Mobile Ad Hoc Networks

1st Week

17.04.-20.04.2007

CoNe Freiburg

University of Freiburg
Computer Networks and Telematics
Prof. Christian Schindelhauer

Christian Schindelhauer
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Organization

- **Web-page**
  - `http://cone.informatik.uni-freiburg.de/teaching/vorlesung/manet-s07/`
- **Lectures**
  - Wednesday, 11 am- 1 pm, c.t. SR 01-016, Building 101
  - Friday, 11 am-12 am, c.t. SR 01-018, Building 101
- **Exercise class**
  - Friday, 11 am-12 am, s.t. SR 01-018, Building 101
  - Start: 27.04.2007
  - Tutors:
    - Chia-Ching Ooi (ooi (at) informatik.uni-freiburg.de)
    - Faisal Aslam (asmal (at) informatik.uni-freiburg.de)
- **Exercises**
  - Appear every Friday on the Web page
  - Solved by the students
  - Solution are discussed and presented by the students during the exercise class

Organization

- **Exam**
  - Under 15 participants: oral exams
  - More than 16 participants: written exam
- **Time**
  - Oral: ask for an appointment on 25.07.2007
  - Written exam, if any: 25.07.2007, 2pm
- **Materials**
  - Powerpoint/PDF slides
    - one day before the lecture on the web-page
  - Lecturnity videos
    - one day beore the lecture on the web-page
  - Literature
    - presented during this lecture

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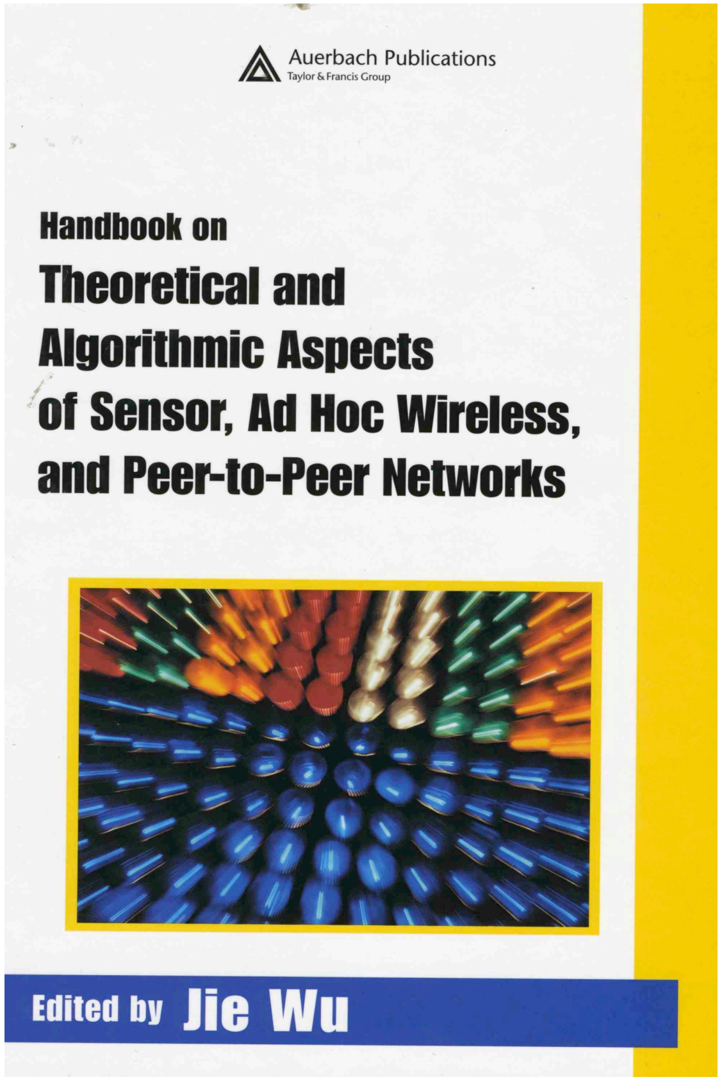
Topics of the Lecture

1. Organization and Literature
2. Introduction
3. Physical Layer
4. Topology Control & MAC Layer
5. Routing
6. Mobility, Deployment & Coverage
7. Transport Layer
8. Theory and Algorithms
9. Recent Advances & Future Challenges

Literature I

- **Editor: Jie Wu**
  - *Handbook on Theoretical and Algorithmic Aspects of Sensor, Ad Hoc Networks and Peer-to-Per Networks*
  - Auerbach, 2005

- **Collection of works written by experts**



Literature II

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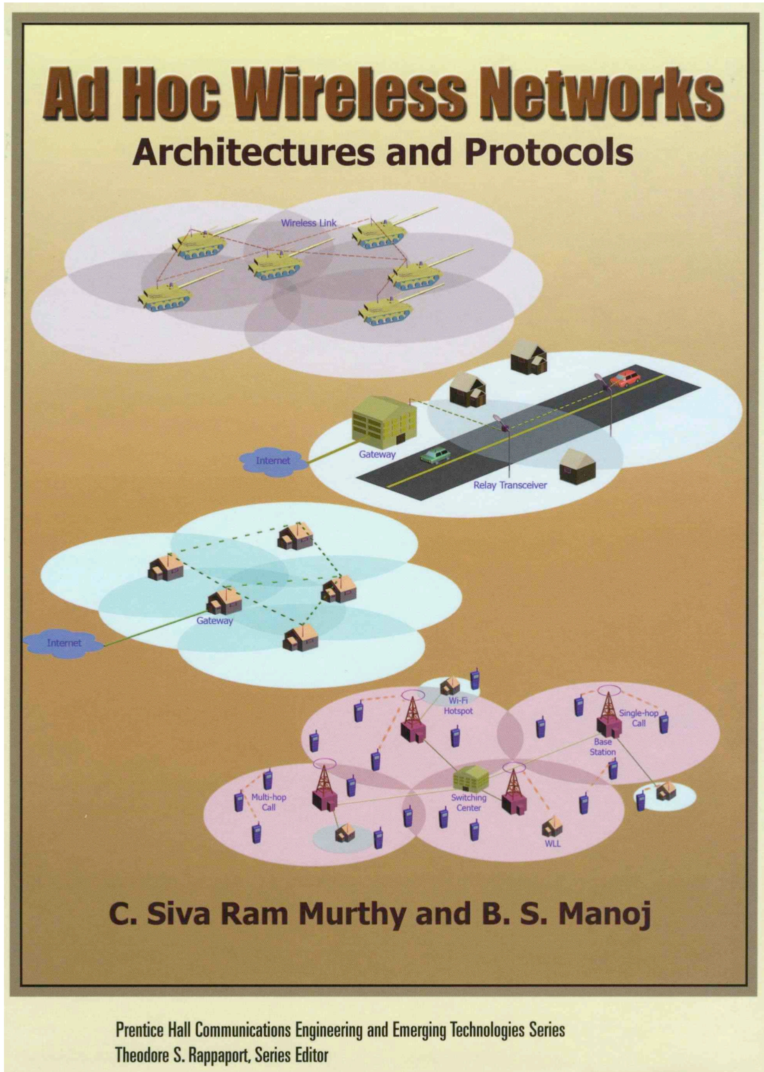
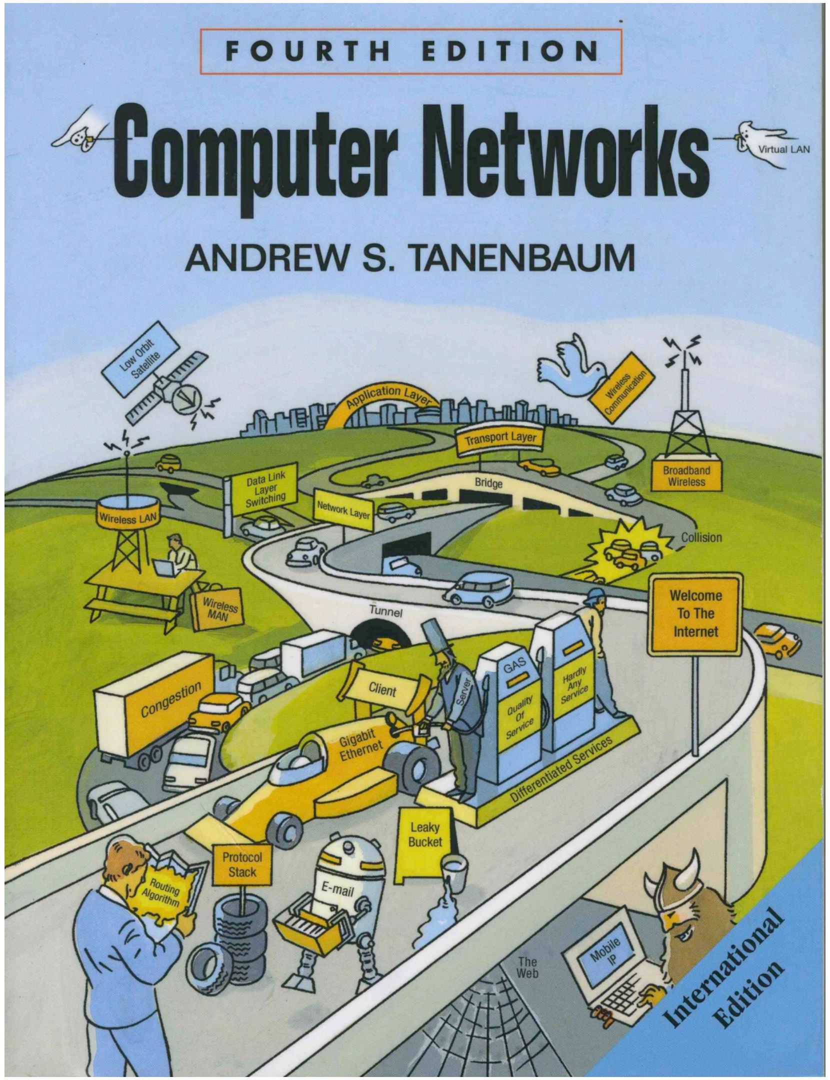
- **Murthy and Manoj**
  - *Ad Hoc Wireless Networks, Architectures and Protocols*
  - Pearson/Prentice Hall, 2004
- **Comprehensive Monography on Ad hoc Wireless Networking**
- **Recommended as one book covering early all aspects of wireless communication**
  - 802.3, 802.11, HiperLAN, GSM, ATM, WATM, MobileIP, MANET, MAC for Wireless, Routing and Multicast Routing in MANETs, Transport layer, QoS, Energy Management, Sensor Networks, Hybrid Networks



