Networking Technologies and Applications

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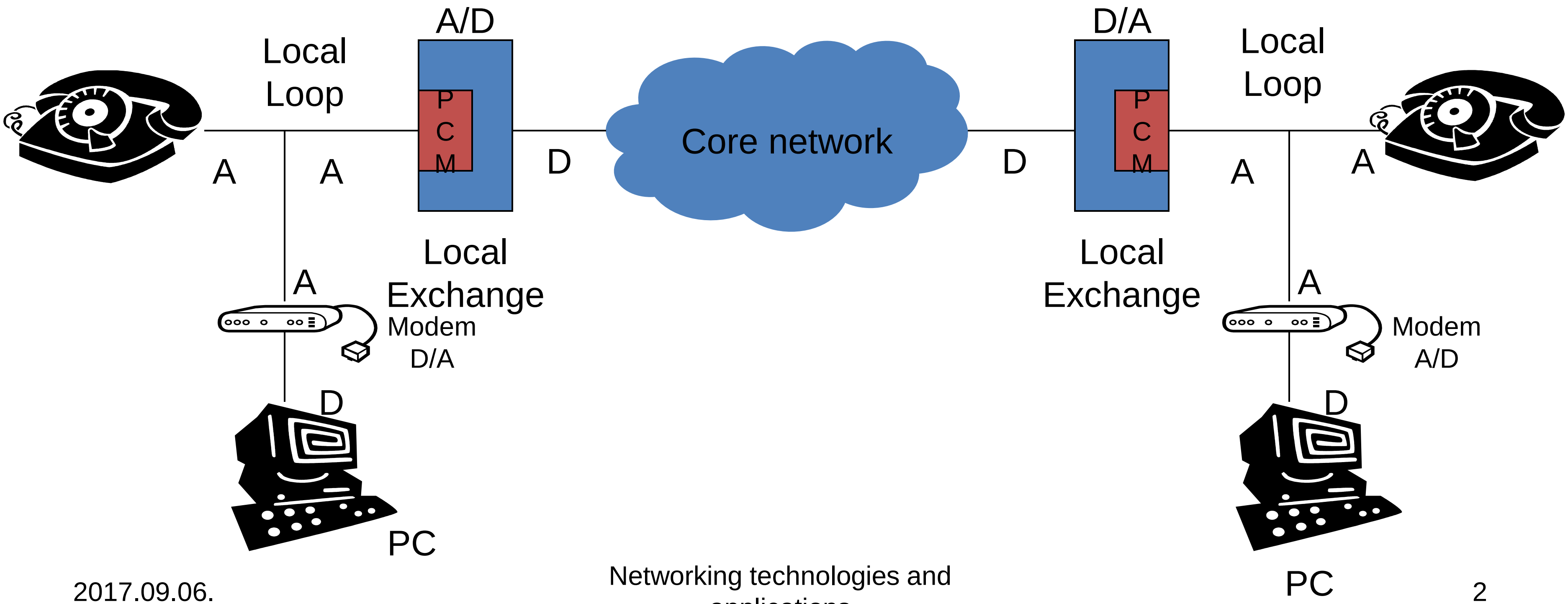
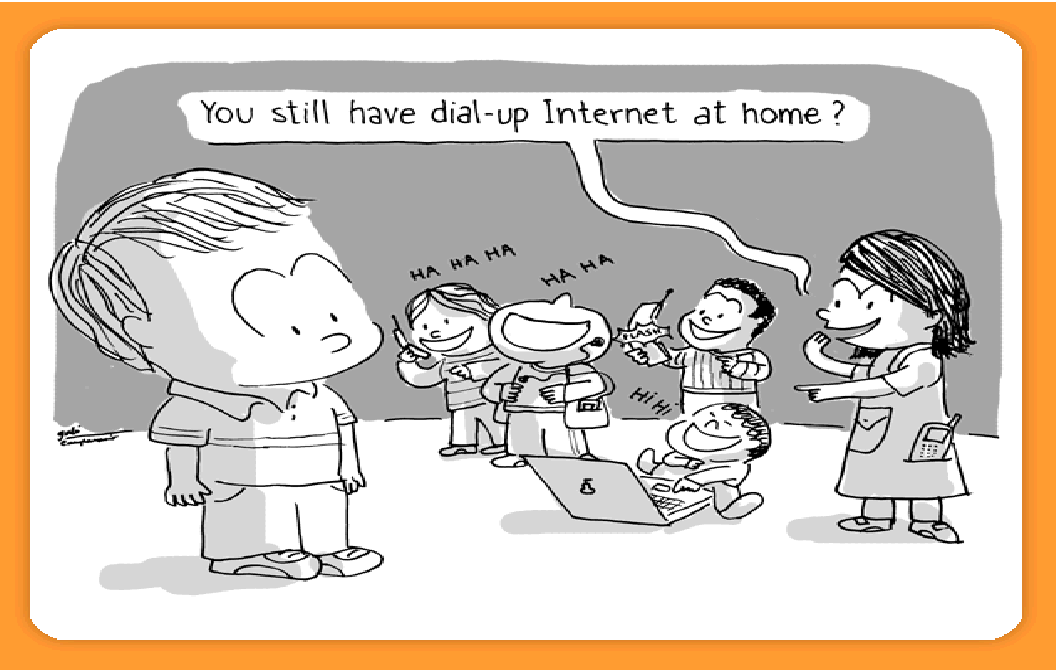
Dial-up access



What's the limit?

