Drahtlose Breitbandkommunikation - Einführung

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Vorlesung Drahtlose Breitbandkommunikationssysteme

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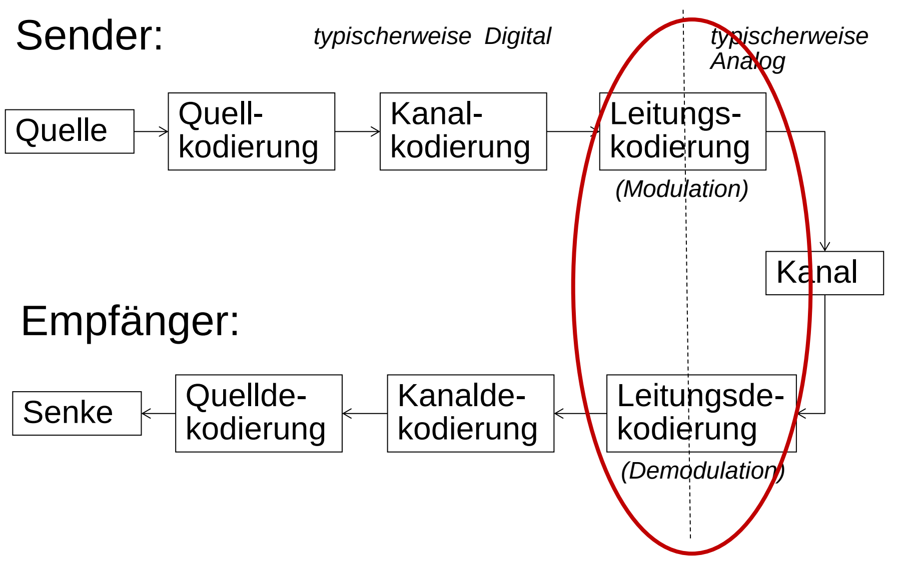
Breitbandkommunikation (PHY-Modell)



Signals

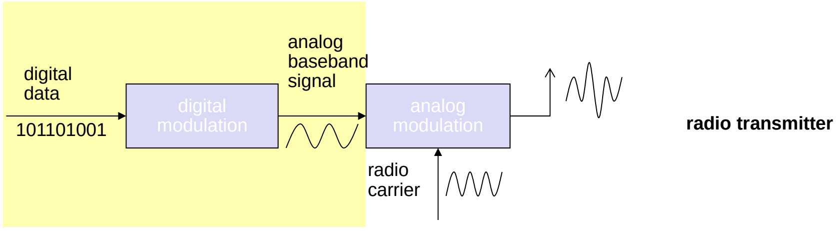
- physical representation of data
- function of time and location
- signal parameters: parameters representing the value of data
- classification
  - continuous time/discrete time
  - continuous values/discrete values
  - analog signal = continuous time and continuous values
  - digital signal = discrete time and discrete values
  - Today also combinations are being used
    - E.g. discrete values and continuous time
- signal parameters of periodic signals:
  period T, frequency f = 1/T, amplitude A, phase shift φ
  - sine wave as special periodic signal for a carrier:

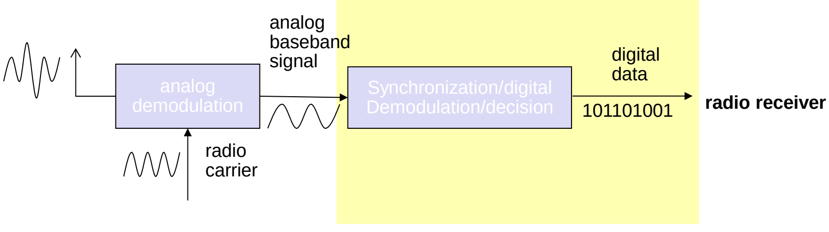
$$s(t) = A_t \sin(2 \pi f_t t + \varphi_t)$$

Modulation

- Digital modulation
  - digital data is translated into an analog signal (baseband)
  - ASK, FSK, PSK - main focus in this chapter
  - differences in spectral efficiency, power efficiency, robustness
- Analog modulation
  - shifts center frequency of baseband signal up to the radio carrier
  - Double sideband -> I/Q modulation
- Motivation
  - smaller antennas (e.g., $\lambda/4$)
  - Frequency Multiplexing
  - medium characteristics
- Basic schemes
  - Amplitude Modulation (AM)
  - Frequency Modulation (FM)
  - Phase Modulation (PM)

