Networking Technologies and Applications

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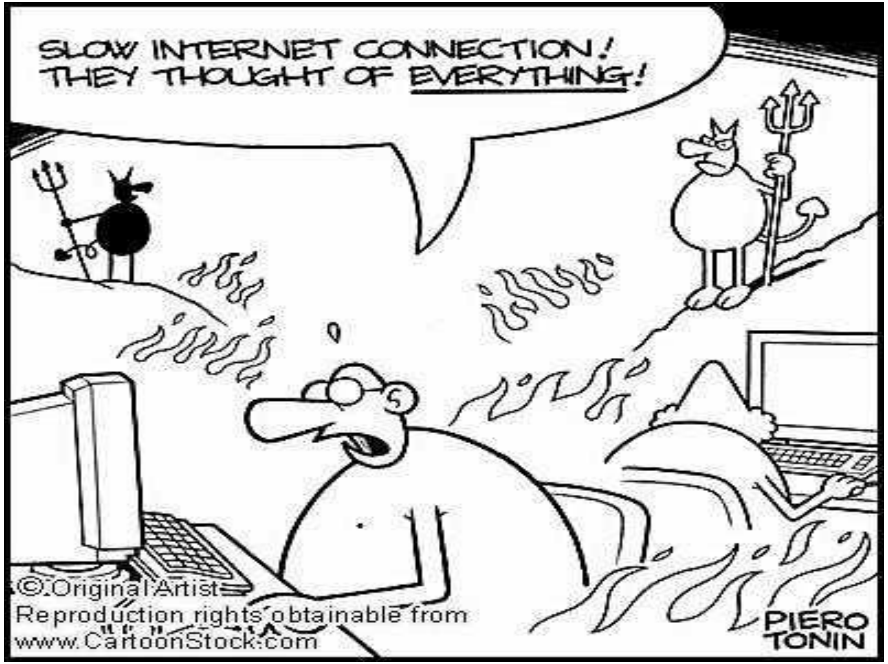
Why fiber?

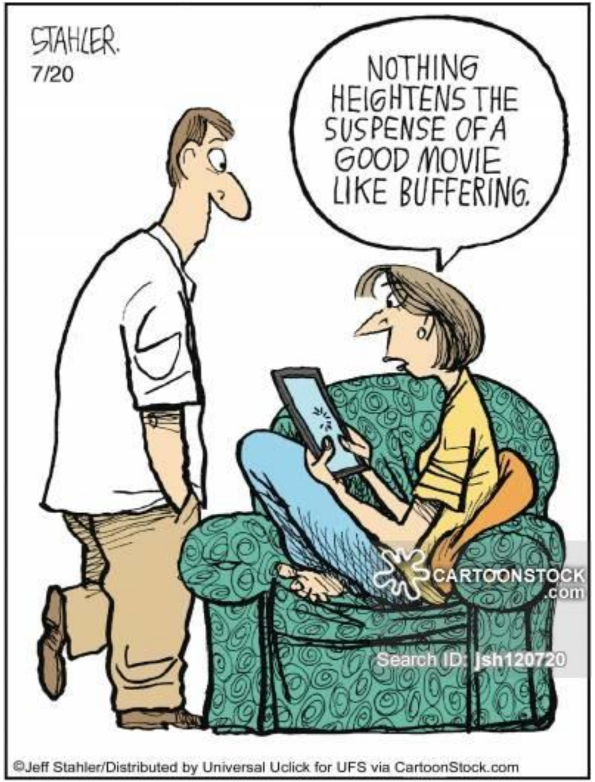
- Today the killer application is not web browsing anymore, but multimedia
  - MPEG-1 – ISO/IEC standard
    - Moving Pictures Experts Group
    - 50:1 – 100:1 compression rate
    - 1.5 Mbps, VHS quality image
  - MPEG-2
    - DVD quality image
  - High resolution, high color depth, high movement video (e.g., sport events) – 4-8 Mbps
  - HDTV – 14 Mbps, **8K UHD TV – 50 Mbps** (7680 x 4320, 60 fps)
- The ADSL speeds are far from being enough
  - Only in case of very short loops

Why fiber?

- HFC (Hybrid Fiber Coax)
  - The traditional 300-550 MHz coaxial cables replaced with 850 MHz cables
    - Additional 300 MHz → 50 new 6 MHz wide channels
    - With QAM-256, 40 Mbps per channel → 2 Gbps new bandwidth
    - 500 houses on a segment → each subscriber gets 4 Mbps downstream, which might be enough for an MPEG-2 stream
  - Sounds nice, but...
    - All the cables should be changed to 850 MHz coax
    - New CMTS, new fiber nodes, two-way amplifiers
    - Nearly the entire network has to be changed
- Why not bringing the fiber as close to the subscriber as possible?

Slow speed is today a torture!





Speed is important!

Estimated minimum download time for the Braveheart movie

MGM, Paramount Pictures, Warner Brothers and Universal Studios announce a common plan to support on-line movie renting”

2002 december 9

„Hollywood’s Latest Flop”, Fortune Magazine:

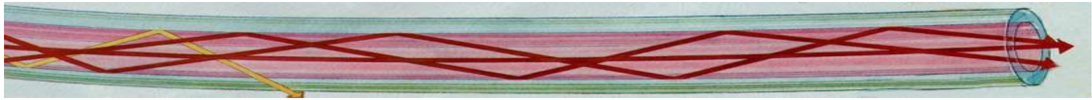
„The data files are huge. At 952 megabytes, Braveheart took just less than five hours to download using our DSL line at home. Video-on-demand? Hardly. In the same time we could have made 20 roundtrips to our neighborhood Blockbuster”

Technology	Minutes	Hours	Days
Modem 56 kb/s			2
FedEx		12	
DSL 1 Mb/s		2.5	
Cable 2.5 Mb/s		1	
BLOCKBUSTER	45		
FTTH	0.4		

Data transfer over the fiber

- Three main components:
  - Source of light
    - LED (light emitting diode), laser
  - Fiber
    - Very thin glass fiber
  - Light detector
- The digital data has to be transformed to light pulses, and vice versa
- The transfer speed is only limited by the speed of the conversion
  - Actual speeds today on a single fiber ~10-50 Gbps

