Self Management in Chaotic Wireless Deployments

This paper ...
- Was supported by the army research office, NSF, Intel and IBM.
- Characterizes the density and usage of 802.11 hardware across major US cities.
- Presents a simulation study of the effect of dense unmanaged wireless deployments on end-user performance.

This paper ...
- Outlines the challenges to make chaotic environments self-managing.
- Describes algorithms to increase the quality of performance.
- Examines these algorithms.

Problems with WiFi networks
- Wireless links are susceptible to degradation (fading).
- Sharing scarce spectrum by wireless deployments causes interference.
- Problems due to wide usage of hardware in an unmanaged and unplanned manner.

Chaotic deployment
- To give you an idea, 4.5 million WiFi APs were sold in 3rd quarter of 2004 and will triple by 2009.
- Unplanned (Not planned to optimize the coverage, spontaneous deployment)
- Unmanaged (Not configured to have the right parameters)

Chaotic deployments bring...
- Serious contention
- Poor performance
- Security risks
- The main goal of the paper is to show the effects of interference on performance.
Related Work

- Evaluation based on current efforts to map 802.11 deployments
- Overview of commercial products for managing wireless networks
- Proposal for wireless self management and examining those.

Several internet websites map WiFi hot-spots in different US cities.
- WiFimaps.com, Wi-Fi-Zones.com, JIWire.com
- Data from wifimaps.com and intel place lab database is used to infer usage characteristics.

Data Sets

<table>
<thead>
<tr>
<th>Data set</th>
<th>Collected in</th>
<th>No. of APs</th>
<th>Stats collected per AP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Place Lab</td>
<td>Aug 2001</td>
<td>9274</td>
<td>MAC, ESSID, GPS coordinates</td>
</tr>
<tr>
<td>WiFimaps</td>
<td>Aug 2004</td>
<td>9293</td>
<td>MAC, ESSID, Channel</td>
</tr>
<tr>
<td>Pittsburgh Wireless</td>
<td>Jul 2004</td>
<td>1008</td>
<td>MAC, ESSID, Channel supported rates, GPS coordinates</td>
</tr>
</tbody>
</table>

Measurement Observations

- Focus on using the wireless spectrum efficiently by developing algorithms in dense wireless networks not saving energy
- Not complete data sets due to increasing rate of wireless networks and density.
- Information about other devices using the same spectrum is not gathered and shown

Deployment Density

<table>
<thead>
<tr>
<th>City</th>
<th>Number of APs</th>
<th>Max AP-dists (ie, # neighbors)</th>
<th>Max expected overlap size</th>
<th>No. of measured overlaps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chicago</td>
<td>2147</td>
<td>10</td>
<td>3</td>
<td>16</td>
</tr>
<tr>
<td>Washington DC</td>
<td>2174</td>
<td>10</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Boston</td>
<td>2011</td>
<td>10</td>
<td>3</td>
<td>20</td>
</tr>
<tr>
<td>Portland</td>
<td>2001</td>
<td>10</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>San Diego</td>
<td>2001</td>
<td>10</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>San Francisco</td>
<td>2001</td>
<td>10</td>
<td>10</td>
<td>20</td>
</tr>
</tbody>
</table>

- Interference range assumed 50m
- Two-modes are neighbors if in each other’s interference range
- In most cities, the degree of APs is 3
- Table shows the close proximity and density of wireless networks.

Channels

- Information here suggests that most APs that overlap in coverage are not configured to optimize performance by minimizing interference.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Percentage of APs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.06</td>
</tr>
<tr>
<td>2</td>
<td>12.29</td>
</tr>
<tr>
<td>3</td>
<td>2.61</td>
</tr>
<tr>
<td>4</td>
<td>1.00</td>
</tr>
<tr>
<td>5</td>
<td>3.15</td>
</tr>
<tr>
<td>6</td>
<td>4.15</td>
</tr>
<tr>
<td>7</td>
<td>1.75</td>
</tr>
<tr>
<td>8</td>
<td>1.12</td>
</tr>
<tr>
<td>9</td>
<td>1.21</td>
</tr>
<tr>
<td>10</td>
<td>3.82</td>
</tr>
<tr>
<td>11</td>
<td>11.84</td>
</tr>
</tbody>
</table>
Vendors and AP Management Support

- If Linksys and Aironet incorporate built-in self-management firmware, we will see a sharp decrease in negative impacts of interference in chaotic deployments.

