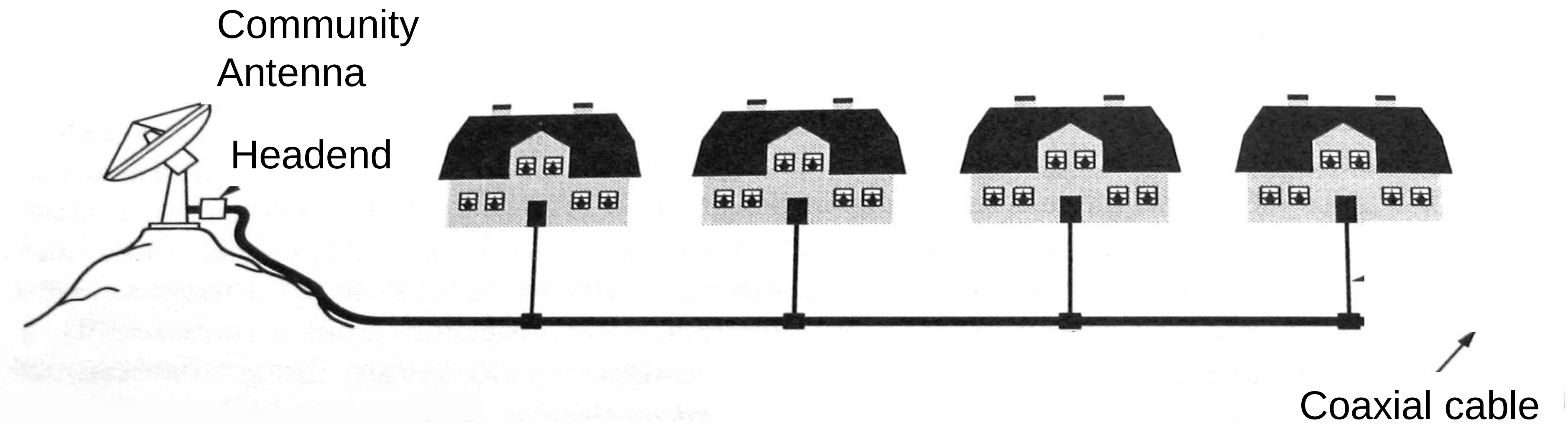
Networking Technologies and Applications

Why cable TV?

- The idea appeared at the end of the 40's
  - Better signal quality for people living in suburbs, or in the mountains
- Community Antenna Television – CATV
  - A big antenna on the top of a hill
  - Headend
  - Coaxial cable
- Family business, anyone could deploy its own network
  - If more users, new cables and amplifiers needed
- One-way traffic, only from the head-end towards the subscriber

Early cable TV system



The development of cable TV

- Thousands of independent systems in the 70’s
- HBO starts in 1974, as the first TV channel transmitted exclusively on cable
  - Many new thematic cable TV channels – news, sports, cooking, etc.
- Big companies start to buy the small local networks, and extend them with new cables
  - Cables linking the different cities
  - Similar process to the evolution of the PSTN networks
- The inter-city links changed later for optical fiber

