Networking Technologies and Applications

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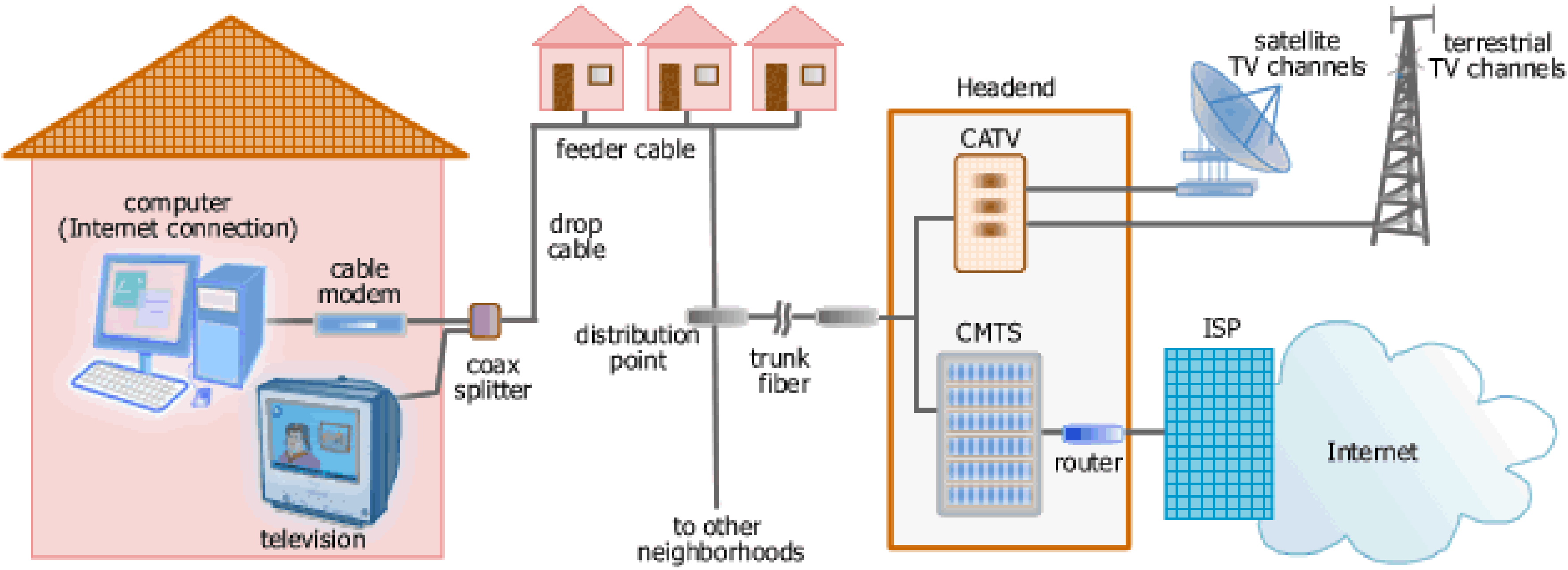
Internet on the cable



Secure communication

- Shared cable
  - Anyone can read the traffic that passes by
- Two way traffic encrypted, to avoid the eavesdropping of the neighbors
  - Agreement between the modem and the CMTS on a common encryption key
    - Between two strangers, on a shared, eavesdropped link
  - Diffie-Hellman algorithm
    - Alice and Bob agree on two large prime numbers n and g
      - Public values, e.g., Alice chooses them, and send them to Bob, without encryption
    - Alice chooses a large (512 bit long) number: x
    - Bob chooses a similar one: y
    - Alice starts the key exchange, and sends the triplet $(n, g, g^x \bmod n)$ to Bob
    - Bob sends back the value $g^y \bmod n$
    - Both of them calculate the shared key:
      - $(g^x \bmod n)^y = (g^{xy} \bmod n) = (g^{yx} \bmod n) = (g^y \bmod n)^x$
    - Carol knows g and n, but cannot obtain x and y
      - It would take too much time, even with a supercomputer

MITM attack

- Diffie-Hellman does not protect against a MITM attack
  - Man-In-the-Middle
  - How do I know that Alice is really Alice?
    - Carol chooses a number z
    - It intercepts the triplet $(n, g, g^x \bmod n)$ sent by Alice, and replaces it with her own triplet $(n, g, g^z \bmod n)$
    - It intercepts Bob's answer $g^y \bmod n$ and replaces it with her own $g^z \bmod n$
    - Carol agrees with Alice in the shared key $(g^{xz} \bmod n)$, and with Bob in a different key $(g^{yz} \bmod n)$
    - Alice and Bob think they talk to each other, but in reality they talk to Carol
- Some authentication scheme is required
  - Digital signature - public/private keys
    - Alice knows Bob's public key
      - Certificate authority – trusted third party
    - Bob attaches a digital signature to its packet, using his private key
    - Alice verifies if the packet was really sent by Bob or not, using his public key

Fiber networks

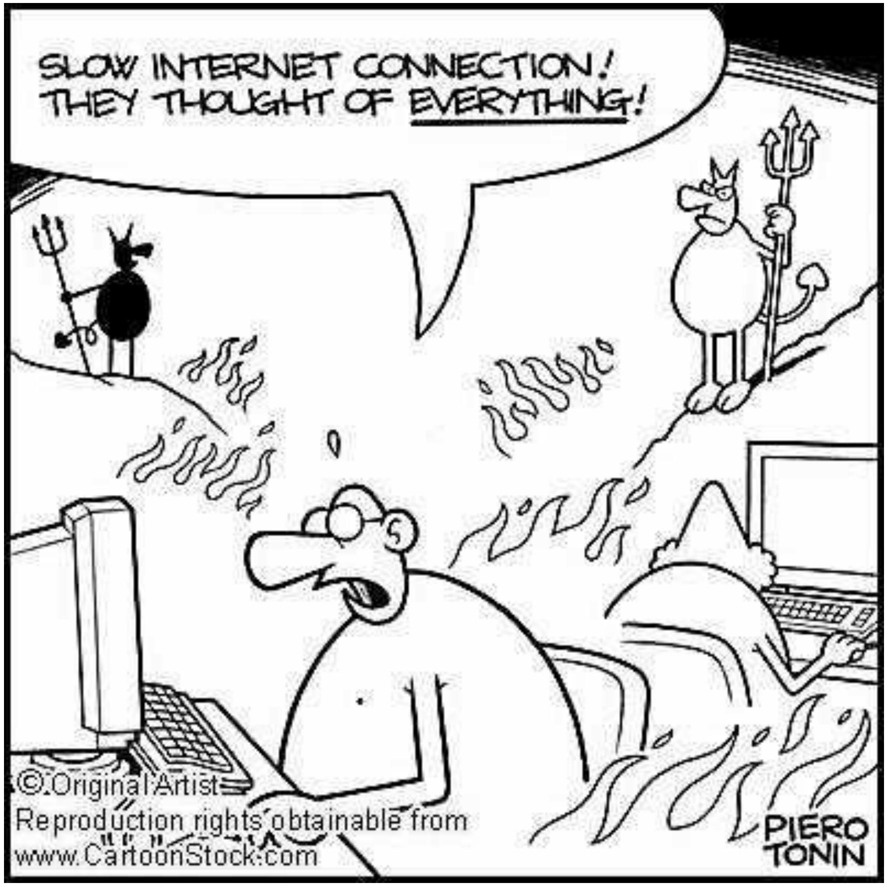
Why fiber?

