Topic: Massive MIMO

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MOOC @ TU9

Week 3

Digital Engineering: From Advanced Physical Layer Technologies in 5G to Secure Services

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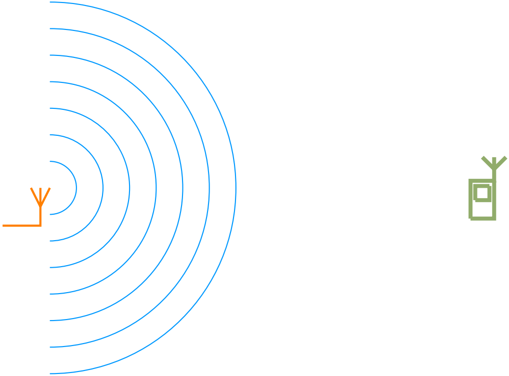
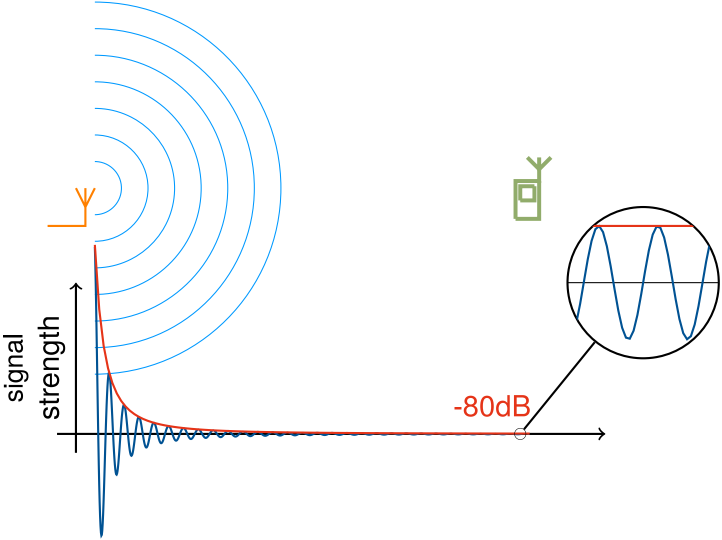
Today’s Agenda

- Wireless communications suffers from attenuation and interference
- Multiple antenna systems (MIMO) are a well-known solution against
- Massive MIMO promises additional advantages over standard solutions

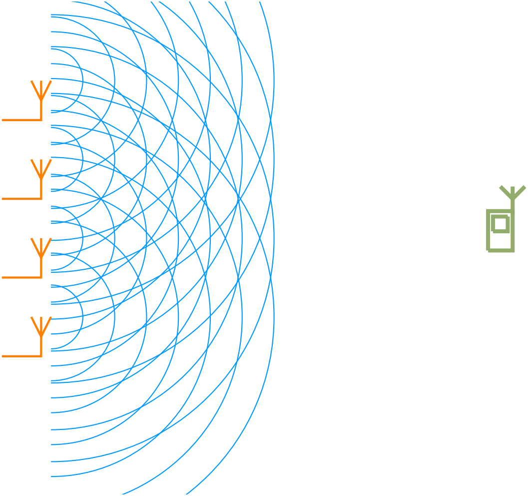
Physical Wireless Communication Link: SISO



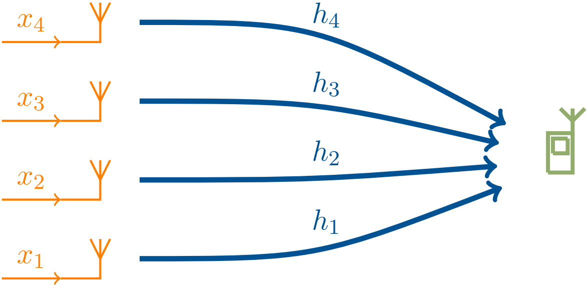
Physical Wireless Communication Link: SISO



