Physical Backgrounds

Physics of Electro-magnetic Waves

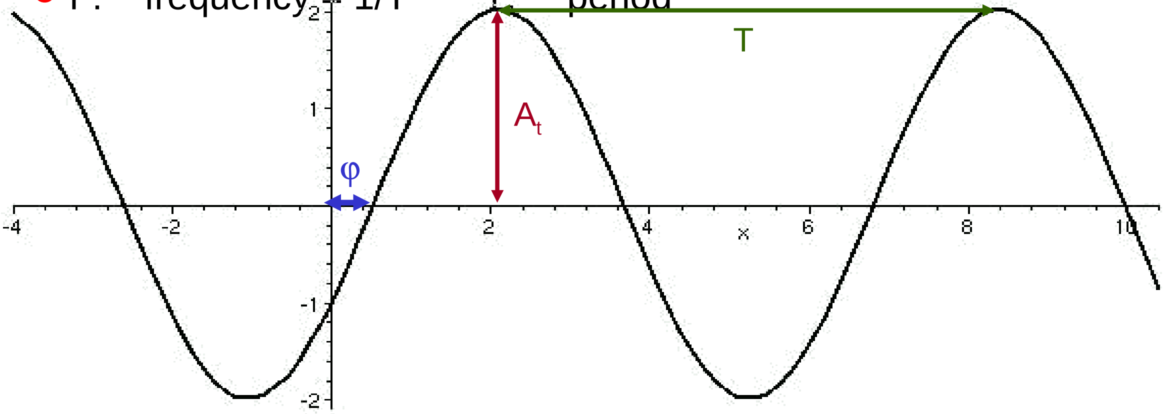
- **Frequency f :** number of oscillations per second
  - unit of measurement : **Hertz**
  - **wave length λ:** distance (in meters) between wave maxima
  - The propagation speed of waves in vacuum is constant: speed of light $c \approx 3 \cdot 10^8$ m/s

- Note that:

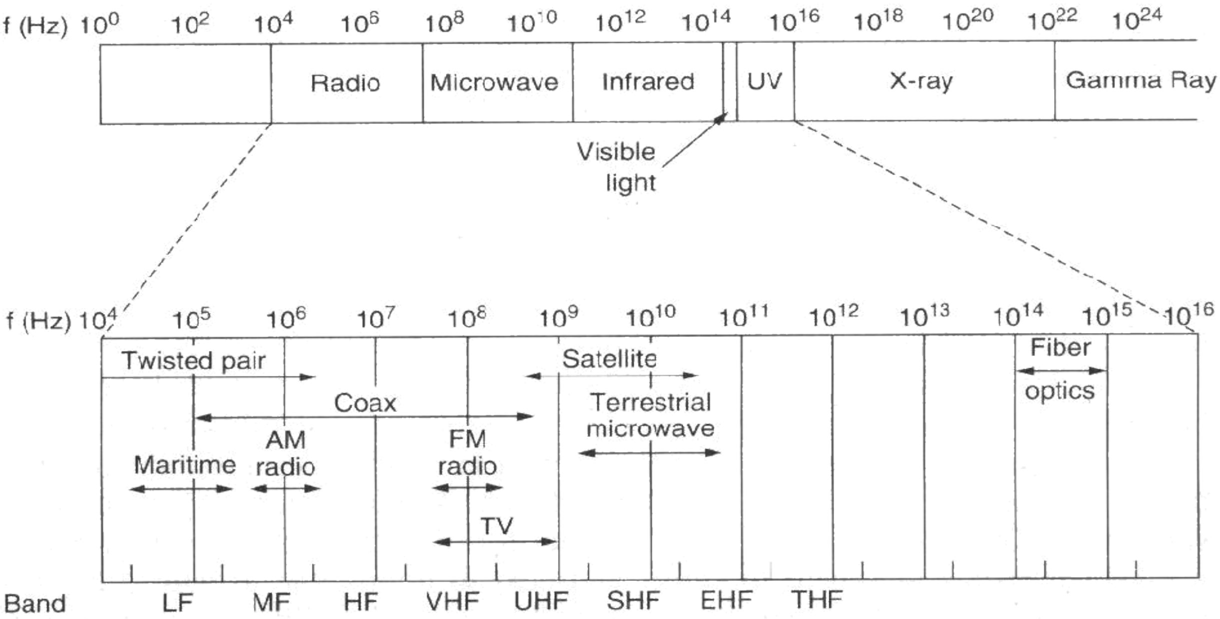
$$\lambda \cdot f = c$$

Amplitude Representation

- Amplitude representation of a sinus curve
  - $s(t) = A \sin(2\pi f t + \varphi)$
  - A: amplitude φ: phase shift
  - f : frequency = 1/T T: period