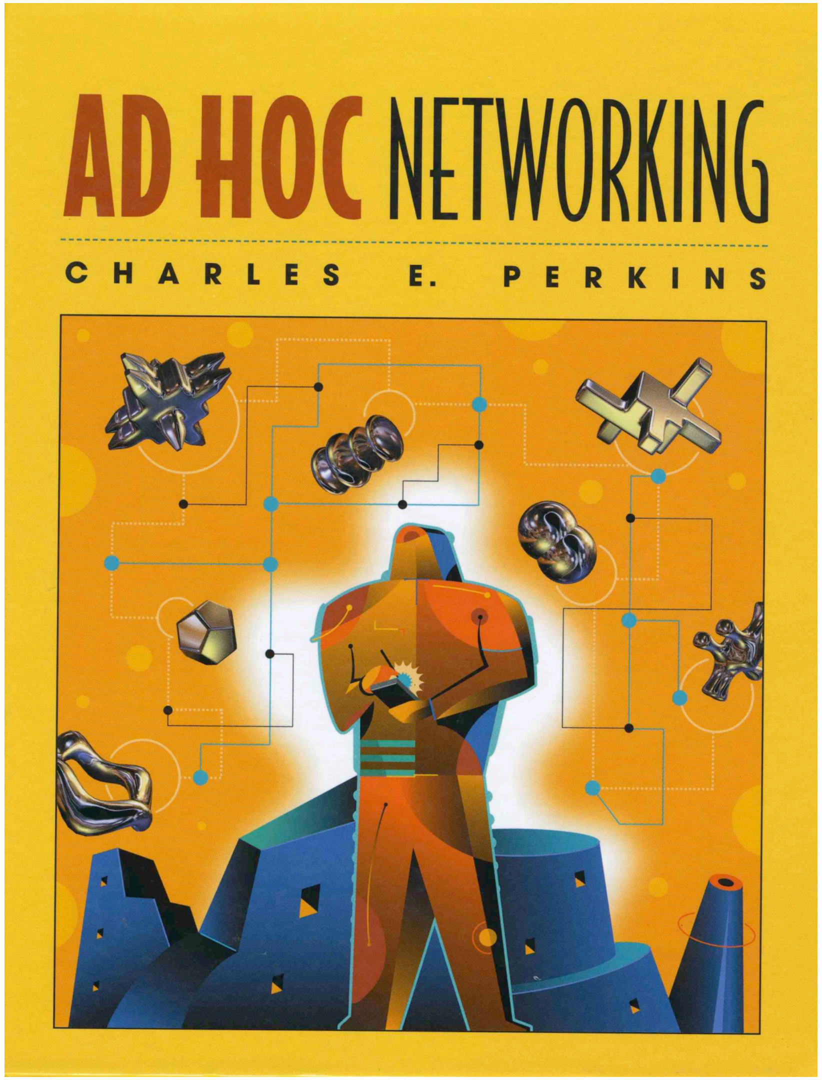
Literature III

- **Andrew S. Tanenbaum**
  - *Computer Networks*
  - Pearson Education International
- **Introduction to Computer Networks**
  - Not a book for mobile ad hoc networks
  - But a book for someone who wants to learn the essentials of computer networks
    - Read it if you haven't visited "Systeme II"



Literature IV

- **Charles E. Perkins**
  - *Ad Hoc Networking*
  - Addison-Wesley 2001
- **Classic book**
  - yet a little outdated
- **Topics:**
  - mainly routing algorithms, like DSDV, Cluster-based Routing, DSR, AODV, ZRP, Link Reversal