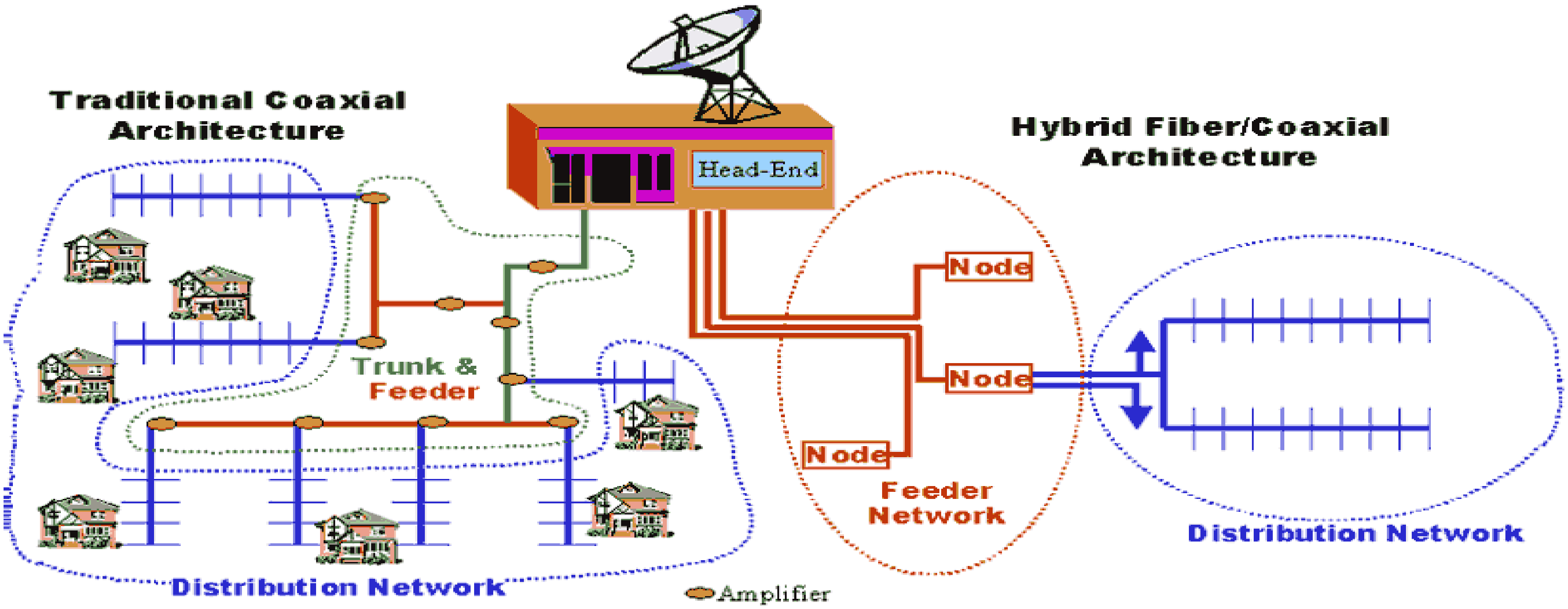
HFC system

- HFC - Hybrid Fiber Coax
  - Optical fiber to span large distances
  - Coaxial cable to reach the homes

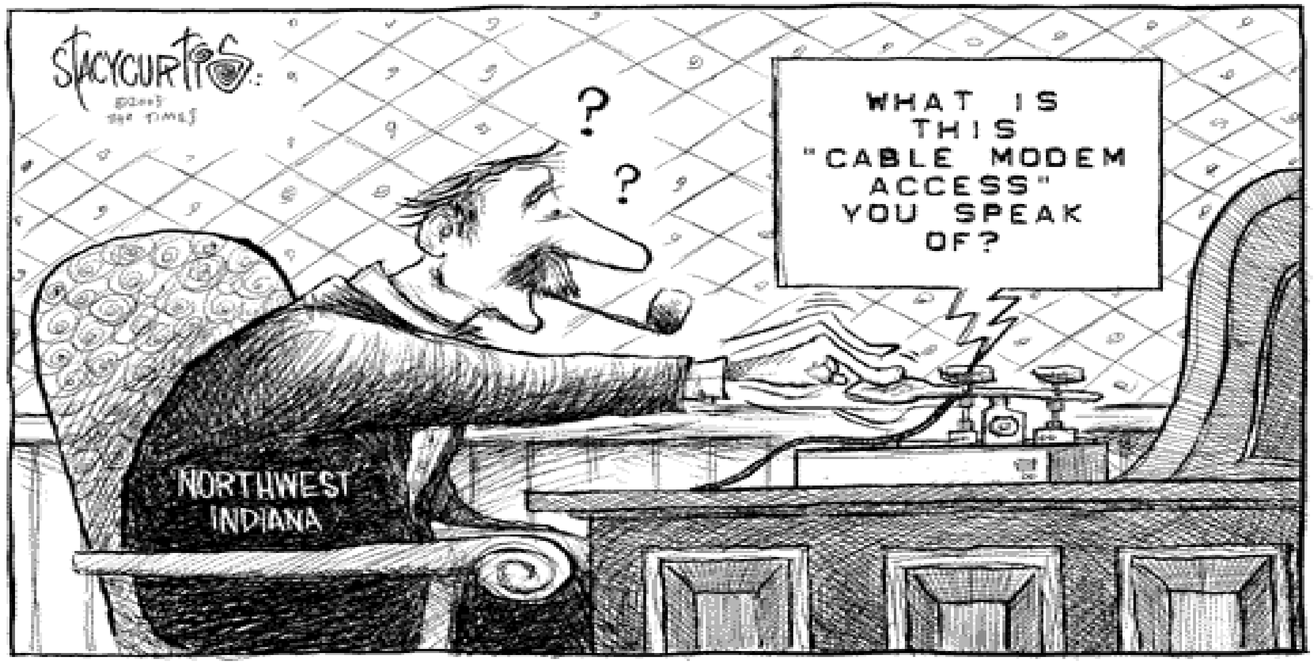
  - Fiber optic node
    - Electro-optical converter
      - Converts optical signals to electrical ones, and vice-versa

