Adaptive Application-Driven WLAN Power Management

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Outline

• Introduction and Motivation
• Background and Related Work
• Adaptive Application-Driven Power Management (AADPM)
  - NIC Characterization
  - Online Idle Period Distribution Learning Algorithm
  - The AADPM Policy
• Evaluation
• Conclusion
• References
Introduction and Motivation

- Wireless networks provide mobile users the opportunities of remote information access and sharing.
- Research has shown that without power management (PM), the NIC may consume up to 10% of the total energy of a high-end portable computer and nearly 50% of the overall energy of a low-end handheld device.
Introduction and Motivation

- Our Goal:
  - Minimize the energy consumption of the NIC while maintaining high throughput for wireless Internet information retrieval applications within the IEEE 802.11b wireless LAN environment.
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Background and Related Work

- Target Environment
  -- IEEE 802.11b infrastructure wireless LAN (as opposed to ad hoc network) [1]

This figure is obtained from “Cisco Aironet 1200 Series Access Point Installation and Configuration Guide, 12.2(8)JA” [2].
Background and Related Work

- IEEE 802.11b Power Save Mode (PSM)
  - AP broadcasts Beacons every BeaconPeriod (100ms).
  - AP buffers data during the BeaconPeriod.
  - Each Beacon contains a traffic indication map (TIM) that shows whether a mobile station has pending data.
Background and Related Work

- IEEE 802.11b Power Save Mode (PSM)
  - 802.11b compliant NICs support two power states: doze and awake.
  - The NIC can be switched to doze mode when the mobile station has no data to send.
Background and Related Work

- **IEEE 802.11b Power Save Mode (PSM)**
  - If the TIM indicates that the mobile station has outstanding data, the mobile station must POLL the AP and retrieve all pending data before it can switch the NIC to doze mode.
Background and Related Work

Problem: 802.11b PSM is static!

Round Trip Time (RTT) Delays

50 ms

100 ms 100 ms

Beacon

Request

Response
Background and Related Work

• Dynamic Power Management (DPM) Strategies
  - Low-level DPM
    • Bounded Slowdown Protocol (BSD) [3]
    • Fast PSP (FPSP) [4]
  - High-level DPM
    • A general application-level DPM [5]
    • Self-Tuning Power Management (STPM) [6]
Background and Related Work

- **Low-level DPM** protocols do not possess application-level information and therefore, they usually act conservatively.

- **High-level DPM** protocols have the advantage of knowing the applications’ intention of network usage, but there is no one-size-fits-all solution.
Background and Related Work

• In general, DPM developers are seeking answers to two fundamental questions:
  - When does an idle period start?
  - How long does the idle period last?

• We proposed an adaptive application-driven power management (AADPM) strategy with online idle period length distribution learning capability that can address these questions.
AADPM

• AADPM differs from other strategies in several ways:
  - It requires no changes to the existing IEEE 802.11b standard.
  - It does not assume a particular request arrival pattern, nor does it make assumptions about the server response time.
  - It explicitly considers the mode change overhead when making mode transition decisions.
  - When an NIC support multiple low-power states, it maximizes energy saving by choosing the most suitable power state.
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AADPM

• NIC Characterization
  - We used the Enterasys Network RoamAbout NIC in our evaluation.

\[ t_{\text{delay}} = 0 \text{ ms}, \quad E_{\text{transition}} = 0 \text{ mJ} \]

\[ t_{BE} = \frac{E_{\text{transition}}}{P_{\text{active}} - P_{\text{doze}}} \]

\[ t_{\text{delay}} = 2 \text{ ms}, \quad E_{\text{transition}} = 1.5 \text{ mJ} \]

\[ t_{BE} = 2 \text{ ms} \]
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AADPM

• Energy-Aware Applications
  - The server sends an application-level ACK to the client upon receiving a request.
  - The client program notifies the OS when an application-level ACK is received.
  - The client program gathers statistics about the idle period history and the last mode transition cost.
AADPM