- 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
- 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

August 17, 2001:

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”

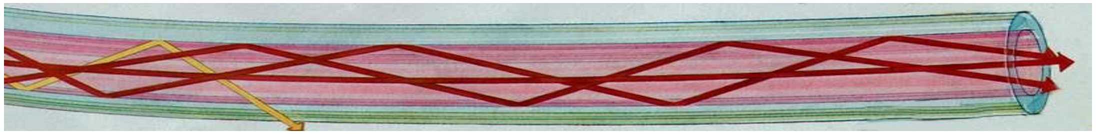
Technology	Minutes	Hours	Days
Modem 56 kb/s			2
FedEx		12	
DSL 1 Mb/s		2.5	
Cable 2.5 Mb/s		1	
BLOCKBUSTER	45		
FTTH	0.4		

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

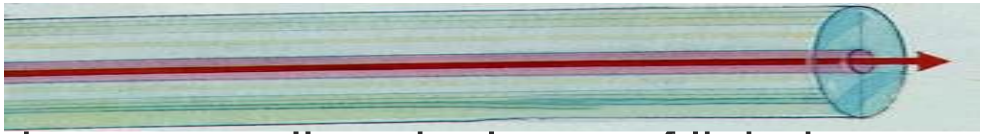
Fiber categories

- Multi-mode fiber



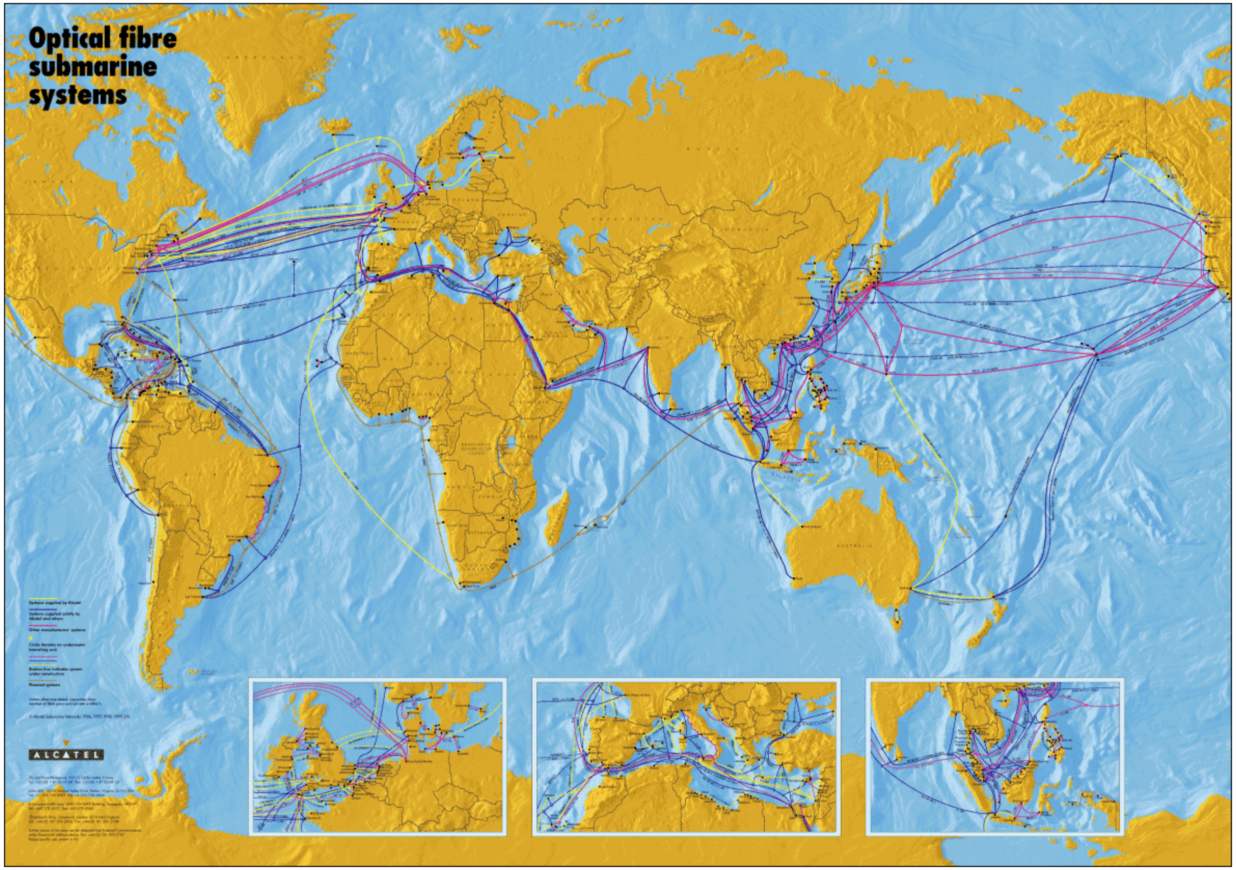
  - Light pulses are spread inside the fiber
  - Many rays of light reflected under different angles
  - Cheap solution, but suitable only for small distances (500 m)

