Multipath Load Balancing in Multi-Hop Wireless Networks

Evan Jones
Martin Karsten
Paul Ward
Multi-hop Wireless Networks

- Nodes with radios
- Self configure to form a network
- Cheap and easy to deploy
- Robust

- Alternative to traditional wired infrastructure
- “Last mile” Internet access
Motivation for Load Balancing

- Multi-hop wireless has low bandwidth
  - Chain with ideal MAC: one quarter channel capacity

- Avoid congestion by distributing load

  Can load balancing improve throughput?
Previous Work

- Improve reliability with backup paths
- Can decrease delay
- Theoretical analysis: improves aggregate throughput
- Improves performance when used with directional antenna, packet caching, new routing metrics
Understanding Load Balancing

- No mobility
- Fixed power transmissions
- Single channel
- Omnidirectional antennas
Protocol Model of Interference

- Nodes must be within transmission range
- No other transmitters within interference range
- Carrier sensing: senders must be outside interference range
Simplifying Assumptions

- No MAC overhead
- Rate limited sender
- Nodes spaced at maximum range
- Fixed sized packets
- Interference range = 2 × (transmission range)
Chain Topology
Chain Topology
Chain Topology

Rate = $\frac{1}{4}$
Two Directions: Out
Two Directions: Out

Rate = \frac{1}{3}
Two Directions: In

Rate $= \frac{1}{2}$
Cross Topology

Transmission range
## Cross Throughput

<table>
<thead>
<tr>
<th>Dir.</th>
<th>Paths (I=2T)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Out</td>
<td>(\frac{1}{4})</td>
</tr>
<tr>
<td>In</td>
<td>(\frac{1}{4})</td>
</tr>
</tbody>
</table>
More Realistic Model

- MAC protocol: 802.11
- Power capture model of interference
  - If SNR > threshold: packet received
  - Two ray ground model
- Simulated with ns2
  - T = 250m, I = 550m = 2.2 T
- 1 Mbps data rate, 1500 byte packets
- CBR sources, rates scaled from low to high load
Cross: Throughput Out
Cross: Throughput In

Maximum Aggregate Inbound Throughput

Throughput (bits/s)

Hops

1 Flow
2 Flows
3 Flows
4 Flows
End Points: Observations

- Protocol model results match ns2 results
- Load balancing can improve throughput
  - Up to 101% increase in throughput
- 2 hops or less: no benefit
- Diminishing returns after adding second flow
- No delay improvement
Simple Multipath Topology

- Two flows
- At least three hops in the shortest path
- Concurrent transmissions must be outside interference range
  - ns2: Physical separation > 550m
- Simple case: 4×4 grid
Simple Multipath: 4×4 Grid

212m

200m
# 4×4 Grid Performance

<table>
<thead>
<tr>
<th>Metric</th>
<th>Single Path</th>
<th>Edge Path</th>
<th>Multipath</th>
</tr>
</thead>
<tbody>
<tr>
<td>Path Length (hops)</td>
<td>4</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Throughput (bps)</td>
<td>252 720</td>
<td>196 440</td>
<td>267 840</td>
</tr>
<tr>
<td>Avg. Delay at 120 kbps</td>
<td>54.4 ms</td>
<td>80.8 ms</td>
<td>78.9 ms</td>
</tr>
</tbody>
</table>
Grid Routing

- Routing using node location
  - Half of the paths have > 35% throughput improvement

- Heuristic using network topology
  - Half of the paths have > 20% throughput improvement

- Some paths have 80% throughput improvement
Load Balancing Conclusions

- Can improve throughput
- Increases delay
  - Longer paths
  - Higher probability of collision
- Need at least three hops
- Longer paths are better
- Diminishing returns with more than two flows
- Very sensitive to interference
Future Work

- Multiple gateways
- Using TCP
- Multiple flows
- Multi-channel networks
- Random topologies
Questions?