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Mobile WiMAX: Downlink Performance Analysis with Adaptive MIMO Switching

Mai Tran, David Halls, Andrew Nix, Angela Doufexi and Mark Beach
Introduction

• Mobile WiMAX supports a number of MIMO techniques. These include space time block coding (STBC), spatial multiplexing (SM) and eigen-beamforming (EBF)

• This paper investigates the MIMO Mobile WiMAX downlink performance in terms of PER, throughput, and operating range

• Adaptive MIMO Switching (AMS) is used to determine the most appropriate MIMO technique based on range, throughput, and PER

• Performance results are presented for both spatially uncorrelated and correlated channels
Mobile WiMAX Description (1)

- Mobile WiMAX builds on the principles of Scalable OFDMA
- SOFDMA supports a wide range of bandwidths (1.25, 5, 10, and 20 MHz) by varying the FFT size from 128 to 512, 1024 and 2048

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFT Size</td>
<td>128</td>
</tr>
<tr>
<td></td>
<td>512</td>
</tr>
<tr>
<td></td>
<td>1024</td>
</tr>
<tr>
<td></td>
<td>2048</td>
</tr>
<tr>
<td>Channel Bandwidth (MHz)</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Subcarrier frequency spacing (kHz)</td>
<td>10.94</td>
</tr>
<tr>
<td>Useful OFDMA symbol period (µs)</td>
<td>91.4</td>
</tr>
<tr>
<td>Guard time</td>
<td>1/32, 1/16, 1/8, 1/4</td>
</tr>
</tbody>
</table>
Mobile WiMAX PHY Description (2)

- Channel bandwidth: 5 MHz (FFT size 512)
- Distributed subcarrier allocation (PUSC)
- There are 3 users, each allocated one third of the total bandwidth
- Channel coding: Convolution code 1/2, 2/3 and 3/4 rate
- Modulation: QPSK, 16QAM, 64QAM
- Channel: 3GPP Spatial Channel Model
- MIMO schemes: 2 x 2 Space Time Block Coding (STBC), Spatial Multiplexing (SM), and eigen-beamforming (EBF)
MIMO Implementation

• Open-loop techniques do not require Channel State Information (CSI) at the Tx:
  1. $M \times N$ Space Time Block Coding (STBC) – standard technique used to improve robustness
  2. $M \times N$ Spatial Multiplexing (SM) – standard technique used to increase throughput (requires equaliser at RX)

• Closed-loop techniques use CSI at the Tx to create $\min(M, N)$ independent parallel ‘eigen-channels’:
  3. $M \times N$ Dominant eigen-beamforming (SVD DE) – uses ‘dominant eigen-channel’ to improve robustness
  4. $M \times N$ SM eigen-beamforming (SVD SM) – uses all ‘eigen-channels’ to increase throughput
The received signal at the MS consists of 6 time-delayed multipath replicas of the transmitted signal. Each path consists of 20 subpaths.
MIMO Wideband Channel Model: Channel assumptions

- Urban micro tap delay line (TDL) with 6 non-uniform delay taps
- MS velocity of 40 km/h
- Omni antenna elements separation at half a wavelength

<table>
<thead>
<tr>
<th></th>
<th>Tap 1</th>
<th>Tap 2</th>
<th>Tap 3</th>
<th>Tap 4</th>
<th>Tap 5</th>
<th>Tap 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay (ns)</td>
<td>0</td>
<td>210</td>
<td>470</td>
<td>760</td>
<td>845</td>
<td>910</td>
</tr>
<tr>
<td>Power (dB)</td>
<td>0</td>
<td>-1.8</td>
<td>-1.5</td>
<td>-7.2</td>
<td>-10</td>
<td>-13</td>
</tr>
<tr>
<td>K factor</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Delay spread</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>279 ns</td>
</tr>
</tbody>
</table>

MIMO wideband channel model parameters
Simulation Performance Analysis

- Our paper analyses (for both high and low spatial correlation):
  - PER vs. SNR for different MIMO schemes
  - Throughput vs. SNR for different MIMO schemes
  - Throughput vs. operating range for different MIMO schemes (using WI with $P_T=43$dBm and $G_T=15$dBi)
  - The Adaptive MIMO Switching (AMS) algorithm decision points (i.e. SNR and BS-MS distance thresholds)
PER vs. SNR for various MIMO schemes (low $\rho$)

- SVD SM outperforms open-loop SM, at $10^{-2}$ PER:
  - For 16QAM ½ the gain is 7dB
  - For 16QAM ¾, the gain is only 2.5dB (much less diversity gain than ½ rate)

- SVD DE outperforms STBC, at $10^{-2}$ PER:
  - For 16QAM ½ there is an array gain of 2.5 dB
  - Both schemes achieve a diversity order of 4
Tput vs. SNR for different MIMO schemes (low $\rho$)

- Throughput is calculated based on a 10% PER threshold
- For 16QAM $\frac{1}{2}$, SVD DE requires 3dB less than STBC for same Tput
- For 16QAM $\frac{1}{2}$ SVD SM requires 3dB less SNR to operate compared to open-loop SM
- For 16QAM $\frac{1}{2}$, SVD SM can double the SISO Tput at 15dB SNR
- Open-loop SM requires 25dB SNR to achieve this
**Tput vs. distance, low channel correlation ($\rho$)**

- Individual envelopes generated using Adaptive Modulation and Coding
- Adaptive MIMO Switching is used to select the optimal MIMO mode
- SVD SM is optimum < 520 m, SVD DE is optimum > 520m
- Open-loop MIMO modes not selected (assumes ideal channel feedback)
**PER vs. SNR for different correlations (\(\rho\))**

- **MIMO uncorrelated channel (\(\rho=0.16\))**
- **MIMO correlated channel (\(\rho=0.8\))**

- 3 dB worse
- 2.5 dB worse
- 7 dB worse
The switching point in the highly correlated MIMO channel is reduced from 520m to 440m.
### Operating range comparison

<table>
<thead>
<tr>
<th>MIMO Scheme</th>
<th>$p=0.16$</th>
<th>$p=0.8$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$d_{\text{max}}$ (m)</td>
<td>SNR (dB)</td>
</tr>
<tr>
<td>SISO</td>
<td>780</td>
<td>9</td>
</tr>
<tr>
<td>SM</td>
<td>640</td>
<td>12</td>
</tr>
<tr>
<td>STBC</td>
<td>1295</td>
<td>0.57</td>
</tr>
<tr>
<td>SVD SM</td>
<td>780</td>
<td>9</td>
</tr>
<tr>
<td>SVD DE</td>
<td>1504</td>
<td>-1.89</td>
</tr>
</tbody>
</table>

Operating range comparison for different MIMO modes and correlations

- Both eigen-beamforming solutions improve the maximum range
- Relative to STBC, the range of SVD DE is improved by 210m (16%)
Conclusions

• The PER, throughput and operating range of both open and closed-loop MIMO Mobile WiMAX scenarios was analysed for two levels of channel correlation

1. Simulations show that an ideal AMS algorithm will always choose the closed-loop techniques (perfect CSI) over the open-loop ones
   • At low SNR, SVD DE is the most robust MIMO mode
   • At high SNR, AMS should be used to switch to SVD SM to maximise throughput

2. The AMS switching point depends on channel correlation

3. In practise: feedback overhead, imperfect CSI, and delayed CSI will reduce the overall Tput making open-loop techniques preferable in certain circumstances
Any Questions?

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