  - One optical cable can feed many coaxial cables
    - Much larger bandwidth

Modern Cable TV system



Internet on the cable



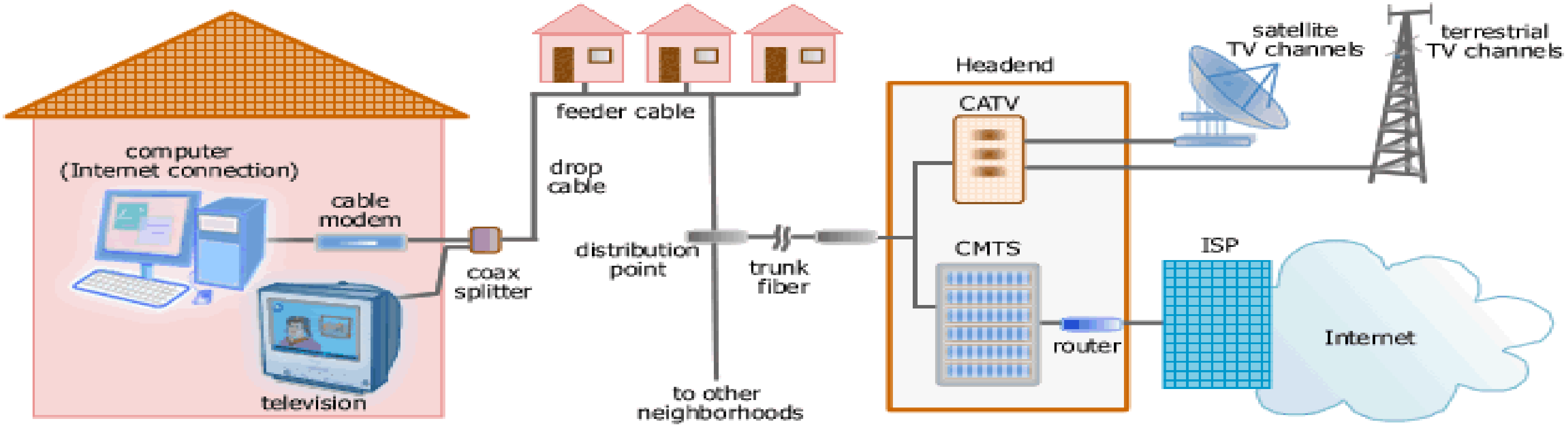
Internet on the cable

- The service providers started to enlarge their services
  - Internet access
  - Telephony
- The network has to be transformed
  - One-way amplifiers changed to two-way amplifiers
  - Upgraded headend
    - The dummy amplifier replaced with an intelligent digital computer system
      - High speed optical connection to an ISP’s network
    - **Cable-Modem Termination System (CMTS)**
  - The coaxial cable a shared medium, many users use it simultaneously
    - In the PSTN network each user has its own twisted pair (local loop)
    - For the broadcast of TV channels this is not important
      - Each program transmitted over the same cable, no matter if there are 10 or 10.000 viewers at the same time
    - In case of internet access, it matters a lot if there are 10 or 10.000 users
      - If someone downloads a large file, no bandwidth for the others
    - On the other hand, much larger bandwidth on a coaxial cable than on a twisted copper pair

Internet on the cable

- Solution: a long cable is divided into many smaller segments
  - Each segment connected directly to the fiber optic node
  - The speed between the headend and the fiber optic nodes basically unlimited
    - If not many homes on a segment, the traffic can be handled
  - Today typically 500-2000 homes on a segment
    - Smaller segments expected if more subscribers and larger speed demands appear

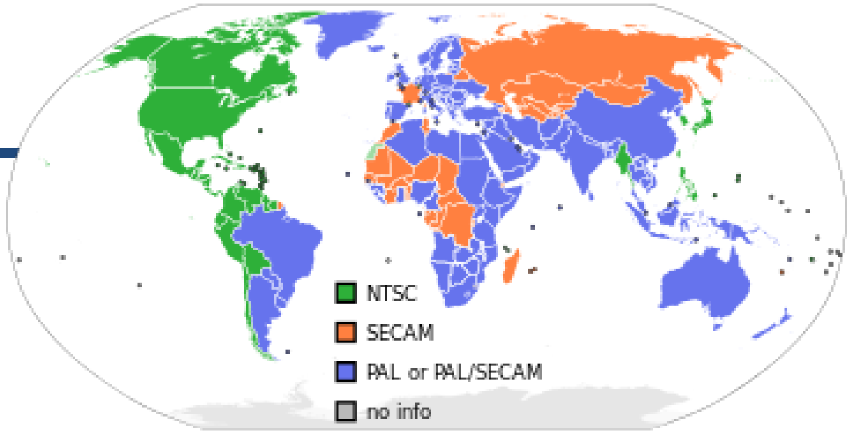
Internet on the cable



Spectrum allocation

- The cable network cannot be used exclusively for internet access (at least not yet…)
  - Many more TV viewers than broadband subscribers
  - The cities regulate what can be offered on the cable, a TV service is mandatory
  - The frequencies should be divided between TV channels and Internet access
- USA, Canada
  - FM radio: 88 – 108 MHz
  - Cable TV channels: 54 – 550 MHz
    - 6 MHz wide channels, with a guard band
      - NTSC - National Television System Committee
      - Resolution: 720 x 480, 29.97 fps

