Physical + Link Layers

Sensor Networks

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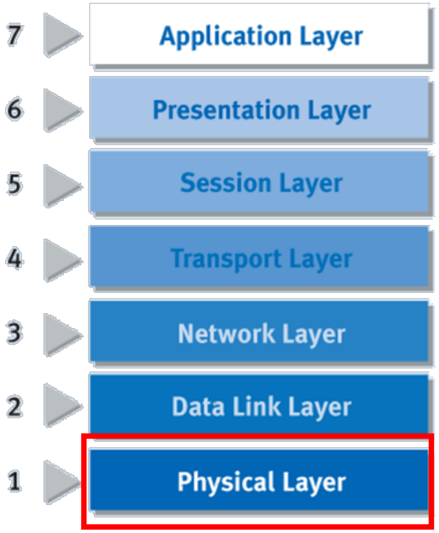
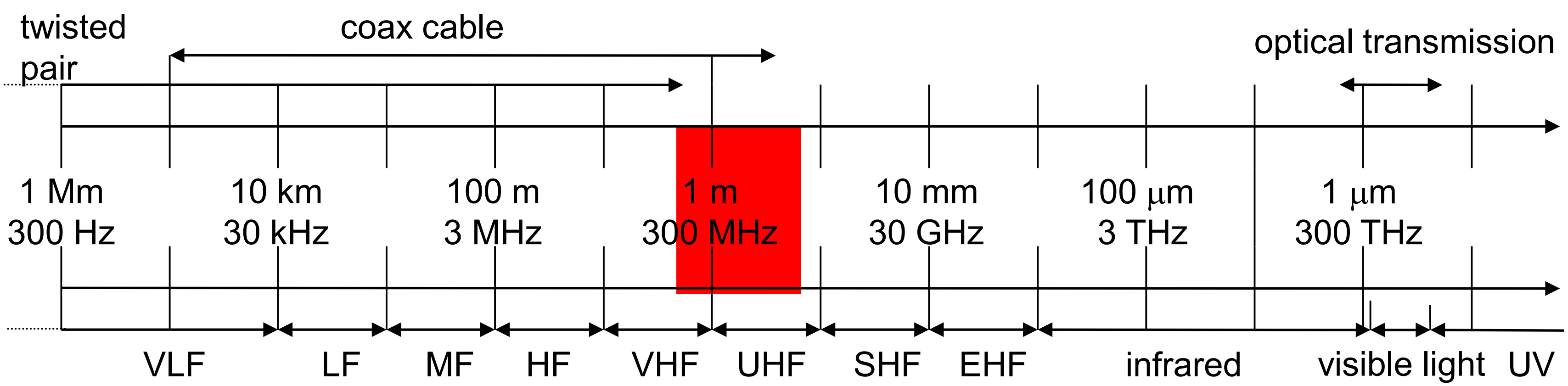
Physical Layer

- Radio-based wireless communication
  - Transmission of bits using radio
  - Layer 1 in ISO OSI model
- Not focus of this lecture, but summary of important aspects
  - Important for medium access control



Frequencies

- Properties are a function of frequency
  - Penetration, attenuation (walls, ice, air, ...)
  - Reflection
  - Energy consumption
  - Antennas (size, complexity, ...)



VLF = Very Low Frequency
LF = Low Frequency
MF = Medium Frequency
HF = High Frequency
VHF = Very High Frequency

UHF = Ultra High Frequency
SHF = Super High Frequency
EHF = Extra High Frequency
UV = Ultraviolet Light

License-Free Frequencies

- Frequencies are assigned to applications
  - Usually a license is needed
- License-free bands most relevant for sensor networks
  - ISM: Industrial, Scientific, Medical

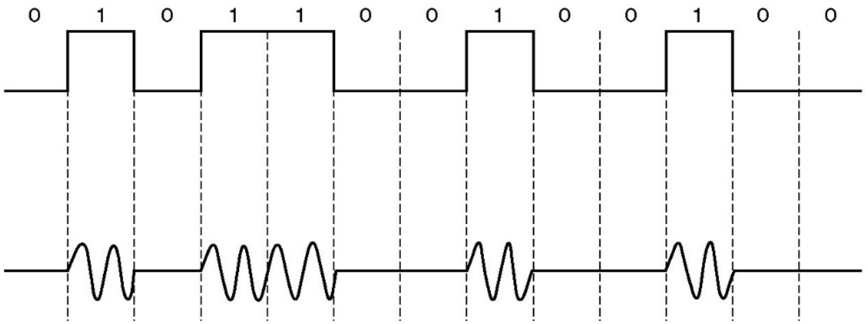
Some typical ISM bands	
Frequency	Comment
13,553-13,567 MHz	
26,957 – 27,283 MHz	
40,66 – 40,70 MHz	
433 – 464 MHz	Europe
863 – 870 MHz	SRD
900 – 928 MHz	America
2,4 – 2,5 GHz	WLAN/WPAN
5,725 – 5,875 GHz	WLAN
24 – 24,25 GHz	