<table>
<thead>
<tr>
<th>Vendor</th>
<th>Percentage of EEs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total counted</td>
<td>98</td>
</tr>
<tr>
<td>Linksys (Cisco)</td>
<td>35.5</td>
</tr>
<tr>
<td>Aironet (Cisco)</td>
<td>12.2</td>
</tr>
<tr>
<td>Cisco Devices</td>
<td>16.4</td>
</tr>
<tr>
<td>D-Link</td>
<td>14</td>
</tr>
<tr>
<td>Apple Computer</td>
<td>8.8</td>
</tr>
<tr>
<td>Netgear</td>
<td>4.4</td>
</tr>
<tr>
<td>Airlink</td>
<td>4.3</td>
</tr>
<tr>
<td>Delphi Communications</td>
<td>4.3</td>
</tr>
<tr>
<td>Lucent</td>
<td>3.8</td>
</tr>
<tr>
<td>Airgo</td>
<td>2.5</td>
</tr>
<tr>
<td>Airware</td>
<td>1.3</td>
</tr>
<tr>
<td>Others</td>
<td>10.7</td>
</tr>
</tbody>
</table>

Impact on End-User performance

- Assumptions made as following:
  - Each node is an AP
  - Each node has D clients (0 < D < 4)
  - Clients are located less than 1m from AP
  - Transmission done on channel 6
  - Fixed transmit power level of 15dBm
  - Transmit rate is the same for all at 2Mbps
  - RTS/CTS is turned off.
  - Stretch: the higher it is, the lower the impact of interference.

Cont...

The impact of interference in chaotic deployments depends largely on users workloads.

- Very likely to not experience any degradation when transmitting data occasionally
- The goal of this evaluation is to quantify the exact impact of user workload

Set of Workloads

- The first set if HTTP.
- There is a think time on client side between each HTTP transfer (s seconds).
- Authors vary s between values 5 and 20s.
- Average loads:
  - 83.3Kbps for 5s sleep time
  - 24.5Kbps for 20s sleep time
- No other interfering traffic than HTTP

Cont...

- The second set is FTP called comb-ftp.
- i clients running long-lived FTP traffic.
- 0 < i < 4
- Average load is 0.89Mbps.
- Each set of workloads run for about 300s.
Interference at Low Client Densities and Traffic Volumes

- Impact of interference under light-weight user traffic on each AP and low client density ($D = 1$).
- Normalized performance is the ratio of average throughput flow to the throughput when operating in isolation.

Results

- Performance of HTTP improves until stretch 10.
- After stretch 10 the behavior stays the same.
- When HTTP component is aggressive ($s = 5s$), FTP suffers by 17%.
- When HTTP not aggressive, the impact on FTP is minimal.

Cont...

- Impact of interference with light-weight traffic but high user density ($D = 3$).

Results

- Performance of both HTTP and FTP suffers significantly under high client density.
- In figure 4a, HTTP and FTP performance decrease about 65% with $s = 5s$.
- When $s = 20s$, HTTP suffers by 20% and FTP performance is lowered by 36%.

Cont...

- Impact of higher traffic loads and client density, Comb-freq{2,3}, $D = 3$
- The impact on performance is sensible.

Limiting the Impact of Interference

- Two goals
  - If Optimal static non-overlapping channel allocation eliminates interference altogether?
  - Preliminary investigation of the effect of reducing transmit power levels at access points on interference.
Optimal Static Channel Allocation

- Impact of static channel allocation, set to the three non-overlapping channels.
- Transmit power level set to 15dBm corresponding to 31m.

Results

- Curves flatten out because of optimal static channel allocation.
- There is still poor performance.
- HTTP is performing 25% lower at stretch 1 comparing to stretch 10.
- FTP performance is still suffering.
- Optimal channel allocation cannot eliminate the interference entirely.

Transmit Power Control

- Optimal static channel along with setting transmit power level at 3dBm corresponding to 15m.

Results

- The overall performance improves significantly.
- At stretch 1, all HTTP and comb-ftp traffic is doing much better, about 20% more.
- At stretch 2 the curve flattens out.
- This experiment shows that transmit power control along with optimal channel allocation could reduce the impact in chaotic networks.

Improvement in Network Capacity

- $D = 1$

Results

- The capacity of a densely packed network of APs is 15% of the maximum capacity.
- Static channel allocation helps the capacity two-fold.
- Lower transmit power on APs improves capacity by nearly a factor of 2.
- Transmit power control along with optimal channel allocation ensures a much better performance.
Benefits of Transmit Power Reduction

- Assumptions made:
  - Consider only downlink traffic as uplink traffic is small.
  - The algorithm works for both.
  - Each AP has a single client at a fixed distance.