Spectrum allocation

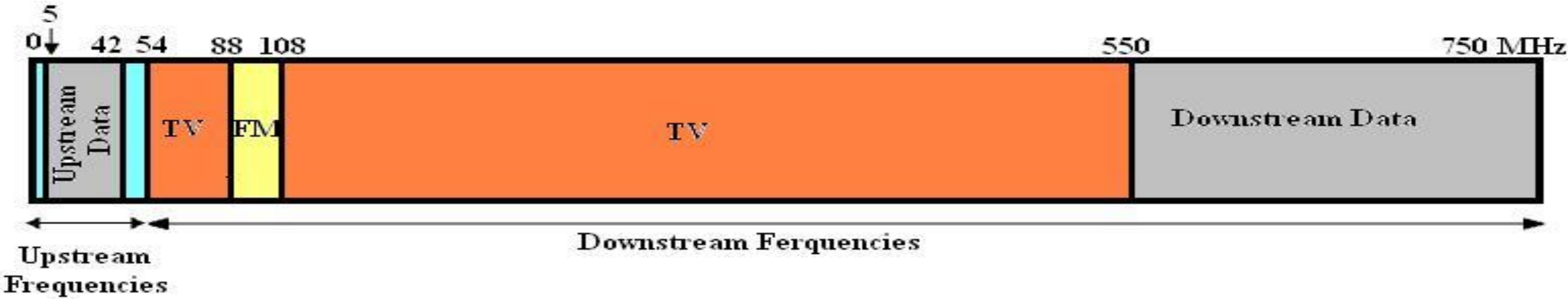


- Europe
  - TV channels above 65 MHz
  - 6-8 MHz wide channels
    - PAL and SECAM systems with higher resolution
      - PAL - Phase Alternating Line
      - SECAM - Système Electronique Couleur Avec Mémoire
      - Resolution: 768 x 576, 25 fps
  - The lower frequencies not used

Spectrum allocation

Modern cables provide good transmission quality above 550 MHz, up to 850 MHz or more

- Solution: uplink traffic between 5 – 42 MHz (5 - 65 MHz in Europe)
- The upper part of the spectrum used for downlink traffic



Asymmetric system

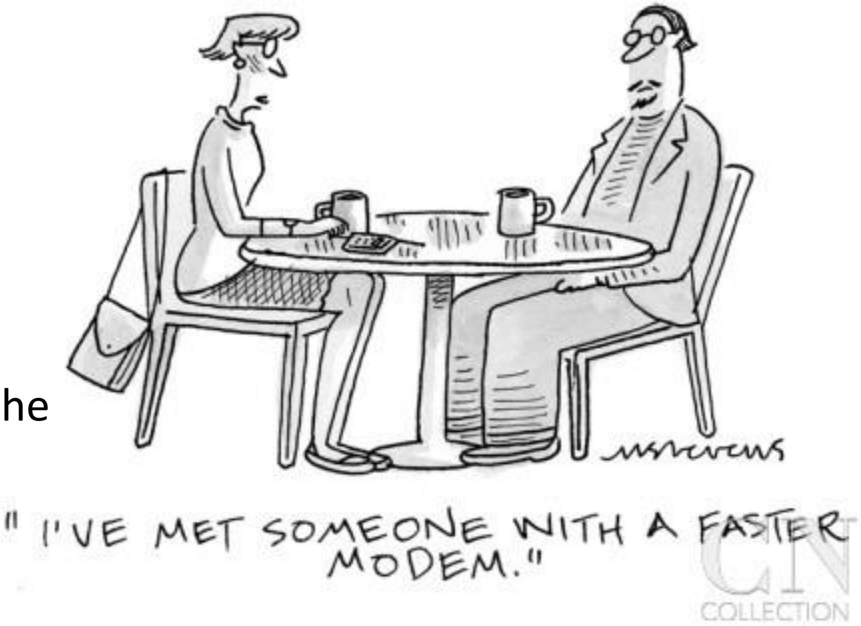
- TV and radio downstream
  - From the headend towards the end user
  - In the upstream direction, amplifiers working in the 5-42 MHz frequency range
  - In the downstream direction, amplifiers that work above 54 MHz
  - Larger downstream than upstream
    - Technological reasons, not like in the case of ADSL
    - Not a good solution for P2P traffic
      - Designed for asymmetric web traffic

