“Testbedding” MIMO HSDPA versus WiMAX

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Outline

- **MIMO Testbed**
- **WiMAX Measurements**
  - signal generation and reception
  - IEEE 802.16-2004 (Section 8.3) with OFDM physical layer
  - feedback realization
  - achievable and measured throughput
- **HSDPA Measurements**
  - signal generation and reception
  - feedback realization
  - achievable and measured throughput
- **Conclusion**
Evaluating MIMO radio communication

- theoretically
- by pure simulation
- by channel sounding
- utilizing a testbed
- utilizing a prototype
- using the final product

degree of realism effort
MIMO Testbed [T1,T2]

Data is created and evaluated in Matlab ...

Number of Antennas

4x4

Bandwidth:

2.5 GHz

Center Frequency:

5 MHz

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MIMO Testbed [T1,T2]

- **MIMO WiMAX 802.16-2004**
  - OFDM physical layer
    - including channel coding and decoding
    - SISO and MIMO

- **MIMO HSDPA (TxAA, DTxAA)**
  - CDMA physical layer
    - including channel coding and decoding
    - SISO and MIMO
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Adaptive Modulation and Coding (AMC)

- **Encoding**
  - concatenated Reed-Solomon / convolutional code
  - puncturing depending on AMC information
  - optional block/convolutional turbo coding
  - Alternatively: LDPC coding

- **Adaptive symbol mapping**

- **Optional Alamouti space-time coding**
## Coding and Modulation

<table>
<thead>
<tr>
<th>AMC value</th>
<th>Modulation</th>
<th>RS Code Rate</th>
<th>CC Rate</th>
<th>Overall Code Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2-PAM</td>
<td>1</td>
<td>1/2</td>
<td>1/2</td>
</tr>
<tr>
<td>2</td>
<td>4-QAM</td>
<td>3/4</td>
<td>2/3</td>
<td>1/2</td>
</tr>
<tr>
<td>3</td>
<td>4-QAM</td>
<td>9/10</td>
<td>5/6</td>
<td>3/4</td>
</tr>
<tr>
<td>4</td>
<td>16-QAM</td>
<td>3/4</td>
<td>2/3</td>
<td>1/2</td>
</tr>
<tr>
<td>5</td>
<td>16-QAM</td>
<td>9/10</td>
<td>5/6</td>
<td>3/4</td>
</tr>
<tr>
<td>6</td>
<td>64-QAM</td>
<td>8/9</td>
<td>3/4</td>
<td>2/3</td>
</tr>
<tr>
<td>7</td>
<td>64-QAM</td>
<td>9/10</td>
<td>5/6</td>
<td>3/4</td>
</tr>
</tbody>
</table>
OFDM Frame Structure

- 3 OFDM symbols preamble
  1. Synchronization
  2. Channel estimation
  3. Control information

- Subcarrier distribution
  - 192 data subcarriers
  - 8 pilot subcarriers
  - 1 zero DC subcarrier
  - 55 guard band subcarriers
  - → 256 total
OFDM Modulation and Demodulation
Measurement Setup [W2]

- 3 scenarios
  1. NLOS, outdoor-to-indoor
  2. NLOS, outdoor-to-outdoor
  3. LOS, outdoor-to-indoor

- Parameters
  - 5 MHz channel bandwidth
  - Cyclic prefix 1/4
  - 192 carrier OFDM
  - Rx antenna distance 1.2λ
  - Tx antenna distance: 2.75λ
  - Tx antenna height: 16m

Measurement distance: 50-100m
1. SIMO, 7 AMC schemes, 3 bit feedback
2. MIMO with Alamouti, 7 AMC schemes, 3 bit feedback
3. MIMO with spatial multiplexing, **same** coding scheme on both antennas, 3 bit feedback
4. MIMO with spatial multiplexing, **individual** coding schemes on both antennas, 6 bit feedback
Measured Channel Coefficients [W2]

Duration of measurements: ~200ms
One Receive Antenna: NLOS outdoor-to-outdoor [W2]
One Receive Antenna: NLOS outdoor-to-indoor [W2]
One Receive Antenna: Conclusions [W2]

- The measured scenarios behave asymmetric with respect to the transmit antenna.
- If channel is known at the transmitter, antenna selection can improve the performance.
- Alamouti loses (slightly) compared to single antenna transmission:
  - more sensitive channel estimation errors
  - 3dB less power for training
  - Asymmetric scenario
- Huge gap of >10dB between measured and achievable throughput!
Two Receive Antennas MRC: LOS outdoor-to-indoor \([W2]\)
Two Receive Antennas: LOS outdoor-to-indoor [W2]
Two Receive Antennas: LOS outdoor-to-indoor [W2]

![Graph showing achievable throughput vs. transmit power for different transmission schemes.]

