Performance Evaluation of Mobile WiMAX with MIMO and Relay Extensions

Y. Q. Bian, A. R. Nix, Y. Sun, P. Strauch

{y.q.bian, andy.nix}@bristol.ac.uk
{yong.sun, paul.strauch}@toshiba-trel.com
Introduction

- WiMAX profiles and PHY air-interface
- Suitable cellular channel models
- Performance for urban micro and macro cells
- Relay-based MIMO mobile WiMAX
- Conclusions
Mobile WiMAX System Profiles

- Mobile WiMAX adopts SOFDMA for improved multi-path performance in NLoS environments
- Currently, WiMAX operation is limited to licensed bands below 6 GHz (IEEE802.16e)
- The WiMAX Forum has proposed a number of profiles
  - These cover variable bandwidths (5, 7, 8.75 and 10 MHz)
  - In worldwide bands at 2.3, 2.5, 3.3 and 3.5 GHz
- This paper focuses on the evaluation of 512-FFT OFDMA in a 5 MHz bandwidth at 3.5 GHz
MIMO-OFDMA

- 802.16e supports Adaptive Modulation and Coding – AMC. This covers $\frac{1}{2}$ rate QPSK to $\frac{3}{4}$ rate 64QAM and also includes smart antenna technologies.
SOFDMA offers flexibility for multi-user radio resource allocation

Assigned clusters (sub-carriers) for each user are spread over the channel bandwidth. Frequency diversity can be fully exploited for all users
WINNER Channel Model

- The WINNER channel model is an evolution of the 3GPP2 SCM channel. This is commonly used to characterise cellular mobile environments
  - Urban micro ($\leq 1$ km distance BS to BS)
  - Urban macro (3 km distance BS to BS)
  - Sub-urban macro (3 km distance BS to BS)
- Key features include:
  - MSs are randomly deployed within each cell
  - Each BS-MS link undergoes fast fading (determined by MS mobility), path-loss and shadowing
  - Consists of multiple cells, sectors, BSs and MSs, as opposed to link-level simulations (where only a single BS-MS link is studied)
# Environment Parameters

