Drahtlose Breitbandkommunikation - Einführung

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Vorlesung Drahtlose Breitbandkommunikationssysteme

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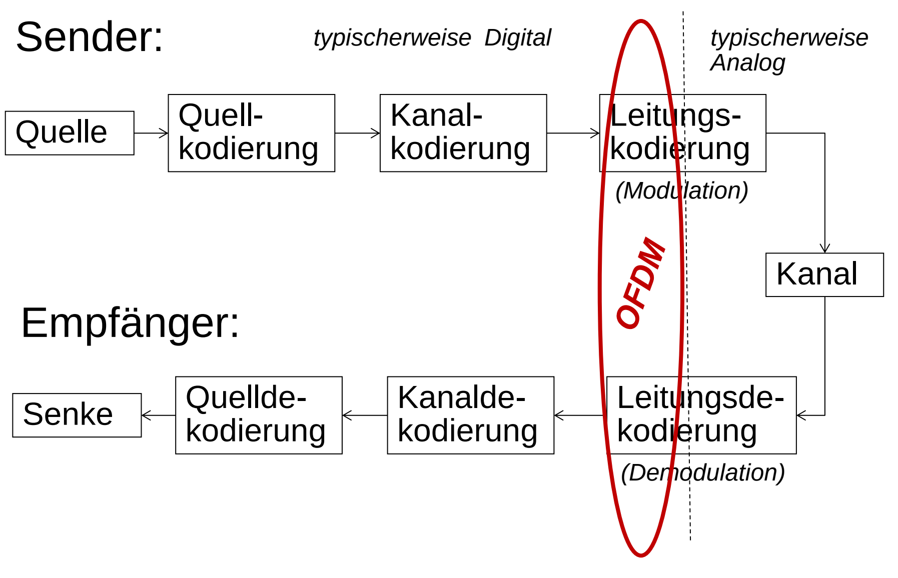
Breitbandkommunikation (PHY-Modell)



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 (ISI), we should 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, …)

History of OFDM

- Frequency division multiplexing published in mid-1960s [B.R. Salzberg]
- US-Patent in 1970 [Pat. 3, 488,4555]
- Use of discrete Fourier transform (DFT) by Weinstein and Ebert in 1971
- Investigations for application in high-speed modems using QAM and FFT in 1981 [B. Hirosaki]
- Application for DSL, ADSL, VDSL, DAB and HDTV in 1990s
- Today, most new wireless (and wired) communication systems use some form of OFDM
- New developments:
  - OFDM-A

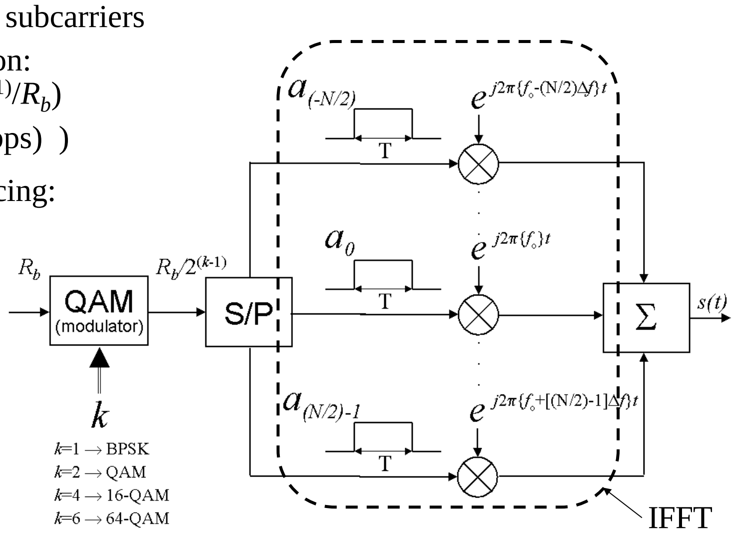
MCM Model for Transmission

N = number of subcarriers

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

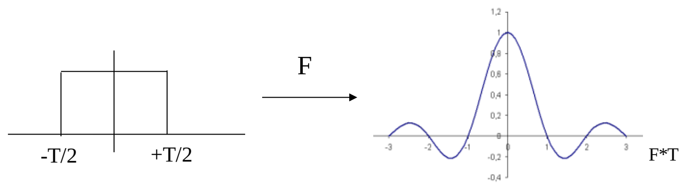
($R_b \equiv$ bit rate (bps))

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



Source: ???