- The core network is digital
  - After the PCM coding, the signal is restricted to a 64 Kbps channel, this is the upper limit
    - In most of the systems 1 bit/byte for signaling
    - Max. 56Kbps
  - Quantization noise due to the A/D and D/A conversions
    - The actual limit is 33.6 Kbps

Dial-up is dying out...?



Why DSL?

- DSL – Digital Subscriber Line

- Dial-up speed – 56 Kbps
  - Other technologies – much higher speeds
  - Obliged to move, if you want to keep the subscribers

- Emerges the broadband connectivity
  - Mostly a marketing term
  - Not clear what broadband means
- xDSL – different DSL versions

Why is DSL fast?

- Why is dial-up slow?
  - The PSTN network optimized for voice transmission
    - A band-pass filter in the local exchange
    - Only the 4 KHz large voice channel remains
  - Data is also restricted to this channel
- The line of the xDSL subscriber has no filter
  - You can use the entire capacity of the local loop
    - It depends on the length of the loop, the thickness and the quality of the cable
    - Optimal case: new cables, thin bundles, short loop
- If you want higher speed, you need many local exchanges
  - If someone lives far away, he or you should move closer
    - Lower the speed, higher the service range – more potential subscribers
    - Lower the speed, fewer interested subscribers

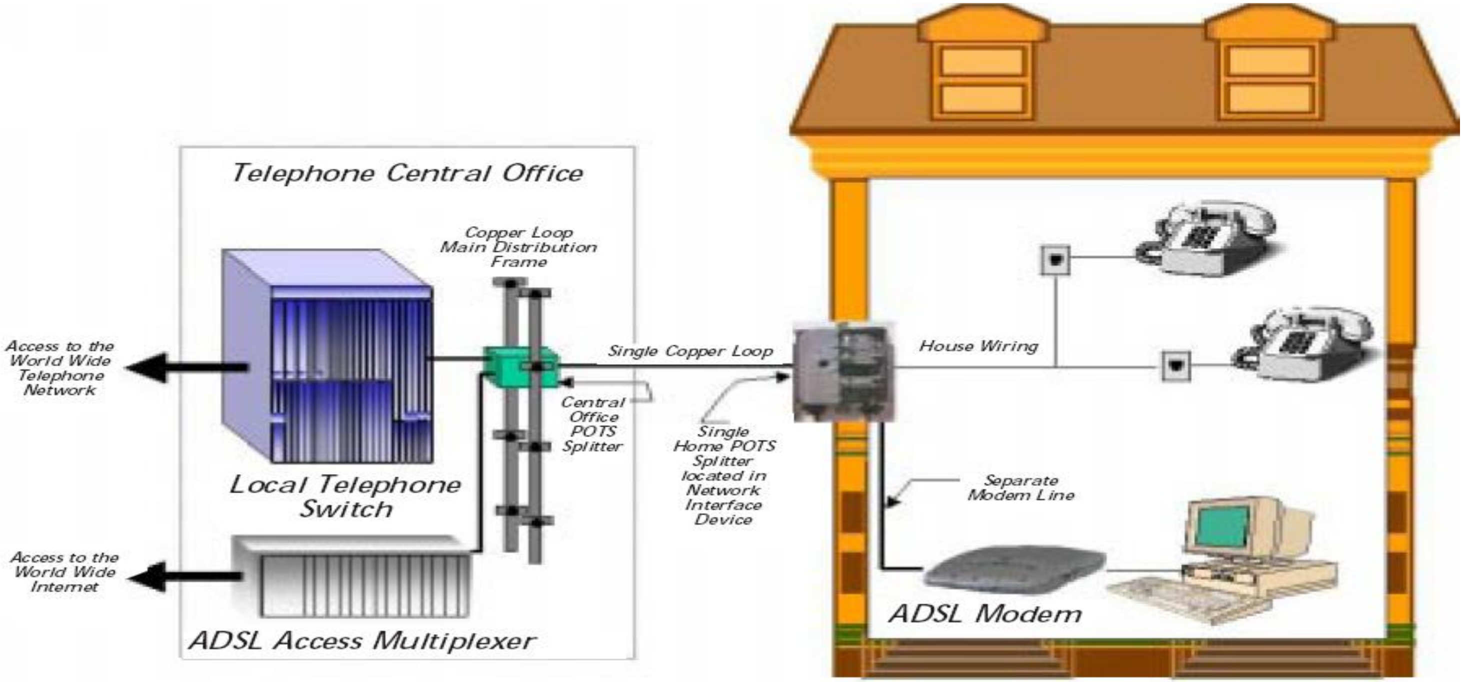
ADSL - Asymmetric Digital Subscriber Line

