Mobile Location Technologies

Jeff Hightower
Intel Labs
A smartphone without location sensing is like a laptop without WiFi.
Why?
Maps and Way Finding

- Where am I?
  - Map View, Nearby stuff
- How do I get to X?
  - Directions & Navigation
- What is around here?
  - Nearest Starbucks
  - Local search

A. Edmond Manor Hotel
   (206) 634-2000
   References: universityedmonthotel.com - 976.mere.a

B. Vashon Hotel
   (206) 828-4242
   References: vashontownseattle.com - 650.mere.a

C. University Plaza Hotel
   (206) 634-0100
   References: universityplazahotel.com - 105.mere.a

D. Four Seasons Homes Inc
   (206) 500-7136
   References: thecityofseattle.com

E. Firming Hospitality Group
   (206) 675-1424
   References: Firming Hospitality Group

Click on any point to re-center the map.
Social-Mobile Services

- Who is around here?
- Where do my friends go?
- What is a good exercise route?
- How far did I walk today?
IT Management & Asset Tracking

• Inventory Tracking
  – Finding lost and stolen devices

• Virus breakout tracking
  – Location as tool in computer virus epidemiology

• Controlling wireless network access
  – e.g. Access denied beyond 20m of building

• Monitoring device usage
  – Measure mobility, usage by device class
How?
# Location Sensing Technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Application Domain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite Positioning Systems</td>
<td>Outdoor navigation</td>
</tr>
<tr>
<td>Manual User-entry</td>
<td>Location-based web services</td>
</tr>
<tr>
<td>Cell-tower Triangulation</td>
<td>Web and Fee-based location transactions</td>
</tr>
<tr>
<td>802.11 Fingerprinting</td>
<td>Process management e.g. Hospitals</td>
</tr>
<tr>
<td>Beacon-based Location</td>
<td>Indoor and fast TTFF mobile computing</td>
</tr>
</tbody>
</table>
Long Range Navigation (LORAN)

Coverage: Outdoors, high seas
Accuracy: 200-400 meters
Infrastructure cost: High
Per-client cost: Low
Privacy: High
Application Domain: Aircraft & Vessels

Simplified LORAN TD lines
Global Navigation Satellite Systems (GNSS)  
(e.g. GPS, GLONASS, Galileo, Compass)

<table>
<thead>
<tr>
<th>Coverage</th>
<th>Outdoors (line of sight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>10m</td>
</tr>
<tr>
<td>Infrastructure cost</td>
<td>High</td>
</tr>
<tr>
<td>Per-client cost</td>
<td>Medium</td>
</tr>
<tr>
<td>Privacy</td>
<td>High</td>
</tr>
<tr>
<td>Application Domain</td>
<td>Outdoor navigation</td>
</tr>
</tbody>
</table>
GPS Variants

• **WAAS (LAAS)**
  – Improve accuracy to 3 meters (LAAS to 10cm)

• **Assisted GPS (A-GPS)**
  – Uses data network, faster lock times, comparable coverage

• **“Relaxed” GPS**
  – Loosen the GPS algorithm requirements improve coverage at the cost of some accuracy
  – Can work indoors, but with >50m error

• **Soft-GPS**
  – GPS antenna + A/D + CPU
  – Slight improvement in coverage, time to lock
## Manual Entry

<table>
<thead>
<tr>
<th>Coverage</th>
<th>Populated Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>10m-50km</td>
</tr>
<tr>
<td>Infrastructure cost</td>
<td>Low</td>
</tr>
<tr>
<td>Per-client cost</td>
<td>Low</td>
</tr>
<tr>
<td>Privacy</td>
<td>High</td>
</tr>
<tr>
<td>Application Domain</td>
<td>Location-based web services</td>
</tr>
</tbody>
</table>

---

![Google search results for pizza in Seattle, WA](image)
# Cell-Tower Triangulation

<table>
<thead>
<tr>
<th>Coverage</th>
<th>Populated Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>50-150m</td>
</tr>
<tr>
<td>Infrastructure cost</td>
<td>Low</td>
</tr>
<tr>
<td>Per-client cost</td>
<td>Medium</td>
</tr>
<tr>
<td>Privacy</td>
<td>Low</td>
</tr>
<tr>
<td>Application Domain</td>
<td>Web services and Fee-based location transactions</td>
</tr>
</tbody>
</table>
802.11 Fingerprinting

