Thema:

Design and implementation of a seamless indoor-/outdoor pedestrian navigation system

Bachelorarbeit

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Themensteller: Prof. Dr. Daniela Nicklas

vorgelegt von: Stefan Schmucker
Matrikelnummer: 1749055
E-Mail: stefan.schmucker@uni-bamberg.de
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Abkürzungsverzeichnis

IoT Internet of Things

AP Access Point

ToA Time of Arrival

TDoA Time Difference of Arrival

OTDoA Observed Time Difference of Arrival

RToF Round Trip Time of Flight

AoA Angle of Arrival

RSSI Received Signal Strength Identification

DR Dead Reckoning

WPAN Wireless Personal Area Network

GSM Global System for Mobile Communications

LBS Location-based Services

WLAN Wireless Local Area Network

GPS Global Positioning System

GNSS Global Navigation Satellite System

IR Infrared

RFID Radio Frequency Identification

BT Bluetooth

SNR Signal-Noise Ratio

WGS84 World Geodetic System 1984

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This paper is about indoor outdoor transitions.

1 Introduction

Seamless indoor-/outdoor (I/O) positioning forms a backbone for numerous upcoming applications: not only for ubiquitous Location-based Services (LBS) like navigation, but also with regard to (wrt.) several Internet of Things (IoT) areas such as in sports, *Smart Healthcare* and *Industry 4.0*.

The fact that people spend between 70% and 90% of their lives indoors (Kalliola 2008) and the emergence of new applications in the area of navigation, decision making and connection of devices might explain the high valuation of the indoor localization market in the coming years. While determined to be at 7.11 Billion in 2017, the forecasts vary between USD 29.4 Billion (reports 2018) and USD 40.99 Billion (Markets and Markets 2017) in 2022, and even USD 58 Billion in 2023 (KBV-Research 2017).

There are various applications conceivable: they range from apps providing location-based traffic and whether information up to emergency systems informing hospitals in case of detected accidents and navigating attending physicians to injured persons, or navigation systems guiding people through complex, large buildings like airports, leisure parks or university campuses.

I/O navigation services require smooth interaction between indoor and outdoor positioning technologies, including a handover strategy for switching between them. That is because outdoor localization technologies are mostly not able to provide satisfying accuracy indoors and vice versa.

Although there are several choices for outdoor localization technologies, most system designers select the (almost) ubiquitous Global Navigation Satellite System (GNSS) technology for outdoor positioning due to its ubiquity, reliability and precision.

GNSSs can also be applied in some special indoor cases:

for example, if persons reside close to windows or in areas where the sky is partially visible (Eissfeller et al. 2005). But in most cases it is not available indoors and people can typically expect signal loss on entrance.

Historically, GNSS-assisted localization has been developed independent but in paralell by the US Department of Defense (GPS NAVSTAR) and the russion federation (Glonass) in the mid 1970's and was first operational in the early 1990's ((Mai 2017); (Cosmos-Indirekt 2017)). In 1996, researchers published the paper "Global Positioning System: Theory and Applications, Volume I", informing about GPS fundamentals like physical and technical concepts and applicable algorithms, and being basis for further research and economical interest in this area. In May 2000, the U.S. government switched off the Selective Availability (SA) interfering signal, which basically made GPS not publicly applicable due to a approximate error of 100m.

Building on those achievements, and the development and dissemination of the WLAN technology, fundamental research in the field of indoor localization has been carried out by Bahl and Padmanadhabhan in 2000 ("RADAR: An In-Building RF-based User Location and Tracking System"), Chen and Kobayashi in 2002 (SSignal Strength Based Indoor Geolocation"), and in 2009 by Tan et al. ("Positioning techniques for fewer than four GPS satellites"), Li and Rizos ("Positinoning where standard GPS fails") and Gallagher et al. ("Wi-Fi + GPS for urban canyon positioning"(Gallagher et al. 2009)).

According to various authors, best practice for seamless positioning is hybridization of GPS and at least one other indoor positioning technology, such as WLAN ((Gallagher et al. 2009), (Hansen et al. 2009), (Atia et al. April 2012)). The used datamodel has to meet challenges origining from the combination of multiple technologies, e.g. supporting different levels of granularity and the ability to handle both symbolic indoor coordinates as well geometric GPS coordinates. Chapter 2 focuses on those and other challenges.

Indoor positioning systems typically make use of WLAN, because the required infrastructure is either already provided in most buildings or can easily be installed. Also Bluetooth, Ultrasound and RFID represent applicable technologies, but they have several drawbacks like the need for additional hardware. The evaluation in Chapter 4d) provides a more detailled overview to the individual pros and cons of positioning technologies.

Localization methods such as triangulation and fingerprinting form the algorithmical backbone for positioning and use provided information to calculate or estimate a person's most likeliest position. Their difference in complexity, applicability and calculation effort and cost will also be evaluated in Chapter 4.3.

This work arised from the idea of the *Living Lab Bamberg*, which is an open research and development environment for sensor-based applications in the domain *Smart Cities*, established at the University of Bamberg and other local stakeholders. The prototype designed in this work constitutes a demonstrator for how seamless, predestrian, I/O navigation with different technologies could be realized in a simple but extendable manner, and thus represents an environment-friendly solution to our cities' last-mile problem. Besides that, an user-supported alternative to high precision solutions is proposed.

Obviously, methods and technologies presented in this work could also applied to localize objects or robots, or measurement accuracy could be improved using artificial intelligence or mathematical models like Kalman filters, but those fields' focus is on other aspects like always improving accuracy and will therefore not be part of this work.

The aim of this work is to give an overview to the field of I/O positioning with a special focus on how seamless navigation indoors and outdoors could be realized and implemented. Therefore, first current outdoor- and indoor positioning technologies as well as suitable methods, data models and I/O transition solutions are presented and evaluated. Subsequently, an indoor/outdoor pedestrian navigation system prototype is implemented based on that evaluation's findings. Finally, the prototype's navigation results are presented and evaluated. The findings are then summarized and flown in future work proposals.

Key questions this work provides answers to are:

- Which techniques, methods and datamodels are available to provide seamless indoor/outdoor transisions in pedestrian navigation systems?
- Which hybrid localization approaches are promising?

- What is the best time and strategy for switching of positioning technologies?
- How could a flexible and expandable datamodel be designed?
- Which possibilities exist to overcome low indoor accuracy in navigation apps?

The rest of this paper is structured as following:

Chapter 2 gives deeper insight to the challenges coming up with hybrid navigation systems. In Chapter 3 related work in this area is reviewed. The technical background including technology and method assessment is filling Chapter 4. Design and implementation of the navigation prototype is presented in Chapter 5. The evaluation of positioning and navigation results is then worked up in Chapter 6. Finally, Chapter 7 gives an outlook to possible future works in the field and concludes this work.

2 Challenges wrt. Hybridization

Facing the need for hybridization in seamless I/O navigation systems, system designers have to conceive and construct solutions for multiple challenges. This section gives an overview to the main challenges and possibly occuring problems in this field.

1. Technology selection:

   First of all, the selection of suitable technologies: There is a spread of technologies available for indoor and outdoor positioning, such as WiMAX, GPS and CellID (GSM) for outdoors and WLAN, Bluetooth, RFID, NFC, Infrared, Ultrasound, ZigBee, Z-Wave etc. for indoors. Outdoor positioning technologies typically require clear sky view for optimal positioning, as walls and steal in buildings attenue the signals by the 100-1000 fold. It is thus necessary to evaluate the technologies' advantages and disadvantages wrt. their suitability to the respective requirements.