- DMT – Discrete Multitone Modulation
  - 1.1 MHz frequency domain
  - 256 channels, 4.3125kHz each
    - Channel 0 – POTS (voice)
    - Channels 1-5 – guard band (empty)
      - To avoid interferences between voice and data channels
    - 1 upstream and 1 downstream channel for signaling
    - The remaining channels split between upstream and downstream user data
- Frequency allocation in ADSL
  - 0-4 kHz – voice
  - 4-25 kHz – guard band
  - 25-160 kHz – upstream band
  - 200 kHz - 1.1 MHz – downstream band

ADSL architecture

- At the operator
  - POTS Splitter
    - Frequency splitter to separate voice and data traffic
      - Voice is directed to the local exchange
      - Everything above 26 KHz is directed to the DSLAM
  - DSLAM – DSL Access Multiplexer
    - Splits the bit stream into packets and sends them to the ISPs network
- At the subscriber
  - POTS Splitter
  - ADSL modem
    - Digital signal processing
  - High speed connection to the PC

ADSL architecture



ADSL G.dmt

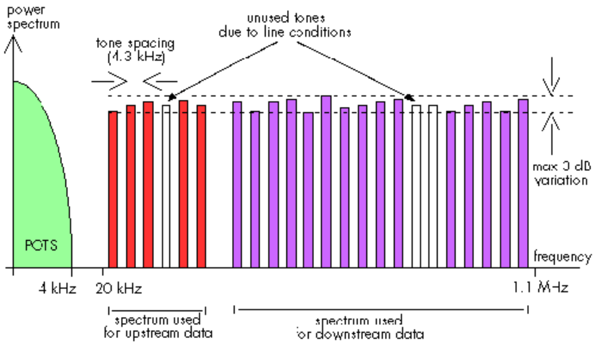
- ITU-T G.992.1 standard (1999)
  - http://www.itu.int/rec/recommendation.asp?type=folders&lang=e&parent=T-REC-G.992.1
- Much larger bandwidth for downstream traffic than for upstream
  - Designed for the needs of web browsing
  - Maximal downlink speed 8 Mbit/s
    - usually 512 Kbit/s – 1 Mbit/s
  - Maximal uplink speed 1 Mbit/s
    - usually 64 Kbit/s – 256 Kbit/s
- Service range of max. 3 km from the local exchange

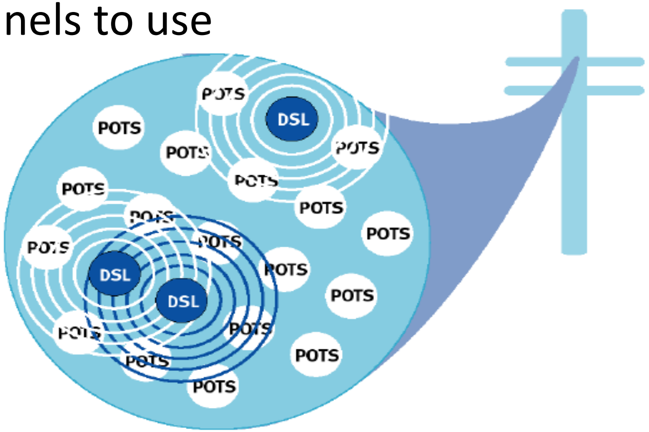
ADSL G.dmt 2

- ITU-T G.992.3 standard (2002)
- Extends the traditional ADSL technology
  - Maximum downlink speed increased to 12 Mbit/s
  - Service range extended with ~ 500 meters
    - The improvements mainly due to the limitation of the interferences on long loops
- ADSL2 is energy efficient
  - As opposed to ADSL, it differentiates between periods with or without traffic
- ADSL2 can temporarily switch to „complete digital” mode
  - The voice and guard channels used for data traffic

