Energy Efficiency Analysis of TCP with Burst Transmission over a Wireless LAN

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Background

• Accessing the Internet by using mobile devices is becoming common situations
  – Laptops, tablet PCs, smartphones
• Mobile devices are battery-driven
• Wireless communications of a mobile device can account for about 10% to 50% of its total power consumption [1]

It is important for lengthening battery’s lifetime to save energy in the wireless communications


Impact of TCP behavior for energy consumption

How do we save energy effectively?

Energy efficiency depends on when and how long a wireless client stays at sleep mode.
Timings of packet transmission and reception depend on the behavior of transport-layer protocols used by upper-layer applications.
We should understand the behavior of transport-layer protocols for effective energy saving.

Energy consumption model for a mobile device in TCP data transfer [9]

To further save energy, we should reduce the number of state transitions between active and sleep modes.

Objectives of this work

Main idea

Introduce TCP-level burst transmission that transmit multiple data segments consecutively to lengthen each idle duration.

Energy efficiency analysis of TCP-level burst transmission by using energy consumption models

1. Construct an energy consumption model of burst transmission in TCP data transfer by extending the model in [9]
2. Show energy efficiency of burst transmission through numerical results


Network model and assumptions for medlling

We model energy consumption of a mobile device in upstream TCP data transfer over WLAN

Assumptions

• Consider TCP bulk data transfer
• Timings of packet transmission and reception are determined by the behavior of TCP congestion control mechanisms, and TCP knows these timings
• Frame collision does not occur in the WLAN, so no frames are lost at the MAC level
• Data segments are lost by congestion in the wired networks, but ACK segments are not lost

Structure of energy consumption models

Our model is a mixture of the MAC-level model and the TCP-level model.

Based on frame exchanges of CSMA/CA, we calculate energy consumption of transmission and reception of one data frame.

The number of packets sent and received in an RTT is determined by the TCP congestion window size.
Energy consumption ratio

<table>
<thead>
<tr>
<th>Burst Transmission</th>
<th>Normal TCP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequent state transitions degrade energy reduction of sleeping because they consume some energy and take some time.</td>
<td></td>
</tr>
</tbody>
</table>

Ideal sleeping with burst transmission

Transmission of TCP- DATA segment
Recall TCP- ACK segment

Burst transmission is realized by varying the parameter of delayed ACK

Ideal sleeping without burst transmission

<table>
<thead>
<tr>
<th>Burst transmission can be realized by varying the parameter of delayed ACK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reducing the number of state transitions is effective for energy saving</td>
</tr>
</tbody>
</table>

Energy consumption of burst transmission

Energy consumption in sleep mode

Energy consumption of state transitions

Energy consumption for packet transmission

Energy consumption for packet reception

Energy efficiency without burst transmission

Energy efficiency with burst transmission

Transition time from sleep to active (ms) - 1ms

Power saving from sleep to active: 1.4 W

Numerical analysis – Parameter settings

1 MB data transfer when changing in RTT and probability (p) of packet drop events in the wired network

Parameter settings

- Data size: 1 MB
- IEEE 802.11a
- Data rate: 54 Mbps
- Data segment size: 1500 bytes
- ACK segment size: 40 bytes

We calculate energy consumption for 1 MB data transfer when changing in RTT and probability (p) of packet drop events in the wired network.

Energy efficiency without burst transmission is improved

Energy efficiency with burst transmission is very small

The number of state transitions is large due to large TCP window size

Energy consumption of state transitions becomes large

Burst transmission can reduce the number of state transitions

Energy consumption of state transitions is reduced
Numerical results – trade-off between energy efficiency and data transfer latency

\[ p \text{: probability of packet drop events in the wired network} \]

\[ p = 0.01, \text{RTT}=100\text{ms} \]

\[ p = 0.005, \text{RTT}=50\text{ms} \]

As \( m \) becomes large, energy consumption converges to a certain value.

The value of \( m \) should be chosen between one and about five according to requirements of users or applications for energy efficiency and acceptable latency.

Number of packets sent in burst

<table>
<thead>
<tr>
<th>( m )</th>
<th>0</th>
<th>0.5</th>
<th>1</th>
<th>1.5</th>
<th>2</th>
<th>2.5</th>
<th>3</th>
<th>3.5</th>
<th>4</th>
<th>4.5</th>
<th>5</th>
<th>5.5</th>
<th>6</th>
<th>6.5</th>
<th>7</th>
<th>7.5</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy consumption ([\text{J}])</td>
<td>0.01</td>
<td>0.015</td>
<td>0.02</td>
<td>0.025</td>
<td>0.03</td>
<td>0.035</td>
<td>0.04</td>
<td>0.045</td>
<td>0.05</td>
<td>0.055</td>
<td>0.06</td>
<td>0.065</td>
<td>0.07</td>
<td>0.075</td>
<td>0.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data transfer latency ([\text{sec}])</td>
<td>10</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>50</td>
<td>60</td>
<td>70</td>
<td>80</td>
<td>90</td>
<td>100</td>
<td>110</td>
<td>120</td>
<td>130</td>
<td>140</td>
<td>150</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As \( m \) becomes large, data transfer latency increases linearly.

Conclusion and future work

**Conclusion**
- We proposed the energy consumption model in TCP data transfer over a WLAN.
- Introduce burst transmission for effective energy saving.
- From numerical results,
  - With burst transmission, ideal sleeping can save energy when RTT and probability of packet drop events are small.
  - Considering trade-off between energy efficiency and data transfer latency, the number of packets sent in burst should be chosen between one to about five.

**Future work**
- Consider frame losses and collisions due to the existence of multiple wireless clients.
- Develop a transport architecture for energy saving based on burst transmission.

**Ideal sleeping with burst transmission**

How to realize TCP-level burst transmission

Without delayed ACK

With delayed ACK

The TCP receiver sends one ACK segment every data segment reception.

When delayed ACK is used, the TCP receiver sends one ACK segment after it received multiple data segments.

Burst transmission can be realized by varying the parameter of delayed ACK.

**Numerical results – Energy efficiency**

Energy consumption ratio = \( \frac{\text{energy consumption with sleeping}}{\text{energy consumption without sleeping}} \)

Ideal sleeping, without burst transmission

Ideal sleeping with burst transmission \( (m=5) \)

Ideal sleeping with and without burst transmission are almost identical.

When RTT is large, energy consumption of state transitions is relatively small and that accounts for only a small portion of total energy consumption.