<table>
<thead>
<tr>
<th>Channel Scenario</th>
<th>Suburban Macro</th>
<th>Urban Macro</th>
<th>Urban Micro</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of paths (N)</strong></td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td><strong>Number of sub-paths (M) per-path</strong></td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>
| **Mean AS at BS** | $E(\sigma_{AS})=5^\circ$  
$\mu_{AS}=0.69$  
$\epsilon_{AS}=0.13$ | $E(\sigma_{AS})=8^\circ$, $15^\circ$  
$\mu_{AS}=0.810$  
$\epsilon_{AS}=0.34$  
$\epsilon_{AS}=0.18$ | NLOS: $E(\sigma_{AS})=19^\circ$  
N/A |
| **AS at BS as a lognormal RV** | $\sigma_{AS}=10^\pm(\epsilon_{AS}+\mu_{AS})$, $x \sim \eta(0,1)$ | $\sigma_{AS}=10^\pm(\epsilon_{AS}+\mu_{AS})$, $x \sim \eta(0,1)$ | $\sigma_{AS}=10^\pm(\epsilon_{AS}+\mu_{AS})$, $x \sim \eta(0,1)$ |
| **r_{AS} = \sigma_{AS} / \sigma_{DS}** | 1.2 | 1.3 | N/A |
| **Per-path AS at BS (Fixed)** | 2 deg | 2 deg | 5 deg (LOS and NLOS) |
| **BS per-path AoD Distribution standard distribution** | $\eta(0, \sigma_{\text{AoD}}^2)$ where $\sigma_{\text{AoD}}^2 = r_{AS}^2 \sigma_{AS}^2$ | $\eta(0, \sigma_{\text{AoD}}^2)$ where $\sigma_{\text{AoD}}^2 = r_{AS}^2 \sigma_{AS}^2$ | $\eta(0, \sigma_{\text{AoD}}^2)$ where $\sigma_{\text{AoD}}^2 = r_{AS}^2 \sigma_{AS}^2$ |
| **Mean AS at MS** | $E(\sigma_{AS,MS})=68^\circ$ | $E(\sigma_{AS,MS})=68^\circ$ | $E(\sigma_{AS,MS})=68^\circ$ |
| **Per-path AS at MS (Fixed)** | 35$^\circ$ | 35$^\circ$ | 35$^\circ$ |
| **MS Per-path AoA Distribution** | $\eta(0, \sigma_{\text{AoA}}^2(Pr))$ | $\eta(0, \sigma_{\text{AoA}}^2(Pr))$ | $\eta(0, \sigma_{\text{AoA}}^2(Pr))$ |
| **Delay spread as a lognormal RV** | $\sigma_{DS}=10^\pm(\epsilon_{DS}+\mu_{DS})$, $x \sim \eta(0,1)$ | $\sigma_{DS}=10^\pm(\epsilon_{DS}+\mu_{DS})$, $x \sim \eta(0,1)$ | $\sigma_{DS}=10^\pm(\epsilon_{DS}+\mu_{DS})$, $x \sim \eta(0,1)$ |
| **$\mu_{DS} = 6.60$**  
$\epsilon_{DS} = 0.289$ | $\mu_{DS} = 6.18$  
$\epsilon_{DS} = 0.18$ | N/A |
| **Mean total RMS Delay Spread** | $E(\sigma_{DS})=0.17 \mu s$ | $E(\sigma_{DS})=0.65 \mu s$ | $E(\sigma_{DS})=0.251 \mu s$ (output) |
| **$r_{DS} = \sigma_{\text{Delay}} / \sigma_{DS}$** | 1.4 | 1.7 | N/A |
| **Distribution for path delays** | $\eta(0, 1.2 \mu s)$ | $\eta(0, 1.2 \mu s)$ | N/A |
| **Lognormal shadowing standard deviation, $\sigma_{\text{SF}}$** | 8dB | 8dB | NLOS: 10dB  
LOS: 4dB |
| **Pathloss model (dB), $d$ is in meters** | $31.5 + 35 \log_10(d)$ | $34.5 + 35 \log_10(d)$ | NLOS: $34.53 + 38 \log_10(d)$  
LOS: $30.18 + 25 \log_10(d)$ |
Due to the path-loss and shadowing at large separation distances, the received power in a macro-cell is seriously reduced compared to microcells.

To ensure system QoS, 802.16 defines a minimum receive power, e.g., \( \frac{1}{2} \) QPSK requires -86 dBm for 5MHz channels (SNR = 9.4 dB)

Typically, an EIRP of 55~57 dBm is acceptable by licensed regulation. QoS cannot be improved by an unlimited increase in transmitter power
Link-Budget for Downlink

\[ SNR = P_r + 10 \log_{10} \left( \frac{F_s \cdot N_{\text{used}}}{N_{\text{FFT}}} \right) \]

\[ R_{ss} = -86 \text{dBm for } \frac{1}{2} \text{ QPSK in 5MHz} \]

\[ -102 \text{dBm} \]

5dB implementation margin
7dB noise figure
KTB

\[ R_{ss} \] Receiver minimum input level sensitivity

\[ EIRP = 55 \text{dBm} \]

15dBi antenna gain

Pathloss

Shadowing

Multipath channel

(IST-Winner)

Receiver

(ieee802.16e)

Transmitter

(Ofcom regulation)

\[ P_t = 40 \text{dBm} \]
Spatial Multiplexing (SM) can increase link capacity only at high SNR. 802.16e struggles to exploit SM in large cells (especially at the cell edge).

STBC offers diversity gain and can be used to extend coverage.
System Performance

- Even with transmit diversity, the macrocell environment experiences a 25% outage probability (in the 3rd zone the throughput is 3.46 Mbps and 42% of users fail to connect).
- With transmit diversity, satisfactory coverage can be achieved for a cell radius of up to 1km.

