

Networking Technologies and Applications

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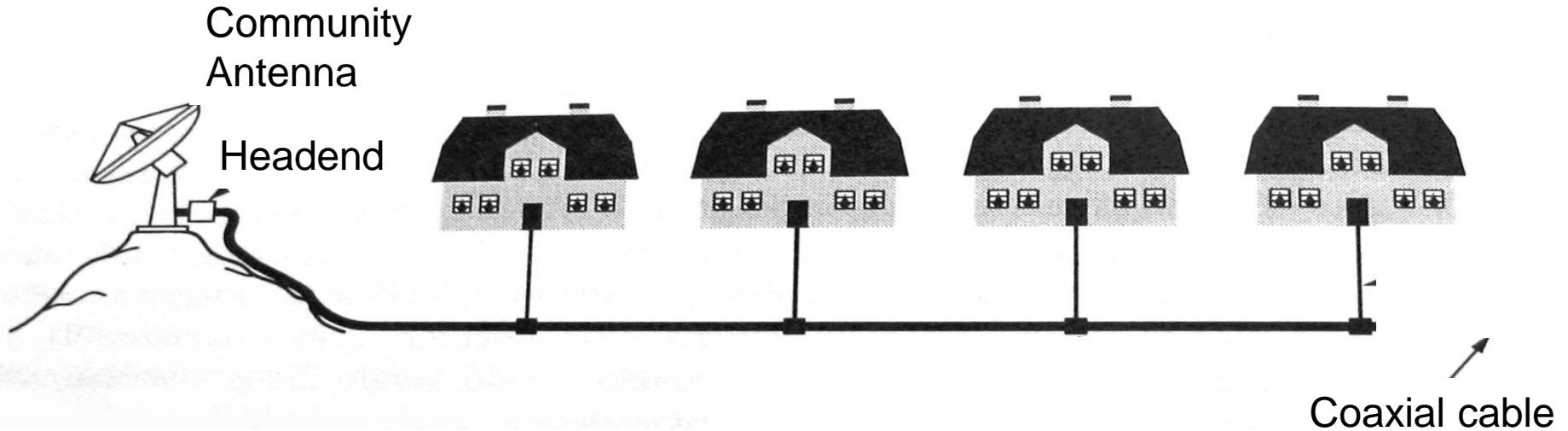
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Why cable TV?

