Introduction

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Introduction

• Short historical note
• Advantages of multi-antenna techniques
• Adaptive antennas
  – Beamforming: spatial focusing of correlated signals
  – Rx/Tx diversity: combining of decorrelated signals
  – MIMO: increasing spectral efficiency/ data rates
• Simple example: SINR improvement
• Definition of MIMO
• Spatial correlation matrix
• Example: Diversity & MIMO in WCDMA
Historical Note

• Multiple antenna transmission used by Marconi in 1901
  – Four 61m high tower antennas (circular array)
  – Morse signal for "S" from England to Signal Hill, St. John, Newfoundland, distance 3425km

• Submarine sonar during 1910's
• Acoustic sensor arrays 1910's
• RF radars 1940's
• Ultrasonic scanners from 1960's
Advantages of Multiple Antenna Techniques

- Resistivity to fading (quality)
- Increased coverage
- Increased capacity
- Increased data rate
- Improved spectral efficiency
- Reduced power consumption
- Reduced cost of wireless network

Some challenges:
- RF: Linear power amplifiers, calibration
- Complex algorithms: DSP requirements, cost
- Network planning & optimisation

Demonstration by Lucent with 8 Tx /12 Rx antennas:
1.2 Mbit/s in 30kHz
Adaptive Antennas

• An adaptive antenna system consists of several antenna elements, whose signals are processed adaptively in order to exploit the spatial dimension of the mobile radio channel.
Adaptive Antenna Operation

• Conventional BTS:
  – radiation pattern covers the whole cell area

• “Smart” Antenna BTS:
  – adaptive radiation pattern, "spatial filter"
  – transmission/reception only to/from the desired user direction
  – minimise antenna gain to direction of other users
**Beamforming (beam steering)**

- Beamforming = phasing the antenna array elements
- Only Direction-of-Arrival (DOA) parameter needed in both TX and RX: simple and robust
- Suits especially well to FDD systems

![Diagram showing beamforming with DOA1 = 0 deg. and DOA2 = 30 deg.](image-url)
RX Diversity

- De-correlated (statistically independent) signals received
- spatial and polarisation diversity arrangements

- combining of fading signals:
  - Maximum Ratio Combining (MRC)
  - Interference Rejection Combining (IRC)
Transmission Diversity

- Multiple antennas available at the BTS
- Terminal: only one antenna
  -> downlink suffers from lack of diversity

**Downlink:**
Use TX instead of RX diversity

- TX diversity gain:
  - Gain against fading
  - Feedback modes: coherent combining ("beamforming") gain
- Downlink capacity improvement

**RX diversity in terminal is coming soon enabling RX diversity at UE, MIMO, …**

Uncorrelated fading

(1) Gain against fading

(2) Coherent combining gain (only feedback modes)
SISO, SI MO, MI SO, MI MO

- Single-Input, Single-Output channel suffers from fading
- Single-Input, Multiple-Output channel: RX diversity
- Multiple-Input, Single-Output channel: TX diversity, Beamforming
Definition of MIMO

- Multiple-Input, Multiple-Output channel
- Mapping of a data stream to multiple parallel data streams and de-mapping multiple received data streams into a single data stream
- Aims at high spectral efficiency / high data rate

![Diagram of MIMO system]

Data stream → Serial/parallel mapping → MIMO radio channel → Parallel/serial mapping → Data stream

- Requires rich scattering environment

\[ R_{xx}, R_{yy}, H_{MN} \]
Tutorial #2: MIMO Communications with Applications to (B)3G and 4G Systems — Introduction

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**TX diversity & Beamforming vs. MIMO**

**Maximum Gain: Transmit Diversity/ BF**

- Same signal on all antennas, i.e. conventional Tx diversity/ BF

- Maximum Gain: Transmit Diversity/ BF

**Maximum Capacity: Parallel channel transmission**

- Different signals on Tx antennas. i.e. *true* MIMO

- Maximum Capacity: Parallel channel transmission

**BLAST (PARC) type of transmission scheme is considered as MIMO, whereas WCDMA STTD is a hybrid, considered as a Tx diversity scheme**
Channel capacity (Shannon)

- Represents the maximum error-free bit rate
- Capacity depends on the specific channel realization, noise, and transmitted signal power.

- Single-input single-output (SISO) channel
  \[ y(t) = \alpha \cdot x(t) + n(t) \]

- Multi-input multi-output (MIMO) channel
  \[ y(t) = Hx(t) + n(t) \]

\[ C = \log_2 \left( 1 + \frac{P}{\sigma_n^2} |\alpha|^2 \right) \]

\[ C = \log_2 \left[ \det \left( I + \frac{1}{\sigma_n^2} HQH^H \right) \right] \]

\( Q \) is the covariance matrix of the transmitted vector