Online Idle Period Distribution Learning

- Partition the set of all possible idle period lengths \((0, \infty)\) into \(n\) intervals. \(n\) is the number of bins in the histogram.
- Let \(l_i\) denote the starting point of interval \(i\). Bin \(i\) represents the idle period range of \([l_i, l_{i+1})\).
- Each bin has a counter \(C_i\) representing the number of idle period lengths that fall in the bin.
- A history window size \(\omega\) is used to determine the total number of history records saved by the histogram.

\[
\sum_{i=0}^{n-1} C_i = \omega
\]
AADPM

• Online Idle Period Distribution Learning (Cont.)

\[ p(i) = \frac{C_i}{\omega} \]

\[ P(i) = \frac{\sum_{j=0}^{i} C_j}{\omega} \]

• Let the user specify an energy/performance tradeoff indicator \textit{ep\_ratio}. \textit{ep\_ratio} = 0 means maximizing performance, and \textit{ep\_ratio} = 1.0 means maximizing energy saving.

• Find the largest \( i, I, \) such that \( P(I) \leq \text{ep\_ratio} \).

• The predicted upcoming idle period length is

\[ t_{\text{idle}} = I_I + \frac{(I_{I+1} - I_I)}{2} \]
AADPM

- \( n = 5 \)
- \( \omega = 10 \)
- Each bin in this histogram has a resolution of 1 second.

\[
\begin{align*}
\text{bin0} & \quad \text{bin1} & \quad \text{bin2} & \quad \text{bin3} & \quad \text{bin4} \\
C_0=2 & \quad C_1=3 & \quad C_2=1 & \quad C_3=2 & \quad C_4=2 \\
l_0 & \quad l_1 & \quad l_2 & \quad l_3 & \quad l_4 & \quad l_5 \\
p(0) = .2 & \quad p(1) = .3 & \quad p(2) = .1 & \quad p(3) = .2 & \quad p(4) = .2 \\
P(0) = .2 & \quad P(1) = .5 & \quad P(2) = .6 & \quad P(3) = .8 & \quad P(4) = 1
\end{align*}
\]

If ep_ratio = 0.8, \( t_{idle} = 3.5 \text{ s} \).
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\[ t_{\text{BE}} = \frac{E_{\text{transition}}}{P_{\text{active}} - P_{\text{doze}}} \]

\[ t_{\text{delay}} = 2 \text{ ms}, \ E_{\text{transition}} = 1.5 \text{ mJ} \]

\[ t_{\text{BE}} = 2 \text{ ms} \]
ADDPM

- **Wait-for-Server-Response Idle Period (after a request is sent and ACKed)**
  - If \( t_{idle} - t_{mode\_transition\_cost} > t_{BE} \)
    - Calculate the sleep duration using equation (2);
    - Switch the NIC to doze mode;
    - When the sleep duration expires, periodically wakeup the NIC to listen to every Beacon till pending data are detected;
    - Switch the NIC to CAM mode.

\[
t_{beacon} = \left( \left\lfloor \frac{(t_{current} + t_{idle})}{t_{bp}} \right\rfloor + 1 \right) \times t_{bp} \quad (1)
\]

\[
t_{sleep} = t_{beacon} - t_{current} - t_{delay} \quad (2)
\]

\( t_{current} \): the current time
\( t_{bp} \): the beacon period
\( t_{beacon} \): the time of the next beacon to listen
ADDPM

- User-Think-Time Idle Period (after a response is received)
  - If \( t_{idle} - t_{mode\_transition\_cost} > t_{BE} \)
    - Switch the NIC to doze mode till the arrival of the next request.
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Evaluation

- We used NS2 to evaluate the effectiveness of AADPM (ep_ratio = 1.0) in comparison to the IEEE 802.11b PSM and the Cisco Aironet FPSP methods.
- In each simulation run, the mobile station executes 10,000 requests using a particular PM strategy or no PM at all (NO_PM).

