Networking Technologies and Applications

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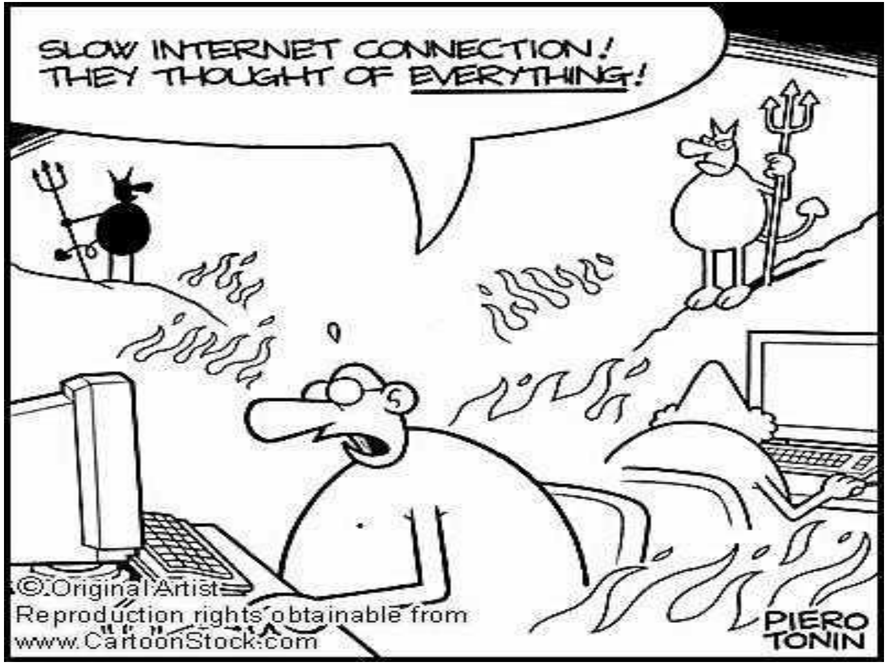
Why fiber?

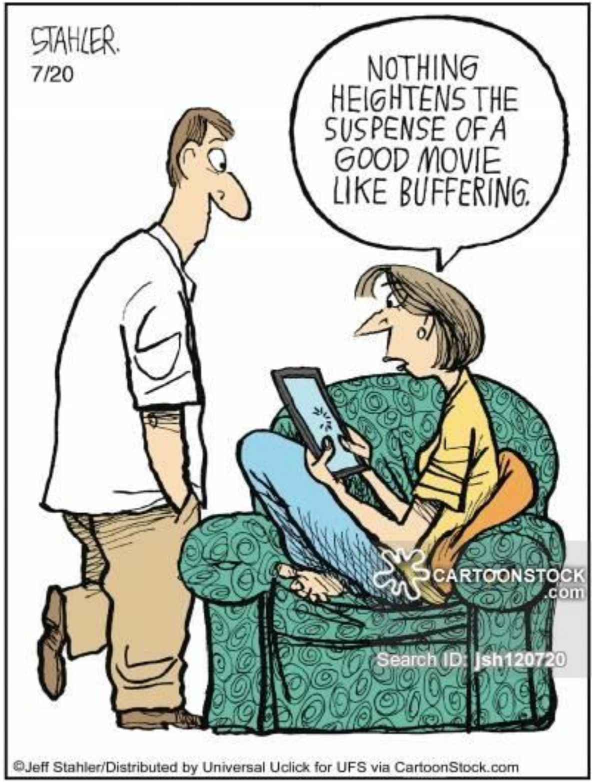
- Today the killer application is not web browsing anymore, but multimedia
  - MPEG-1 – ISO/IEC standard
    - Moving Pictures Experts Group
    - 50:1 – 100:1 compression rate
    - 1.5 Mbps, VHS quality image
  - MPEG-2
    - DVD quality image
  - High resolution, high color depth, high movement video (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:

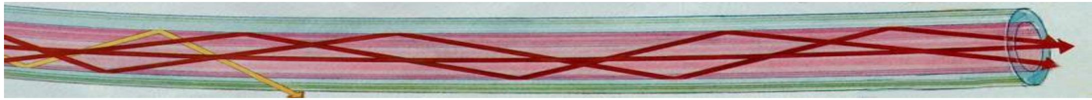
„The data files are huge. At 952 megabytes, Braveheart took just less than five hours to download using our DSL line at home. Video-on-demand? Hardly. In the same time we could have made 20 roundtrips to our neighborhood Blockbuster”

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
    - If it detects a light pulse – logical 1 bit
    - If not – logical 0 bit
- 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

