Towards Eco-Friendly Home Networking

Mathias Gibbens, Chris Gniady and Beichuan Zhang
Department of Computer Science
The University of Arizona
Tucson, Arizona
Home networks are complex

- More and more demand is being placed on router performance
- Routers require more computing power, bandwidth and features
• Power consumption doubled in 5 years, what about the future?
• Always on in 88 million homes, energy footprint of $1 billion
Previous solutions

• Wired: IEEE 802.3az introduced Energy-Efficient Ethernet
  ▪ First deployed in home networks
  ▪ Physical connection, easy to detect client

• Large mesh networks: many routers, many clients
  ▪ Power down redundant access points
  ▪ Client picks optimal network when more than one is available

• Home networks: one router, many clients
  ▪ Goma et al: aggregate individual networks
  ▪ Requires: dense networks, cooperation, client modifications

We need energy management for individual routers
Our contribution

• Transparent energy optimization of personal networks
  ▪ Individual routers
  ▪ No user intervention or modification of clients
  ▪ No cooperation between networks

• Implementation approach
  ▪ Discarding unnecessary wireless traffic
  ▪ Powering down routers when idle
  ▪ Power cycling with active clients

• Increased energy efficiency of individual home routers
Outline

- Introduction
- Trace collection and categorization
- Proposed optimizations
- Methodology
- Results
- Conclusion
Traffic categorization

- Traffic seen even without clients connected
- Lots of idle time when clients are present
- Router is in full power mode independent of clients
Eliminating broadcast traffic

- Broadcast traffic, but no clients around to respond
- Traffic from wired interface retransmitted over wireless
- No one listening $\rightarrow$ drop broadcast traffic
- Safe to perform: clients must be present in order to respond
Powering down when idle

- No clients → power down antennas after a timeout
- Periodically check for the arrival of new clients
Optimizing duty cycle: Downtime

- Duty cycle impacts a client's ability to connect
- Need to balance extra delay with potential energy savings
- Infrequent initial associations, which impact only first client
Optimizing duty cycle: Uptime

- Antennas must be up for at least 4 seconds for clients to connect
- From observed delays, we chose a 5/5 second up/down cycle
Idle connected clients

- During sufficiently long idle periods, turn off transmit antenna
- Possible because either clients initiate or data arrives on wire
- Router must still periodically announce its presence
Idle connected clients

- WiFi spectrum is inherently error prone
  - Existing protocols have built in transparent retransmission to compensate
- Clients typically disconnect from network after 7 seconds
- Transparent retransmission gives us opportunity to power up
Idle connected clients

- Additional delay due to power up may be seen by applications
  - Can be hidden in the time it takes for a response to return to the router
- Transitioning router's state has an energy cost
  - Only sufficiently long periods should be optimized
  - Ensures real time data is not interrupted
## Methodology

- Monitor traffic seen at router: week long traces
- Very few initial associations when no other clients present
- Detailed power/delay model of ASUS RT-N16 profiled using NI

<table>
<thead>
<tr>
<th>Trace</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average concurrent devices</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Maximum concurrent devices</td>
<td>1</td>
<td>9</td>
<td>7</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Initial associations</td>
<td>13</td>
<td>16</td>
<td>14</td>
<td>31</td>
<td>35</td>
</tr>
<tr>
<td>Average time with no client [h]</td>
<td>10.7</td>
<td>0.08</td>
<td>2.07</td>
<td>1.32</td>
<td>0.92</td>
</tr>
<tr>
<td>Traffic volume [GB]</td>
<td>5.57</td>
<td>40.21</td>
<td>4.22</td>
<td>3.52</td>
<td>12.97</td>
</tr>
</tbody>
</table>
Eliminating broadcast traffic

- No client period increased by 10% average in traces 2-5
- More opportunities for router to power down
Power cycling no clients

- Power cycling with no clients has significant impact
- Additional connection delay for first client paid only occasionally

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![Graph](image_url)

- NB: No Broadcast
- PC: PowerCycle

**Energy (MJ)**

- T1
- T2
- T3
- T4
- T5
Active client optimizations

- More aggressive power cycling can reduce energy consumption by an additional 20-30%
- Cumulative energy savings observed to be 12-59%
Delay due to state transition

- Active clients see some delay when initiating activity after a period of idle time
- All delays within perception threshold, not noticed by user
Conclusion

- Investigated opportunities to reduce energy consumption of consumer wireless routers
- Collected traces from personal networks
- Predicted wireless energy consumption reduced by 12-59%
- Changes do not break backwards compatibility
Thank You

Questions?
Trace collection and analysis

- Five unique week-long traces collected from households
- Routers recorded just the wireless traffic seen
- Networks used as normal to produce representative traces
Idle periods with clients

- To save energy with clients, there must be many idle periods of sufficient length.
- Each trace has many long idle periods.

![Graph](Image)

- **T1**: Yellow line
- **T2**: Green line
- **T3**: Teal line
- **T4**: Purple line
- **T5**: Red line

Weighted idle time against Idle time [s]