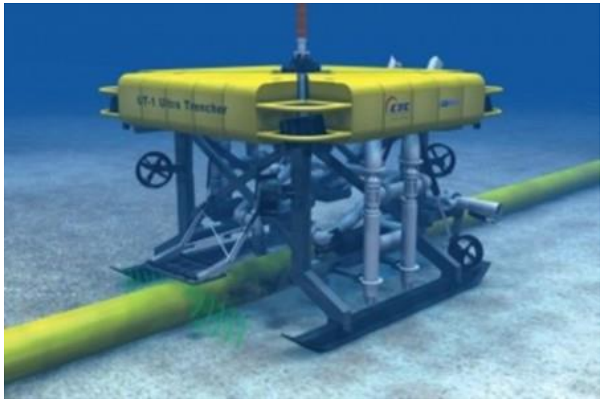
- Single-mode fiber



  - 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

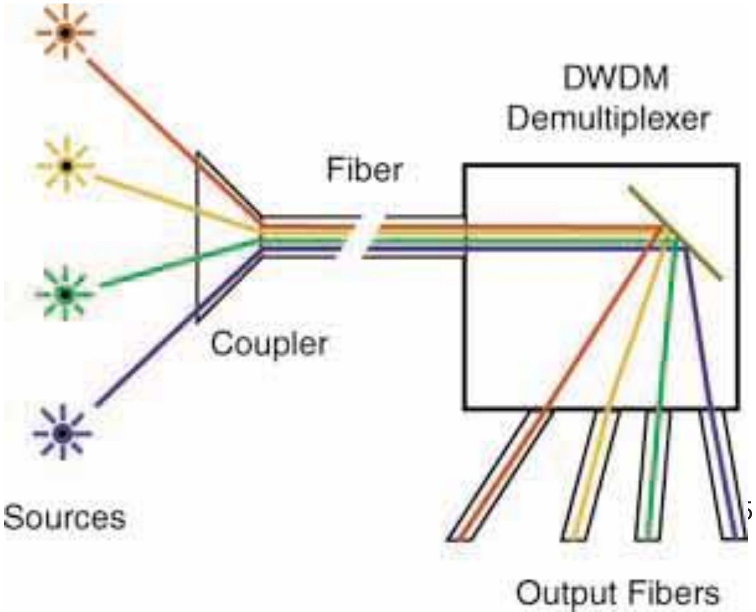
Submarine optical systems





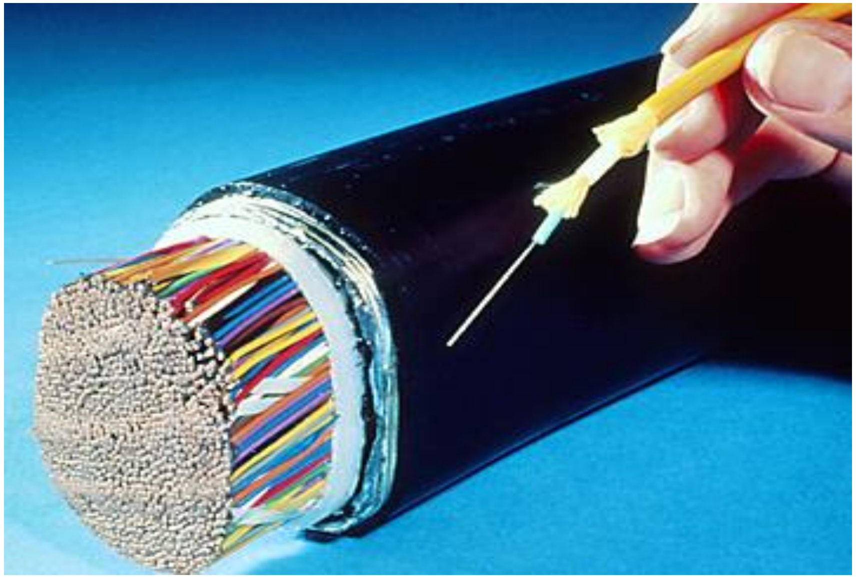
WDM – Wavelength Division Multiplexing

- Many wavelengths (colors) on the same fiber
- At the beginning only 2 colors
  - Today up to 160
  - On a 10 Gbit/s fiber a theoretical speed of 1.6 Tbit/s

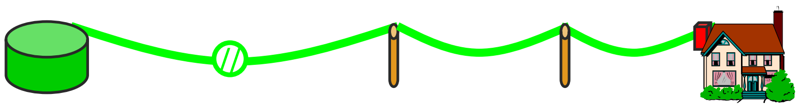


Fiber vs. Copper

- 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

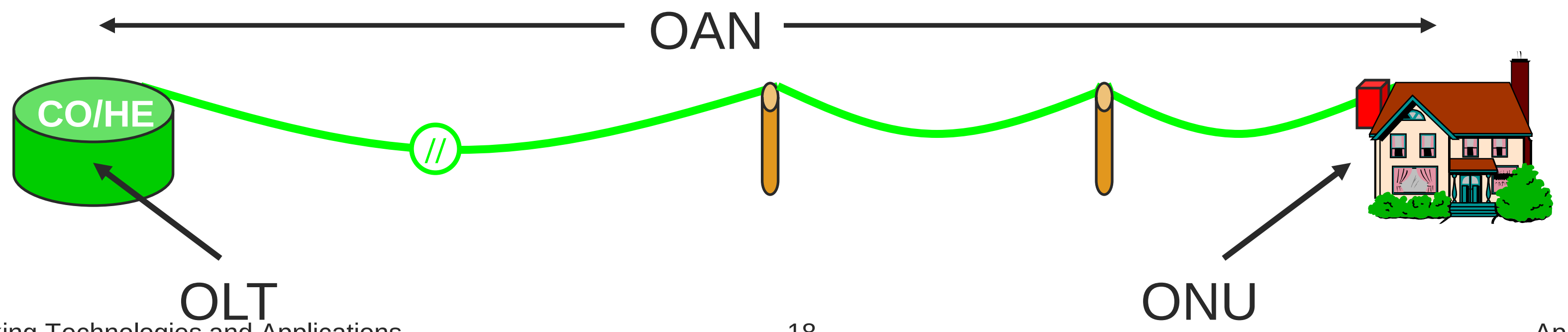
- FTTx – Fiber To The x
  - FTTB – Fiber To The Building
  - FTTC – Fiber To The Curb
  - FTTD – Fiber To The Desk
  - FTTE – Fiber To The Enclosure
  - FTTH – Fiber To The Home
  - FTTN – Fiber To The Neighborhood
  - FTTO – Fiber To The Office
  - FTTP – Fiber To The Premises
  - FTTU – Fiber To The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

FTTC

- Fiber To The Curb
- Fiber from the local switching center near to the homes
  - The connection terminated by an ONU at the subscriber
    - 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