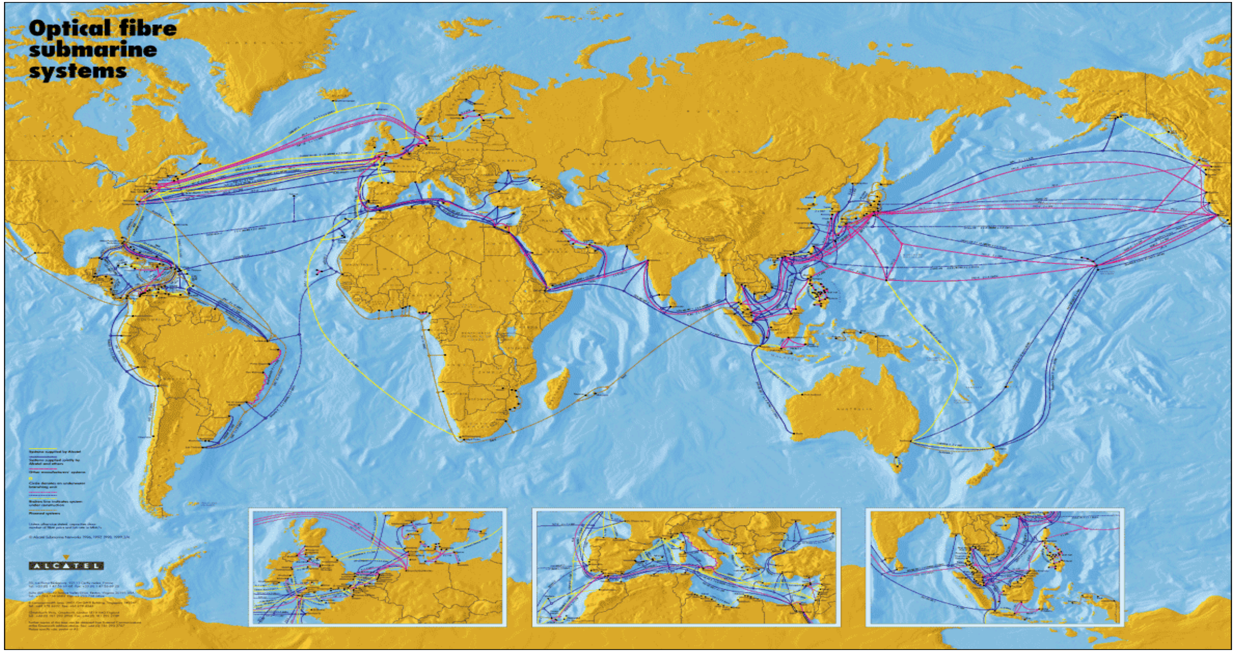
Fiber categories

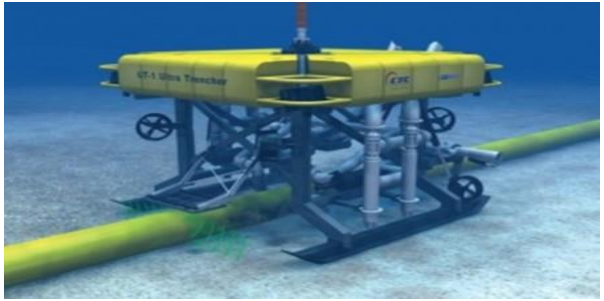


- Multi-mode fiber
  - Light pulses are spread inside the fiber
  - Many rays of light reflected under different angles
  - Cheap solution, but suitable only for small distances (500 m)

- 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

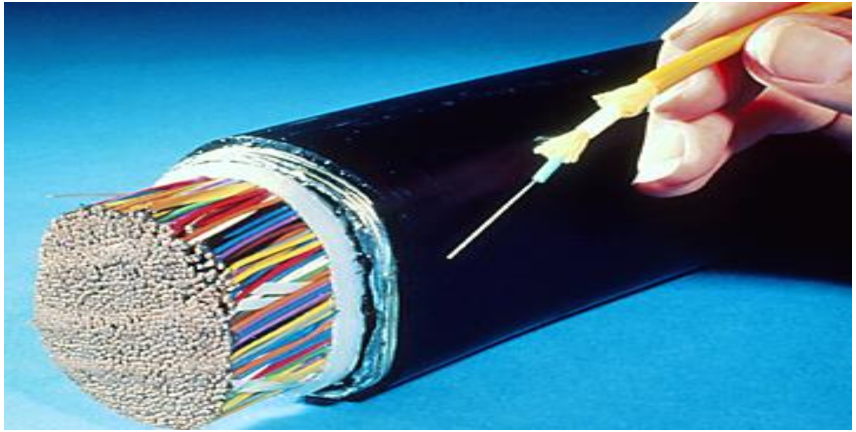
Submarine optical systems



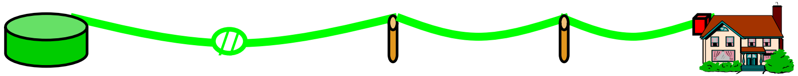


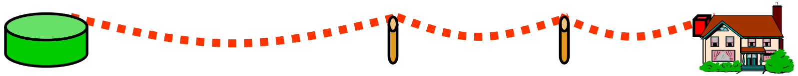
Fiber vs. Copper

- 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



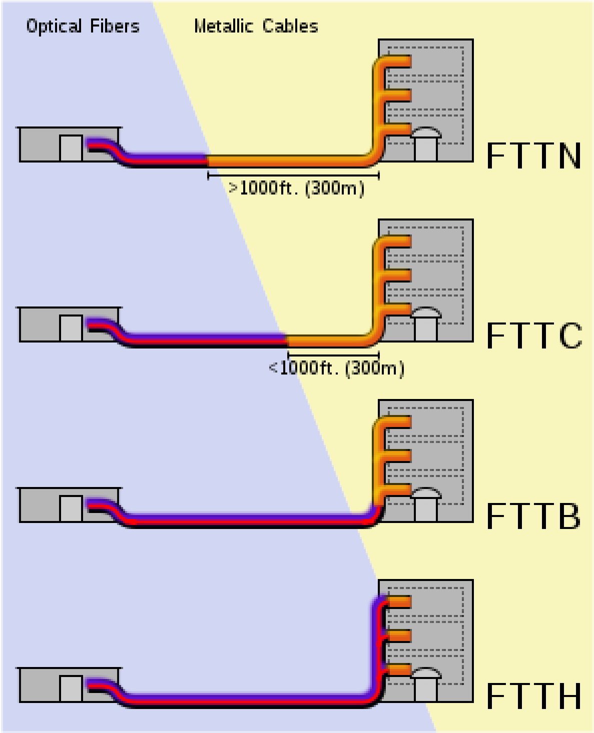


- Optical fiber
  - Transports light pulses
  - Not influenced by electromagnetic interferences
  - Repeaters after ~30 kms
  - Low dilatation
  - Fragile, quite rigid material
  - Chemically stable