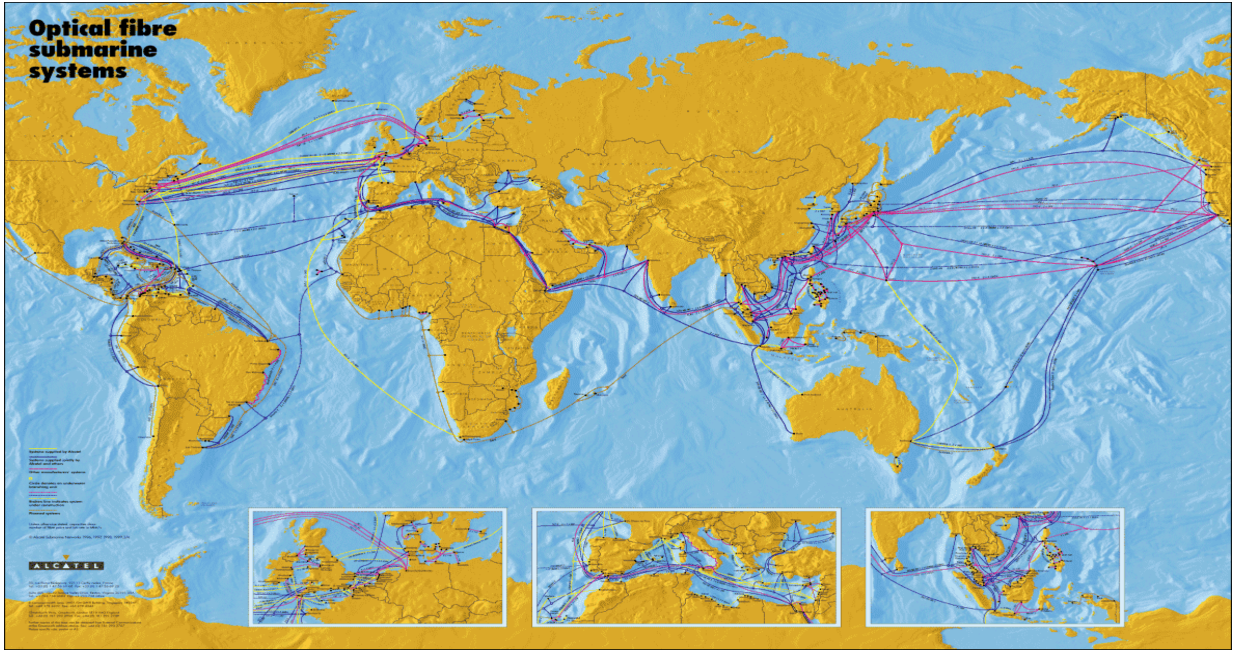
Fiber categories

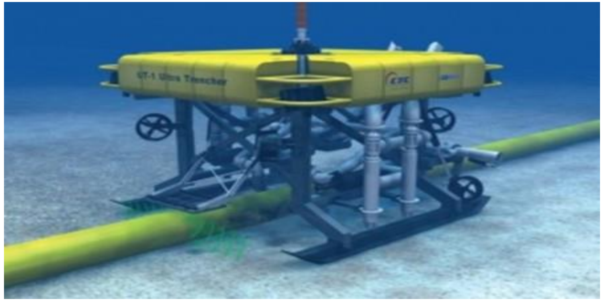


- Multi-mode fiber
  - Light pulses are spread inside the fiber
  - Many rays of light reflected under different angles
  - Cheap solution, but suitable only for small distances (500 m)

- Single-mode fiber
  - The diameter of the fiber is very small, a single ray of light is transmitted inside the fiber, no reflections
  - Much more expensive, needs much higher capacity lasers
  - Suitable for much larger distances
    - 50 Gbps on 100 km without amplifiers
    - Very important for transatlantic cables, where amplifiers are hard to install
  - The core network is built only with single-mode fibers

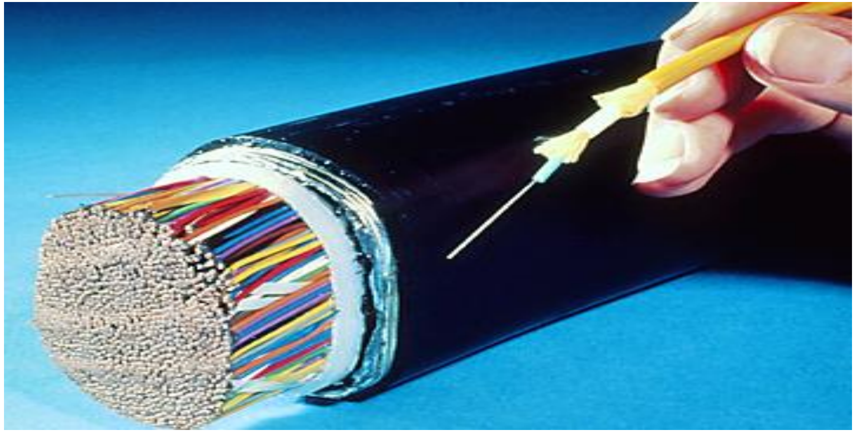
Submarine optical systems



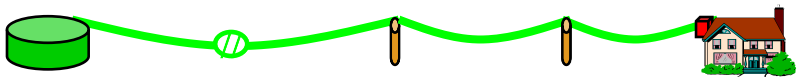


Fiber vs. Copper

- On an optical fiber more than 2.5 million parallel phone calls
- Compared to a similar capacity bundle of twisted pair connections, 1% in weight and size



Fiber vs. Copper

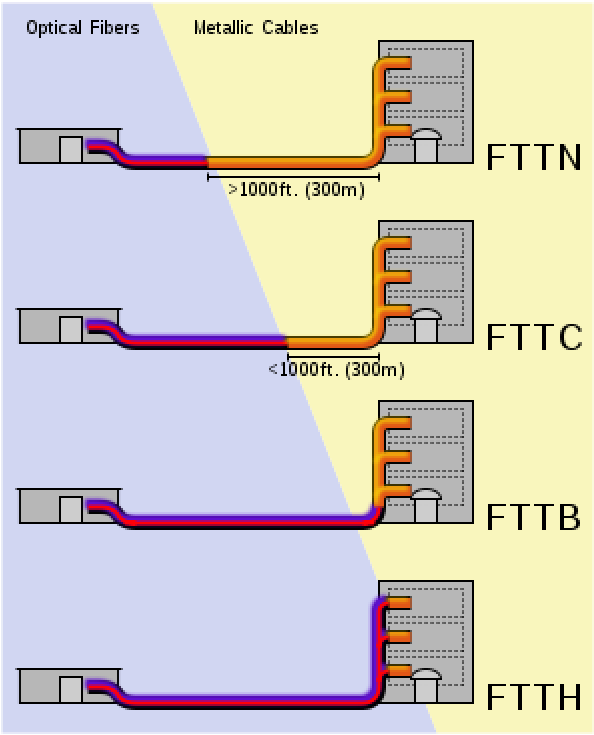


- Optical fiber
  - Transports light pulses
  - Not influenced by electromagnetic interferences
  - Repeaters after ~30 kms
  - Low dilatation
  - Fragile, quite rigid material
  - Chemically stable

