Energy Consumption Anatomy of 802.11 Devices and its Implication on Modeling and Design

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What we wanted

- To design an energy efficient comm. protocols we need to understand the power consumption
- Previous experimental work
  - Per-packet analysis of the wireless interface

Rantala et al. “Modeling energy efficiency in wireless internet communication”, ACM Mobiheld, 2009

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What we wanted

- To design an energy efficient comm. protocols we need to understand the power consumption

- Previous experimental work
  - Per-packet analysis of the wireless interface
  - Per-state measurements of the device

A.Rice, S. Hay “Measuring mobile phone energy consumption for 802.11 wireless networking”, PMC. 2010

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What we found

- Non-card can dominate the consumption
- Questions previous schemes
  - E.g. relaying in multihop
- Enables new designs
  - E.g. packet batching

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## Energy Consumption Anatomy

- **Hardware used**

<table>
<thead>
<tr>
<th>Device</th>
<th>WiFi chipset</th>
<th>CPU</th>
<th>Memory</th>
<th>Software</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soekris net4826-48</td>
<td>Atheros AR5414 (11a/b/g)</td>
<td>233 MHz AMD SC1100</td>
<td>128 MB SDRAM</td>
<td>Gentoo 10.0 Kernel 2.6.24 / OpenBSD 5.1</td>
</tr>
<tr>
<td>Alix 2d2</td>
<td>Broadcom BCM4319 (11b/g)</td>
<td>500 MHz AMD LX800</td>
<td>256 MB SDRAM</td>
<td>Ubuntu 10.04 Kernel 2.6.29</td>
</tr>
<tr>
<td>Linksys WRT54GL</td>
<td>Broadcom BM4320 (11b/g)</td>
<td>200 MHz BCM5352</td>
<td>16 MB RAM</td>
<td>OpenWrt Backfire Kernel 2.6.32</td>
</tr>
</tbody>
</table>

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Methodology

- With one device
  - Results are not very precise (e.g. ~6%)
  - We added more devices (~2%)

<table>
<thead>
<tr>
<th>Config.</th>
<th>Description</th>
<th>Cons. (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>w/o card</td>
<td>no NIC connected</td>
<td>2.29 ± 2.2%</td>
</tr>
<tr>
<td>WiFi off</td>
<td>NIC connected driver not loaded</td>
<td>2.58 ± 2.0% (+0.29)</td>
</tr>
<tr>
<td>Idle ($\rho_{id}$)</td>
<td>NIC activated+associated to AP no RX/TX besides beacons</td>
<td>3.56 ± 1.7% (+0.98)</td>
</tr>
</tbody>
</table>

Baseline power consumption

Energy Consumption Anatomy of 802.11 Devices and its Implication on Modeling and Design
Power consumption: Transmission

- Varying frame length -> Airtime = $T_{plcp} + (H+L)/R$

Energy Consumption Anatomy of 802.11 Devices and its Implication on Modeling and Design
Power consumption: Transmission

\[ P = P_{\text{base}} + P(\text{fps}) + P_{\text{tx}}(\text{MCS}, \text{power}) \times \text{Airtime} \]

- 24Mbps, 1200fps, 15dBm
- UDP, no ACKs, no retx.
- 24Mbps, 400fps, 15dBm
- 6Mbps, 400fps, 15dBm
- 6Mbps, 400fps, 5dBm

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Per-Packet “energy toll”

Soekris: 0.93 mJ/frame (Linux), 1.27 mJ/frame (OpenBSD)
Linksys: 0.46 mJ/frame  
Alix: 0.11 mJ/frame

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Energy Consumption Anatomy

“Cross-Factor”
- User space
  - mgen
- Kernel space
  - TCP/IP
  - Driver
- Transmission
  - Wireless NIC
    - ASIC
    - PA

- (a) App.: disc. before the OS
- (b) TCP/IP: disc. before driver
- (c) Driver: disc. after driver
- Total

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Anatomy Results

Energy Consumption Anatomy of 802.11 Devices and its Implication on Modeling and Design
The Cross Factor