- 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



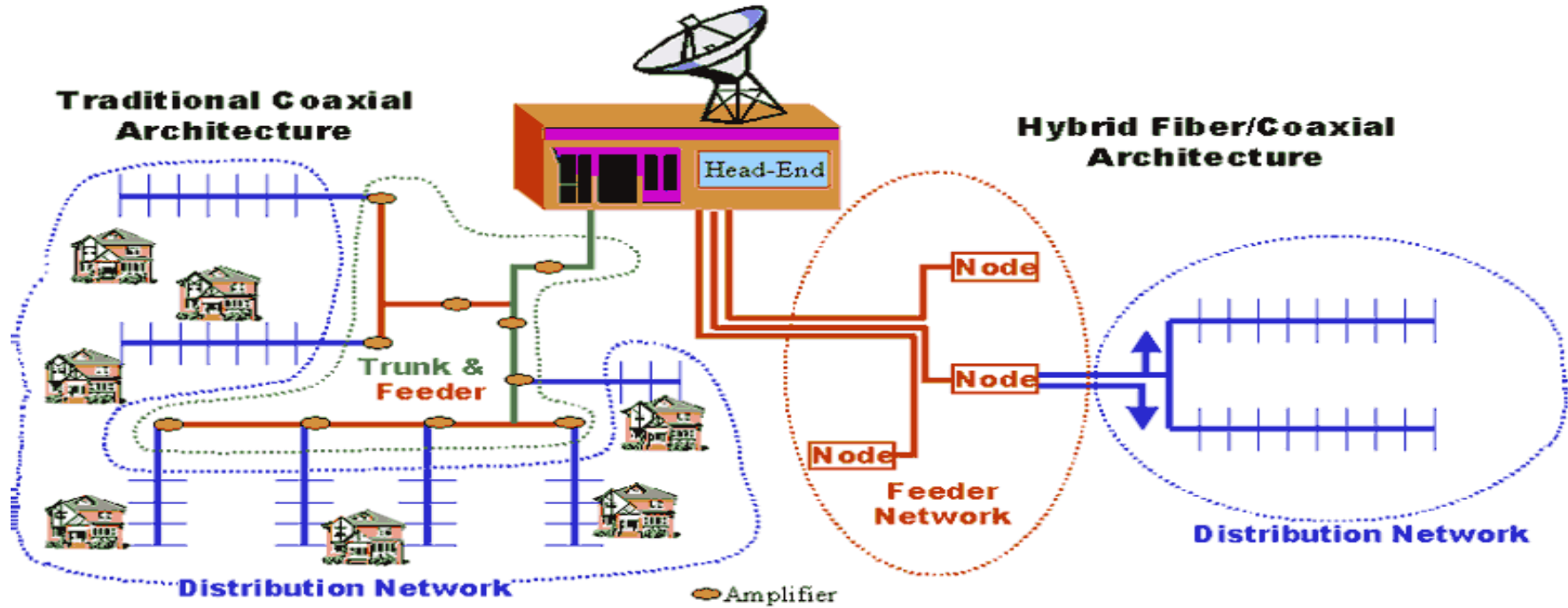
- Thousands of independent systems in the 70's
- HBO starts in 1974, as the first TV channel transmitted exclusively on cable
 - Many new thematic cable TV channels – news, sports, cooking, etc.
- Big companies start to buy the small local networks, and extend them with new cables
 - Cables linking the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

HFC system

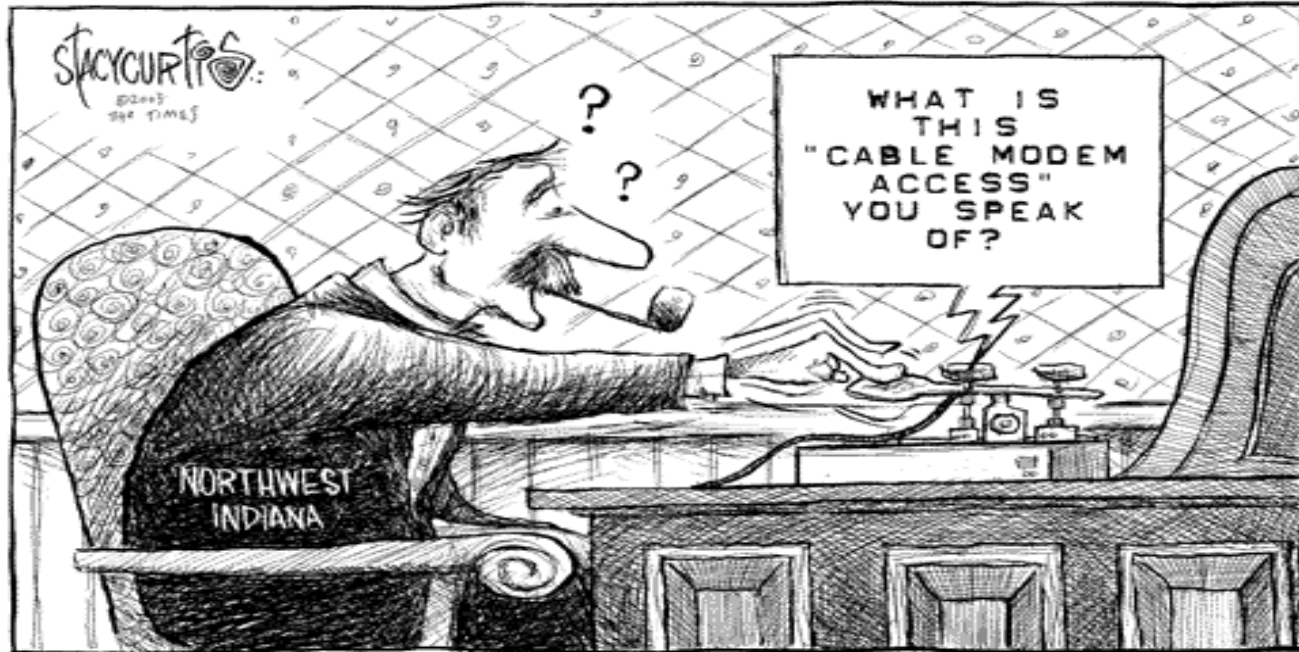
- HFC - Hybrid Fiber Coax
 - Optical fiber to span large distances
 - Coaxial cable to reach the homes
 - Fiber optic node
 - Electro-optical converter
 - Converts optical signals to electrical ones, and vice-versa
 - One optical cable can feed many coaxial cables
 - Much larger bandwidth