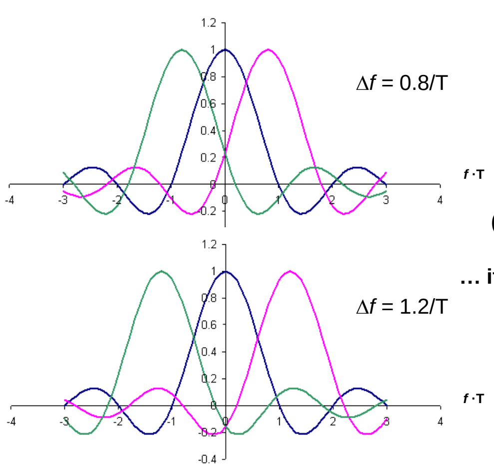
Fourier transform of a single puls



$$\mathrm{rect}(T) \circ\!\!-\!\!\!-\!\!\bullet\ \mathrm{si}(T) = \sin(T)/T$$

Source: ???

OFDM model for transmission (cont‘d)

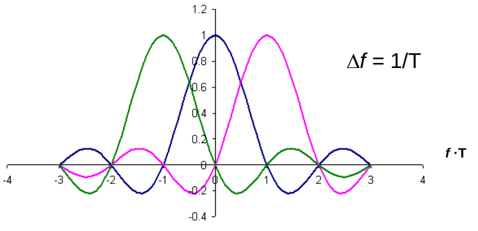


We observe ICI (Inter-Carrier-Interference) …

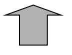
… if subcarriers are not orthogonal

Source: ???

OFDM model for transmission (cont'd)



No ICI



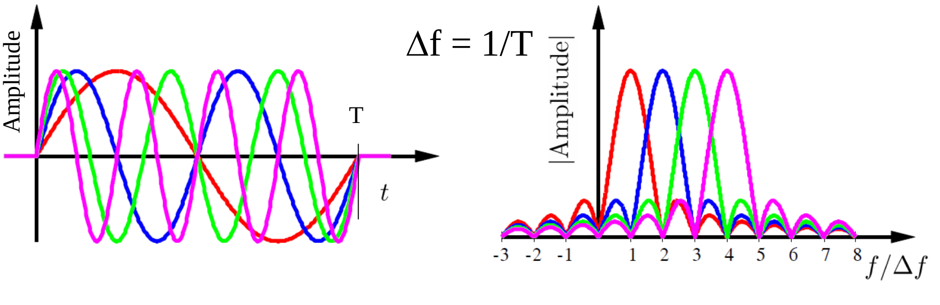
If we have orthogonality between the different subcarriers

Source: ???

Orthogonality in Time Domain

Example: WLAN IEEE 802.11a

OFDM Symbol Duration:	3.2 + 0.8µs (Guard Interval, Cyclic Prefix)
Number of subcarriers:	64 (52 used)
Subcarrier Spacing:	312.5 kHz
Signal Bandwidth:	16.66 MHz
Channel Spacing:	20 MHz



Source: L. Häring (Uni Duisburg, 2011)