- 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

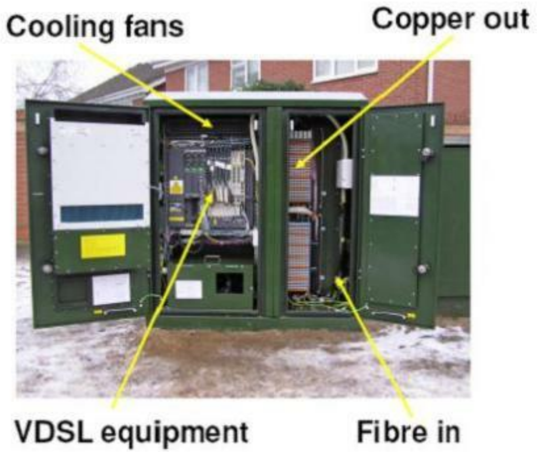
FTTx

- 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



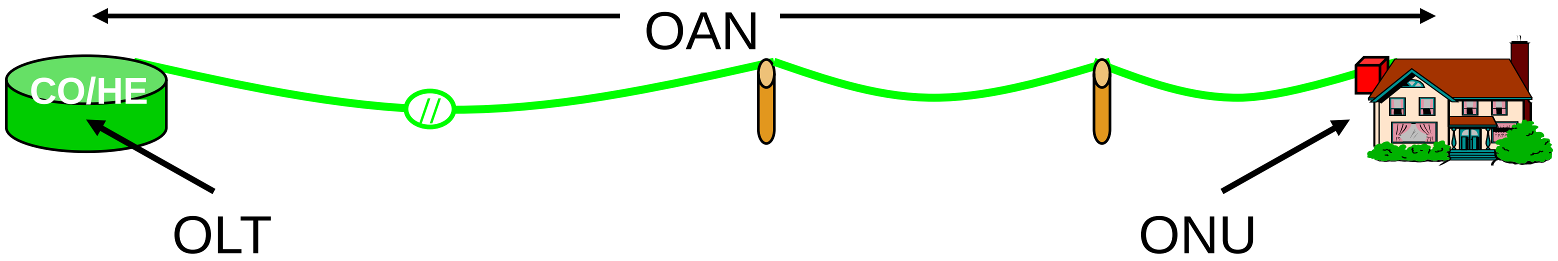
FTTC

- 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



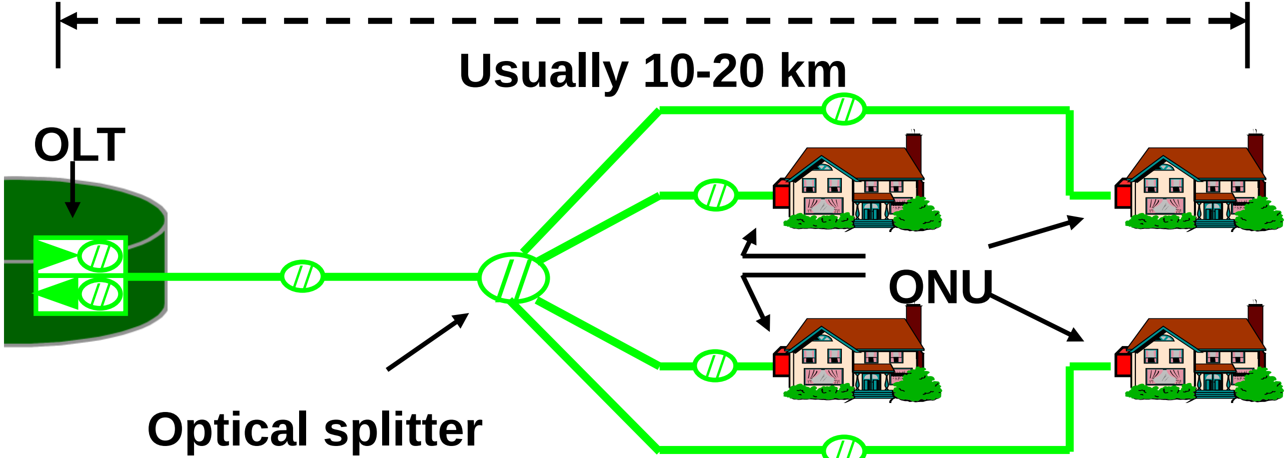
FTTH

- 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



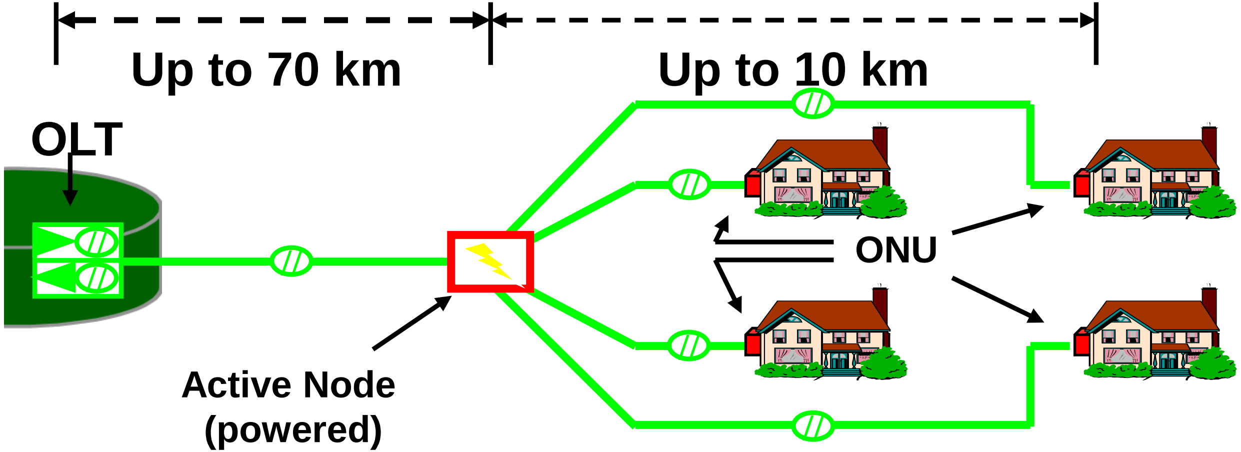
FTTH architectures

- 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)