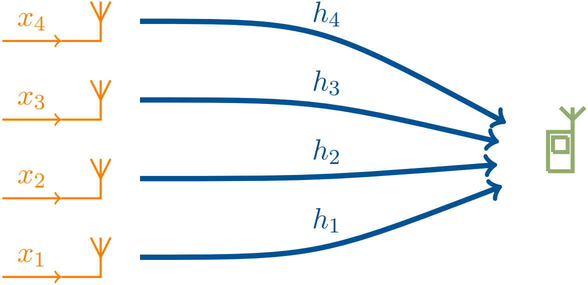
MISO



MISO



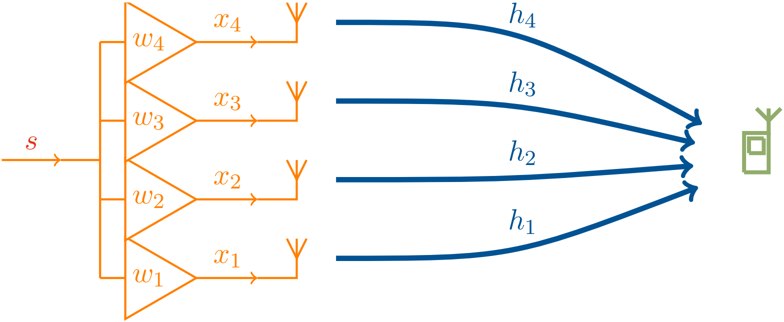
MISO



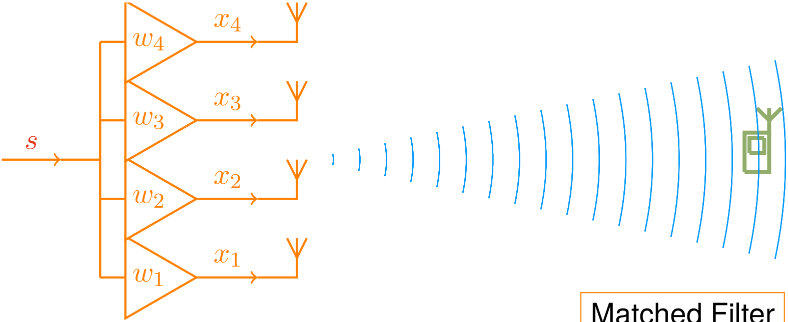
Transmission Model (baseband representation)

$$y = \sum_{m=1}^{4} h_m x_m + n = \boldsymbol{h}^{\mathrm{T}} \boldsymbol{x} + n, \quad h_m \in \mathbb{C}$$

Beamforming



Beamforming



Matched Filter

$$\boldsymbol{w} = \frac{\boldsymbol{h}^*}{\|\boldsymbol{h}\|}$$

Received Signal (baseband rep.)

$$y = \frac{\boldsymbol{h}^{\mathrm{T}}\boldsymbol{h}^*}{\|\boldsymbol{h}\|} s + n = \|\boldsymbol{h}\| s + n$$

Array Gain

Matched filter

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Received Signal (baseband rep.)

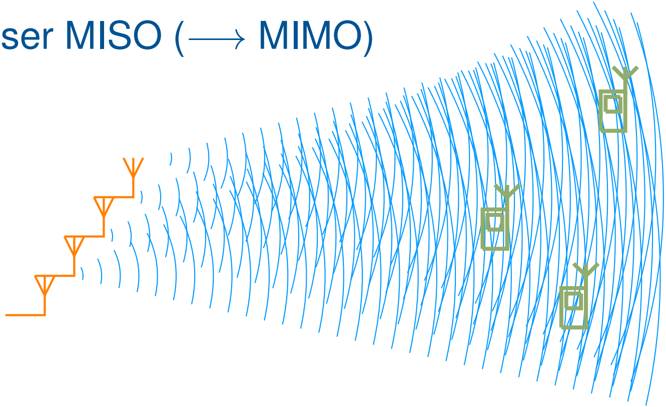
$$y = \frac{\boldsymbol{h}^{\mathrm{T}}\boldsymbol{h}^*}{\|\boldsymbol{h}\|} s + n = \|\boldsymbol{h}\| s + n$$

$$\text{SNR} = \frac{\|\boldsymbol{h}\|^2 \sigma_s^2}{\sigma_n^2} \propto M$$

M $\equiv$ number of antenna elements

σ_s^2 (σ_n^2) $\equiv$ signal (noise) variance

Multi-User MISO ($\longrightarrow$ MIMO)