Modulation

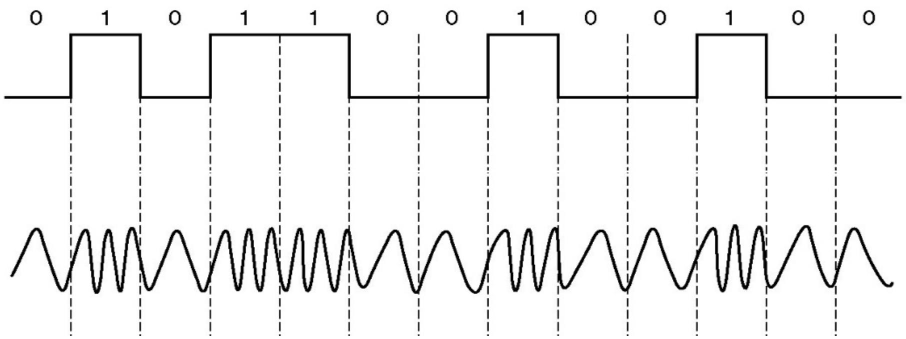
- Transmission of information (Bits) using an EM wave
  - Presence of EM wave (carrier)
  - Parameters (amplitude, phase, frequency)
- Modulation: encoding bits onto EM wave
  - Different variants to change above parameters over time
  - Bandwidth, robustness, ...
- Modulation vs. keying
  - Modulation: arbitrary parameter values
  - Keying: finite „alphabet“ of parameters values

Modulation

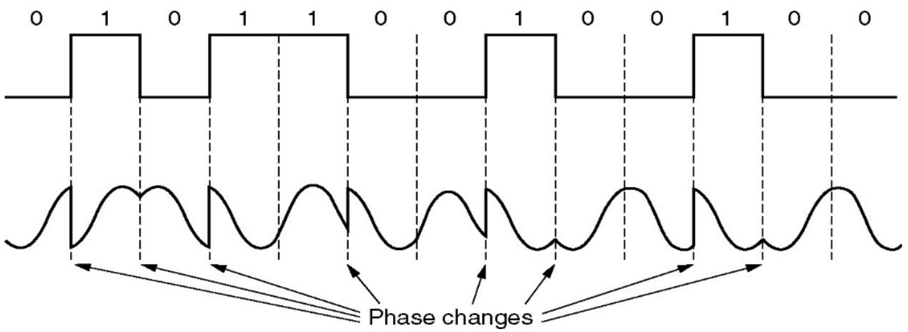
- ASK (Amplitude Shift Keying)
  - Change of carrier amplitude
  - Special case OOK (On-Off Keying)



- FSK (Frequency Shift Keying)
  - Change of carrier frequency



- PSK (Phase Shift Keying)
  - Change of carrier phase



Demodulation

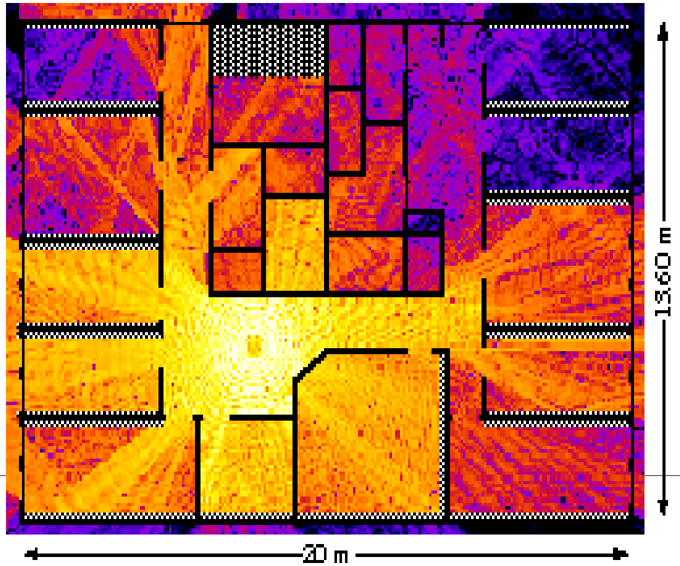
- Reconstruction of bit sequence from received EM wave
  - Sampling EM wave (amplitude) in receiver
- Problems
  - Received wave != transmitted wave
  - Synchronization
    - When do bit, byte, packet start?

