Wireless Sensor Networks for Smart Environments: A Focus on the Localization

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SPIN Event
Smart Spaces: Challenges and Opportunities

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Plan

- Introduction
- Wireless Sensor Networks
  - Presentation
  - Localization overview
- Indoor localization / Smart Home
  - Overview
  - Schemes with multiple antennas
  - Performance evaluation
  - Conclusion
- Conclusion
Introduction

• Smart Home
  • High interconnection
  • Highly Automated
    • Light control
    • Climate control
    • Windows and doors control
    • Security and surveillance systems
  • Multi-media entertainment systems
**Smart Home**

**Requirements**
- **Noise Rejection**
  - Network has to allow for reliable communication
  - Requires preservation of data and synchronization of data lines
- **Bandwidth**
  - Smart Homes can contain many sensors and actuators
  - Sensor data can be generated at different rates
- **Connectivity**
  - Sensors have to be connected to processing units
- **Integration**
  - Network structures have to be integrated into buildings
- **Privacy and Security**
  - Smart Home networks will transfer private and sensitive data

**The problem**
- Accurate localization and detection of events is challenging indoor, no GPS
- We are interested in Indoor Localization with wireless sensors network
Wireless Sensor Networks

- Wireless Sensor Network (WSN)

  - Health care
  - Environmental monitoring
  - Smart Home
  - Traffic control

Knowledge of the exact position of nodes is crucial.

Large variation of its measurements (Shadowing + Multipath propagation)

Use of various RSSI based indoor localization schemes

- Cost
- Energy consumption
Wireless Sensor Networks

• Location Discovery
  • During aggregation of sensed data, the location information of sensors must be considered.
  
  • Each node couples its location information with the data in the messages it sends.
  
  • GPS is not always feasible because it cannot reach nodes in dense foliage or indoor, and it consumes high power
  
  • We need a low-power, inexpensive, and reasonably accurate mechanism.
**WSN Localization**

- **Measurements with reasonably priced hardware**
  - **Distance estimation**
    - Received Signal Strength Indicator (RSSI)
      - The further away, the weaker the received signal.
      - Mainly used for RF signals.
    - Time of Arrival (ToA) or Time Difference of Arrival (TDoA)
      - Signal propagation time translates to distance.
      - Routing trip time measurements with specific hardware: accuracy 2-3m
      - Better: Mixing RF, acoustic, infrared or ultrasound.
  - **Angle estimation**
    - Angle of Arrival (AoA)
      - Determining the direction of propagation of a radio-frequency wave incident on an antenna array.
    - Directional Antenna
    - Special hardware, e.g., laser transmitter and receivers.
**WSN Localization**

- **Problem:** Given distance or angle measurements or mere connectivity information, find the locations of the sensors.

- **Anchor-based**
  - Some nodes know their locations, either by a GPS or as pre-specified.

- **Anchor-free**
  - Relative location only. Sometimes called virtual coordinates.
  - Theoretically cleaner model (less parameters, such as anchor density)

- **Range-based**
  - Use range information (distance or angle estimation)

- **Range-free**
  - No distance estimation, use connectivity information such as hop count.
  - It was shown that bad measurements don’t help a lot anyway.
WSN Localization

• Resume

<table>
<thead>
<tr>
<th>With anchors</th>
<th>Without anchors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positioning</td>
<td>Distance/Angle based</td>
</tr>
<tr>
<td>(Solution quality depends on anchor density)</td>
<td>Connectivity based</td>
</tr>
<tr>
<td>Virtual Coordinates</td>
<td>Virtual Coordinates</td>
</tr>
</tbody>
</table>

Distance/angle measurement | Connectivity information only
- **Trilateration and Triangulation**
  - Use geometry, measure the distances/angles to three anchors.

- **Trilateration**: use distances
  - Global Positioning System (GPS)

- **Triangulation**: use angles
  - Some cell phone systems

- **Dealing with inaccurate measurements**
  - Least squares type of approach
  - Filters
WSN Localization

- **Iterative Multilateration**
  - initial anchor
  - becomes anchor in 1\textsuperscript{st} step
  - becomes anchor in 2\textsuperscript{nd} step
  - becomes anchor in 3\textsuperscript{rd} step

- **Cooperative Multihop Multilateration**
Wireless Sensor Networks

- **Indoor Localization**
  - Fixed beacon nodes are placed in the field of observation, such as within building.
  - The distributed sensors receive beacon signals from the beacon nodes and measure the signal strength, angle of arrival, time difference between the arrival of different beacon signals.
  - The nodes estimate distances by looking up the database instead of performing computations.
  - Only the BS may carry the database.
Indoor Localization

- Mobile node inside building
- The mobility model is given by the equation of a sphere centered on the previous position and having $V_{\text{max}}$ (max speed) as radius:

$$
(x_1(t) - x_1(t-1))^2 + (x_2(t) - x_2(t-1))^2 + (x_3(t) - x_3(t-1))^2 = V_{\text{max}}^2
$$

where $x_1(t)$, $x_2(t)$ and $x_3(t)$ are the 3D coordinates of the sensor at the instant $t$; the period of localization should be determined (should be less than 1 s).
Indoor Localization

- Measuring distance with two radios, example
- Particularly interesting if the signal speed differs substantially, e.g. sound propagation is at about 331 m/s (depending on temperature, humidity, etc.), which is of course much less than the speed of light.