- Copper twisted pair
  - Transports electric waves
  - Sensible to electromagnetic interferences
  - Repeaters after 5 km
  - Dilatation in case of high temperatures
  - Can be bended
  - Sensible to galvanic reactions
  - Can be reused
    - The copper could be sold

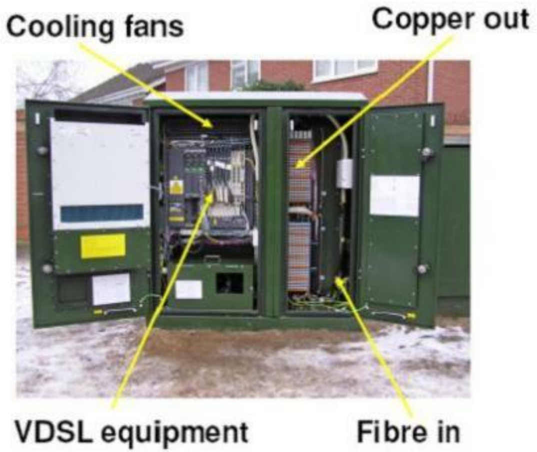
FTTx

- FTTx – Fiber To The x
  - FTTB – Fiber To The Building
  - FTTC – Fiber To The Curb
  - FTTD – Fiber To The Desk
  - FTTE – Fiber To The Enclosure
  - FTTH – Fiber To The Home
  - FTTN – Fiber To The Neighborhood
  - FTTO – Fiber To The Office
  - FTTP – Fiber To The Premises
  - FTTU – Fiber To The User



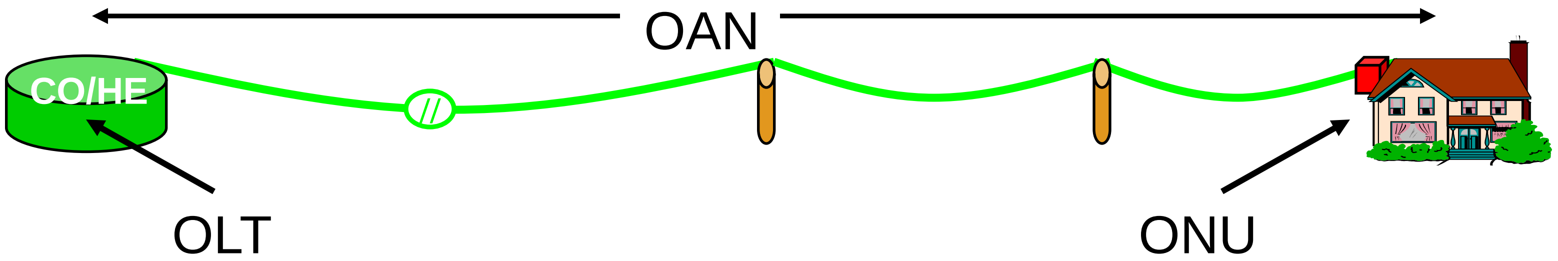
FTTC

- Fiber To The Curb
- Fiber from the local switching center near to the homes
  - The connection terminated by an ONU
    - Optical Network Unit
  - Many twisted pairs or coaxial cables added in the „last mile”
    - Very short loops, can be extended with a DSL segment
      - e.g., VDSL – very popular in South-East Asia
    - Suitable for MPEG-2 streams and videoconferencing



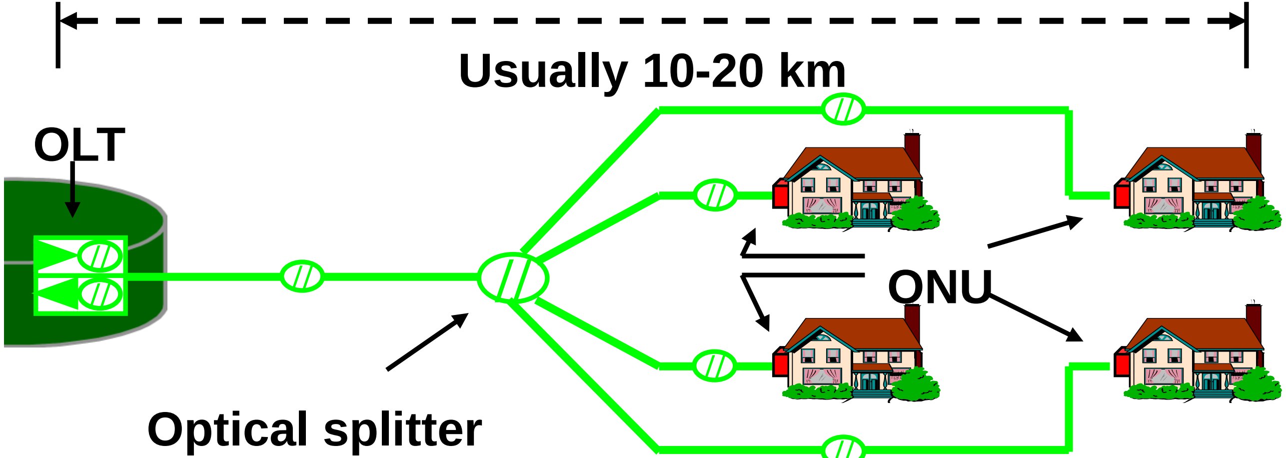
FTTH

- Fiber To The Home
- System components
  - OAN: Optical Access Network
  - ONU/ONT: Optical Network Unit/Terminal
    - At the subscriber
  - OLT: Optical Line Termination
    - At the service provider



