Eberhard Karls Universität Tübingen — AmbiSense — Universität Stuttgart

# Indoor Positioning via Three Different RF Technologies

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# Outline

- Introduction
- Positioning methods based on
  - RFID
  - Bluetooth
  - WLAN
- Experiments (incl. video)
- Conclusion

# Introduction

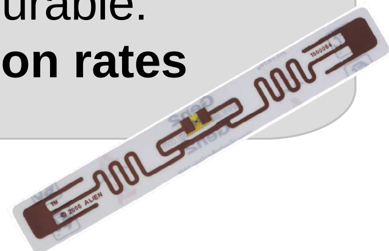
- Positioning: Position estimation in a given environment by means of sensor information
- Position information highly relevant for context-aware services and tracking purposes
- Potential scenarios
  - Patient and asset tracking
  - Product localization
  - Warehousing and logistics
  - Positioning for mobile systems, e.g. transport containers, autonomous vehicles, persons with laptops
- GPS fails indoors ⇨ requirement for alternatives
- Desirable: reuse of existing, inexpensive infrastructure

# Focus on Radio Frequency Technologies

Expected coexistence of common RF technologies:

**Passive UHF RFID**
(EPC Class 1 Gen. 2)

- 868 MHz
- Range: up to 7 m
- Measurable: **detection rates**



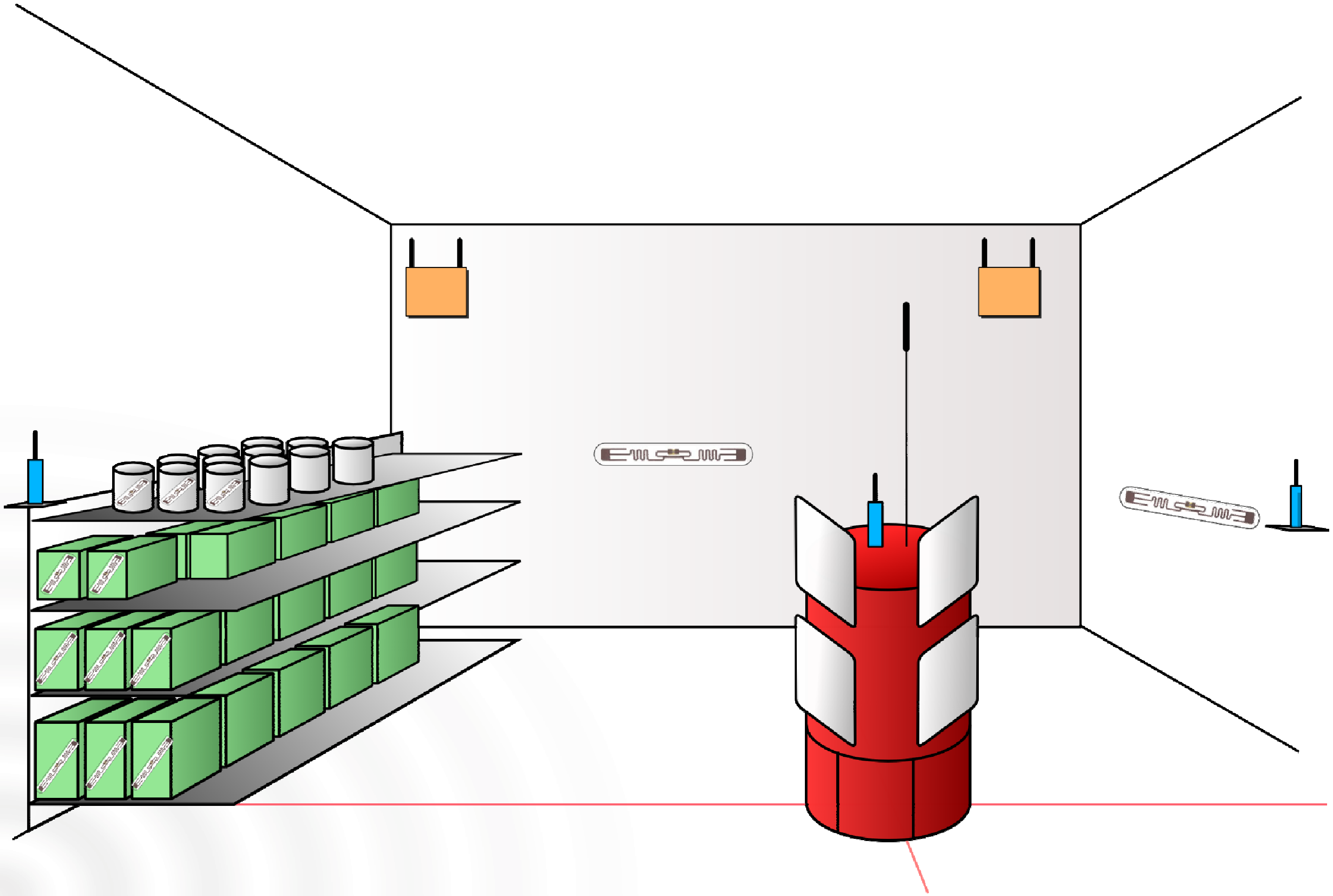
**Bluetooth**
(IEEE 802.15)

