Strategies and Guidelines for Improving Wireless Local Area Network Performance

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Outline of Talk

- Factors Influencing WLAN Performance
- Methods of Improving WLAN
- WLAN Deployment Guidelines
- Conclusions
Routing and Transport Protocols

(Event 1)

Cross-layer Optimization

Radio Propagation

Network Protocols

My Research @AUT University

Routing and Transport Protocols

(Ad hoc network: UDP traffic; Load = 80%; Packet size = 1500 bytes; BW=11 Mbps)

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Wi-Fi Networks!

Wireless takes lead role on networking stage

By David Watson

Despite their well-known security sensitivities, wireless networks dominated the scene—locally and globally—in 2003. Smart switches, 10-gigabit ethernet and the promotion of IPv6 and Internet next-generation Internet also made worldwide headlines, as did work and customer deployments on Telecom's 10G Ethernet access network, and Vector's takeover of United Networks Communication, which resulted in two external providers becoming key drivers in the evolving bandwidth market.

But it was wireless which was hailed by some observers and equipment vendors as the future of networking. Others sounded a cautionary note, pointing out that in such areas as security and ubiquitous access, standards have not yet matured. A milestone in wireless this year was the approval of the 802.11g standard in July. 802.11g-enabled hardware can run at data rates at a theoretical maximum of 54Mbit/s and is backwards-compatible with installed 802.11b gear. Unlike rival specifications, the 802.11g specification was not developed as a supplement to but as a replacement for the 802.11b standard.

An evolutionary step in 2003 was a burst of interest in Wi-Fi. The Wi-Fi Planet alliance was formed in May when it was said wireless networks are easier to carry and easier access than wired networks. Despite the several ambitious Wi-Fi projects that were commenced, including a large-scale roll out of wireless LNaNs at Christchurch Community Hospital and several other projects, but not New Zealand.

New Zealand's wireless scrappin led to a boost, however, with expansion of the CableNet network in downtown Wellington and a trial by Telecom of wireless LANs in Air New Zealand's domestic flights. Ralph Brown has continued to produce smarter switches and 10Gigabit Ethernet to find the best first data link. While there appears to be little demand for the latter in New Zealand, 100MB speeds strides overseas, in the enterprise space more so than the carrier. It is estimated that only 4000 10G ports would be shipped by the end of this year and that's 3000 more than in 2002, the compound growth rate is only a fraction of that seen by gigabit ports, which adds...
IEEE Standards

- 802.11b/a/g
- 802.11e - QoS
- 802.11s - Wireless mesh for access points
- 802.11n – High data rate (up to 300 Mbps)
- 802.11ac - Very high throughput (1Gbps) – introduced in 2011
- 802.11u – WLAN emergency support (2011)
- 802.11p – Vehicle-to-vehicle comms. (2011)
WLAN Performance Issues

Why are wireless networks slower ...?

Data error rates are higher in WLANs.

WLAN has to retransmit corrupted data more often to keep communication going and slows things down.
Research Question

How can we make a WLAN better and faster?
Outline of Talk

- Factors Influencing WLAN Performance
- Methods of Improving WLAN
- WLAN Deployment Guidelines
- Conclusions
Factors Influencing WLAN Performance

**Upper layer**
- MAC protocol and overhead
- Contention window size
- Packet length
- Routing protocols
- Traffic type
- Traffic distribution

**Link layer**
- Signal strength
- Noise and interference
- Ceiling
- Propagation environment
- Wall partition and corner
- Concurrent transmission
- Type of wall materials
- Bit error rate
- Multipath
- Modulation
- Antenna type

**Physical layer**

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Impact of radio propagation environments on WLAN performance
(Empirical results)
Propagation environments (1)

Office building (Duthie Whyte)
Propagation environments (2)

Computer Laboratory (AUT Tower)
Propagation environments (3)

Suburban residential house
Propagation measurements (4)

Measurements
- Two office buildings
- Suburban residential house

Investigation
- Transmitting and receiving antennas orientation
- Office wall partitions
- Single wall separation
- Microwave oven interference
- Floors
- Line-of-sight (LOS) blockage by walls

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Effect of LOS blockage on WLAN

Obstructed office environment
IEEE 802.11 (11 Mbps)

Throughput: 4.5 Mbps
Distance: 35 m

Throughput: 0.8 Mbps
Distance: 35.01 m

Connection lost
Distance: 35.03 m

File size: 144 MB
## Effect of LOS blockage

<table>
<thead>
<tr>
<th>File size (MB)</th>
<th>Distance between Tx and Rx</th>
<th>Link throughput (Mbps)</th>
<th>Throughput degradation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>144</td>
<td>Trial 1: 35m</td>
<td>4.5</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Trial 2: 35m+ 1m</td>
<td>0.8</td>
<td>82.2</td>
</tr>
<tr>
<td></td>
<td>Trial 3: 35m +2m</td>
<td>Connection lost</td>
<td></td>
</tr>
</tbody>
</table>

