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

Conventional BTS radiation pattern

Smart Antenna BTS
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
**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)

![Diagram of RX Diversity](image)

**Graph:**
- Received signal power vs. seconds at 3km/h speed
- Lines for 0MRC, 2MRC, 4MRC
- Power levels: -15dB to 10dB

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Tutorial #2: MIMO Communications with Applications to (B)3G and 4G Systems — Introduction

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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, ...

(1) Gain against fading
(2) Coherent combining gain (only feedback modes)
SI SO, 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 showing MIMO channel with serial/parallel mapping and parallel/serial mapping](image_url)

Requires rich scattering environment
**TX diversity & Beamforming vs. MIMO**

**Maximum Gain: Transmit Diversity/ BF**

![Diagram of transmit diversity](image)

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

**Maximum Capacity: Parallel channel transmission**

![Diagram of parallel channel transmission](image)

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

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
  \[ y(t) = \textbf{H}x(t) + \textbf{n}(t) \]

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

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

\( \textbf{Q} \) is the covariance matrix of the transmitted vector