   Mostly, a single technology is insufficient for seamless I/O positioning: on the one hand, outdoor technologies are either not available indoors or do not provide satisfactory accuracy. On the other hand, indoor positioning technologies require configuration and/or installation of hardware and are thus only available (and reliable) in presence of sensors. Regarding this fact, various other challenges arise, such as the

2. Determinition of handover strategies:

   Positioning systems need a strategy to decide which technology to trust more in case both indoor and outdoor positioning signals are available. Multiple variants are conceivable, e.g., one could either consequently only use one of the available technologies, or use mathematical functions like the mean of all received positioning results origining from both indoor and outdoor technology. Also solutions assigning weights to the measurements in different, predefined situations are imaginable, but this would require elaborate pre-configuration for every building (and the area around it). (Hansen et al. 2009) reveals that a strategy where GPS is prefered over WLAN uppon continuous readings (in intervals of five seconds) performs more accurate than use one of both until signal loss. The main drawback of the 'use GPS or WLAN until signal loss' strategy, for example, is that WLAN signals are typically available outdoors for a long distance but with a remarkable worse accuracy and reliability than GPS would provide.

3. A common datamodel:

   In order to combine GPS with an indoor localization technologies like WLAN, Bluetooth and RFID, a common datamodel has to be implemented which has to include different levels of granularity. It has to support various types of symbolic indoor spaces (coordinates), i.e., the differing between building parts like entrances, floors, corridors, rooms, stairs, elevators and possibly more entities, which all shall be annotatable with semantic information like naming and spatial relations and distances to other entities and other specific attributes. Additionally, the model has to include geometric GPS coordinates, i.e. measurement values indicating latitude, longitude, and altitude of buildings for outdoor positioning.

4. Method selection:

   Like for technologies, there is a need for evaluation of localization methods, as they different properties also aim at different areas of application. According to (Farid et al. 2013), fundamental aspects in method selection are accuracy, coverage, the requirement for line of sight, the affection by multipath and cost. It can be obeserved that there is a tradeoff between cost and accuracy: the article reveals that methods like Time of Arrival (ToA) and fingerprinting, for example, provide high accuracy at medium to high costs, whereas dead-reckoning and proximity detection require low costs, but also typically provide low accuracy.

5. Navigation requirements:

   For outdoor navigation issues one could easily use the road network detected by GPS, but for indoor approaches spatial relations like containment, adjacent entities and distances between entities have to be explicitly modeled. Also the different movement patterns, i.e. walking, taking stairs or the elevator, with their specificly required time shall be considered. For further refinement one could provide semantic information like accessibility, barrier liberty or the room type.

6. Positioning strategy evaluation:
   The determinition of which positioning strategy to use highly depends on a system's requirements: in case security and privacy is essential, all positioning calculations have to be done on client-side. In contrast, if a real-time monitoring of all entities in a certain area is required, a server-based approach is a better option. Another alternative represent cooperative strategies where positioning is based on other entities' signals (i.e. not only from satellites and APs). The respective advantages and drawbacks are discussed in Section 4.

3 Related Work

This section presents and assess related works covering indoor/outdoor navigation and datamodels. Their respective drawbacks are determined and their approaches delimited in relation to this work.

The research area of indoor and outdoor positioning technologies and methods also forms part of this work, but this area is already explored sufficiently in recent years by various other researchers ((Maghdid und Lami 2016); (Gu et al. 2009); (Farid et al. 2013)), such that no prototyping and testing is required anymore and one can use their well-confirmed evaluation results.

Among others surveying different technologies and methods for indoor positioning systems, (Gu et al. 2009) covers an evaluation of systems wrt. the criteria security and privacy, cost, performance, robustness, complexity, user preferences, commercial availability, and limitations. However, the authors' focus is on indoor localization only, aspects like I/O transitions or hybridization are ignored. Also, they have only regard to existent systems and used technologies and methods are not included in any evaluation tables, such that there is no satisfying overview to the systems' most relevant components (on one page).

In contrast to the survey discussed before, the authors of (Farid et al. 2013) examine single technologies like GPS, Infrared, WLAN, Ultrasound, RFID, BT, ZigBee and FM regarding the criteria accuracy, applicable positioning methods, coverage, power consumption and cost. Methods are evaluated wrt. measurement type, indoor accuracy, coverage, the requirement for line of sight, multipath affection and cost. Nevertheless, topics like hybridization of methods or combination with GPS technology and seamless IO transitions are not discussed.

Some authors treating I/O transition only focus on single technologies and methods like (Xia et al. 2017) (fingerprinting) and (Török et al. 2014) (dead-reckoning), or basically only present their system design like in (Zhu et al. 2019) (machine learning approach), such that their foundings can not (or only partially) be used for a sensible overview and assessment of technologies and methods.

I/O transitions are also topic in (Kray et al. 2013), but they focus on finding and presenting examples for transitional spaces and their properties only, and a answer to the question how to integrate this knowledge into a positioning system is not provided.

A comparison of existent systems can be found in (Jinlong et al. 2013), but there only four existing systems are presented, which does not even yield a sensible overview - other authors assess more than ten solutions (Maghdid und Lami 2016). Also, existing technologies, methods and transition strategies are poorly described - and a series of them even completely omitted.

Fortunately, various authors also provide sensible overviews to indoor/outdoor transitions, such as (Hansen et al. 2009), who worked out and evaluated four different strategies for transition in I/O positioning with WLAN fingerprinting and GPS: 1) always prefer GPS, 2) always prefer WLAN, 3) prefer GPS until lost signal, then prefer WLAN until lost signal and 4) prefer GPS upon continuous readings (until signal loss of five seconds). The authors conclude that strategy 4) is the most precise and reliable solution, which is also confirmed by (Jinlong et al. 2013). However, they do not assess other technologies and methods, specially hybride low-cost approaches like with RFID or BT technology and approaches focusing on minimal configuration are left out. Furthermore, their system design is ineffizient, cause as soon as users pass a building (and do not enter it) its indoor radio map is downloaded, which could possibly lead to massive overhead. This work's Section 4.2.1 gives deeper insight to drawbacks of the WLAN fingerprinting solution.

(Maghdid und Lami 2016) discusses available indoor positioning systems, outdoor positioning systems and also hybride approaches being able to seamlessly locate smartphones inside and outside buildings. Different technologies, methods and their combinations are also part of discussion. The authors claim aspects like poor performance or accuracy, the absence of a plattform for integrating multiple positioning solutions, and demand infrastructureless, cooperative solutions and hybridization of methods and technologies in combination with sensor fusion and Kalman filters.

However, they do not implement their own positioning system and focus on evaluating other solutions. Their aim is to identify weaknesses and opportunities and upcoming challenges wrt. seamless and precise IO positioning.

Another related work is (Kim et al. 2012), where the handover from GPS to an indoor localization technology is faced. The authors experimentally found that GPS signal loss might be an insufficient indicator to mark outdoor/indoor handover points. The Signal-Noise Ratio (SNR) is rather a better choice, as SSNRs of the specific satellites rapidly decrease around building entrances". This refers to the fact that satellites at elevation of 30-90 degrees show significantly higher SNR drop when entering a building than those at 0-30 degrees (sometimes even no significant changes are apparent). SNR does not provide any significance in case of indoor/outdoor handovers, as the values it supplies outdoors are almost equal to values measurable indoors near windows. In this case, GPS accuracy attribute turned out to be decisive. More details on their foundings and other GPS fundamentals are rehashed Secton 4. Unfortunately, they do not evaluate the aid of indoor localization technologies and methods and other possibilities to determine the best handover time and only focus on GPS technology. In addition, their current system design is worthy of improvement: it requires a user to visit a respective building at least once before being fully operable. Cooperative strategies would represent a promising alternative to that issue.