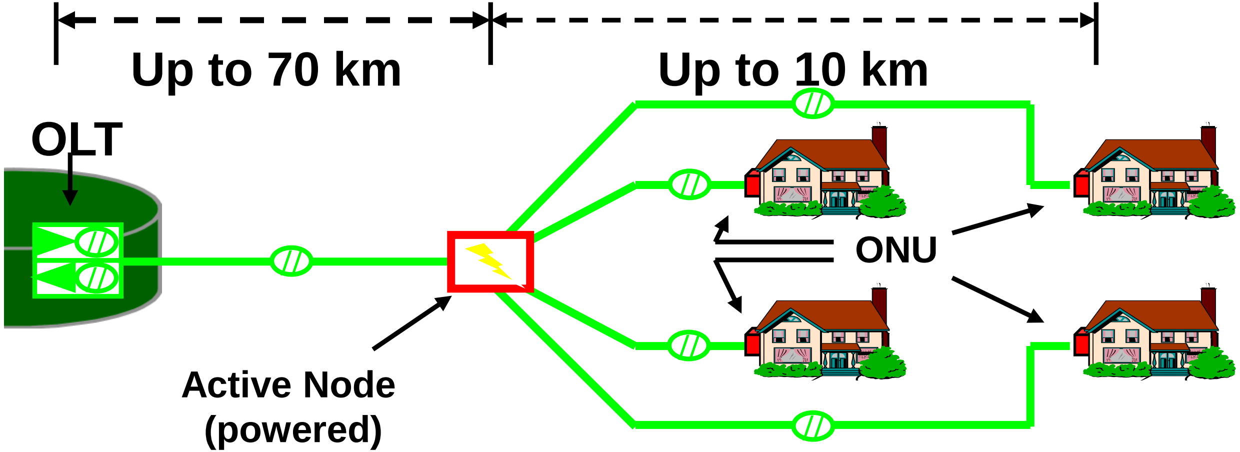
FTTH architectures

- PON – Passive Optical Networks
  - Many subscribers (max. 32) share an optical fiber
  - Optical splitters to separate or aggregate the signals to/from different subscribers
  - No need for power supply for the splitters
  - Shared network – Point to Multipoint (P2MP)



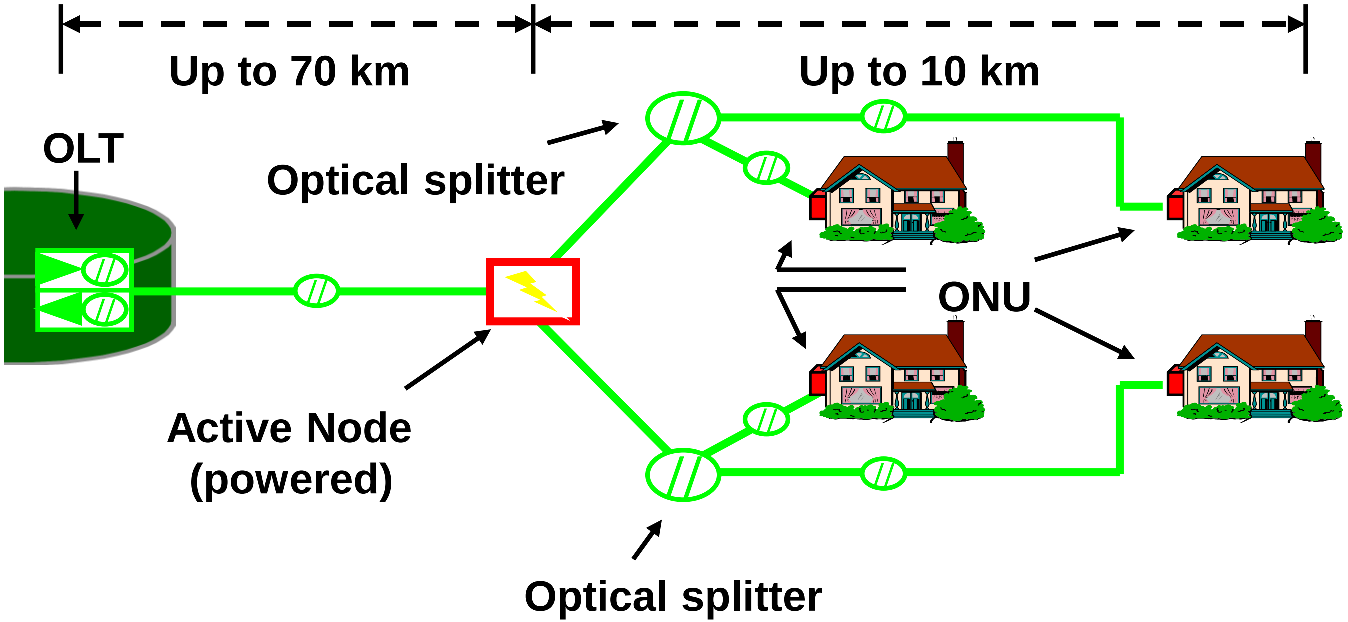
FTTH architectures

- Active Node
  - Each subscriber has his own optical fiber
    - Point to Point (P2P)
  - Active, powered nodes to separate the traffic
    - Ethernet switch
  - Layer2/Layer3 switching/routing



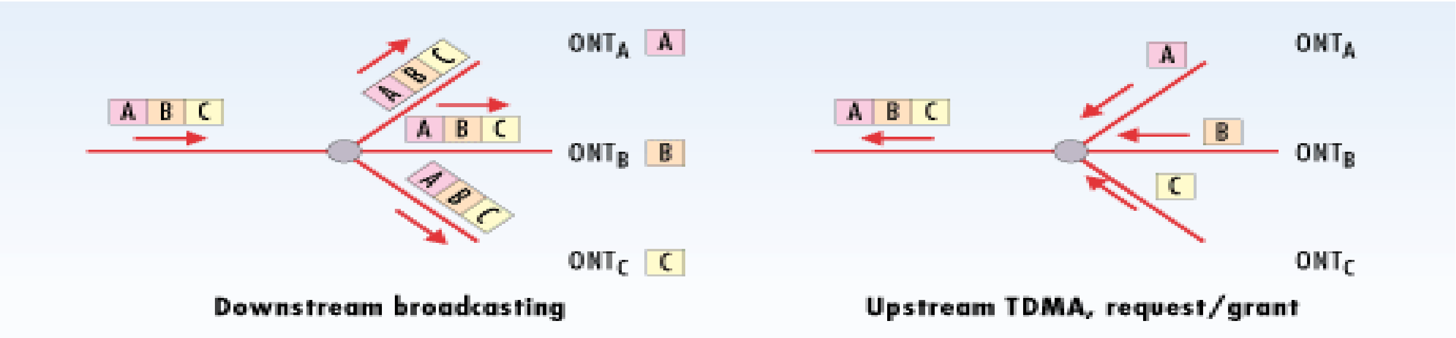
FTTH architectures

- Hybrid PON
  - A combination of the two architectures



PON - upstream and downstream traffic

- The upstream and downstream traffic handled differently
  - Broadcast downstream
    - The splitter forwards all the data to all the connected segments
    - The ONU handles only the packets that it is the destination of (based on the header)
  - Upstream traffic with TDMA
    - The OLT assigns time slots to the ONUs
    - Synchronized sending of packets
    - The ONU can ask for further slots, if needed



Ethernet or ATM?

