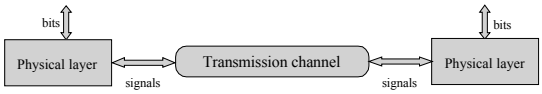
Part 2
Transmission

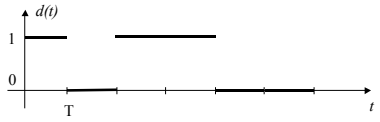
Physical layer
Bandwidth, bit rate
Channel coding
Modems
Multiplexing

Physical layer



- Functions
  - channel coding: encode a series of bits into signals
  - modulation: adapt signal to the transmission channel
  - multiplexing: share the channel

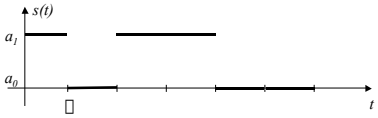
Bit rate



- Information to transmit: series of bits 0 et 1
  - bit period: T
- Bit rate
  - number of bits per time unit [b/s]

$$D = 1/T$$

Coded signal



- Series of symbols represented by a signaling element (amplitude, frequency, phase)
  - V symbols a_i
  - V: number of symbols per signaling element (*valence* du signal)
  - τ: symbol duration *(intervalle significatif)*

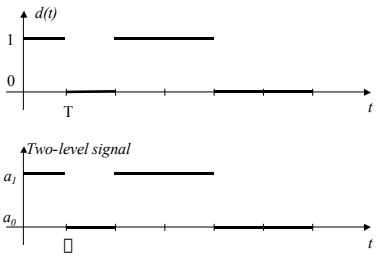
Signaling rate vs. bit rate

- Signaling or modulation rate *(rapidité de modulation)*
  - number of symbols per time unit [bauds] (Émile Baudot); maximum rate at which the encoded signal changes levels

$$R_m = 1/\tau$$

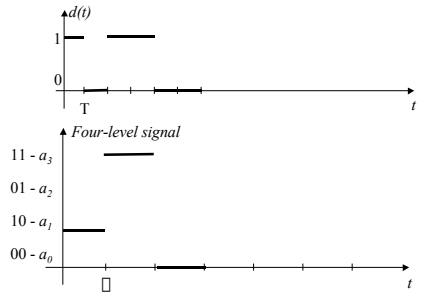
$$D = \tau / T \cdot R_m \qquad D = R_m \cdot \log_2 V$$

Example: two-level signal



- $T = \tau$, $V = 2$, $R_m = 1/\tau$ baud, $D = 1/T$ b/s

Example: four-level signal



- $2T =$ □, $V = 4$, $R_m = 1/$□ baud, $D = 1/T$ b/s $= 2/$□ b/s

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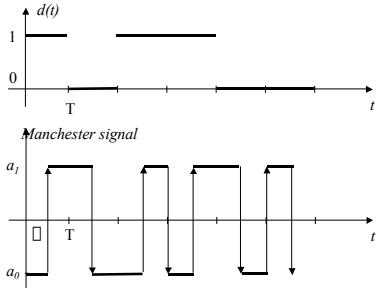
Example: Manchester *(bi-phase)*



- $T = 2$□, $V = 2$, $R_m = 1/$□ baud, $D = 1/T$ b/s

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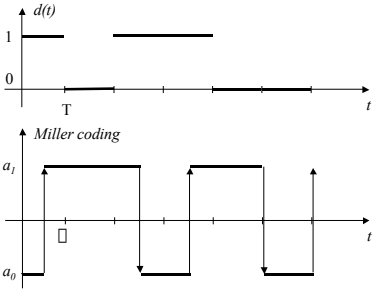
Example: Miller coding



- $T =$?, $V =$? , $R_m =$? baud, $D =$? b/s

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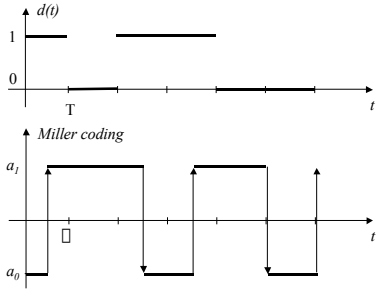
Example: Miller coding