- The minimum physical spacing between APs is important.
- First the medium utilization is computed:
  - \( \text{Util}_P = \frac{\text{load}}{\text{throughput}_{\text{max}}} \)
  - \( \text{Pathloss} = 40 + 3.5 \times 10 \times \log(d_{\text{client}}) \)
  - \( \text{RSS} = \text{txPOWER} - \text{pathloss} \)
  - \( \text{SNR} = -100 \)

Results

<table>
<thead>
<tr>
<th>Rate (Mbps)</th>
<th>Minimum SNR (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.80</td>
</tr>
<tr>
<td>2</td>
<td>1.7</td>
</tr>
<tr>
<td>5.5</td>
<td>3.9</td>
</tr>
<tr>
<td>11</td>
<td>4.9</td>
</tr>
</tbody>
</table>

Table 5: Minimum required SNR for 802.11b

<table>
<thead>
<tr>
<th>Rate (Mbps)</th>
<th>Throughput (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.80</td>
</tr>
<tr>
<td>2</td>
<td>1.7</td>
</tr>
<tr>
<td>5.5</td>
<td>3.9</td>
</tr>
<tr>
<td>11</td>
<td>4.9</td>
</tr>
</tbody>
</table>

Table 6: Maximum 802.11b throughput

After computing utilization for a single link by the formula above, the minimum utilization is computed by summing utilization of all in range APs.

- Two APs are in range if \( \text{RSS} > \text{interference threshold} \)
- For this paper: interference threshold = -100
- Next graph shows the results for a client distance of 10m and loads ranging from 0.1 Mbps to 1.1 Mbps.

Resulting Graph

Conclusions from Graph

- The minimum distance between APs decreases (higher density)
- By lowering the transmit power rate, denser networks can be deployed.
- the upper bound of power is in hand (x-axis).
- When the load is not high, the node can reduce both transmit rate and power in order to increase network capacity.
Deployment Challenges

- There is a trade-off when using these techniques and that is a reduction in throughput of the channel by forcing the transmitter to use a lower rate to deal with the reduced signal to noise ratio.
- Determining the right moment and environment to use them can greatly affect the network.
- There is a trade-off between selfish and social congestion control in the internet.
- One advantage is that lower transmission rate limits the chances of eavesdropping for malicious attackers.

Transmission Power and Rate Selection

- A prism chipset 2.5 NIC card is used.
- Driver is a modified version of hostAP prism driver in Linux.
- The driver achieves per packet control over transmission rate by tagging each packet with the rate at which it should be sent (transmission is set to 2).
- Prism based cards do not support per packet transmission power control (prism 2.5 firmware).
- Overcome to this limitation is to wait for the NIC buffers to empty and then queue packets at a new rate.

Fixed Power Rate Selection Algorithms

- ARF: Auto Rate Fallback (mostly used)
- ERF: Estimated Rate Fallback

Auto Rate Fallback

- ARF attempts to choose the best transmission rate via in-band probing using 802.11’s ACK mechanism.
- There are variations of ARF. The one used in 802.11b assumes the following:
  - Failed transmission indicates a very high transmission rate.
  - Successful transmission indicates a good transmission rate and that a higher one is possible.
  - An increment threshold of 6, decrement threshold of 3 and 10s idle timeout.

Proposed ARF Algorithm

- The authors make modifications to ARF as following if a threshold number of consecutive packets are:
  - sent successfully, the node chooses the next rate.
  - Not sent successfully, the node decrements the rate.
  - Dropped entirely, the highest rate is chosen.
  - Thresholds are set to 6 successful, 4 failed and 10s for idle timeout.

SNR, Alternative for ARF and Challenges

- Advantage:
  - Using channel’s SNR to select the optimal rate for a given SNR instead of probing channels for best rate.
- Disadvantage:
  - Card measurements of SNR can be inaccurate and may vary between different cards.
  - SNR measurement can completely identify channel degradation due to multi-path interference.
Proposed ERF Algorithm

- SNR based algorithm.
- A hybrid between SNR and ARF.
- Uses path-loss information to estimate the SNR with which transmission is received.
- ERF then determines the highest rate supportable by this SNR.
- In case of a successful or unsuccessful attempt, it increments or decrements the rate.
- If all packets are dropped, ERF will begin to fall back towards the lowest rate until new channel info is received.

PARF and PERF

- Both algorithms try to reduce the transmission power.
  (social reduction interference)
- At highest rate, PARF reduces the power after successful operation.
- Repeats the process until the lowest power is reached or fails.
- Then the power is raised until no fails occur.

Performance Evaluation and Conclusion

- PARF shows unstable in initial experiment.
- PERF reacts more slowly to transmission failure.
- Poor performance of ERF and ARF because of asymmetric carrier sense.
- The authors also introduce one strategy to improve PERF called LPERF (load-sensitive PERF) in which transmitters reduce their power even if it reduces their transmission rate.
- They claim that LPERF like algorithms are a promising direction.