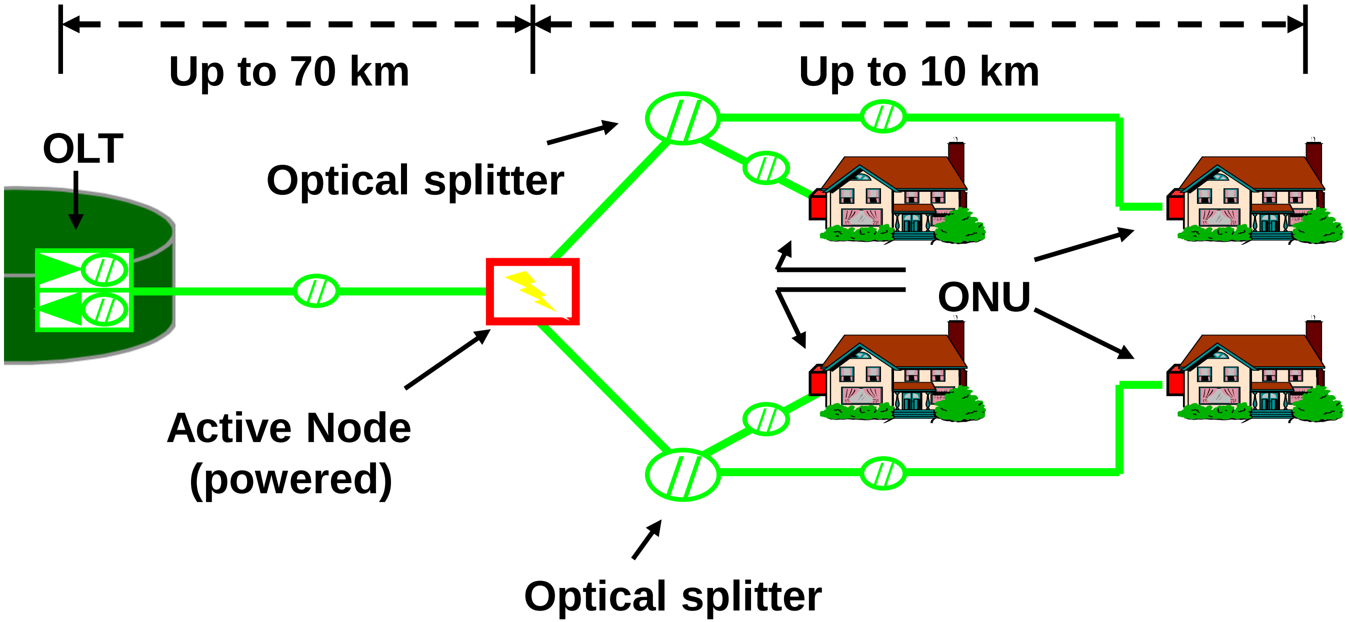
FTTH architectures

- 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



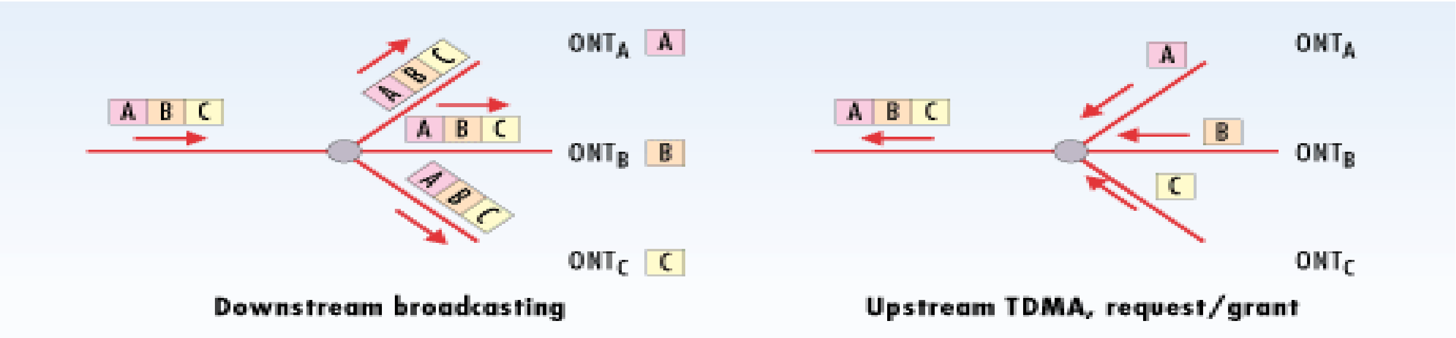
FTTH architectures

- 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?