Types of Networks

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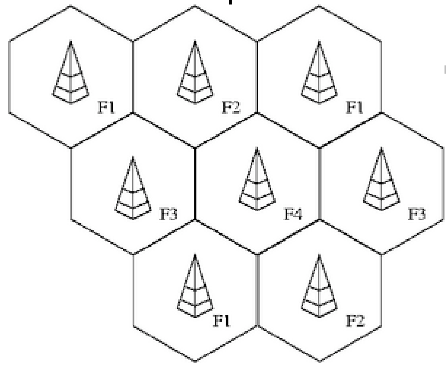
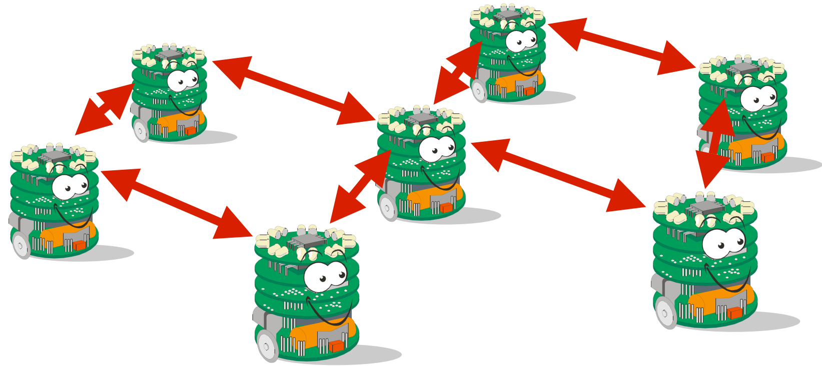
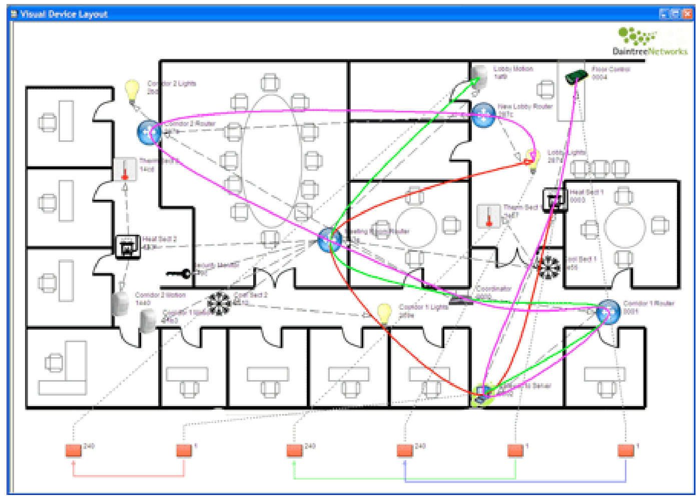
- **Cellular Networks**
  - base stations distributed over the field
  - each base station covers a cell
  - used for mobile phones
  - WLAN can be seen as a special case
- **Mobile Ad Hoc Networks**
  - self-configuring network of mobile nodes
  - node serve as client and router
  - no infrastructure necessary
- **Sensor Networks**
  - network of sensor devices with controller and radio transceivers
  - base station with more resources







Applications of MANETs

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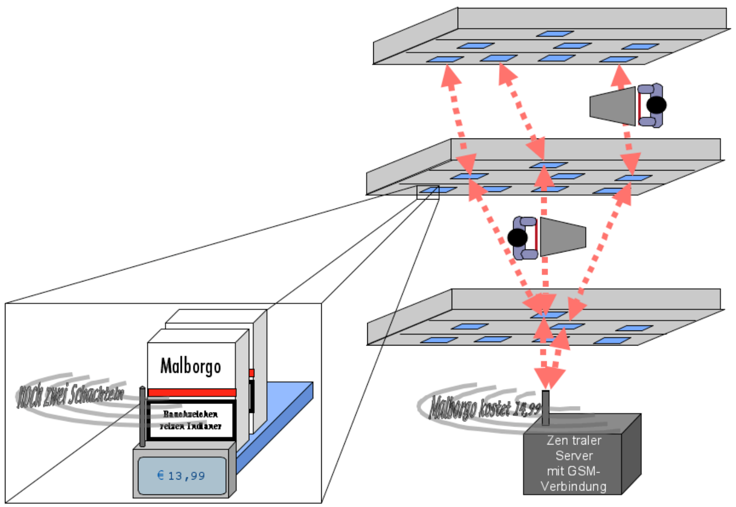
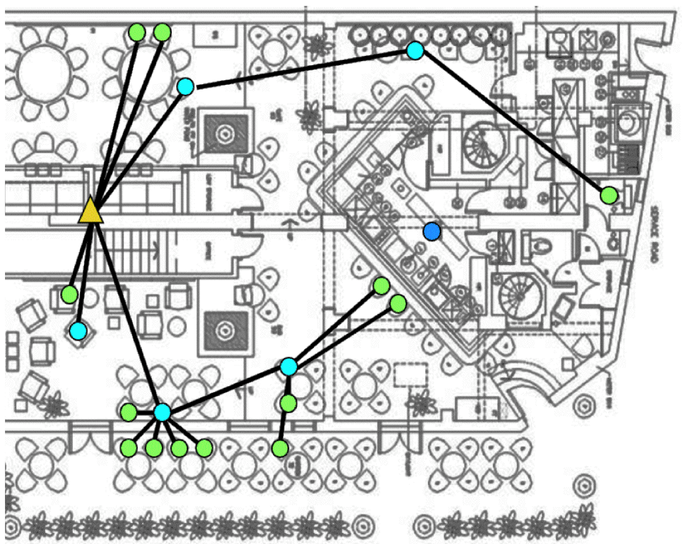
- **Network Failure**
- **Military**
- **Deserted Areas**
- **Entertainment**
  - Spontanous games
  - Dating-Tool
- **Sensor networks**
  - Environmental control
  - Intelligent Home
  - Supermarket
- **Car technology**
  - Inter-car communication
  - Car coordination
- **WLAN hotspot extension**





ISO/OSI Reference model

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7. Application
- Data transfer, E-Mail, Terminal, Remote login