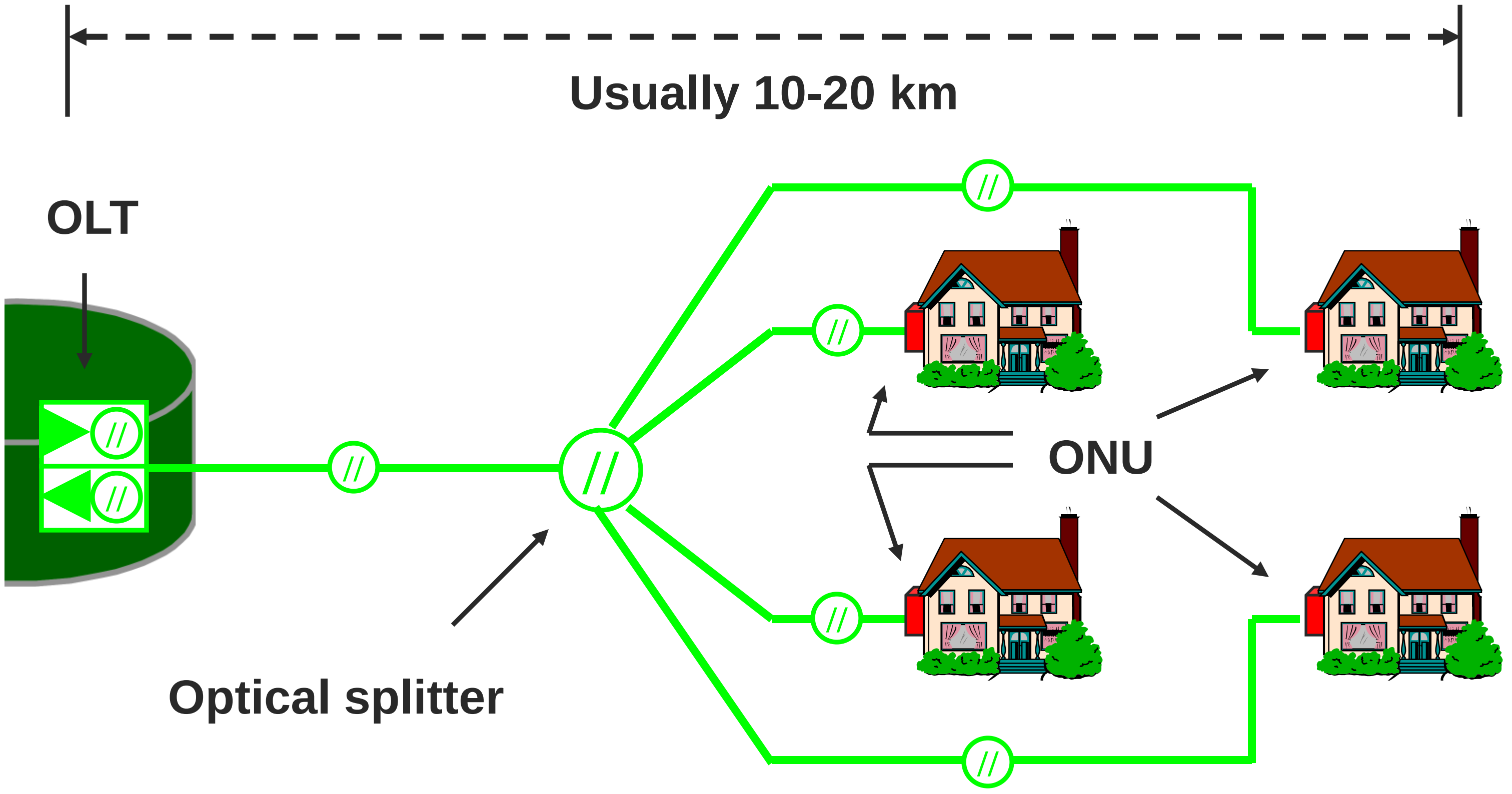
- Fiber To The Home
- System components
  - OAN: Optical Access Network
  - ONU/ONT: Optical Network Unit/Terminal
    - At the subscriber
  - OLT: Optical Line Termination
    - At the service provider



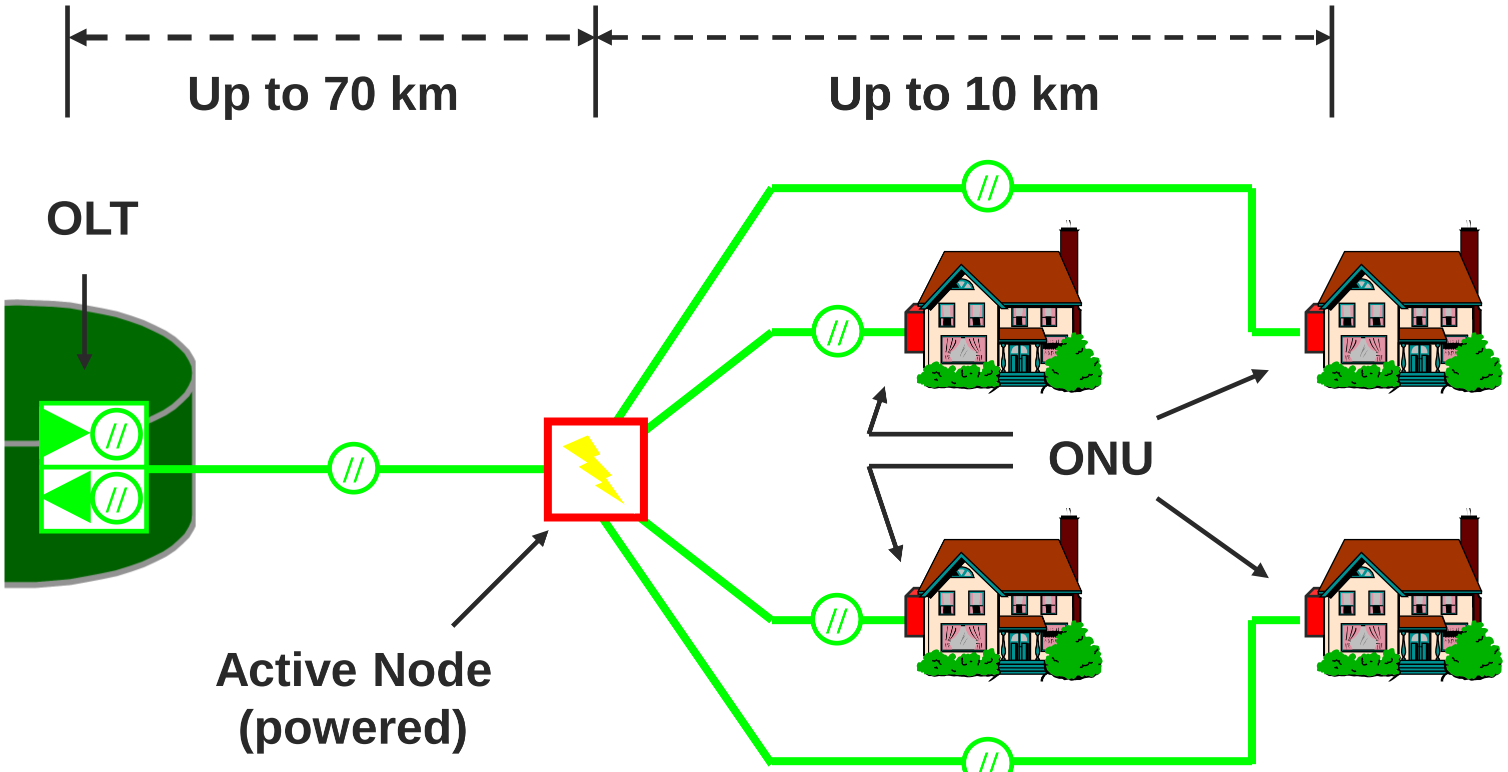
FTTH architectures

- 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)
- Active Node
  - Each subscribers has his own optical fiber
    - Point to Point (P2P)
  - Active, powered nodes to separate the traffic
    - Ethernet switch
  - Layer2/Layer3 switching/routing
- Hybrid PON
  - A combination of the two architectures