Modulation

- Each 6-8 MHz is modulated with 64-QAM
  - Quadrature Amplitude Modulation
  - If a good quality cable, 256-QAM
- On a 6 MHz channel with 64-QAM → ~ 36 Mbps
  - Effective bandwidth without headers 27 Mbps
  - With 256-QAM, ~ 39 Mbps
  - In Europe larger bandwidths, because of the 8 MHz channels
- On the upstream channel 64-QAM is not acceptable
  - Too much noise, from microwave systems, CB-radios, etc.
    - Citizen Band – walky-talky
  - QPSK modulation
    - Quadrature Phase Shift Keying, much slower
  - Much larger difference between the upstream and downstream speeds

Cable modem

- Transforms the analog signals coming on the cable to digital data, and vice versa
  - MOdulates és DEModulates
- Two interfaces – one towards the PC, one towards the cable network
  - Ethernet/USB/WLAN connection between the cable modem and the PC



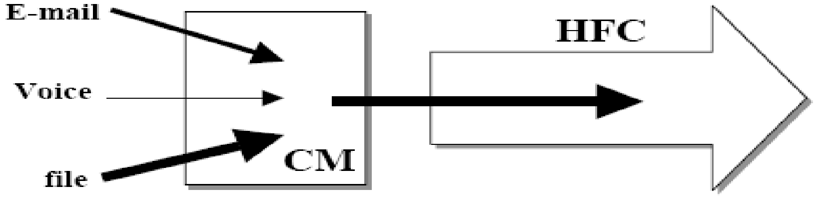
Cable modem

- In the early years each operator had its own modems, installed by a technician
  - An open standard was needed
    - Open the market, lower the prices
    - Contributes to the spread of the technology
    - If the users installs the modem, costs can be cut
- CableLabs
  - Association of the largest cable operators
  - DOCSIS standards
    - Data Over Cable Service Interface Specification
    - EuroDOCSIS – European version
  - Many were not happy about it
    - Could not hire out anymore their expensive modems to the defenseless subscribers

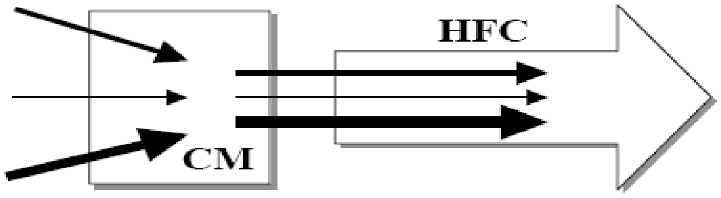
DOCSIS

- DOCSIS 1.0 (1997)
  - RF Return
    - Two-way communication
  - Telco Return
    - Dial-up connection for the upstream traffic
    - No need to modify the infrastructure, one-way communication on the cable
  - Modem prices fall from $300 (1998) to < $30
- DOCSIS 1.1 (1999)
  - VoIP, gaming, streaming
  - Compatible with DOCSIS 1.0
  - QoS