<table>
<thead>
<tr>
<th></th>
<th>Urban micro SISO</th>
<th>Urban macro SISO</th>
<th>Urban micro 2x1</th>
<th>Urban macro 2x1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2 QPSK</td>
<td>23%</td>
<td>7%</td>
<td>21%</td>
<td>20%</td>
</tr>
<tr>
<td>3/4 QPSK</td>
<td>-</td>
<td>9%</td>
<td>13%</td>
<td>15%</td>
</tr>
<tr>
<td>1/2 16-QAM</td>
<td>16%</td>
<td>10%</td>
<td>11%</td>
<td>14%</td>
</tr>
<tr>
<td>3/4 16-QAM</td>
<td>11%</td>
<td>14%</td>
<td>8%</td>
<td>9%</td>
</tr>
<tr>
<td>2/3 64-QAM</td>
<td>6%</td>
<td>6%</td>
<td>4%</td>
<td>3%</td>
</tr>
<tr>
<td>3/4 64-QAM</td>
<td>29%</td>
<td>49%</td>
<td>10%</td>
<td>14%</td>
</tr>
<tr>
<td>Outage probability</td>
<td>15%</td>
<td>5%</td>
<td>33%</td>
<td>25%</td>
</tr>
<tr>
<td>System throughput (Mbps)</td>
<td>8.7</td>
<td>11.7</td>
<td>5.4</td>
<td>6.3</td>
</tr>
</tbody>
</table>

EIRP = 55dBm
Relay-based WiMAX System

- Relay systems are well-suited for areas with low throughput, or high outage probabilities. Relaying is currently under consideration within the 802.16j study group.
- For practical relay deployment, the Relay Station (RS) should be applied to cover coverage holes.
MIMO WiMAX with Relay Extension

- When the cell radius exceeds 1km, it is difficult to meet the target of 90% coverage (especially in the 3\textsuperscript{rd} zone)
- With relays, both capacity and coverage are enhanced
- The benefits of relaying are much larger in the 3\textsuperscript{rd} zone (see table below)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-relay</td>
<td>11.7</td>
<td>95%</td>
<td>7.3</td>
<td>87%</td>
<td>3.5</td>
<td>58%</td>
</tr>
<tr>
<td>With relay</td>
<td>n/a</td>
<td>n/a</td>
<td>14.2</td>
<td>98%</td>
<td>14.2</td>
<td>98%</td>
</tr>
<tr>
<td>Relay gain</td>
<td>n/a</td>
<td>n/a</td>
<td>95%</td>
<td>11%</td>
<td>305%</td>
<td>40%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-relay</td>
<td>14.1</td>
<td>98%</td>
<td>12.3</td>
<td>98%</td>
<td>8.1</td>
<td>86%</td>
</tr>
<tr>
<td>With relay</td>
<td>n/a</td>
<td>n/a</td>
<td>15.6</td>
<td>~100%</td>
<td>15.6</td>
<td>~100%</td>
</tr>
<tr>
<td>Relay gain</td>
<td>n/a</td>
<td>n/a</td>
<td>27%</td>
<td>2%</td>
<td>93%</td>
<td>14%</td>
</tr>
</tbody>
</table>

Cap.: Capacity (Mbps); Cov.: Coverage; relay zone: 300m

Average throughput: 14.24 Mbps
Conclusions

- MIMO enabled mobile WiMAX was evaluated using the IST-WINNER channel models
- For microcells, 2x1 STBC combined with AMC achieved a good level of performance (11.7 Mbps of throughput with 95% coverage)
- For macrocells, the system failed to meet the target of 90% coverage, even exploiting 2x2 STBC
- Relay-based WiMAX in combination with MIMO-STBC (2x1 and 2x2) is able to achieve near ideal coverage
Thanks

Yan Bian, Andrew Nix, Yong Sun, Paul Strauch
y.q.bian@bristol.ac.uk