- $T =$ □ , $V = 2$, $R_m = 1/$□ baud, $D =$ 1/T b/s

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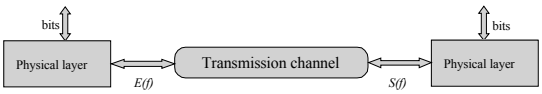
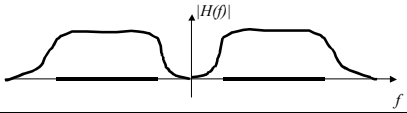
Bandwidth



- Transfer function

$$H(f) = S(f) / E(f)$$

- Bandwidth



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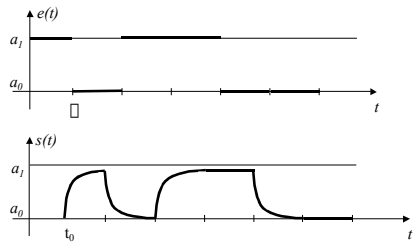
Signal distorsion



- Attenuation and distortion
- Depends on the distance

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Bit rate limitation

- Nyquist
  - bandwidth *B,* noiceless channel

$$R_m \leq 2B$$
$$D \leq 2B \log_2 V$$

  - example : V = 2, B = 3000 Hz, D_{max} = 6 Kb/s

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Bit rate limitation

- Shannon
  - bandwidth *B*
  - noise :
    - » signal to noise ratio

$$(S/N)_{dB} = 10 \log_{10}(P_S / P_N)$$

    - » limitation

$$D \leq B \log_2(1 + P_S / P_N)$$

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Bit rate limitation

- Example :
  - S/N = 30 dB, P_s/P_n = 1000
  - B = 3100 Hz
  - D_{max} = 30 894 b/s
  - S/N = 38 dB, P_s/P_n = 6309
  - B = 3100 Hz
  - D_{max} = 39 600 b/s
- Conclusion
  - a noisy channel of a given bandwidth has limited bit rate

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Transmission media

- Twisted pair
  - unshielded
    - » UTP-3 *(Unshielded Twisted Pair)* phone quality
    - » UTP-5 data quality
  - shielded
    - » STP *(Shielded Twisted Pair)*

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Transmission media

- Twisted pair
  - UTP -3 of 100m
    - » bandwidth: 16 MHz
  - UTP -5 of 100m
    - » bandwidth: 100 MHz
  - error rate: 10^{-5}

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Transmission media

- Coaxial cable
  - 50 Ω, 75 Ω (TV)
  - bandwidth: several hundreds MHz
  - several hundreds Mb/s on 100 m
  - error rate: 10^{-8}, 10^{-9}

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Transmission media

- Fiber
  - multimode stepped index (50-125 μm)
    - » 40 MHz sur 1 km
  - multimode graded index (50-125 μm)
    - » 500 MHz sur 1 km
  - monomode (2-8 μm)
    - » 100 GHz sur 1 km

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Transmission media

- Fiber
  - Erbium-Doped Fiber Amplifiers - Tb/s
  - limit: 1 Gb/s - electric/optical junction
  - low error rate (no electro-magnetic interference): 10^{-10}

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Transmission media

- Radio waves
  - length ($\lambda f = c$) :
    - » 1 MHZ - 300 m
    - » 30 GHz - 1 cm
  - propagation
    - » > 100 Mhz straight line
    - » < 5 GHz traverses concrete (2.4 GHz WaveLAN)
    - » ~ 8 GHz absorbed by water
  - GSM :
    - » 124 channels of 200 KHz around 900 MHz

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Transmission media

- Satellites
  - geo-stationnary - 36 000 km
    - » between 3 and 30 GHz
    - » 12-20 channels of 36-50 MHz (50 Mbit/s)
  - LEO *(Low Earth Orbit)* - 750 km
    - » 1.6 GHz
    - » 77 satellites that cover all the surface
  - broadcast medium