DOCSIS



DOCSIS 1.0



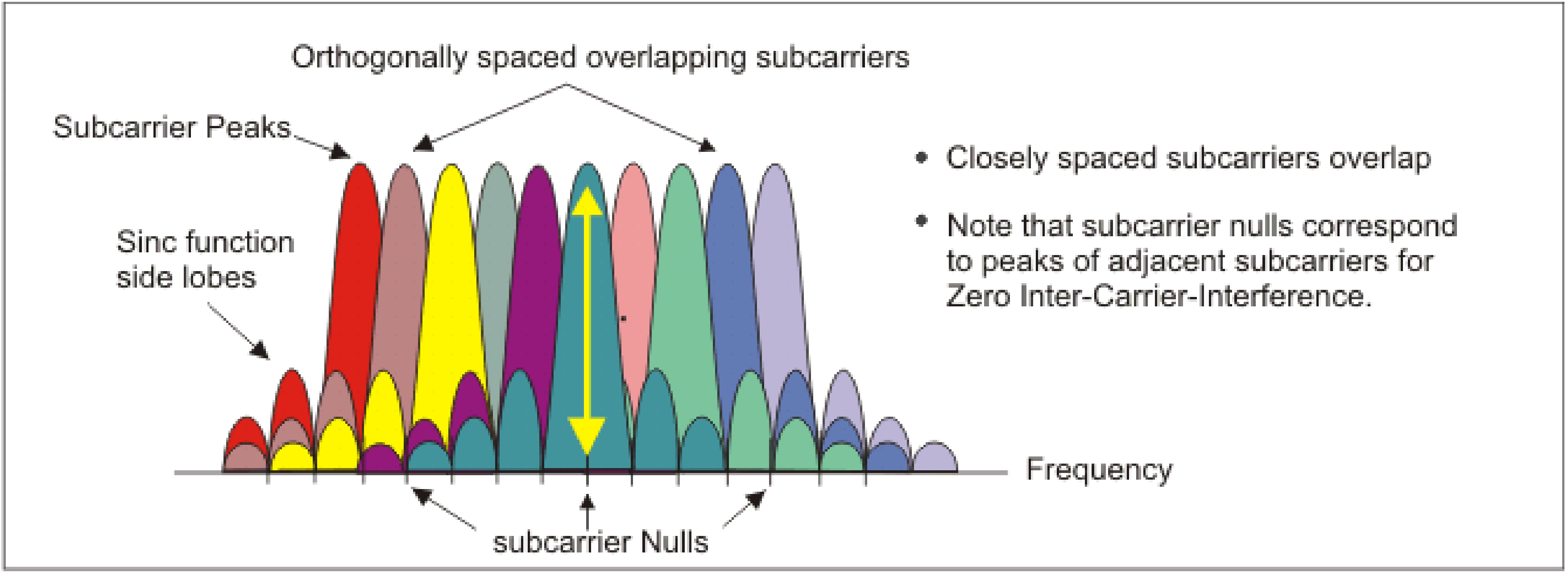
DOCSIS 1.1

- In DOCSIS 1.0 all the services are in contention for upstream bandwidth, on a „best effort” basis
- In DOCSIS 1.1 QoS guarantees can be associated to applications

DOCSIS

- DOCSIS 2.0 (2002)
  - Capacity for symmetric services
    - Larger upstream capacity than for DOCSIS 1.0 (x6) or DOCSIS 1.1 (x3)
    - Instead of QPSK, it uses 32-QAM, 64-QAM or 128-QAM on the upstream part as well
    - TDMA and S-CDMA in the MAC layer, instead of simple TDMA
- DOCSIS 3.0 (2006)
  - 160 Mbps downstream, 120 Mbps upstream
  - Channel bonding
    - Many channels associated in parallel to the same user
- DOCSIS 3.1 (2013)
  - 10 Gbps downstream, 1 Gbps upstream, 4096 QAM modulation
  - Instead of 6-8 MHz wide channels it uses narrow channels of 20-50 KHz, and OFDM (Orthogonal Frequency Division Multiplexing)
  - Channel bonding – spectrum width up to 200 MHz