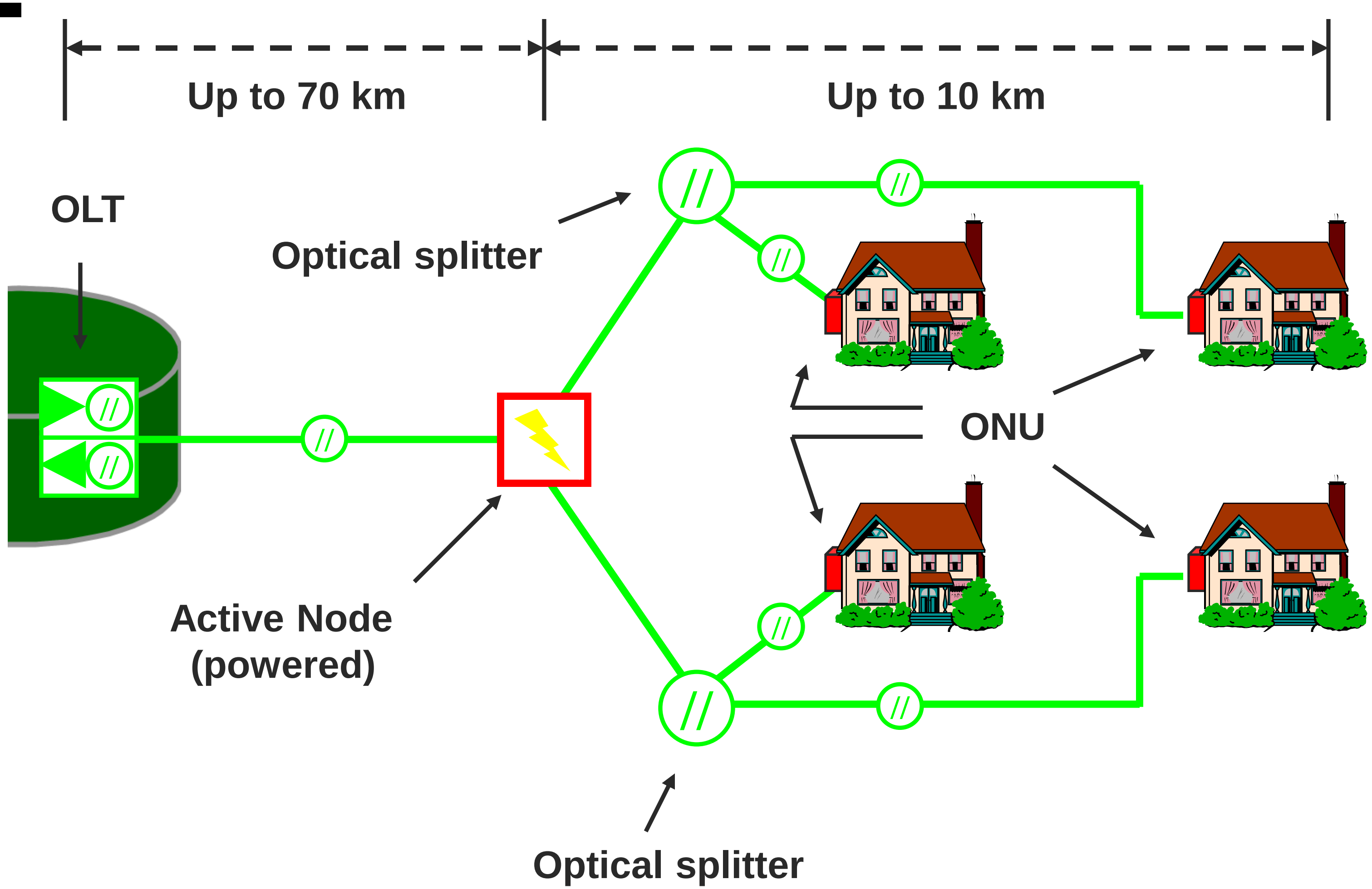
PON architecture



Active Node architecture

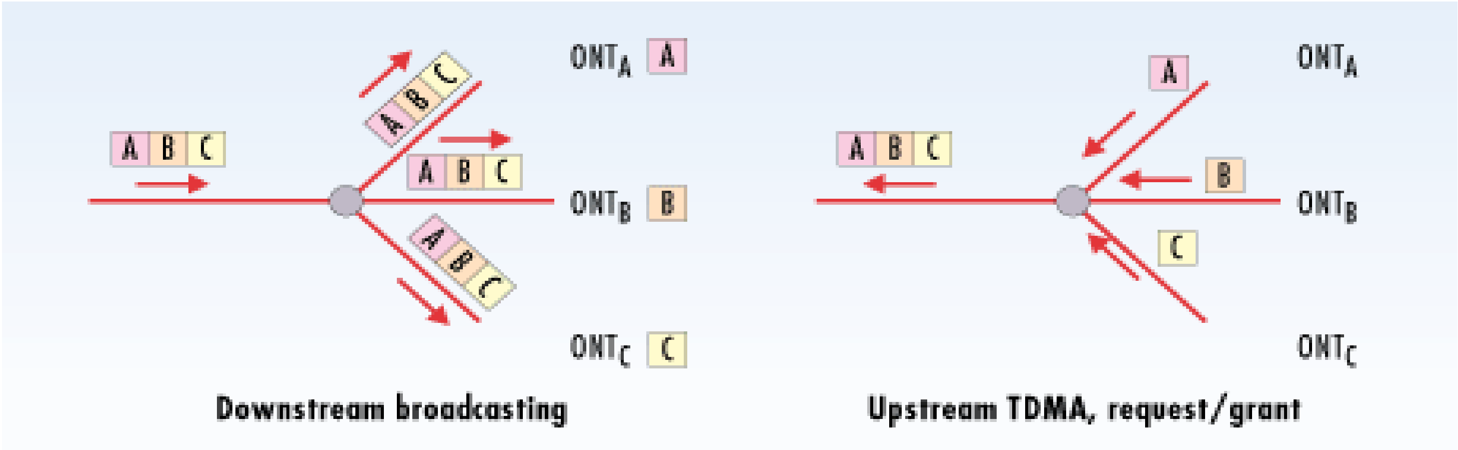


Hibrid architecture



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?

- One OLT connected to several PONs
  - ONUs reached through cheap optical splitters
  - No need for active electronic devices, and for their maintenance
- Two concurrent technologies
  - APON – ATM-based PON
    - ITU-T G.983.x
    - The first PON implementation
  - EPON – Ethernet-based PON