- Energy toll to handle a frame
  - Independent of frame size
  - Total power > base power + card power

- Energy split:

<table>
<thead>
<tr>
<th></th>
<th>App</th>
<th>TCP/IP</th>
<th>Driver</th>
<th>NIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>24%</td>
<td>33%</td>
<td>21%</td>
<td>22%</td>
<td></td>
</tr>
</tbody>
</table>

- **Very far from negligible (vs. Tx Power)**
  - Previous slide: 37% ~ 97% energy/frame
Retransmissions (and control frames)

- E.g. 2 retries, but only 1 cross factor

Diagram:
- User space: mgen
- Kernel space: TCP/IP → Driver
- Wireless NIC: ASIC → PA

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Retransmissions

Energy Consumption Anatomy of 802.11 Devices and its Implication on Modeling and Design
Model for the power consumption

- Similar results for reception.
- Model: \( P = \rho_{id} \) Baseline
  + \( \rho_{tx}(\tau_{tx}) \) TX airtime
  + \( \rho_{rx}(\tau_{rx}) \) RX airtime
  + \( \gamma_{gx} \lambda_{g} + \gamma_{xr} \lambda_{r} \) Packet processing

- Parametrization for the Soekris, Linksys, Alix

<table>
<thead>
<tr>
<th>MCS</th>
<th>6 Mbps</th>
<th>12 Mbps</th>
<th>24 Mbps</th>
<th>48 Mbps</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \rho_{rx} (W) )</td>
<td>0.24 ± 4.2%</td>
<td>0.27 ± 3.7%</td>
<td>0.31 ± 6.4%</td>
<td>0.44 ± 6.8%</td>
</tr>
</tbody>
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</tr>
</thead>
<tbody>
<tr>
<td>( \rho_{tx} (W) )</td>
<td>0.19 ± 5.3%</td>
<td>0.29 ± 3.4%</td>
<td>0.53 ± 2.3%</td>
<td>0.74 ± 4.4%</td>
</tr>
</tbody>
</table>

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<th>24 Mbps</th>
<th>48 Mbps</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \rho_{tx} (W) )</td>
<td>0.16 ± 8%</td>
<td>0.27 ± 5.6%</td>
<td>0.6 ± 11%</td>
<td>1.14 ± 3.5%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MCS</th>
<th>6 dBm</th>
<th>9 dBm</th>
<th>12 dBm</th>
<th>15 dBm</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \rho_{tx} (W) )</td>
<td>0.52 ± 3.1%</td>
<td>0.57 ± 2.1%</td>
<td>0.70 ± 1.7%</td>
<td>0.86 ± 2.2%</td>
</tr>
</tbody>
</table>

\( \rho_{id} (W) \) 3.56 ± 1.7% \( \gamma_{gx} \) (mJ) 0.93 ± 1.2% \( \gamma_{xr} \) (mJ) 0.93 ± 2.2%

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Validation of the model

- General scenarios

![Graph showing energy consumption versus rate for different scenarios. The graph includes lines and markers for different data points.](image)

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Ok, but...

• Does it matter?

• What are the implications?

1. Revisit old proposals based on the classical model

2. Design of new schemes building on the detailed anatomy

Cross factor:
37% ~ 97% △ energy / frame
Old: Packet relays

Energy Consumption Anatomy of 802.11 Devices and its Implication on Modeling and Design
Old: Packet relays

![Diagram showing packet relays between AP, STA 1, and STA 2 with power consumption graph.]

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New: Packet batching

- Group n packets before they transverse the protocol stack
  - Fixed energy cost per bundle
  - Same information over the medium
New: Packet batching

- Substantial savings (~80%)
- No savings according to the classical model

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Other implications

- Data compression in multihop
  - Old model: savings
  - New model: not

- Directed Multicast
  - Where to generate frames

- Use of raw sockets
  - E.g., skipping TCP/IP: 0.2 mJ/frame
Summary

• Per-packet analysis of the energy consumption of a wireless device
  – Parametrized for various devices

• Characterization of the cross factor

• Two-fold impact
  – Revisit previous schemes
  – Enable new designs
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Thanks!