ADSL G.dmt 2

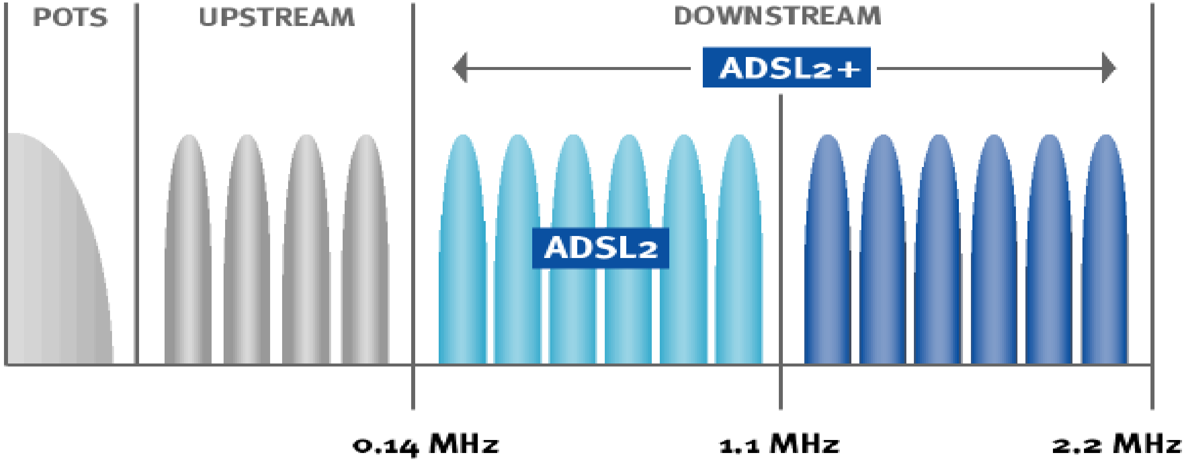
- Seamless rate adaptation (SRA)
  - 20-25 twisted pairs in a bundler
  - „Crosstalk” from the neighboring pairs
    - Might lead to the ADSL connection being dropped
  - ADSL2 can adapt the speed
    - If too much noise on a channel, it can be blocked
    - The modem and the DSLAM agree on which channels to use





ADSL 2+

- ITU-T G.992.5 (2003)
- Bandwidth is increased by enlarging the frequency domain
  - The frequencies used for voice and upstream traffic do not change
  - The upper frequency of the downlink channel is increased from 1.1 to 2.2 MHz.
    - The maximum downlink speed increases from 8Mbit/s to 16 Mbit/s
      - The service range is lowered to 1.5 km



G.SHDSL

- Symmetric High-speed DSL
  - ITU-T G.991.2 (2001)
- 2.3 Mbit/s maximum speed in both directions
  - If a second twisted pair is added, it can be extended to 4.6 Mbit/s
  - service range of 3 km
    - As distance increases, the transmission quality is gradually decreasing

SHDSL applications for business

- **Web hosting**
  - If a web server is operated over a DSL connection
  - High upstream bandwidth needed
- **Videoconferencing**
  - Text, voice and video data to be transmitted
  - Symmetric traffic
- **VPN (Virtual Private Network) services**
  - Private network over a public telecommunication infrastructure
  - The privacy of the data transfer ensured through tunneling and encryption
  - VPN connections over SHDSL, linking the remote offices of a company, if there is no FTTx solution, or it is too expensive
- **Remote LAN Access**
  - Teleworking or SOHO (Small Office Home Office)
  - High speeds needed to ensure the same user experience as in the real office

SHDSL applications at home

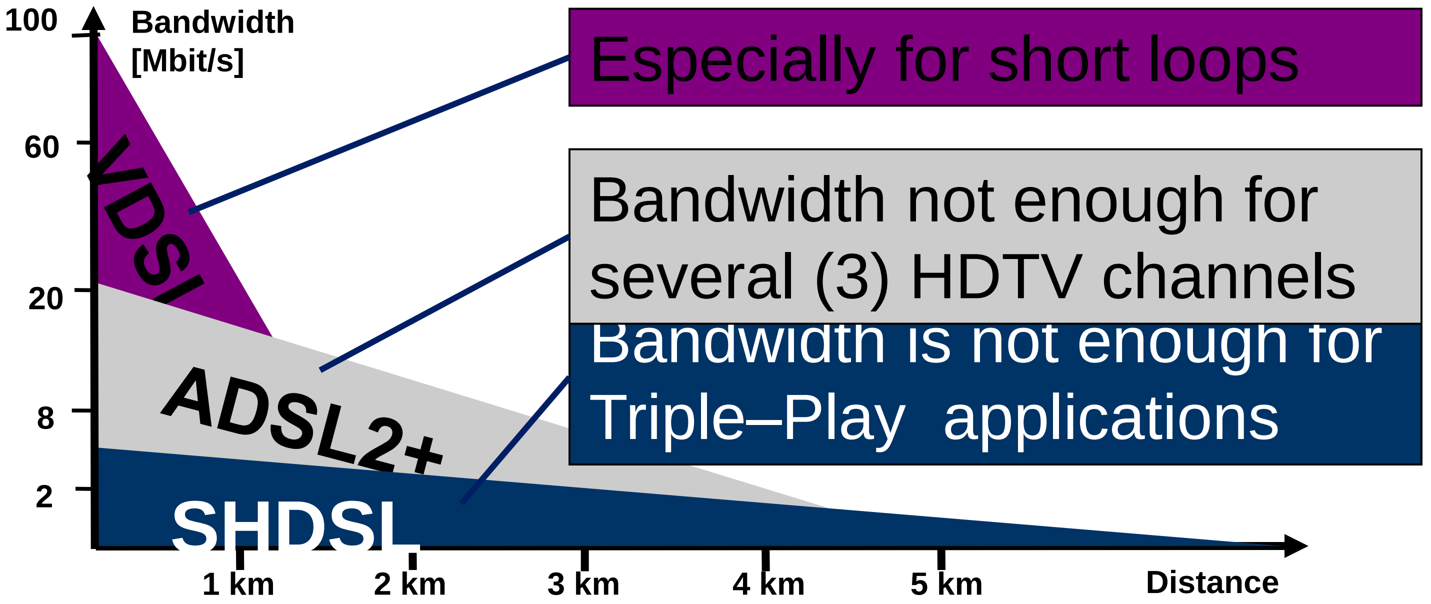
- **Internet Gaming**
  - The home user operates a game server, or plays against other home users
  - A good upstream connections is essential
- **Residential Gateway Access**
  - A CPE (Customer Premises Equipment) that provides access to several services such as home video monitoring or intelligent home applications
- **Peer-to-peer applications**
  - File sharing, application layer multicast
  - Symmetric connection is needed

