Multi-rate Medium Access Control

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What is Multi-Rate?

- Ability of a wireless card to automatically operate at several different bit-rates (e.g. 1, 2, 5.5, and 11 Mbps for 802.11b)
- Part of many existing wireless standards (802.11b, 802.11a, 802.11g, HiperLAN2...)
- Virtually every wireless card in use today employs multi-rate
Example Carrier Modulations

- **Binary Phase Shift Keying**
  - One bit per symbol
  - Made by the carrier and its inverse

- **Quadrature Phase Shift Keying**
  - Two bits per symbol
  - Uses quadrature carrier in addition to normal carrier
  - (90° phase shift of carrier)
  - 4 permutations for the inverse or not of the two carriers
Example Carrier Modulations (cont.)

- 16 - Quadrature Amplitude Modulation
  - 4 bits per symbol
  - Also uses quadrature carrier
  - Each carrier is multiplied by +3, +1, -1, or -3 (amplitude modulation)
  - 16 possible combinations of the two multiplied carriers
Example Carrier Modulations (cont.)

- **64 - Quadrature Amplitude Modulation**
  - 6 bits per symbol
  - Also uses quadrature carrier
  - Each carrier is multiplied by +7, +5, +3, +1, -1, -3, -5, or -7 (amplitude modulation)
  - 64 possible combinations of the two multiplied carriers
### 802.11a Rates resulting from Carrier Modulation and Coding

<table>
<thead>
<tr>
<th>Data rate (Mbits/s)</th>
<th>Modulation</th>
<th>Coding rate (R)</th>
<th>Coded bits per subcarrier (N_{BPSC})</th>
<th>Coded bits per OFDM symbol (N_{CBPS})</th>
<th>Data bits per OFDM symbol (N_{DBPS})</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>BPSK</td>
<td>1/2</td>
<td>1</td>
<td>48</td>
<td>24</td>
</tr>
<tr>
<td>9</td>
<td>BPSK</td>
<td>3/4</td>
<td>1</td>
<td>48</td>
<td>36</td>
</tr>
<tr>
<td>12</td>
<td>QPSK</td>
<td>1/2</td>
<td>2</td>
<td>96</td>
<td>48</td>
</tr>
<tr>
<td>18</td>
<td>QPSK</td>
<td>3/4</td>
<td>2</td>
<td>96</td>
<td>72</td>
</tr>
<tr>
<td>24</td>
<td>16-QAM</td>
<td>1/2</td>
<td>4</td>
<td>192</td>
<td>96</td>
</tr>
<tr>
<td>36</td>
<td>16-QAM</td>
<td>3/4</td>
<td>4</td>
<td>192</td>
<td>144</td>
</tr>
<tr>
<td>48</td>
<td>64-QAM</td>
<td>2/3</td>
<td>6</td>
<td>288</td>
<td>192</td>
</tr>
<tr>
<td>54</td>
<td>64-QAM</td>
<td>3/4</td>
<td>6</td>
<td>288</td>
<td>216</td>
</tr>
</tbody>
</table>
Advantage of Multi-Rate?

- Direct relationship between communication rate and the channel quality required for that rate
- As distance increases, channel quality decreases
- Therefore: tradeoff between communication range and link speed
- Multi-rate provides flexibility to meet both consumer demands

Lucent Orinoco 802.11b card ranges using NS2 two-ray ground propagation model
Throughput vs. Distance for 802.11a
802.11 Frame Exchange Overhead

- Exchange means not all time is spend sending actual data

Sender

Receiver

\[ \text{Medium time used for transmission} \]

\[ \text{Actual time sending application data} \]
Multi-rate Frame in 802.11b

Figure 127—Long PLCP PPDU format
802.11b Frame Exchange Duration

Medium Time consumed to transmit 1500 byte packet
Multi-rate Frame in 802.11a

PLCP Header

<table>
<thead>
<tr>
<th>RATE</th>
<th>Reserved</th>
<th>LENGTH</th>
<th>Parity</th>
<th>Tail</th>
<th>SERVICE</th>
<th>PSDU</th>
<th>Tail</th>
<th>Pad Bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 bits</td>
<td>1 bit</td>
<td>12 bits</td>
<td>1 bit</td>
<td>6 bits</td>
<td>16 bits</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Coded/OFDM (BPSK, r = 1/2)

Coded/OFDM (RATE is indicated in SIGNAL)

<table>
<thead>
<tr>
<th>PLCP Preamble</th>
<th>SIGNAL</th>
<th>DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 Symbols</td>
<td>One OFDM Symbol</td>
<td>Variable Number of OFDM Symbols</td>
</tr>
</tbody>
</table>

52 us
Hops vs. Throughput

- Since the medium is shared, adjacent transmissions compete for medium time.
- Effective end-to-end throughput decreases when sending across multiple hops.
Effect of Transmission

Request to Send (RTS)
Clear to Send (CTS)
DATA
ACK
Multi-Hop Throughput Loss (TCP)
Auto Rate Protocols

- Selects the rate to use for a packet
- ARF
  - Adaptive based on success/failure of previous packets
  - Simple to implement
  - Doesn’t require the use of RTS CTS or changes to 802.11 spec
- Receiver Based Auto Rate (RBAR)
  - Uses SNR measurement of RTS to select rate
  - Faster & more accurate in changing channel
  - Requires some tweaks to the header fields
- Opportunistic Auto Rate (OAR)
  - Adds packet bursting to RBAR
  - Allows nodes to send more when channel conditions are good
  - Implements temporal fairness instead of packet fairness
MAC Layer Fairness Models

- **Per Packet Fairness**: If two adjacent senders continuously are attempting to send packets, they should each send the same *number of packets*.

- **Temporal Fairness**: If two adjacent senders are continuously attempting to send packets, they should each be able to send for the same *amount of medium time*.

- In single rate networks these are the SAME!
Temporal Fairness Example

<table>
<thead>
<tr>
<th></th>
<th>802.11 Packet Fairness</th>
<th>OAR Temporal Fairness</th>
</tr>
</thead>
<tbody>
<tr>
<td>11 Mbps Link</td>
<td>0.896</td>
<td>3.533</td>
</tr>
<tr>
<td>1 Mbps Link</td>
<td>0.713</td>
<td>0.450</td>
</tr>
<tr>
<td>Total Throughput</td>
<td>1.609</td>
<td>3.983</td>
</tr>
</tbody>
</table>

Per Packet Fairness

Temporal Fairness

11 Mbps

1 Mbps