Frequency Bands

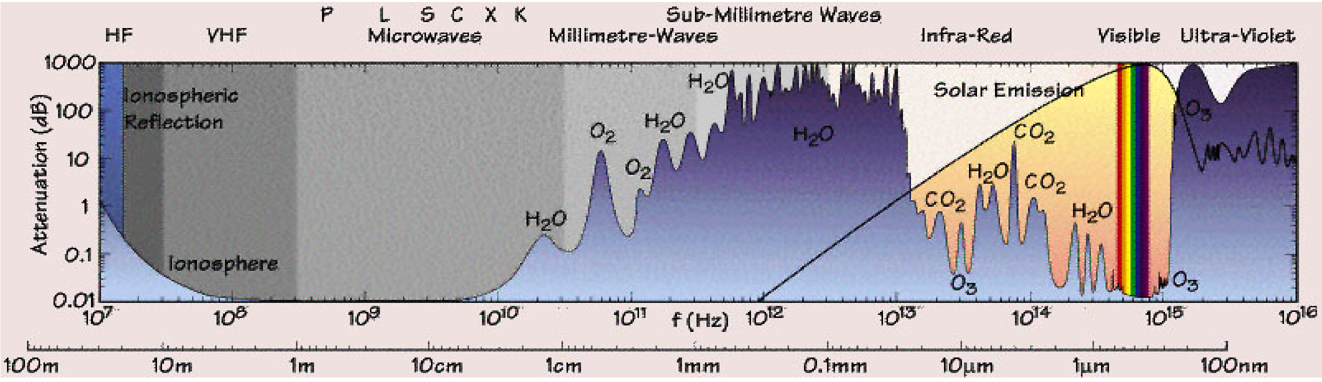


LF Low Frequency **MF** Medium Freq. **HF** High Freq. **VHF** Very High Freq. **UHF** Ultra High F. **SHF** Super High Fr.

EHF Extra High Frequency **UV** Ultra Violet

Different Frequencies – Attenuation

- **Attenuation** depends on the used frequency
- Can result in a frequency-selective channel
  - if bandwidth spans frequency ranges with different attenuation properties



http://www.geographie.uni-muenchen.de/iggf/Multimedia/Klimatologie/physik_arbeit.htm

Noise and Interference

- If we assume just one transmission:
  - The only disturbing effect is the self-interference: the signal arrives in multiple paths (multi-path fading)
- More disturbing effects in practice:
  - **Noise** – due to effects in receiver electronics, depends on temperature
    - Typical model: an additive Gaussian variable, mean 0, no correlation in time
  - **Interference** – from third parties
    - Co-channel interference: another sender uses the same spectrum
    - Adjacent-channel interference: another sender uses some other part of the radio spectrum, but receiver filters are not good enough to fully suppress it

- Received signal is distorted by channel, corrupted by noise and interference

Signal to Interference and Noise Ratio (SINR)

- Receiving-power = Transmission-power · path-loss
  - path loss ~ $1/r^{\beta}$
  - $\beta \in [2,5]$
- Signal to Interference + Noise Ratio = SINR
  - S = receiving power from desired sender
  - I = receiving power from interfering senders
  - N = other interfering signals (e.g. noise)
- Necessary for recognizing the signal:

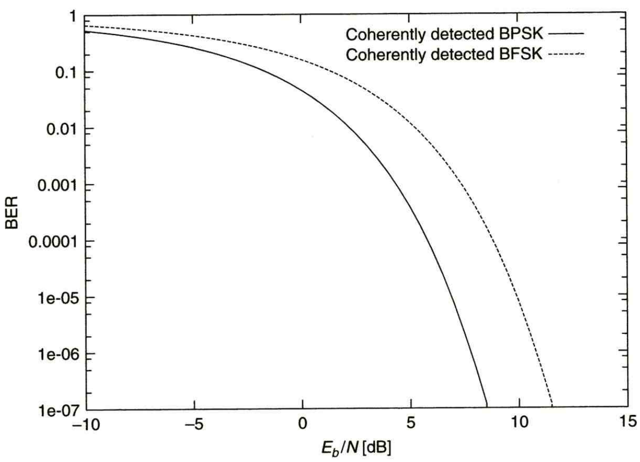
$$SINR = {}''\frac{S}{I+N}'' \geq {}''\, Threshold$$