Modern Cable TV system



Internet on the cable



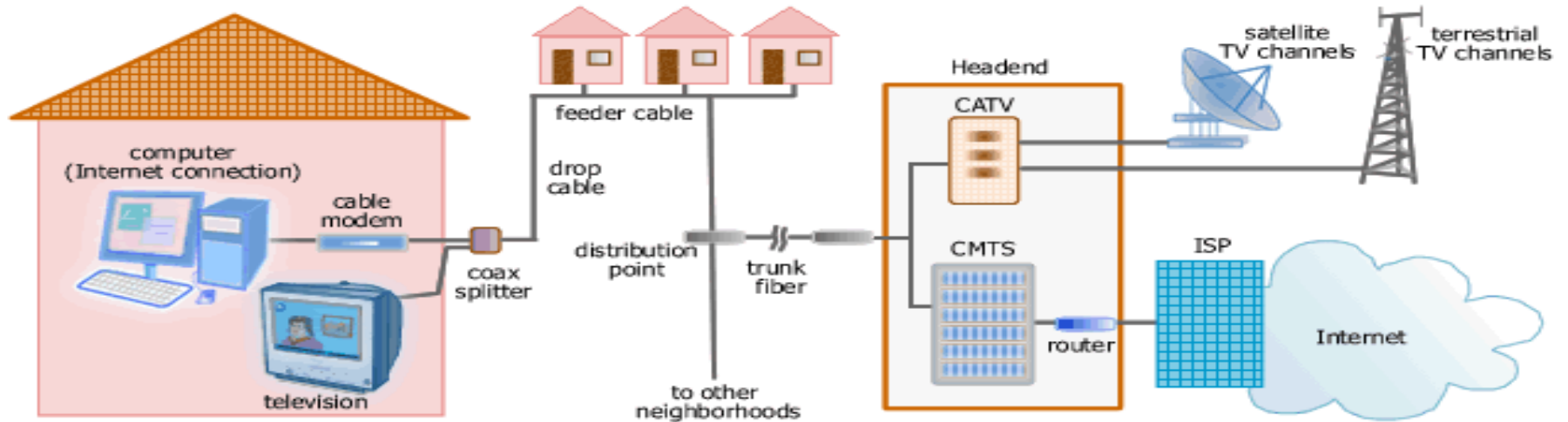
Internet on the cable

- 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

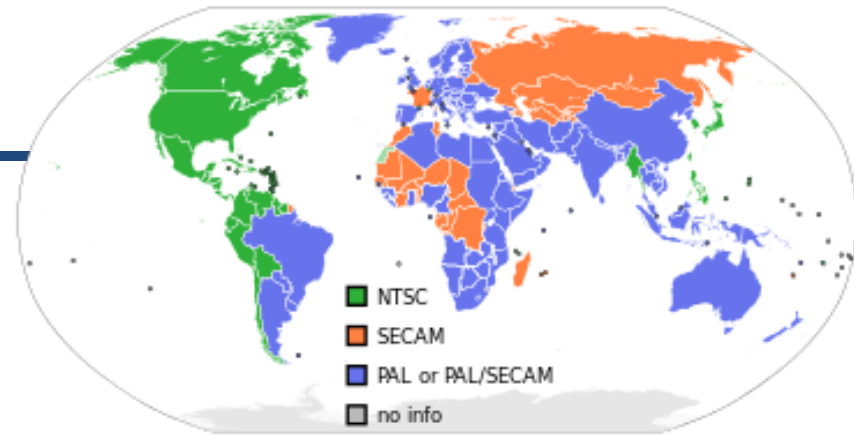
Internet on the cable



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



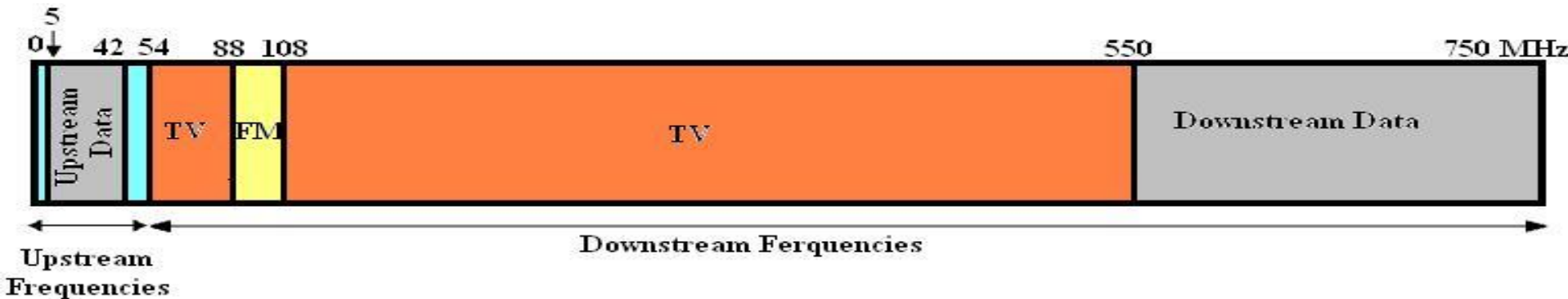
- Europe
 - TV channels above 65 MHz
 - 6-8 MHz wide channels
 - PAL and SECAM systems with higher resolution
 - PAL - Phase Alternating Line
 - SECAM - Système Electronique Couleur Avec Mémoire
 - Resolution: 768 x 576, 25 fps
 - The lower frequencies not used

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
 - **MO**dulates és **DEM**odulates