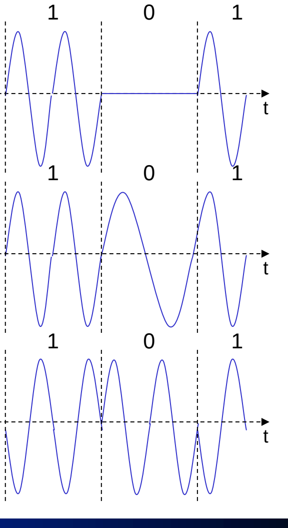
Modulation and Demodulation





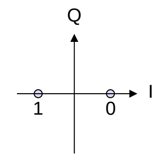
Digital modulation

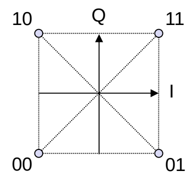
- Modulation of digital signals known as “Shift Keying”
- Amplitude Shift Keying (ASK):
  - very simple
  - low bandwidth requirements
  - very susceptible to interference
- Frequency Shift Keying (FSK):
  - needs larger bandwidth
- Phase Shift Keying (PSK):
  - more complex
  - robust against interference

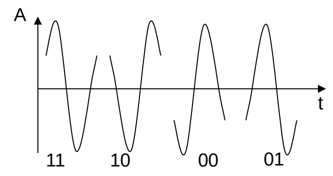


Advanced Phase Shift Keying

- BPSK (Binary Phase Shift Keying):
  - bit value 0: sine wave
  - bit value 1: inverted sine wave
  - very simple PSK
  - low spectral efficiency
  - robust, used e.g. in satellite systems
- QPSK (Quadrature Phase Shift Keying):
  - 2 bits coded as one symbol
  - symbol determines shift of sine wave
  - needs less bandwidth compared to BPSK
  - more complex
- Often also transmission of relative, not absolute phase shift: DQPSK - Differential QPSK (IS-136, PHS)

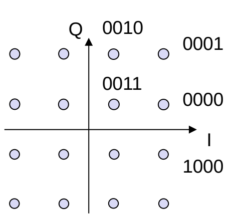






Quadrature Amplitude Modulation

- Quadrature Amplitude Modulation (QAM): combines amplitude and phase modulation
- it is possible to code n bits using one symbol
- 2^n discrete levels, n = 2 identical to QPSK
- bit error rate increases with n, but less errors compared to comparable PSK schemes

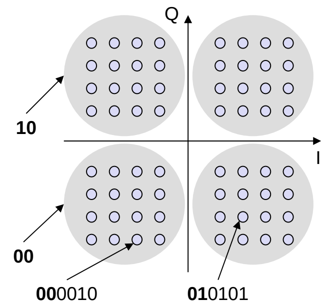


Example: 16-QAM (4 bits = 1 symbol)

Symbols 0011 and 0001 have the same phase, but different amplitude. 0000 and 1000 have different phase, but same amplitude.
Used in several high speed systems

Hierarchical Modulation

- DVB-T modulates two separate data streams onto a single DVB-T stream
- High Priority (HP) embedded within a Low Priority (LP) stream
- Multi carrier system, about 2000 or 8000 carriers (OFDM)
- QPSK, 16 QAM, 64QAM
- Example: 64QAM
  - good reception: resolve the entire 64QAM constellation
  - poor reception, mobile reception: resolve only QPSK portion
  - 6 bit per QAM symbol, 2 most significant determine QPSK
  - HP service coded in QPSK (2 bit), LP uses remaining 4 bit



- Also known as uneaqual error protection (UEP)

I/Q-Modulator

- … an der Tafel.

Special (higher) Modulation Schemes

- Mulitcarrier Modulation
- OFDM
- Spread Spectrum Techniques
- Ultra Widband Modulation
  - Frequency Hopping
  - Pulse UWB

Multi Carrier Modulation (MCM)

- With Multi Carrier Modulation (MCM) the data stream is spilt into several concurrent communication streams using different frequencies
- Example of MCM are ADSL and OFDM where each frequency is further modulated using BPSK or QAM
- For IEEE802.11a/g/n and LTE, OFDM is used
- OFDM uses orthogonal frequencies to avoid inter carrier interference
- It uses long symbols to reduce ISI and to avoid complex equalization
- The initial symbol rate n can be divided onto m carriers such that the symbol rate/carrier is n/m.
- The distance between symbols (in the time domain) becomes larger and thus the ISI smaller.