Papers published in the past two years mostly use advanced methods like fuzzy logic, artificial intelligence (Iwata et al. 2018), sensor fusion (Wang et al. 2019) and extended Kalman or particle filters to overcome noisy measurements and improve accuracy. One of the drawbacks of such techniques is their complexity and high calculation effort, such that the required computing power can either not be provided on smartphones or is only feasible under massive energy consumption.

As shown in this section, some articles in this area only consider single technologies and methods but not hybridization (of methods or IO technologies) and IO transitions. Most papers also do not show an interest in presenting the invented datamodel for localization systems.

This work catches up with this issue and examines indoor-/outdoor transition and positioning strategies as well as relevant datamodels with the aim to provide proposals for various system requirements.

4 Technical Background/Technology Assessment

This section focuses on the technical background and theoretical foundations for I/O positioning systems. Advantages and disadvantages of single solutions are worked out to build a knowledge basis for the implementation of an I/O navigation prototype. This prototype shall be able to navigate users at arbitrary locations outdoors to a predefined location indoors, in this case a room at the university campus. The transition between indoor and outdoor positioning shall be as smooth and user-friendly as possible.

To fulfil this task, the system needs several components such as at least one indoor and one outdoor positioning technology, localization methods, an underlying data model and a transition strategy for positioning technologies. Representatives of those components are presented in the following and then evaluated at the end of this chapter wrt. their applicability. As this work focuses on the transition between outdoor and indoor navigation, for the prototype only one indoor and one outdoor technology is used. A combination of several technologies and methods would improve quality of positioning services (Patterson et al. 2003). Further system design considerations and decisions are part of the next chapter.

4.1 Positioning Methods

Localization methods can be used in combination with both indoor and outdoor technologies and form the algorithmical basis of every positioning system. Although GNSSs which uniquely make use of the ToA method, are the most promising solutions for outdoor positioning, the application of other methods outdoors is also conceivable and partially already in operation.

There exist several methods for position determination, such as *Proximity Detection*, *Dead-Reckoning*, the time-based methods *ToA* and *Round Trip Time of Flight (RToF)*, also refered to as *Trialateration*, *Fingerprinting*, *Map Matching* and *Particle Filters*. Their applicability depends on environmental properties and the required positioning accuracy.

Hint: The content of the following section 4.1 Positioning Methods *is extracted in reduced form from the author's last paper 'Indoor Localization - A Comparison of Different Methods and Approaches' (Schmucker 2019)*

Like depicted in Figure 4.1, there are three classes of methods: proximity detection, triangulation and scene analysis.

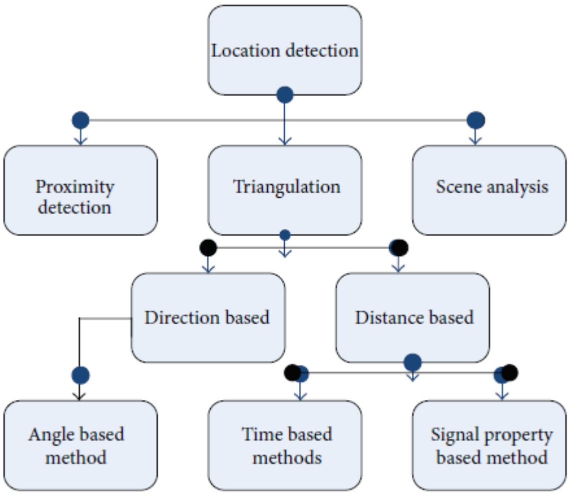

Abb. 4.1: An overview to indoor localization methods (Farid et al. 2013)

The later includes image- and video-based positioning, but also fingerprinting techniques that "first collect features (fingerprints) of a scene and then estimate the location of an object by matching online measurements with the closest a priori location fingerprints."(Liu et al. 2007b) Related to scene analysis techniques are map matching and particle filters. Triangulation can either be performed with the angulation or lateration methods. Proximity detection methods estimate a target's current position based on proximity to base stations or on movement patterns like Dead Reckoning (DR).

Proximity Detection

The proximity detection method is a very simple localization method where multiple detection sensors (like routers, Infrared (IR) or Radio Frequency Identification (RFID)) are used to mark proximity areas.

On detection, an object can be estimated to positioned in the detector's area. Whenever more than one sensor detects the same object, it is expected to be in the area of that sensor receiving the strongest signal. This process is also called *forwarding*. An illustration of this method can be seen in Figure 4.2.

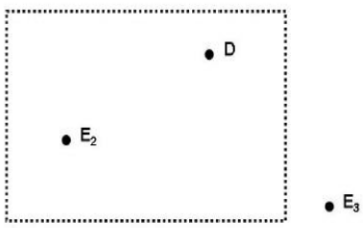

Abb. 4.2: The proximity detection method (Khudhair et al. 2016)

In case further or even global range is required, the cellular mobile Global System for Mobile Communications (GSM) network can be used to identify the radio station the device is allocated to (e.g. its cell-id). The observable is then expected to be in proximity to the radio station, hence in its cell. (Liu et al. 2007b, p.5) For this reason, this method is also called cell of origin or cell identification.

For both, indoor and outdoor localization, the method's accuracy highly depends on the "density of beacon point deployment and signal range"(Khudhair et al. 2016, p. 3). For improvement of accuracy, which is very limited in general, parameters like signal travel time can be included (see methods RSS, ToA and TDoA).

Triangulation

This family of methods is based on calculations on the properties of triangles. For location determination, the known position and distance of three or more base stations is used to locate an object. There are basically two derivations of triangulation, namely lateration, which subsumes time- and distance-based methods, and angulation.

There are several varieties of triangulation methods, e.g. angle-based, time-based and signal property-based methods (Farid et al. 2013).

4.1.0.1 Angulation - Angle-Based

In the angle, or Angle of Arrival (AoA)-based localization method, intersections of at least two lines of bearing are computed. Although angulation with two base stations could work in some cases, it is mostly implemented with three base stations to improve accuracy - then also called triangulation. (Farid et al. 2013) reveals that for "finding direction, it requires highly directional antennas or antenna arrays", which forms, despite the fact that they are very costly, a big issue for indoor localization. Interferences origining from entities (people, walls, other signals) in indoor environments distort measurement values and result in erroneous position calculation. In (one of the rare) cases the signals remain uninterferenced, this technique would bring excellent accuracy. Figure 4.3 shows basic operations with that method.

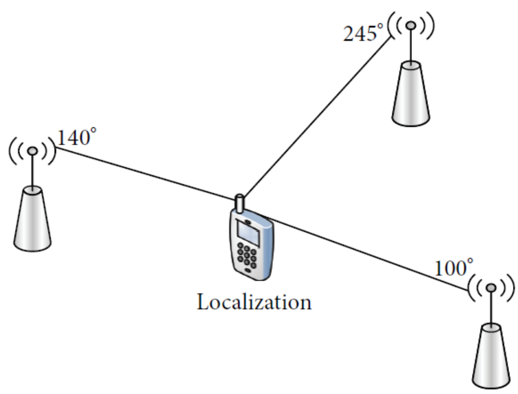

Abb. 4.3: The angle-based method(Farid et al. 2013)

4.1.0.2 Lateration - Time-Based

Lateration methods calculate ä position determined from distance measurements"(Farid et al. 2013), either relying on abolute or relative travel time. Unlike to angulation, lateration with two base stations does not bring any significance: like depiced in Figure 4.4, two hyperbolic shapes (here simplified as cycles) always have two intersection points such that an exact position can not be determined. Thus, lateration methods are implemented with three or more base stations, then refered to as trilateration or multilateration.
All methods share the assumption that electromagnetic waves propagate with the same speed as light (∼300.000 km/second).
There are four approaches:

- ToA:
  This method requires all nodes in the network (object under observation and receiving stations) to be highly synchronized at any time. The localization process starts at client side, where a timestamped signal is emitted and received by multiple base stations. The single distances d_i are computed using absolute travel time t and the assumed propagation speed c:
  Assume
  $$t_i = t_{receive_i} - t_{send}$$
  with t_{send} as sending and $t_{receive_i}$ as time of arrival at receiver station i, then
  $$d_i = t_i * c \ .$$
  Observing the equation, it can be seen why precise synchronization is an absolute requirement for this method: due to constant c being that high, even small discrepancies in time can result in a completely different distance.
  Due to time-based signals are not directed in any way, an object must be located anywhere on a circle around the receiver station, with a radius of the computed distance. The intersection of those circles is then the most likeliest position.