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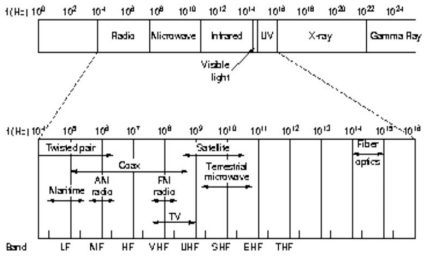
Electromagnetic spectrum



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Typical bit rates

- Twisted pair
  - 200 Mb/s on short distances
- Coaxial cable
  - 1 Gb/s on 1 km
- Radio wave
  - 11 Mb/s
- Satellite
  - 4-6 Gb/s
- Fiber
  - 10-100 Gb/s

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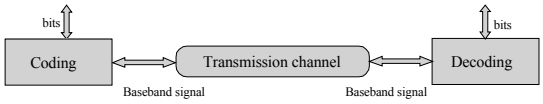
Baseband transmission



- Coding
  - no frequency transposition
  - no modulation

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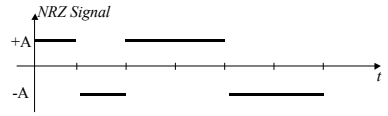
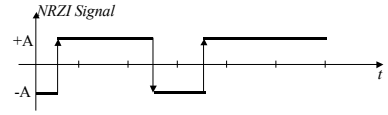
Channel coding

- NRZ *(Non Return to Zero)*



- NRZI *(Non Return to Zero Inverted)*



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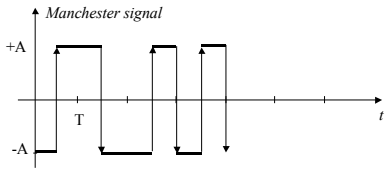
Channel coding

- Manchester
  - at least one transition
  - used in Ethernet



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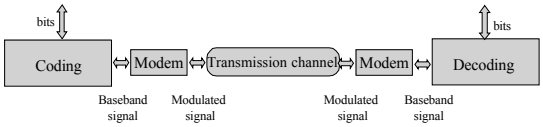
Broadband transmission



- Modulation
  - frequency transposition
  - adapt signal to the channel

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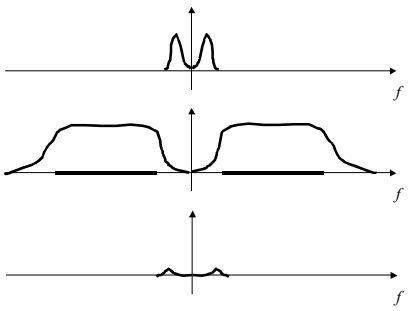
Modulation



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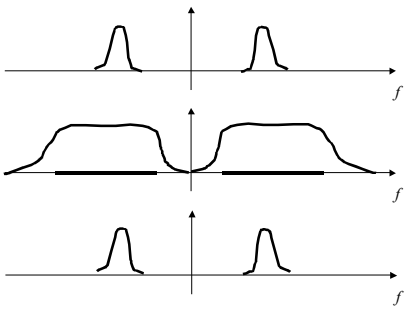
Modulation



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Types of modulation

- Carrier signal

$$s(t) = A\cos(2\pi ft + \varphi)$$

- Modulation
  - amplitude *(ASK - Amplitude Shift Keying)* : *A(t)*
  - frequency *(FSK - Frequency Shift Keying)* : *f(t)*
  - phase *(PSK - Phase Shift Keying)* : $\varphi(t)$

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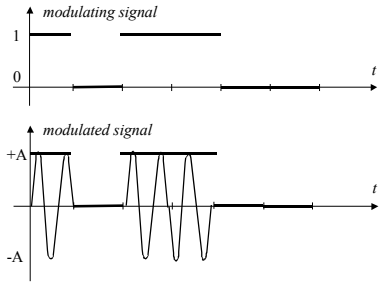
Amplitude modulation



