Algorithms for Radio Networks

MIMO
Smart Antennas

- **Alternative terms**
  - Adaptive Array Antennas
  - Multiple Input Multiple Output (MIMO)

- **Principle**
  - Multiple antennas are coordinated
    - used to improve reception or transmission of behavior
    - to allow additional features

- **Features**
  - Directional receivers
  - Directional senders
    - better path loss exponent
    - spatial multiplexing
    - MIMO communication
DOA Estimation

- With two antennas, one can determine the receive direction (DOA)

- Idea:
  - The signals arrive at different times to the antennas. By parallel testing of overlays can be candidates for the angle of incidence findenn

\[
\sin \alpha = \frac{\Delta t \cdot c}{d}
\]
Beam forming

- Simulation of receiving or transmitting antenna behavior of any of Smart Antennas

- **Active**
  - By suitably chosen time shift, receipt of signals at the antennas will transmit the desired direction preference
    - Other directions only increase only background noise
  - Applications: radar, mobile communications, MIMO

- **Passive**
  - As with the DOA-detection, the signals are delayed and superimposed
  - Applications: Microphones, MIMO
Smart Antennas Combinations

- **SISO (Single Input Single Output)**
  - Classic radio model

- **SIMO (Single Input Multiple Output)**
  - Classical transmitter with an antenna
  - Antenna array at the receiver
  - Different channels can be received in parallel from different angles

- **MISO (Multiple Input Single Output)**
  - Antenna array as a transmitter
  - Individual recipients (groups) can be individually reached

- **MIMO (Multiple Input Multiple Output)**
  - Directed (and parallel) communication between the transmitter and receiver possible
  - Efficient utilization of the medium
Motivation for MIMO

\[ \text{SINR} = \frac{S}{I + N} > \text{threshold} \]

Increase of SINR by
- more sender antennas
- more receiver antennas

Multipaths
- are used for increasing the channel capacity

Capacity
- grows with the complexity of the environment
- with the number of senders and receivers

\[ \# \text{bits} \sim b \cdot \log \left( \frac{S}{IN} + 1 \right) \]

Shannon's Theorem

\[ \# \text{bits} = \log \left( \frac{S}{IN} \right) \]
MIMO Free Space Model

- The message \( m \) is modulated as \( x(t) \) over a carrier
  - i.e. \( s(t) = x(t) e^{j2\pi ft} \)
- Electric field is described by the signal
  - \( \sim \) force on charged particles
  - adds up (superposition)
  - decreases proportional to the distance
- **Power is proportional to the square of the electric field**

\[
\text{SINR} = \left( \frac{\sum_{\text{sender } i} \sum_{\text{receiver } k} s_i \cdot \frac{e^{j|u_i-v_k|}}{|u_i-v_k|} \cdot g_k}{\sum_{\text{receiver } k} |g_k|^2 \left( N + \sum_{\text{interference } i} \frac{P_i'}{|w_i-v_k|^2} \right)} \right)^2
\]
MIMO Free-Space SINR

amplitude & phase modification by
sender channel receiver

\[
\text{SINR} = \frac{\left| \sum_{\text{sender } i} \sum_{\text{receiver } k} s_i \cdot \frac{e^{j|u_i - v_k|}}{|u_i - v_k|} \cdot g_k \right|^2}{\sum_{\text{receiver } k} |g_k|^2 \left( N + \sum_{\text{interference } i} \frac{P_i'}{|\omega_i - v_k|^2} \right)}
\]

channel matrix

\[
\text{SINR} = \frac{|s \cdot H \cdot g|^2}{N' + I}
\]
MIMO-SINR = SINR

- SINR model adds the power of interferers
  \[
  \frac{P_s}{N + \sum_{i \neq s} P_i} \geq \beta
  \]
- Superposition of principle (only) for electrical fields
  \[
  P = \left( \sum_i E_i \right)^2
  \]
- Independent interferences

\[
\mathbb{E} \left[ \sum_{i \neq s} E_i \right]^2 = \mathbb{E} \left[ \sum_{i \neq s} |E_i|^2 \right] = \mathbb{E} \left[ \sum_{i \neq s} P_i \right]
\]
\[ e^{ix} = 1 + ix - \frac{x^2}{2} - \frac{ix^3}{3!} + \frac{x^4}{4!} \ldots \]

\[ \cos x = \text{Re}(\sqrt{1 - x^2}) \]

\[ e^x = 1 + x + \frac{x^2}{2} + \frac{x^3}{3!} \ldots \]

\[ \cos x = 1 - \frac{x^2}{2} + \frac{x^4}{4!} - \frac{x^6}{6!} \ldots \]