- Two interfaces – one towards the PC, one towards the cable network
 - Ethernet/USB/WLAN connection between the cable modem and the PC



"I'VE MET SOMEONE WITH A FASTER MODEM."

CN
COLLECTION

Cable modem

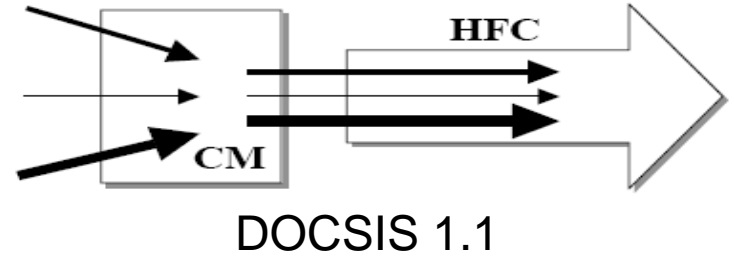
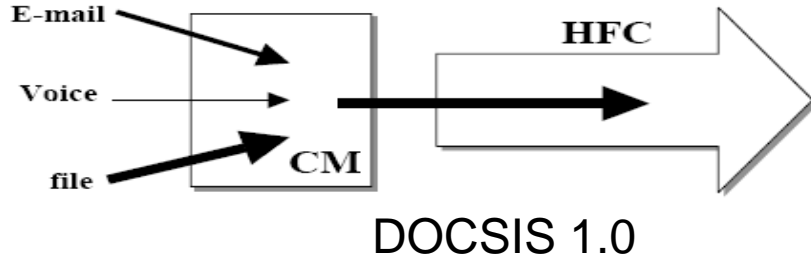
- In the early years each operator had its own modems, installed by a technician
 - An open standard was needed
 - Open the market, lower the prices
 - Contributes to the spread of the technology
 - If the users installs the modem, costs can be cut
- CableLabs
 - Association of the largest cable operators
 - 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