Coverage: Indoor, Campus
Accuracy: 2-10m
Infrastructure cost: High
Per-client cost: Low
Privacy: Low/High
Application Domain: Process Management (e.g. hospitals)

Access Point | RSSI
---|---
00:0f:f7:0c:e9:c0 | -80 dB
12:0f:f5:82:22:19 | -96 dB
00:0f:34:ab:0c:e0 | -65 dB

Exploit radio’s temporal stability and spatial variability
# Radio Beacon Location

<table>
<thead>
<tr>
<th>Coverage</th>
<th>Populated Areas + Outdoors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>5-150M</td>
</tr>
<tr>
<td>Infrastructure cost</td>
<td>Low</td>
</tr>
<tr>
<td>Per-client cost</td>
<td>Low</td>
</tr>
<tr>
<td>Privacy</td>
<td>Low-High</td>
</tr>
<tr>
<td>Application Domain</td>
<td>Mobile computing, fast TTFF</td>
</tr>
</tbody>
</table>

---

[Diagram of beacon coverage areas and a map showing beacon locations.]
Basic Operation
1) Store and updates radio database
2) Scan for radio sources
3) Combine observations sensibly

<table>
<thead>
<tr>
<th>Beacon ID</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:0f:f7:0c:e9:c0</td>
<td>47.6411</td>
<td>-122.3079</td>
</tr>
<tr>
<td>00:0f:34:ab:0c:e0</td>
<td>47.6409</td>
<td>-122.3075</td>
</tr>
<tr>
<td>00:0e:6d:83:68:ff</td>
<td>47.6461</td>
<td>-122.3081</td>
</tr>
<tr>
<td>310:380:1323:52020</td>
<td>47.6456</td>
<td>-122.3078</td>
</tr>
</tbody>
</table>
| ...
Signal Strength is a Mediocre Indicator of Distance

802.11 signal strength by distance

GSM signal strength by distance
Response Rate Another Indicator of Distance

Response rate = 1 - loss rate of beacon frames

802.11 response rate by distance

GSM response rate by distance
Self-Mapping Radio Beacons

- Grows beacon database using everyday radio traces
- Accuracy and coverage improve over time
One User’s Experience with Self-Mapping

Self-mapping with sporadic GPS for one volunteer

![Graph showing Coverage and Accuracy over days]

- **Coverage**
- **Accuracy (m)**

Day range: 0 to 30

Coverage: 0% to 100%

Accuracy (m): 0 to 100

Coverage of self-mapping

Accuracy of self-mapping
Location in Today’s Smartphones

- **A-GPS**
  - Accurate navigation and tracking

- **Beacon Location**
  - Fast TTFF

- **Cell-ID Lookup**
  - Highly available fallback
Hot Topics in Mobile Location

- Computer vision and Indoor Location
- Mobile Augmented Reality
- Discovering the Places people go
- Mobile [Push] Advertising
Computer Vision Location

3D mapping

- Accuracy of 30cm and 10°, 80% of the time
- 4 fps with GPU
- Google starting major 3D indoor mapping effort, startup out of Cambridge

3D localization

Camera image sequence

Bundle adjustment algorithm

Metrically accurate 3D map
Use your mobile phone’s camera to estimate location/orientation and find web content about where you are right now!
Discovering the Places People Go

Knowing types and sequences of places we go is valuable
- Predict likely destinations
- Build personal quick-lists
- Develop behavior models and detect changes

Manual “Check-ins” to places is the commercial state-of-the-art approach

Research underway to augment check-ins with automatic methods for place detection and recognition
## Place Learning – Two Approaches

<table>
<thead>
<tr>
<th></th>
<th><strong>Geometry-based</strong></th>
<th><strong>Fingerprint-based</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input</strong></td>
<td>Location coordinates (e.g., GPS, WiFi/Cell tower triangulation)</td>
<td>Radio environment (e.g., currently visible cell towers, WiFi access points)</td>
</tr>
<tr>
<td><strong>Pros</strong></td>
<td>Tightly coupled with the geographical location of the place</td>
<td>Does not depend on the underlying positioning system’s accuracy (especially indoors)</td>
</tr>
<tr>
<td><strong>Cons</strong></td>
<td>Depends on the underlying positioning system’s accuracy and availability</td>
<td>Radio environment may change over time (affecting recognition, not necessarily detection)</td>
</tr>
</tbody>
</table>
Sample Trace of WiFi APs encountered
Results from a 4 week place learning experiment

Fingerprint-based techniques outperform geographic techniques due to the challenge of accurately clustering coordinates.