Technische Universität Braunschweig

Institut für Nachrichtentechnik

# Fundamentals of Mobile Radio Communications

## Exercise 10: OFDM-based Communication Systems

M.Sc. Maik Weber

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## 1 OFDM - Basics

### 1.1 Explain the difference between single-carrier and multi-carrier transmission systems. What are the advantages of OFDM compared to single-carrier systems?

OFDM is a multi-carrier transmission technique where data is transmitted over many narrowband subcarriers, while single-carrier systems transmit over a wideband single carrier.

**Advantages of OFDM:**

- Robustness against frequency-selective fading
- flexible spectrum allocation and high spectral efficiency
- efficient signal processing using IFFT / FFT

### 1.2 Prove that the following signals are orthogonal over the interval $[0, T]$, assuming $m$ and $n$ are integers and $f_{sc}$ is the subcarrier spacing.

$$s_1(t) = A \cdot \cos(2\pi m f_{sc} t),\ s_2(t) = A \cdot \cos(2\pi n f_{sc} t)$$

**1.3 Sketch a simplified OFDM transmitter and receiver and explain the function of each component.**

**1.4 Why is it impractical to implement OFDM using analog oscillators for every subcarrier? What technique is used in practice instead?**

It is impractical to use analog oscillators for each subcarrier due to hardware complexity and instability. Instead, (Inverse) Fast Fourier Transform is used to generate the signal in the baseband.

**1.5 A wireless channel has a maximum delay spread of $\tau_{\text{max}} = 5\,\mu\text{s}$. The useful OFDM symbol duration is $T = 66.7\,\mu\text{s}$. What is the minimum required Cyclic Prefix to avoid ISI? Assuming $T_{\text{CP}} = 5.2\,\mu\text{s}$, what is the relative overhead introduced by the CP?**

**1.6 An OFDM system has a bandwidth $B$ of 2 MHz, which is divided into $N_{SC} = 16$ subcarriers. Each OFDM symbol is preceded by a 2 µs guard interval.**

**1.6.1 Calculate the subcarrier spacing $\Delta f$, usable symbol duration $T_S$, and total symbol duration $T_{total}$.**

**1.6.2 Sketch the time-frequency grid for a duration of 100 µs.**

**1.6.3 Every fourth subcarrier in every fifth symbol is used for the transmission of pilots. What is their purpose? Mark the pilots in the time-frequency grid.**

Pilots are known symbols that can be used by the receiver to estimate how the channel affects the transmitted signal. This enables correction (equalization) of amplitude and phase to reduce distortions. Also, they can be used for timing and frequency synchronization.

# 2 WLAN-based Communication Systems

The WLAN standard IEEE 802.11ac enables data rates of over 1 Gbit/s in the 5 GHz frequency band by using OFDM in combination with MIMO antenna systems and high bandwidths. Figure 1 shows the allocation of the available spectrum for a possible system configuration with a channel bandwidth B of 80 MHz, subdivided into $N_{SC} = 256$ subcarriers.

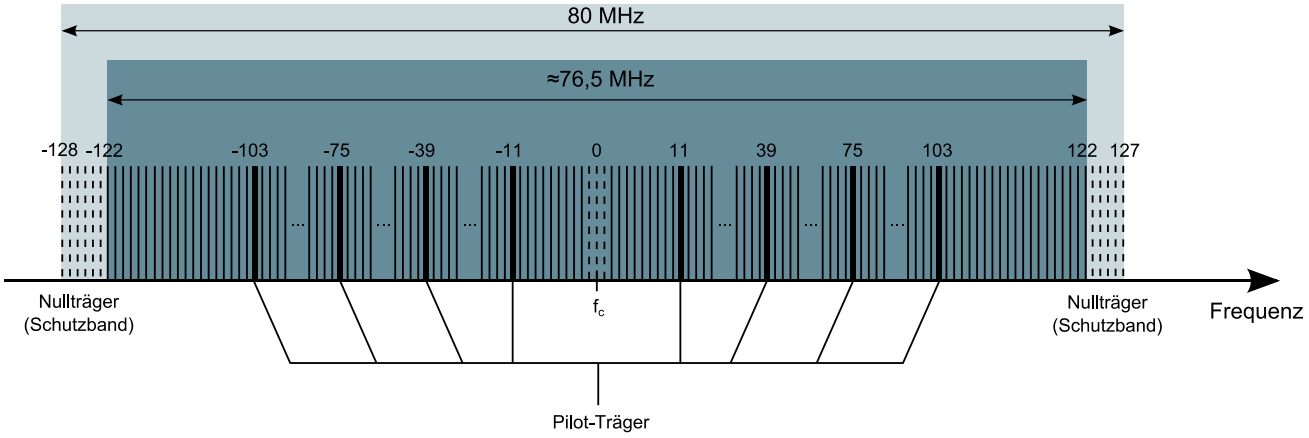


Figure 1: Schematic representation of the frequency spectrum allocation in IEEE 802.11ac for a channel bandwidth B of 80 MHz