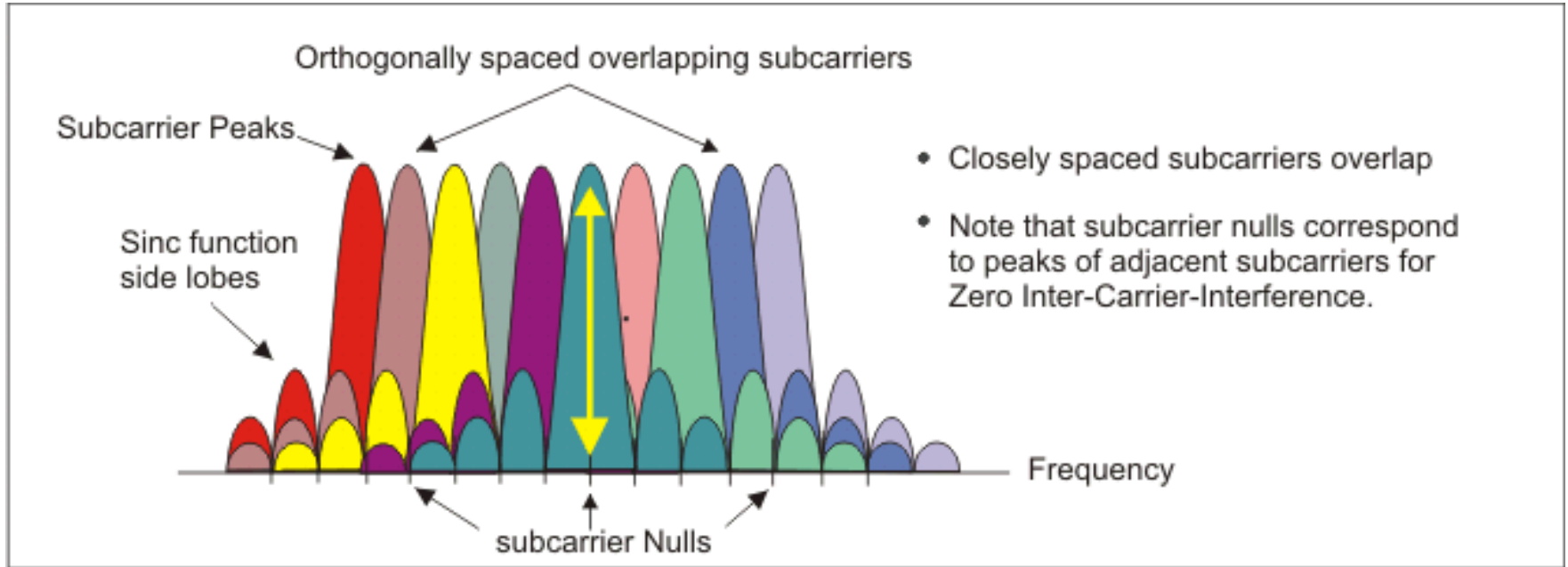


- In DOCSIS 1.0 all the services are in contention for upstream bandwidth, on a „best effort” basis
- In DOCSIS 1.1 QoS guarantees can be associated to applications