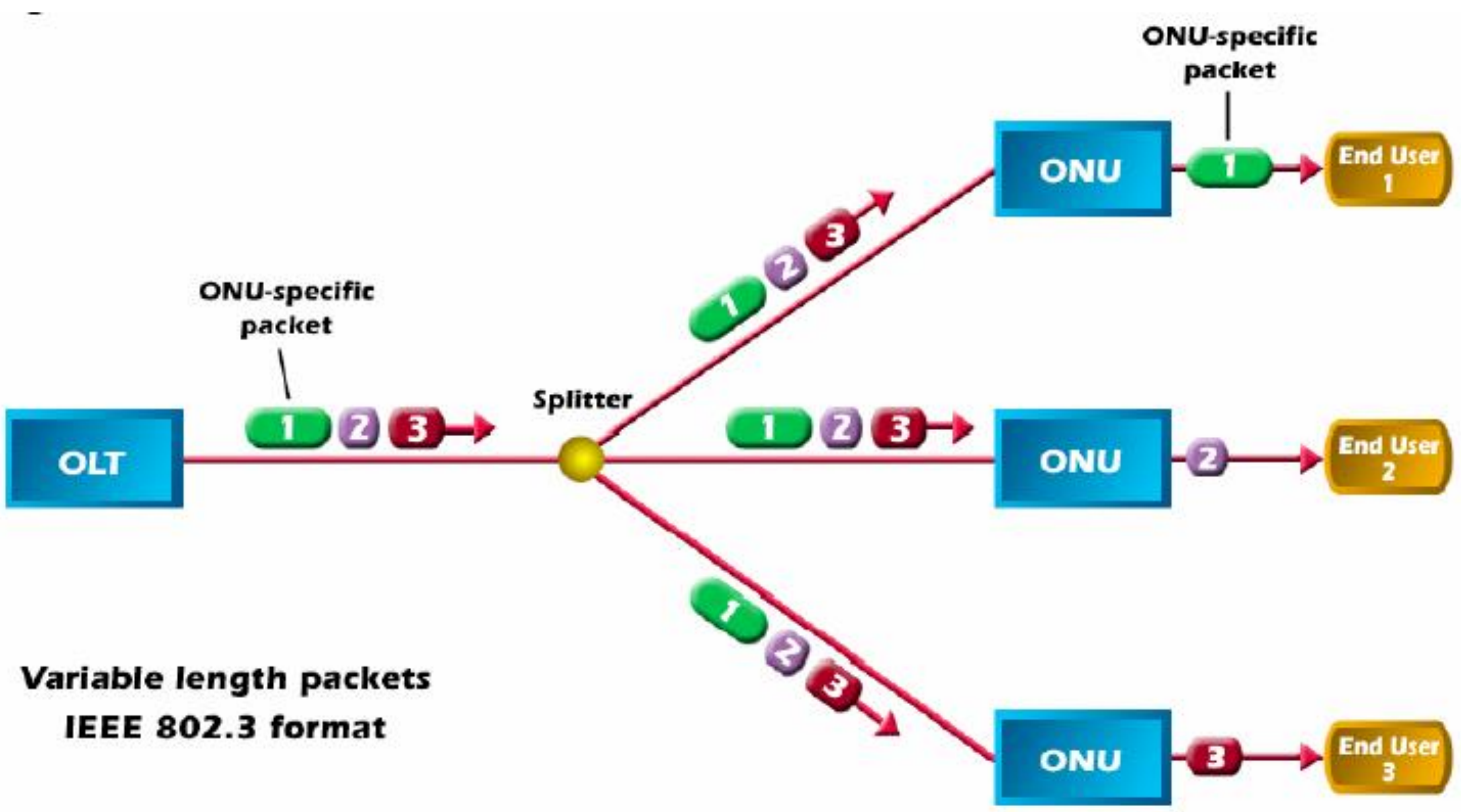
APON

- 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

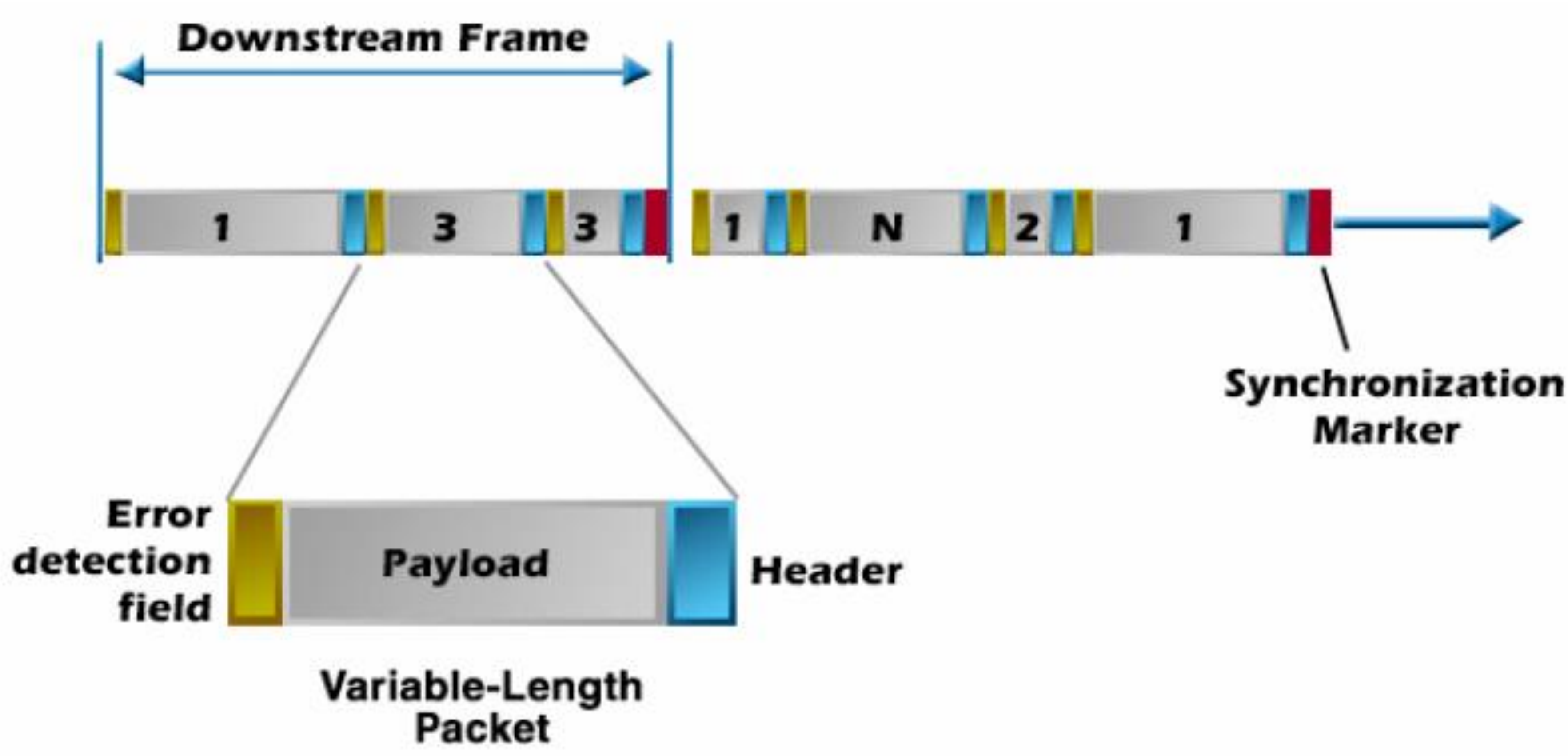
EPON

- 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

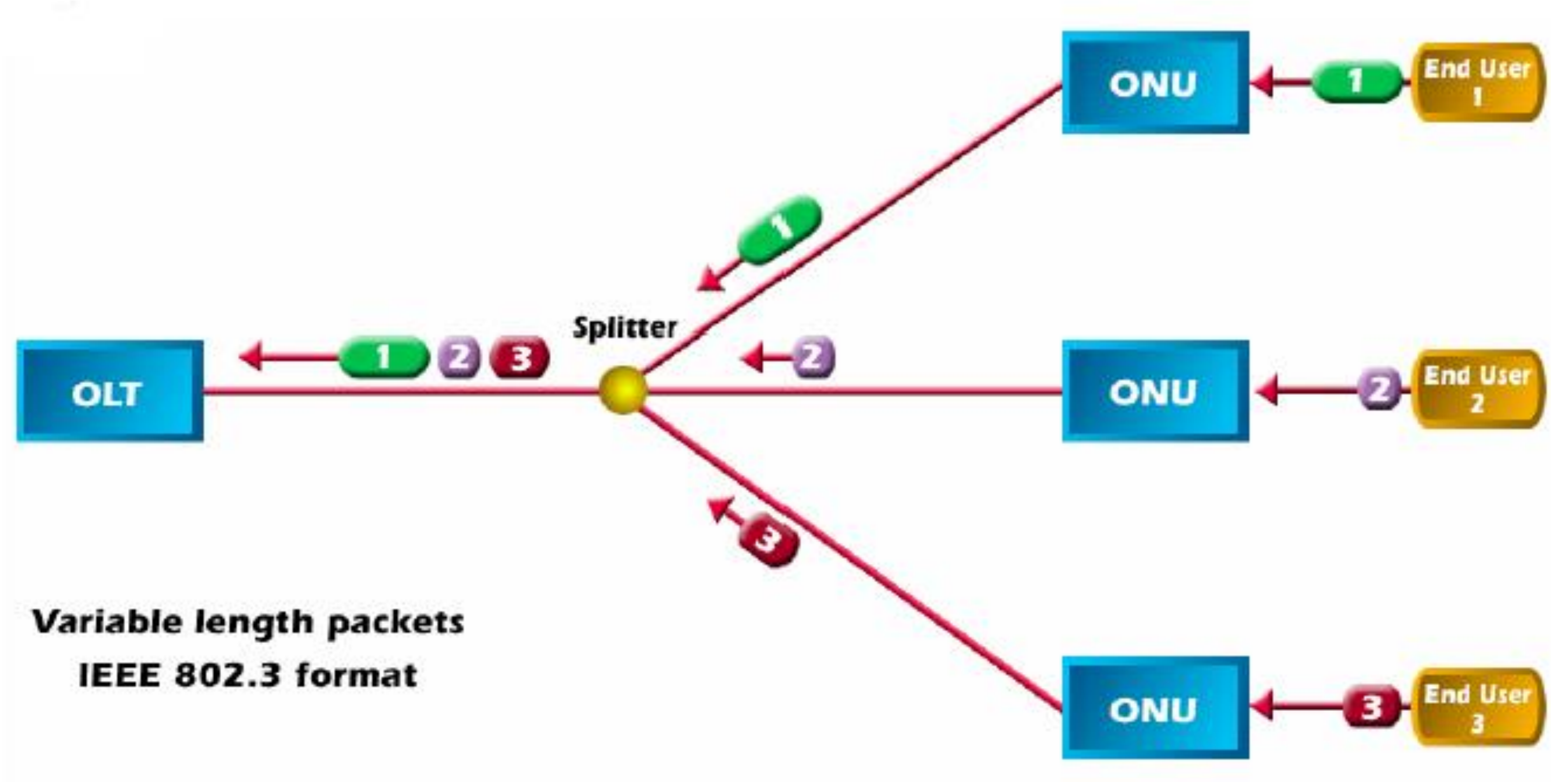
EPON downstream traffic



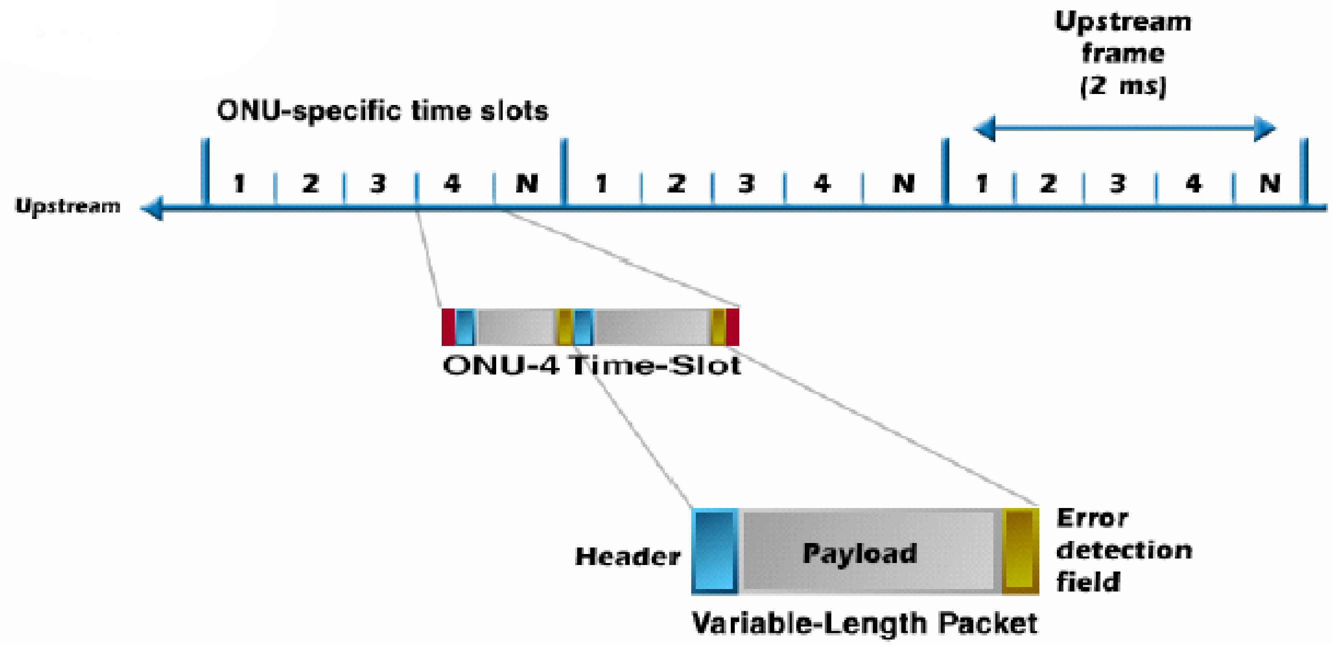
EPON downstream packets