- Observed Time Difference of Arrival (OTDoA):
  This time-based method, also called multilateration, infers positions by using relative arrival times captured by at three time-synchronized base stations with known location. A signal's OTDOA at the base stations can also be converted to a distance:
  $$D = OTDOA * c$$
  For example, regarding two base stations BS1 and BS2, an OTDOA of +3.3 μs would indicate, that BS1 is 1000m closer than BS2. There are infinitely many points where the transmitter is exactly D entities closer to the one base station than to another. Combining those points results in a hyperbolic shape. The intersection of multiple hyperbolic curves then represents the most likeliest position of the transmitter.

- RToF:
  Similary to ToA, the RToF method uses absolute time to localize objects. The only difference is that the

RtoF method uses rount trip time, i.e. the time required to send a message from mobile transmitter to receiver station and back to transmitter, instead of only the time required to send and receive once. In case interferences occur only in one of the two transmissions, averaging can be applied, such that this method can supply a more accurate positioning result than ToA. Obviously, the above kinds of lateration could also be combined with RtoF method in order to improve positioning accuracy. Also, positioning calculations could then be done on client-side.

The lateration method is illustrated in Figure 4.4, on which the bespoke hyperbolic curves are depicted in green.

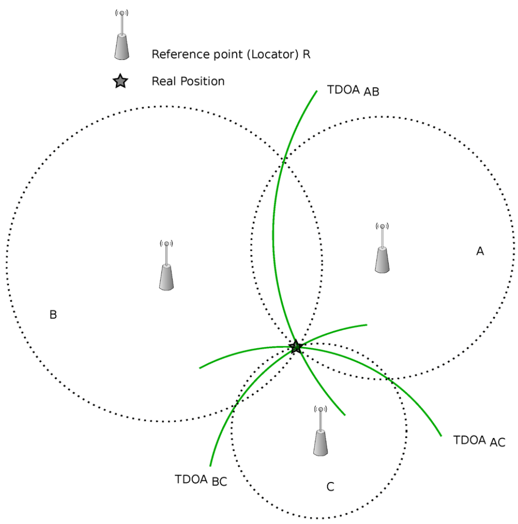

Abb. 4.4: The observed time difference of arrival method (Alarifi et al. 2016)

- Time Difference of Arrival (TDoA):
  TDoA makes use of at least two different technologies, or rather their different propagation times, and relative arrival times. In many systems, electromagnetic and ultrasound waves are used, such as in (Yang et al. 2012). A mobile client simultanously emmits signals using both technologies. At receiver side, the (relative) difference of arrival times and the actual phase difference are used to compute the distance. (Priyantha et al. 2001)

4.1.0.3 Signal Property-Based - Received Signal Strength Identification (RSSI)

Besides regarding time as mayor indicator for distance, the received signal strength indicator (RSSI) approach focuses on a technology's propagation model. The distance to a sending point can then be estimated based on inverse-square law:

$$intensity \sim \frac{1}{distance^2}$$

Assuming an isotropic source (like APs or routers), the intensity of the emitted signal is inversely proportional to the square of the distance. Figure 4.5 illustrates this relation: in nearby areas, the intensity (illustrated with red arrows and red dots in the single areas), is significantly bigger than in marginal areas.

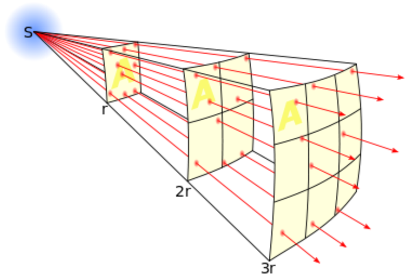

Abb. 4.5: The inverse square law used in signal property-based methods(*Image source:* o. J.a)

As in other trilateration techniques, the single distances from a mobile client to the base stations form circles around them, whose intersection finally represents the positioning result.

Dead Reckoning (DR)

Another very simple but widely used method is *Dead Reckoning*, where localization is "based on last determined position and incrementing that position based on known or estimated speeds over elapsed time"(Farid et al. 2013). The result can thus only result in an estimation of the current position. Furthermore, ïnaccuracy of the process is cumulative, so the deviation in the position fix grows with time"(Farid et al. 2013). DR is also implemented in inertial navigation systems and is employed when GPS signal is lost, e.g. in tunnels.

For indoor purposes, according to (Pratama et al. o. J.), accelerometer sensors in smartphones or attached sensors modules can be utilized to obtain the travelled distance, where distance estimation is then based on steps detected and the direction obtained by the magnetic sensor. Besides this orientation projection, the overall localization process includes "filtering, step detection and step length estimation"(Pratama et al. o. J.). As gravity and noise interferences accelerometer measurements, the values are filtered using physical constants and formulas, which will not be explained further here but can be looked up at (Pratama et al. o. J., p.3). Step detection can either be performed with zero-crossing or peak detection, whereas the later uses local maxima of the curve emerging from accelerometer measurement values. Unfiltered, all maximas were considered as steps, such that thresholds for further filtering are applied: all values under a certain threshold and also those not fitting in a typical time intervals of steps while walking (120ms – 400ms, according to (Pratama et al. o. J.)) are rejected.

An exemplary measurement result with three valid steps detected (depicted in blue) and the threshold (in red) is illustrated in Figure 4.6.

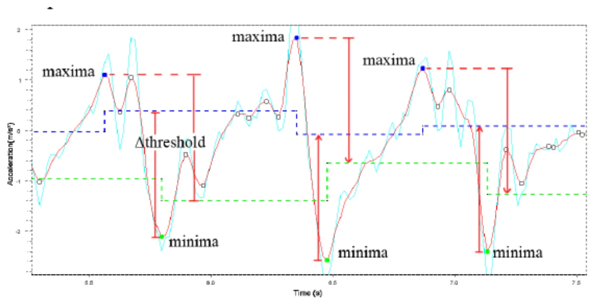

Abb. 4.6: An exemplary DR measurement result with three steps detected (Pratama et al. o. J.)

Zero-cross detection announces a step whenever the x-axis is crossed within a typical time interval (see peak detection). Obviously, this process is very errorprone, especially when step-size or -interval change.

Last step in the process is step length estimation. Besides some dynamic methods, which can be looked up in (Pratama et al. o. J.), the static approach uses a person's height and a gender-specific constant:

$$stepSize = height * k$$

with "k equal to 0.415 for men and 0.413 for women."(Pratama et al. o. J.)

Map Matching

The Map Matching method makes use of a building's roadmap and (mostly noisy) localization samples, such that "building information provide a logical threshold to bound the solution into a certain region"(Attia et al. 2014). Thus, a system is able to return valid positions somewhere on the floor plan, even if the real measurement values diverge.

Map matching positioning samples mostly origin from WLAN signal strength values. The required electronic map can either be designed in a floor plan builder or generated automatically using crowd-sourced data samples.