FFT-Equation

$$X[k] = \sum_{n=0}^{N-1} x[n] W_N^{nk}, \qquad k = 0, 1, \ldots, N-1$$

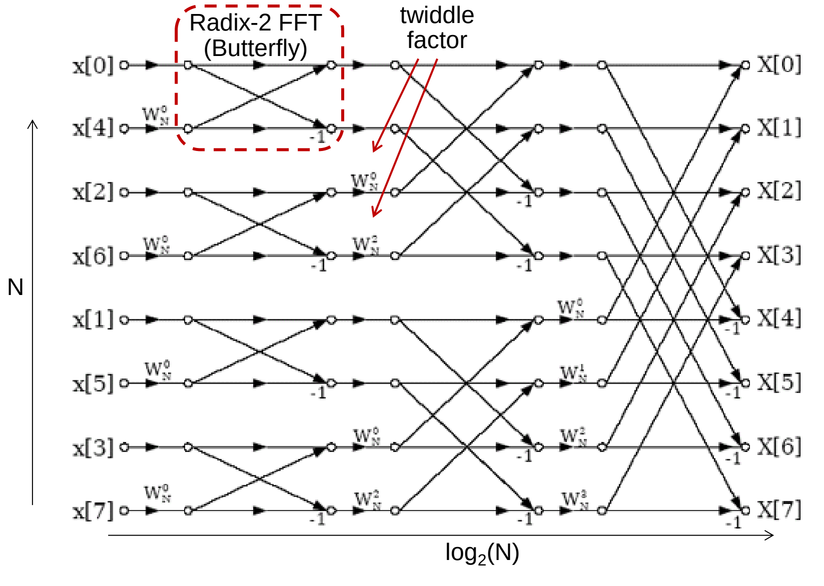
$$W_N = e^{-j\frac{2\pi}{N}}$$

$$X[k] = \sum_{r=0}^{\frac{N}{2}-1} x[2r] W_{\frac{N}{2}}^{rk} + W_N^k \sum_{r=0}^{\frac{N}{2}-1} x[2r+1] W_{\frac{N}{2}}^{rk}$$

- Based on complex multiplications with constant „twiddle factors“ and additions
- Can be decomposed into „butterfly“ operations with twiddle factors

Source: ???

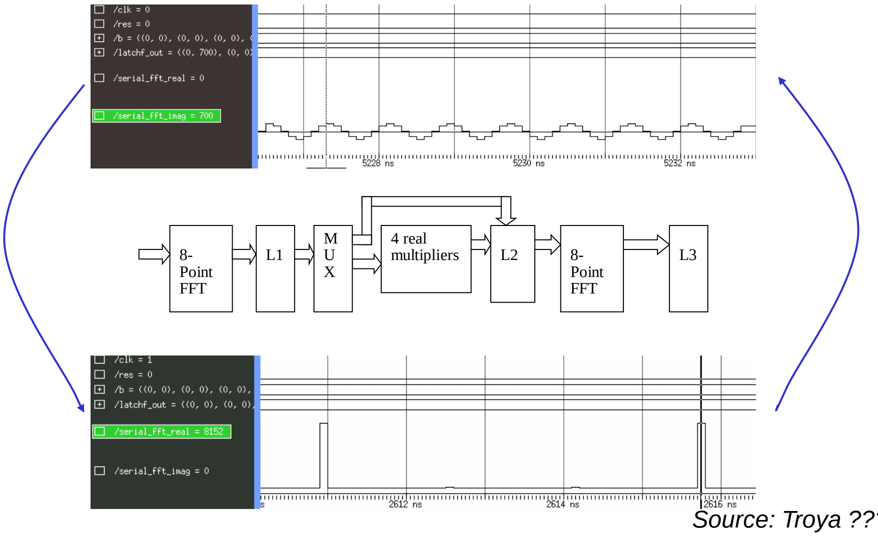
Flow Graph of 8-point Complex FFT



Complexity C of N-point FFT is C = N * $\log_2$ (N) !!!

Source: versci.com/fft/index.html

Our FFT Implementation



Source: Troya ???