VDSL

- Very-high-data-rate digital subscriber line
  - ITU-T G.993.1 (2004)

- Significantly higher speeds on lower distances
  - 52 Mbit/s downstream,16 Mbit/s upstream
    - Might be symmetric as well (26-26 Mbit/s)
  - 12 MHz bandwidth
  - Max. 1 km service range
    - Usually rather 300 m
- Mainly used to extend the optical access inside buildings
  - Optical cables are not recommended inside buildings, because of the many necessary inflections
  - The twisted copper pair (VDSL) is a good replacement

VDSL2

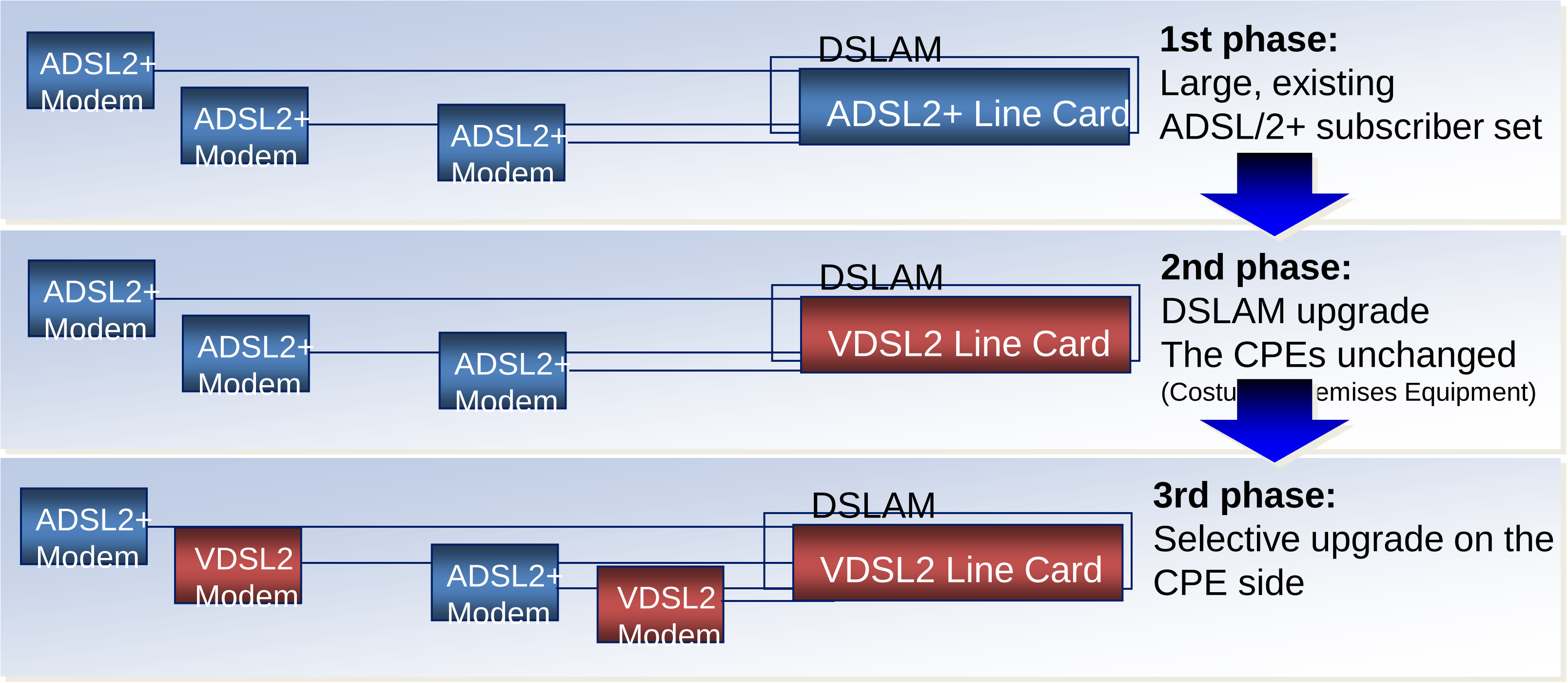


VDSL2 = VDSL speeds with ADSL/2+ service range

VDSL2

- ITU-T G.993.2 (2005)
  - 100 Mbit/s downstream and upstream
  - 30 MHz frequency domain
  - 3 km service range
    - High speed and large range are not compatible
- 8 specified profiles, different service levels
  - Different user expectations in different geographical areas
- ADSL-compatible (VDSL is not)
  - Easy to deploy, attractive technology for the service providers

ADSL compatibility



Triple Play

- Triple Play
  - marketing term for 3 parallel IP services:
    - internet
    - television
      - Video on Demand (VoD) or Live Streaming
    - telephony
      - Voice over IP (VoIP)
  - Rather a business model more than a technology standard
- Quad(ruple) Play
  - The same 3 services, over a wireless interface

VDSL2 QoS

- No Quality of Service support in VDSL
  - In VDSL2 yes
  - Necessary for triple-play services
- Applications have different requirements

Application	Sensible to delay	Sensible to packet loss
Data	/	Yes
Video	No	Yes
Voice	Yes	No
Gaming	Yes	Yes

- Voice
  - Delay – max. 150ms end-to-end
  - BER – between 10^{-5} and 10^{-2}, depending on the used codec
- Video
  - Delay – seconds! for VoD or streaming
    - Zapping delay
  - BER – from 10^{-7} (video telephony) to 10^{-13} for HDTV
    - High Definition Television

VDSL2 QoS

- Different traffic types
  - Voice
    - Small packets (100-400 byte/packet)
    - Generated with constant speed
  - Video
    - Large packets
    - Generated with changing speeds (bursty traffic)
- „dual path" - „dual latency" support in VDSL2
  - Specified bandwidth per traffic type