- Topology
Evaluation

• Application Characterization
  - Parameters such as the server response time, server response size, and request size are extracted from UC Berkeley-Home-IP web trace. User think time is a randomly generated number between 1 s and 15 s.
Evaluation

• Performance Metrics
  - Average Round Trip Time Delay
  - NIC Energy Consumption
  - AP Buffer size
Evaluation - RTT Delay

Average Round Trip Time Delay

- PSM: 1.1824
- FPSP: 0.0922
- AADPM: 0.1127
Evaluation - NIC Energy

![Energy Consumption Chart]

- **NO_PM**: 7.73 J
- **PSM**: 2.03 J
- **FPSP**: 4.63 J
- **AADPM**: 0.83 J
Evaluation – AP Buffer Length

![AP Buffer Length Chart]

<table>
<thead>
<tr>
<th></th>
<th>Max AP Buffer Length</th>
<th>Average AP Buffer Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSM</td>
<td>20.00</td>
<td>1.09</td>
</tr>
<tr>
<td>FPSP</td>
<td>3.00</td>
<td>0.06</td>
</tr>
<tr>
<td>AADPM</td>
<td>3.00</td>
<td>0.03</td>
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Conclusion

• PSM achieved 74% energy saving compared to NO_PM at the cost of 118% increase in RTT delay.
• FPSP accomplished the shortest RTT delay of 9.2% at the highest energy cost.
• AADPM achieved a good balance between energy and performance - it introduced 11.3% RTT delay while consuming the least amount NIC energy. Compared to NO_PM, PSM, and FPSP, AADPM’s energy saving is 90%, 59%, and 82%, respectively.
• We augmented the network simulator to support IEEE 802.11b PSM. Our NS2 extension can significantly shorten the design and test cycles of future DPM development.
References

Background and Related Work

- **Continuous Awake Mode (CAM)**
- **Power Save Mode (PSM)**
- Switching between the CAM and PSM requires a successful frame exchange between the AP and the mobile station.

A Frame Exchange Sequence

Request to Send

Clear to Send

Data

ACK
Background and Related Work

• IEEE 802.11b PSM Specification
  - The mobile station switches the NIC to doze mode as soon as there is no data waiting to be sent.
  - The mobile station periodically wakes the NIC up to listen to Beacon.
    • If there is no pending data, set the NIC to doze.
    • Otherwise, retrieve all data then set the NIC to doze.
Background and Related Work

- **The Bounded Slowdown Protocol [3]**
  
  **Idea**: Under the assumption that the mobile station power management mode change is instantaneous and always successful, this protocol can provide a mathematically provable performance (RTT delay) bound.

  +: Provide a provable performance bound.
  -: It requires minor changes to the IEEE 802.11 standard.
  -: The assumption is not realistic.

- **Fast PSP [4]**
  
  **Idea**: Switch the NIC to CAM when retrieving a large number of packets and switch back to PSM after the retrieval.

  +: Save power during idle period.
  -: It uses a fixed timeout of 800 ms to determine whether the current time period is an idle period.
Background and Related Work

- **The General Application-Level DPM [5]**
  - **Idea:** Use a fixed timeout period to determine whether or not to suspend the NIC and used a sleep duration parameter to determine how long the NIC should be suspended.
  - **+:** Increase the power saving of web browsing, joint project, and email applications by 83%.
  - **-:** It requires major changes to the IEEE 802.11 standard.
  - **-:** It introduces long delays -- the RTT delays range from 0.4 s to 3.1 s.

- **Self-Tuning Power Management (STPM) [6]**
  - **Idea:** Use the history information of a group of requests that are closely related in time (150 ms) to determine whether of not the change between the CAM and PSM.
  - **+:** It improves the energy saving as well as shortens the RTT delays of latency sensitive applications such as Network File System (NFS).
  - **-:** It is not suitable for wireless Internet information retrieval applications, because the low request rate will never trigger the mode switch. As a result, the STPM protocol will behave the same as PSM.