- At the beginning, two concurrent technologies
  - APON – ATM-based PON
    - The first PON implementation
  - EPON – Ethernet-based PON

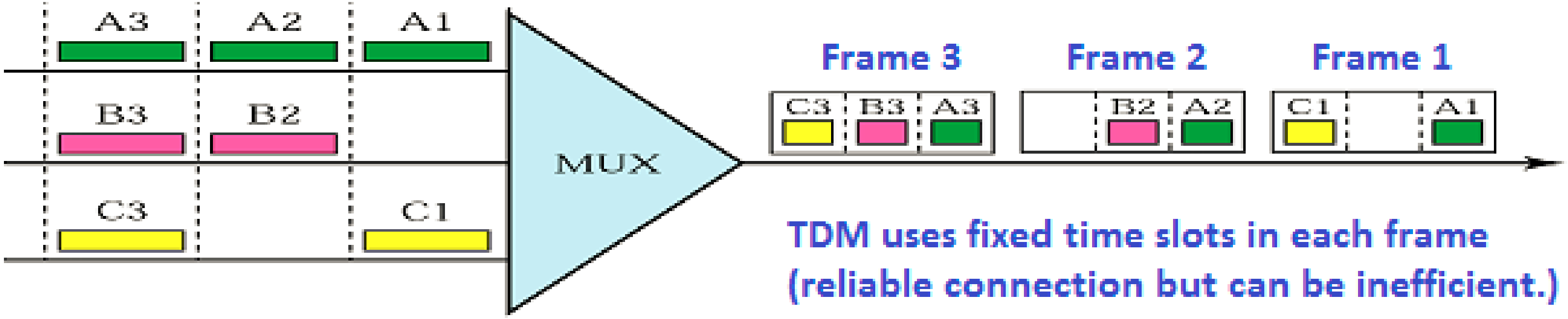
ATM (Asynchronous Transfer Mode)

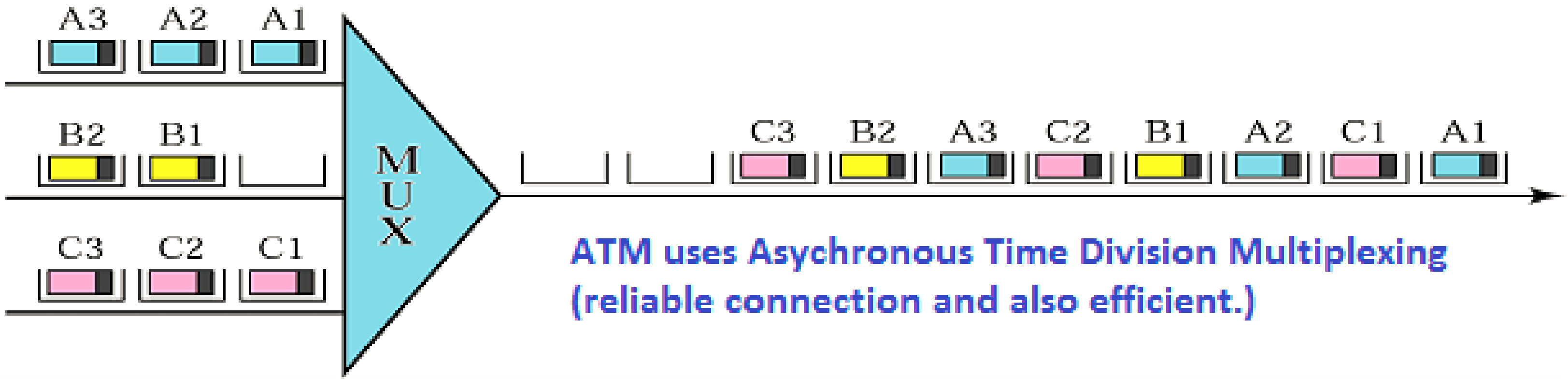
- Proposed for parallel handling of different traffic types (audio, video, data)
  - 1500 byte Ethernet frames are too large
    - 1.500 byte = 12.000 bit
    - On 10 Mbps Ethernet 0.1 μs bit time → 1.2 ms / frame
  - If more sources (stations or applications) are waiting in a queue, too long waiting times
- Audio and video applications have strict **delay** and **jitter** requirements

ATM (Asynchronous Transfer Mode)

- ATM solution
  - Fixed size **ATM cells**: 5 byte header + 48 byte data = **53 byte**
  - **Segmentation and Reassembly (SAR)**
    - Variable length frames are fragmented at the sender, and reassembled at the receiver, based on the header
  - **Asynchronous Time Division Multiplexing**

ATM (Asynchronous Transfer Mode)





APON

- Segmentation and Reassembly (SAR)
  - Fix sized packets
    - 53 byte long ATM cells
  - Data passes through an ATM Adaptation Layer-en (AAL), where it is split in 48 byte long packets
    - Plus 5 byte long headers
  - Packets are reassembled at the destination
- Because of the SAR, ATM is very suitable for video and voice transfer
  - Delay-sensitive traffic can be well transmitted in small, fixed size cells
- Fixed sized cells well suited for the PON TDMA upstream traffic
  - Easy to handle time slots, no collisions

