PowerSpy

Location Tracking using Mobile Device Power Analysis

Yan Michalevsky\textsuperscript{(1)}, Gabi Nakibly\textsuperscript{(2)}, Aaron Schulman\textsuperscript{(1)}, Gunaa Arumugam Veerapandian\textsuperscript{(1)} and Dan Boneh\textsuperscript{(1)}

\textsuperscript{(1)} Stanford University, \textsuperscript{(2)} National Research and Simulation Center, Rafael Ltd.
Smartphones have many sensors

- accelerometer
- gyroscope
- magnetometer
- front and rear cameras
- NFC
- barometer
- speaker
- microphone
- proximity
- light sensor
- Bluetooth
- GPS
- WiFi + cellular
- humidity
- temperature
Related Work on Information Leakage Through Sensors

- Speaker on/off status [Zhou et al. '13]
- Accelerometers [Hua et al. '15, Han et al. '12]
- Microphone [Schlegel et al. '11]
- and many more...
Accessing Location Requires Permissions

Even coarse location based on cellular network information
Reading Voltage and Current Requires NO Permissions

/sys/class/power_supply/battery/voltage_now
/sys/class/power_supply/battery/current_now
Reading Voltage and Current **Requires NO Permissions**

/sys/class/power_supply/battery/voltage_now
/sys/class/power_supply/battery/current_now

Nexus 4, Nexus 5, HTC Desire, iPhone 6...

Sampling at order of 100 Hz
Power Meter Reveals Location
A seemingly innocent application can read the power meter

Angry Hedgehogs does not require any special permissions. Learn More

Updates to Battery Hedgehog may automatically add additional capabilities within each group. Learn more

Send email
Permission details
Signal Strength Depends on Location and Environment
Signal Strength is Stable Across Days

06/23/2014

06/24/2014
$\text{Power} = f(\text{Signal Strength})$

- More power used upon transmission under low SNR
- Signal amplification, error correction on the receive part
- Verified experimentally in \textbf{Bartendr} [Schulman et al. '10]
Power Profile is Consistent Across Devices

Two phones of same model, same route

Different models, same route
What can we achieve with that?
Goal 1: Route Distinguishability

- Determine the route taken by the user from a given set
- Learn past locations
- Application: advertisement, etc.
Goal 2: Real-Time Tracking

along a known (or assumed) route

Perform tracking of the user's current location on a given route
Goal 3: New Route Inference

Learn the route using previously measured power profiles of many short road segments
Distinguishing Routes

Each power profile is a time-series Classifier based on time series comparison using Dynamic Time Warping (DTW) [Sakoe and Chiba 1978]
Dynamic Time Warping

Euclidean distance

DTW distance
DTW Alignment
Data Processing

- DC offset removal and normalization
  - Compensate for background applications introducing a constant offset
  - Compensate for gain differences
- Smoothing: Moving Average filter (obtain general trends)
- Downsampling (important for computation reduction)
Evaluation
## Goal 1: We can Distinguish between Routes

<table>
<thead>
<tr>
<th>Unique Routes</th>
<th># Ref. Profiles/Route</th>
<th># Test Routes</th>
<th>Success %</th>
<th>Random Guess %</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>10</td>
<td>55</td>
<td>85</td>
<td>13</td>
</tr>
<tr>
<td>17</td>
<td>5</td>
<td>119</td>
<td>71</td>
<td>6</td>
</tr>
<tr>
<td>17</td>
<td>4</td>
<td>136</td>
<td>68</td>
<td>6</td>
</tr>
<tr>
<td>21</td>
<td>3</td>
<td>157</td>
<td>61</td>
<td>5</td>
</tr>
<tr>
<td>25</td>
<td>2</td>
<td>182</td>
<td>53</td>
<td>4</td>
</tr>
<tr>
<td>29</td>
<td>1</td>
<td>211</td>
<td>40</td>
<td>3</td>
</tr>
</tbody>
</table>
Real-Time Tracking

- A window of received samples is a subsequence of the reference power profile
- Using Subsequence-DTW determine the offset of the subsequence
- Infer location from reference profile
Goal 2: We can Track Along a Route
Goal 2: We can Track Along a Route

Error(time)

Error histogram
Goal 2: We can Track Along a Route
Goal 2: We can Track Along a Route

Error(time)

Error histogram
And compensate for obvious errors...
Improved tracking using Optimal Subsequence Bijection (OSB) [Latecki et al. '07]
Tracking using OSB
Goal 3: New Route Inference based on Road Segments

- Points on map represented by nodes
- Connecting road segments represented by edges
- Probabilistic graphical model of location
New Route Inference based on Road Segments: The Area Map
Route Inference based on Road Segments

Evaluation metric based on Levenshtein Distance

\[ d = 0.125 \] \[ d = 0.25 \] \[ d = 0.43 \]
Future Work

- Build a big dataset of power profiles for US routes
- Improved route inference (Hidden Markov Model, Viterbi...)
Future Warning!

- HTML5 provides battery API that enables receiving notifications about changes in battery level.
- The derivative of the battery level is a very coarse power consumption profile.
- Keep power measurement coarse!
Non-Defenses

- Adding noise
- Limiting power sampling rate (1 Hz)
Defenses

- Secure hardware design
  - Exclude TX/RX chain from power measurement
- Power consumption as a coarse location indicator
- Provide abstractions, not raw data [Jana et al. '13]
Conclusion

- Sensors can have unintended consequences
- Power meter access should be restricted
- Permissions needed to address sensor access
Thank you for attending

Questions?

yanm2@cs.stanford.edu
www.stanford.edu/~yanm2
A phone call can be easily distinguished and removed from a power profile.