6. Presentation
- System dependent presentation of data (EBCDIC/ASCII)

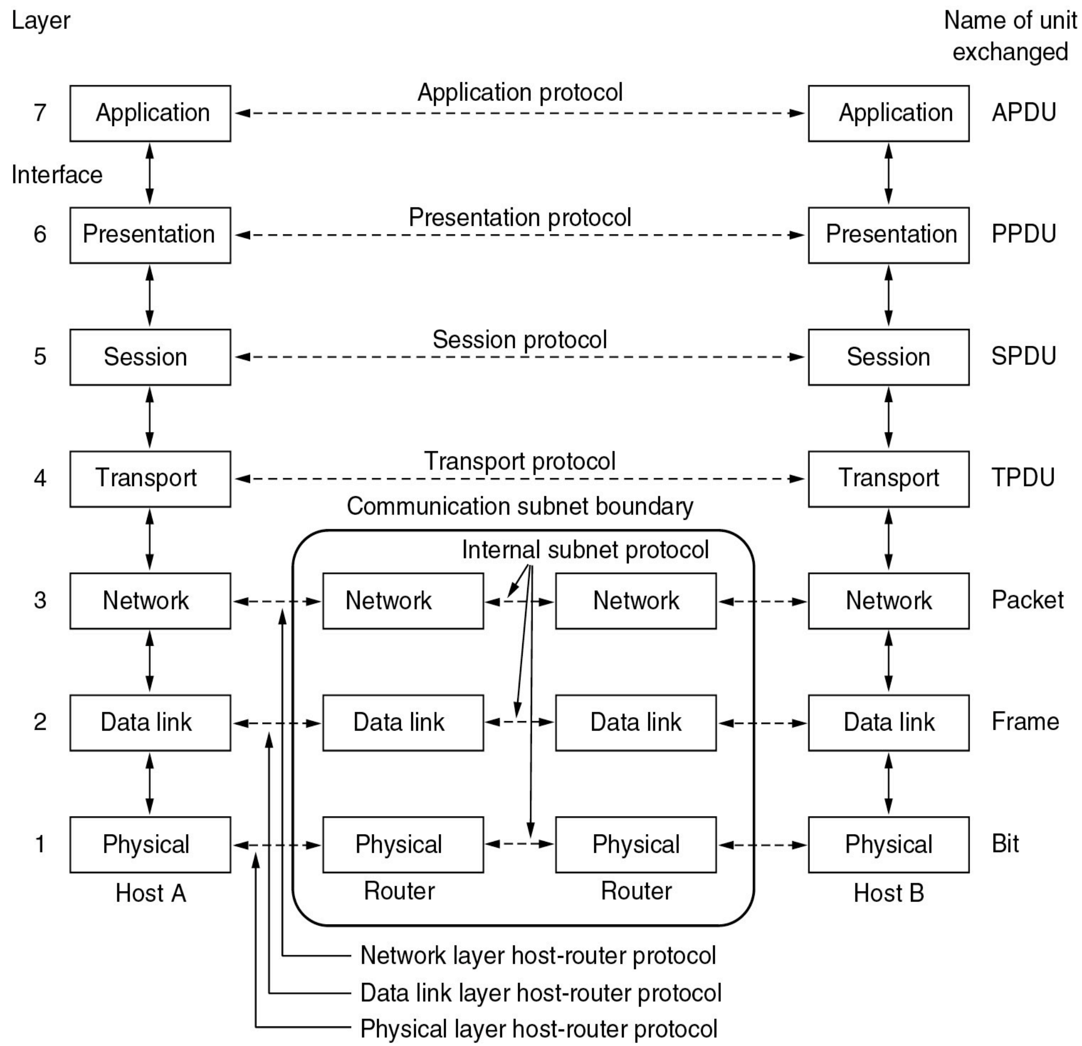
5. Session
- Begin, end, return points

4. Transport
- Segmentation, congestion avoidance

3. Network
- Routing

2. Data link
- Checksum, flow control

1. Physical layer
- Mechanical, electric methods



Comparison Internet Layers

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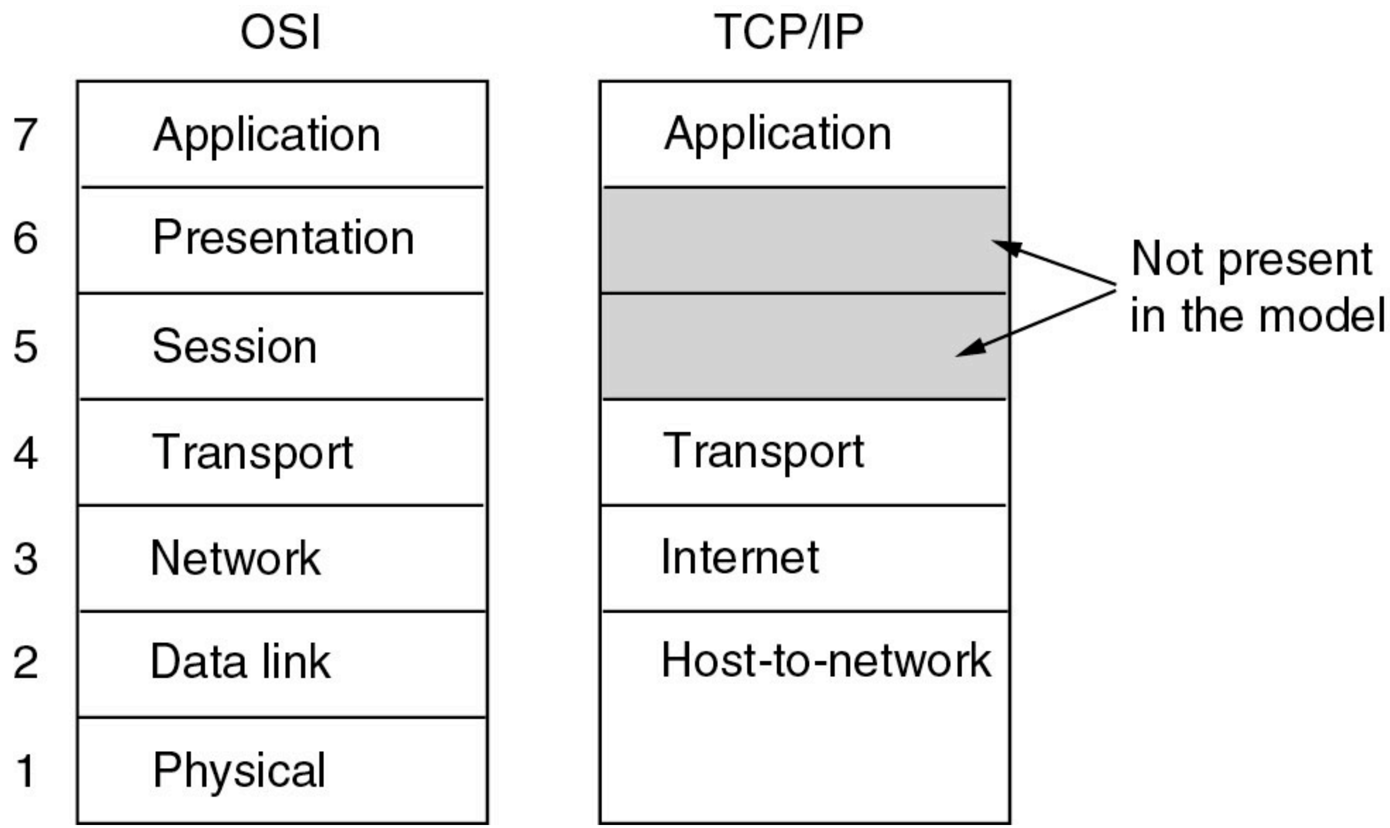


Physics of Electro-magnetic Waves

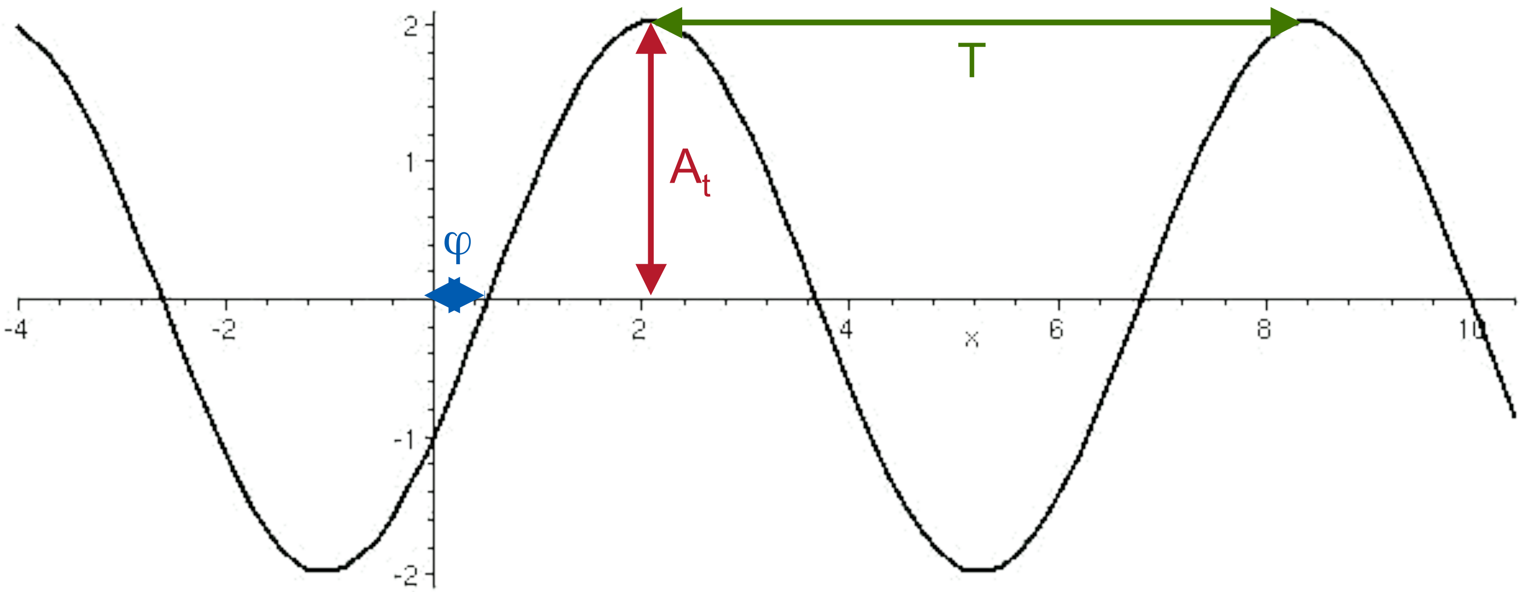
- Frequency f: number of oscillations per second
  - unit of measurement : **Hertz**
  - **wave length λ:** distance (in meters) between wave maxima
  - The propagation speed of waves in vacuum is constant:
  - **speed of light $c \approx 3 \cdot 10^8$ m/s**