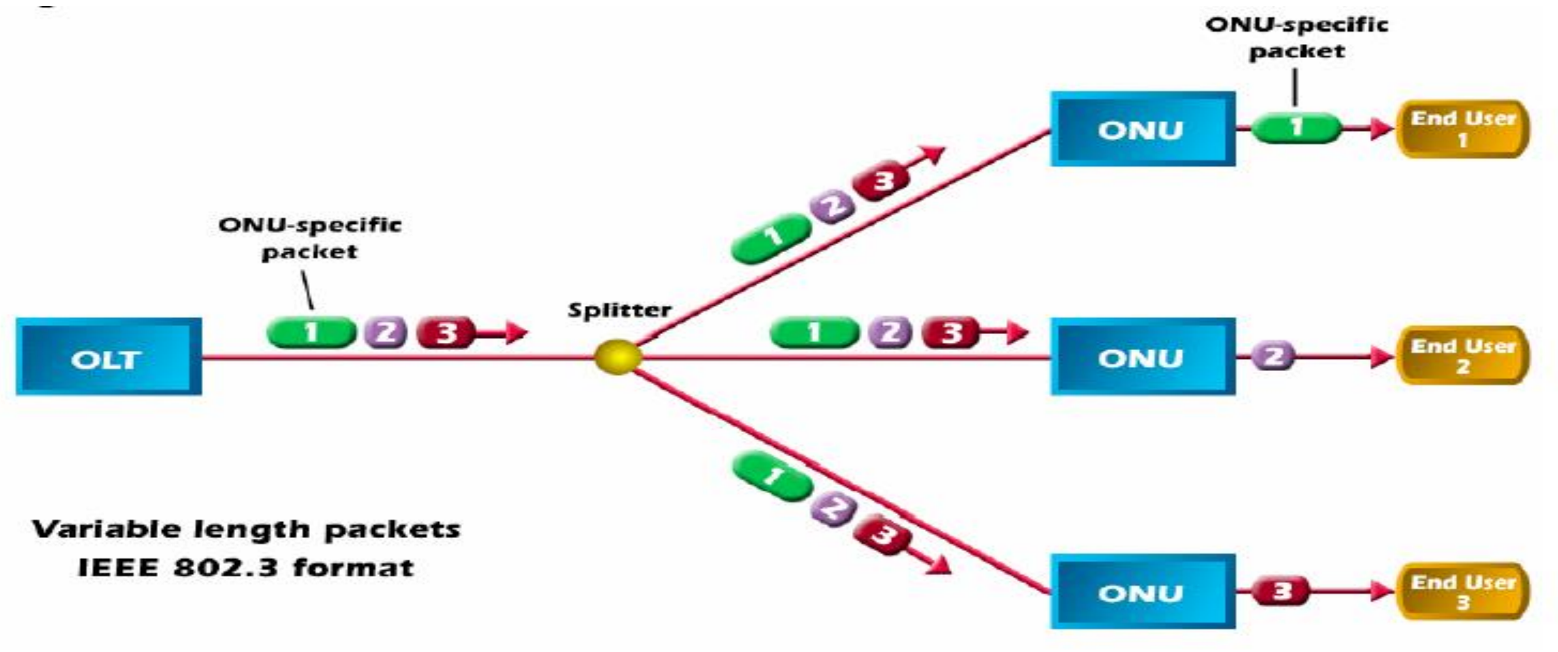
Why ATM is not (really) used?

- Very popular at the beginning of the 90's
  - More and more multimedia traffic, with QoS requirements
- **Drawbacks**
  - Too much overhead with the headers
    - Ethernet – 14 byte / 1500 byte (~ 1%)
    - ATM – 5 byte / 53 byte (~ 10%)
  - Fragmentation and reassembly (SAR) too complicated
    - High speed ATM cards too expensive, compared to similar speed Ethernet cards
  - On 10 Gbps Ethernet, instead of 1.2 ms, only 1.2 μs is the sending time of a 1500 byte frame
    - With such speeds, no need to worry about QoS

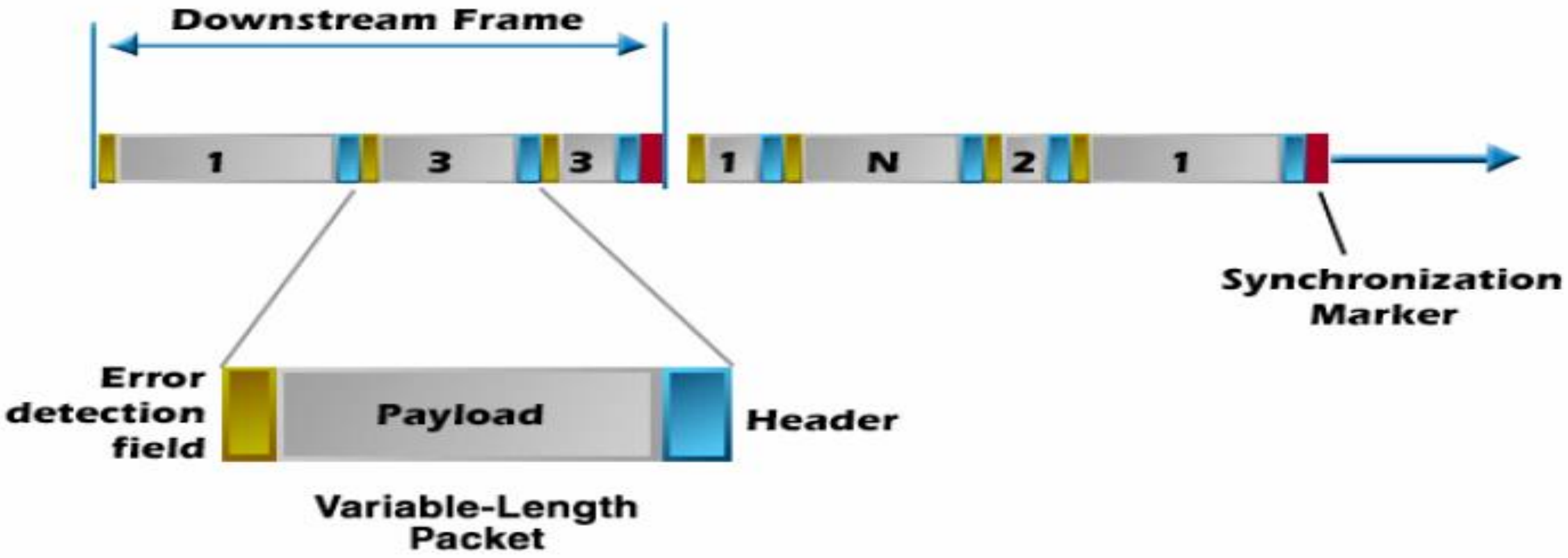
EPON

- Data sent in IEEE 802.3 (Ethernet) frames
  - Variable size frames, between 64 and 1518 bytes
- How to handle TDMA-based upstream communication?
  - We might use maximum length slots
    - Any frame can fit in
    - Not efficient, too much bandwidth wasted
  - We might have fixed length slots, filled with several frames
    - More efficient
    - Hard to fill a fixed length slot with variable size frames