EPON upstream traffic



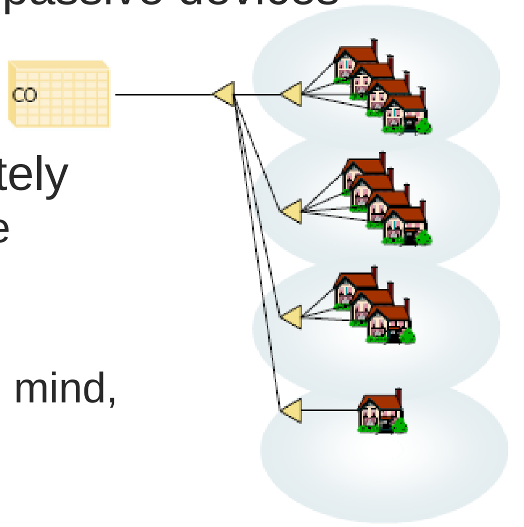
EPON upstream packets



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

Traditional PON

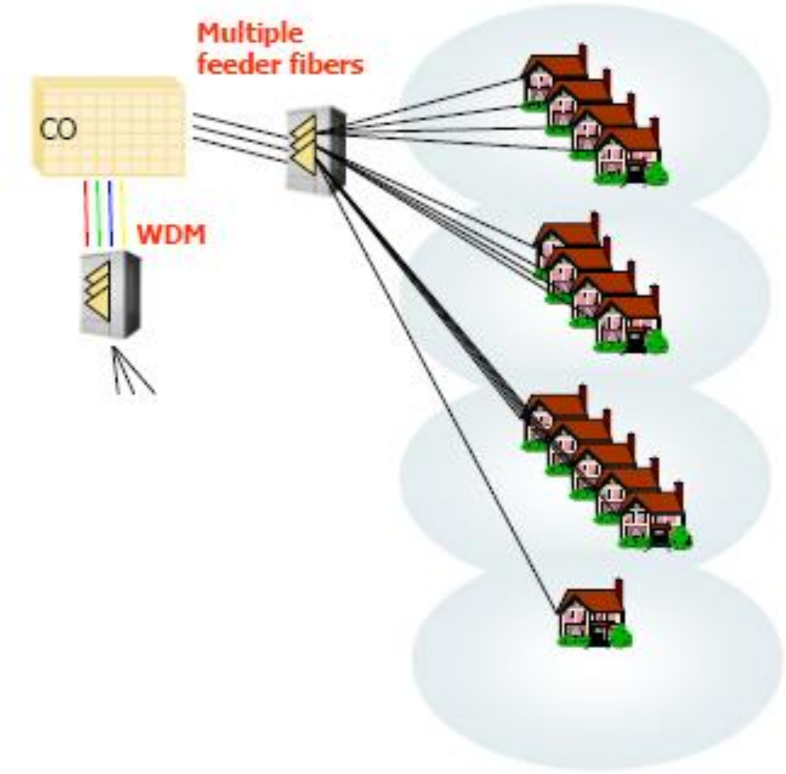
- Main idea:
  - Its is not worth having a separate fiber for each user from the OLT
  - Bring on fiber close to the subscribers, and share it with passive devices