Symbols and Bit Errors

- Extracting symbols out of a distorted/corrupted waves can cause errors
  - Depends essentially on strength of the received signal compared to the corruption
  - Captured by **signal to noise and interference ratio (SINR)** given in decibel***:***

$$SINR = {}''\, 10\log_{10}\left(\frac{P_{recv}}{N_0 + \sum_{i=1}^{k} I_i}\right)$$

- SINR allows to compute **bit error rate** (**BER**) for a given modulation
  - Also depends on data rate (# bits/symbol) of modulation



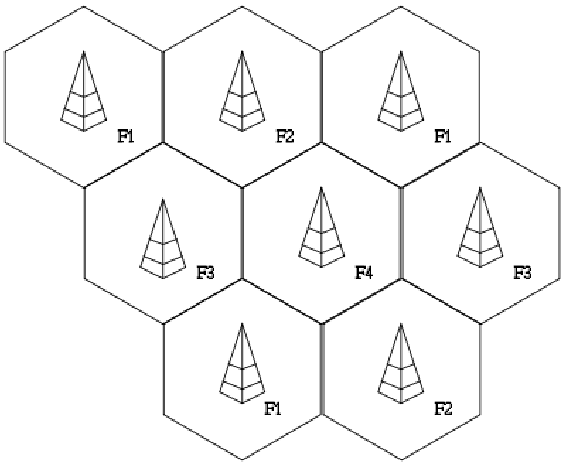
Bit error rate for coherently detected binary PSK and FSK

Sharing the Medium

- Space-Multiplexing
  - Spatial distance
  - Directed antennae
- Frequency-Multiplexing
  - Assign different frequencies to the senders
- Time-Multiplexing
  - Use time slots for each sender
- Spread-spectrum communication
  - Direct Sequence Spread Spectrum (DSSS)
  - Frequency Hopping Spread Spectrum (FHSS)
- Code Division Multiplex

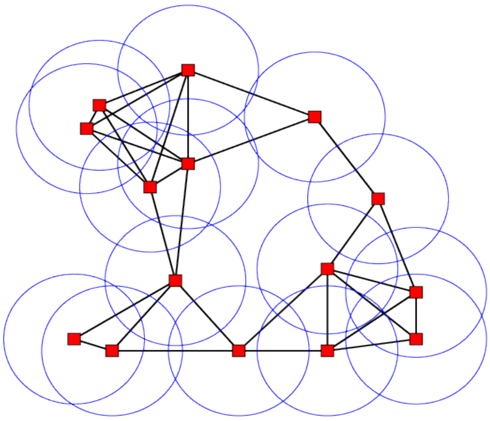
Space Division Multiple Access in Cellular Networks

- Mobiles use closest base station
  - In an ideal situation it leads to a Voronoi diagram
- Directional antennae
  - Divide the area of each base station in smaller subsets
- Power Control
  - E.g. UMTS networks „breathe“,
  - i.e. base stations with large number of participants reduce the sending power
  - So, neighbored base stations can take over some of the mobile nodes of the overcrowded base station



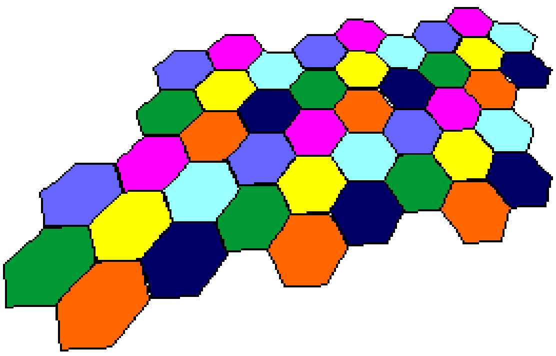
Space Division Multiple Access in MANET

- Power Control of the sender
  - Possible use of multiple sending power
    - decreases the chance of interferences
    - Increases the maximum throughput for ad-hoc-networks
    - decreases the energy consumption
  - Possible to temporarily switching off
    - decreases energy consumption
- Directional Antenna
  - Increase the maximum throughput
  - Decrease energy consumption
  - Problematic for Medium Access