Beacon

- Achievement of about a 1 cm accuracy
  - If line of sight
- But there are problems:
  - (Ultra)sound does not travel far
  - For good results you really need line of sight
  - You have to deal with reflections
**Indoor Localization**

- **Multiple antennas:**
  - Important results in terms of position accuracy have been achieved when using multiple antennas.

<table>
<thead>
<tr>
<th>SISO</th>
<th>SIMO</th>
<th>MISO</th>
<th>MIMO</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="SISO Diagram" /></td>
<td><img src="image" alt="SIMO Diagram" /></td>
<td><img src="image" alt="MISO Diagram" /></td>
<td><img src="image" alt="MIMO Diagram" /></td>
</tr>
</tbody>
</table>

- => a comparison relative to the position accuracy among these system models when using the trilateration as well as the multilateration algorithm.
Indoor Localization

System Model

Figure 1: Trilateration algorithm for SISO system

Figure 2: Trilateration algorithm for SIMO system

The accuracy of the RSS ranging is improved when reducing the Bit Error Rate (BER).

<table>
<thead>
<tr>
<th>Error probability Pe</th>
<th>SISO</th>
<th>SIMO</th>
</tr>
</thead>
<tbody>
<tr>
<td>BER can be defined in terms of Pe</td>
<td>$P_e \leq \exp\left(-\frac{</td>
<td>h^2</td>
</tr>
</tbody>
</table>
Indoor Localization

System Model

Figure 3: Trilateration algorithm for MISO system

Figure 4: Trilateration algorithm for MIMO system

<table>
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<th>SIMO</th>
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<tr>
<td>$P_e$</td>
<td>$P_e \leq \frac{1}{\langle 1 + \frac{SNR}{2} \rangle^M}$</td>
<td>$P_e \leq \frac{1}{\langle 1 + \frac{SNR}{2m \cdot n(M)} \rangle^{NM}}$</td>
</tr>
</tbody>
</table>
Indoor Localization

- Simulation environment - Propagation model

- To estimate the transmitter-receiver distance, we use the Rappaport propagation model which calculate the received signal power with the combined effect of path loss and shadowing.

\[ P_r = P_t + 20\log\left(\frac{\lambda}{4\pi d_0}\right) - 10n\log\left(\frac{d}{d_0}\right) + \psi_{dB} \]

- **Parameters**
  - \(\lambda\): the wavelength
  - \(d_0\): Reference distance (1m)
  - \(n\): path loss exponent (4)
  - \(\Psi_{dB}\): zero-mean Gaussian random variable
  - \(P_t\): transmitter power in dB
  - \(P_r\): Receiver power in dB
  - Range: (40m)
  - Frequency: (9e8)
Indoor Localization

- Position of nodes

**Figure 5**: Position of the nodes for the trilateration algorithm

**Figure 6**: Position of the nodes for the multilateration algorithm
The localization error increases when the shadowing standard deviation increases.

- The closer the target position to the center of gravity, the better the results are.
- Both SIMO and MISO systems have similar performance.
The localization error increases when the shadowing standard deviation increases.

The closer the target position to the center of gravity, the better the results are.

Both SIMO and MISO systems have similar performance.
The multilateration algorithm performs the trilateration one.
The worst result is obtained for the SISO system.
The MIMO system perform the SIMO, MISO and SISO systems.
Both SIMO and MISO systems have similar performance.
The performance accuracy improves while increasing the number of antennas.
Indoor Localization

- Conclusion

- We studied the impact of using multiple antennas on localization accuracy in indoor environments when varying the shadowing effect.

  - The accuracy of SIMO, MISO and MIMO systems are improved compared to the SISO system (MIMO system perform the MISO and SIMO systems which present the same performance).

  - The multilateration algorithm perform the trilateration one.

  - The closer is the target position to the center of gravity, the better the results are.

Future work

- Evaluate these models by using real platform implementation.
**Conclusion**

**Health Smart Home** can help mainly elderly people

- Detect falls
  - More than third of elderly of 65 years old and more, living at home, fall every year
- Prevention of the fall before it arises
- Estimation of the stability:
  - Estimation of the movements speeds and the accelerations involved during usual movements
  - => Embedded Accelerometers
- Cameras for video surveillances
- Sensors to detect borders of staircases
Plan

Localization: references

Localization: references


Thank you for your attention