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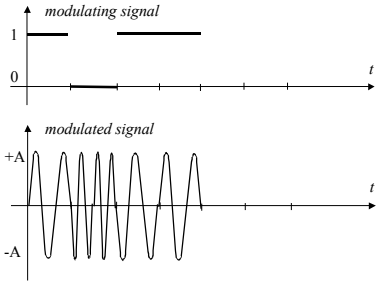
Frequency modulation



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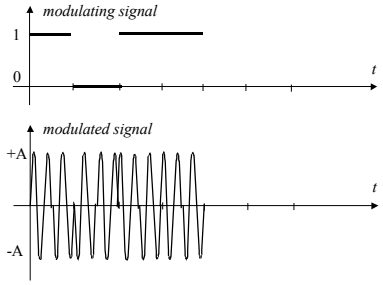
Phase modulation



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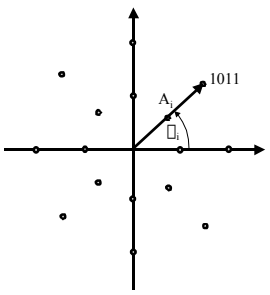
Phase and amplitude modulation



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Phase and amplitude modulation

- *QAM - Quadrature Amplitude Modulation*
- V.32
  - D = 9600 b/s
  - R_m = 2400 baud
  - V = 16
  - one point corresponds to 4 bits
- V.34
  - 33.6 Kb/s

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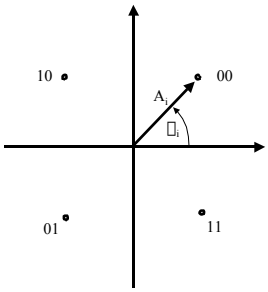
What type of modulation?



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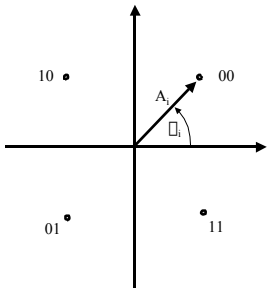
Phase modulation



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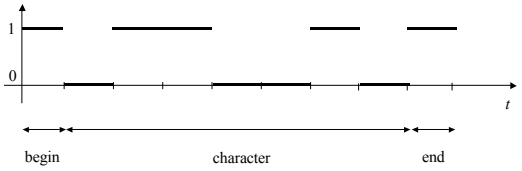
Asynchronous transmission

- One character at a time; beginning and end markers



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Asynchronous transmission

- Start Bit
- character: 7, 7 + parity, 8
- Stop Bit (1, 2 ou 1.5)
- overhead

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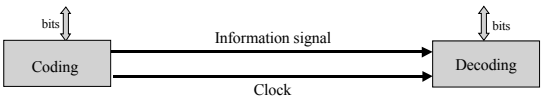
Synchronous transmission

- Clock ticks with information signal
- Two channels



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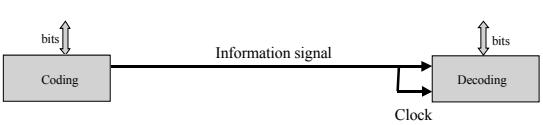
Synchronous transmission

- One channel



- Recover clock from the information signal
  - Manchester

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Transmission errors

- Signal distorsion, noise, synchronisation errors → transmission errors
- Media of a given length
  - bandwidth *B*
  - signal to noise ratio *S/N* → error rate
- Longer media, higher error rate
- More noise, higher error rate

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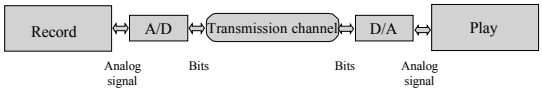
PCM - Pulse Coded Modulation
MIC - *Modulation par Impulsion Codés*

- PCM - Pulse Coded Modulation
  - digital sound
  - A/D Analog/Digital



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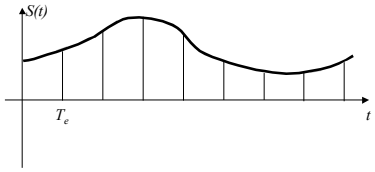
Sampling

