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

-80dB
MISO
MISO

\[ x_1 \quad x_2 \quad x_3 \quad x_4 \]

\[ h_1 \quad h_2 \quad h_3 \quad h_4 \]
MISO

Transmission Model (baseband representation)

\[ y = \sum_{m=1}^{4} h_m x_m + n = h^T x + n, \quad h_m \in \mathbb{C} \]
Beamforming
Beamforming

Received Signal (baseband rep.)

\[ y = \frac{h^T h^*}{\|h\|} s + n = \|h\| s + n \]

Matched Filter

\[ w = \frac{h^*}{\|h\|} \]
Array Gain

Matched filter

\[ w = \frac{h^*}{\|h\|} \]
Array Gain

**Matched filter**

\[ w = \frac{h^*}{\|h\|} \]

**Received Signal (baseband rep.)**

\[ y = \frac{h^T h^*}{\|h\|} s + n = \|h\| s + n \]
Array Gain

Matched filter

\[ w = \frac{h^*}{\|h\|} \]

Received Signal (baseband rep.)

\[ y = \frac{h^T h^*}{\|h\|} s + n = \|h\| s + n \]

SNR

\[ \text{SNR} = \frac{\|h\|^2 \sigma_s^2}{\sigma_n^2} \propto M \]

\( M \equiv \text{number of antenna elements} \)
\( \sigma_s^2 (\sigma_n^2) \equiv \text{signal (noise) variance} \)
Multi-User MISO (→ MIMO)
Multi-User MISO (\(\rightarrow\) MIMO)
Multi-User MISO (→ MIMO)

Received Signal (baseband rep.)

\[ y_i = h_i^T x + n_i, \quad x = \sum_{i=1}^{K} \frac{h_i^*}{\|h_i\|} s_i \]
Multi-User Transmission

Beamforming

\[ y_i = \|h_i\| s_i + \sum_{j=1}^{K} \frac{h_i^T h_j^*}{\|h_j\|} s_j + n_i \]

useful signal

interference
Multi-User Transmission

Beamforming

\[ y_i = \|h_i\|s_i + \sum_{\substack{j=1 \\ j \neq i}}^{K} \frac{h_i^T h_j^*}{\|h_j\|} s_j + n_i \]

useful signal

interference

Received Signal (baseband rep.)

\[ \text{SNR}_i = \frac{\|h_i\|^2 \sigma_{s_i}^2}{\sigma_{n_i}^2} \quad \rightarrow \quad \text{SINR}_i = \frac{\|h_i\|^2 \sigma_{s_i}^2}{\sum_{\substack{j=1 \\ j \neq i}}^{K} \frac{|h_i^T h_j^*|^2}{\|h_j\|^2} \sigma_{s_j}^2 + \sigma_{n_i}^2} \]
Massive MIMO

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

Array Gain

SNR vs. \( M \)
Benefits

Array Gain

\[ \frac{h_i^H h_j}{M} \rightarrow 0 \quad \Rightarrow \quad \text{SINR} \rightarrow \text{SNR} \]

Asymptotic Orthogonality

- Robust and simple signal processing methods
Task of the Week
Channel State Information (CSI) Acquisition

Uplink Training

\[ \hat{h} = h + n \]
Channel State Information (CSI) Acquisition

Uplink Training

\[ \hat{h} = h + h_I + n \]

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 $K = 1$)
- $w_i$ is the weight vector (beamformer) at the transmitter dedicated to the $i$-th receiver (in case $K > 1$)
- $w_i$ 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
- $x$ 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 $K = 1$)
- $h_i$ is the channel vector from the transmitter unit to the $i$-th receiver (in case $K > 1$)
- $h_i$ 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
- $\hat{h}_i$ is an estimate of the channel vector $h_i$
- $\hat{h}_{I,i}$ 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
- $h^T$ is the transposed vector $h$, $\|h\|$ is the norm (length) of $h$, and $h^*$ is the conjugate complex vector $h$