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

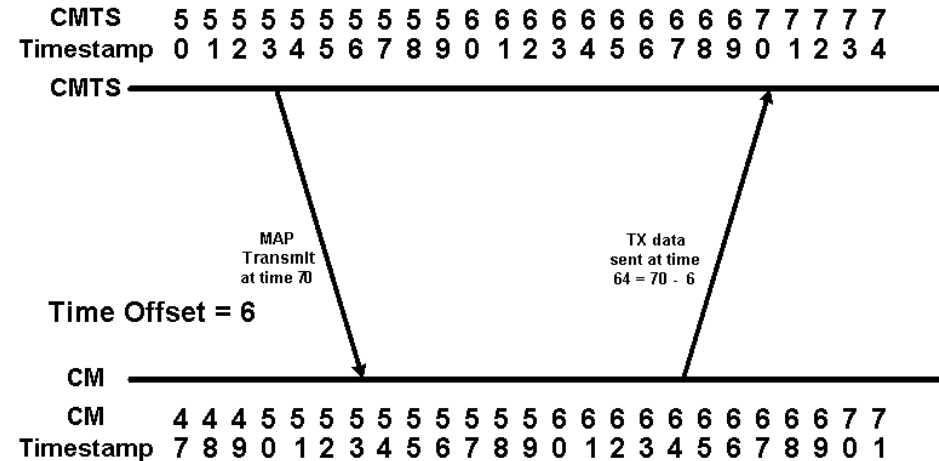


OFDM Signal Frequency Spectra

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

- 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

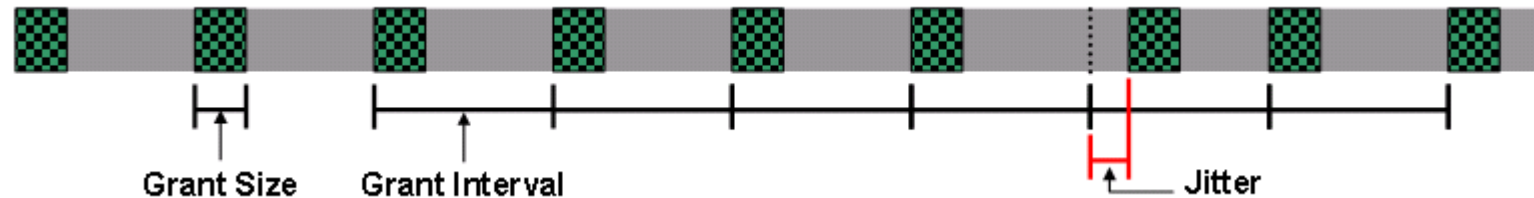
- The upstream channel is divided (in time) into mini-slots -FDD/TDMA
 - Each upstream packet has to fit in one or more mini-slots
 - The length of the mini-slots is different in different networks
 - Typically 8 bytes of user data have to fit in one mini-slot
- The CMTS periodically announces the start 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 an 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