OFDM



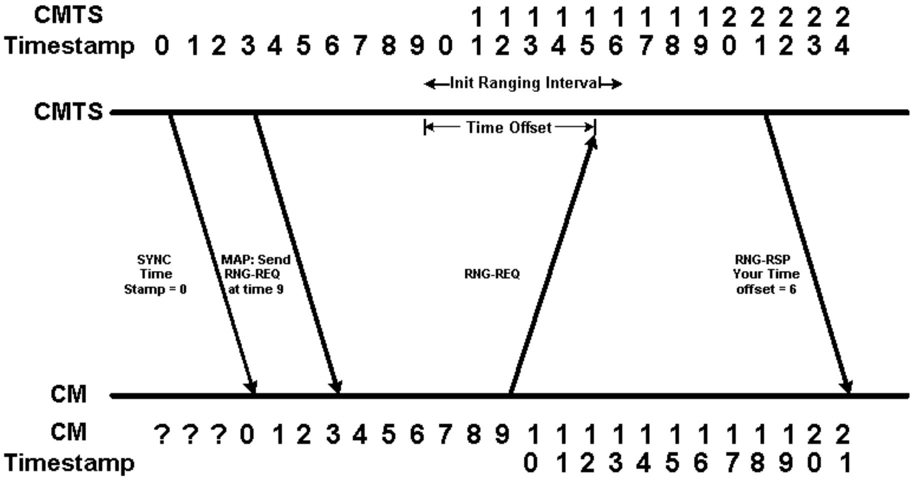
OFDM Signal Frequency Spectra

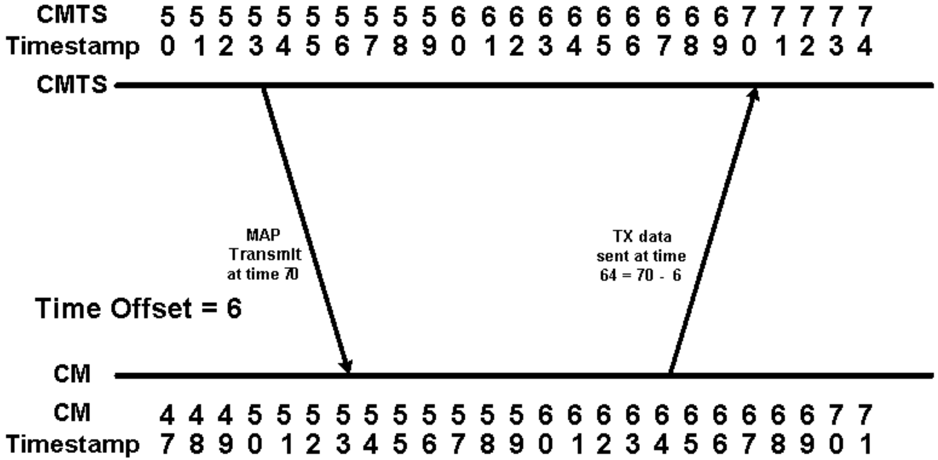
Connection

- When establishing the connection, the modem starts to scan the downlink channels
  - The CMTS periodically sends a special packet, with system parameters to enable new modems to connect
  - The modem register itself at the CMTS
  - The CMTS assigns the uplink and downlink channels of the newcomer
    - This can be changed later, e.g., for load balancing
    - Many modems on the same uplink channel
  - The first packets from the modem to the ISP
    - Ask for an IP address, through the DHCP protocol
      - Dynamic Host Configuration Protocol
    - Time synchronization with the CMTS

Contention based reservation for upstream traffic

- The modem measures its distance to the CMTS
  - Ranging – similar to a ping
  - Necessary to handle time slots correctly





Contention based reservation for upstream traffic

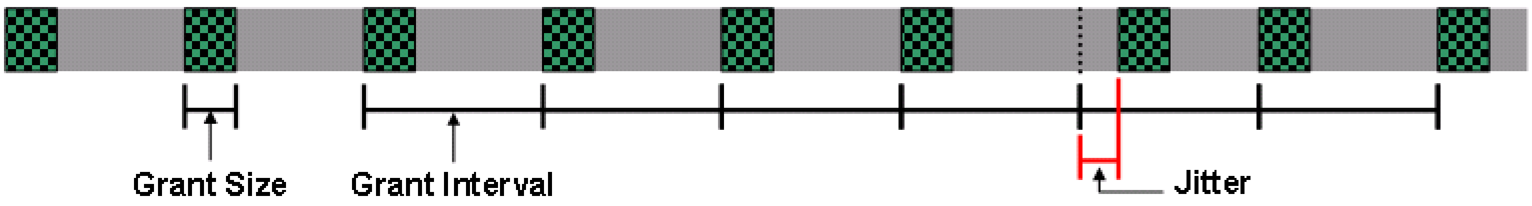
- The upstream channel is divided (in time) into mini-slots -FDD/TDMA
  - Each upstream packet has to fit in one or more mini-slots
    - The length of the mini-slots is different in different networks
    - Typically 8 bytes of user data have to fit in one mini-slot
- The CMTS periodically announces the start of a new group of mini-slots
  - Because of the signal propagation on the cable, the modems do not hear it in the same time
    - Each modem can calculate the beginning of the first mini-slot (using the results of the previous ranging)
  - Each modem is assigned a special mini-slot (**Bandwidth Request Slot**) to ask for upstream bandwidth
    - Several modems on the same mini-slot

Contention based reservation for upstream traffic

- If a modem wants to send a packet, asks for sufficient mini-slots
  - If the CMTS accepts the request, it sends and acknowledgment with the assigned mini-slots
    - If the modem wants to send further packets, in the headers it can ask for new slots
  - If two modems ask in the same time for slots, collision occurs, no acknowledgment is received
    - The modem waits for a random time interval, and then tries again
      - A timer set to random value chosen from the [0, x] interval
    - If a new collision occurs, the upper limit of the interval is doubled
      - A timer set to random value chosen from the [0, 2x] interval

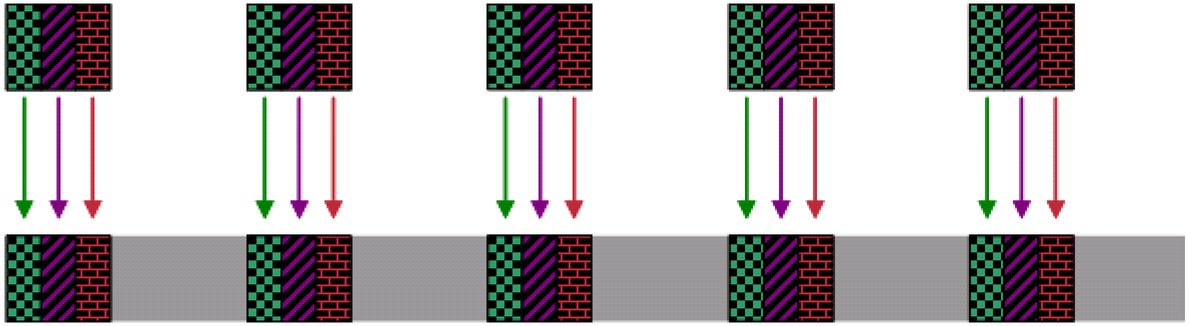
Providing Quality of Service

- Different applications have different QoS requirements
- CBR – Constant Bit Rate (pl. VoIP)
  - **Unsollicited Grant Services (UGS)**
    - No need to sollicit uplink slots all the time
    - Tolerated jitter in grant allocation