Why OFDM

- In order to cope with inter-symbol interference, we can increase the symbol duration
- If we increase the symbol duration the data rate goes down
- In order to limit the reduction in data rate, several carriers can be used (Multi Carrier Transmission)
- → One OFDM symbol consists of several subcarriers
- In order to reduce the interference between subcarriers, their frequencies are chosen such that they are orthogonal
- In order to efficiently use the digital hardware the number of subcarriers is usually a power of 2 (i.e. 64, 256, 1024, …)

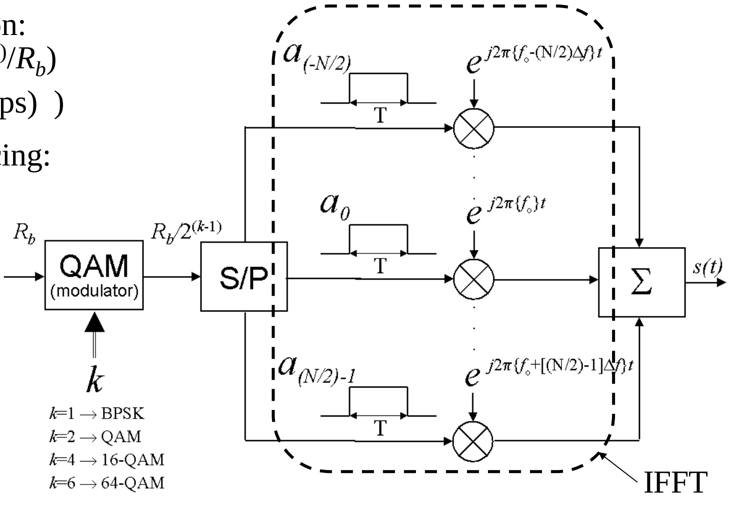
MCM Model for Transmission

N = number of subcarriers

Symbol duration:
$T_s = T = N(2^{(k-1)}/R_b)$

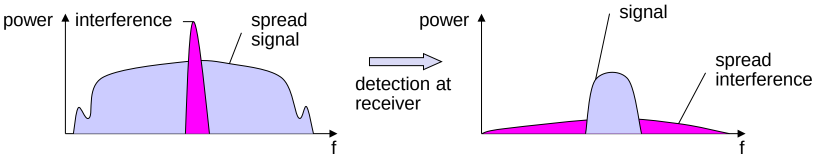
$(R_b \equiv$ bit rate (bps) $)$

Subcarrier spacing:
$\Delta f = 1/T$



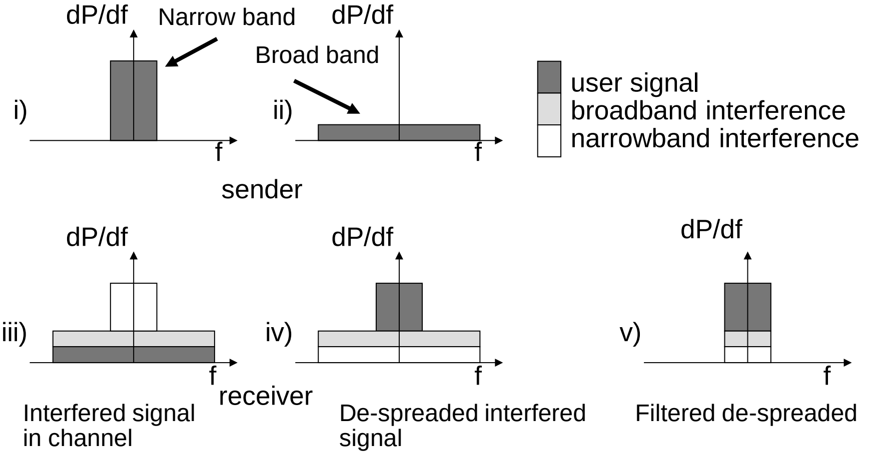
Spread spectrum technology

- Problem of radio transmission: frequency dependent fading can wipe out narrow band signals for duration of the interference
- Solution: spread the narrow band signal into a broad band signal using a special code

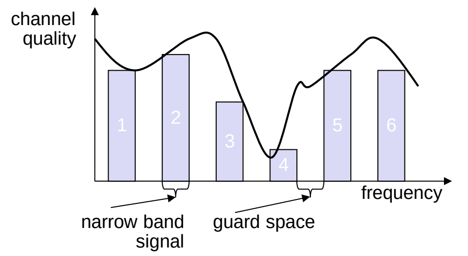


- Side effects:
  - coexistence of several signals without dynamic coordination
  - tap-proof
  - High bandwidth increases noise power at receiver
- Alternatives: Direct Sequence, Frequency Hopping