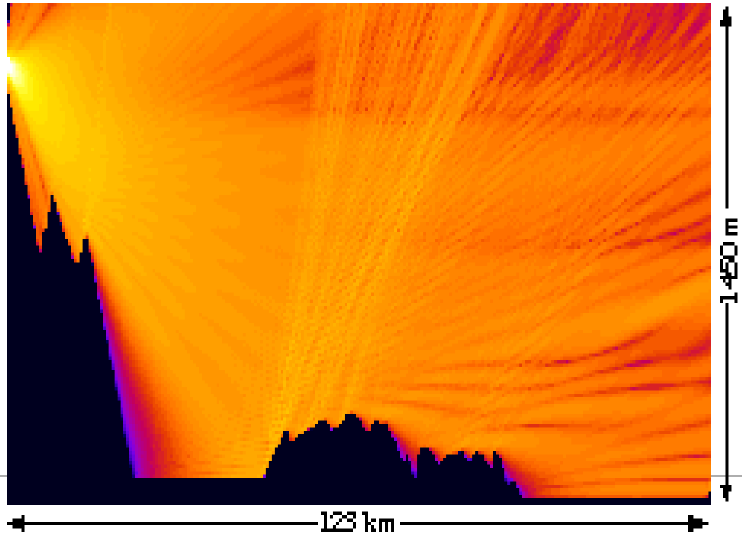
Distortion

- Received wave != transmitted wave
  - Attenuation – distribution of energy over increasing volume
  - Reflection, refraction, diffraction, scattering
- Impact
  - Communication without free line-of-sight
  - Constructive or destructive interference of multiple reflected and direct signals at receiver
  - Echoes: longer reflected paths

Received Signal Strength

- Amplitude of received wave
  - Function of channel and distance d from sender to receiver
  - Simplified model: $P_r = P_s K / d^n$
  - Typical values for path loss exponent n
    - Free space: 2
    - Close to ground: 4
    - Buildings: 2 ... 6, typically 2.5 ... 4 (smaller values for long corridors)





SNIR

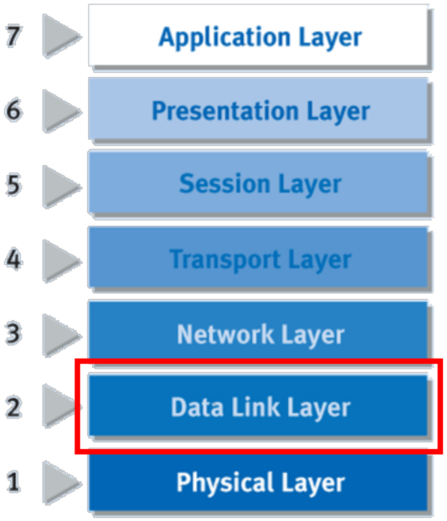
- P_{noise} – white noise generated by electronics
- P_{inf} – interference from other transmitters / technologies in range
- Signal-to-noise-and-interference-ratio (SNIR)
  - $SINR = P_r / (P_{noise} + P_{inf})$
- SNIR and modulation scheme define bit error rate (BER)
  - Fraction of incorrectly received bits
  - Typical value: 10^{-3} (10^{-2} ... 10^{-4})
  - BER ~ e^{-SNIR}

Synchronization

- Preambles
  - Bit stream before message starts, 0101010101010101 (typically very long!)
  - Allows detection of transmission vs. noise
  - Allows synchronization of transmitter and receiver

Link Layer

- Reliable transmission of bits over erroneous channel
  - Layer 2 in ISO OSI model
  - Also in this layer: medium access control (MAC), see next chapter
- Not focus of lecture, summary of important concepts



Error Control

- Mechanisms to detect and correct incorrect bits
- Option 1: Backward Error Control
  - Detect error and retransmit
- Option 2: Forward Error Control
  - Redundant coding to allow detection and correction of certain bit errors without retransmission

Backward Error Control

- Approach
  - Group bits into blocks, add check sum
  - Verify check sum, retransmit if incorrect
    - Positive ACKs: Acknowledge correct message, retransmit after timeout
    - Negative ACKs: Request retransmission after incorrect message
- Examples
  - Alternating bit protocol
  - Sliding window protocol