- Sampling frequency
  - *B* - maximal frequency of the signal
  - $f_e = 1/T_e \geq 2B$



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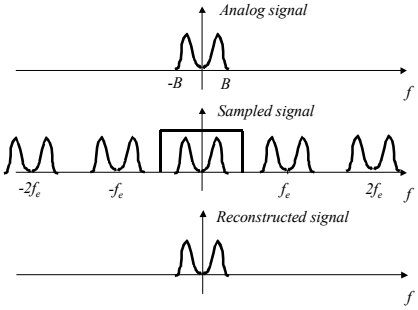
Reconstruction



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Coding and quantification

- Sample coded on N bits
  - ex. N = 8, 0… 255
- Quantification error results in a noise measured in dB (S/N)
  - 1 bit increases S/N by 6 dB
  - 8 bits → 48 dB
  - 16 bits → 96 dB
  - ideal: 20 bits → 120 dB (quality required by human ear)

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Examples

- Phone
  - B = ~4 KHz
  - f_e = 8 KHz, T_e = 125 µs
  - sample coded on 8 bits
  - bit rate required: 8 bits × 8 KHz = 64 Kb/s
  - GSM : 15.2 Kb/s, ADPCM : 32 Kb/s
- Hi-Fi (CD)
  - B = ~20 KHz
  - f_e = 44.1 KHz, professional 48 KHz
  - sample coded on 16 bits , professional 20 bits
  - bit rate required: 176 Kbyte/s

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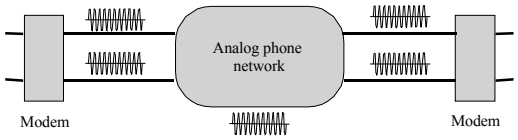
Modem on analog lines



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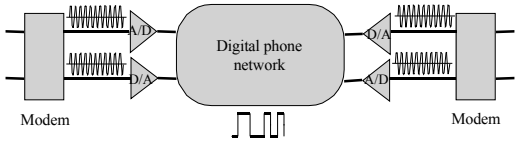
Modem on digital lines



- V.34 modem
  - 33.6 Kb/s

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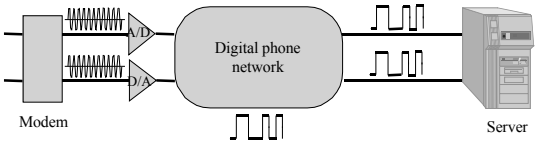
Server on digital line



- V.90 modem
  - sending at 33.6 Kb/s
  - receiving at 56 Kb/s

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V.90

- Bit rate limited by noise (S/N)
  - A/D conversion adds noise: S/N = 38 dB
  - D/A conversion does not add noise
  - D_{max} = 39 600 b/s
- Server on digital line
  - generates appropriate digital signal
  - theoretical 64 Kb/s, in fact 56 Kb/s

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V.90

- *Hype?*
  - FCC limits the bit rate to 53 Kb/s
  - effective reception bit rate:
    - » 42 Kb/s on high quality lines
    - » 27 Kb/s on low quality lines

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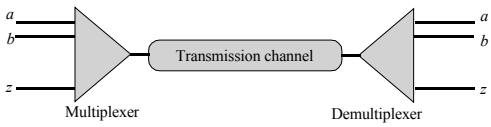
Multiplexing



- Channel shared by several signals
  - TDM *(Time Division Multiplexing)*
  - FDM *(Frequency Division Multiplexing)*

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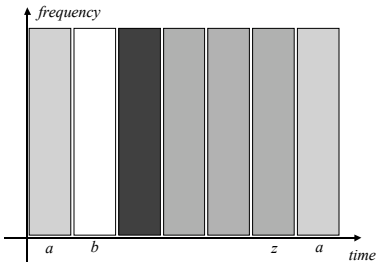
TDM