Guard Interval

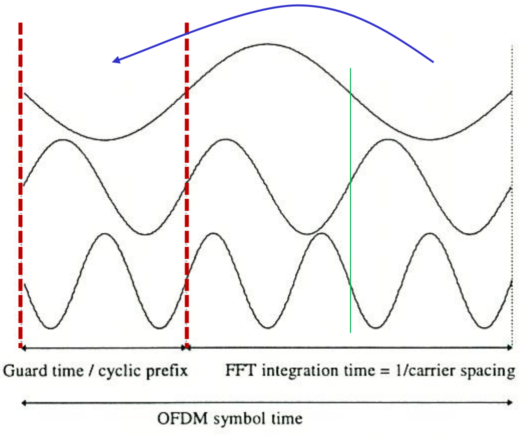


Figure 2.7 OFDM symbol with cyclic extension.

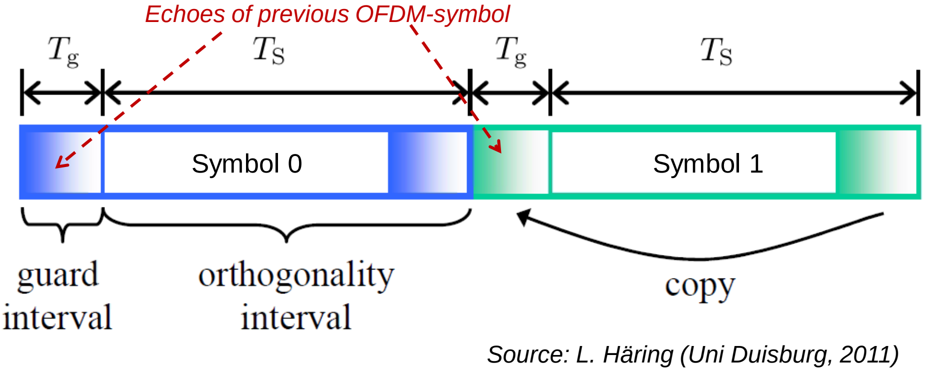
Source: Raghu Rao and Kevin Chen; 2002

Guard Interval

T_g ~ max. delay spread of channel (T_{rms})

-> Reflections (echos) of previous symbol fall into the guard interval of the actual symbol

-> The actual FFT-Window (orthogonality interval) is not affected



Source: L. Häring (Uni Duisburg, 2011)

Guard Gap (Guard Lücke)

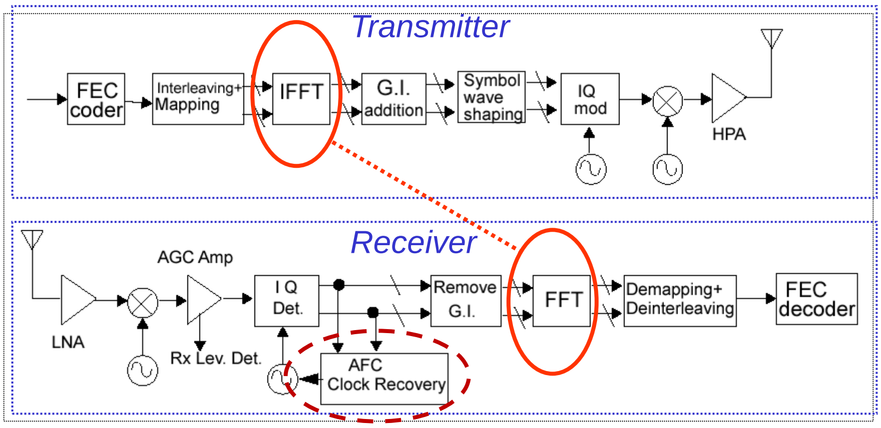
… can also be used to reduce inter-symbol interference (ISI)

Advantage:
-Total energy to be transmitted is reduced

Disadvantage:
-Automatic Gain Control (AGC) at receiver is much more complicated
-More effort for signal processing