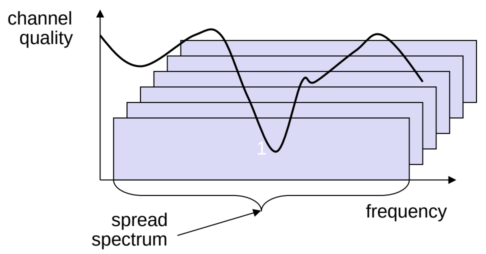
Effects of spreading and interference



Spreading and frequency selective fading



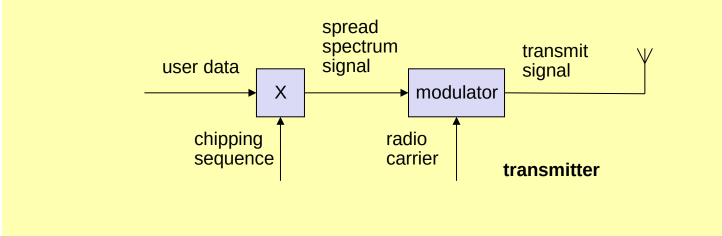
narrowband channels

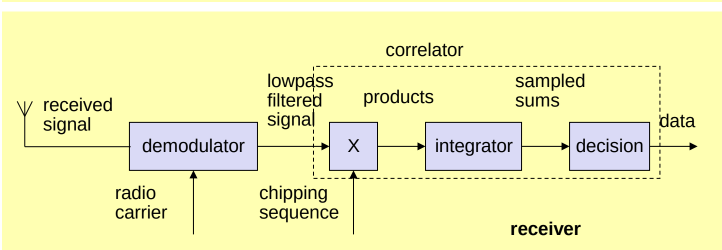


spread spectrum channels

By spreading the effect of the fading channel is equally distributed to all users!
How can we avoid interference of the chips?

DSSS (Direct Sequence Spread Spectrum) II

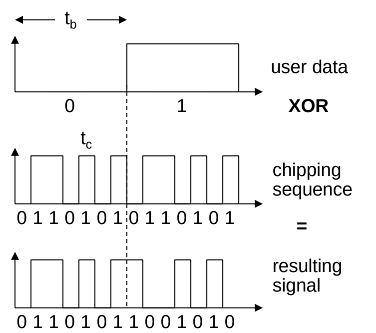




DSSS (Direct Sequence Spread Spectrum) I

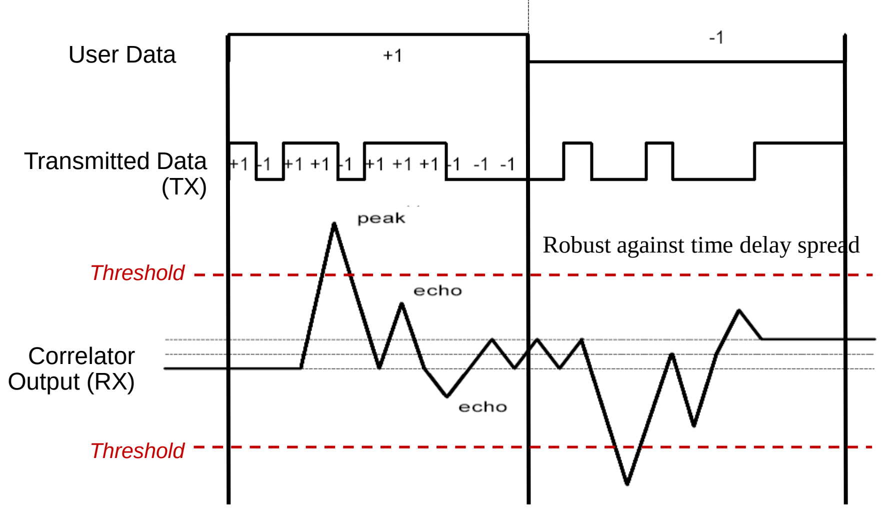
- XOR of the signal with pseudo-random number (chipping sequence)
  - many chips per bit (e.g., 128, best known 11) result in higher bandwidth of the signal
- Advantages
  - reduces frequency selective fading
  - in cellular networks
    - base stations can use the same frequency range
    - several base stations can detect and recover the signal
    - soft handover
- Disadvantages
  - precise power control necessary
  - Precise synchronization necessary (multi correlators can take advantage from multi-path propagation (Rake-receiver)
  - Cell breathing in cellular systems

