Idle Sense:

An Optimal Access Method for High Throughput and Fairness in Rate Diverse Wireless LANs

Presented by Nikki Benecke, October 10th, 2006 for CS577

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Objective:

“Define an access method optimized for throughput and fairness, able to dynamically adapt to physical channel conditions, to operate near optimum for a wide range of error rates, and to provide equal time shares when hosts use different bit rates.”
Access method

• Way of deciding who can access the media at a given time
• In WLANs, CSMA/CA as implemented by DCF (required) or PCF
Optimized for throughput and fairness

- Throughput
  - Not goodput
  - Expect to maintain, not increase, with IS

- Fairness in *Idle Sense*:
  - Jain Index
  - Time Fairness
Dynamic channel adaptation

• Physical conditions vary wildly with time
• Frames received in error -> sender’s bitrate lowered to reduce error rate
• *Idle Sense* tries to intelligently decide when lowering the bitrate is worthwhile
Supporting a wide range of error rates

• Sort of superfluous – handled by dynamic channel adaptation
Equal time shares

• Step away from min-max fairness
• Keep slow senders from unnecessarily restricting fast senders
Motivation

- 802.11 currently requires DCF as the access method
  - Also allows PCF
- Idle Sense addresses some key problems with DCF
DCF: Operation

- [DCF in a nutshell]

Martin Heusse's presentation at SIGCOMM '05
DCF: Backoff

Figure 52—Backoff procedure
DCF: “Bad Day” Problem

Bad transmission conditions -> host will lose many frames

High error rate -> frequent backoffs

CW is increased -> transmission attempt probability is lower

So the host will try to send less often and may eventually starve!
DCF: Physical Layer Capture

- The stronger signal in a collision may be successfully received
- It causes long term unfairness
  - Farther host has a greater average contention window

(Kochut et al., ICNP'04)
Two Modifications to DCF

1. No exponential backoff
2. All senders have equal CW

Figure 2: Two hosts contending for the channel.
Ideal channel contention

$N$ - number of hosts

$P_t$ - probability of one host successfully transmitting

$P_e$ - probability of one host attempting to transmit
Channel contention

For a transmission to occur, one host must try to send and all others must be idle, so:

\[ P_t = N P_e (1 - P_e)^{N-1} \]
Channel contention

\( P_i \) - probability that no hosts are sending

\[ P_i = (1 - P_e)^N \]

\( P_c \) - probability of a collision

\[ P_c = 1 - P_t - P_i \]
Channel contention

\( \bar{n}_i \) - average number of consecutive idle slots

\[
\bar{n}_i = \frac{P_i}{1 - P_i}
\]
Channel contention

Since all CW are equal:

\[ P_e(CW) = \frac{2}{CW + 1} \]
Channel contention

Throughput as a function of $P_e$

$$X(P_e) = \frac{P_{tsd}}{P_tT_t + P_cT_c + P_iT_{SLOT}}$$
Channel contention

Goal: maximize the throughput by minimizing the time spent in collisions and contention
Channel contention

Maximizing $X(P_e)$ equivalent to

minimizing $cost(P_e)$ defined as:

$$cost(P_e) = \frac{T_c}{T_{SLOT}} \frac{P_c}{Pt} + P_i$$
Channel contention

Define $\eta$ as

$$\eta = 1 - \frac{T_{SLOT}}{T_C}$$

Take the first derivative of the cost function to get:

$$1 - N P_e^{opt} = \eta(1 - P_e^{opt})^N$$

$P_e^{opt}$ is the unique solution for this equation that is in $[0,1]$
Formulas

\[ \zeta = N P_e^{opt} \]

\[ 1 - \zeta = \eta e^{-\zeta} \]

\[ P_i^{opt} = \left(1 - \frac{\zeta}{N}\right)^N = e^{-\zeta} \]

\[ \overline{n_i^{opt}} = \frac{e^{-\zeta}}{1 - e^{-\zeta}} \]
value based on variant

This is because it is based on the \( \frac{T_C}{T_{SLOT}} \) ratio, which varies by flavor of 802.11