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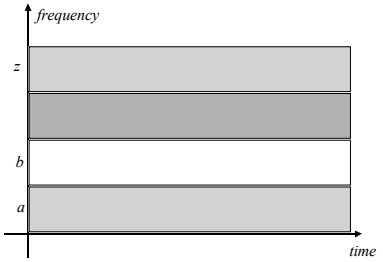
FDM



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Statistical multiplexing

- Channel shared by several active signals
  - active channel does not wait for its turn (eg. channels *a* et *b* have data to send)
  - channel identifier in data

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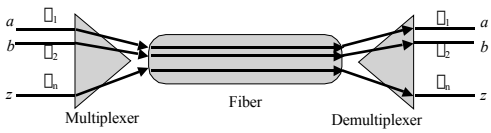
Wavelength Division Multiplexing



- WDM *(Wavelength Division Multiplexing)*
- Optical channel - wavelength λ_i
- Thousands channels of 1 Gb/s in one fiber

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Channel Partitioning (CDMA)

- **CDMA (Code Division Multiple Access)**: exploits **spread spectrum** (DS or FH) encoding scheme
- unique "code" assigned to each user; ie, **code set** partitioning
- Used mostly in **wireless** broadcast channels (cellular, satellite,etc)
- All users share the **same frequency**, but each user has **own "chipping" sequence** (ie, code)
- Chipping sequence like a **mask**: used to **encode** the signal

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Channel Partitioning (CDMA)

- **encoded signal** = (original signal) X (chipping sequence)
- **decoding**: innerproduct of encoded signal and chipping sequence (note, the innerproduct is the sum of the component-by-component products)
- To make CDMA work, chipping sequences must be chosen orthogonal to each other (i.e., innerproduct = 0)

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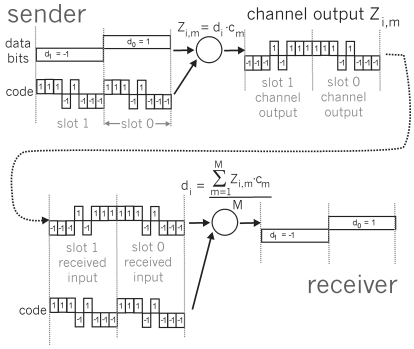
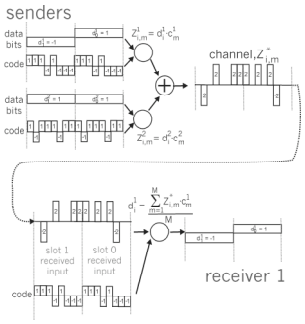
CDMA Encode/Decode



CDMA: two-sender interference



CDMA

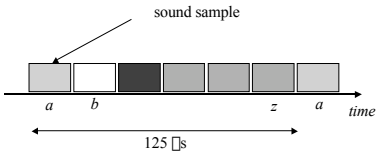
CDMA Properties:

- protects users from interference and jamming (used in WW II)
- protects users from radio multipath fading
- allows multiple users to “coexist” and transmit simultaneously with minimal interference (if codes are “orthogonal”)

Examples

- Temporal multiplexing
  - EU hierarchy
    - » E1 : 30 × 64 Kb/s = 2 Mb/s
    - » E3 : 480 × 64 Kb/s = 34 Mb/s
  - US hierarchy
    - » T1 : 24 × 64 Kb/s = 1.5 Mb/s
    - » T3 : 672 × 64 Kb/s = 44 Mb/s

TDM - phone

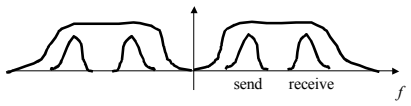


Examples

- TDM on fiber
  - SDH *Synchronous Digital Hierarchy,* SONET *Synchronous Optical Network*
    - » OC-1 : 51 Mb/s
    - » OC-3 : 155 Mb/s
    - » OC-12 : 622 Mb/s
    - » OC-48 : 2.4 Gb/s

Examples

- FDM
  - modems



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Examples

- Hybrid multiplexing
  - GSM
    - » 124 channels of 270 Kb/s
    - » each channel divided into 8 time slots