- Two concurrent technologies
  - APON – ATM-based PON
    - The first PON implementation
  - EPON – Ethernet-based PON

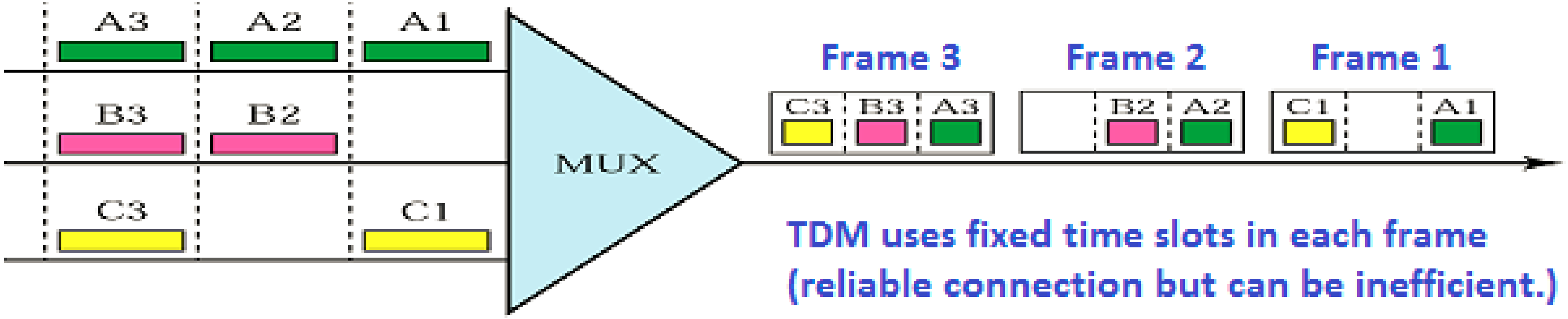
ATM (Asynchronous Transfer Mode)

- 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 Etherneten 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

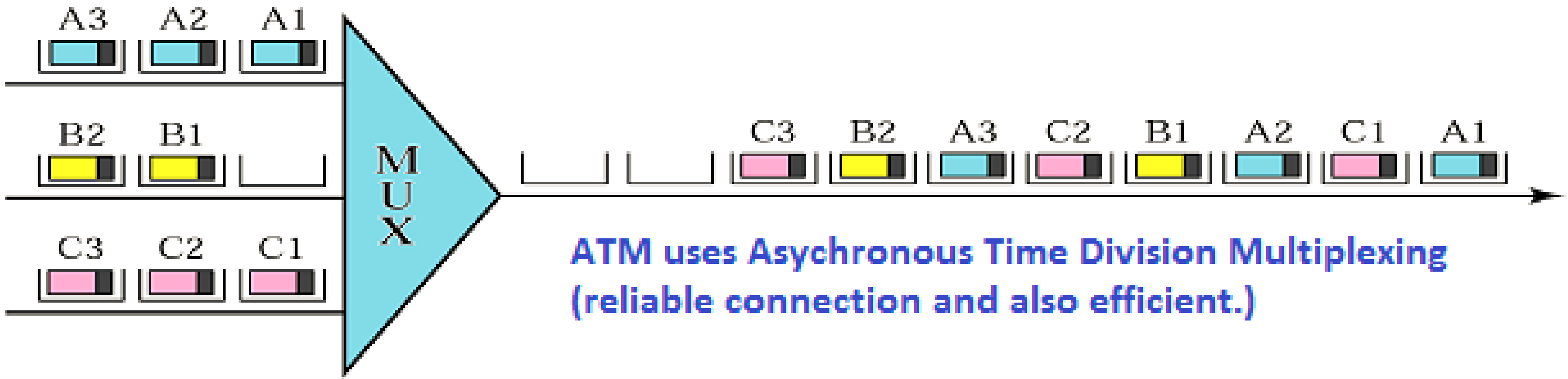
ATM (Asynchronous Transfer Mode)

- 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)



TDM uses fixed time slots in each frame
(reliable connection but can be inefficient.)



ATM uses Asychronous Time Division Multiplexing
(reliable connection and also efficient.)