\( \zeta = 0.1622 \) for 802.11b

(important for later use)
Idle Sense: Principles

Each host estimates $\hat{n}_i$ and uses it to compute its CW

By adjusting CW, a host makes $\hat{n}_i$ converge to $\bar{n}_i^{\text{target}}$ (common across hosts)
\( \bar{n}_{i \text{ opt}} \) vs \( \bar{n}_{i \text{ target}} \)

\( \bar{n}_{i \text{ opt}} \) requires knowing \( N \) (# of hosts), which we would like to avoid.
\[ \bar{n}_{i}^{\text{opt}} \quad \text{vs} \quad \bar{n}_{i}^{\text{target}} \]

\[ \bar{n}_{i}^{\text{opt}} \quad \text{quickly approaches} \quad \bar{n}_{i}^{\infty} , \quad \text{though,} \quad \text{so we can use this value as} \quad \bar{n}_{i}^{\text{target}} \quad \text{with little penalty} \]
Channel adaptation

\[ \hat{n}_i > \bar{n}_i^{\text{target}}, P_e \leftarrow P_e + \epsilon \]

\[ \hat{n}_i < \bar{n}_i^{\text{target}}, P_e \leftarrow \alpha P_e \]
Channel adaptation

\[ \hat{n}_i > \bar{n}_i^{target}, \text{ } CW \leftarrow \frac{2CW}{2 + \epsilon CW} \]

\[ \hat{n}_i < \bar{n}_i^{target}, \text{ } CW \leftarrow \frac{CW}{\alpha} \]
Adaptation example

$802.11b \ (\bar{n}_i^{target} = 5.68)$

$N = 5$

$CW = 60$

$\frac{1}{\alpha} = 1.2$

$\epsilon = 0.001$
Adaptation example

1. CW = 60 \rightarrow P_e = 0.033, \quad P_i = 0.847, \quad \hat{n}_i = 5.53

\hat{n}_i < 5.68, \text{ so increase CW}

\[ CW = \frac{CW}{\alpha} = 1.2 \times 60 = 72 \]

(Multiplicative decrease)
Adaptation example

2. This increase leads to $\hat{n}_i = 6.71$

$6.71 > 5.68$, so decrease CW

$$CW = \frac{2CW}{2 + \epsilon CW}$$

$CW = 69$ (Additive Increase)
Adaptation example

3. \( \hat{n}_i \) is now 6.41, still greater than 5.68. So decrease again, CW gets value 67.

As this continues, we will oscillate around \( \bar{n}_i \) (target) (Additive Increase)
Time-fairness

Argument: using min-max fairness restricts fast hosts by making them send as slowly as slow hosts
Time-fairness

Using time-fairness eliminates two problematic situations:

(i) Slower hosts limit the throughput of faster hosts

(ii) Slow hosts suffer starvation because an access point will not switch to a slower rate
Time-fairness

They say TF is better for both slow hosts and fast hosts.
Time-fairness

In *Idle Sense*, accomplish TF by controlling the access probability for the hosts

Slow host transmitting at bit rate $r_{c\text{urr}}$ receives a modified CW, $CW' = CW \times \frac{r_{\text{max}}}{r_{c\text{urr}}}$, so $P_e$ scales down.
Miscellaneous

• Determining idle slots is easy
• Efficiency may be slightly lower for small num. of hosts (N)
• Near optimal utilization for certain ratios
  \[ \frac{T_C}{T_{SLOT}} \] -- real traffic may behave differently and have lower utilization
Idle Sense: Performance

• Developed discrete-event simulator that implements 802.11 DCF and *Idle Sense*
  – No source code provided
• Three variants of 802.11
  – 802.11b, 802.11g, theoretical 100Mb/s 802.11
• *Idle Sense* parameters:
  \[
  \frac{T_C}{T_{SLOT}} = 
  \begin{align*}
  68.17 & \text{ for } 802.11b \\
  31.0 & \text{ for } 802.11g \\
  19.3 & \text{ for } 100\text{Mb/s } 802.11
  \end{align*}
  \]
Performance