Forward Error Control

- Approach
  - Group bits to symbols
  - Injective mapping («coding») of symbols to transmission symbols
    - More bits per symbol
  - Correct inverse mapping also possible when given number of bit errors not exceeded
- Example
  - Triple redundancy (one bit error)
  - Hamming code (one bit error)

Backward vs. Forward

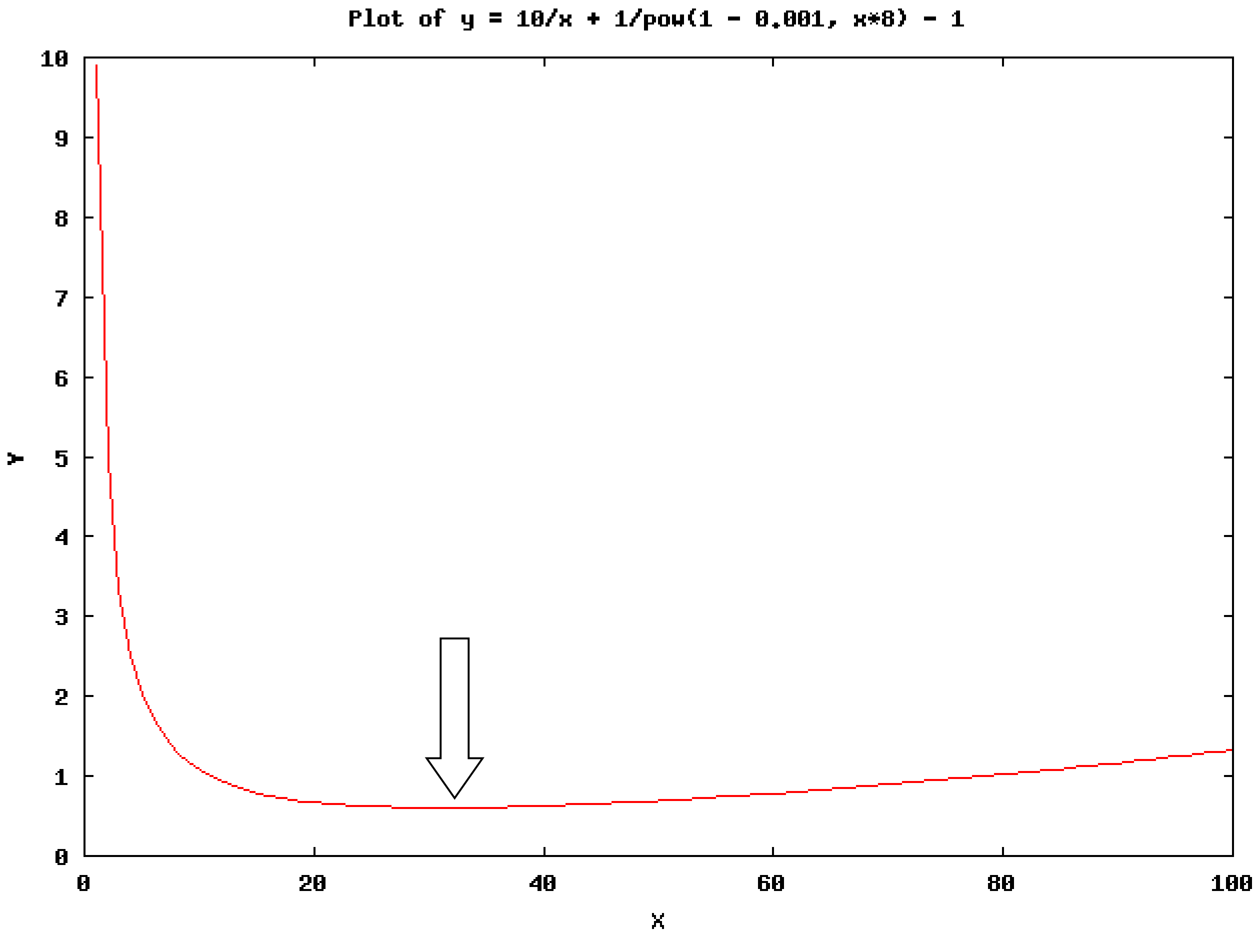
- Backward
  - Overhead for retransmission in case of error
  - Favor if low BER
- Forward
  - Always overhead for redundant code
  - Favor if high BER
- Note: BER ~ 1 / transmit power!
  - Transmit power can be changed with many radios!
- Adaptive and hybrid variants
  - Measure/estimate BER -> select approach
  - Low BER: forward, else backward

