MIMO Propagation Channels

• Elementary Characteristics

• Measurements and What We Learn from Them
  • Multi-antenna equipment
  • Basic observations: double-directional, clusters, diffuse
  • Local variability
  • Channel richness, number of scatterers
  • Time variation – Doppler
  • Polarization

• MIMO Models and Representations
  • MIMO Specials
  • New Challenges
MIMO Measurement

n = 8
m = 2x8

Some signal processing...

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Measurement equipment

Elektrobit PropSound CS™ Channel Sounder

<table>
<thead>
<tr>
<th>Parameter</th>
<th>2.55 GHz</th>
<th>5.25 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmit power [dBm]</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Chip frequency [MHz]</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Channel sampling rate [Hz]</td>
<td>92.6</td>
<td>59.4</td>
</tr>
<tr>
<td>Measurable excess delay [μs]</td>
<td>2.55</td>
<td>2.55</td>
</tr>
</tbody>
</table>
3D Measurements at Mobile Station

32 dual-polarized patch antennas

Helsinki University of Technology, Radio Laboratory

Kimmo Kalliola et al., 2000
Superresolution Direction-of-Arrival
3D Measurement at Base Station
Channel „Photograph“ at 15 cm Wavelength

Power over the Azimuth-Elevation-plane of TX 3

Elevation [°]

Azimuth [°]

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Panoramic Photography

- Orange Labs, Mulhouse
- 2.2 GHz
- 21x21 array
- 360° view

Courtesy J.-M. Conrat, P. Pajusco, A. Dunand, COST 2100 TD(09)901
Panoramic Photography

- Diffraction over rooftop, Single bounce, Double bounce
- Street canyon, Far cluster, Single buildings
- High azimuth spread
- High elevation spread

Courtesy J.-M. Conrat, P. Pajusco, A. Dunand, COST 2100 TD(09)901
Impulse Response and Aggregate Parameters

Spatially resolved complex impulse response

\[ h(t, \tau, \phi) \]

- squared magnitude

\[ |h(t, \tau, \phi)|^2 \]

- averaging over \( t \)

\[ |h(\tau, \phi)|^2 \]

- integrating over azimuth

\[ |h(\phi)|^2 \]

- integrating over delay

rms AS = \( \sigma_\phi \)

- second central moment

Cluster angular spreads

- rms DS = \( \sigma_\tau \)

average ADPS

- delay spread

- angular spread

average PDP

- average APS
Multipath Clusters

- **Clusters** modify the temporal and angular dispersion:

- Global dispersion parameters:
  - rms delay spread
  - (total) rms angular spreads ("composite AS")

- Cluster dispersion parameters:
  - cluster rms delay spread
  - cluster rms angular spreads ("intra-cluster AS", "component AS")
Total RMS Angular Spread?

\[ \text{rmsAS} = \sqrt{\frac{1}{180^\circ} \int_{-180^\circ}^{180^\circ} (\varphi - \bar{\varphi})^2 \text{APS}(\varphi) d\varphi} \]

- \text{rmsAS} = 20^\circ = 20^\circ!
- Much better: angular spread for each cluster

„component“ angular spread

PhD thesis Kuchar 1999
APS along sample route (microcell)
Observed MIMO effects

- DOA depends on DOD => double-directional
- DOAs and DODs different for different delays
- Strong discrete multipath components, which appear in… clusters, plus… diffuse power
- As a consequence, the benefits of MIMO exhibit
  - local variation
  - time dependence
  - frequency-selectivity
- Dual polarization can be exploited
The Double-directional Propagation Channel

Radio Channel

"Single-directional" Channel for DOAs

Double-directional Propagation Channel

h(t, τ, φ_R, θ_R, φ_T, θ_T)

h(t, τ)

M_T

DODs

DOAs

scatterers

M_R

TX-Site

RX-Site

M. STEINBAUER, COST259 TD(98)027, Feb.1998, Berne, Switzerland
M. STEINBAUER et al., IEEE VTC-2000-Spring, Tokyo, May 15-18, 2000
M. STEINBAUER et al., IEEE AP Magazine, August 2001, pp. 51-63
Double-directional View Point

- Essential for MIMO - System design, modeling, and deployment
- Impulse response as a function of DOAs and DODs
- Data acquisition: direction-capability by antenna arrays at both link ends
- Separates the propagation environment from the antenna configuration used
- What is a “direction of departure”? For instance, with an omnidirectional antenna?
A DoD terminates in a DoA!