- Simulations run for $10^6$ transmissions
- Experimentally determined parameters

\[
\epsilon = 0.001
\]

\[
\frac{1}{\alpha} = 1.2
\]

\[
N_{\text{trans}} = 5 \text{ (see figure 6)}
\]
Throughput

Compare 802.11b DCF, Slow Decrease, Asymptotically Optimal Backoff (AOB) and *Idle Sense* for an increasing number of hosts

Throughput is the average of the throughput for all hosts active in the network
Throughput

Figure 7: Throughput comparison.
## Throughput

<table>
<thead>
<tr>
<th>$N$</th>
<th>1</th>
<th>2</th>
<th>4</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>50</th>
<th>100</th>
<th>200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throughput, 802.11b (Mb/s)</td>
<td>6.39</td>
<td>3.35</td>
<td>1.67</td>
<td>0.63</td>
<td>0.41</td>
<td>0.29</td>
<td>0.23</td>
<td>0.10</td>
<td>0.05</td>
<td>0.02</td>
</tr>
<tr>
<td>Throughput, Idle Sense (Mb/s)</td>
<td>7.59</td>
<td>3.38</td>
<td>1.67</td>
<td>0.62</td>
<td>0.42</td>
<td>0.32</td>
<td>0.27</td>
<td>0.13</td>
<td>0.07</td>
<td>0.03</td>
</tr>
<tr>
<td>Throughput gain</td>
<td>19%</td>
<td>1%</td>
<td>0%</td>
<td>5%</td>
<td>9%</td>
<td>12%</td>
<td>15%</td>
<td>25%</td>
<td>40%</td>
<td>63%</td>
</tr>
<tr>
<td>Throughput, Slow Decrease (Mb/s)</td>
<td>7.32</td>
<td>3.40</td>
<td>1.65</td>
<td>0.63</td>
<td>0.41</td>
<td>0.31</td>
<td>0.24</td>
<td>0.12</td>
<td>0.05</td>
<td>0.03</td>
</tr>
<tr>
<td>Throughput, AOB (Mb/s)</td>
<td>5.64</td>
<td>3.04</td>
<td>1.57</td>
<td>0.37</td>
<td>0.28</td>
<td>0.22</td>
<td>0.25</td>
<td>0.12</td>
<td>0.06</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Table 3: MAC-level throughput and collision rate for 802.11b DCF, Idle Sense, AOB, and Slow Decrease.

<table>
<thead>
<tr>
<th>$N$</th>
<th>1</th>
<th>2</th>
<th>4</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>50</th>
<th>100</th>
<th>200</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.11g, 54 Mb/s</td>
<td>31.79</td>
<td>16.18</td>
<td>7.85</td>
<td>2.92</td>
<td>1.87</td>
<td>1.36</td>
<td>1.06</td>
<td>0.49</td>
<td>0.22</td>
<td>0.09</td>
</tr>
<tr>
<td>Idle Sense ($\epsilon = 0.001$)</td>
<td>38.12</td>
<td>15.49</td>
<td>7.86</td>
<td>3.12</td>
<td>2.08</td>
<td>1.56</td>
<td>1.25</td>
<td>0.62</td>
<td>0.31</td>
<td>0.15</td>
</tr>
<tr>
<td>Idle Sense ($\epsilon = 0.1$)</td>
<td>38.12</td>
<td>16.53</td>
<td>7.94</td>
<td>3.00</td>
<td>1.96</td>
<td>1.46</td>
<td>1.17</td>
<td>0.57</td>
<td>0.28</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Table 4: Throughput comparisons between high bit rate variants of 802.11 and Idle Sense.
Throughput: Conclusion

- Authors expected throughput to stay around that of DCF
- Throughput actually improves slightly
Fairness: Jain Index

Figure 8: Fairness comparison for $N = 50$ competing hosts.

Much better than DCF!
Delay

\[ K = \# \text{ of intertransmissions between other hosts between two transmissions of a given host} \]

For larger K, hosts experience greater delays
Delay

<table>
<thead>
<tr>
<th>Bit rate (Mb/s)</th>
<th>11</th>
<th>54</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.11</td>
<td>1484</td>
<td>2600</td>
<td>2700</td>
</tr>
<tr>
<td><em>Idle Sense</em></td>
<td>94</td>
<td>93</td>
<td>87</td>
</tr>
</tbody>
</table>

Table 5: Maximum values of $K$, the number of inter-transmissions, for $N = 10$, observed over $10^6$ transmissions.