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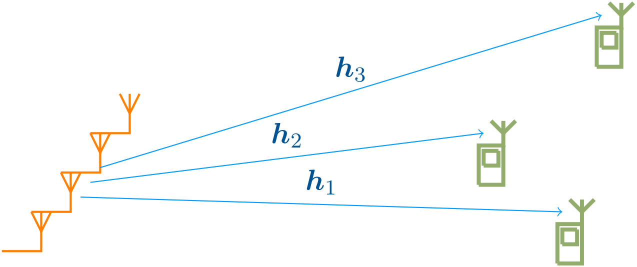
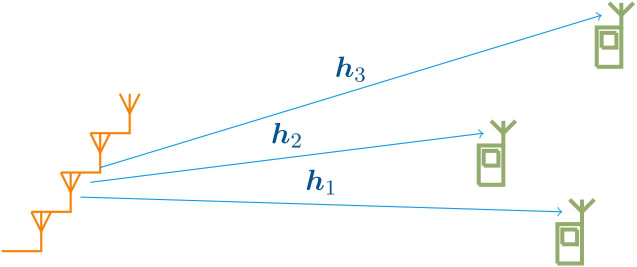


Multi-User MISO ($\longrightarrow$ MIMO)



Received Signal (baseband rep.)

$$y_i = \boldsymbol{h}_i^{\mathrm{T}} \boldsymbol{x} + n_i, \qquad \boldsymbol{x} = \sum_{i=1}^{K} \frac{\boldsymbol{h}_i^*}{\|\boldsymbol{h}_i\|} s_i$$

Multi-User Transmission

Beamforming

$$y_i = \underbrace{\|\boldsymbol{h}_i\| s_i}_{\text{useful signal}} + \underbrace{\sum_{\substack{j=1 \\ j \neq i}}^{K} \frac{\boldsymbol{h}_i^{\mathrm{T}} \boldsymbol{h}_j^{*}}{\|\boldsymbol{h}_j\|} s_j}_{\text{interference}} + n_i$$

Multi-User Transmission

Beamforming

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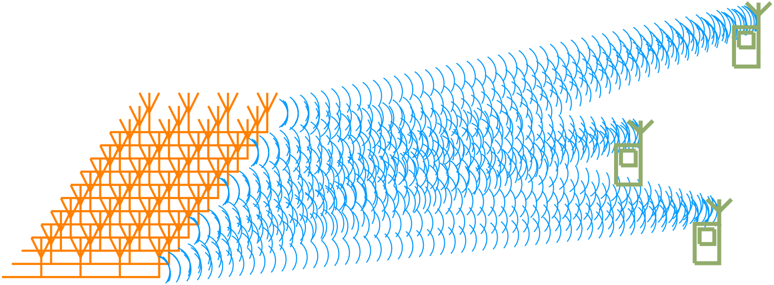
Received Signal (baseband rep.)

$$\mathrm{SNR}_i = \frac{\|\boldsymbol{h}_i\|^2 \sigma_{s_i}^2}{\sigma_{n_i}^2} \quad \rightarrow \quad \mathrm{SINR}_i = \frac{\|\boldsymbol{h}_i\|^2 \sigma_{s_i}^2}{\sum_{\substack{j=1\\ j\neq i}}^{K} \frac{|\boldsymbol{h}_i^{\mathrm{T}} \boldsymbol{h}_j^{*}|^2}{\|\boldsymbol{h}_j\|^2} \sigma_{s_j}^2 + \sigma_{n_i}^2}$$

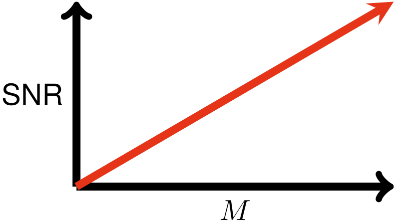
Massive MIMO



- Large number of base station antennas
- $M \gg K$

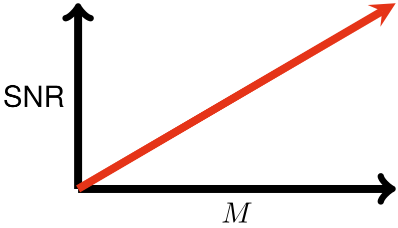
Benefits

Array Gain



Benefits

Array Gain



Asymptotic Orthogonality

$$\frac{\boldsymbol{h}_i^{\mathrm{H}}\boldsymbol{h}_j}{M} \to 0 \quad \Rightarrow \quad \text{SINR} \to \text{SNR}$$