- 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



Fourier Transformation

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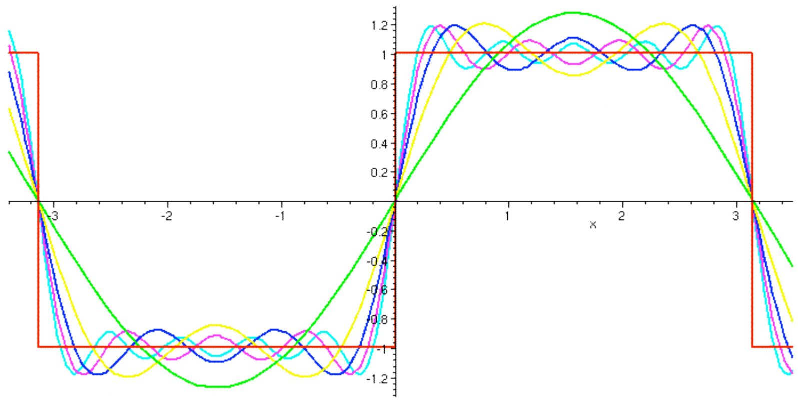
- **Fourier transformation of a periodic function:**
  - Decomposition into sinus curves



- **Dirichlet‘s conditions for a periodic function:**
  - f(x) = f(x+2π)
  - f(x) is continuous and monotone in finitely many intervals of (-π,π)
  - If is non-coninuous in x_0, then $f(x_0)=(f(x_0-0)+f(x_0+0))/2$
- **Theorem of Dirichlet:**
  - f(x) satisfies Dirichlet‘s conditions . Then the Fourier coefficients $a_0,a_1,a_2,\ldots,b_1,b_2,\ldots$ exist such that:

$$\lim_{n\to\infty} \frac{a_0}{2} + \sum_{k=1}^{n} a_k \cos kx + b_k \sin kx = f(x) \ .$$

Computation of Fourier coefficients

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- **Fourier coeffizients a_i, b_i can be computed as follows**
  - For k = 0,1,2,…

$$a_k = \frac{1}{\pi}\int_{-\pi}^{\pi} f(x)\cos kx\ dx$$

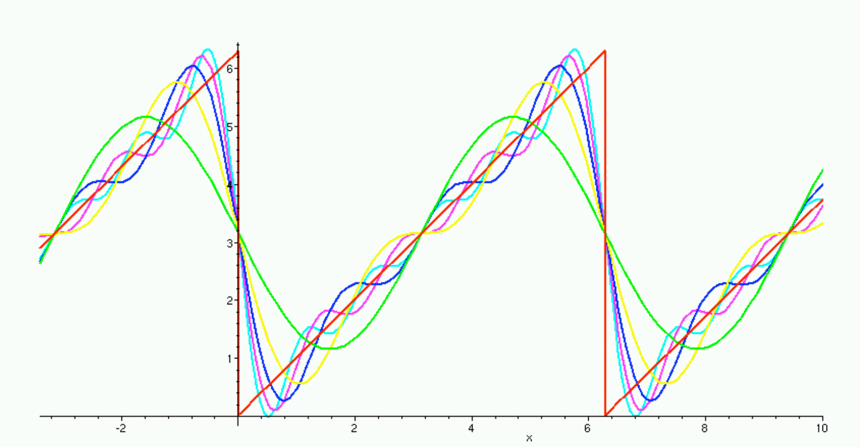
  - For k = 1,2,3,…

$$b_k = \frac{1}{\pi}\int_{-\pi}^{\pi} f(x)\sin kx\ dx$$

- **Example: saw tooth curve**

$f(x) = x$, für $0 < x < 2\pi$

$$f(x) = \pi - 2\left(\frac{\sin x}{1} + \frac{\sin 2x}{2} + \frac{\sin 3x}{3} + \dots\right)$$



Fourier-Analysis

- **Theorem of Fourier for period T=1/f:**
  - The coefficients *c*, a_n, b_n can be computed as follows

$$g(t) = \frac{a_0}{2} + \sum_{k=1}^{\infty} a_k \cos(2\pi k f t) + b_k \sin(2\pi k f t)$$

$$a_k = \frac{2}{T} \int_0^T g(t) \cos(2\pi n f t) dt$$

$$b_k = \frac{2}{T} \int_0^T g(t) \sin(2\pi n f t) dt$$

- **The square of the sum of the k-th terms is proportional to the energy in this frequency** $(a_k)^2 + (b_k)^2$

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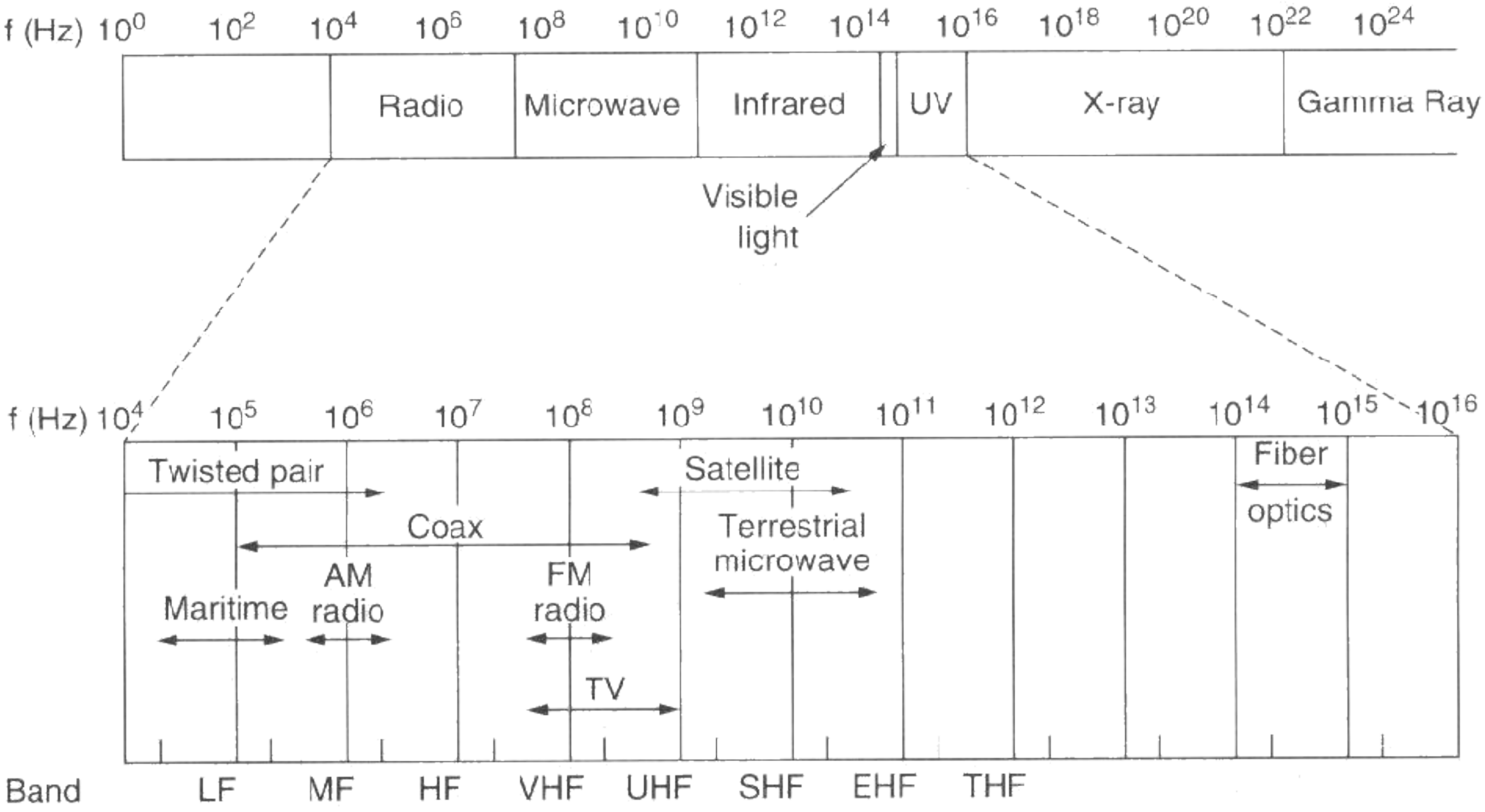
Frequency Bands