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# IEEE 802.11g Throughput

<table>
<thead>
<tr>
<th>Rx position</th>
<th>AP-Rx separation (m)</th>
<th>RSS (dBm)</th>
<th>Transmission time (seconds)</th>
<th>Throughput (Mbps)</th>
<th>Throughput degradation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>14.2</td>
<td>-73</td>
<td>12.6</td>
<td>6.92</td>
<td>36.51</td>
</tr>
<tr>
<td>B</td>
<td>11.4</td>
<td>-68</td>
<td>9.5</td>
<td>9.18</td>
<td>15.79</td>
</tr>
<tr>
<td>C</td>
<td>11.4</td>
<td>-60</td>
<td>8.2</td>
<td>10.63</td>
<td>2.44</td>
</tr>
<tr>
<td>D</td>
<td>5.8</td>
<td>-62</td>
<td>9.4</td>
<td>9.28</td>
<td>14.89</td>
</tr>
<tr>
<td>E</td>
<td>3.0</td>
<td>-43</td>
<td>8.2</td>
<td>10.63</td>
<td>2.44</td>
</tr>
<tr>
<td>F</td>
<td>3.0</td>
<td>-55</td>
<td>8.1</td>
<td>10.77</td>
<td>1.23</td>
</tr>
<tr>
<td>G</td>
<td>10.3</td>
<td>-63</td>
<td>8.5</td>
<td>10.26</td>
<td>5.88</td>
</tr>
<tr>
<td>H</td>
<td>9.0</td>
<td>-60</td>
<td>8.0</td>
<td>10.90</td>
<td>0.00</td>
</tr>
<tr>
<td>L</td>
<td>6.0</td>
<td>-55</td>
<td>8.7</td>
<td>10.02</td>
<td>8.05</td>
</tr>
<tr>
<td>M</td>
<td>10.5</td>
<td>-57</td>
<td>9.5</td>
<td>9.18</td>
<td>15.79</td>
</tr>
</tbody>
</table>
Summary of findings

Signal blockage by walls and floors was found to have a significant effect on throughput of 802.11 networks.


Outline of Talk

- Factors Influencing WLAN Performance
  - Methods of Improving WLAN
  - WLAN Deployment Guidelines
  - Conclusions
Methods of Improving WLAN Performance
Shortcomings of 802.11 WLANs

• Low bandwidth utilization
  – Low throughput and high packet delay
• High transmission overhead

Solution: IEEE 802.11 requires an improvement

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Improving 802.11 performance by modifying MAC protocols

- We have developed a wireless MAC protocol called buffer unit multiple access (BUMA).

- **Key idea: Maximize packet transmission**
  - Spend less time in the backoff state
  - Send a larger payload under good channel state


MAC design strategies

**Wireless MAC protocol design mechanisms**

- Optimisation of contention window size
- Devise better backoff algorithms

- Use of control frames
- Collision prevention on control channel
- Handshaking
- Dual channels
- Channel cycles

- Topology-blind
- Station synchronisation

**TDMA-based polling technique**

**Packet concatenation**

**Examples of MAC protocols**

- MACAW
- PUMA, DIDD
- FCR
- SDP
- C-PRMA
- 802.11 +
- Dynamic 802.11

- MACA
- CSMA/CP
- ICSMA
- DFWMAC
- CD MAC
- FAMA
- GAMA-PS

- Fair MAC
- CSMA/IC

**Improvement to 802.11 DCF**

TRAP
BUMA Architecture
Frame structure of BUMA

- MAC header
- MPDU$_1$
- MPDU$_2$
- ... (Ellipsis)
- MPDU$_n$
- CRC

Content of a buffer unit

- CRC: Cyclic Redundancy Check
- MPDU: MAC Protocol Data Unit
- MSDU: MAC Segment Data Unit
802.11 Overheads

- **MAC header** (30 bytes)
- **Payload**
- **CRC** (4 bytes)
- **DIFS**
- **Backoff**
- **PHY header**
- **ACK** (14 bytes)

$\text{t}_{\text{Ir}}$

$\text{t}_{\text{phy}}$

$\text{t}_{\text{ack}}$

$50 \mu s$

$\text{t}_{\text{count}}$

$10 \mu s$

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Overhead: 802.11 DCF Vs BUMA