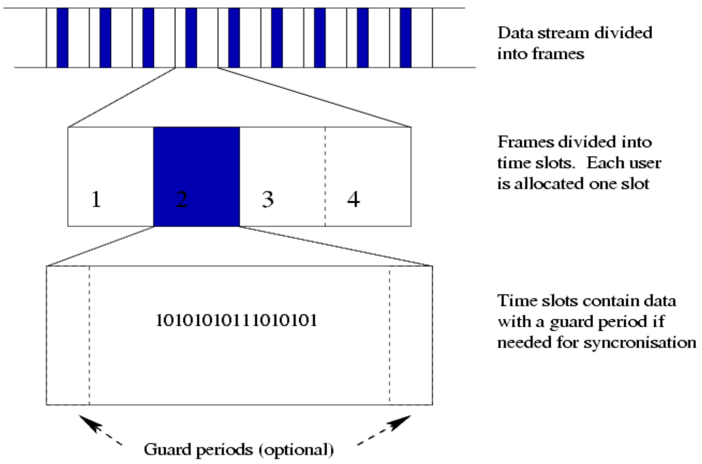
Frequency Division Multiple Access (FDMA)

- Neighbored links or cells are using different frequencies
  - with sufficient distance
- Used in cellular networks like
  - GSM, UMTS
- Allocation
  - is a combinatorically hard problem (coloring problem - NP-hard)
  - static allocation for cellular networks
  - dynamic allocation necessary for mobile ad-hoc networks



Time Division Multiple Access (TDMA)

- Time slots are assigned to the participants
- Static or flexible assignment
- Features:
  - Single frequency can be shared with multiple users
  - Slots can be assigned on demand
- Used in
  - GSM, GPRS, UMTS,...



wikipedia.com

Spread-Spectrum Communication: DSSS

- Direct Sequence Spread Spectrum (DSSS)
  - Transmitted signal takes up more bandwidth (frequencies)
  - It „spreads“ over the full „spectrum“ of frequencies
- Originally intended for military use to „jam“ all frequencies
- Phase Modulation with a pseudo-random code symbols
  - Collection of symbols, called chip, encode a bit

Direct Sequence Spread Spectrum

- A Chip is a sequence of bits (given by {-1, +1}) encoding a smaller set of symbols
  - E.g. Transform signal: 0 = (+1,+1,-1), 1=(-1,-1,+1)

    0 1

    +1 +1 -1 -1 -1 +1
- Decoding (Despreading):
  - Compute inner product for bits c_i of the received signals s_i and the chips $c_0 = -c_1$:

$$\sum_{i=1}^{m} c_{0,i} s_i \qquad \sum_{i=1}^{m} c_{1,i} s_i$$

  - When an overlay of the same, yet shifted, signals is received then the signal can be deconstructed by applying dedicated filters
- DSSS is used by GPS, WLAN, UMTS, ZigBee, Wireless USB based on an
  - Barker Code (11Bit): +1 +1 +1 −1 −1 −1 +1 −1 −1 +1 −1
  - For all v<m

$$\left| \sum_{i=1}^{m} a_j a_{j+v} \right| \leq 1$$

Code Division Multiple Access (CDMA)

- Use chip sequence such that each sender i has a different chip C_i with
  - $C_i \in \{-1,+1\}^m$
  - $-C_i = (-C_{i,1}, -C_{i,2}, \ldots, -C_{i,m})$
- For all i≠j the normalized scalar product is 0:

$$C_i \cdot C_j =" \frac{1}{m} C_i (C_j)^T = \frac{1}{m} \sum_{k=1}^{m} C_{i,k} C_{j,k} = 0.$$

- Sender i encodes bit 1 as C_i and bit 0 as $-C_i$.
- Assuming synchronized transmission, the receiver hears a linear combination of the senders transmissions.
- By multiplying with proper chip it can decode the message.

CDMA (example)

- Example:
  - chip C_X = (+1,+1,+1,+1)
  - chip C_Y = (+1,+1,-1,-1)
  - chip C_Z = (+1,-1,+1,-1)
- X sends 1, Y sends 0, Z sends nothing:
  - $V = C_X + (-C_Y) = (0,0,2,2)$
- Decoding with the chip of X: $V \bullet C_X = (0,0,2,2) \bullet (+1,+1,+1,+1) = 4/4 = 1$
  - Result: bit 1
- Decoding with the chip of Y: $V \bullet C_Y = (0,0,2,2) \bullet (+1,+1,-1,-1) = -4/4 = -1$
  - Result: bit 0
- Decoding with the chip of Z: $V \bullet C_Z = (0,0,2,2) \bullet (+1,-1,+1,-1) = 0$
  - Result: no signal.

References

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- Andrew S. Tanenbaum: Computer Networks**.** *4th edition, Prentice Hall*, 2003.
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