Framing

- Grouping of bits / symbols into packets
- Long packets
  - High probability for >= 1 bit error
  - Low header overhead
- Short packets
  - Low probability for >= 1 bit error
  - High header overhead
- Note: optimal packet size for given BER and header size
  - Measure/estimate BER, adapt packet length

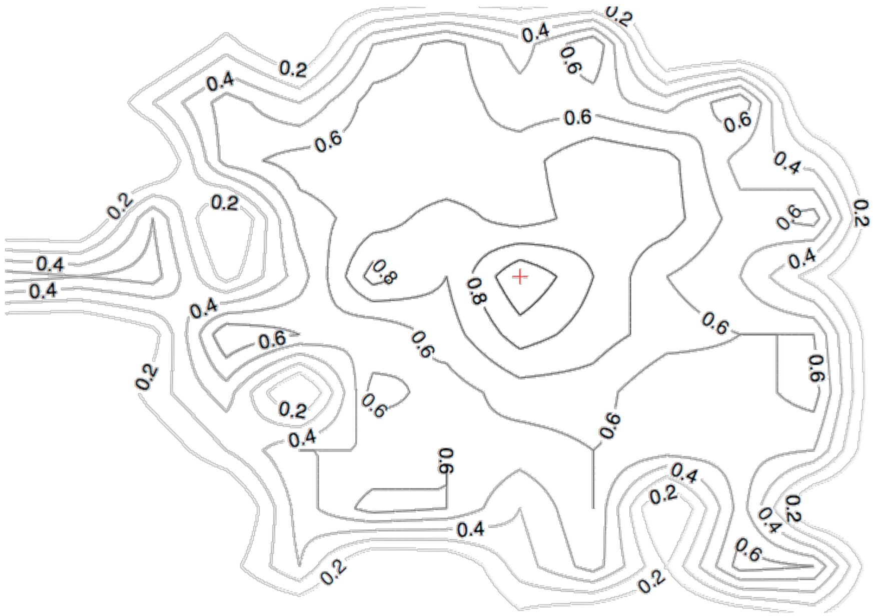
Optimal Packet Size

Header = 10 Bytes BER = 0.001



Link Management

- Knowledge of neighbor nodes often needed
- When is a node a neighbor?
  - SNIR >= min
  - BER, PER <= max
- Irregular
  - Not isotropic
    - Not a circle!
  - Asymmetric links
  - Changes over time



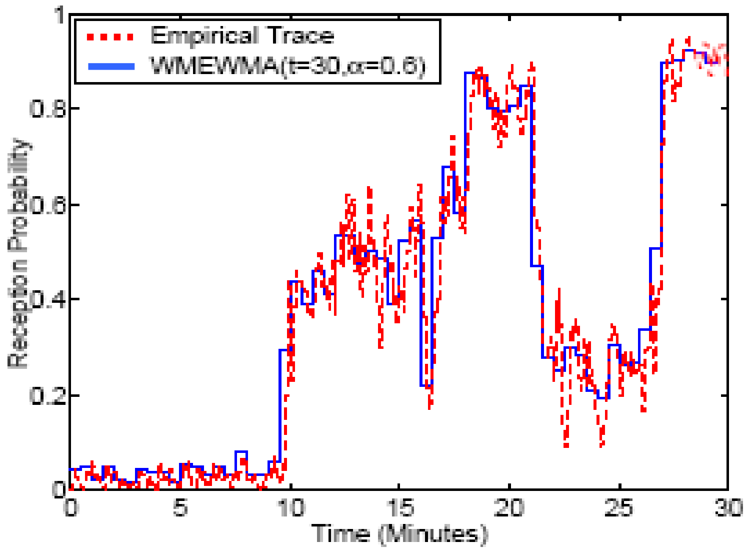
Link Quality

- Estimation of link quality (BER, PER, SINR) needed for neighbor management
  - Accurate, adaptive, stable, efficient
- Example
  - Exponentially weighted moving average over packet loss per time interval

$$P_n = \alpha P_{n-1} + (1-\alpha)\frac{r_n}{r_n+f_n}$$

r_n: received packets in interval

f_n: packets identified as lost



Reference

- Slides contain material by the following authors
  - Holger Karl – Uni Paderborn
  - Randy Katz, Alec Woo – UC Berkeley
  - Jochen Schiller – FU Berlin
  - Deepak Ganesan – Amherst