Spreading Factor $s = t_b/t_c$



t_b: bit period
t_c: chip period

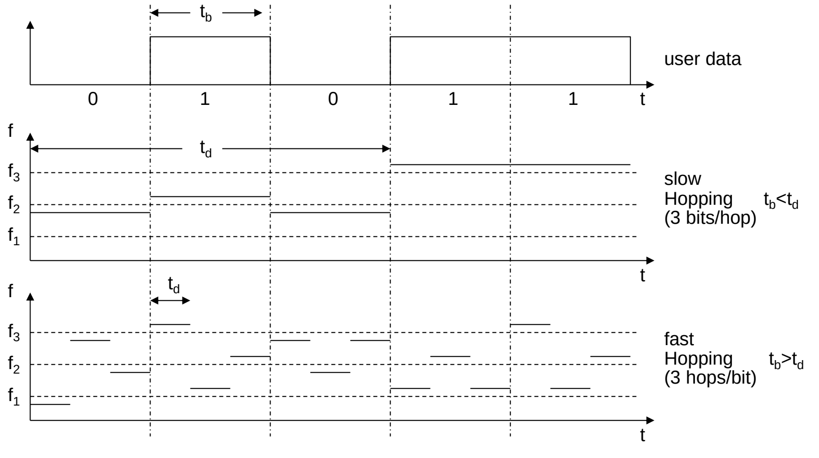
Example Barker Code



FHSS (Frequency Hopping Spread Spectrum)

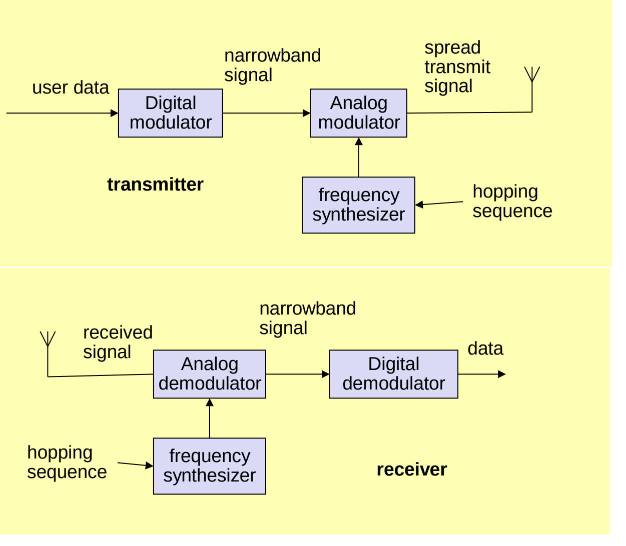
- Discrete changes of carrier frequency
  - sequence of frequency changes determined via pseudo random number sequence
- Two versions
  - Fast Hopping:
    several frequencies per user bit
  - Slow Hopping:
    several user bits per frequency (Bluetooth)
- Advantages
  - frequency selective fading and interference limited to short period
  - simple implementation
  - uses only small portion of spectrum at any time
- Disadvantages
  - not as robust as DSSS
  - simpler to detect

FHSS (Frequency Hopping Spread Spectrum) II



t_b: bit period t_d: dwell time

FHSS (Frequency Hopping Spread Spectrum) III



Example Bluetooth Frequency Hopping

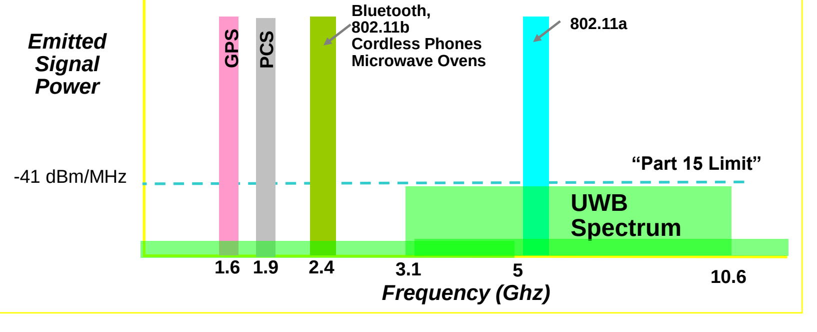
- Bluetooth uses a *slow frequency hopping* scheme
- The frequency is changed every slot (625 µs) so approximately 1600 hops/s
  (-> ca. 450 bit/slot @ 721 kbit/s)
- For multi-slot packets the frequency is changed with the next packet
- The hopping sequence is determined by the master (derived from the Bluetooth MAC address)
- During inquiry and paging, the master MAC and timing offset is exchanged with the slaves
- The slots are enumerated from 0 to $2^{27}-1$
- The master uses always the even slot
- The slot size is 1, 3 or 5

