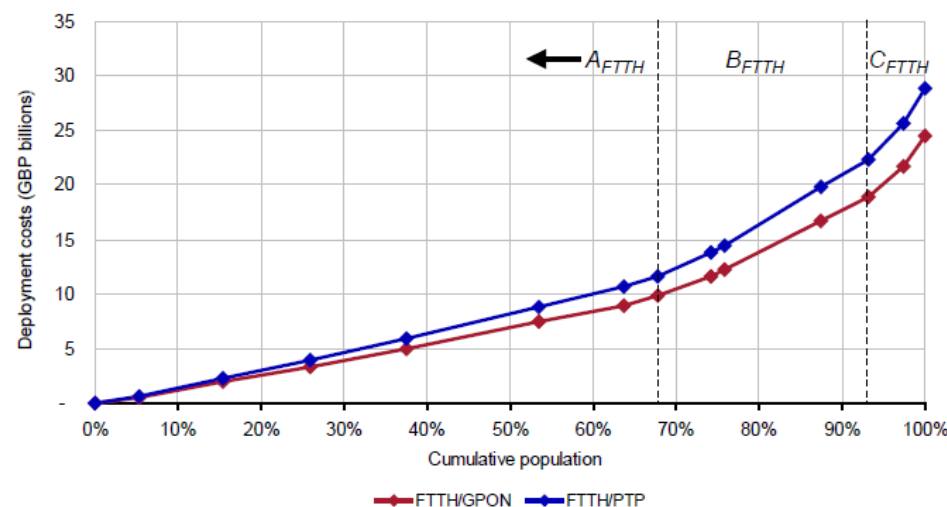


Deployment of NGAN in Italy

- In Italy VDSL solutions are relatively convenient, due to the shorter span of final copper twisted pairs
- Moreover, in Italy about 60% of the user population lives in apartments (densely populated areas) while in UK the percentage drops to 15%
- The two situations are quite different, because deployment costs for densely populated areas are smaller than for suburban areas

Deployment of NGAN

- The cost per user grows as we pass from users living in metropolitan areas to users living in rural areas
- Cost per users is steady for the first 60% of population (urban A population in metropolitan areas)
- Then it increases for the next 20/30% of population (urban B: suburban areas)
- The highest cost per user is for rural users



Digital divide

- Covering 100% of the population may not be convenient
- This is creating a second-generation digital divide, between users with ULB access and users with standard LB access
- It is likely that the gap of the second-generation digital divide can be filled only through government funding, based on the principle of providing equal access to all people

Digital divide

- Great Britain:
- Standard LB to all users by the end of year 2012
- ULB access to 90% of users within year 2017
- France:
- LB acces @512 kbit/s to all users by the end of year 2012

Evolution of services

- The technological migration to the NGAN requires an adaptation of current services provided through the copper infrastructure
- Services may be:
 - emulated/simulated
 - replaced
- In order to analyze the evolution of services, we will classify services as
 - Intermediate services (services internally used by one Operator or services among two operators)
 - Wholesale services for other operators (including unbundling and colocation)
 - Retail services

Intermediate services

- A typical example of this class of services is the connection of mobile network antennas to the core network (UMTS, HSPA, LTE)
- This connection is called “backhauling” and potentially a “fiber deep” access could help building a more cost-efficient backhauling
- However, currently a widely adopted technical solution is using groups of E1 lines for backhauling
- This makes it difficult to distribute the synchronism needed by mobile radio stations
- Pseudowire could be used as a possible technical solution. Another possibility is to use Synchronous Ethernet, synchronization over packet network ...

Intermediate services

- However, the E1 legacy in backhauling places a significant constraint and operators are still using hybrid solutions where dedicated E1 lines are used to distribute synchronism
- GPS receivers could be used as well, but the GPS system is under the administration of the Defense Department of the USA, who can decide to turn it down without any notice
- This calls for alternative solutions such as hybrid, pseudowire, synchronism over packet networks