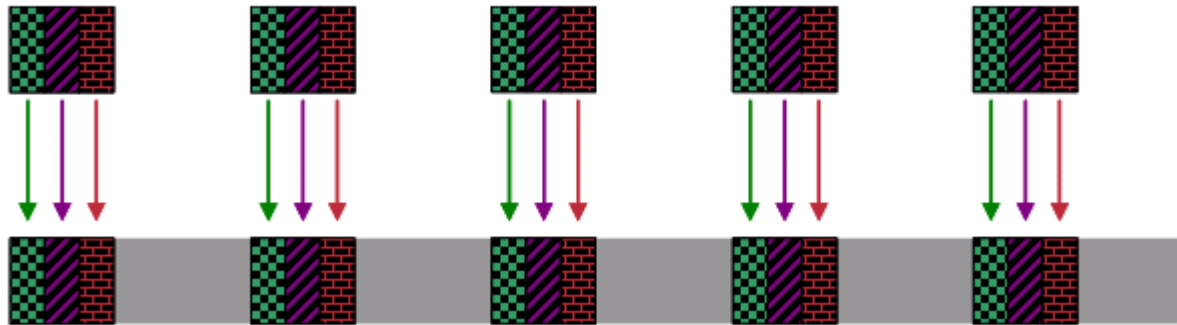
Providing Quality of Service

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



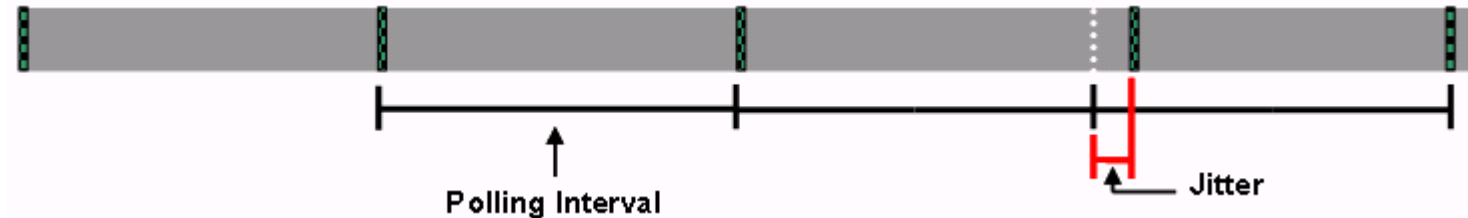
Admission Control

- 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



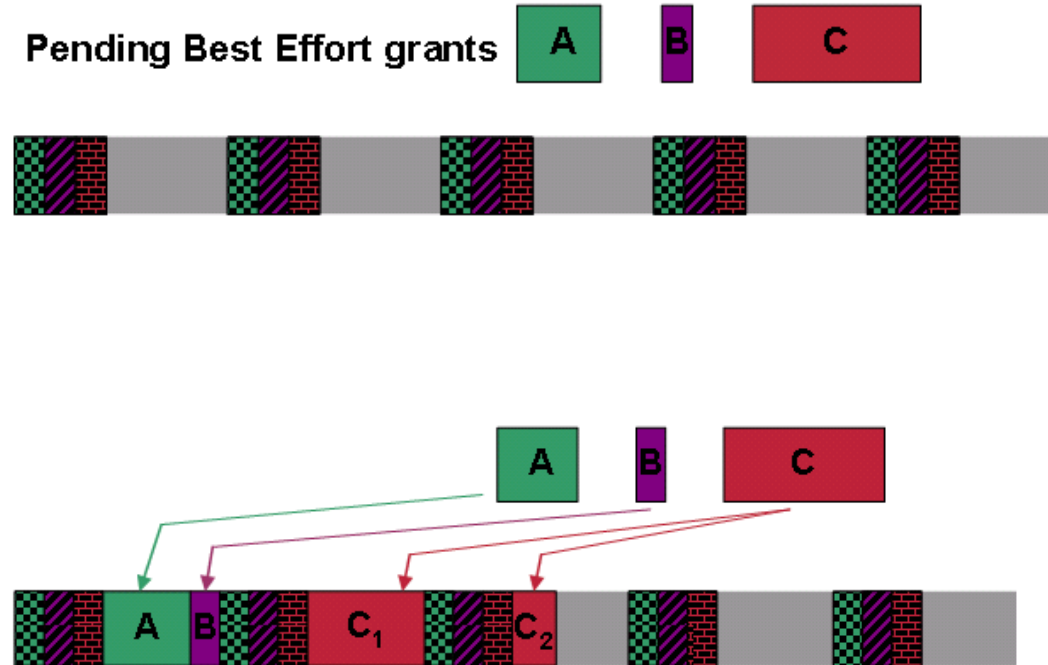
Providing QoS

- **Unsolicited 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