(a) 802.11 DCF

(b) BUMA

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Example: Transmitting short packets

If a single user sends 56 bytes IP datagram over a 11 Mbps channel, the proportional throughputs achieved by:

BUMA = 8.36 Mbps
802.11b DCF = 0.66 Mbps
Transmission overhead comparison

<table>
<thead>
<tr>
<th>IEEE 802.11b</th>
<th>BUMA Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>High packet delay</td>
<td>Low packet delay</td>
</tr>
</tbody>
</table>

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Throughput Vs. Offered load
(Ad hoc network)

(Ad hoc network; N=40 stations; UDP traffic; Packet size = 1500 bytes; BW=11 Mpps)

Network Throughput (Mbps)

Throughput improvement: 45%

IEEE 802.11b
BUMA Protocol
Throughput Vs. Offered load (Infrastructure network)

Infrastructure network; N = 40 stations

Network Throughput (Mbps)

Offered Load (%)

IEEE 802.11b
BUMA Protocol

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Packet delay Vs. Offered load (Ad hoc network)

Packet delay improvement: 96%
IEEE 802.11 Vs. BUMA

<table>
<thead>
<tr>
<th></th>
<th>IEEE 802.11b</th>
<th>BUMA Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low throughput</td>
<td>~ 45% higher throughput</td>
<td>~ 96% lower delay</td>
</tr>
<tr>
<td>High packet delay</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simple</td>
<td></td>
<td>Simple and easy to implement</td>
</tr>
</tbody>
</table>

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Improving 802.11 performance using cross-layer design optimization

- We have developed a channel aware MAC protocol called C-BUMA.

- Key idea: Maximize packet transmission
  - Send more data under good channel state
  - Pause when channel state is very weak


Cross-layer design approach

- Channel aware MAC protocol
  - Schedule multiple packets under good channel state; pause transmission if channel state is very bad.

- Related work
  - Rayleigh channel predictability
  - Pham et al. [225]

- MAC Protocol Modelling
- Proposed cross layer design (CLD) framework

- Propagation Modelling

- Performance evaluation and comparison (with and without CLD)
## Performance improvement using CLD

<table>
<thead>
<tr>
<th>Link (Source to destination)</th>
<th>Link throughput (Mbps)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TCP Traffic CLD (Mbps)</td>
<td>Without CLD (Mbps)</td>
<td>Improvement (%)</td>
<td>TCP Traffic CLD (Mbps)</td>
<td>Without CLD (Mbps)</td>
<td>Improvement (%)</td>
<td></td>
</tr>
<tr>
<td>0-&gt;1</td>
<td>0.179</td>
<td>0.162</td>
<td>9.50</td>
<td>0.308</td>
<td>0.24</td>
<td>22.08</td>
<td></td>
</tr>
<tr>
<td>0-&gt;2</td>
<td>0.187</td>
<td>0.163</td>
<td>12.83</td>
<td>0.444</td>
<td>0.36</td>
<td>18.92</td>
<td></td>
</tr>
<tr>
<td>2-&gt;3</td>
<td>0.117</td>
<td>0.077</td>
<td>34.19</td>
<td>0.512</td>
<td>0.478</td>
<td>6.64</td>
<td></td>
</tr>
<tr>
<td>3-&gt;4</td>
<td>0.038</td>
<td>0.017</td>
<td>55.26</td>
<td>0.49</td>
<td>0.476</td>
<td>2.86</td>
<td></td>
</tr>
<tr>
<td>4-&gt;5</td>
<td>0.254</td>
<td>0.216</td>
<td>14.96</td>
<td>0.36</td>
<td>0.308</td>
<td>14.44</td>
<td></td>
</tr>
<tr>
<td>4-&gt;6</td>
<td>0.204</td>
<td>0.165</td>
<td>19.12</td>
<td>0.404</td>
<td>0.343</td>
<td>15.10</td>
<td></td>
</tr>
<tr>
<td>5-&gt;6</td>
<td>0.1</td>
<td>0.08</td>
<td>20.00</td>
<td>0.22</td>
<td>0.187</td>
<td>15.00</td>
<td></td>
</tr>
<tr>
<td>5-&gt;7</td>
<td>0.09</td>
<td>0.06</td>
<td>33.33</td>
<td>0.344</td>
<td>0.308</td>
<td>10.47</td>
<td></td>
</tr>
<tr>
<td>6-&gt;7</td>
<td>0.17</td>
<td>0.12</td>
<td>29.41</td>
<td>0.47</td>
<td>0.267</td>
<td>43.19</td>
<td></td>
</tr>
<tr>
<td><strong>Overall network</strong></td>
<td><strong>1.7</strong></td>
<td><strong>1.3</strong></td>
<td><strong>40</strong></td>
<td><strong>3.6</strong></td>
<td><strong>3</strong></td>
<td><strong>60</strong></td>
<td></td>
</tr>
</tbody>
</table>
Outline of Talk