  - The bursty video does not affect the voice traffic

G.fast

- Proposed in 2014, to be deployed in 2016
- Speeds between 150 Mb/s and 1 Gb/s, for very short loops (100-200 m)
- **Time Division Duplexing (TDD)** instead of **Frequency Division Duplexing (FDD)** as in ADSL2 and VDSL2
  - FDD – separate frequencies for uplink and downlink
  - TDD – alternating time slots for uplink and downlink
  - Better usage of spectrum, possibility for energy saving
    - Discontinuous TDD, transmitter and receiver disabled for longer intervals than needed for the direction change.
    - Trade-of between throughput and power consumption

Other DSL solutions

- HDSL (*High bit-rate DSL*)
- IDSL (*ISDN DSL*)
- MSDSL (*Multirate Symmetric DSL*)
- RADSL (*Rate-Adaptive DSL*)

- No large-scale deployment

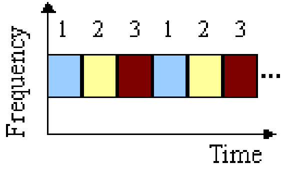
Networking basics

- The different access networks often are using a ***shared transmission medium***
  - Many others can hear me, I can hear many others
  - Providing a dedicated channel to every subscriber might be either impossible, or too expensive

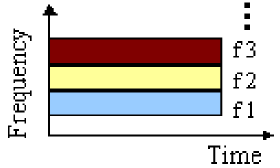
- The problem is to solve the ***access control*** to the transmission medium
  - Users do not know about each other who wants to send and when
  - Access to the medium has to be coordinated

Multiple Access

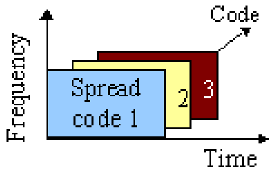
- **Solutions based on fixed allocations**
  - **TDMA – Time Division Multiple Access**
    - Each user has its own timeslot to send
    - Can use the entire frequency band



  - **FDMA – Frequency Division Multiple Access**
    - The spectrum is split into channels
    - Each user has its own channel



  - **CDMA – Code Division Multiple Access**
    - Each user communicates over the entire frequency domain, all the time
    - Traffic is separated based on code theory
      - The sender multiplies the signal with a spreading code, and sends over the result
      - The eceiver multiplies again the received signal with the same spreading code, to reproduce the original signal
      - Codes are orthogonal
        - » Multiplying two different codes returns a series of 0s