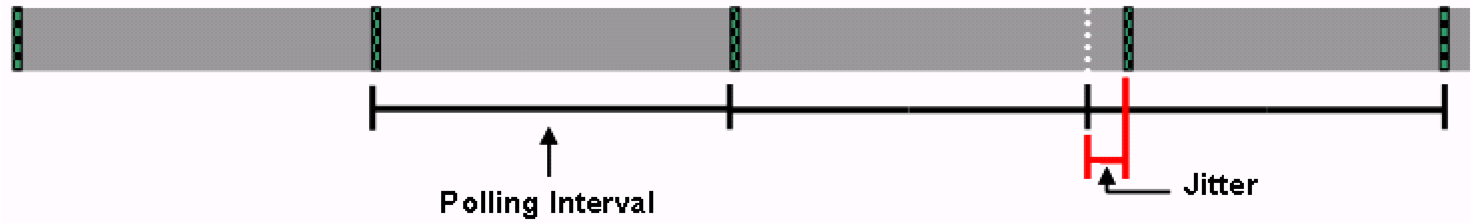
Admission Control

- UGS demands are accepted only in limited number
  - You have to leave room for other traffic types as well



Providing QoS

- rt-VBR (Real Time Variable Bit Rate)
  - E.g., live video stream
  - **Real Time Polling Service (RTPS)**
    - Bandwidth Request Slot dedicated to one specific application / modem
    - Can send his request for sure, no collision
    - Tolerated jitter in polling

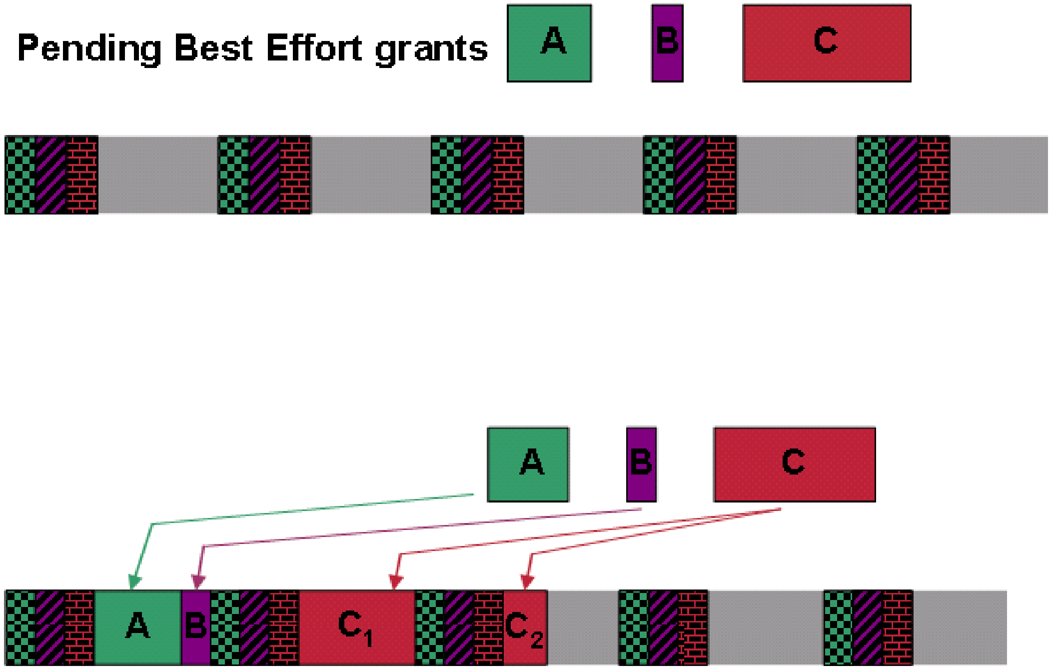


Providing QoS

- **Unsollicited Grant Service with Activity Detection (UGS-AD)**
  - Operates in UGS mode only if it has data to be sent
  - If temporarily no data, switches to RTPS mode
  - If needed, can switch back to UGS mode
  - E.g., VoIP with Voice Activity Detection (VAD)
- **Non-Real Time Polling Service (nRTPS)**
  - For nrt-VBR traffic
  - The polling intervals are not uniform

Providing QoS

- **Best Effort Grants (BEG)**
  - No strict requirements for delay or jitter
  - Fragmentation – if needed, the slot requests can be split in time
    - More headers, but sometimes it is worth doing it



No contention in the downstream traffic

- Downstream traffic is sent only by the CMTS
  - No contention, no need for mini timeslots
    - No collisions, lower probability for bit errors, no need for retransmission
  - Large packets in the downstream traffic
    - Typical packet length: 204 bytes
      - Includes Reed-Solomon error correcting code
      - 184 bytes for user data