✓ Factors Influencing WLAN Performance
✓ Methods of Improving WLAN
  o WLAN Deployment Guidelines
  o Conclusions
WLAN Deployment Guidelines

◆ WLAN Deployment Scenarios
- Single floor office scenario
- Multi-floor office scenario
- Computer laboratory
- Residential house environment

◆ Deployment Guidelines
- Find an optimum AP position that provides a better coverage and performance.
- Estimate the number of wireless clients that an AP can support.
Outline of Talk

✓ Factors Influencing WLAN Performance
✓ Methods of Improving WLAN
✓ WLAN Design Guidelines
  ○ Conclusions
Summary and conclusions

• The **key factors** influencing WLAN performance have been quantified.

• BUMA protocol offers **significantly better** delay and throughput performance than 802.11 DCF.

• **Signal blockage by walls and floors** was found to have a significant effect on 802.11 throughput.

• Minimum **two APs** are required (one for each region) to cover the WY office floor.

• WLAN throughput can be optimized by carefully configuring and placing APs.
Future research directions

- Rate adaptation QoS-aware MAC protocol design for multimedia WLANs.
- Cross-layer design with adaptive payload and rate adaptation for multimedia WLANs.
- Development of an adapting routing protocol for WLANs.
- Development of antenna-aware propagation models.
Thank you for your attention

Terima kasih

با تشکر از توجه شما

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IEEE 802.11 MAC Architecture

- **DCF**: Distributed coordination function
- **PCF**: Point coordination function

- **DCF**: Used for contention services and basics for PCF
- **PCF**: Required for contention free services
## Buffer unit size optimisation

<table>
<thead>
<tr>
<th>Buffer unit size (packet)</th>
<th>Offered load (%)</th>
<th>Throughput (Mbps)</th>
<th>Delay (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>70</td>
<td>4.03</td>
<td>887</td>
</tr>
<tr>
<td>2</td>
<td>70</td>
<td>5.76</td>
<td>665</td>
</tr>
<tr>
<td>3</td>
<td>70</td>
<td>6.66</td>
<td>399</td>
</tr>
<tr>
<td>4</td>
<td>70</td>
<td>6.19</td>
<td>638</td>
</tr>
<tr>
<td>10</td>
<td>70</td>
<td>6.84</td>
<td>625</td>
</tr>
<tr>
<td>100</td>
<td>70</td>
<td>6.89</td>
<td>1464</td>
</tr>
</tbody>
</table>

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## Ns-2 simulation parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data rate</td>
<td>11 Mbps</td>
</tr>
<tr>
<td>Basic rate</td>
<td>2 Mbps</td>
</tr>
<tr>
<td>Wireless card</td>
<td>802.11b</td>
</tr>
<tr>
<td>Slot duration</td>
<td>20 µs</td>
</tr>
<tr>
<td>SIFS</td>
<td>10 µs</td>
</tr>
<tr>
<td>DIFS</td>
<td>50 µs</td>
</tr>
<tr>
<td>MAC header</td>
<td>30 bytes</td>
</tr>
<tr>
<td>CRC</td>
<td>4 bytes</td>
</tr>
<tr>
<td>PHY header</td>
<td>96 µs</td>
</tr>
<tr>
<td>Traffic</td>
<td>TCP and UDP</td>
</tr>
<tr>
<td>Data packet length</td>
<td>1500 bytes</td>
</tr>
<tr>
<td>Channel model</td>
<td>Two-ray ground</td>
</tr>
<tr>
<td>RTS/CTS</td>
<td>Off</td>
</tr>
<tr>
<td>PHY modulation</td>
<td>DSSS</td>
</tr>
<tr>
<td>CWmin</td>
<td>31</td>
</tr>
<tr>
<td>CWmax</td>
<td>1023</td>
</tr>
<tr>
<td>Simulation time</td>
<td>10 minutes</td>
</tr>
</tbody>
</table>
Throughput Vs. Stations
(Ad hoc network)

Ad hoc network; Load = 80%

IEEE 802.11b
BUMA Protocol
Throughput Vs. Stations
(Infrastructure network)
Packet delay Vs. Stations
(Ad hoc network)

(Ad hoc network; Load = 80%; UDP traffic; Packet size = 1500 bytes; BW=11 Mbps)

Network mean delay (ms)

Number of active stations

IEEE 802.11b
BUMA protocol