Multiple Access vs. **Multiplexing** vs. **Duplexing**

- **Multiple Access (TDMA, FDMA, CDMA)**
  - Regulating channel access in case of many parallel sources
  - Normally in the uplink direction
- **Multiplexing (TDM, FDM, CDM, …)**
  - Combining multiple signals, from one or many sources, onto the same shared medium
  - Uplink or downlink direction
- **Duplexing (TDD, FDD)**
  - Regulating the resources for downlink and uplink traffic
  - FDD – Frequency Division Duplexing
    - „Paired" frequencies, separate uplink and downlink channels
  - TDD – Time Division Duplexing
    - „Unpaired" frequencies, divided adaptively between uplink and downlink traffic

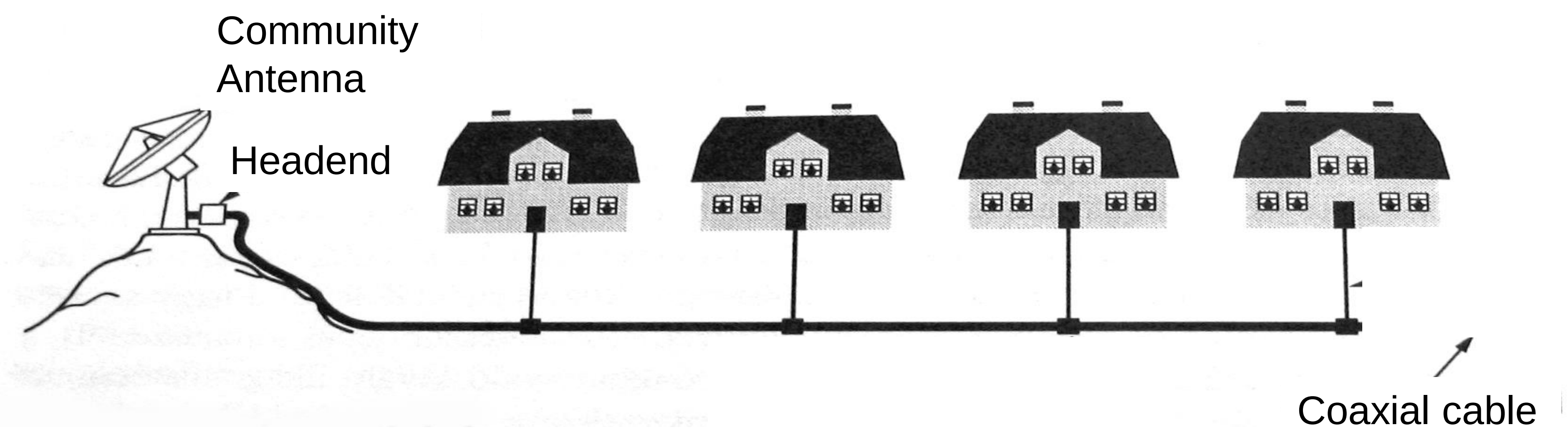
Multiple Access

- Fixed allocation is not efficient if traffic is sparse, and bursty
- **Contention-based Channel Access**
  - **Polling**
    - **Reserving and scheduling resources** based on current demand
  - **Random access**
    - A node starts sending when it wants, no previous reservation
    - If several nodes start speaking in the same time, collision occurs, the packet should be retransmitted later
    - ALOHA, Slotted ALOHA, CSMA/CD