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

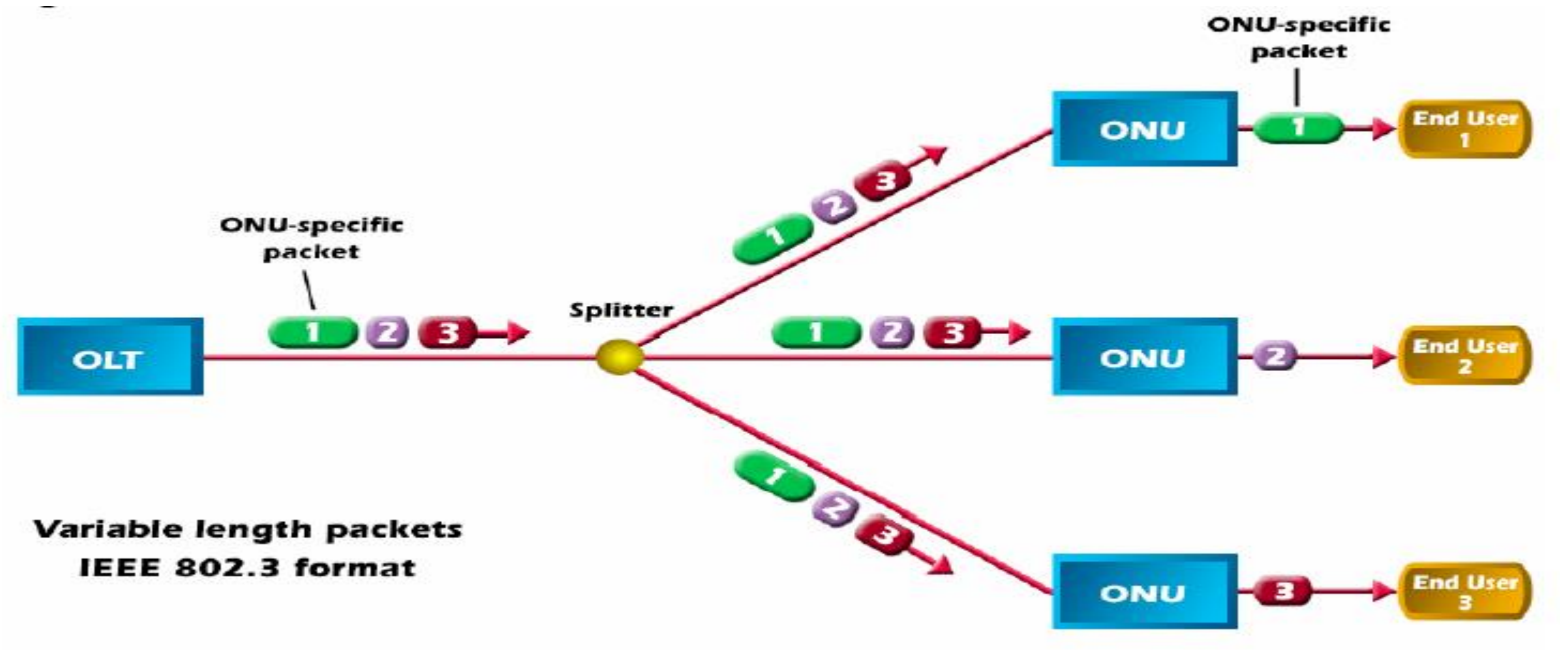
APON

- 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
  - Time consuming procedure
  - 5-byte headers are too long (10% overhead)
- Fixed sized cells well suited for the PON TDMA upstream traffic
  - Easy to handle time slots, no collisions

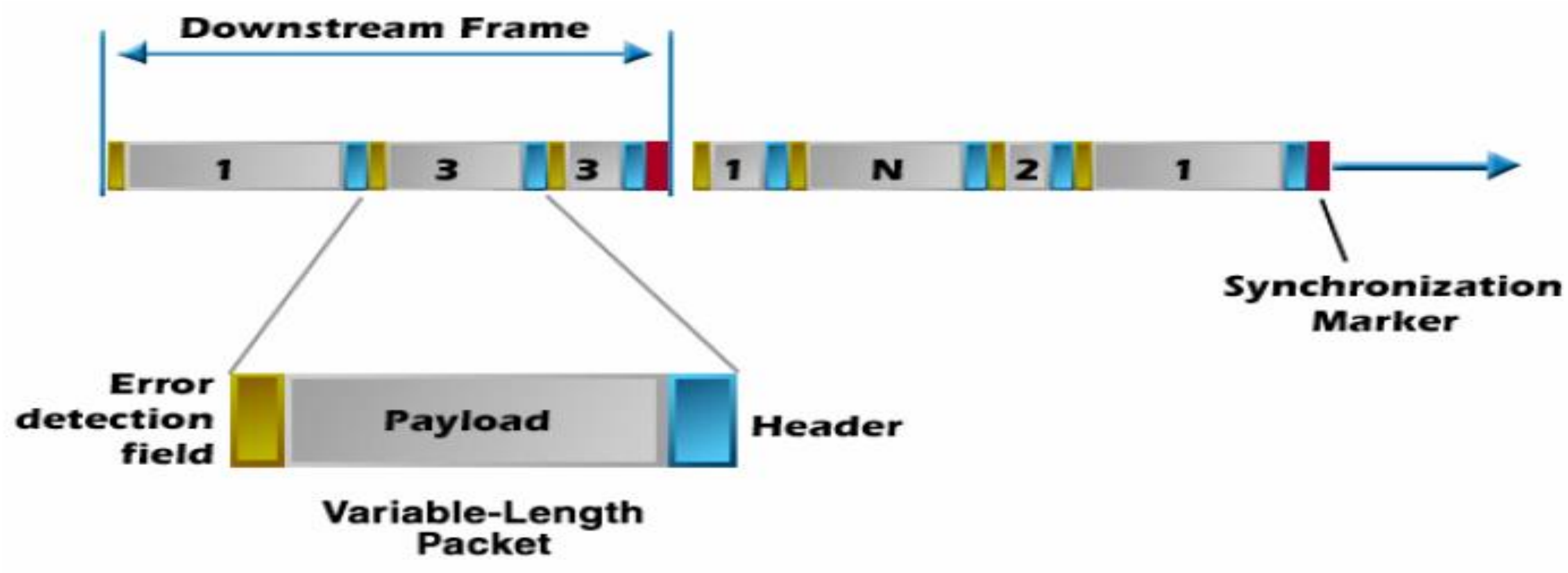
EPON

- 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, but not ideal
    - Hard to fill a fixed length slot with variable size frames
  - Ethernet frames could be divided in fixed length chunks
    - Easier to upload
    - The price is a SAR function that has to be added to the EPON protocol stack