- 2.4 GHz
- Range: class 2 typ. 15 m
- Measurable: **RSSI**

**WLAN**
(IEEE 802.11)

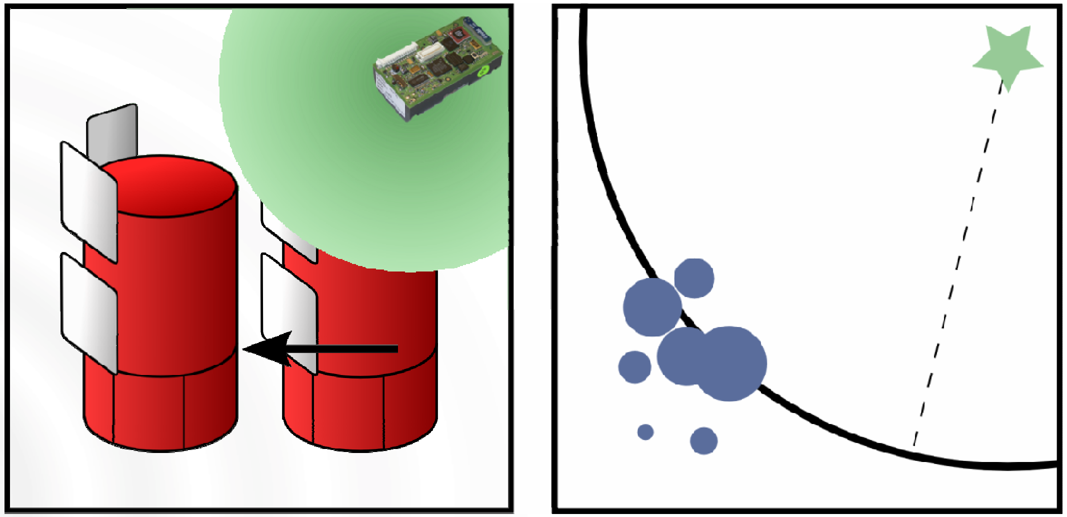
- 2.4 GHz
- Range: up to 100 m
- Measurable: **time of arrival**

# Positioning – General Idea



# Particle Filtering

- Estimation of the state of a dynamic system
  Here: location of a mobile system
- **Bayesian filtering** technique, probability density function (PDF) over state space
- Discrete approximation of the PDF by set of **weighted samples**
- **Robust and accurate**, applicable to virtually any sensor
- Iterations of prediction, correction, normalization, and resampling



Prediction
(motion model)

Correction
(sensor model)