Ultra-Wide-Band (UWB)-System

- Definition: A signal is considered to be Ultra Wide Band if the Bandwidth of the signal is at least 25 % of the carrier frequency
- Special definition of FCC: For the UWB-Bands it is sufficient if the channel bandwidth is 500 MHz in the spectrum between 3.1 and 10.6 GHz
- UWB systems spread the signal power over a very broad band.
  - They interfere, therefore, minimally with existing narrowband systems
- Spreading makes the system more stable against fading channel influences
- More bandwidth allow more data-rate
- More bandwidth allows more accurate location determination

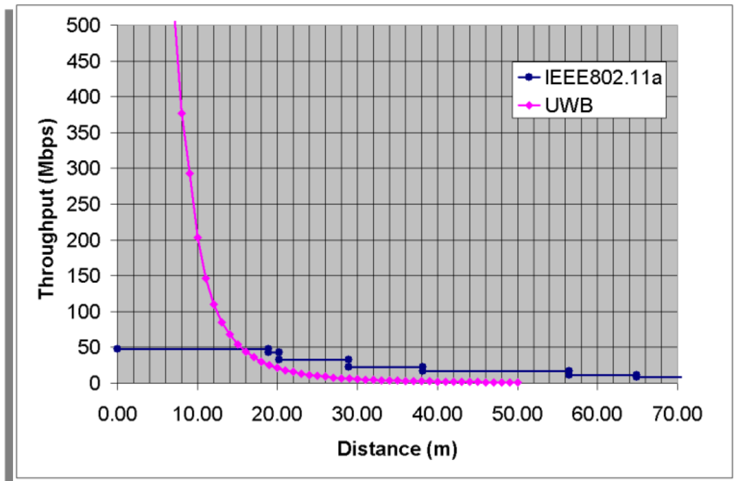
UWB Spectrum

- FCC ruling permits UWB spectrum overlay



- FCC ruling issued 2/14/2002 after ~4 years of study & public debate
- FCC believes current ruling is conservative

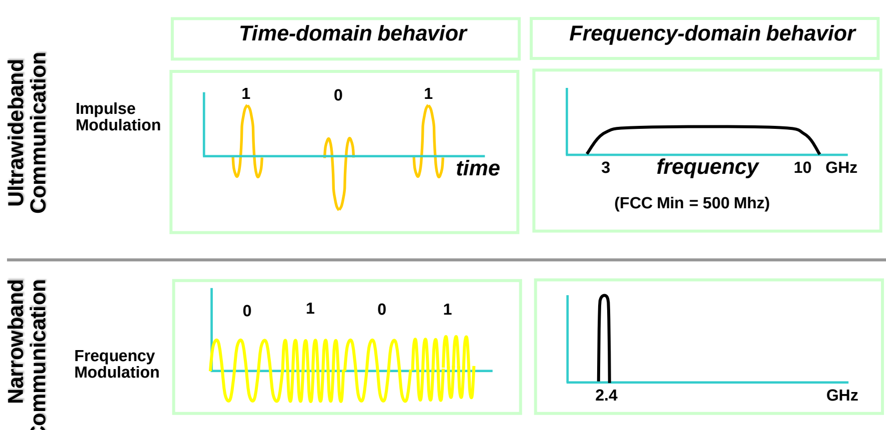
Theoretical Data Rates over Range



UWB shows significant throughput potential at short range

What is Pulse Ultra Wideband?

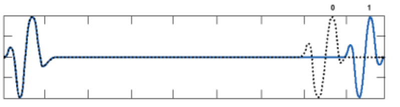
Radio technology that modulates impulse based waveforms instead of continuous carrier waves



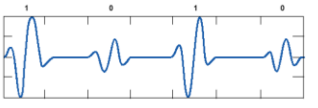
Information Modulation

Pulse length ~ 200 ps; Energy concentrated in 2 – 6 GHz band;
Voltage swing ~100 mV; Power ~ 10 µW

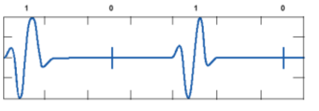
- Pulse Position Modulation (PPM)



- Pulse Amplitude Modulation (PAM)



- On-Off Keying (OOK)



- Bi-Phase Modulation (BPSK)