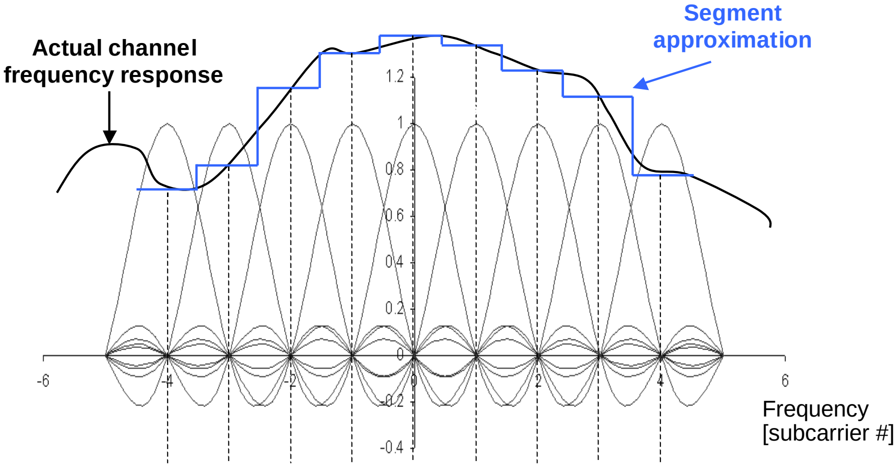
Source: L. Häring (Uni Duisburg, 2011)

Detailed Structure of OFDM Transceiver



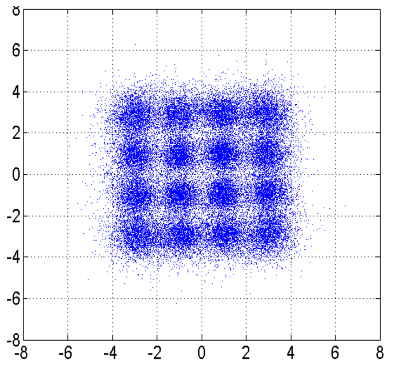
OFDM: Effects of Fading Channels

- **CHANNEL'S PIECEWISE APPROXIMATION**

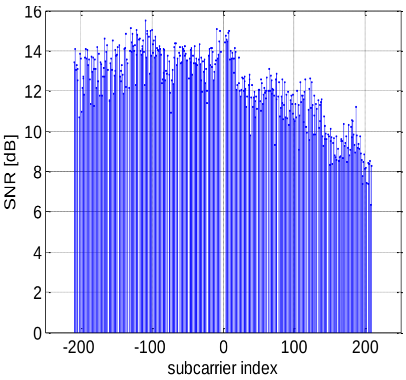


Measurement Results of Real System

Constellation diagram

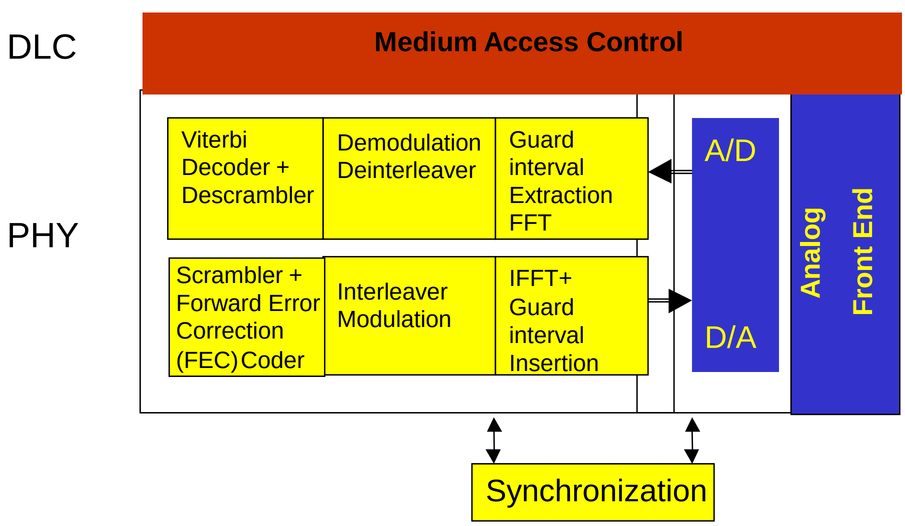


Subcarrier SNR



- Error free transmission demonstrated with 960 MBit/s, using Wideband PHY mode (800 MHz FFT-BW) and 16-QAM-1/2
- 100 frames with 2 kByte payload per frame evaluated

