Indoor positioning based on radio communication technology: a comparative survey

Lieven De Strycker
IMEC – Wireless Community – 19/02/2009
DraMCo

- Research group: DraMCo: Wireless and Mobile Communications
- Started in 2002
  - JP. Goemaere
  - L. De Strycker

- Follow the trends in wireless, mobile and embedded communication systems to assist the industrial partners to incorporate new technologies in their products
- … as provided by the ‘Technology Transfer’ mission
- Industry driven research
- Support
- Advise
- Networking

L De Strycker/H Motte - Indoor positioning based on radio communication technology: a comparative survey
Indoor RF-based localization

• Introduction
  – Context and applications
  – General principle

• Localization
  – Overview
  – RSS
  – TOA
  – AOA
  – Proximity Sensing/signpost

• Indoor localization in practice
Introduction

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Positioning of objects and persons *indoor* based on *RF-signals* (signals from wireless LAN and PAN: WiFi, ZigBee, UWB, RFID, …)

- Context awareness
- Location-based services
- RTLS
- Technology in background
- Automatic configuration
- Ambient assisted living
- Ambient intelligence
- …
Introduction

Applications

- Two categories
  - tracking-and-tracing/asset management
  - location-based services

- Examples
  - Hospitals
    - tracking expensive equipment
    - administration based on positioning
  - Rest homes
    - monitoring dementing patients
  - Logistics
    - just-in-time and in-sequence delivery
  - Emergency services
    - tracing the patient
    - tracing critical equipment
  - Transport
    - tracking-and-tracing deliveries indoor/outdoor
  - Entertainment
    - location-based information e.g. in museum
    - mobile gaming
  - Security
Introduction

General principle

- Measurements between known-location nodes (**reference nodes**) and unknown-location nodes (**blind nodes**) or measurements between any pair of nodes (cooperative)
General principle

- RF-Localization techniques:
  Based on physical signal propagation properties:
  - Signal strength
  - Signal speed
  - Signal phase
  - Signal frequency
  - …
Localization

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Localization

Overview

• Positioning methods/algorithms
  – Measurement → distances → position
    • Circular lateration
    • Hyperbolic lateration
  – Position directly from measurements
    • Proximity sensing/signpost
    • Pattern matching
    • Statistical algorithms

• Measurements:
  – Signal strength: RSS : signal detection, power decay
  – Signal speed: TOA
  – Signal direction: AOA
Radio propagation

- Propagation of RF-waves in free space:
  - (unobstructed) Waves propagate in a straight line
  - Received power \( \approx \frac{\text{Transmitted power}}{\text{distance travelled}^2} \)
  - Propagation speed equals the speed of light
  - Only one signal component (line-of-sight) present per location ↔ multipath
Lateration

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Localization

Multilateration: basics

- A number of precisely known distances allow unambiguous localization
- Interpolation required for inaccurates distance estimates (least squares, weighted least squares, …)
- Absolute ranges: circular lateration
- Range differences: hyperbolic lateration

A hyperbola: set of all points for which the difference in the range to two fixed points is constant
Localization

Multilateration: specs.

+ Relatively low processing needs (fast, easy to implement)
+ Point-based

- Accuracy heavily dependent on distance estimates
RSS: Received Signal Strength

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RSS: basics

- Varies due to effects like:
  - Multipath fading
    - Destructive and constructive interference
    - Fast fading; great signal variations over small distances
  - Loss of Line-of-Sight (LOS) path and shadowing

- Unpredictable relation RSS-distance

![Ideal relation](image1)

![Multipath environment](image2)
Localization

RSS: Relation Path loss – Travelled distance

• Path loss
  – Difference between sent and received signal power
  – Expressed by *path loss exponent*
    • In free space:
      \[
      \frac{P_r}{P_s} \approx \frac{1}{d^2}
      \]
    • Indoor:
      \[
      \frac{P_r}{P_s} \approx \frac{1}{d^n}
      \]
      Empirically defined for different indoor environments

