Control theoretic optimization of 802.11 WLANs: Design, implementation and experimental evaluation of two schemes

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Jointly with...

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Motivation

- IEEE 802.11: access scheme whose performance depends on the *Contention Window (CW)*
- “Slotted ALOHA”: Given the number of stations, there exists a CW* that maximizes performance
Previous works

• Adjust the CW based on conditions
  – A lot of activity: increase the CW
  – Less activity: decrease the CW

• Two types of solutions
  – Centralized approaches (e.g., [3-5]) – AP computes the configuration and distributes it (now a standard feature)
  – Distributed approaches (e.g., [6-8]) – stations compute their configuration independently → suitable also for ad-hoc mode
(some) Previous works


Limitations

- Require modifications of the hardware and/or firmware
- Their performance has not been assessed in real deployment
- Based on heuristics
Motivation, revisited

• Bianchi’s seminal work [1]: in \textit{saturation}

\[
\tau_{opt} \approx \frac{1}{n} \sqrt{\frac{2T_e}{T_c}}
\]

• This results in a “constant” (conditional) collision probability

\[
P_{opt} = 1 - (1 - \tau_{opt})^{n-1} = 1 - \left(1 - \frac{1}{n} \sqrt{\frac{2T_e}{T_c}}\right)^{n-1} \approx 1 - e^{-\sqrt{\frac{2T_e}{T_c}}}
\]
Centralized Algorithm

- Use this $p_{opt}$ as a **reference signal**
  - No need to estimate the number of stations

- Also for non-sat conditions?
The Controller

- Well established scheme from discrete-time control theory: Proportional Integrator (PI) controller
- Takes as input an error signal
- The AP computes and distributes the $CW$ configuration to the stations
Simulation: it works!

Validation of the designed controller

- A large \(\{K_p, K_i\}\) setting yields unstable behavior
- A smaller \(\{K_p, K_i\}\) setting gains stability but induces slow response

Pablo Serrano – Control theoretic… – Trinity College Dublin, June 10\textsuperscript{th}, 2015
Distributed Approach

• A different (more challenging) approach to performance optimization
  – Each station computes its own configuration by observing the current WLAN conditions (no coordination)
  – Reasons
    • Eliminates single point of failure
    • No need for additional signaling
    • Can operate without an Access Point
Challenge: Short-sightedness

- Driving the WLAN’s collision probability to an “optimal” value can result in fairness problems

\[ p_1 = 1 - (1 - \tau_2)(1 - \tau_3) \]

<table>
<thead>
<tr>
<th>CW_1</th>
<th>CW_2</th>
<th>CW_3</th>
</tr>
</thead>
<tbody>
<tr>
<td>48</td>
<td>3</td>
<td>28</td>
</tr>
<tr>
<td>9</td>
<td>18</td>
<td>42</td>
</tr>
<tr>
<td>19</td>
<td>19</td>
<td>19</td>
</tr>
</tbody>
</table>

Nodes should use the same CW to ensure **fairness**
Restoring fairness: two error terms

- Similar to the centralized solution, first term ensures that the collision probability in the network is driven to the optimal value

\[ e_{\text{collision},i} = p_{\text{obs},i} - p_{\text{opt}} \]

- If two stations do not share the bandwidth fairly due to having different \( CW_{\text{min},i} \), the error should be large

\[ e_{\text{fairness},i} = p_{\text{obs},i} - p_{\text{own},i} \]

- Hence,

\[ e_i = 2 \cdot p_{\text{obs},i} - p_{\text{own},i} - p_{\text{opt}} \]
Mechanism

- Distributed implementation, but same vision of the WLAN
Simulation: it also works!
Time for experimentation

\[ \text{Practice what you know, and it will help to make clear what now you do not know.} \]

Rembrandt
Test-bed

- Under raised floor
- 17 clients, 1 AP
- ≠ link qualities
Total UDP throughput

- EDCA
- CAC
- DAC

Total throughput [Mbps]
CAC: Validation – real-hw limitations

![Graph showing C\textsubscript{W}\textsubscript{min} and Collision probability over time]
DAC: Validation
Per-station UDP throughput

![Graph showing per-station UDP throughput for different station indices and EDCA, CAC, and DAC methods.](image)
Throughput vs. SNR
Real-life: Capture effect

- EDCA: Better link quality results in higher throughput.
- CAC: reduces the number of collisions, the impact of the capture effect is reduced.
- DAC: nodes with high capture probability will experience smaller collision rates than the others, acting “more gentle”.

\[ e_{\text{fairness},i} = p_{\text{obs},i} - p_{\text{own},i} \]
TCP transfers (10 MB) – non sat. cond.
Summary

• CAC and DAC: two schemes to adapt the CW to optimize performance
  – Based on analysis (vs. heuristics)
  – Distributed: need to account for fairness

• Tested with real-life devices
  – DAC suffers from link heterogeneity
  – CAC works for sat. & non-sat conditions
Many Thanks!

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