- achievable throughput
- dual Tx
- single Tx (1)
- single Tx (2)
- best of all schemes
- 1x2
- 2x2 SM, 6 bit
- 2x2 Alamouti
- 2x2 SM, 3 bit

throughput [Mbit/s]

transmit power [dBm]
Spatial multiplexing with 6 bit feedback outperforms spatial multiplexing with 3 bit feedback
  – The 6 bit feedback allows to exploit the asymmetric channels
Alamouti is better than spatial multiplexing with 3 bit feedback due to transmit diversity
Still, a huge gap of >10 dB between measured and achievable throughput is observed!

- **Enhancements**
  – Better channel coding
    - e.g. Low Density Parity Check (LDPC) codes
  – Enhanced channel estimation techniques
    - e.g. LMMSE channel estimation to exploit correlation between subcarriers
AWGN Performance of the Reed Solomon-Conv.Coder
AWGN Performance of LDPC codes
SNR Gain of Improved Channel Estimators over the LS Estimator [W1]

<table>
<thead>
<tr>
<th>Scenario 1</th>
<th>LMMSE</th>
<th>genie-driven</th>
</tr>
</thead>
<tbody>
<tr>
<td>1x1 SISO</td>
<td>0.6 dB</td>
<td>1.2 dB</td>
</tr>
<tr>
<td>2x1 Alamouti</td>
<td>1.8 dB</td>
<td>2.9 dB</td>
</tr>
<tr>
<td>1x2 SIMO</td>
<td>0.5 dB</td>
<td>1.2 dB</td>
</tr>
<tr>
<td>2x2 Alamouti</td>
<td>1.9 dB</td>
<td>3.2 dB</td>
</tr>
<tr>
<td>2x2 Spatial Multiplexing (3 bit)</td>
<td>1.4 dB</td>
<td>2.4 dB</td>
</tr>
<tr>
<td>2x2 Spatial Multiplexing (6 bit)</td>
<td>1.1 dB</td>
<td>2.2 dB</td>
</tr>
</tbody>
</table>
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Channel adaptation is performed by means of
- a Channel Quality Indicator (CQI) and
- a Precoding Control Indicator (PCI) when two transmit antennas are available
Transmission Timing [H4]

- Large number of possible transmit blocks require channel evaluation at the receiver
- Minireceiver estimates channel and noise and calculates the CQI and PCI
The post equalization SINR is given by

\[
\text{SINR}_{\text{est}} = \frac{P_s}{\sigma_{n'}^2 + P_{\text{ISI}} + P_{\text{INT}}} 
\]

SINR is calculated for all possible precoding vectors and mapped to the supported CQI values. The precoding vector maximizing the transport block size is selected.
Verification of the SINR Estimation in the Simulation [H5]
Simulation and Measurement Results

**Simulation**
Uncorrelated ITU Pedestrian B channel

**Measurement**
Outdoor-to-indoor scenario

Graphs showing the relationship between throughput [Mbit/s] and post equalization SINR [dB] vs. \( I_{or}/I_{oc} \) [dB] and total transmit power [dBm]. The graphs compare various antenna configurations, including 2x2 D-TxAA, 2x2 TxAA, 1x2 SIMO, and 2x1 TxAA.
Conclusion

- WiMAX suffers from inferior channel coding
  - 5dB can be gained in SNR by using an out-of-the-box LDPC code
  - Before deploying MIMO in WiMAX systems one should consider using advanced channel coding schemes

- Channel estimation is a key issue for MIMO WiMAX
  - Enhanced channel estimators can easily gain ~2 dB in the case of 2x2 Alamouti transmission

- SINR metrics used in HSDPA system simulations do not consider a saturation at high SINR.
  - Refined SINR metrics are required to increase the accuracy of system simulations.
Thank you for your attention.

http://www.nt.tuwien.ac.at/
Testbed References


HSDPA References


WiMAX References