There is a variety of applicable algorithms and data models such as graph- and link-based or room- and floor 3D-models. In the link-based approach, an ID and respective coordinates are assigned to each room. Map matching algorithms typically origin from the following types: 1) geometrical, where the shortest distance from a measurement point to a trajectory is calculated, 2) topological, where links, i.e. the floors own attributes like "floor number, proximity of a height change access, stairs, and all possible links diverged from its start and destination nodes"(Attia et al. 2014), 3) probabilistic, where a target's direction and speed is considered (i.e. DR) and 4) sophisticated methods using fuzzy logic, belief theory and Bayesian networks. Figure 4.7 shows a typical map matching navigation result with floorplan in black, measurement values in blue and map matched path in red.

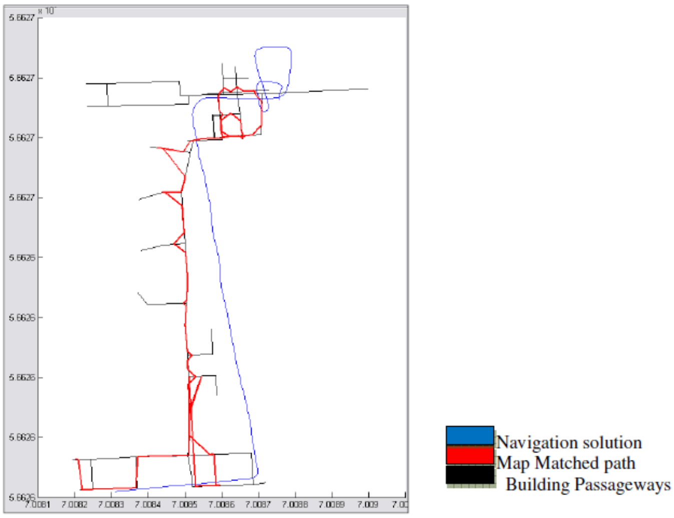

Abb. 4.7: A typical map matching navigation result (Attia et al. 2014)

Fingerprinting

Fingerprinting can be seen as an extended version of the RSSI method, where a database and further positioning algorithms are added to improve accuracy. The overall process is splitted into two parts, namely training (calibration, offline) and tracking (localization, online) phase. The basic idea in the training phase is to "collect features of the scene (fingerprint) from the surrounding signatures at every location in the areas of interest and then build a fingerprint database"(Farid et al. 2013). In the tracking phase, a mobile client requests all base stations in its region to reply to its positioning query. The strengths of signals received by the client can then be compared with those in the database, resulting in the closest known position.

A mobile device could for example collect WLAN signal strengths from different Access Point (AP)s at every point of interest in a building and safe them together with actual location in a database. During online phase, current RSSI measurements can be mapped to known locations.
The overall process is illustrated in Figure 4.8.

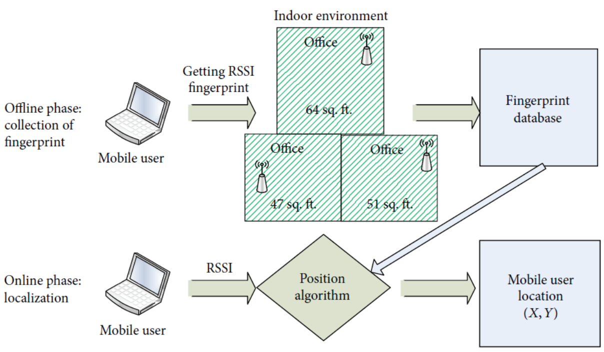

Abb. 4.8: The location fingerprinting process (Farid et al. 2013)

Particel Filters

Particel filter method represents a class of hybrid methods combining the advantages of DR and Map Matching with sequential Monte Carlo approximations.(Davidson et al. o. J.)
The idea is to use randomly distributed samples - so-called *particles* to represent all possible positions of an object. Based on any available information, e.g., pre-configured floorplans, motion profiles and laws of physics (e.g., targets move away with a well-known speed throgh buildings and can not go through walls, etc.), a *weight* or probability is assigned to each particle. The next step is *resampling*: Whereas unlikely particles are removed, those with enough weight are re-distributed according to their density and weight. The resampled particle set is then relocated based on the motion model. In order to eliminate noise in the resulting set, the particles are again distributed among the now likeliest places (see step *Diffuse* in Figure 4.9) and finally weighted based on available DR (and possibly additional) positioning information. That location showing the highest probability density is then the particle filtering positioning result.

The overall particle filtering process including subprocesses is depicted in Figure 4.9.

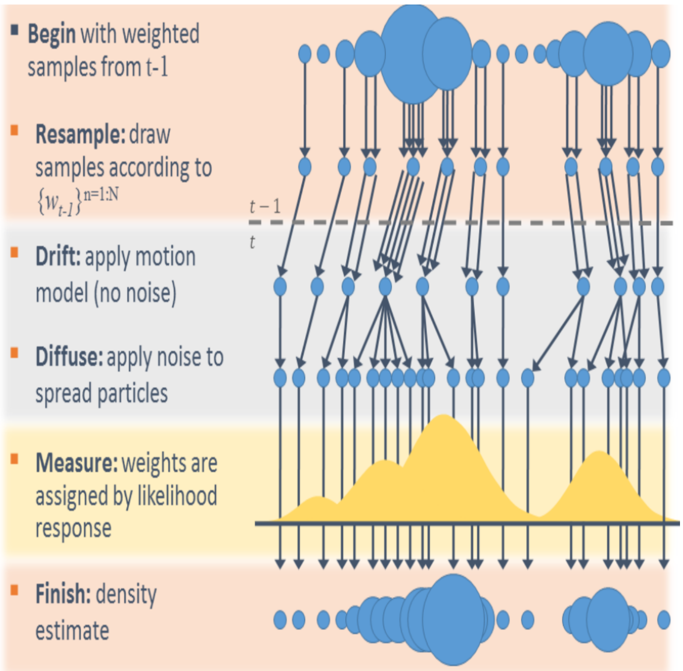

Abb. 4.9: The processes involved in particle filtering (*Image source:* o. J.b)

4.2 Outdoor Positioning

This section is about the outdoor positioning technologies GNSS, WiMAX and cellular networks. GNSSs are on the rise and only global solution, but other technologies are also capable to provide localization services in limited outdoor areas. Although their main drawback, limited coverage, makes them hardly applicable in a global context. Besides that a globally networked installation fails due to its inapplicability in many places at earth (oceans, high mountains or deep valleys), also the required density and amount of base stations to reach comparable coverage and accuracy to GNSSs is technically and monetarily inconceivable.

GNSS

Global Navigation Satellite Systems provide positioning functionalities with global range for navigation, emergency rescue and other applications of public and military use to land, air and water.

As already briefly outlined in Section 1, the only fully operational and most popular GNSS is NAVSTAR (Navigational Satellite Timing and Ranging) Global Positioning System (GPS). It was developed by the U.S. DoD since 1973 until being fully operational in 1995. Besides GPS, there are various other GNSS approaches, such as China's Beidou (Kompass), India's IRNSS (Indian Regional Navigation Satellite System) Russia's Glonass and E.U.'s Galileo. (Link 2018)

GPS is applied in social, economic and scientific areas. Typical applications range "from spacecraft navigation and geodesy, to land surveying and mapping, to precise agriculture and vehicle fleet management, to emergency services and professional navigation, to mass market applications such as in mobile devices (cars and smartphones) and location based services (LBS)."(Li et al. 2010)

The common concept of all GNSSs are interconnected, clock-synchronized satellites (mostly more than 20) and ground stations such that trilateration (ToA) with a radio signals (GPS L1 signals: 1575,42 MHz) and calculations respecting the doppler effect are applicable. By that, an accuracy of 2-500m can be achieved.

General information about exact satellite orbits, statuses, clock deviations and atmospheric data is summarized under the GPS Almanach. Clients with corresponding GPS receiver can download this Almanach and start positioning. The Almanach is mostly receiced over the GSM network, as downloads directly from the satellite might take several minutes and is thus not applicable.

