Indoor positioning using WLAN coverage area estimates

IPIN 2010

Laura Koski, Tommi Perälä, Robert Piché

http://math.tut.fi/posgroup/
Outline

- Coverage area estimation and positioning
- Floor plan in filtering
- Filters
- RSSI measurements
- Example
Coverage area-based positioning

Coverage area estimation

- Collect fingerprint data
- Arrange the fingerprint data so that for every AP, there is a list of location reports \( Y = (y_1, \ldots, y_n) \)
- For every AP, calculate coverage are estimates

Positioning

- Measure IDs of heard APs
- Use coverage area estimates of heard APs to determine the position
Coverage area estimation, Prior

Measurement model:

\[ Y = 1_n \mu^T + \epsilon, \quad \text{where } \epsilon_{(i)} | \mu, \Sigma \sim N(0_2, \Sigma) \]
Coverage area estimation, Likelihood
Coverage area estimation, Posterior

\[ x|c \sim N(\mu, \Sigma) \]
\( \mathbf{x} \sim \mathcal{N}(\hat{\mathbf{x}}, C) \), in which

\[
\hat{\mathbf{x}} = (\sum_{i=1}^{k} \Sigma_i^{-1})^{-1} (\sum_{i=1}^{k} \Sigma_i^{-1} \mu_i)
\]

and

\[
C = (\sum_{i=1}^{k} \Sigma_i^{-1})^{-1}
\]
Floor plan

- Floor plan is divided into boxes
- Graph describes the connection between boxes

\[
G = \begin{pmatrix}
1 & 1 & 1 & 0 & 0 \\
1 & 1 & 0 & 1 & 1 \\
1 & 0 & 1 & 1 & 0 \\
0 & 1 & 1 & 1 & 1 \\
0 & 1 & 0 & 1 & 1
\end{pmatrix},
\]

\[
\Phi^T = \begin{pmatrix}
1/3 & 1/3 & 1/3 & 0 & 0 \\
1/4 & 1/4 & 0 & 1/4 & 1/4 \\
1/3 & 0 & 1/3 & 1/3 & 0 \\
0 & 1/4 & 1/4 & 1/4 & 1/4 \\
0 & 1/3 & 0 & 1/3 & 1/3
\end{pmatrix}.
\]
Filters, Box Filter (BF)

- \( \mathbf{p} = ((\mathbf{p})_1, \ldots, (\mathbf{p})_{n_B})^T \) is the state vector, \((\mathbf{p})_i\) is the probability mass inside the \(i\)th box
- use the transition matrix \( \Phi \) for the state evolution
- Predict:
  \[
  p_k^- = \Phi p_{k-1}
  \]
- Update
  \[
  (p_k)_j = (p_k^-)_j \pi(j),
  \]
  \(\pi(j)\) is the probability mass inside the \(j\)th box
- Position estimate
  \[
  x_k = \sum_{i=1}^{n_B} (p_k)_i m_i
  \]
Filters, Particle Filter (PF)

- Standard bootstrap filter, but for every time step $t_k$ for every particle $x_k$, we determine the box $j_k$ it is associated with.

- Weights are assigned as follows:

$$w_{k+1}^i \propto \begin{cases} L(c|x_{k+1}^i) & \text{if } G_{j_k^i,j_{k+1}^i} = 1 \\ 0 & \text{if } G_{j_k^i,j_{k+1}^i} = 0. \end{cases}$$
RSSI measurements

Discarding weak signals leads to

- Smaller coverage area estimates
- More accurate positioning performance

Difficulty: definition of RSSI may vary in different MT models.
Idea: Each MT could construct its own histogram of RSSI values observed over a long time interval.
Test deployment

- 96 calibration points
- 206 heard APs
- ~29 heard APs per fingerprint
## Results

<table>
<thead>
<tr>
<th></th>
<th>Track 1</th>
<th>Track 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ME [m]</td>
<td>Max [m]</td>
</tr>
<tr>
<td>Coverage area</td>
<td>7.5</td>
<td>29.8</td>
</tr>
<tr>
<td>NN</td>
<td>9.9</td>
<td>31.3</td>
</tr>
<tr>
<td>KF Coverage area</td>
<td>7.4</td>
<td>26.4</td>
</tr>
<tr>
<td>PKFNN</td>
<td>7.4</td>
<td>21.6</td>
</tr>
<tr>
<td>BF</td>
<td>6.4</td>
<td>18.2</td>
</tr>
<tr>
<td>PF</td>
<td>6.4</td>
<td>19.3</td>
</tr>
</tbody>
</table>

![Diagram with tracks and coverage areas]
Results, RSSI threshold

Threshold in coverage area estimation is median of RSSI values and in positioning mean of RSSI values

<table>
<thead>
<tr>
<th></th>
<th>ME [m]</th>
<th>Max [m]</th>
<th></th>
<th>ME [m]</th>
<th>Max [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>KF</td>
<td>7.4</td>
<td>26.4</td>
<td>KF</td>
<td>5.5</td>
<td>18.7</td>
</tr>
<tr>
<td>BF</td>
<td>6.4</td>
<td>18.2</td>
<td>BF</td>
<td>4.5</td>
<td>14.2</td>
</tr>
<tr>
<td>PF</td>
<td>6.4</td>
<td>19.3</td>
<td>PF</td>
<td>5.0</td>
<td>15.5</td>
</tr>
</tbody>
</table>

It is not straightforward to find the optimal RSSI values that works in every environment.
Conclusion

- Coverage area-based positioning achieves same accuracy as NN
- Floor plan improves the positioning accuracy
- KF achieves almost the same accuracy as PF and BF with significantly lower computational load
- Use of RSSI values improve positioning accuracy
Conclusion

- Coverage area-based positioning achieves same accuracy as NN
- Floor plan improves the positioning accuracy
- KF achieves almost the same accuracy as PF and BF with significantly lower computational load
- Use of RSSI values improve positioning accuracy

Thank You!
Questions?