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SDR-based Passive Indoor Localization System for GSM

Islam Alyafawi, Desislava Dimitrova, Torsten Braun
Universität Bern
braun@iam.unibe.ch, cds.unibe.ch
Passive Localization of Wireless Devices

> System can
  — overhear radio (e.g., GSM, WiFi) signals,
  — process them to retrieve user identity, and
  — locate user based on the signal properties.

> System components based on software-defined radio
  — Radio signal acquisition
  — Signal property retrieval, e.g., timestamps, power levels
  — Message parsing, e.g., identifiers
  — Localization algorithms

> Applications
  — Analysis of customer behaviour in shopping centres /
    amusement parks
  — Analysis of number of people and movements in public areas
Passive Localisation System

AN: anchor node / radio sensor

wireless device

AN1

AN2

signal processing and localization algorithm

storage

AN3

base station
> USRP hardware is controlled by open source USRP Hardware Driver, which translates instructions between FPGA hardware and signal processing software

> GNUradio applications
  — Airprobe intercepts GSM downlink messages.
  — OpenBTS implements base station protocol stack up to layer 3.
System Implementation
GSM Message Capturing

a. Sample capturing
b. GNUradio
   low pass filter
c. Interpolator
d. Time synchronization
   — Training sequence discovery
   — Normal burst detection
   — Message reconstruction
e. Message parsing

Localization Algorithms

- Range-based positioning using Time/Angle (Difference) of Arrival, Received Signal Strength (RSSI) and multi-lateration
- Finger-printing
- Proximity-based positioning, e.g., Centroid
Linear Weighted Centroid (LWC)

\[
(x_{est}, y_{est}) = \left( \frac{\sum_{i=1}^{NC} w_i \cdot (x_i, y_i)}{\sum_{i=1}^{NC} w_i} \right)
\]
Differential RSS

\[ RSS = P_r(d) = A - 10 \alpha \log \left( \frac{d}{d_0} \right) - \psi \]

\[ DRSS_{ij} = RSS_i - RSS_j = P_r(d_i) - P_r(d_j) = 10 \alpha \log \left( \frac{d_j}{d_i} \right) - \psi_{ij} \]

- Select 3 ANs with largest RSS values
- Calculate DRSS values between each AN pair
  - \( X = RSS_1 - RSS_2 \)
  - \( Y = RSS_1 - RSS_3 \)
  - \( Z = RSS_2 - RSS_3 \)
- \( Q_1 = \frac{Y}{X} \)
- \( Q_2 = \frac{Z}{X} \)
- \( Q_3 = \frac{Z}{Y} \)
- \( \omega_1 : \omega_2 : \omega_3 = Q_1 : Q_2 : Q_3 \)
- \( \omega_1 + \omega_2 + \omega_3 = 1 \)

Chicago, August 18, 2014
Combined Differential RSS (CDRSS)

1. Form all possible K triangles
2. Calculate weights $\omega_{ik,DRSS}$
   - $i = 1,2,3$
   - $k = 1..K$ for all K triangles
3. Calculate weights $\omega_{i,CDRSS}$ for the 3 ANs with highest RSS

\[
\omega_{i,CDRSS} = \frac{1}{K} \sum_{k=1}^{K} \omega_{ik,DRSS}, \quad \text{for } i = 1,2,3
\]
Weighted Circumcenter (WCC)

1. Form triangle using 3 ANs with largest RSS values
2. Calculate circumcenter
3. Calculate DRSS values
   - $X = \text{RSS}_1 - \text{RSS}_2$
   - $Y = \text{RSS}_1 - \text{RSS}_3$
   - $Z = \text{RSS}_2 - \text{RSS}_3$
   - $h_1 = X/Y$, $h_2 = X/Z$, $h_3 = Y/Z$
4. Move circumcenter point to each AN:
   \[(x'_i, y'_i) = h_i \times O(x_{wcc}, y_{wcc}) + (1 - h_i) \times (x_i, y_i)\]
5. Calculate AN weights $\omega_{i,WCC}$ using differential RSS for new triangle
6. Estimate coordinates of mobile device

\[
(x_{est}, y_{est}) = \left( \sum_{i=1}^{3} w_{i,WCC} \times (x'_i, y'_i) \right) / \left( \sum_{i=1}^{3} w_{i,WCC} \right)
\]
# Localization Performance

## Torsten Braun: SDR-based Passive Indoor Localization System for GSM

### Localization Performance

<table>
<thead>
<tr>
<th>MD Location</th>
<th>LWC $\mu$</th>
<th>LWC $\sigma$</th>
<th>CDRSS $\mu$</th>
<th>CDRSS $\sigma$</th>
<th>WCC $\mu$</th>
<th>WCC $\sigma$</th>
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<tbody>
<tr>
<td>L1</td>
<td>3.36</td>
<td>0.28</td>
<td>2.52</td>
<td>0.93</td>
<td>2.72</td>
<td>1.18</td>
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<tr>
<td>L2</td>
<td>6.45</td>
<td>0.09</td>
<td>4.47</td>
<td>0.20</td>
<td>3.19</td>
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<tr>
<td>L3</td>
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<td>4.21</td>
<td>0.91</td>
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<tr>
<td>L4</td>
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<td>2.68</td>
<td>1.49</td>
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<tr>
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<td>5.17</td>
<td>0.12</td>
<td>3.67</td>
<td>0.19</td>
<td>1.83</td>
<td>0.21</td>
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<tr>
<td>L6</td>
<td>1.94</td>
<td>0.76</td>
<td>0.74</td>
<td>0.17</td>
<td>1.02</td>
<td>0.48</td>
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<tr>
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<td>0.19</td>
<td>4.88</td>
<td>0.77</td>
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<td>1.29</td>
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<tr>
<td>L8</td>
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<td>4.50</td>
<td>0.19</td>
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<tr>
<td>L9</td>
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<td>0.10</td>
<td>1.15</td>
<td>0.11</td>
<td>0.97</td>
<td>0.13</td>
</tr>
<tr>
<td>L10</td>
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<td>0.11</td>
<td>3.67</td>
<td>0.20</td>
<td>2.01</td>
<td>0.51</td>
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<tr>
<td>L11</td>
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<td>0.40</td>
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<tr>
<td>L12</td>
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<td>1.15</td>
<td>2.17</td>
<td>1.54</td>
<td>2.00</td>
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<tr>
<td>L13</td>
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<tr>
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<td>1.01</td>
<td>2.32</td>
<td>1.89</td>
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<tr>
<td><strong>Average</strong></td>
<td><strong>4.75</strong></td>
<td><strong>0.31</strong></td>
<td><strong>3.21</strong></td>
<td><strong>0.54</strong></td>
<td><strong>2.43</strong></td>
<td><strong>0.90</strong></td>
</tr>
</tbody>
</table>
Impact of Open/Closed Doors
RSS of (Non-)Line-of-Sight Signals

During day

Over night

Line of sight

Non line of sight

RSS (dBm)
Summary and Outlook

- SDR systems allow new opportunities for signal processing
- Positioning based on proximity-based localization algorithms (CDRSS and WCC) outperform LWC
- Promising results but challenges remain, main challenge: multi-path mitigation
Thanks for your attention!

> braun@iam.unibe.ch
> cds.unibe.ch