OFDM PHY Layer Blocks



OFDM: Advantages

- Transforms frequency selective fading to flat fading (of each subcarrier)
- High bit rate possible even for fading channel
- Adaptive modulation technique will allow adaptation to almost any environment
- Orthogonality of carriers eliminates inter-carrier interference (ICI)
- Channel correction (equalization) possible in frequency domain
- Guard period that combats and eliminates inter-symbol interference (ISI)
- Very high bandwidth efficiency [(bit/s)/Hz]

OFDM: Disadvantages

- Sensitive to Carrier Frequency Offset
  - Carrier frequency offset will make the receiver to incorrectly determine the carrier frequency
- Large Peak to Average Ratio (PAR)
  - Added sinusoids cause large PAR and issues of amplifier non-linearity arise (large dynamic range required).
- Sensitive to Channel Fade
  - Flat Fading might have deep fades that totally destroy the information in that particular sub-carrier
- Relatively complex digital baseband processor required
  - FFT, Synchronisation, Equalisation, …

WLAN: IEEE 802.11a

Data rate
- 6, 9, 12, 18, 24, 36, 48, 54 Mbit/s, depending on SNR
- User throughput (1500 byte packets): 5.3 (6), 18 (24), 24 (36), 32 (54)
- 6, 12, 24 Mbit/s mandatory

Transmission range
- 100 m outdoor, 10 m indoor
  - E.g., 54 Mbit/s up to 5 m, 48 up to 12 m, 36 up to 25 m, 24 up to 30 m, 18 up to 40 m, 12 up to 60 m

Frequency
- Free 5.15 - 5.25, 5.25 - 5.35, 5.725 - 5.825 GHz ISM-band

Security
- Limited, WEP-insecure, WPA2, SSID

Cost: few Euros

Availability
- Many products, many vendors

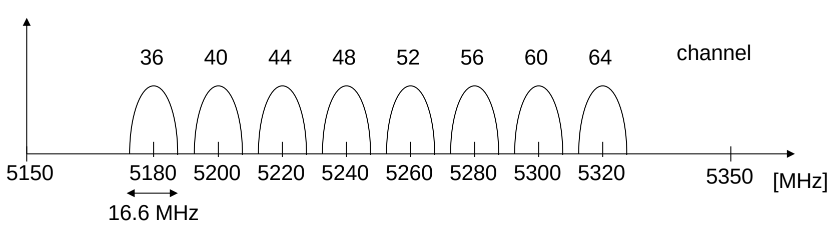
Connection set-up time
- Connectionless/always on

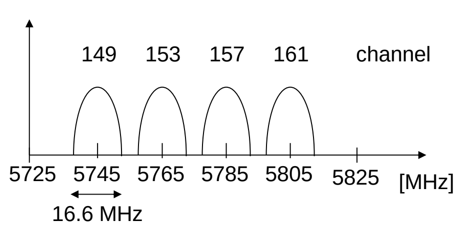
Quality of Service
- Typ. best effort, no guarantees (same as all 802.11 products)

Manageability
- Limited (no automated key distribution, sym. Encryption)

Special Advantages/ Disadvantages
- Advantage: fits into 802.x standards, free ISM-band, available, simple system, uses less crowded 5 GHz band
- Disadvantage: stronger shading due to higher frequency, no QoS