### 2.1 Calculate the symbol duration $T_S$ and subcarrier spacing $\Delta f$.

### 2.2 Determine the number of user data bits transmitted per OFDM symbol in an IEEE 802.11ac system employing 64-QAM modulation and a coding rate of 2/3. Use the schematic representation of the OFDM subcarrier allocation to derive the necessary parameters.

$$N_{\text{bits}} = N_{\text{SC,data}} \cdot \text{ld}(M) \cdot r_c$$

# 3 LTE - Long Term Evolution

**3.1 In LTE, different scheduling algorithms are used for resource allocation. Name three examples.**

- Round Robin - Equal allocation of resources among users in a rotating order
- Maximum Throughput - Prioritize users with highest channel quality to achieve highest throughput (since good channel quality enables high MCS)
- Proportional Fair - Balances throughput and fairness by allocating resources based on current data rate vs. average rate (favors users with currently good channel and low data throughput in the past)

**3.2 In contrast to GSM systems, the cells of an LTE network transmit in the same frequency band, which means that neighboring cells interfere with each other (inter-cell interference). Table 1 shows an example of the local received power levels of the five strongest cells for a specific location and point in time.**

| cell id | receive power level |
|---|---|
| 1 | –73.19 dBm |
| 2 | –83.53 dBm |
| 3 | –83.65 dBm |
| 4 | –55.57 dBm |
| 5 | –74.26 dBm |

Table 1: Receive power levels of the five strongest cells

**3.2.1 To which cell would a mobile station be connected with the highest probability?**

**3.2.2 Calculate the interference power in dBm for the cell selected before.**

**3.2.3 The bandwidth-dependent thermal noise is –104 dBm. The receiver has a noise figure of 5 dB. Calculate the signal-to-interference-and-noise-power ratio (SINR) at the output of the receiver in dB.**

**3.3 The use of OFDM in LTE enables the efficient use of the frequency spectrum. Resources are allocated to individual users in multiples of resource blocks, or RBs. Throughput is an important key figure for assessing performance and will be analyzed in this task.**

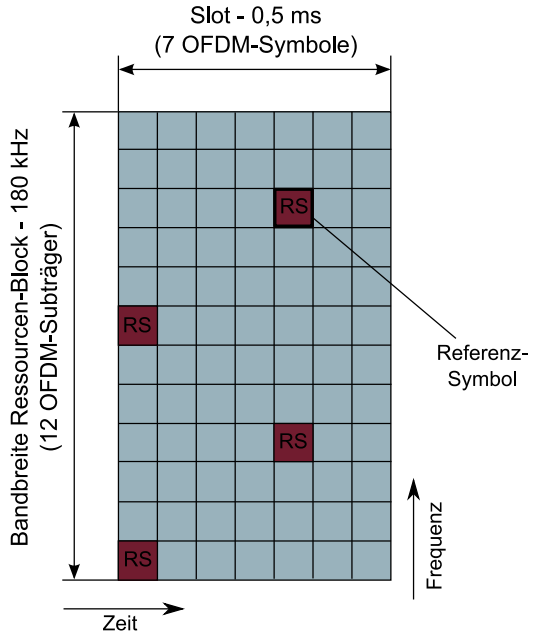


Figure 2: Structure of a LTE Resource Block

| MCS | Modulation (order) | Code Rate $r_c$ |
|---|---|---|
| 1 | QPSK (2) | 0.121 |
| 12 | 16QAM (4) | 0.329 |
| 28 | 64QAM (6) | 0.831 |

Table 2: Modulation and Code Rate for selected MCS

**3.3.1 Depending on the quality of the transmission channel, the modulation technique and the code rate (modulation and coding scheme, or MCS) are adapted in LTE. Using the given structure of a resource block, calculate the maximum gross data rate achievable for the MCS in Table 2.**

**3.3.2 For channel estimation, certain reference symbols are used that are unavailable for user data (see Figure 2). Due to the regular transmission of system-related overhead (e.g., signaling channels), approximately 7 % of the symbols cannot be used additionally for user data in an LTE system with a bandwidth of 10 MHz and 50 available resource blocks. What is the maximum estimated net throughput that a user can achieve with the given MCS?**