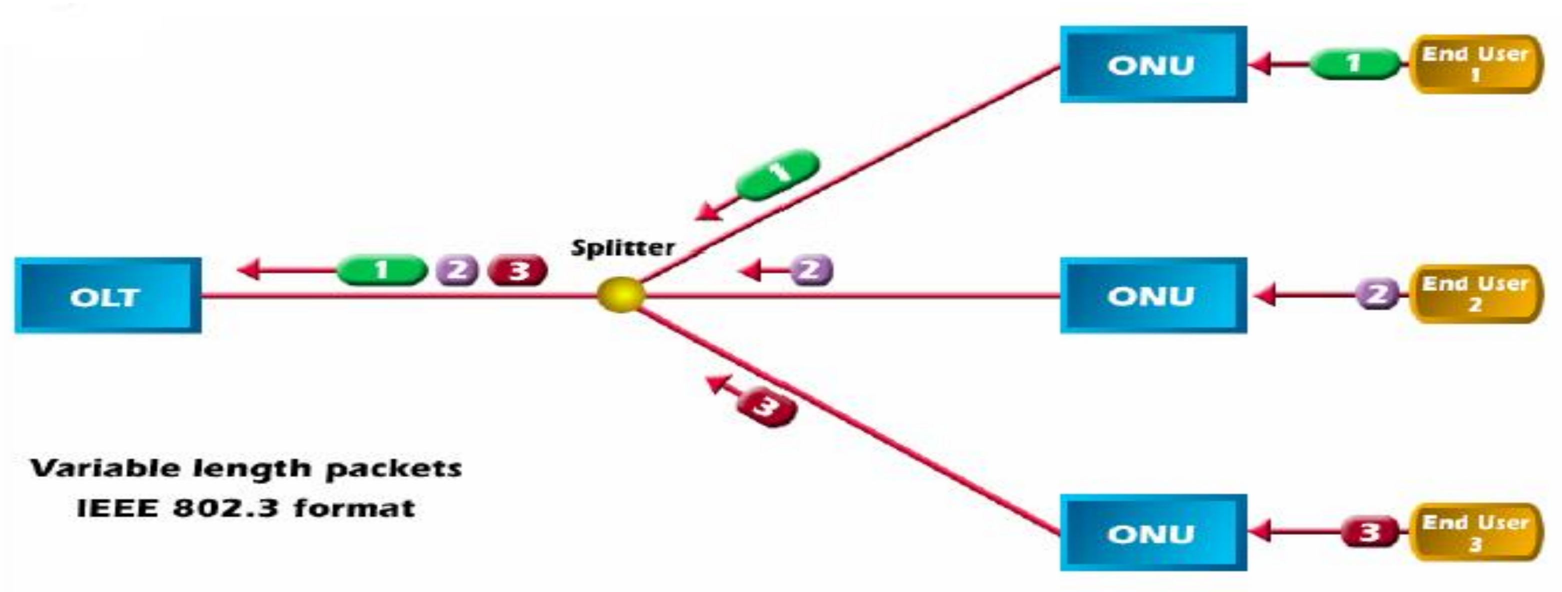
EPON downstream traffic



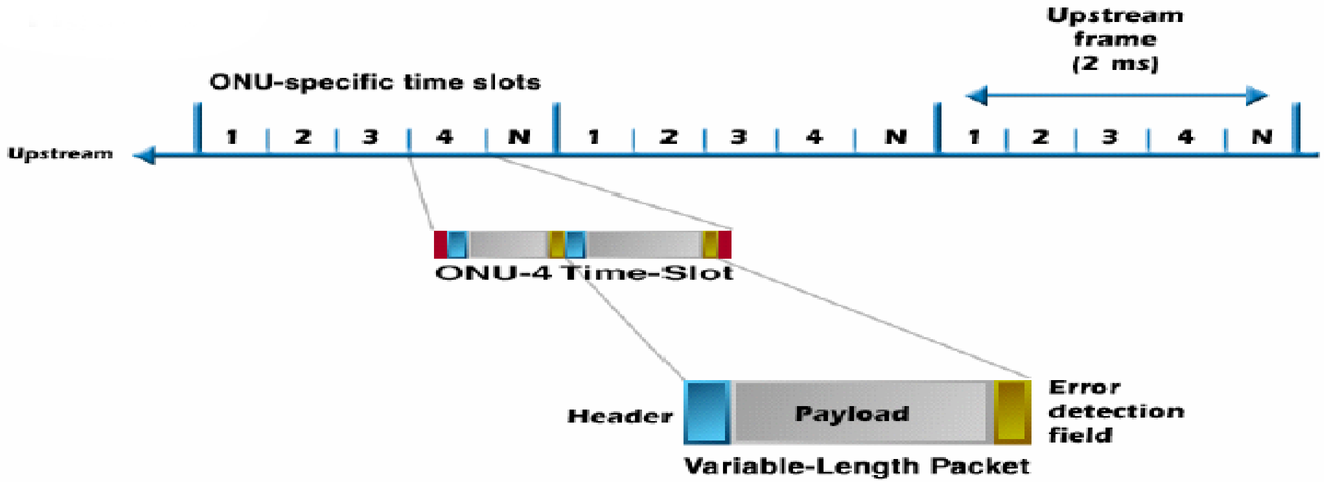
EPON downstream packets



EPON upstream traffic



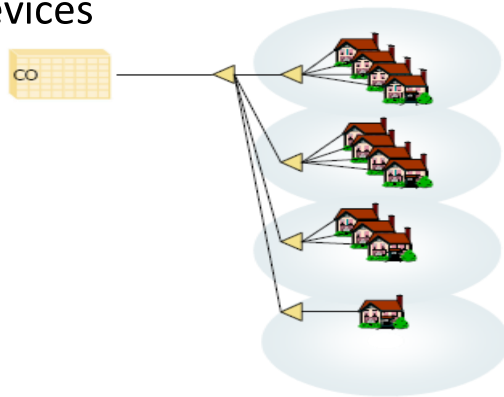
EPON upstream packets



- The upstream traffic divided to frames
- Each ONU has its own time slot, that it fills with his own variable length packets

Traditional PON

- Main idea:
  - Its is not worth having a separate fiber for each user from the OLT
  - Bring on fiber close to the subscribers, and share it with passive devices

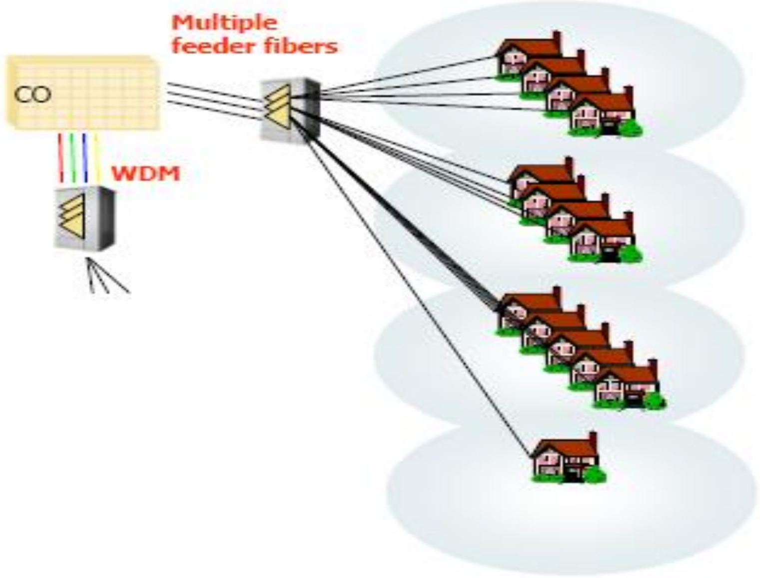


- Drawbacks
  - Splitters are dummy devices, cannot be controlled remotely
    - If a problem occurs, splitters has to be checked one by one
  - Not flexible
    - A 5th subscriber cannot be added to a 4-line splitter
    - The networks should be designed with over-provisioning in mind