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

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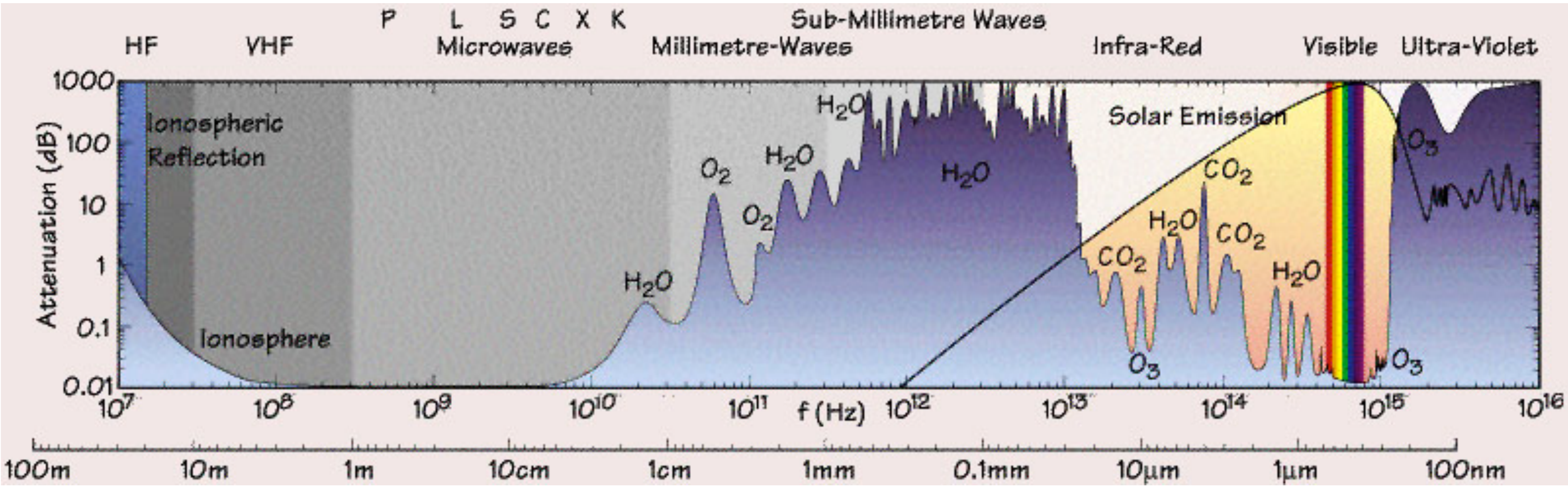
Suitability of different frequencies – Attenuation

- **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

Radio Propagation

- **VLF, LF, MF**
  - follow the curvature of the globe (up zu 1000 kms in VLF)
  - pass through buildings
- **HF, VHF**
  - absorbed by earth
  - reflected by ionosphere in a height of 100-500 km
- **>100 MHz**
  - No passing through walls
  - Good focus
- **> 8 GHz absorption by rain**

Radio Propagation

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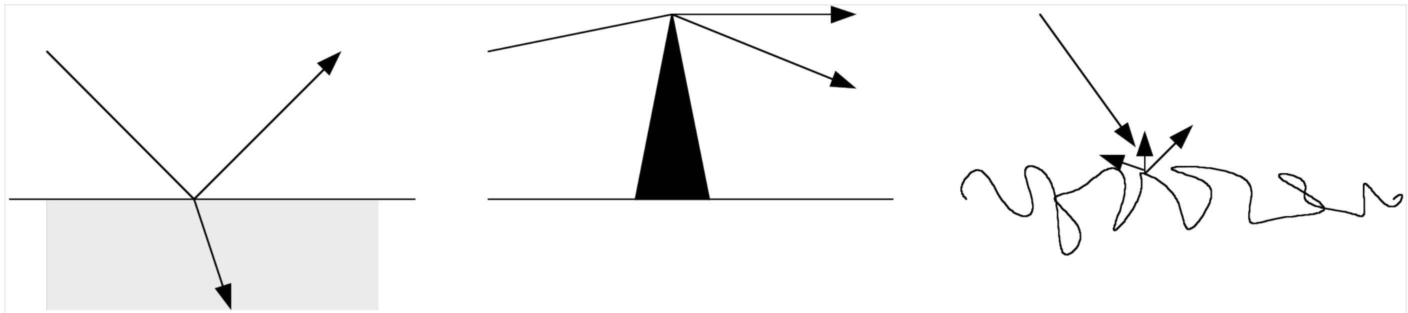
- **Multiple Path Fading**
  - Because of reflection, diffraction and diffusion the signal arrives on multiple paths
  - Phase shifts because of different path length causes interferences

- **Problems with mobile nodes**
  - Fast Fading
    - Different transmission paths
    - Different phase shifts
  - Slow Fading
    - Increasing or decreasing the distance between sender and receiver

Radio Propagation

- **Propagation on straight line**
- **Signal strength is proportional to $1/d^2$ in free space**
  - In practice can be modeled by $1/d^c$, for c up to 4 or 5
- **Energy consumption**
  - for transmitting a radio signal over distance d in empty space is d^2
- **Basic properties**
  - Reflection, Refraction (between media with slower speed of propagation)
  - Interference
  - Diffraction
  - Attenuation in air (especially HV, VHF)
  - Scattering – multiple reflections at rough surfaces
  - Doppler fading – shift in frequencies (loss of center)



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Path loss exponents

- **Some example measurements**
  - γ path loss exponent
  - Shadowing variance σ^2
  - Reference path loss at 1 m

Location	Average of γ	Average of σ^2[dB]	Range of PL(1m)[dB]
Engineering Building	1.9	5.7	$[-50.5, -39.0]$
Apartment Hallway	2.0	8.0	$[-38.2, -35.0]$
Parking Structure	3.0	7.9	$[-36.0, -32.7]$
One-sided Corridor	1.9	8.0	$[-44.2, -33.5]$
One-sided patio	3.2	3.7	$[-39.0, -34.2]$
Concrete canyon	2.7	10.2	$[-48.7, -44.0]$
Plant fence	4.9	9.4	$[-38.2, -34.5]$
Small boulders	3.5	12.8	$[-41.5, -37.2]$
Sandy flat beach	4.2	4.0	$[-40.8, -37.5]$
Dense bamboo	5.0	11.6	$[-38.2, -35.2]$
Dry tall underbrush	3.6	8.4	$[-36.4, -33.2]$