<table>
<thead>
<tr>
<th>Environment</th>
<th>$n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free space</td>
<td>2</td>
</tr>
<tr>
<td>Urban</td>
<td>2.7 – 3.5</td>
</tr>
<tr>
<td>Urban with shadowing</td>
<td>3 – 5</td>
</tr>
<tr>
<td>Line-of-sight in buildings</td>
<td>1.6 – 1.8</td>
</tr>
<tr>
<td>Non Line-of-sight in buildings</td>
<td>4 - 6</td>
</tr>
<tr>
<td>Non Line-of-sight in industrial env.</td>
<td>2 - 3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material</th>
<th>Attenuation[dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass</td>
<td>3-8</td>
</tr>
<tr>
<td>Wood (8cm)</td>
<td>6</td>
</tr>
<tr>
<td>Stone (9-27 cm)</td>
<td>8-10</td>
</tr>
<tr>
<td>Concrete (20 cm)</td>
<td>26</td>
</tr>
<tr>
<td>Concrete (30 cm)</td>
<td>38</td>
</tr>
<tr>
<td>Reinforced Concrete (20 cm)</td>
<td>30</td>
</tr>
</tbody>
</table>
Localization

RSS with lateration: specs.

+ Applicable in virtually all existing RF networks

+ Virtually no overhead
  • Can be measured during normal data communication (without requiring any additional bandwidth or energy)
  • Average power can be measured without any specific knowledge of the transmitted pulse shape

• Scalable accuracy (hardware expenses ↑)

− Low overall accuracy

− Tracking limited to active network members
Finger printing (pattern matching)

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Fingerprinting: basics

- Pre-measured training points (*fingerprint*) are stored
- Localization compares current RF-measurements to measurements database
  - Popular in WLAN
  - Many variants
  - Ray trancing assistance
Localization

RSS with fingerprinting: specs.

+ Higher overall accuracy

- Scalable accuracy (database expenses ↑)
  - High deployment costs (making the fingerprint)
  - Non dynamic (environment changes → new fingerprint needed)
  - High processing needs (large database, search algorithms)
T(D)OA: Time (Difference) Of Arrival

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TOA: basics

- Method based on measurements of the propagation delay of signals travelling from transmitter (node A) to receiver (node B)

\[ d = c.T \]
\[ c = 3 \times 10^8 \text{ m/s} \]
Two Way Ranging (TWR) – Alternative

- A blind node will now communicate with each fixed node through a datasignal travelling back and forth

- Synchronisation is no longer necessary since time measurements are concentrated in one node

- Take processing delay in node 2 into account
Localization

T(D)OA: specs.

+ High accuracy possible (with LOS)
- Causes extra overhead
- Specific hardware needs
- Suitable synchronisation and bandwidth needed
- Tracking limited to active network members
AOA: Angle Of Arrival

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Localization

AOA: basics

- Directive antennas determine the incoming signal angle.
- 2 fixed nodes delimit a position.
- Ref. cellular networks
Localization

AOA: specs.

+ Virtually no overhead

- Scalable accuracy (hardware expenses ↑)
  - Very LOS dependent
  - Specific hardware needs: antenna array
  - Tracking limited to active network members
Proximity sensing/signpost

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Proximity sensing

- Localization by presence detection
- Implemented with (passive) RFID
  - Inductive coupling: wireless energy transfer
  - Load Modulation: data transfer

- Active RFID as part of WLAN localization
Localization

RFID: specs.

+ Tracking requires no active tag

• Scalable accuracy: choke points (hardware expenses ↑)
  - Low range
  - Only detection at certain points
Signpost: basics

• Point of closest estimated fixed node equals blind node’s location.
Localization

Signpost: specs.

+ Low processing needs (fast, easy to implement)

- Scalable accuracy (hardware expenses ↑)

- Low overall accuracy

  *room-accuracy* is enough in many applications
Indoor localization in practice

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Indoor localization in practice

Research projects - TETRA

LADI – WITEPA
- 2006-2008 project
- Survey of existing indoor localization systems
- Cooperation KaHo Sint-Lieven and Artesis Hogeschool Antwerpen

SCALA
- 2008-2010
- Middleware for easy access to localization systems and combining them
- Cooperation KaHo Sint-Lieven and Artesis Hogeschool Antwerpen + ERA-SME partner in Austria (CUAS)
Indoor localization in practice