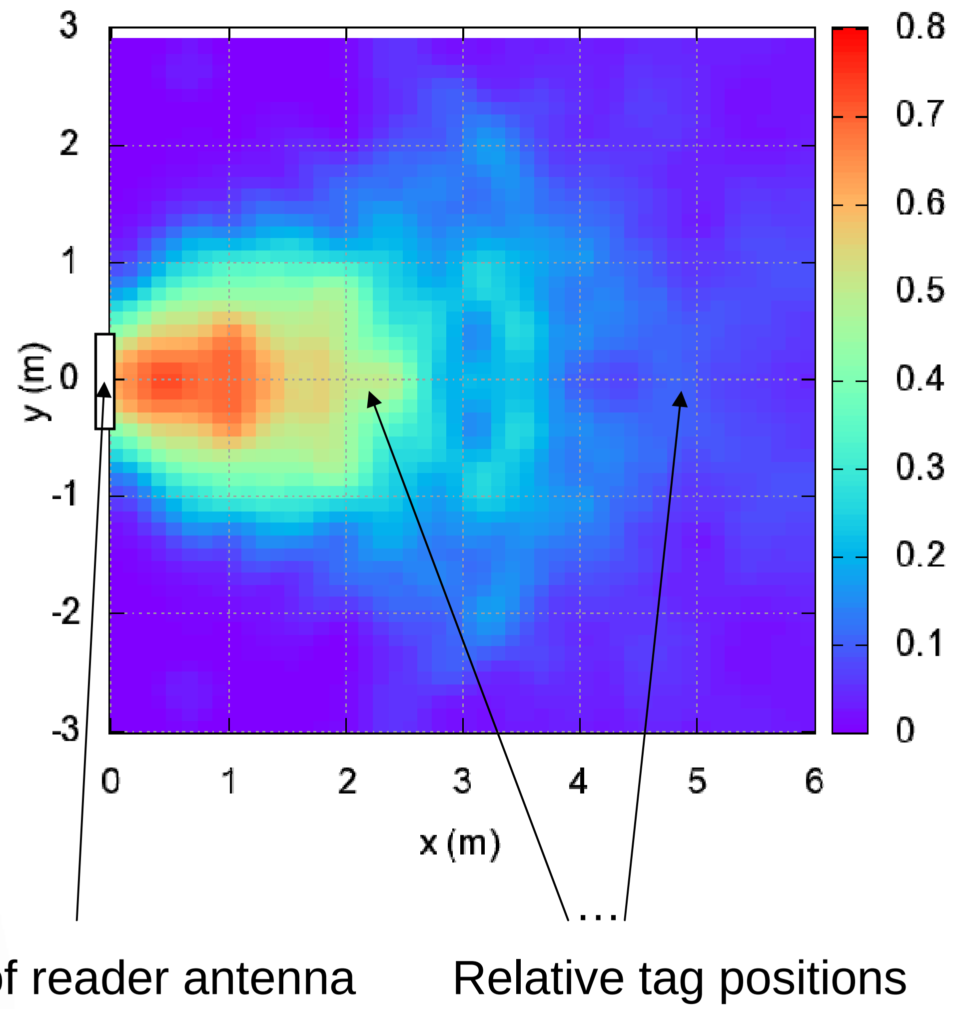
Normalization
+ resampling

# 1. Positioning via Passive UHF RFID

- Near future: palettes, cartons, and products RFID tagged
- Mobile system carries RFID reader
  ⇨ one reader only, lots of inexpensive tags
- Usual positioning method: proximity to tag of known position determines cell-based location
- Shortcomings:
  - Position resolved to coarse area only
  - Well-known problems of passive tags: false negatives, reflections, …
- Our goal: accurate, metric localization

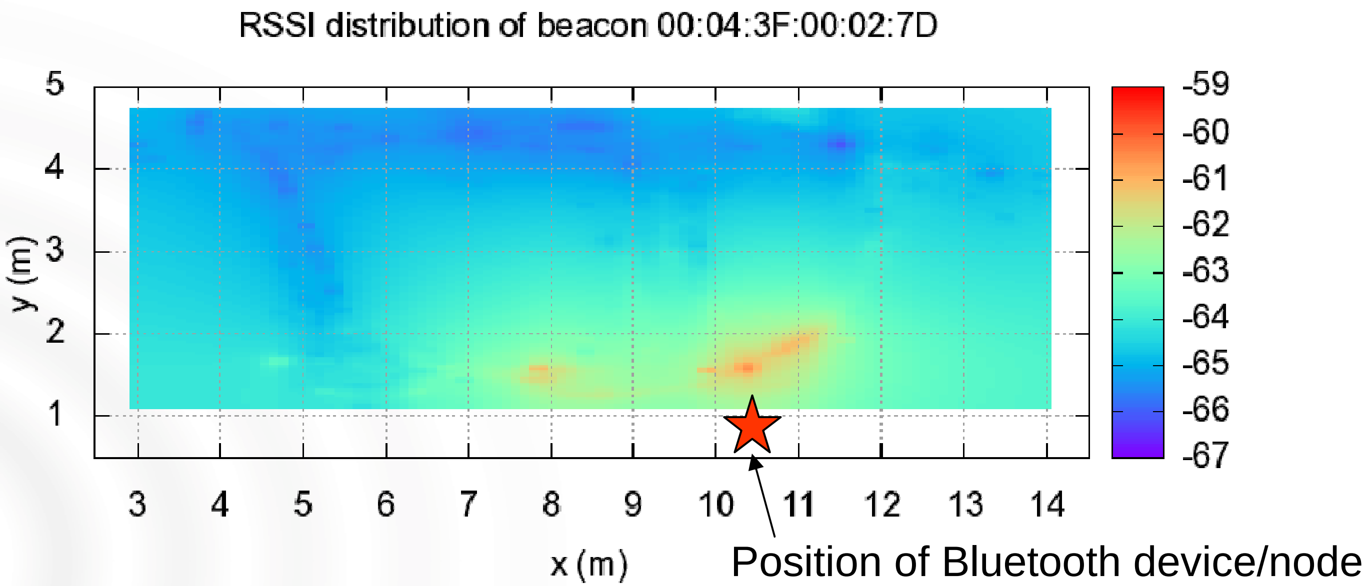
# Positioning via Passive UHF RFID – cont‘d

- Idea: Exploitation of the fact that tag **detection rates depend on relative position** between RFID tag and RFID antenna
- Detection rate model (see figure) is used in particle filtering
  ⇨ probabilistic position refinement over time
- See (Hähnel et al. 2004, Vorst et al. 2008)



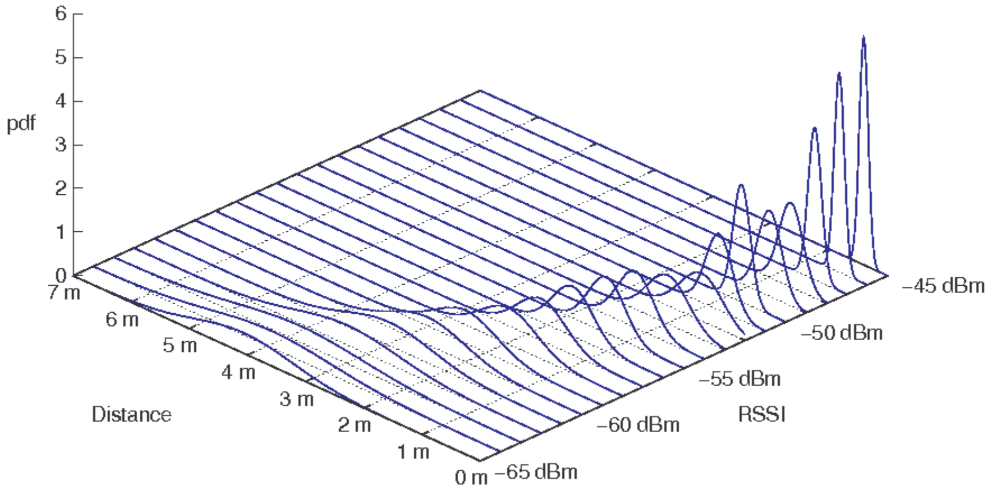
# 2. Positioning via Bluetooth

- Variety of mobile devices equipped with Bluetooth radio transceivers
- Received **signal strength** (RSSI) can be measured
- RSSI values decrease with distance between sender and receiver ⇨ **distance estimation**



# Positioning via Bluetooth – continued

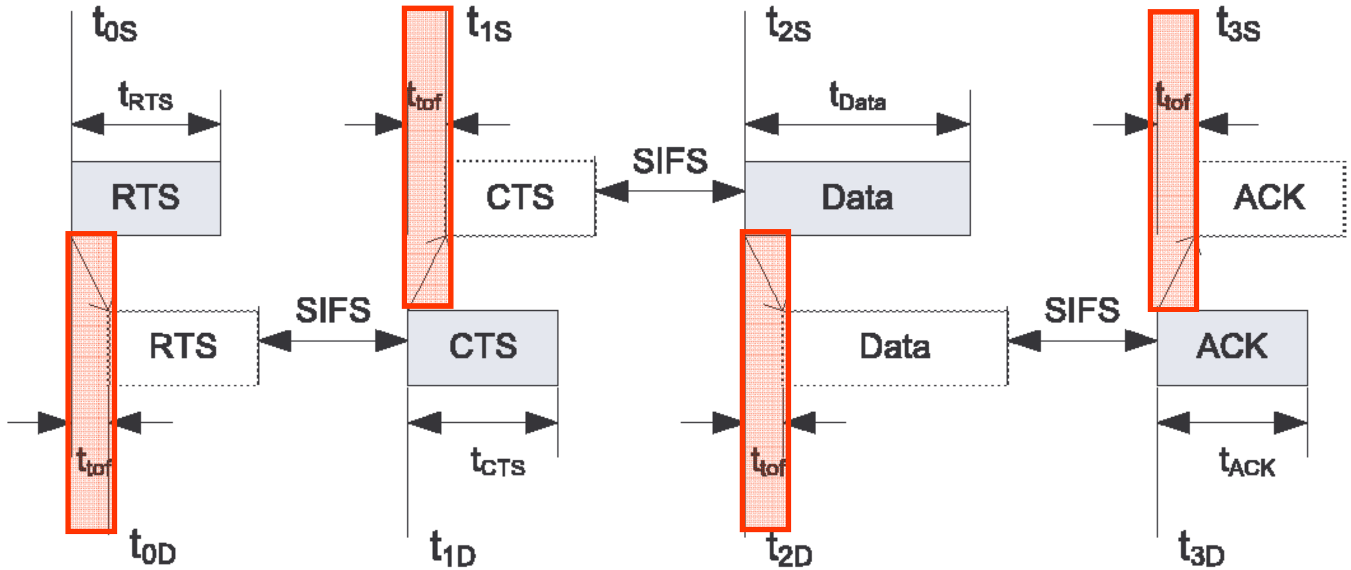
- Each RSSI value can be assigned a **PDF over possible distances**
- Observation: **noise**, low resolution for small RSSI values
- Positioning: multilateration (e.g., MMSE), particle filtering
- PDF used for particle reweighting in correction step



# 3. Positioning via Wireless LAN

- Usual positioning approach with WLAN: usage of RSSI values
- Alternative: **time of arrival** (**TOA**)
- Idea: Position has impact on the time of flight of WLAN packages between sender and receiver
- Advantage: TOA measurements scale **linearly** with open-air propagation distances
- Challenge: **low clock resolution** of off-the-shelf hardware (1µs ~ 300 m)

# Positioning via WLAN – continued




- Novel four-way TOA: TOA measurements conforming to IEEE 802.11 protocol using 4 transmission steps
- Improvement by averaging over 500-2000 packets
- Open-source software Goodtry provided freely
- See (Hoene et al. 2008)

# Experimental Setup

Mobile service robot
(RWI B21)

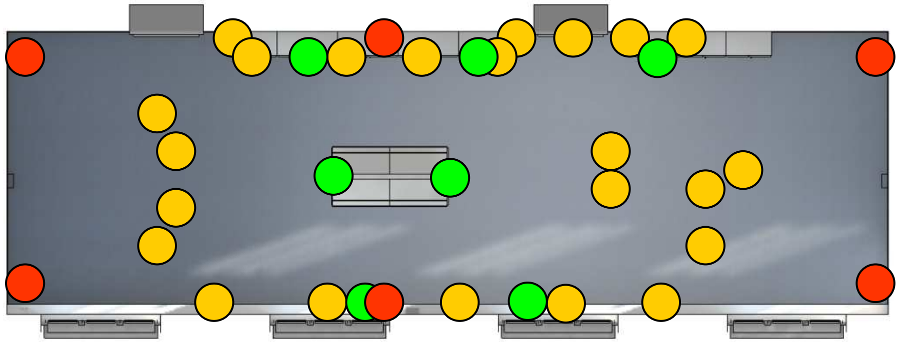
- UHF RFID reader
  (ALR-8780)
- 2 Bluetooth USB sticks
- 2 WLAN PCI cards +
  antennas
  (for pings and TOA
  measurements)
- 240° laser scanner
  (reference positioning)

# Experimental Setup – Environment

Laboratory with landmarks of known positions

- 24 RFID tags (Alien Techn. „Squiggle")
- 7 Bluetooth nodes (BTnodes, ETH Zürich)
- 6 WLAN access points

Additionally: 400 RFID-labeled products of unknown positions in a supermarket shelf (metal)



# Experimental Results

- Data: 11+4 sample trajectories with RFID/BT+WLAN recordings plus accurate laser reference positions, > 5 min.
- Particle filter with 300 samples using odometry
- Investigation: **Tracking**, i.e., coarse initial pose estimate provided; mean absolute positioning errors over time

| Method | Mean ± Std. dev. | Median | 90th percentile |
|---|---|---|---|
| **RFID (model)** | **0.432 m** ± 0.095 m | 0.435 m | 0.527 m |
| **Bluetooth** | **0.494 m** ± 0.149 m | 0.474 m | 0.678 m |
| **WLAN** | **3.315 m** ± 0.738 m | 3.545 m | 4.274 m |

# Video

[ play video ]

# Conclusion

- Presented: Three RF-based positioning techniques
  - RFID tag detection rates
  - Bluetooth signal strength
  - WLAN time-of-arrival measurements
- Accuracies obtained in tracking a mobile robot:
  - ≈ 0.5 m for RFID, Bluetooth
  - ≈ 3-4 m for WLAN
- Low-cost, off-the-shelf hardware used
  in common RF infrastructures
- Future work:
  - Fusion of the techniques ⇨ easily possible due to particle filters
  - Refinements of methods and experiments in larger environments

Thank you for your interest!