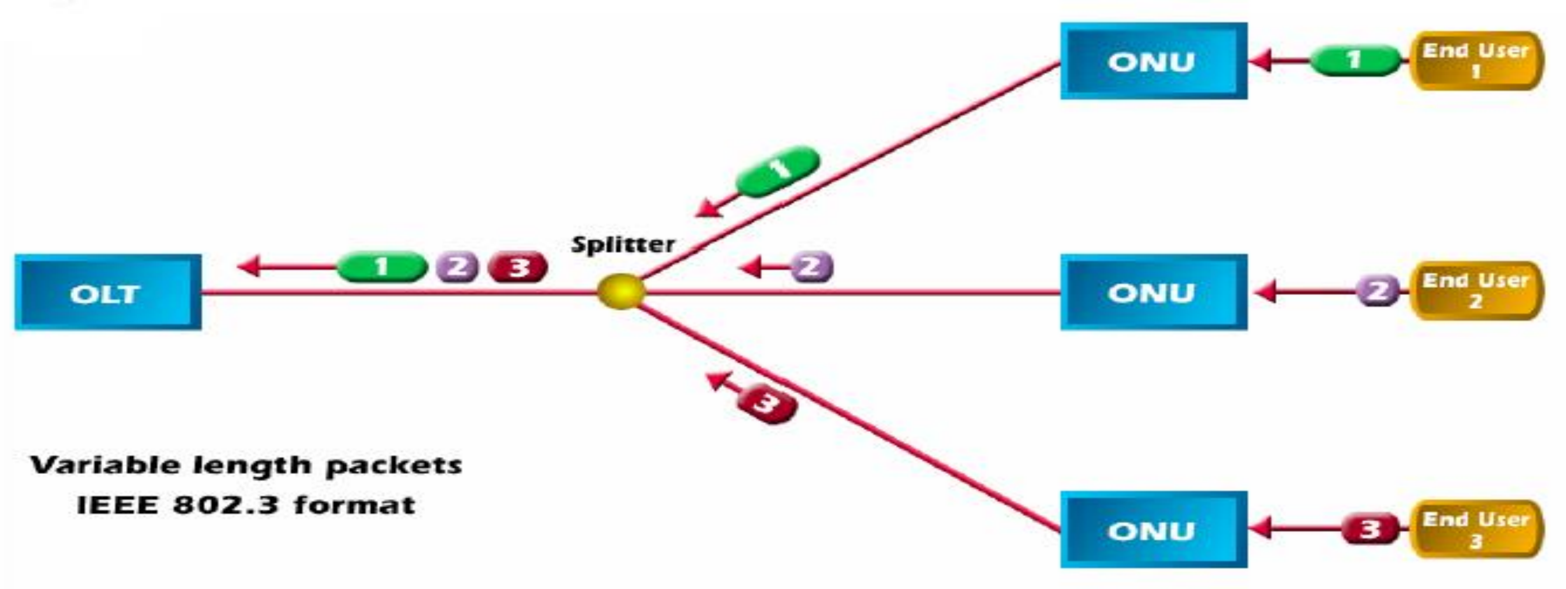
EPON downstream traffic



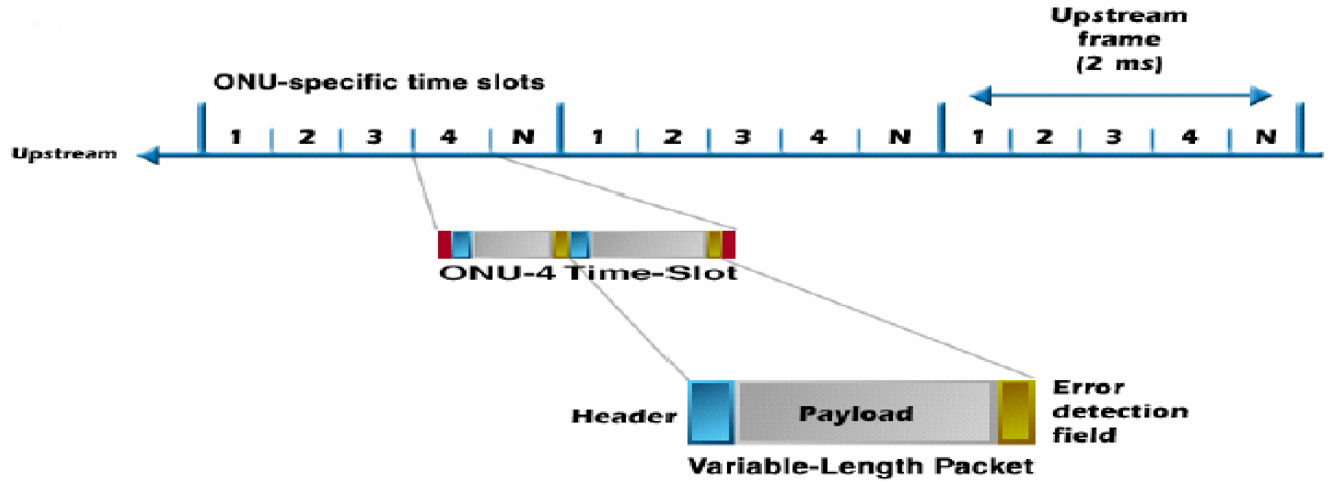
EPON downstream packets



EPON upstream traffic



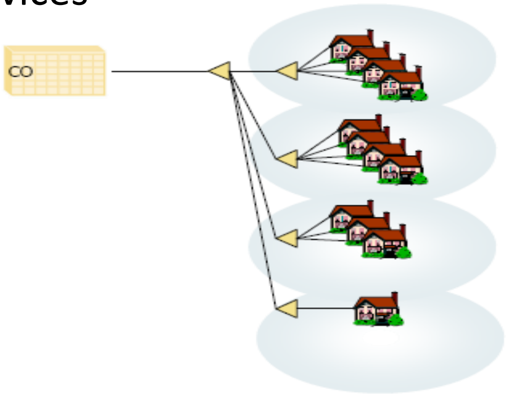
EPON upstream packets



- 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

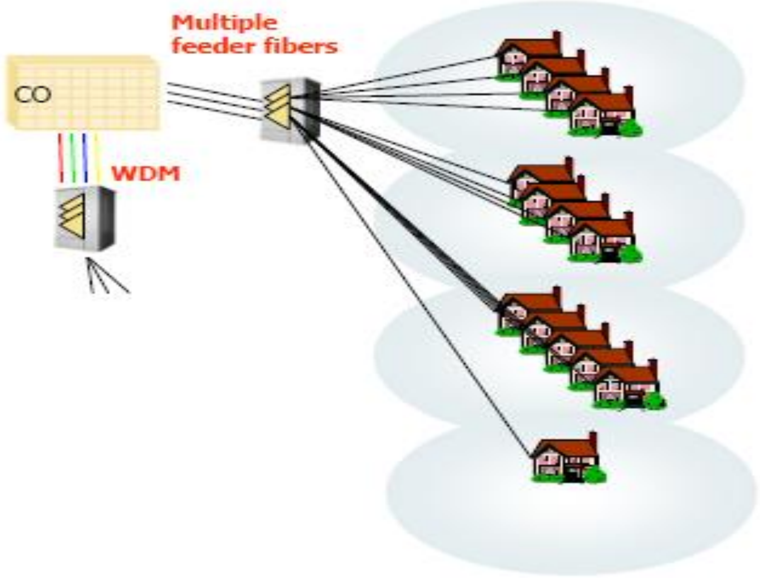


- Drawbacks
  - Splitters are dummy devices, cannot be controlled remotely
    - If a problem occurs, splitters has to be checked one by one
  - Not flexible
    - A 5th subscriber cannot be added to a 4-line splitter
    - The networks should be designed with over-provisioning in mind, not violating the 32 rule

- Solution: plan the network with 16 or 24-line splitters
  - Place for extensions
  - The remaining 16 subscribers will pay more

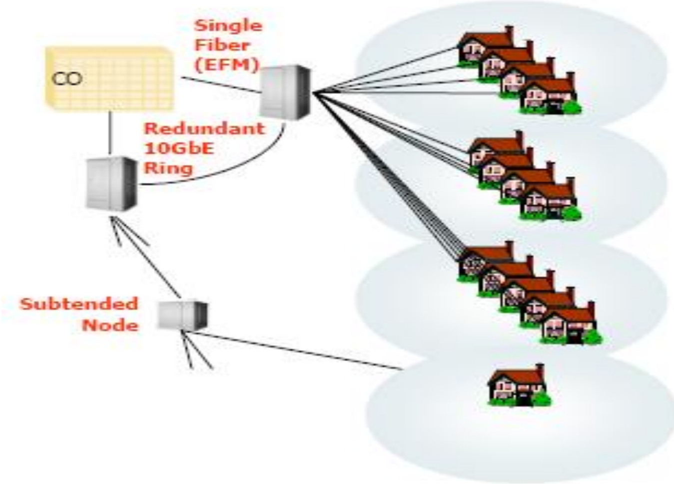
Passive Star PON

- 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