Hosts should experience significantly less delay!
Collision Overhead

<table>
<thead>
<tr>
<th>( N )</th>
<th>1</th>
<th>2</th>
<th>4</th>
<th>10</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision rate, 802.11b</td>
<td>0.0%</td>
<td>3.1%</td>
<td>7.8%</td>
<td>15.9%</td>
<td>20.0%</td>
</tr>
<tr>
<td>Collision rate, <em>Idle Sense</em></td>
<td>0.0%</td>
<td>3.0%</td>
<td>4.7%</td>
<td>6.1%</td>
<td>6.6%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>20</th>
<th>25</th>
<th>50</th>
<th>100</th>
<th>200</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.8%</td>
<td>25.1%</td>
<td>32.4%</td>
<td>40.5%</td>
<td>49.9%</td>
<td></td>
</tr>
<tr>
<td>6.9%</td>
<td>7.3%</td>
<td>8.4%</td>
<td>9.2%</td>
<td>9.7%</td>
<td></td>
</tr>
</tbody>
</table>

\[
\frac{1}{2} \text{ of } \frac{1}{5} \quad \text{DCF}
\]
Convergence Speed

Start out with 5 greedy hosts, add another 5 at 2000, drop 5 at 3000

Stabilizes quickly after every change

Figure 11: Convergence of the *Idle Sense* method.
Time fairness

- One 1Mb/s host and N-1 11Mb/s hosts
- By TF, fast hosts should get 11 x the throughput of the slow host in Idle Sense
Time fairness

<table>
<thead>
<tr>
<th>N</th>
<th>2</th>
<th>4</th>
<th>10</th>
<th>15</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.11b (slow host)</td>
<td>0.77</td>
<td>0.60</td>
<td>0.35</td>
<td>0.25</td>
<td>0.20</td>
</tr>
<tr>
<td>802.11b (fast host)</td>
<td>0.77</td>
<td>0.60</td>
<td>0.35</td>
<td>0.25</td>
<td>0.20</td>
</tr>
<tr>
<td>802.11b (average)</td>
<td>0.77</td>
<td>0.59</td>
<td>0.35</td>
<td>0.25</td>
<td>0.20</td>
</tr>
<tr>
<td>Idle Sense (slow host)</td>
<td>0.34</td>
<td>0.18</td>
<td>0.06</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>Idle Sense (fast host)</td>
<td>3.90</td>
<td>2.16</td>
<td>0.68</td>
<td>0.45</td>
<td>0.34</td>
</tr>
<tr>
<td>Idle Sense (average)</td>
<td>2.12</td>
<td>1.67</td>
<td>0.62</td>
<td>0.42</td>
<td>0.32</td>
</tr>
</tbody>
</table>

Table 6: Performance anomaly: throughput when a single host transmits at a lower bit rate (1 Mb/s vs. 11Mb/s).

In DCF, all hosts get the slow host’s throughput – tput much lower than in IS!
Conclusions

• Throughput equivalent (sometimes better) than in DCF
• Better short-term fairness
• Shorter delay
• Less collision overhead
• Converges quickly
• Is time fair/doesn’t cripple fast senders
Possible weaknesses?

- No info provided on actual simulation tool/we can’t recreate experiments
- Some “experimentally derived” parameters
- How is this actually implemented?
- What happens if some senders have IS and others don’t?
- Is time-fairness really “fair”?
Oddities

- Figure 9 never referenced in text (second Jain fairness figure)
Questions/Comments
Acknowledgements

• Most figures taken directly from the paper
• Slide 10 is from the 1999 801.11 technical specifications (Section 9.2, DCF)
• Slides 9 & 12 and the “Bad Day” and physical capture ideas are from Martin Heusse’s presentation of Idle Sense at SIGCOMM ‘05