Whereby other trilateration methods calculate positions using distances to three base stations, GPS uses the Time-of-Arrival method which requires clock synchronization in all entities and thus four satellites: As the clocks on receivers like smartphones might differ form those on satellites, a fourth satellite is required to deal with that synchronization task. (Maghdid 2015, p. 58)

The geomatric position of used satellites is also an important factor: if satellites rely closed to each other, the intersection line is larger and positioning more imprecise (see ToA method section). Thus, in order to inform about such positioning deteriorations, every GPS signal carries the so-called dilutions of precision (DOP) which is calculated wrt. geometric, horizontal and vertical orientation. Values ranging from 1 to 6 indicate good precision, signals with DOP higher than 10 are basically not evaluable.

Every satellite emitts a radio signal including timestamp and individual code, which can then be received by e.g. smartphones or car navigation systems. All positioning calculations are thus performed on client-side. In order to be synchronized and precise, satellites are mostly equipped with multiple, frequently updated atomic clocks, such as Galileo satellites with two passive hydrogen maser clocks (deviation of 1s/3 mio years) and, alternatively, two rubidium atomic clocks (1s/760.000 years).

Accuracy and functioning of GNSSs has also its limits and is susceptible to faults. Occuring issues are clock deviations, cheap (inaccurate) GNSS receivers on smartphones or navigation systems, ionospheric disturbances leading to angle change of signals, change of satellite constellation (less/other satellites available), signal reflection and multipath issues.

A Satellite-based augmentation systems (SBAS), such as the European Geostationary Nevigation Overlay Service (EGNOS) can be used to improve accuracy: reference stations deployed across the area of interest report all measured GNSS errors to base stations, where errors are collected, processed and send to geostationary satellites. The satellites then broadcast the augmentation information as overlay to the origninal GNSS message. (*What is EGNOS?* 2018) Inside and around buildings GNSS signals are not or rarely available. (Eissfeller et al. 2005) state that in houses there is an attenuation of 5-15dB (4-20 fold), in offices around 30dB (1000 fold) and in underground parking over 30dB. They conclude that signal acquisition through concrete walls with 25dB attenuation and more is not possible without further assistence.

WiMAX

This technology is part of the IEEE 802.16 protocol family and like WLAN (IEEE 802.11) a radio technology. Unlike WLAN, WiMAX (Worldwide Interoperability for Microwave Access) can operate at "higher speeds, over greater distances and for a greater number of users"(Brain und Grabianowski 2004).

In particular, this technology works with partially interconnected base stations which are connected to the internet via high bandwidth, wired connection and are wireless accessible by receivers within a cell radius of three to ten kilometers (WiMAX Forum 2019).

The overall functioning is illustrated in Figure 4.10.

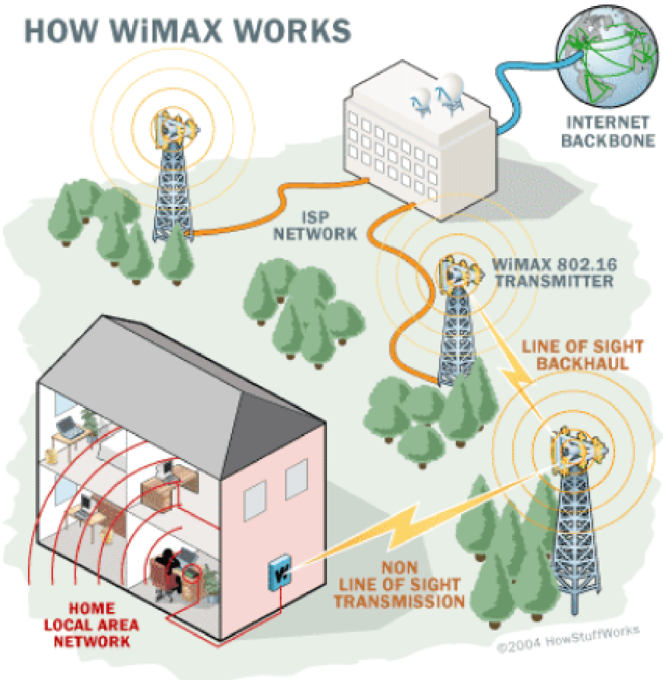

Abb. 4.10: How WiMAX works (Brain und Grabianowski 2004)

There are two modes of operation: Line-of-sight and non-line-of-sight, whereas the former sends at higher frequencies (licenced 2-11 GHz and unlicenced 10-66 GHz) and is thus more stable and offers lots more bandwidth (Brain und Grabianowski 2004). By that, wireless internet access in rural areas and small cities can be provided, and can even deep indoors be accessed, e.g. with receiver stations on buildings acting like as repeaters.

Cellular Networks/GSM

Cellular networks such as mobile GSM networks for telecommunication are organized in cells of different size. In general, positioning in those cells is done with distance-based methods and is thus, due to the base stations' high distance, not very percise (25-100m whenever there is good coverage). Cellular-based positioning is also possible in combination with triangulation and high-directional antennas.

Nevertheless, researchers found that accuracy with GSM could also be improved to up to 2.5m indoors using wide signal-strength fingerprints of up to "29 additional GSM channels, most of which are strong enough to be detected but too weak to be used for efficient communication."(Liu et al. 2007a)

4.3 Indoor Positioning

This subsection presents various indoor positioning technologies and methods. Whereas outdoor positioning typically relies GNSSs, indoors other technologies, such as WLAN, Bluetooth, RFID and Ultrasound can provide much higher accuracy.

WLAN

Wireless Local Area Network (WLAN) (IEEE 802.11) was standardized in 1997 and is the most popular midrange local wireless networking technology. Its infrastructure, i.e. routers and APs, is usually provided in most buildings. WLAN devices operate at 11, 54, or 108 Mbps and have a typical range of 50-100m.

The most applied method with WLAN are signal-strength-based methods, such as RSSI and fingerprinting. Time- and distance-based methods are "less common in WLAN due to the complexity of time delay and angular measurements"(Khudhair et al. 2016). The accuracy of positioning systems using RSS can vary from "3 to 30m, with an update rate of a few seconds"(Liu et al. 2007a). However, most systems can provide accuracy of less than 5m (Maghdid und Lami 2016), such as RADAR which was invented by a Microsoft research group in 2000 and provides 2-3m accuracy using “signal strength and signal-to-noise ratio with the triangulation location technique"(Gu et al. 2009).

Bluetooth

Bluetooth (IEEE 802.15) is a wireless Wireless Personal Area Network (WPAN) standard operating at the 2.4 GHz ISM band. It offers "high security, low cost, low power and small size"(Farid et al. 2013) but has, compared to WLAN, also a smaller range of 10m to 15m and lower bit rates of 1 Mbps (Liu et al. 2007a). Localization with Bluetooth works with small transceivers, called tags, which have unique IDs that can be used for localization.

The main drawback of Bluetooth-based positioning is the lengthy positioning process which requires Bluetooth (BT) device discovery to be processed. As this step takes several seconds (10-30), it is unsuitable for real-time approaches (Farid et al. 2013). Also pre-installation of tags in various points of interest is required. Nevertheless, indoor navigation with Bluetooth tags is a lightwight alternative to WLAN or Ultrasound.

RFID

Localization with the RFID technology works with wearable tags which emit or reflect radio waves. Scanning devices are organized in a network, whereas a single device can cover an area of several meters. RFID readers can read emitted data from tags which are available in two variants, active or passive. The former are battery-driven transceivers and are mostly applied in combination with proximity detection due to range limitations. But there are also tags which can transmit signals over tens of meters (Liu et al. 2007a), such there is basically any positioning method applicable. The RFID technology offers three different radio frequencies: low (125-134 kHz), high (13.56 MHz) and ultra-high frequency (860-960 MHz) and can thus (at lower frequencies) successfully operate at non-line-of-sight environments (Khudhair et al. 2016).