Modulation (keying!) examples

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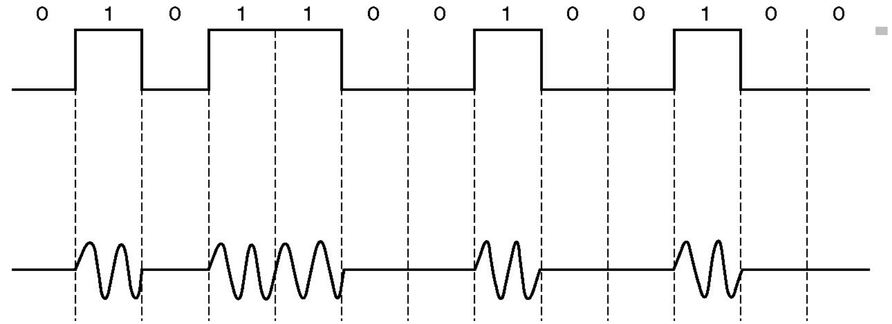
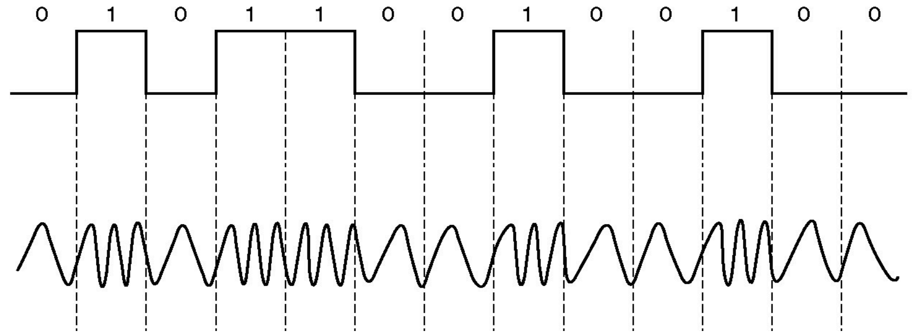
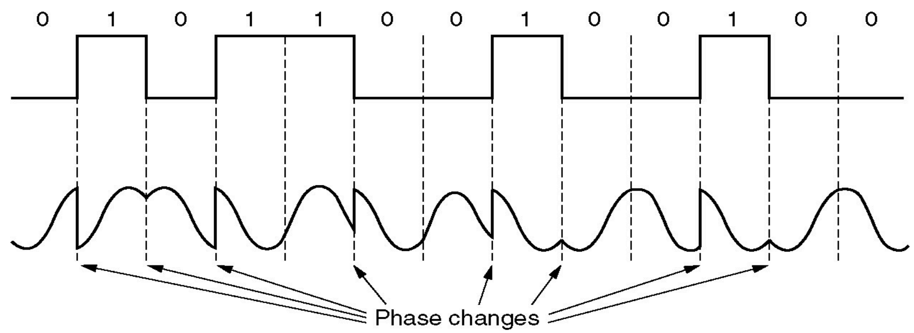
- **Use data to modify the amplitude of a carrier frequency**
  → *Amplitude Shift Keying*



- **Use data to modify the** *frequency* **of a carrier frequency**
  → *Frequency Shift Keying*



- **Use data to modify the** *phase* **of a carrier frequency**
  → *Phase Shift Keying*



Amplitude Shift Keying (ASK)

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- **Let $E_i(t)$ be the symbol energy at time t**

$$s_i(t) = \sqrt{\frac{2E_i(t)}{T}} \cdot \sin(\omega_0 t + \phi)$$

- **The first term is a convention such that E_i denotes the energy**
- **Example: $E_0(t) = 1$, $E_1(t)=2$ for all t**

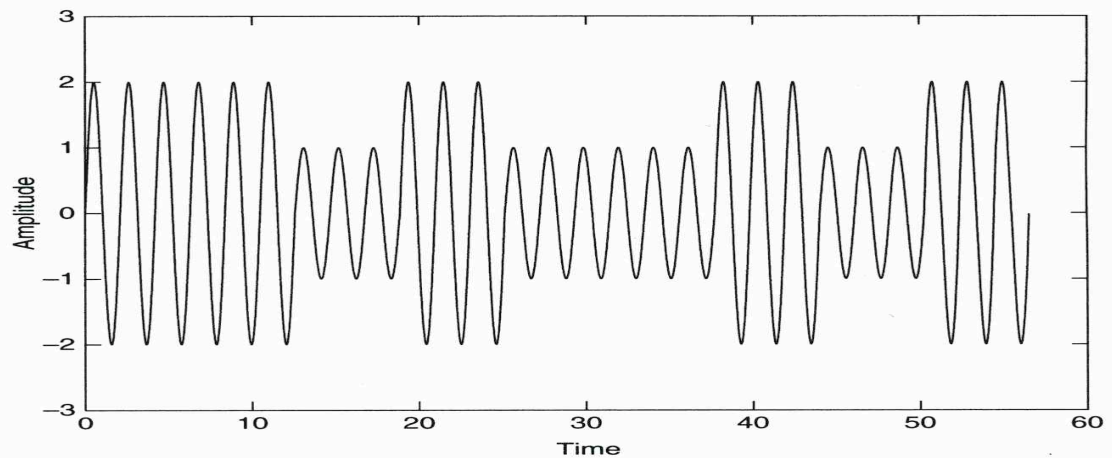

Figure 4.2 Amplitude shift keying (ASK) example

Phase Shift Keying (PSK)

- **For phase signals $\phi_i(t)$**

$$s_i(t) = \sqrt{\frac{2E}{T}} \cdot \sin(\omega_0 t + \phi_i(t))$$

- **Example:**

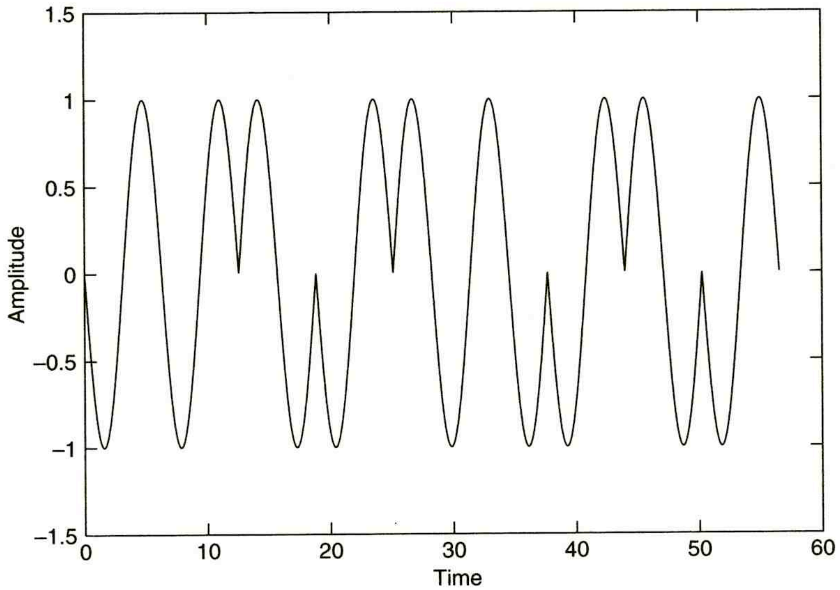

Figure 4.3 Phase shift keying (PSK) example

Frequency Shift Keying (FSK)