- Solution: plan the network with larger splitters
  - Place for extensions
  - The subscribers will have to cover the costs

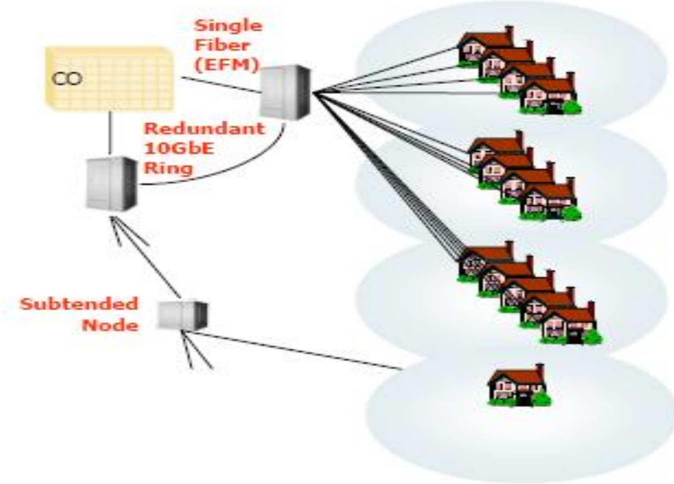
Passive Star PON

- Splitters in the same box
  - Easier to discover the faulty splitter
- Still a tree topology
  - If the connection between the splitter and the Central Office is cut, no backup



Active Star

- Drawback: need for powered active nodes
- Using intelligent devices at the edge of the network has many advantages
  - The active node can act as an IGMP proxy for multicast traffic
    - Detailed in a later course
  - Fault-tolerant solution
    - Active nodes joined in a ring
    - Ethernet Protection Switching Rings (EPSR)
    - 50 ms switching time in case of an error
      - Minor image quality degradation for a video stream
      - A phone conversation is not interrupted
  - Easy to manage, easy to repair



BPON

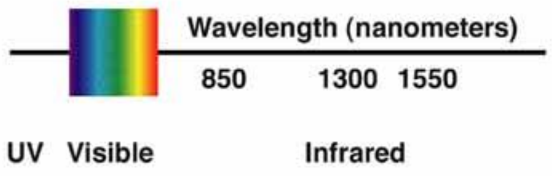
- Broadband PON
  - ATM-based
  - Better than traditional APON
    - Higher transmission speed
    - DBA – Dynamic Bandwidth Allocation
    - Security enhancements

GPON

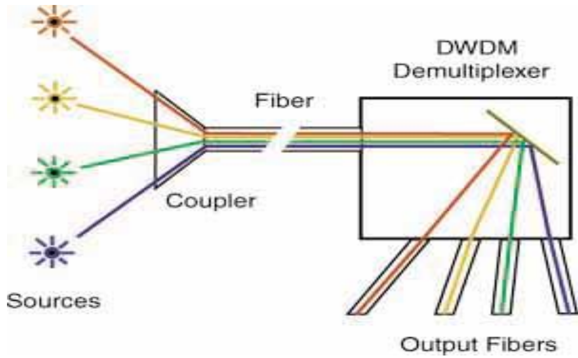
- Gigabit PON
  - ITU-T G.984 standard
  - Several downstream/upstream versions
    - Most popular - 2.48 Gbps dowsntream, 1.244 Gbps upstream

WDM-PON

- WDM – Wavelength Division Multiplexing
  - Several wavelengths (colors, frequencies) on the same fiber
  - Up to 160 colors
    - On a 10 Gbit/s fiber, speed of 1.6 Tbit/s



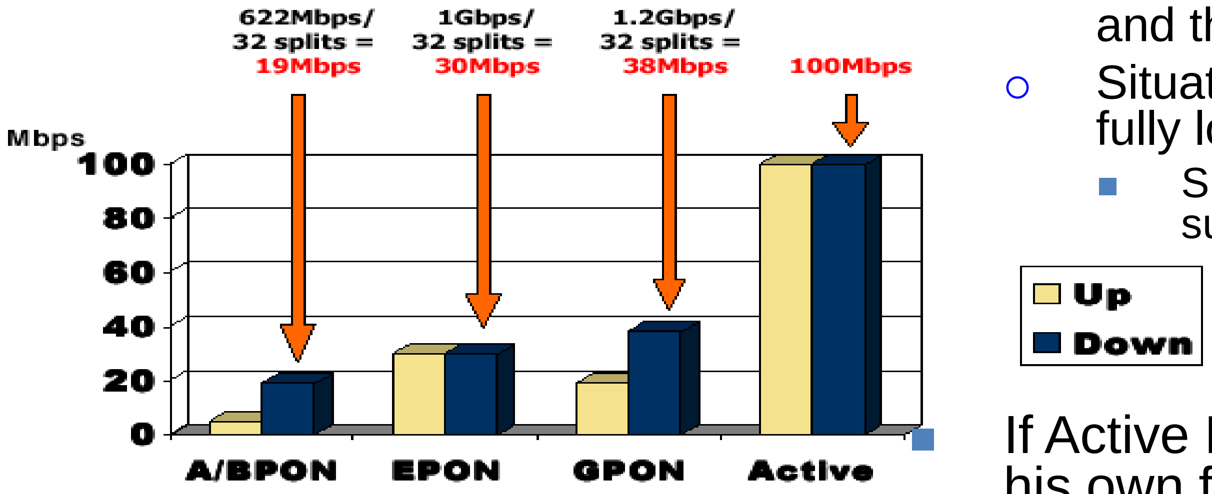
- WDM-PON
  - Combines the advantages of TDM-PON and AON
  - Virtual P2P connection for each ONU
  - Lower delay than in TDM-PON



WDM-PON versions

- No standardized solution
  - We can have deicated uplink and downlink wavelength for each ONU
  - We can allocate adaptively wavelengths to ONUs, based on their actual needs – adaptive lasers
  - We can have many ONUs over the same wavelength, and use TDM
  - Composite PON (CPON) – WDM technology for downstream, TDMA for upstream

Comparison of transfer speeds



- With PON, slower speeds
  - Shared segment between the OLT and the first splitter
  - Situation is better if splitters are not fully loaded
    - Shared between 16 or 24 subscribers, not 32
- If Active Nodes, each subscriber has his own fiber
  - Individual users usually 100 Mbps in the two directions
  - Business subscribers – up to 1 Gbps