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

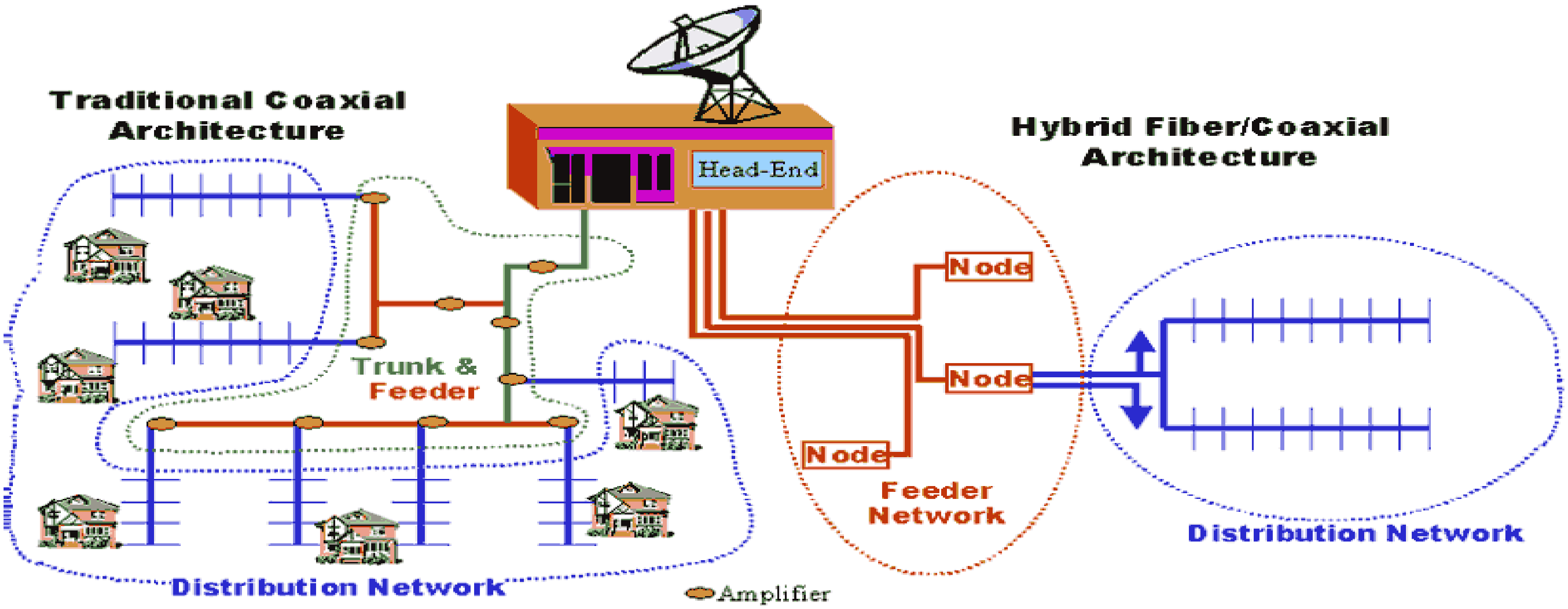
HFC system

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

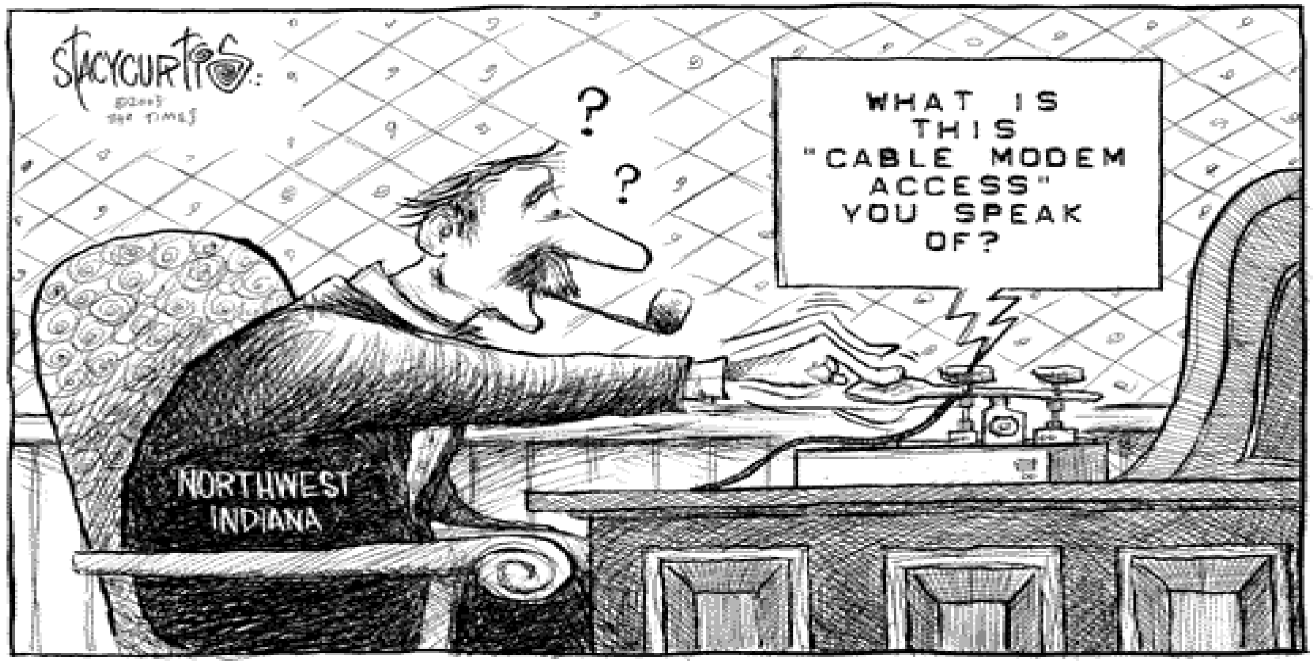
  - Fiber optic node
    - Electro-optical converter
      - Converts optical signals to electrical ones, and vice-versa

  - 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