- Indoor, office building, thick brick and light walls
- 8-element Rx antenna with backplane
- 8 dipole Tx antenna
- NLOS
- RX-TX distance: 18m
Diffuse Multipath Component

Blue: measured IR
Red: discrete multipath

Blue: measured IR minus discrete multipath
Red: diffuse multipath (est.)

PhD thesis
A. Richter, TU Ilmenau, 2005

Is DMC spatially white? F.Quitin et al, EuCAP 2010 say „NO“
Mutual Information is a locally varying phenomenon!

8x8 MIMO

5.2 GHz

Indoor office

Average over all frequencies, RX2/D1
Average Mutual Information

Direction to transmit matrix

Window

outer wall

Corridor

Door

SNR = 10

Not accessible

13.9 10
14.1 11
15.7 15

6.2 4
6.3 4.3
6.1 4.7

11.5 4.4
14.9 4.5
9.9 11.2

4.4
4.5
4.7
4.3

2.3
8.8
8.1

8.1
4.5
4.5

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MIMO Propagation Channels
5.2 GHz Pathloss

Direction to transmit matrix

Corridor

Door

Not accessible

Window

outer wall

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Another Myth: One can set the SNR to arbitrary values

- Theoreticians’ darling

- Only if you had unlimited TX power available (or sophisticated TPC)

- What is more important for mutual information $MI$?
  - High received power (SNR = $\gamma$) or „LOS“
  - channel „richness“ „NLOS“

$$MI = \log_2 \left( \det \left[ I_{n_R} + \frac{\gamma}{n_T} HH^H \right] \right) \text{bits / s / Hz}$$
**Channel richness**

Within the same environment, received power dominates capacity, but...

Reference position
SNR=10dB
8x8 MIMO
Özcelik et al.
ICEAA Torino 2003

A.G. Burr
ICEAA Torino 2003

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Time-variation by human shadowing

- Strong variation only when people interrupt dominant paths (e.g. LOS)

5.3 GHz, 8x8 MIMO
Office

2.45 GHz
Normalized to 10dB
Doppler spectrum

- IEEE 802.11n
- Indoor Doppler (stationary terminals, moving people)
Doppler in car2car channels

Acosta-Marum & Ingram 2007:
Polarization

- Obviously advantageous – small space
- Co-located perpendicularly-polarized antennas
- Metrics
  - XPD (cross-Polarization Discrimination)
  - CPR (Co-Polarization Ratio)

- But beware!
- Capacity up (pattern diversity), capacity down by sharing the power between two polarizations
- Distinguish between
  - Antenna XPD (cross-polarization discrimination)
  - Environment XPD, actually depolarization
Fresnel’s Formulas - Reflection

\[ |\Gamma| \]

\[ \text{streifender Einfall} \]

\[ \text{TM-Fall (p-Polarisation)} \]

\[ \text{TE-Fall (p-Polarisation)} \]

\[ \text{senkrechter Einfall} \]

\[ \arg(\Gamma) \]

\[ \text{streifender Einfall} \]

\[ \text{senkrechter Einfall} \]

\[ \text{TM-Fall (p-Polarisation)} \]

\[ 0.3\% \]

\[ 10\% \]

\[ 20\% \]

\[ 30\% \]
Depolarization by reflection

\[ E_{c}(t) \]

\[ E_{c,TE}(t) \]

\[ E_{c,TM}(t) \]

\[ \theta \text{...Einfallswinkel} \]

\[ x' \equiv \text{TE}, \ y' \equiv \text{TM} \]

\[ \text{elliptische Polarisation (} \delta \phi \neq 0) \]

\[ \Gamma_{TE}, \Gamma_{TM} \text{ komplex} \]

\[ E_{r,TE} = E_{c,TE} \Gamma_{TE} \]

\[ E_{r,TM} = E_{c,TM} \Gamma_{TM} \]

\[ x'' \equiv \text{TE}, \ y'' \equiv \text{TM} \]
Polarization channel characterization

- Received multipath as seen from RX
- numbered and colored by delay
- signal strength indicated by dot size

by courtesy of B. Fleury et al. 2000, 2002
Polarization channel characterization

TX horizontally polarized

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Received multipath as seen from RX
numbered and colored by delay
signal strength indicated by dot size

Polarization channel characterization
by courtesy of B. Fleury et al. 2000, 2002

TX horizontally polarized
Polarization channel characterization

TX vertically polarized

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