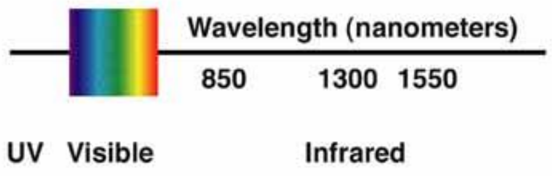
- Broadband PON
  - ATM-based
  - Better than traditional APON
    - Higher transmission speed
    - DBA – Dynamic Bandwidth Allocation
    - Security enhancements
  - Current APON/BPON systems in 3 operation modes
    - 155 Mbps downstream, 155 Mbps upstream
    - 622 Mbps downstream, 155 Mbps upstream
    - 622 Mbps downstream, 622 Mbps upstream

GPON

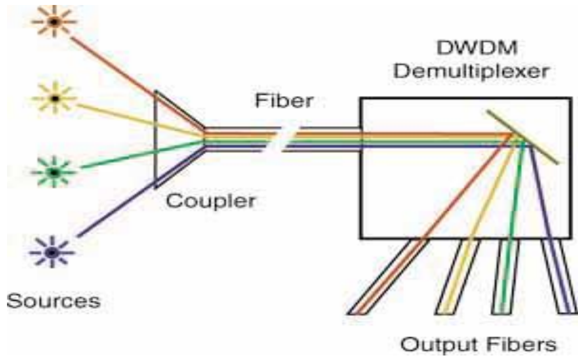
- Gigabit PON
  - ITU-T G.984 standard
  - Several downstream/upstream versions
    - Most popular - 2.48 Gbps dowsntream, 1.244 Gbps upstream

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



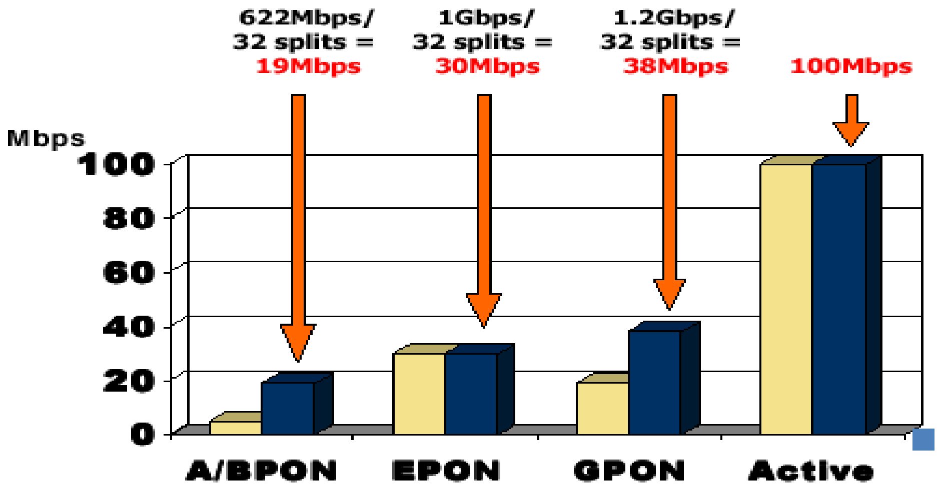
- WDM-PON
  - Combines the advantages of TDM-PON and AON
  - Virtual P2P connection for each ONU
  - Lower delay than in TDM-PON



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