Joint Rate and Channel Width Adaptation for 802.11 MIMO Wireless Networks

Lara Deek
Eduard Garcia-Villegas
Elizabeth Belding
Sung-Ju Lee
Kevin Almeroth
# 802.11 Rate Adaptation

<table>
<thead>
<tr>
<th>Legacy 802.11 a/b/g clients</th>
<th>802.11 n</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Traditional 20MHz</td>
<td>- Traditional 20MHz</td>
</tr>
<tr>
<td>- Single-Input Single-Output (SISO)</td>
<td>✓ Channel Bonding 40MHz</td>
</tr>
</tbody>
</table>

4 PHY rates 802.11 b
8 PHY rates 802.11 a/g

- 4x4 MIMO : 256 PHY rates & channel width combinations!
802.11 Rate Adaptation

<table>
<thead>
<tr>
<th>Legacy 802.11 a/b/g clients</th>
<th>802.11 n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solutions fall short when applied in 802.11n MIMO settings</td>
<td></td>
</tr>
</tbody>
</table>

- Traditional 20MHz
- ✓ Channel Bonding 40MHz
- ✓ Multiple-Input Multiple-Output (MIMO)

4x4 MIMO: 256 PHY rates & channel width combinations!
802.11n Rate Adaptation

**Desired 802.11n RA solution**

1. Standard-compliant
2. Channel bonding support
3. Practical link metric that accurately characterizes MIMO link performance
4. Agile, per-packet, response to changing channel conditions

**Existing 802.11n RA solutions**

- Incur unnecessary overhead to determine best rate
  - Require form of guided search [Pefkianakis10, Peng07]
  - Adopt form of random sampling [Ath9k, MinstrelHT]
- Do not consider Channel Bonding [Kim09, Ath9k, Pefkianakis10, Peng07]
- Built over expensive link layer metrics, ex. CSI [Halperin10, Xi08]
# 802.11n Rate Adaptation

<table>
<thead>
<tr>
<th>Desired 802.11n RA solution</th>
<th>Existing 802.11n RA solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Standard-compliant</td>
<td></td>
</tr>
<tr>
<td>2. Channel bonding support</td>
<td></td>
</tr>
<tr>
<td>3. Practical link metric that accurately characterizes MIMO link performance</td>
<td></td>
</tr>
<tr>
<td>4. Agile, per-packet, response to changing channel conditions</td>
<td>We need a new solution!</td>
</tr>
</tbody>
</table>

Our RA solution achieves these goals
Overview of ARAMIS (Agile Rate Adaptation for MIMO Systems)

- Estimates PRR* of a link for all rates and bandwidth.
- Improves accuracy of PRR surfaces using statistics of received frames.
- Maintains updated information on channel conditions using data traffic.
- Stores measurement-based performance models.
- Determines best operating point based on performance model.
- Encapsulates information on best operating point in ACK frames.

PRR* = Packet Reception Rate
Overview of ARAMIS (Agile Rate Adaptation for MIMO Systems)

Maintains updated information on channel conditions using data traffic.

Estimates PRR* of a link for all rates and bandwidth.

Improves accuracy of PRR surfaces using statistics of received frames.

Stores measurement-based performance models.

Determines best operating point based on performance model.

Encapsulates information on best operating point in ACK frames.

PRR* = Packet Reception Rate
An 802.11 OFDM MIMO Link Metric

- **SNR**
  - Unreliable metric [Pefkianakis10, Aguayo04, Reis06, Zhang08]

- **Channel State Information (CSI)** [Halperin10]
  - Costly to obtain [Crepaldi10]
  - Not supported by all 802.11n devices
A Practical MIMO Link Metric: $\text{diffSNR}$

- Link $i$: $\text{Tx}_i \rightarrow \text{Rx}_i$ for $i \in \{1, 2, 3\}$

- $\text{SNR}_1 \approx \text{SNR}_2 \approx \text{SNR}_3 \approx 40\,\text{dB}$

- Best: $\text{diffSNR}_1 = 0.3\,\text{dB}$

- Worst: $\text{diffSNR}_3 = 13.41\,\text{dB}$
A Practical MIMO Link Metric: \textit{diffSNR}

Performance depends on both SNR and \textit{diffSNR} together.

80\% certainty \textit{diffSNR} peaks correspond to fading!
A Practical MIMO Link Metric: \( \text{diffSNR} \)

Well-behaved, measurement-based surfaces that allow us to predict the PRR of a link for a given MCS and bandwidth combination.
A Practical MIMO Link Metric: \textit{diffSNR}

Average 95% accuracy in predicting link performance!
ARAMIS Testbed Environment

20 testbed links
Throughput performance
Average over 5 runs

11:05pm
5GHz

WiSpy Spectrum Analyzer
802.11n 2x3 MIMO PC Card w/ Atheros chipset
Ath9k driver
Interference Results

• From 40MHz channel leakage
Interference Results

- From *20MHz channel leakage*
ARAMIS Outcomes

ARAMIS **consistently performs well** and **outperforms** existing solutions

<table>
<thead>
<tr>
<th>ARAMIS</th>
<th>Minstrel</th>
<th>Ath9k</th>
<th>RAMAS [Nguyen11]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interference-free</td>
<td>+26%</td>
<td>+124%</td>
<td>+287%</td>
</tr>
<tr>
<td>Mobility</td>
<td>+7%</td>
<td>+15%</td>
<td>+25%</td>
</tr>
<tr>
<td>Interference</td>
<td>+251-412%</td>
<td>+366-1908%</td>
<td>+76-220%</td>
</tr>
</tbody>
</table>

(%) ARAMIS **throughput** performance improvement

*Image of a diagram showing the processes involved in ARAMIS, including Receiver, Link Predictor, Decision maker, Frame Monitor, Feedback Generator, Data frames, MCS feedback in ACK frames, Rate Management, Feedback Receiver, and Timer.*
Conclusion

• Satisfies need for **intelligent** and **adaptive** 802.11n MIMO transmission strategy

• Drives need for **per-packet, joint rate and channel width adaptation** solutions for complex systems

• Proposes model to operate in conjunction with a **channel management** solution through **Channel** and **MCS feedback**

• Model can be applied in 802.11ac
Thanks!

Lara Deek
laradeek@cs.ucsb.edu