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Numéris

- Digital channel
  - B : 64 Kb/s (data)
  - D : 16 Kb/s (signaling; packets)
- Base access
  - 2B + D
- Primary access
  - 30B + D

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ADSL

- *Asymmetric Digital Subscriber Link*
- High speed residential access on twisted pair
- Assymetric bandwidth
  - 8 Mb/s downstream
  - 1 Mb/s upstream
- Short distance between home and switch

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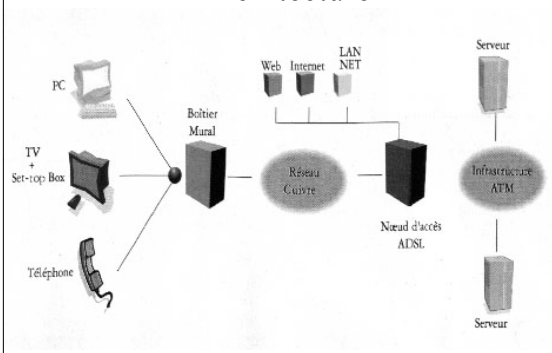
Architecture



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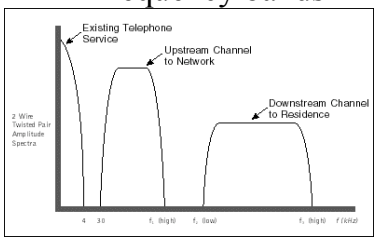
Frequency bands



- FDM
- 0 - 4 kHz: POTS, 94 - 106 kHz: upstream, 120 - 420 kHz: downstream
- high frequency ⇨ small distances

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Modulation

- CAP Carrier-less Amplitude/Phase modulation
  - carrier frequency suppressed
- DMT Discrete Multi-Tone
  - several different sub-carrier frequencies

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G.Lite, Universal ADSL

- Future standard
- Lower bit rate
  - downstream up to 1,5 Mbps
  - upstream up to 128 Kbps

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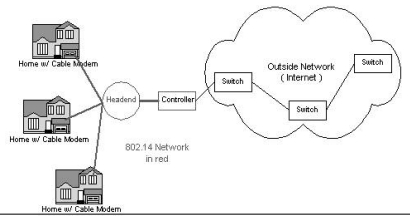
HFC: hybrid fiber coax - cable modem

- Tree structure
  - » Head-End: CMTS (Cable Modem Termination System) connected to CM (Cable Modem) => Virtual LAN
  - » from 500 to 2000 modems per node - shared!



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Modulation

- Different types
  - 64 QAM : 64-state Quadrature Amplitude Modulation
  - QPSK : Quadrature Phase Shift Keying
  - DQPSK : Differential Quadrature Phase Shift Keying
  - BPSK : Biphase Shift Keying

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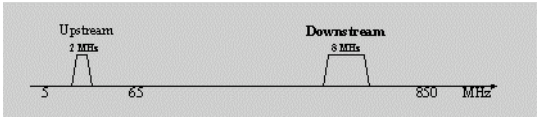
Downstream flow

- Received by CM
- Frequency: 65-850 MHz (EU)
- Bandwidth: 8 MHz (EU)
- Modulation: 64 QAM / 256 QAM
- Bit rate: 10 Mb/s
- All modems receives the flow



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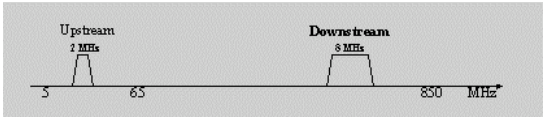
Upstream flow

- Sent by CM
- Frequency: 5-65 MHz (EU)
- Bandwidth: 2 MHz (EU)
- Modulation: QPSK / 16 QAM / DQPSK
- Bit rate: 768 Kbps



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Facts to remember

- Complex relations between length, quality of the media, S/N, and performance (bit rate, error rate)
- Physical layer
  - hides signal transmission problems
  - provides interface for unreliable transmission of bits
- Future?
  - fiber for every stationnary equipment
  - radio for mobiles