WiFi based systems
### Indoor localization in practice

#### Commercial systems

<table>
<thead>
<tr>
<th>Positioning</th>
<th>Artesis</th>
<th>EkaHau</th>
<th>AeroScout</th>
<th>Cisco Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>Client based RSSI</td>
<td>Infrastructure based RSSI</td>
<td>TDOA</td>
<td>Infrastructure based RSSI</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>Any 802.11 AP</td>
<td>Partner WiFi infrastructure</td>
<td>Dedicated AeroScout HW</td>
<td>Partner WiFi infrastructure</td>
</tr>
<tr>
<td>Usage</td>
<td>Indoor, walled environments</td>
<td>Open spaces / outdoor</td>
<td>Indoor, walled environments</td>
<td>Indoor, walled environments</td>
</tr>
<tr>
<td>Accuracy</td>
<td>With filter: 1 m (2-3 sec delay)</td>
<td>NVT</td>
<td>3-10 m</td>
<td>3.4 m</td>
</tr>
<tr>
<td>Clients</td>
<td>EkaHau tags can be tracked</td>
<td>Other WiFi devices can be tracked when EkaHau is installed (software clients)</td>
<td>AeroScout tags can be tracked</td>
<td>Other WiFi devices can be tracked</td>
</tr>
<tr>
<td>Tags</td>
<td>Battery life</td>
<td></td>
<td>NVT</td>
<td></td>
</tr>
<tr>
<td>Extras</td>
<td>-</td>
<td>++</td>
<td>Tamper proof</td>
<td>NVT</td>
</tr>
<tr>
<td></td>
<td>Display to send messages, industrial tags with call buttons</td>
<td>Tags with integrated temperature sensor</td>
<td>Telemetry sensors (motion, humidity, pressure,...)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Buttons to indicate accident, disaster,...</td>
<td></td>
<td>Buttons to indicate accident, disaster,...</td>
<td></td>
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<tr>
<td></td>
<td>Many mounting options</td>
<td></td>
<td>Many mounting options</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WiFi - GPS tag (new)</td>
<td></td>
<td>WiFi - UWB tag (new)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WiFi - Ultrasound tag (new)</td>
<td></td>
<td>WiFi - Ultrasound tag (new)</td>
<td></td>
</tr>
<tr>
<td>Support</td>
<td>++++</td>
<td>++</td>
<td>+++</td>
<td>-</td>
</tr>
<tr>
<td>General</td>
<td>Great site survey tool, Great support</td>
<td>Relatively easy setup and maintenance, Good end user applications</td>
<td>Great end user application, Good support</td>
<td>Fewer support: Most expensive</td>
</tr>
<tr>
<td></td>
<td>Association is needed</td>
<td>Easiest out of the box solution</td>
<td>Promising player in integration of WiFi, GPS, UWB,...</td>
<td>Simple end user application with few functionality</td>
</tr>
<tr>
<td></td>
<td>Free choice of database (SQL, Oracle,...)</td>
<td>Complicated installation (course needed)</td>
<td>Complicated installation (course needed)</td>
<td></td>
</tr>
</tbody>
</table>
Other systems

- RSS/ZigBee (Based on Greenpeak nodes)
- TOA/ZigBee (Based on NanoLOC Development kit)
- Passive RFiD (13.75MHz system, Based on MLX90121 IC)
Indoor localization in practice

RSS/ZigBee

- Reliable applications limited to room-based localization (Signpost algorithm)
Indoor localization in practice

TOA/ZigBee (based on NanoLOC Development kit)

- IEEE802.15.4a
- Adjusted localization
- To 1 m accuracy
- Dynamic/static operation
RFID (13.75MHz system, Based on MLX90121 IC)

- Localization/presence detection in small spaces
- Adapted to work in metal environments (metal racks, industrial environments)
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About the DraMCo Research Group

Research at the Electronics Department - KU Leuven

The main research domain for the electronics group is the study of standards and systems for wireless and mobile communication, the search for error-free and secure transmissions, the implementation of existing standards in practical implementations, and the development of new applications. Also the reduction of power consumption and the efficiency of wireless systems are hot topics.

Research is done by the members of the DraMCo (Draadloze en Mobiele Communicatie - Wireless and Mobile Communication) research group. This young group includes seven members; three of them started the preparation of their Ph.D. research.

With the help of LNT (Flanders' research supporting institution) some projects are successfully elaborated, e.g.:
- Error correction in wireless communication systems.
- The development and evaluation of embedded applications for wireless, short-distance data exchange, using existing standards.
- Location-dependent services and wireless technology for positioning applications.

For more information, please contact Lieven De Strycker, head of the research group or Jean-Pierre Groeneveld, project mentor.

In cooperation with that research group, the electronics department also organizes a bi-annual conference: EUCIMET (European Conference on the Use of Modern Information and Communication Technologies). The aim is to offer a forum to researchers where they can present the results of their work to European colleagues, and to stimulate scientific cooperation between institutes in different European countries. More information is available on the website: