AmbiSense –
Identifying and Locating Objects with Ambient Sensors

"When Ambient Intelligence meets Web 2.0: Wiki-City
A City interacts with its citizen"
AmI'08 Ambient Intelligence - Erlangen, 22. November

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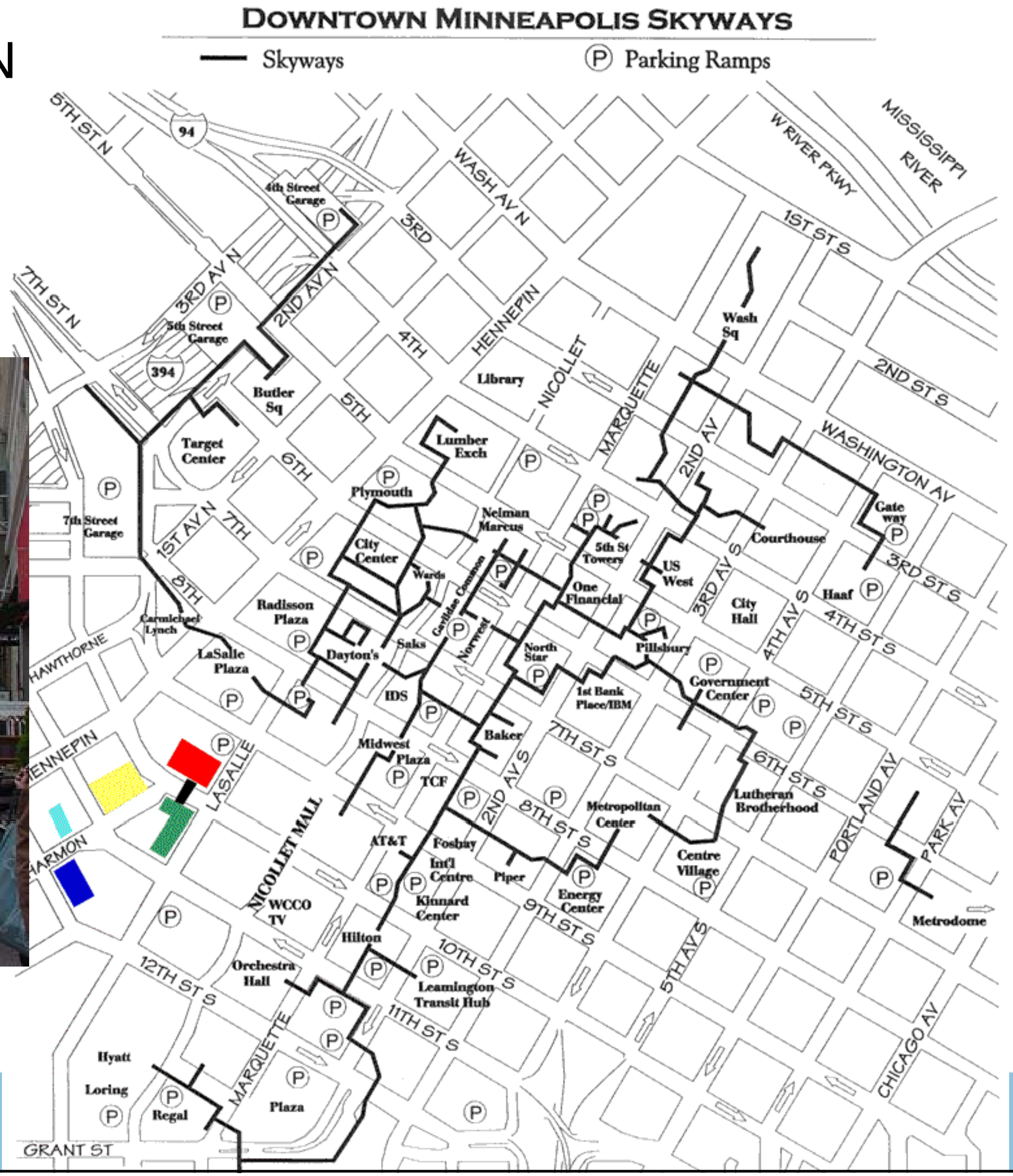
The City is Indoors…

- at least in Minneapolis, MN



Skyways

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Outline

- Introduction
- Application Scenario

- Overall system
  - Robots and localization
  - Vision-based object recognition
  - World model
  - ERP/Database
  - Visualization and Interaction

- Results
- Conclusion and Outlook

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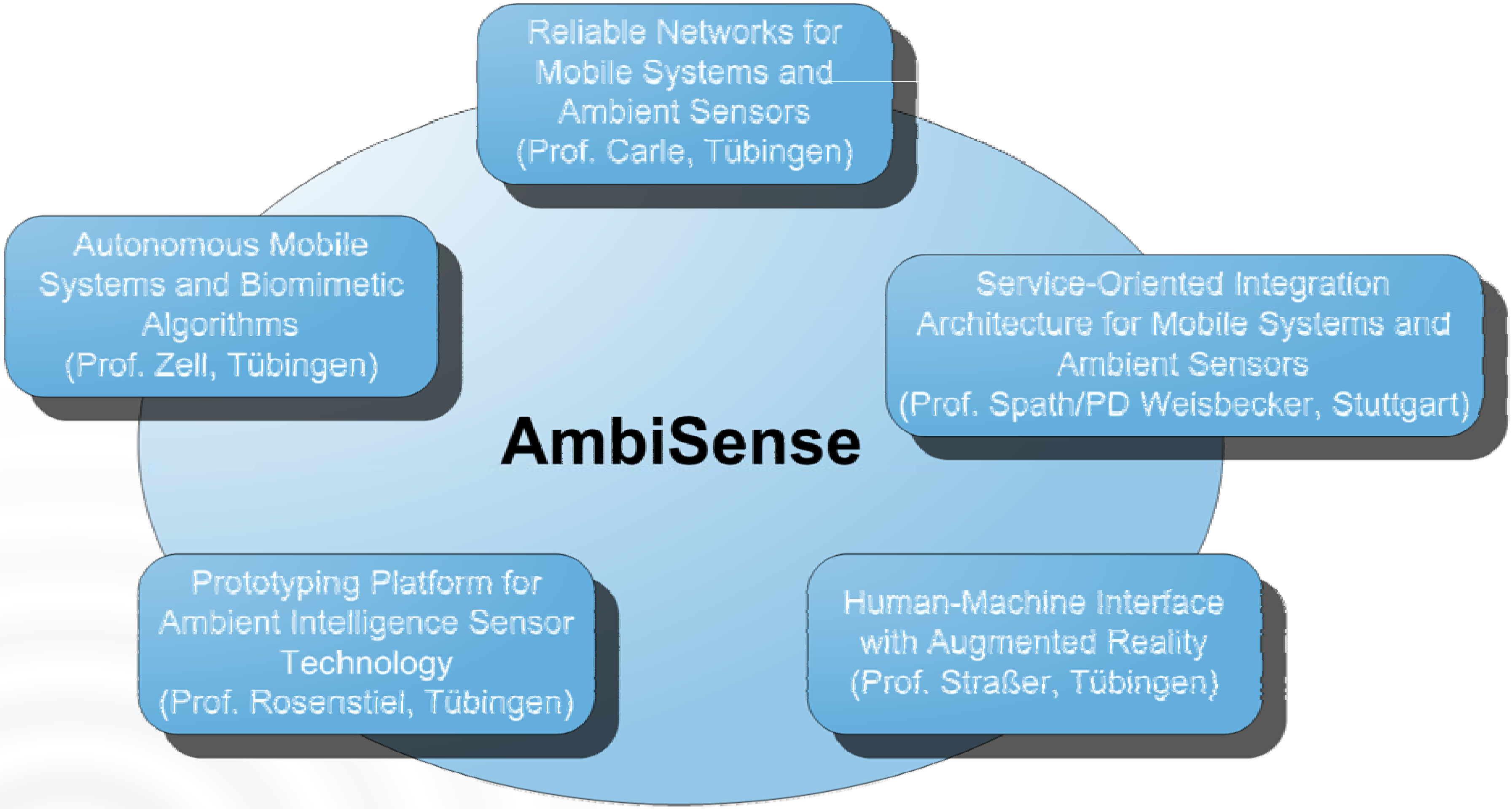
Project AmbiSense



What AmbiSense is about

- **Focus of interest**
  - **What** is located in the environment of a mobile system?
  - **Where** are entities (objects, mobile systems, humans) located?
  - **Which** information is required in a particular context?
  - **How to** present relevant information?

Application Scenario

- **Key component of the project:**
  - Continuous integration into a real-world demonstrator
  - Test bed for developed algorithms and techniques
  - Illustrate practicability and usefulness

→ **Need reasonable / extensible application scenario**

- **Warehousing and retail:**
  - We expect goods to be labeled individually with RFID tags in the near future

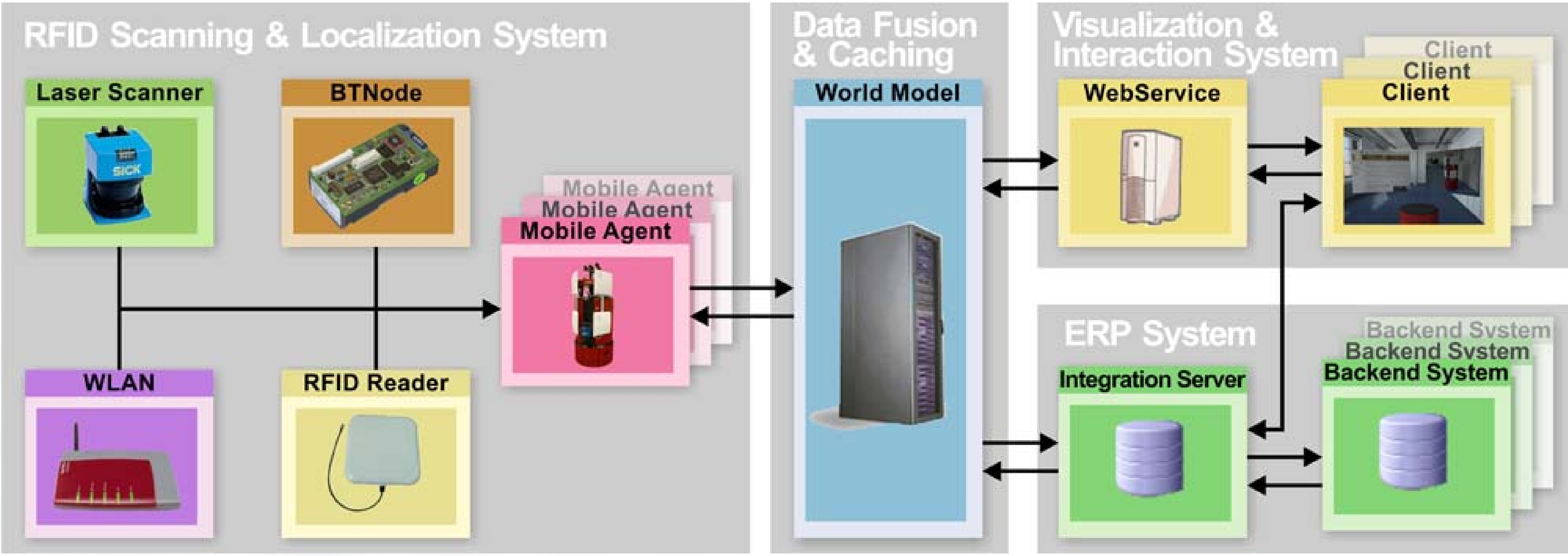
  → **Robot-assisted inventory in a supermarket**

  → **Synchronizing product stock automatically**

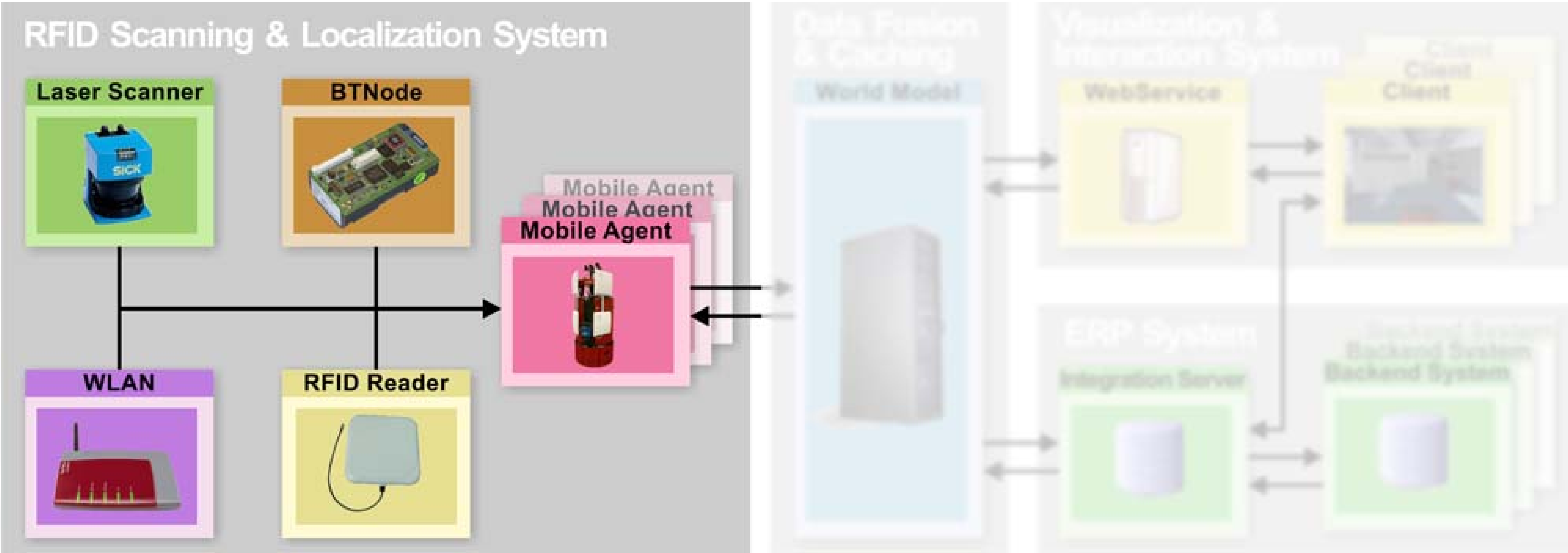
Application Scenario

- The **AmbiSense lab** at the University of Tübingen:
  - >400 individually RFID tagged products (passive UHF, EPC Class 1 Gen. 2)
  - Typical shop shelves
  - Ambient technology (WLAN, Bluetooth, RFID)
  - Robot with UHF RFID reader (ALR-8780)


Overall System



Overall System



Robots and Localization

- Robot navigation
  - Robots need to know their **current position**
  - Laser scanners are **accurate** but **expensive**

  → **Exploit existing infrastructure**

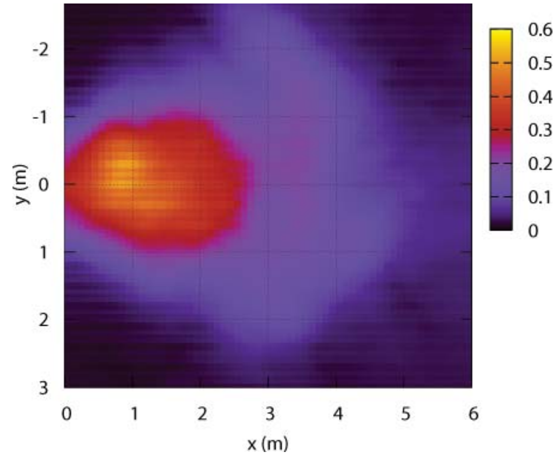
- Robots
  - Laser scanner (ground truth position information)
  - Color cameras (object recognition)
  - Alien technology ALR-8780 UHF RFID reader
  - WLAN
  - Bluetooth
  - Touch screen monitor for interaction

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

Robots and Localization

- Localization using **RFID**
  - Stationary tags (known positions)
  - Multiple detected tags allow for estimating position
  - Use of explicit sensor model of the antennas
    - manually or automatically generated
  - Fingerprinting-based method
    - Distribution of tags is learned in a training phase



- Localization using **Bluetooth**
  - Mapping RSSI to Bluetooth landmarks in the environment to distances

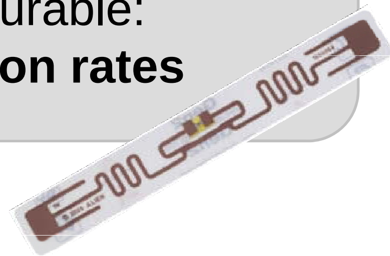
- Localization using **WLAN**
  - Based on ToF of signals between WLAN devices

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**



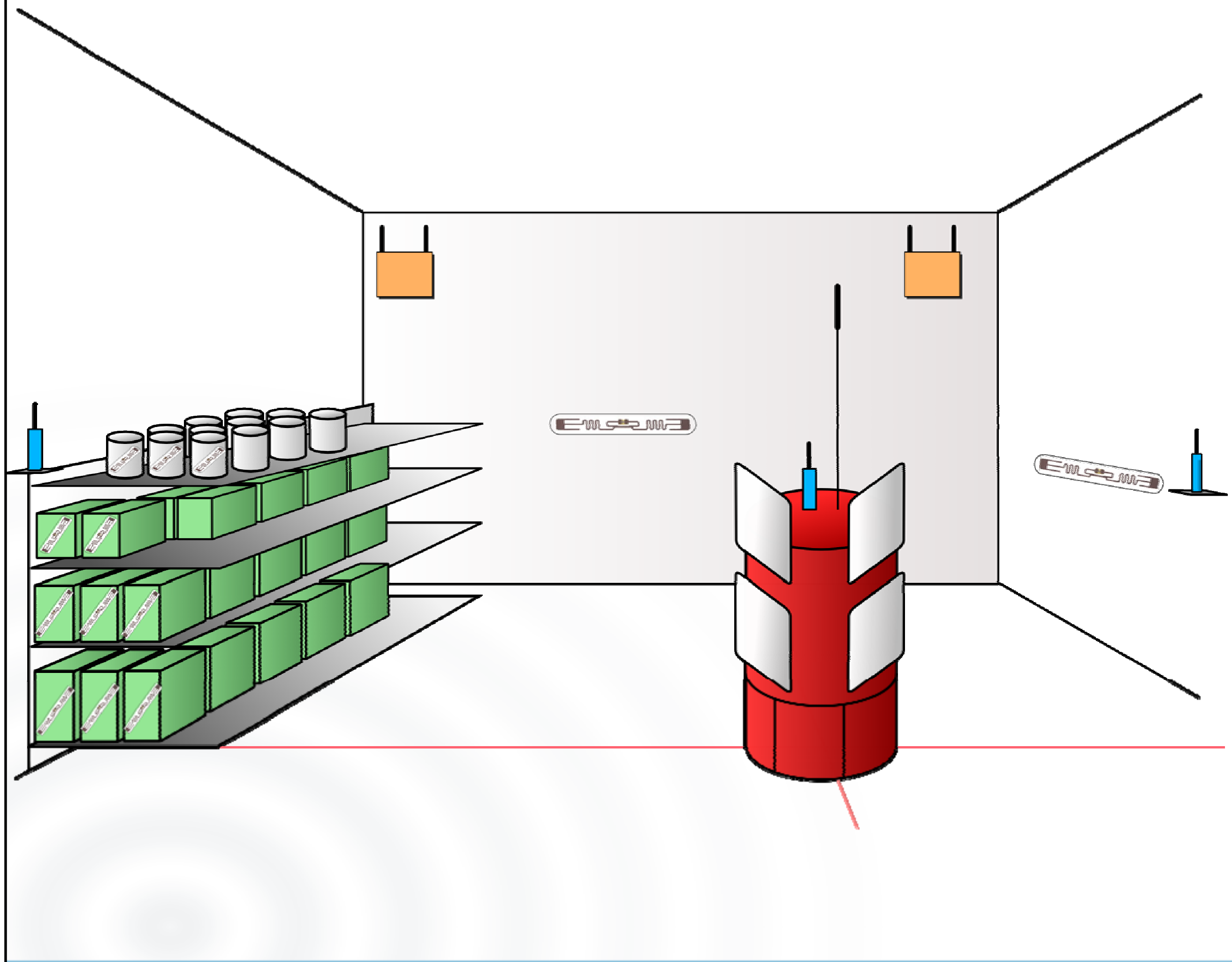
Bluetooth
(IEEE 802.15)

- 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



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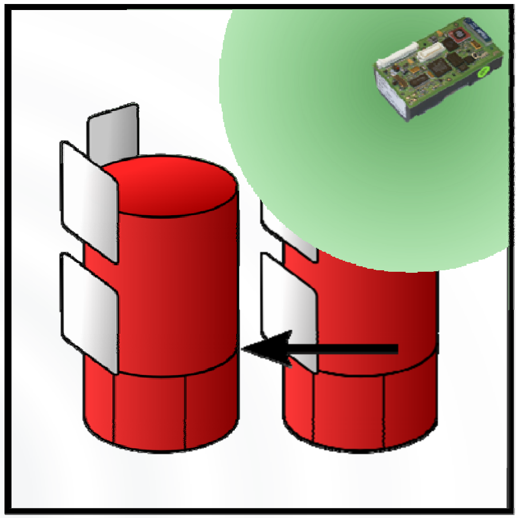
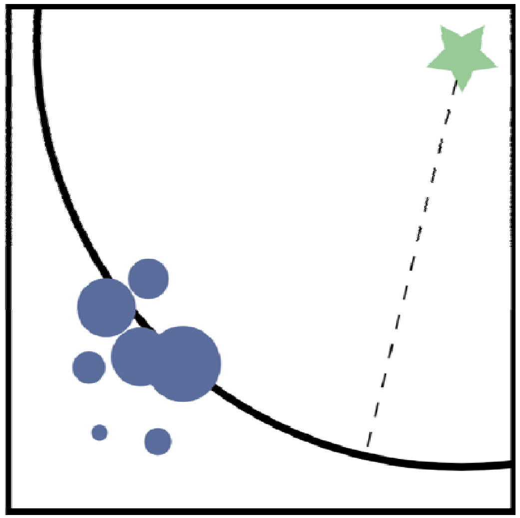
Particle Filtering

- 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





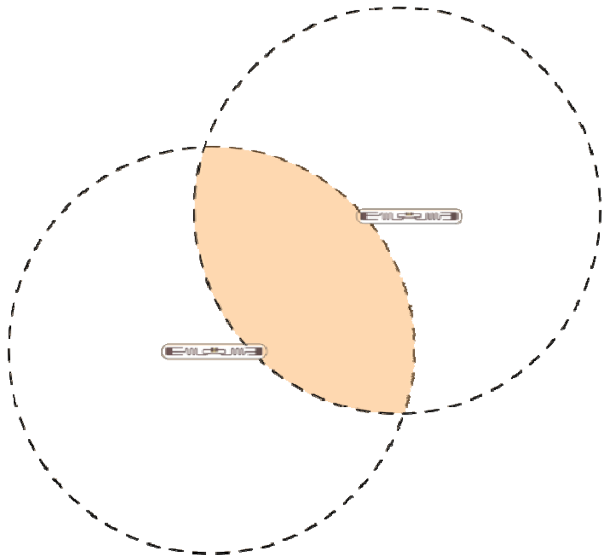
Prediction (motion model)

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**



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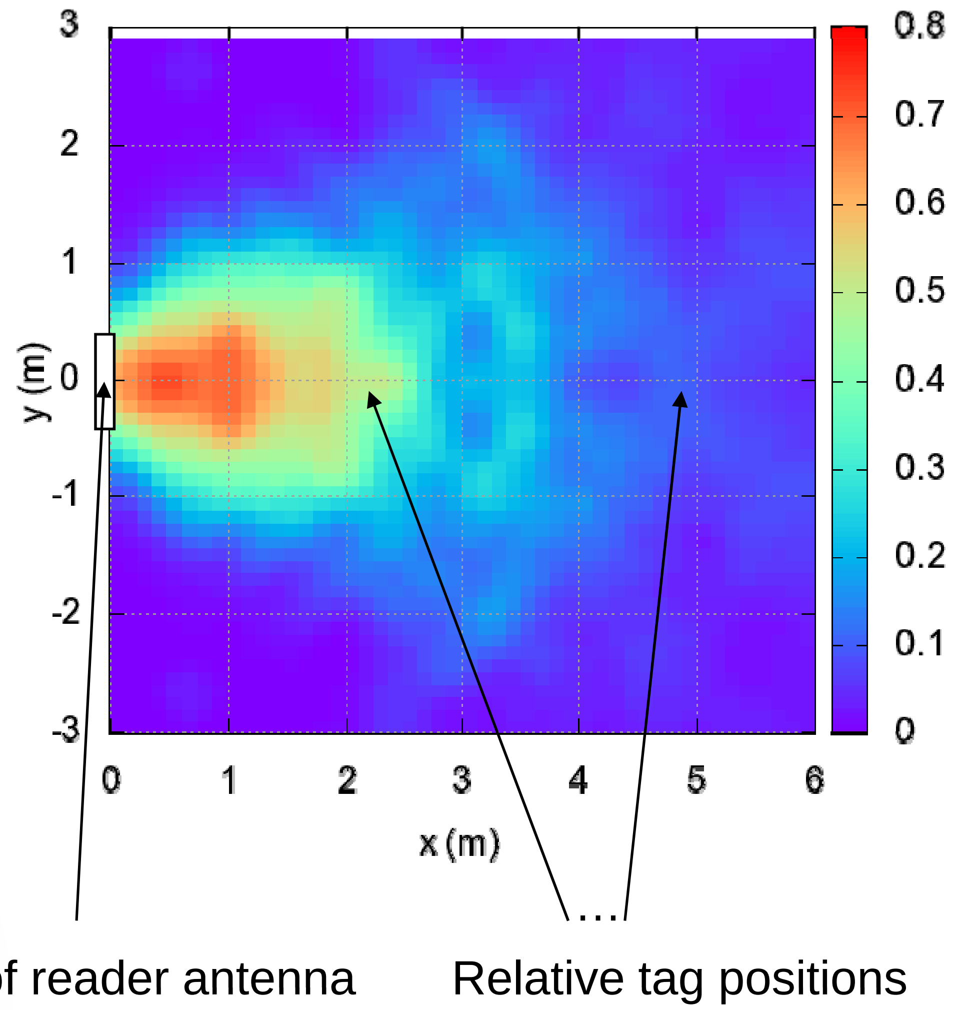
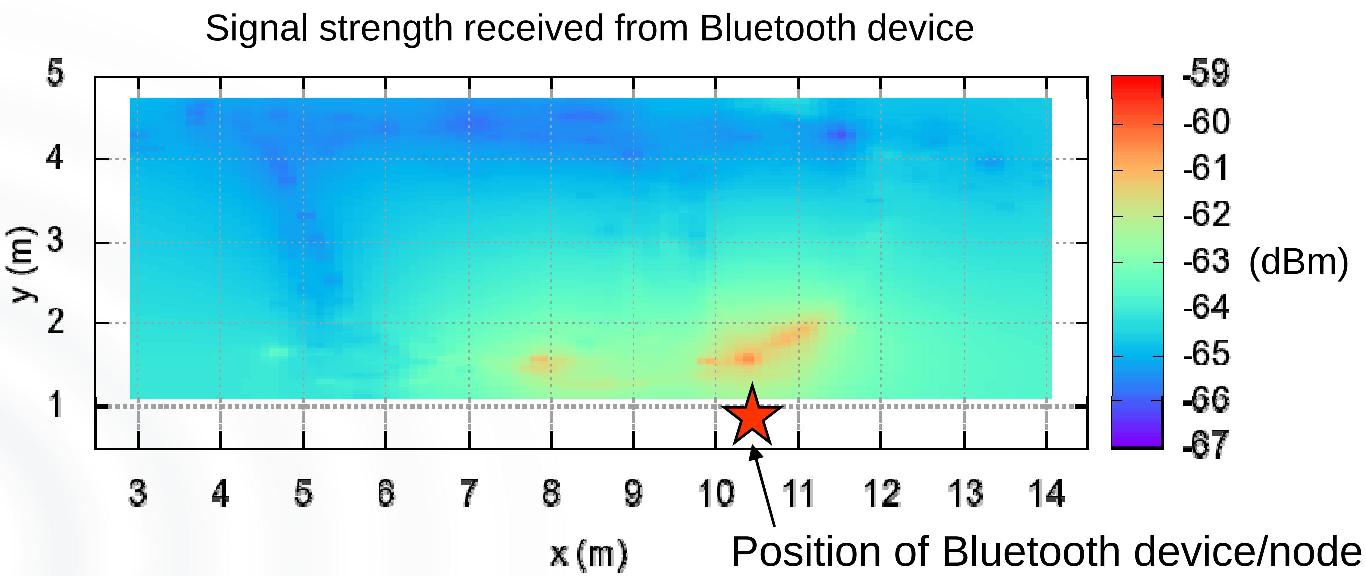
Positioning via Passive UHF RFID – cont‘d

- 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)



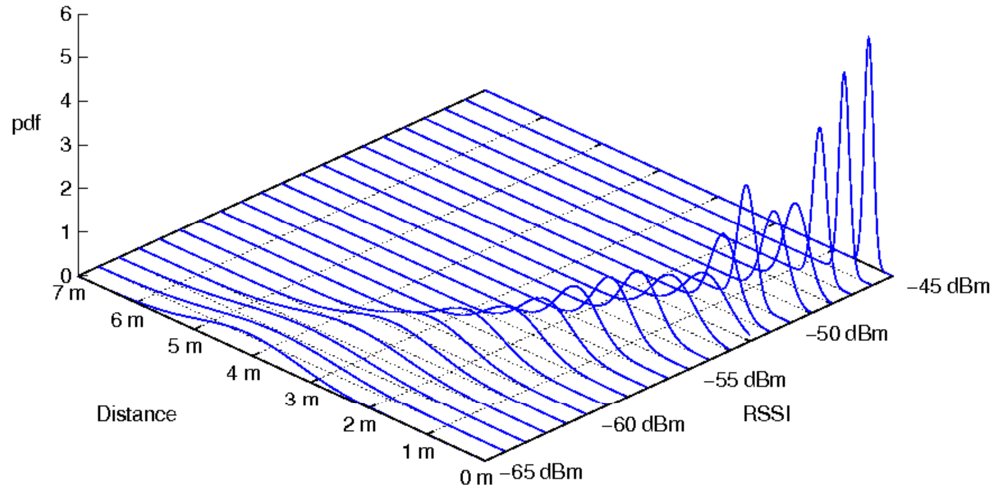
2. Positioning via Bluetooth

- 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

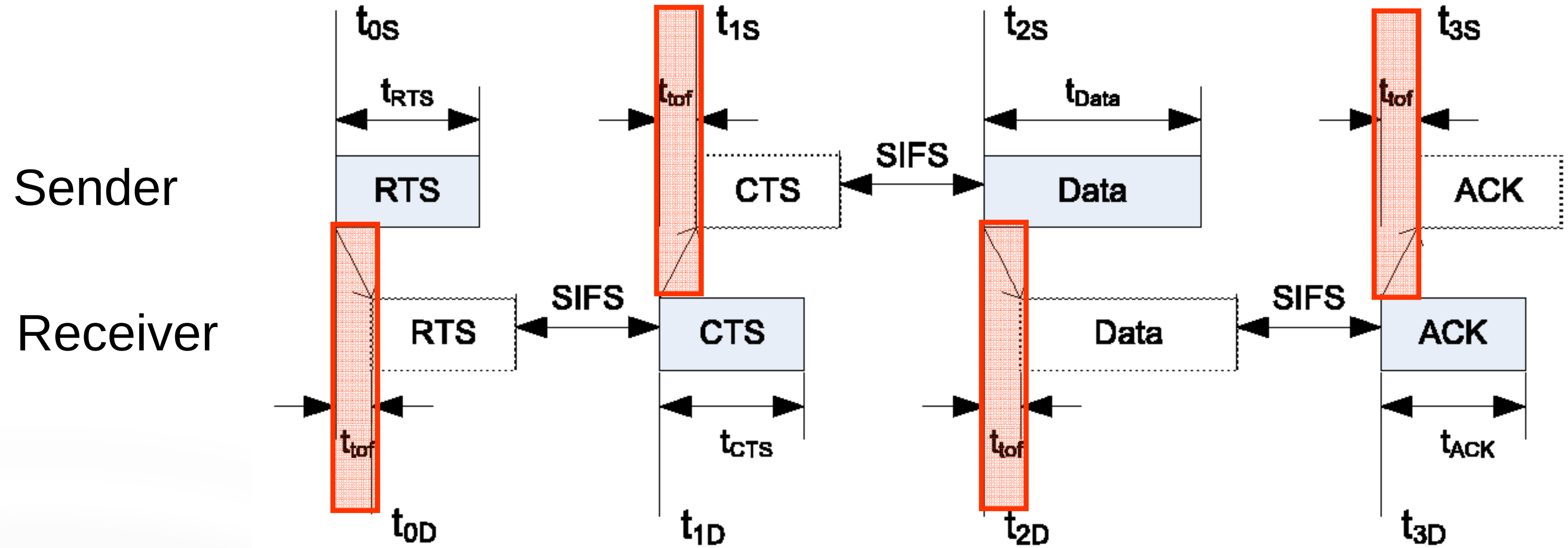
- Each RSSI value can be assigned a **PDF over possible distances**
- Observation: **noise**, low resolution for small RSSI values
- Positioning: multilateration (e.g., MMSE), particle filtering
- PDF used for particle reweighting in correction step



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 on the web
- See (Hoene et al. 2008)

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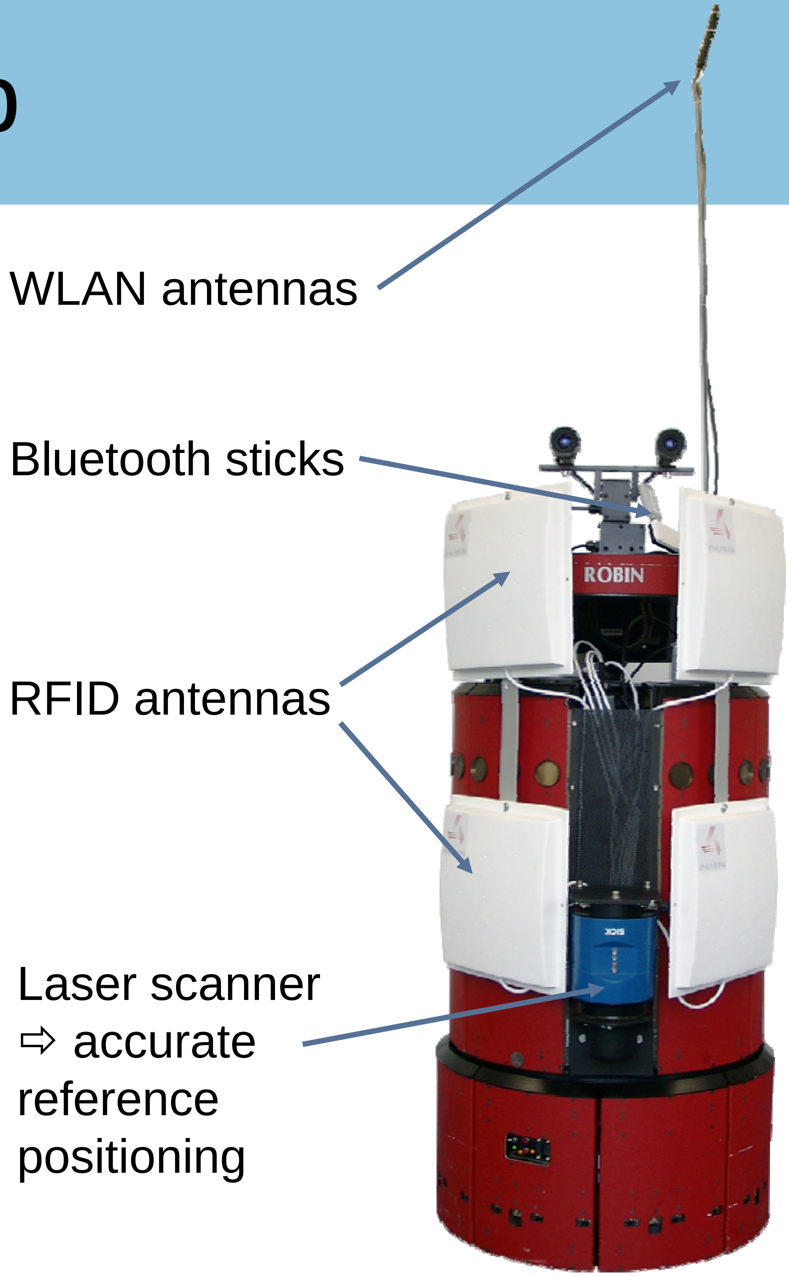
Experimental Setup

Mobile service robot (RWI B21)

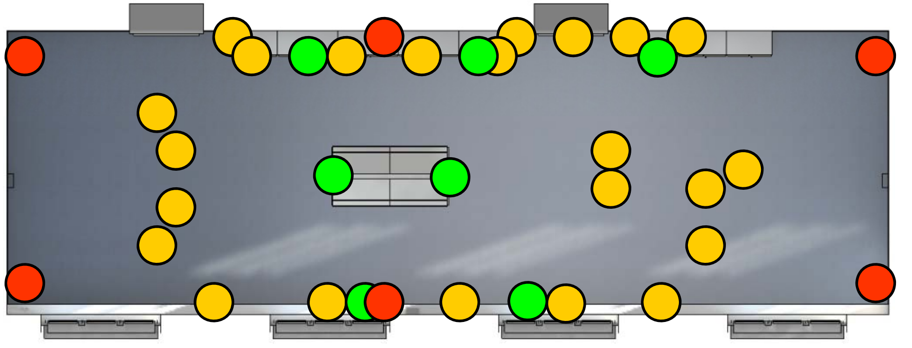
- UHF RFID reader (ALR-8780)
- 2 Bluetooth USB sticks
- 2 WLAN PCI cards + antennas (for pings and TOA measurements)
- 240° laser scanner (reference positioning)



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

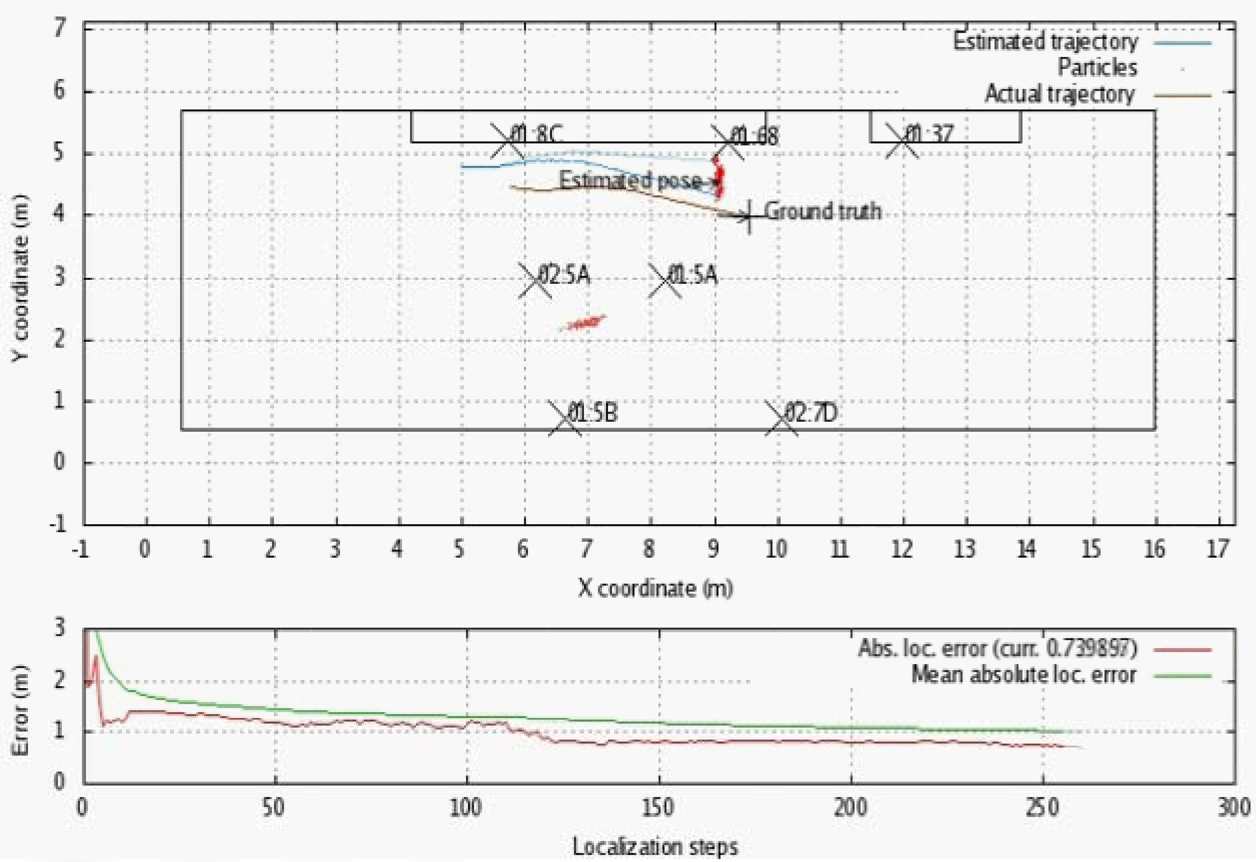


Experimental Results

- 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	**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



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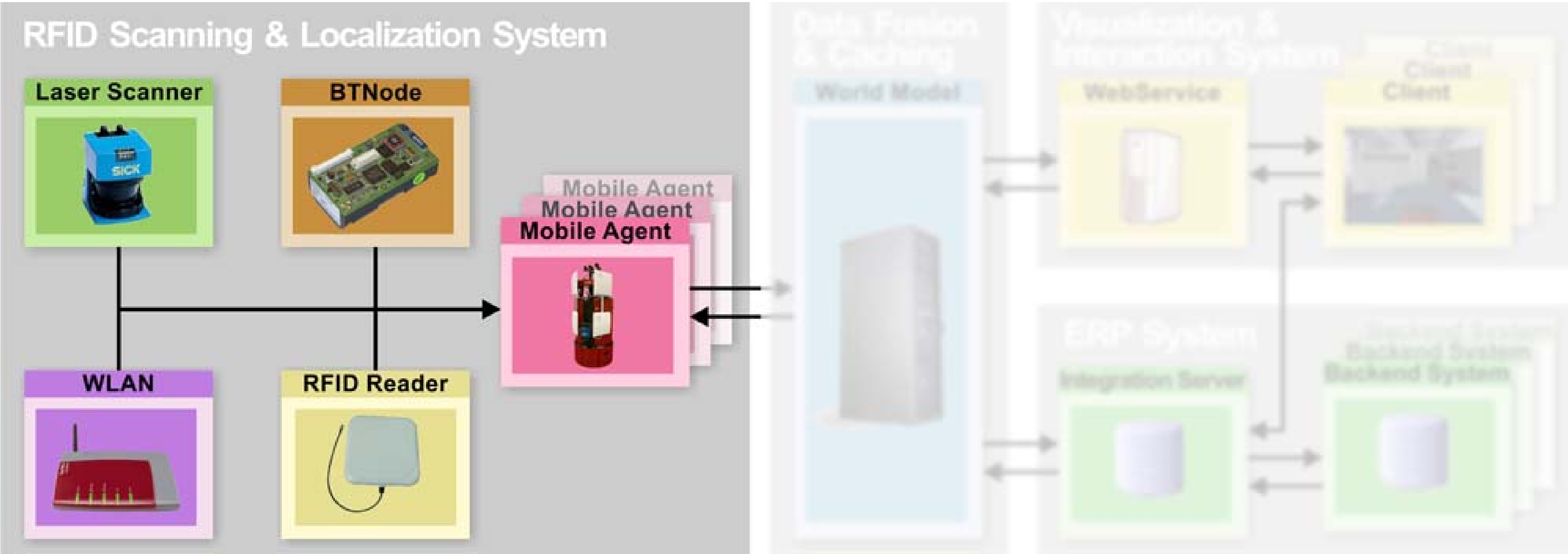
Low-cost position tracking

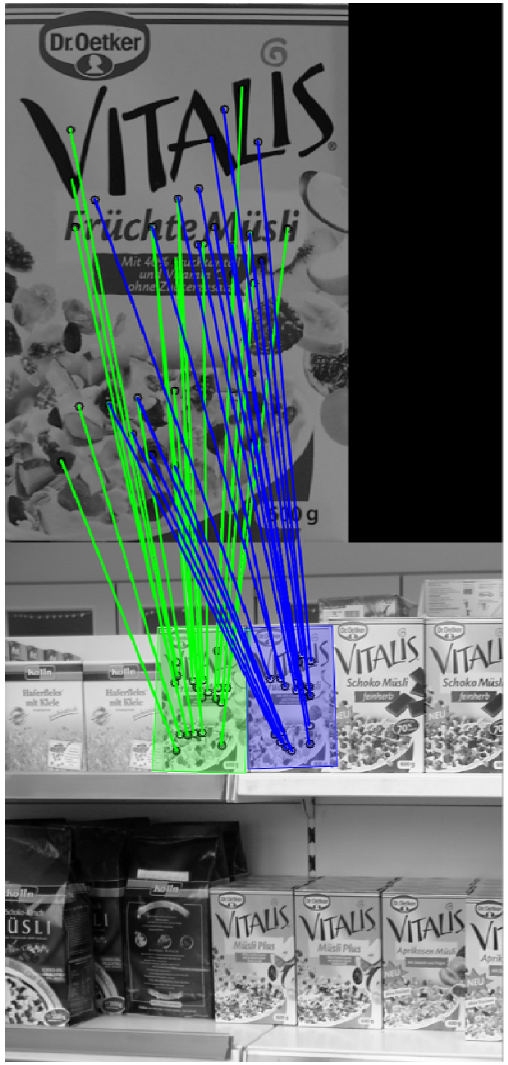
- Presented: Three RF-based positioning techniques
  - RFID tag detection rates
  - Bluetooth signal strength
  - WLAN time-of-arrival measurements
- Accuracies obtained in tracking a mobile robot:
  - ≈ 0.4 m for RFID
  - ≈ 0.5 m for Bluetooth
  - ≈ 3-4 m for WLAN
- Low-cost, off-the-shelf hardware
- Future work:
  - Fusion of the techniques ⇨ easily possible due to particle filters
  - Refinements of methods and experiments in larger environments

Overall System

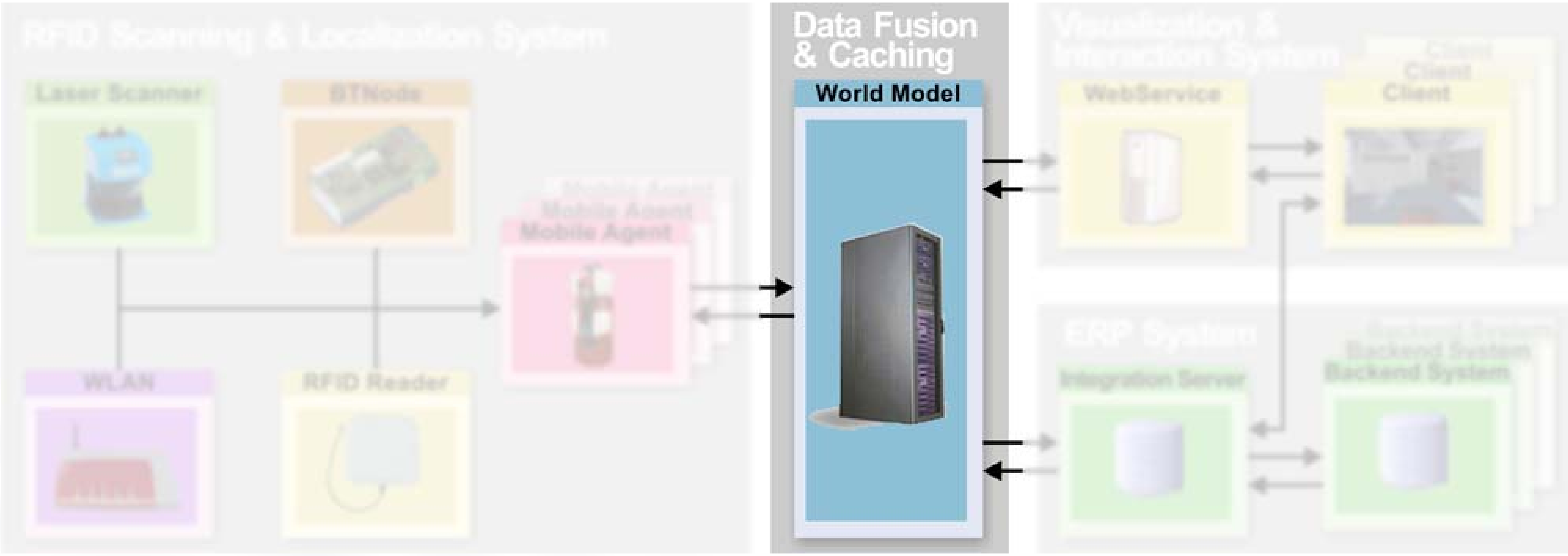


Vision-based Object Recognition

- Use of **local image features**
  - Scale-Invariant Feature Transform **(SIFT)**
  - Speeded Up Robust Features **(SURF)**
- Preprocessing
  - Database containing features of all known packages
- At runtime
  - Feature extraction of current view
  - Comparison with features in database
- Benefit
  - **Better detection rates** by using multimodal sensors
  - **Bearing information**



World Model



RFID Scanning & Localization System
Laser Scanner
BTNode
Mobile Agent
WLAN
RFID Reader
Data Fusion & Caching
World Model
Visualization & Interaction System
WebService
Client
ERP System
Integration Server
Backend System

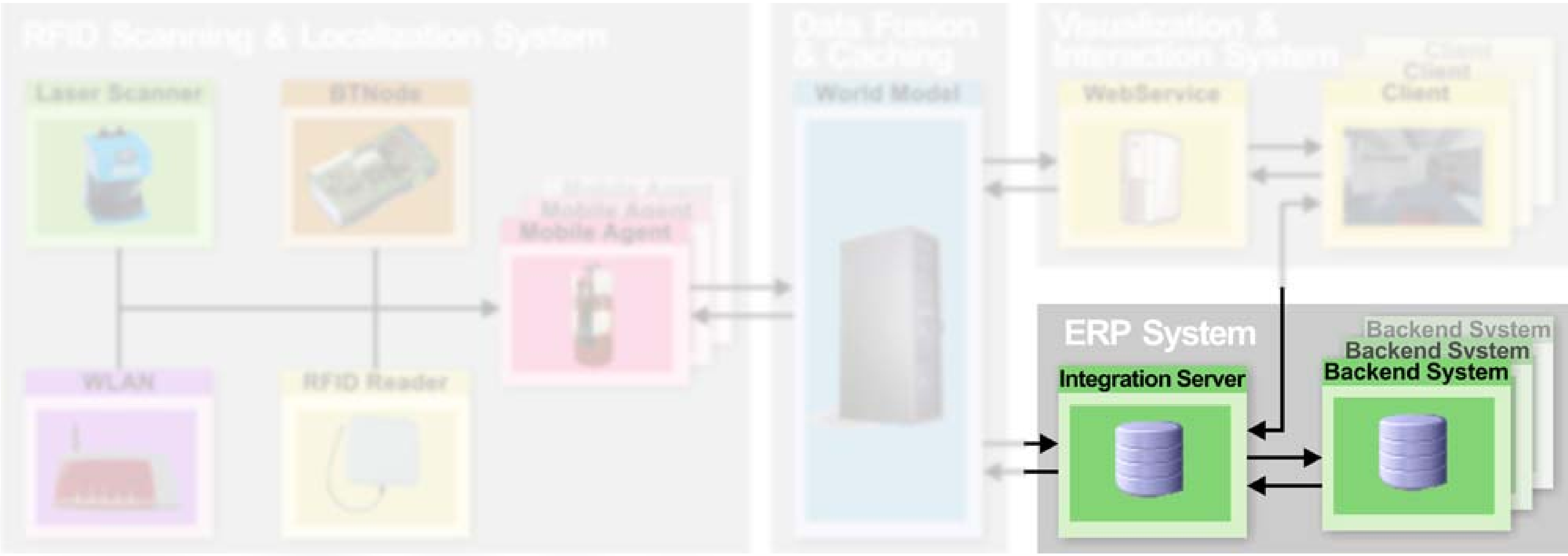
World Model

- **Central point of integration** for connected subsystems
  - Communication with mobile agents by **IPC**
    (CARMEN toolkit, real-time requirements!)
  - ERP and visualization use **SOA paradigm**
    (web service interfaces, SOAP-over-HTTP protocol)

- Provision of different **maps of the environment**
  - Based on sensory information from RFID readers, Bluetooth nodes and WLAN access points

  → Used by connected agents for **self-localization** and **path planning**

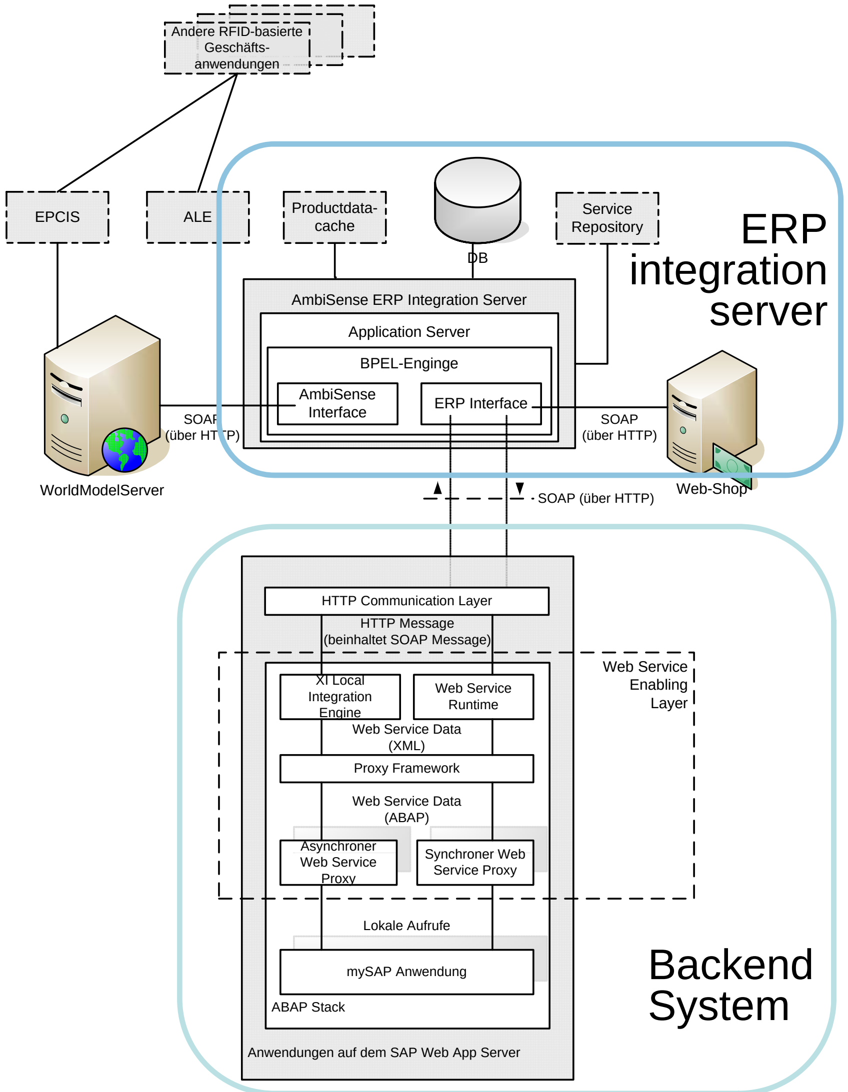
ERP/Database



ERP/Database

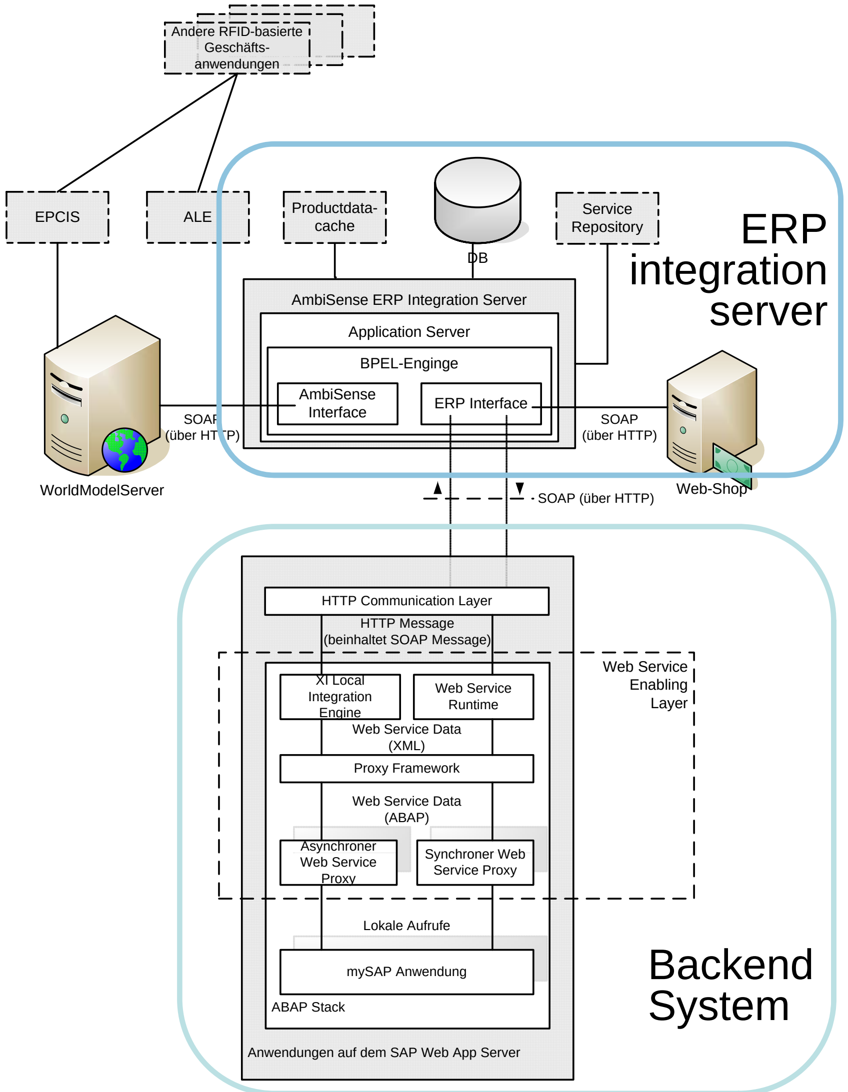
- **Service oriented integration** of backend systems
  - Provision of product information from ERP system(s)

- **Flexible integration** of ERP systems
  - non-proprietary
  - Focus on functional aspects
  - → ERP integration server allows for the integration of different ERP systems

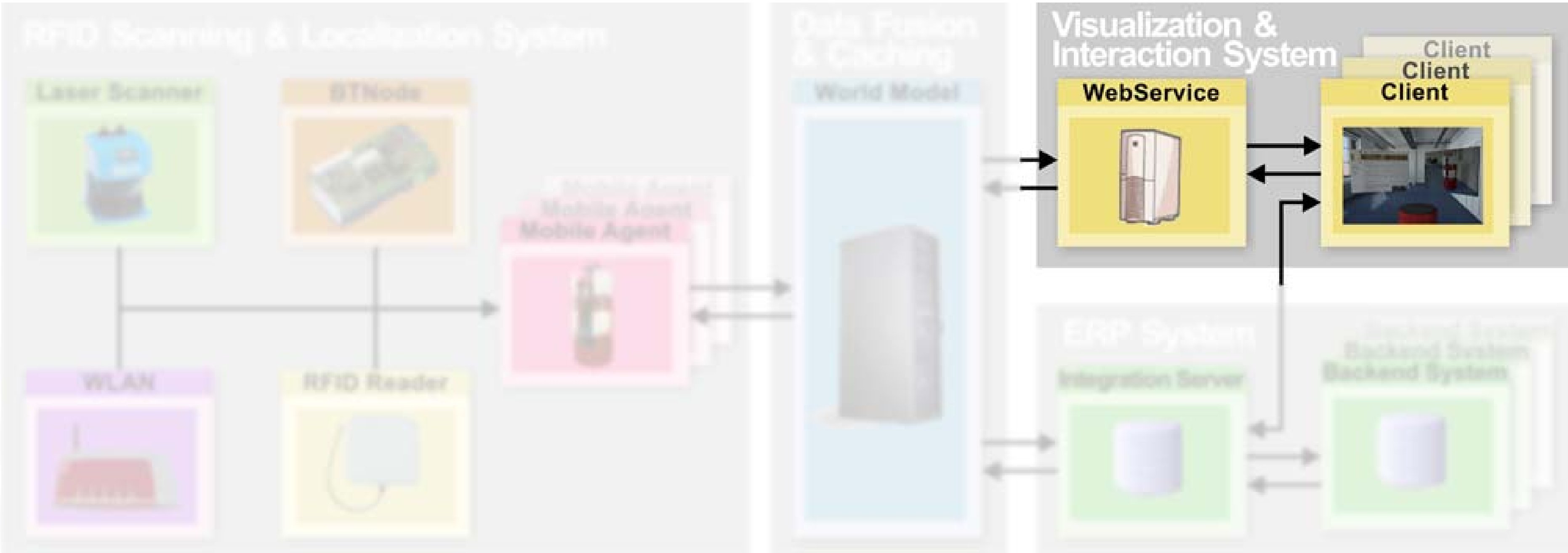


ERP/Database

- **Universality** of business processes, mapping onto BPEL and executable services
- Service oriented integration architecture
- Connection of **near-real-time** systems with **non-real-time** ERP systems



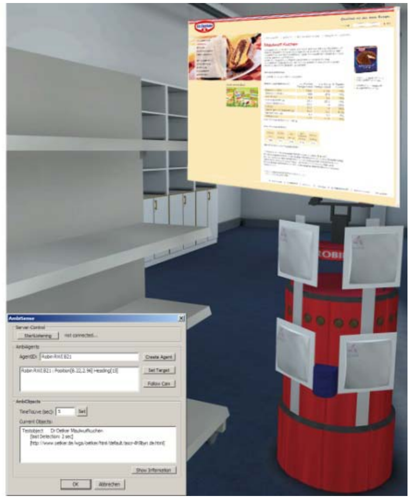
Visualization and Interaction



Visualization and Interaction

- Photorealistic visualization in real-time using ***RadioLab***
  - **Spatial reference** of information

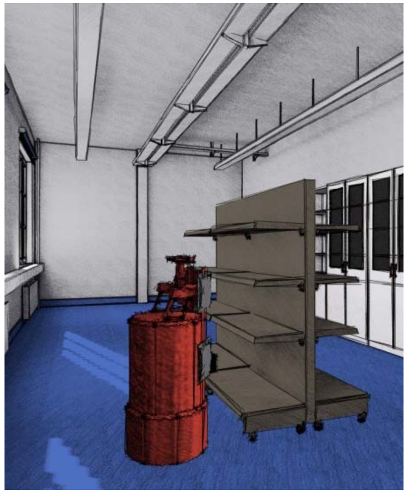
  → Mobile agents and product specific data displayed at estimated positions in **virtual scene**



- Human-Machine-Interface (HMI)
  - 3D navigation
  - Interactive display of product specific data using an **integrated webbrowser**
  - **Ubiquitous visualization** through flash-player connection

Visualization and Interaction

- Connected to visualization web service
  - **multiple visualization instances** on different machines possible
- Different types of visualization
  - Higher level of **legibility**
  - Suited for **different hardware**
- Visualization supports the user in
  - **Planning** the operation
  - **Observing** mobile agents
  - **Localizing** the products
  - **Distributing** the information



Results

- Live demonstration at the **AmbiSense workshop** in Tübingen
- Typical tasks shown:
  - **Exploration** of the supermarket to find specifically chosen product
  - **Control** of robot by specifying goal position in virtual scene

Results

→ **Movie**

Conclusion and Outlook

- **Presented:**
  - Novel prototype system for robot-assisted inventory
  - Suitable components for scenario

- **Current work:**
  - **Improve self-localization**
    → Fusion of different types of sensor data
  - **Increase detection rates**
    → Test different readers and exploit reader models optimally
  - **Optimize avg. access time to product data in backend system**
    → Product cache
  - **Augment visualization with live video streams**
    → Fast low-latency transmission and display

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Thank you for your interest!

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Contact

- **www.AmbiSense.org**

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