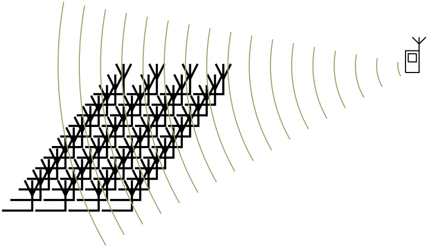
- Robust and simple signal processing methods

Task of the Week

Channel State Information (CSI) Acquisition

Uplink Training

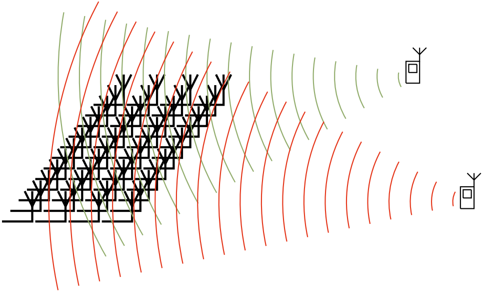
$$\hat{\boldsymbol{h}} = \boldsymbol{h} \qquad + \boldsymbol{n}$$



Channel State Information (CSI) Acquisition

Uplink Training

$$\hat{\boldsymbol{h}} = \boldsymbol{h} + \boldsymbol{h}_I + \boldsymbol{n}$$



Pilot-Contamination

Questions

- What is the impact of PILOT CONTAMINATION (PC) on the downlink communication mode?
- What kind of COUNTERMEASURES (against PC) could be thought of?

- **Hint**: Compute the SINR at the i-th receiver based on the erroneous channel vector estimates

Appendix

- SISO stands for SINGLE-INPUT SINGLE-OUTPUT and – in the context of wireless communications – refers to a single antenna element at the transmitter and a single antenna element at the receiver side of a communication link
- MISO stands for MULTIPLE-INPUT SINGLE-OUTPUT
- MIMO stands for MULTIPLE-INPUT MULTIPLE-OUTPUT where the multiple antenna elements at the receiver side are either deployed at a single receiver or distributed among multiple receivers

Appendix (cont'd)

- M is the number of antenna elements at the transmitter
- K is the number of receivers
- s_i is the dedicated signal for the i-th receiver
- w_i is the weight at the i-th antenna element of the transmitter (in case $K = 1$)
- $\boldsymbol{w}_i$ is the weight vector (beamformer) at the transmitter dedicated to the i-th receiver (in case $K > 1$)
- $\boldsymbol{w}_i$ consists of the weights $w_{i,1}, w_{i,2}, \ldots, w_{i,M}$ where $w_{i,m}$ is the m-th weight of the i-th beamformer
- x_i is the transmitted signal from the i-th antenna element at the transmitter
- $\boldsymbol{x}$ is the transmitted signal vector
- n_i is the noise at the i-th receiver
- y_i is the received signal at the i-th receiver

Appendix (cont'd)

- h_i is the channel coefficient from the i-th antenna element at the transmitter to the single receiver (in case $K = 1$)
- $\boldsymbol{h}_i$ is the channel vector from the transmitter unit to the i-th receiver (in case $K > 1$)
- $\boldsymbol{h}_i$ consists of the channel coefficients $h_{i,1}, h_{i,2}, \ldots, h_{i,M}$ where $h_{i,m}$ is the channel coefficient between the m-th antenna element at the transmitter and the i-th receiver
- $\hat{\boldsymbol{h}}_i$ is an estimate of the channel vector $\boldsymbol{h}_i$
- $\hat{\boldsymbol{h}}_{I,i}$ is the distortion of the estimated channel vector due to pilot contamination
- $\sigma_{s_i}^2$ and $\sigma_{n_i}^2$ are the variances of signal s_i and noise n_i
- SNR is the Signal-to-Noise Ratio
- SINR is the Signal-to-Interference-and-Noise Ratio
- $\boldsymbol{h}^{\mathrm{T}}$ is the transposed vector $\boldsymbol{h}$, $\|\boldsymbol{h}\|$ is the norm (length) of $\boldsymbol{h}$, and $\boldsymbol{h}^*$ is the conjugate complex vector $\boldsymbol{h}$