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# Contact

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# References


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- C. Hoene, J. Willmann. *Four-way TOA and Software-Based Trilateration of IEEE 802.11 Devices,* IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), Cannes, Sep. 2008.

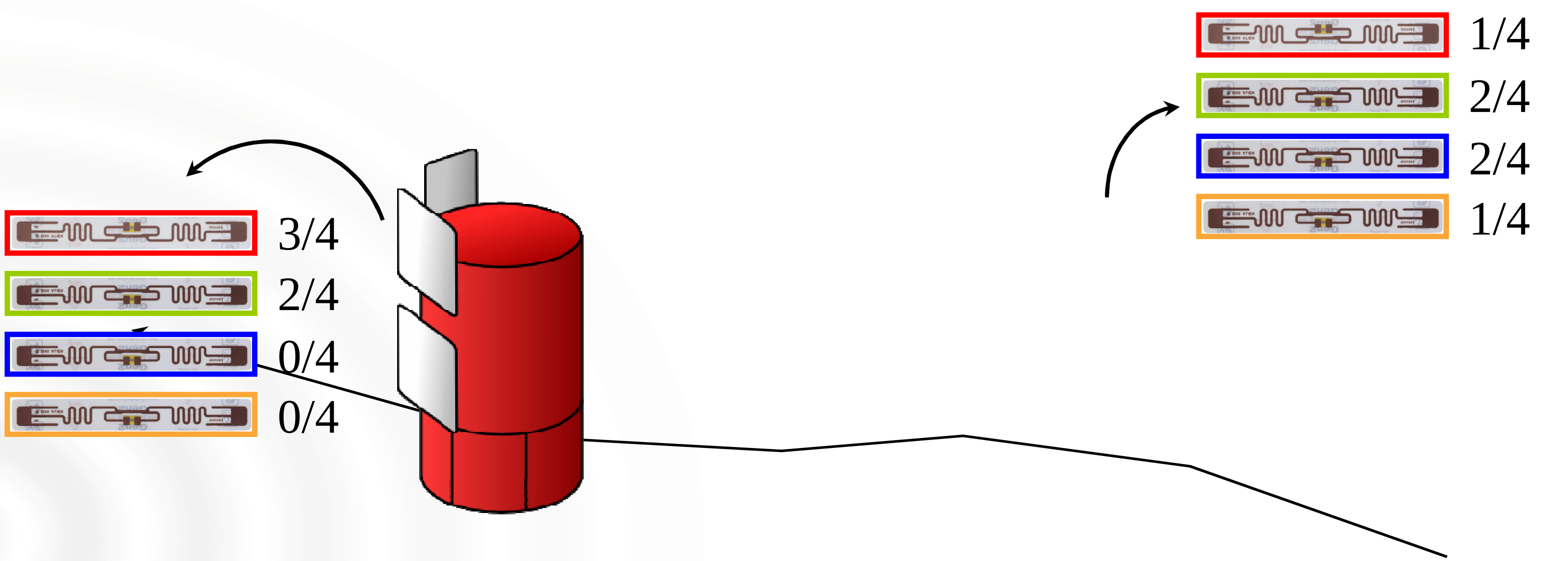
# Picture Credits

- RFID Tag (slides 2,4,5,23) from Alien Technology
  (http://www.alientechnology.com/tags/index.php)
- BTnode (slides 4,6) from ETH Zürich
  (http://www.btnode.ethz.ch/Main/Purchase)
- PDA (slides 2,4) from PIXmania
  (http://www.pixmania.lu/lu/de/554386/art/htc/pda-mit-telefonfunktion-t.html)
- WLAN router (slides 2,4,11) from Litec Computer
  (http://www.litec-computer.de/popup_image.php?pID=9611/imgID=0)
- Other pictures: courtesy of the corresponding AmbiSense subprojects

Extra slides

# Positioning via RFID Snapshots

- Further possibility: **fingerprinting**
- **Prior training**: learning of a database of RFID measurements for different positions
- **Positioning** phase: Comparison of current list of detected tags with trained database
- Again: particle filtering to increase robustness



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| RFID (snapshots) | 0.264 m ± 0.047 m | 0.267 m | |
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(higher tag density)