3   Multiuser MIMO

- We distinguish two cases:
  - multipoint‑to‑point transmission
  - point‑to‑multipoint transmission
- Multipoint‑to‑point transmission
  - typical uplink scenario in cellular systems
  - information theoretical channel model: Multiple Access Channel (MAC)
  - **Bild einfügen und diese Zeile löschen**
- Point‑to‑multipoint transmission
  - typical downlink scenario in cellular systems
  - information theoretical channel model: Broadcast Channel (BC)
  - **Bild einfügen und diese Zeile löschen**
- Advantage of multiuser MIMO compared to point‑to‑point MIMO
  - multiplexing gain can be exploited even if users have only single antenna
  - users are spatially distributed in cell $\rightarrow$ channels to different users are independent

3.1   Multiple Access Channel (MAC)

We consider two aspects:
- Detector structures
- Rate region

3.1.1   Detector structures

Channel model: **Bild einfügen und diese Zeile löschen**

$\rightarrow$ general MAC: $\mathbf{y} = \sum\limits_{k=1}^{K} \mathbf{H}_k \mathbf{x}_k + \mathbf{n}$

with:

- K users
- user k has $N_{T,k}$ transmit antennas
- N_R receive antennas
- $\mathbf{H}_k \in \mathbb{C}^{N_R \times N_{T,k}}$

$$\mathbf{y} = \underbrace{\begin{bmatrix} \mathbf{H}_1 & \mathbf{H}_2 & \dots & \mathbf{H}_k \end{bmatrix}}_{\mathbf{H}} \cdot \underbrace{\begin{bmatrix} \mathbf{x}_1 \\ \vdots \\ \mathbf{x}_k \end{bmatrix}}_{\mathbf{x}} + \mathbf{n}$$

Observation:

- same equivalent channel model as for a point-to-point MIMO system transmitting $N_T = \sum_{k=1}^{K} N_{T,k}$ independent signal streams *(Anmerkung: kein Unterschied für Empfänger, ob Signale von einem Nutzer oder von mehreren)*

- the receiver (e.g. base station) can use detection schemes as for point-to-point MIMO systems

    - linear receiver

    - DFG

    - sphere decoder

Typical problems in uplink multiuser MIMO For given receiver structure:

- calculate SNR_k for all users k based on the expressions developed in Chapter 2.4

- optimize transmit power of users, $E_k = \mathcal{E}\{\|x_k\|^2\}$ for maximization of the sumrate or maximization of the minimum SNR_k *(Anmerkung: Maximierung der sumrate kann durch Maximierung des SNR des Users mit bestem Kanal erfolgen, aber: unfair anderen Usern gegenüber $\Rightarrow$ starving)*

3.1.2 Rate region

For point-to-point links, we can decode error free, if the rate, R, meets

a) SISO $R < \log_2\left(1 + \frac{\mathcal{E}_s}{\sigma_n^2}\right)$

b) MIMO $R < \log_2 \underbrace{\left|\mathbf{I} + \frac{\mathcal{E}_s}{N_T \sigma_n^2}\mathbf{H}\mathbf{H}^H\right|}_{\det}$

Questions: What happens if there are multiple users?

Rate Region for Single Antenna Users and Receivers

- Gaussian channel

- $N_R = N_{T,k} = 1 \forall k$

- received signal:

$$y = \sum_{k=1}^{K} x_k + n$$
$$*\mathcal{E}_k = \mathcal{E}\{||x_k||^2\}$$
$$*\sigma_n^2 = \{||n||^2\}$$

Example: 2 Users   **Bild einfügen und diese Zeile löschen**

- How should we choose R_1 and R_2 to ensure error free decoding of <u>both</u> signal streams?

- It is no longer sufficient to maximizie a single rate. Instead we have to consider rate pairs (R_1, R_2)

- All possible rate points, that allows error free decoding, define the rate region $\underline{C}$

- Possible desing goals of the system:
    - maximized sumrate $R_{\text{sum}} = \max\limits_{(R_1,R_2)\in\underline{C}} R_1 + R_2$
    - maximize minimum user rate: $R_{\text{max-min}} = \max\limits_{(R_1,R_2)\in\underline{C}} \min\limits_{i\in\{1,2\}} R_i$

- Rate Region of two user Gaussian MAC   *Anmerkung: Einschränkungen*

$$R_1 < \log_2\left(1 + \frac{\mathcal{E}_1}{\sigma_n^2}\right) \tag{1}$$

$$R_2 < \log_2\left(1 + \frac{\mathcal{E}_2}{\sigma_n^2}\right) \tag{2}$$

$$R_1 + R_2 < \log_2\left(1 + \frac{\mathcal{E}_1 + \mathcal{E}_2}{\sigma_n^2}\right) \tag{3}$$

- Interpretation:
    - (1) and (2) (= single-to user constraint) are the "single-user bounds, i.e., the maximum rates of user 1 and 2, if the other user was not there
    - (3) can be interpreted as the maximum rate if streams of users 1 and 2 were jointly encoded. The separate encoding in the MAC cannot yield a better performance
    - Graphical represantation: **Bild einfügen und diese Zeile löschen**