Operating Channels for IEEE802.11a / US U-NII



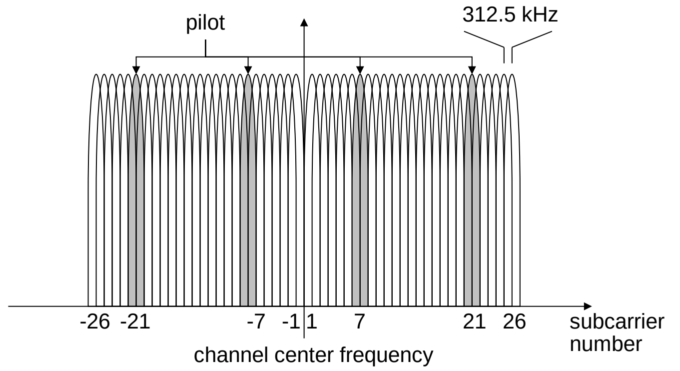


center frequency =
5000 + 5*channel number [MHz]
20 MHz/64 = 312.5 kHz per OFDM carrier

52 * 312.5 + 312.5 = 16.562 MHz

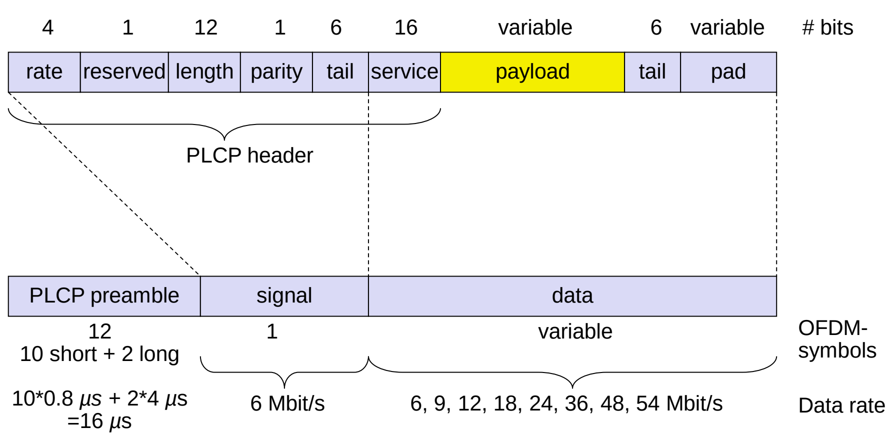
OFDM in IEEE802.11a

- OFDM with 52 used subcarriers (64 in total)
- 48 data + 4 pilot
- (plus 12 virtual subcarriers)
- 312.5 kHz spacing

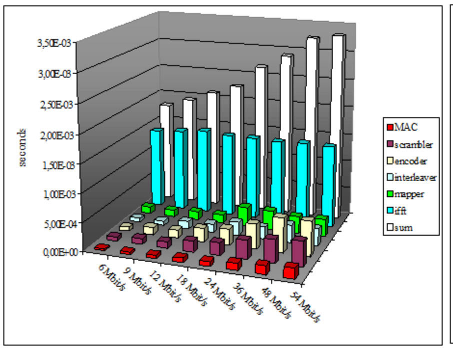


IEEE 802.11a – PHY Frame Format

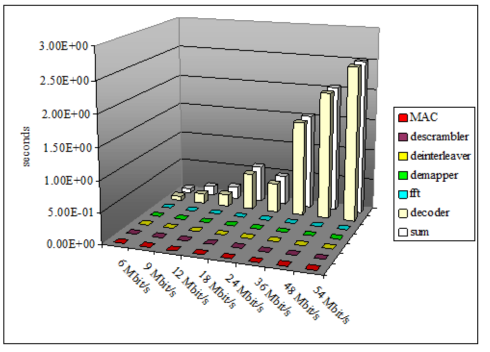
One OFDM-Symbol: 0.8 µs (guard interval) + 3.2 µs (data) = 4 µs



Processing demands per OFDM Symbol for C-model in transmit mode (a) and receive mode (b)



a)



b)