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- **For frequency signals $\omega_i(t)$**

$$s_i(t) = \sqrt{\frac{2E}{T}} \cdot \sin(\omega_i(t) \cdot t + \phi)$$

- **Example:**

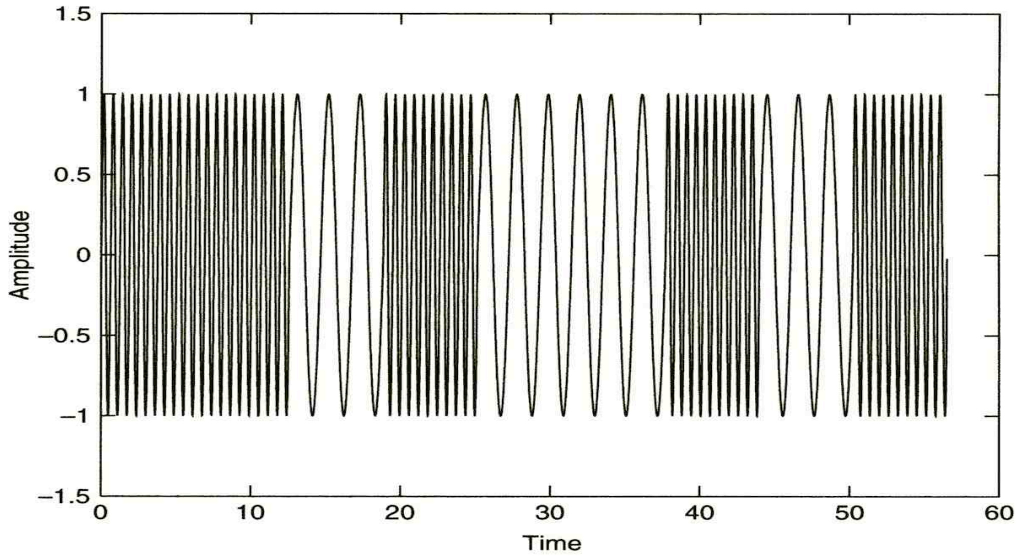

Figure 4.4 Frequency shift keying (FSK) example

Signal Interference Noise Ratio

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- **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:**

$$\text{SINR} = \frac{S}{I+N} \geq \mathrm{T}\mathit{hreshold}$$

Attenuation results in path loss

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- **Effect of attenuation: received signal strength is a function of the distance *d* between sender and transmitter**
- **Captured by** *Friis free-space equation*
  - Distance: R
  - Wavelength: λ
  - P_r: power at receive antenna
  - P_t: power at transmit antenna
  - G_t: transmit antenna gain
  - G_r: receive antenna gain

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi R} \right)^2$$

$$P_r(d) = P_r(d_0) \cdot \left(\frac{d_0}{d} \right)^2$$

Symbols and bit errors

- **Extracting symbols out of a distorted/corrupted wave form is fraught with 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:***

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

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

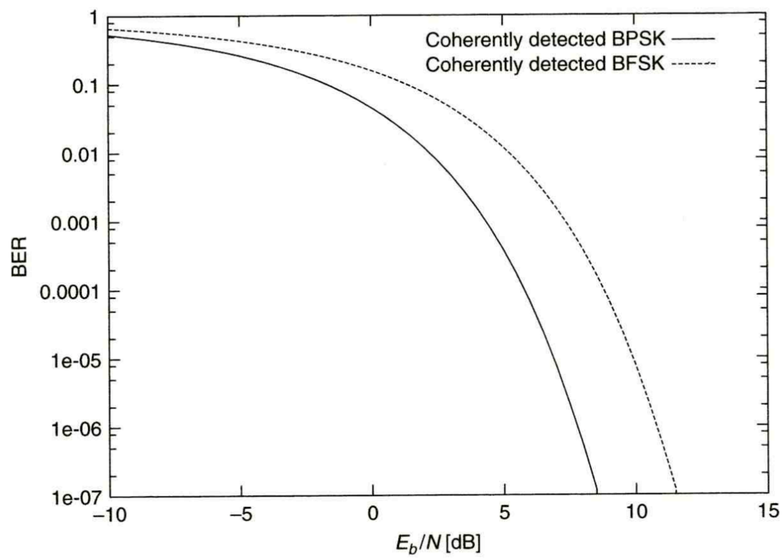

Figure 4.7 Bit error rate for coherently detected binary PSK and FSK

Wireless signal strength in a multi-path environment

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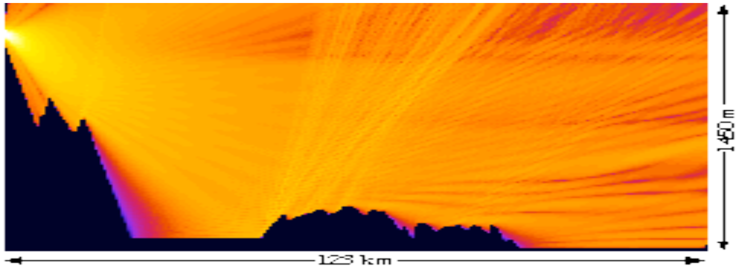
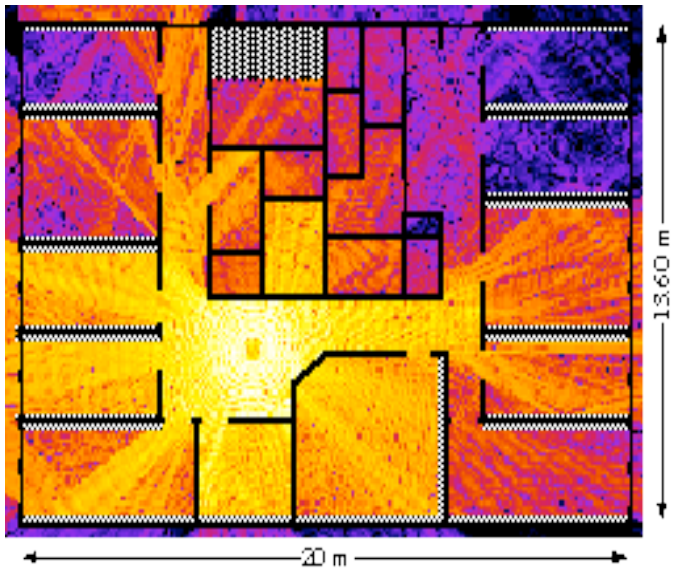
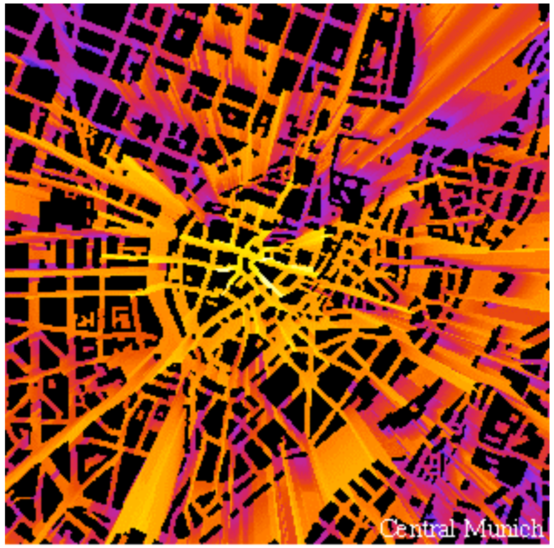
- Brighter color = stronger signal
- Obviously, simple (quadratic) free space attenuation formula is not sufficient to capture these effects







Noise and interference

- **So far: only a single transmitter assumed**
  - Only disturbance: self-interference of a signal with multi-path “copies” of itself
- **In reality, two further disturbances**
  - ***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
- **Effect:**
  - Received signal is distorted by channel, corrupted by noise and interference

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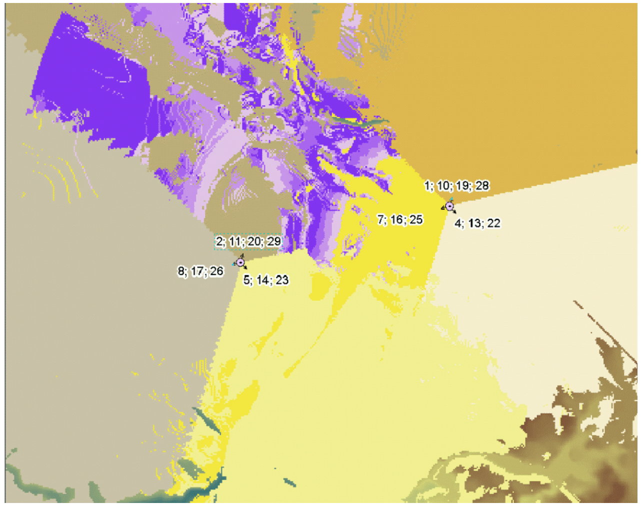
Sharing the Medium

- **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**



Thank you!

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