Passive tags act as replacement for traditional bar-code technology. They have no battery and can thus only "reflect the RF signal transmitted to them from a reader and add information by modulating the reflected signal"(Liu et al. 2007a).

The main drawback of the RFID technology is its limited range, the need for a tag to be carried along and the required installation of receivers.

Ultrasound

Another positioning technology is Ultrasound, which is inspired by the orientation system of bats. It works with sound waves of frequencies higher than 16kHz which can not penetrate walls, i.e. positioning requires line-of-sight and obstacles can cause reflections. Among advanced approaches, a wearable tag is still required. Ultrasound tags periodically emit signals which can be received at multiple stations.

Besides the remarkable positioning accuracy of several centimeters and a high sampling rate of 50 samples per second there is a dense network of sensors required and a single sensor can cover only a small area of approximately 1 m^2 (Gu et al. 2009). The Active Bat positioning system, for example, which was invented by researchers at AT&T Cambridge uses multilateration and 720 receivers fixed on the ceiling to cover an area of 1000 m^2. By that it is able to "determine the positions of up to 75 objects each second, accurate to around 3cm in three dimensions"(Ward et al. 2002).

4.4 Datamodels for Indoor Localization

The data model is an essential part of transitional navigation systems, as it combines properties of both indoor and outdoor positioning. For example, GNSSs can only provide geometric location information, i.e. altitude and values in World Geodetic System 1984 (WGS84) format (longitude, latitude). In contrast to that, localization inside buildings is oriented towards possibly hierarchical, symbolic cellspaces, i.e. rooms, corridors and floors. The model has also to consider navigation requirements such as distance, expected speed between locations, and the topological relations *connected-to* and spatial containment.

There exist geometric and symbolic models. A geometric model focuses on the shape of locations using points and polygons. Symbolic data models could be designed with set-based, hierarchical, graph-based or combined approaches.

In a *set-based* model all symbolic locations are organized in a set. Special locations, such as all rooms in a floors, can be modelled as subsets. In this approach, only qualitative distances can be used and there is no possibility to model relations, so it is not very useful for navigation.

Hierarchical approaches model buildings hierarchically in sets according to the components' spatial relation. For example, buildings contain sets of floors and floors contains a sets of rooms. There are still no real distances or connected-to relations included.

Graph-based models express connected-to relations between symbolic cellspaces with edges. They can also be weighted in order to express distances between locations. Based on the number of hops and their weight, a distance function and also range queries are applicable (Becker und Dürr 2005).

Combining different models improves capacity, for example adding range-based sets to the graph-based approach allows as well range queries as connected-to relations and calculation of distances.

As indicated before, for the prototype a hybrid location model is required which can handle both gemetric and symbolic locations. There are two approaches: the subspaces or the partial subspaces approach. Whereas the former assignes a geometric location to *every* symbolic location, the later does so only for some locations, for example only for a building. The subspaces approach makes it possible to integrate symbolic cellspaces into geometric maps, whereby also geometric range queries are applicable (Becker und Dürr 2005) (e.g. query for restaurants or libraries within a radius of n kilometers).

4.5 Indoor-/Outdoor Transition Solutions

There are various strategies for switching between positioning technologies. For reasons of simplicity, in this section GPS is assumed to be used for outdoor navigation and WLAN indoors. Of course the algorithms could also be applied to other techologies.

The most obvious and less technical strategy is to let the user decide. As pedestrians who navigate with smartphones through the city need to look at their smartphone anyway, the UI could also have interactive elements for I/O transition. For example, a hit on a respective button in the user interface (UI) could trigger a switching of technologies in the system.

(Hansen et al. 2009) presents various strategies for I/O transitions.
Two possible strategies are to always *prefer GPS over WLAN* or vice versa. The additional technology is only used if the main positioning technology detects no signal within a defined time interval (e.g. 5 seconds). In case GPS is prefered, this leads to good outdoor positioning accuracy and an user's position could be detected successfully in the presence of windows. However, GPS positioning indoors is either not very good or not possible. It is thus more likely that a received GPS signal indoors interrupts reliable WLAN positioning. The other option, *always prefer WLAN over GPS*, leads to good indoor accuracy but I/O transitions could not or way too late be detected, as WLAN signals can be received outdoors even tens of meters away from the buildings.
Another strategy, *prefer GPS or WLAN until signal loss*, aims to solve the problem of bad GPS signals indoors or bad WLAN signals outdoors. Although the transition between outdoors and indoors could be successfully detected due to GPS signal loss, going back outdoors would cause the same detection delay than the prefer-WLAN approach, which makes this strategy also not applicable for seamless I/O navigation.
According to (Hansen et al. 2009), the most promising strategy is to *prefer GPS upon continuous readings*, which

aims at solving the problem of bad WLAN positioning being further used outdoors. In this solution GPS is used when a signal is received every second for the last 5 seconds, if not, WLAN positioning is switched on.

(Kim et al. 2012) propose a more advanced and very precise handover strategy. They found that while the äverage SNR dropped from 30 dB to lower than 20 dB [..](,) satellites at an elevation of 30–90 degrees showed a dip in SNR changes [..] (while others) showed no noticeable SNR drop"(Kim et al. 2012, p. 6). That means the use of an average value of all received satellites could impair transition detection. The authors thus recommend to use only satellites of high altitude for outdoor-indoor transitions. Furthermore, the authors found that SNR values are not adequate for handover from indoor to outdoor, as the SNR indoors in presence of windows or glass roofs is comparable to the SNR outdoors. In fact, their experiments show that GPS accuracy is a better indicator for indoor-outdoor transition: accuracy indoors varies from 20-50m, even in presence of windows or glass roofs, whereas accuracy outdoors is around 10m. The comparison of SNR and GPS accuracy in indoor places with outdoors is shown in Figure 4.11.

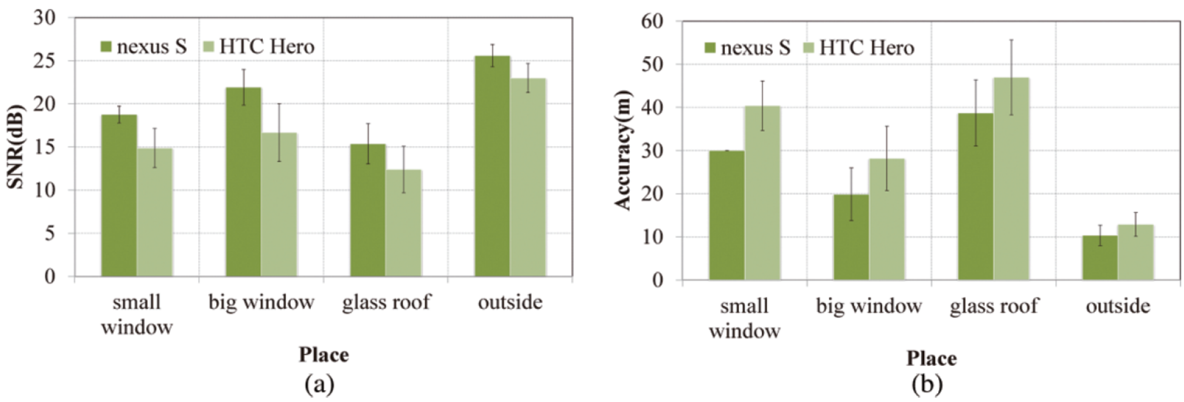

Abb. 4.11: Comparison of (a) SNR and (b) GPS accuracy in the indoor places with those in outdoor environment. (Kim et al. 2012)

4.6 Assessment and Conclusion

This chapter presented various methods, technologies, data models and transition solutions. Recent works ((Khudhair et al. 2016); (Farid et al. 2013); (Kim et al. 2012)) already evaluated the bespoke components. The results are rehashed in the following.