- 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

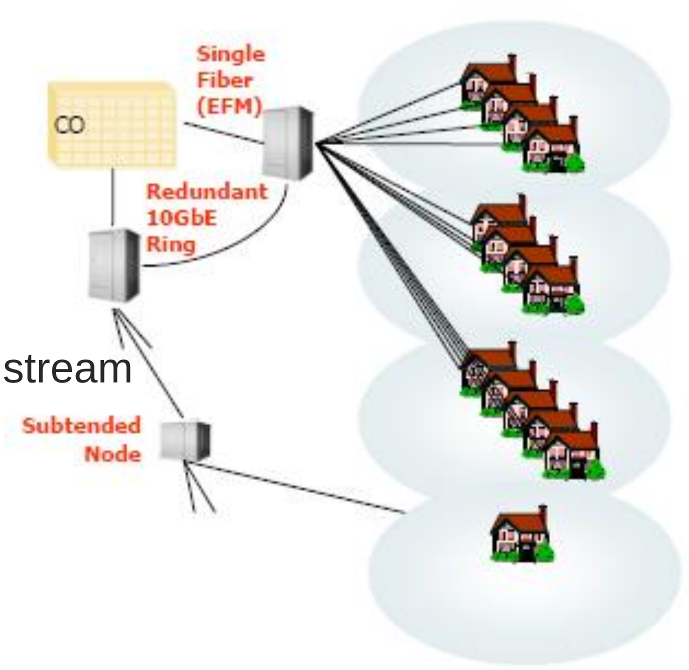
Passive Star PON

- 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



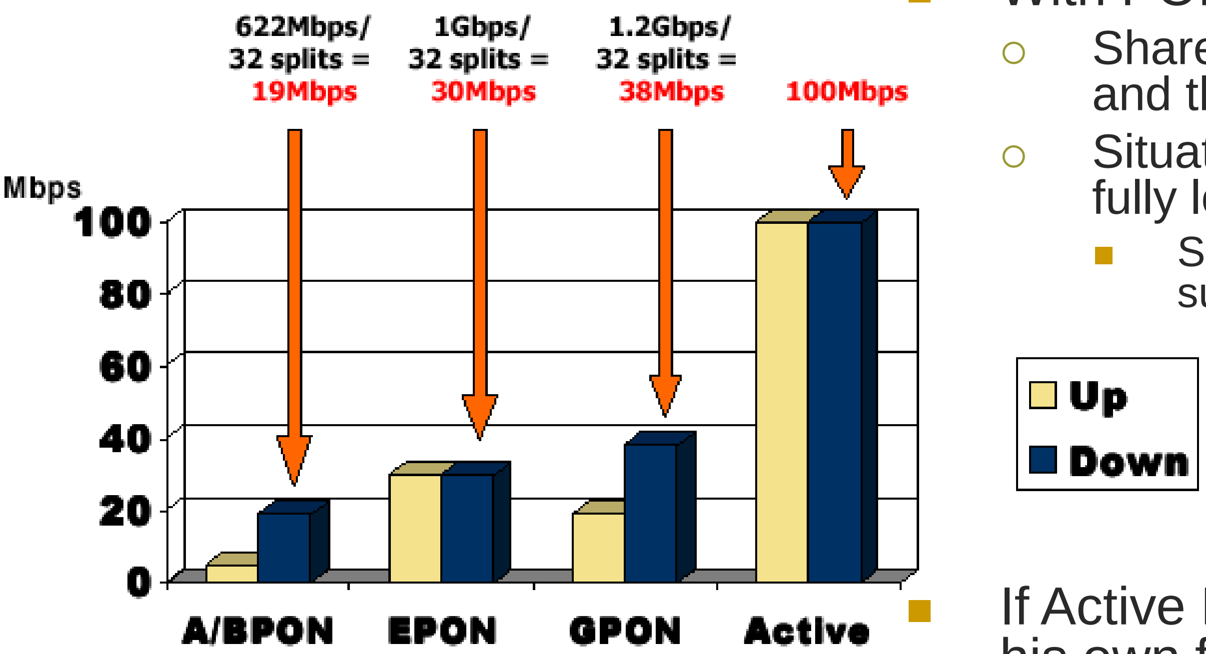
BPON

- 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

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