Tran, M., Halls, DE., Nix, AR., Doufexi, A., & Beach, MA. (2009). Mobile WiMAX: MIMO performance analysis from a Quality of Service (QoS) viewpoint. In IEEE Wireless Communications and Networking Conference (WCNC2009), Budapest, Hungary (pp. 1 - 6). Institute of Electrical and Electronics Engineers (IEEE). https://doi.org/10.1109/WCNC.2009.4917808

Peer reviewed version

Link to published version (if available):
10.1109/WCNC.2009.4917808

Link to publication record in Explore Bristol Research
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Mobile WiMAX: MIMO Performance Analysis from a Quality of Service (QoS) Viewpoint

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Introduction and Objectives

- Mobile WiMAX supports a wide range of applications with different QoS requirements
- TCP-based applications (e.g., web browsing) can tolerate a relatively high PHY PER due to the use of Automatic-Repeat-reQuest (ARQ) to resend lost packets
- In contrast, UDP-based applications (e.g., real-time video) cannot afford the latency induced by ARQ and thus require a very low PER
- This paper analyses how the difference in required PHY PER results in differences in the achievable throughput and operating range for a mobile WiMAX system
Mobile WiMAX Description: Medium Access Control (MAC) layer

- In the mobile WiMAX MAC:
  - Higher layer packets from a range of applications (i.e. voice, video and web browsing) are classified into unique service flows.
  - Each service flow is associated with a unique set of QoS parameters: latency, throughput, max ARQ etc.
  - Service flows are mapped to different scheduling services: Unsolicited Grant Service (UGS), real-time Polling Service (rtPS), non real-time Polling Service (nrtPS) and Best Effort (BE).
  - Each MS can support multiple applications over multiple logical connections, each with different QoS.
Mobile WiMAX Description: Physical (PHY) Layer

- 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>128 512 1024 2048</td>
</tr>
<tr>
<td>Channel bandwidth (MHz)</td>
<td>1.25 5 10 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

Key simulation parameters

- 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 scheme: 2 x 2 Space Time Block Coding (STBC), Spatial Multiplexing (SM), and Eigen Beamforming
Considered MIMO Techniques

• Open-loop MIMO
  • Space-Time Block Coding: Alamouti scheme
  • Spatial Multiplexing: 2 x 2 SM with MMSE reception

• Closed-loop MIMO – Eigen Beamforming
  • Eigen beamforming uses Singular Value Decomposition (SVD) to transform a MIMO channel into $N$ equivalent SISO Eigen-channels
  • Diversity can be achieved by transmitting data over the strongest Eigen-channel: Dominant Eigen beamforming (SVD DE)
  • Spatial multiplexing can be achieved by transmitting data over parallel Eigen-channels: SVD SM
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>279 ns</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Simulation Performance Analysis

• The paper analyses:
  • PER for different MIMO schemes
  • Achievable throughput for TCP and UDP-based applications
  • Achievable operating range for TCP and UDP-based applications
  • SNR thresholds used in the AMC scheme for TCP and UDP-based applications
Simulation Performance Analysis:
PER versus SNR for different MIMO techniques

- SVD SM offers a large improvement compared with SM
- For 16QAM 1/2 and 3/4 rate, at $10^{-2}$ PER, the gain is 7dB and 2.5 dB, respectively. Note there is little diversity gain for the 3/4 code rate
- SVD DE outperforms STBC. For 16QAM 1/2, at $10^{-2}$ PER, there is an array gain of 2.5 dB. No diversity gain is achieved when compared with STBC
Simulation Performance Analysis: Throughput and operating range analysis

- Different PER thresholds are used to determine the achievable throughputs and operating range for TCP and UDP applications.
- 10% PER is considered the highest acceptable for TCP applications (web browsing and FTP); any PER in excess of this value is assumed too severe to maintain a practical data link.
- For UDP applications (real time voice and video) a PER threshold of 1% is assumed.

```plaintext
[voice] 1% PER (UDP)
[video] 10% PER (TCP)
[web browsing]
[FTP]
```
Simulation Performance Analysis: Throughput and operating range analysis – SM 2x2

- AMC used to adjust the link-speed depending on received SNR and threshold PER
- Compared with the 1% PER case, the 10% case:
  - achieves: a higher throughput, a higher operating range
  - requires lower minimum SNR to operate
  - achieves a higher maximum achievable range
Simulation Performance Analysis: Throughput and operating range analysis – STBC 2x2

- At SNR < 18dB or distance > 450m, we observe the same trend as in SM 2x2
- At SNR > 18dB, or distance < 450m, both PER thresholds achieve the same max throughput. The reason is that STBC allows both types of applications to run at the highest MCS mode (64QAM 3/4 rate) and still guarantee the PER threshold
Simulation Performance Analysis: Throughput and operating range analysis – SVD SM

SM and SVD SM 2x2 Throughput vs. SNR envelope

SM and SVD SM 2x2 Throughput vs. distance envelope
Simulation Performance Analysis: Throughput and operating range analysis – SVD DE

STBC and SVD DE 2x2 Throughput vs. SNR envelope

STBC and SVD DE 2x2 Throughput vs. distance envelope
Conclusion

• A detailed study of the throughput and operating range of MIMO enabled mobile WiMAX was presented for two different PHY PER QoS thresholds.

• The results show that TCP applications achieve a higher throughput and a longer operating range when compared with UDP applications. This means that voice and video applications will fail before web browsing and FTP applications.

• UDP applications require higher SNR in order to switch to the same link speed as TCP applications. This demonstrates the importance of cross-layer interaction when determining the AMC switching points: the system needs to know the SNR from the PHY layer and the QoS from the higher layers in order to select the optimum link speed.
THANK YOU

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