Methods

(Farid et al. 2013) evaluated the bespoke methods under the parameters accuracy, coverage, line of sight (LOS) requirement, multipath affection and cost. The evaluation table is shown in Figure 4.12.

Method	Measurement type	Indoor accuracy	Coverage	Line of sight (LOS)/nonline-of sight (NLOS)	Affected by multipath	Cost	Notes
Proximity	Signal type	Low to high	Good	Both	No	Low	(1) Accuracy can be improved by using additional antenna. However, it will increase the cost. (2) Accuracy is on the order of the size of the cells.
Direction (AoA)	Angle of arrival	Medium	Good (Multipath issues)	LOS	Yes	High	(1) Accuracy depends on the antenna's angular properties. (2) Location of antenna must be specified.
Time (ToA, TDoA)	Time difference of arrival	High	Good (Multipath issues)	LOS	Yes	High	(1) Time synchronization needs. (2) Location of antenna must be specified.
Fingerprinting	Received signal strength	High	Good	Both	No	Medium	(1) Need heavy calibration. (2) Location of antenna is not necessary.
Dead reckoning	Acceleration, velocity	Low to medium	Good	NLOS	Yes	Low	Inaccuracy of the process is cumulative, so the deviation in the position fix grows with time.
Map matching	An algorithm based on algorithms based on projection and pattern recognition	Medium	Medium (indoor) Good (outdoor)	NLOS	Yes	Medium	(1) Map matching purely focus on algorithms and not fully on position methods, coordinate transformation, and geocoding. (2) Using pattern recognition, high computing complex and poor real time issue occur.

Abb. 4.12: Evaluation of positioning methods wrt. accuracy, coverage, multipath affection and cost (Farid et al. 2013)

Angle-based and distance-based methods require LOS, which is typically not given inside buildings. However, in lofts and big halls those methods are applicable but interconnected with high costs.
An advantage of fingerprinting is its low cost: it does "not require specialized hardware in either the mobile device or the receiving end nor is no time synchronization necessary between the stations."(Farid et al. 2013) On the other hand, the method has its drawbacks in the heavy calibration process: Ïn order to eliminate the deviation of attenuation in the signal, RSS values are to be averaged over a certain time interval up to several minutes at each fingerprint location"(Farid et al. 2013). Infrastructural changes, for instance (re-) moving of objects and APs entail modifications in the RSSI database, such that the calibration process must be repeated periodically to keep the system up-to-date.
Advanced methods, such as particle filters, Kalman filters and neural networks are complex to setup and aim at improving accuracy more and more, which is basicall not required for simple navigation tasks. In contrast to them, Dead-Reckoning can provide coverage of a large building even with few sensors. In case cost or simplicity is required this method fits best.

Outdoor positioning

For outdoor positioning, a network of satellites is the only way to cover global range, as for example networked base stations would require partially infeasible installation of transceivers anywhere on earth (e.g. in oceans, mountains, dells and gorges etc.) to provide equal coverage. Local I/O navigation systems of limited range could also be implemented with other solutions such as WiMAX or cellular networks

Indoor positioning

The choice of appropriate indoor positioning technology/technologies depend/s on the project's requirements, existing digital infrastructure and resources. If high accuracy is required, Ultrasound positioning might be the right choice. If costs are to be safed, existing infrastructure (WLAN) and smartphones or cheap RFID tags can be used. Compared to BT, RFID positioning is faster and thus more applicable for real-time applications. (Farid et al. 2013) evaluated the bespoke indoor postioning technologies wrt. the parameters accracy, coverage, power consumption and cost. The table is shown in Figure 4.13.

System	Accuracy	Principles used for localization	Coverage	Power consumption	Cost	Remarks
GPS	6 m–10 m	ToA	Good outdoor Poor indoor	Very high	High	(1) Satellite based Positioning. (2) Processing time and computation is slow.
Infrared	1 m-2 m	Proximity, ToA	Good Indoor	Low	Medium	(1) Short range detection. (2) No invasion of multipath.
WiFi	1 m–5 m	Proximity, ToA, TDoA, RSSI Fingerprinting, and RSSI theoretical propagation model	Building level (outdoor/indoor)	High	Low	(1) Infrastructure available everywhere. (2) Initial deployment is expensive. (3) Multipath susceptible slightly.
Ultrasound	3 cm–1 m	ToA, AoA	Indoor	Low	Medium	(1) Sensitive to environmental. (2) No invasion of multipath.
RFID	1-2 m	Proximity, TOA, RSSI theoretical propagation model	Indoor	Low	Low	(1) Real time location system. (2) Response time is high. (3) Manual programming.
Bluetooth	2 m–5 m	RSSI fingerprinting and RSSI theoretical propagation model	Indoor	Low	High	(1) Data transfer speed is high. (2) Limitation in mobility.

Abb. 4.13: Evaluation of positioning technologies wrt. accuracy, coverage, power consumption and cost (Farid et al. 2013)

Datamodel

For an I/O navigation system obviously a hybrid (geometric and symbolic) model is required. An evaluation of symbolic models can be found in Figure 4.14. Graph-based or combined symbolic models are the most promising for navigation due to the support of distance and connected-to relation. The implementation of the final data model is presented in the following chapter.

symbolic model type	**supported coordinate types**	**modeling effort**[1]	**distance support**	**“connected to” relation support**	**containment relation support**
set-based	symbolic	high	limited	yes	good
hierarchical	symbolic	low to medium	very limited	no	good
graph-based	symbolic	low to medium	good to very good	yes	limited
combined (set-based & graph-based)	symbolic	medium	good to very good	yes	good

Abb. 4.14: Evaluation of symbolic location models(Becker und Dürr 2005)

Transition solution

The most reliable transition solution is to ask the users, as they can basically not fail. As already mentioned in the respective section, the only applicable technical strategies are *prefer GPS upon continuous readings* or (Kim et al. 2012)’s approach with SNR drop of satellites at elevation of 30-90 degrees for outdoor/indoor transition and significant GPS accuracy rise for indoor/outdoor transition.

Also a combination of different approaches is conceivable, e.g. a navigation system could ask the user whether the detected transition is valid.

5 System Design und Implementation

This chapter aims at the documentation of objectives and requirements for the navigation prototype. System design decisions, such as the choice of technologies, methods, the datamodel and transition strategy, but also decisions wrt. the implementation, e.g. the used software libraries, system architecture and appearance.

5.1 Objective and Requirements

The navigation prototype shall navigate persons from locations outdoors to a predefined indoor location. It shall also provide the possibility to add new locations (cellspaces) to the model or reconfigure existing structures. The prototype shall as simple as possible; it shall use android smartphones and existing infrastructure. In the case of the test area, the university campus at the Erba, there are Bluetooth beacons at the entrance and WLAN APs all over the building.

5.2 System Design Decisions

Technologies and Methods

Datamodel

IO and OI Transition

Software

5.3 Implementation

Programm Logic

Appearance

6 Evaluation

6.0.1 Positioning and Navigation Results

6.0.2 Maybe: Users Experience

7 Conclusion and Future Work

Anhang

Weitere Informationen werden im Anhang abgedruckt (z. B. Listings). Für die Überschriften wird der Gliederungs- und Nummerierungslose section*-Befehl verwendet. Die Nummerierung erfolgt dann mittels Großbuchstaben.

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Erklärung

Ich erkläre hiermit gemäß § ### Abs. ### APO, dass ich die vorstehende ###arbeit selbst-ständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe.

Ort, Datum Unterschrift