Frameworks for Hybrid Positioning

Auditorium G3

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Tracking Framework for Heterogeneous Sensor Sources

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1 Summary
We describe a scale-independent (space and time) tracking framework for moving items (objects, animals, humans). Different sizes and characteristics of the items are considered as well as different tracking environments / contexts. This work enables the integration and processing of spatial temporal data obtained by heterogeneous sensor sources. The framework does not rely upon one tracking / positioning technology but instead considers the combination of several technologies to calculate the best positioning result. The data is processed in a core and provided by different internal and external interfaces. The framework consists of different applications. One application is used for visualization of the context and tracked items. Other applications analyze large amounts of data e.g. via machine learning techniques. Two different use cases (laboratory mice / service technicians) were used to develop the framework.

2 Introduction
Tracking and localization technologies are used to gather spatial temporal data of moving items to obtain information about behavior or to support them with location-based information. Problem: Tracked items and/or their environments are equipped with sensors to get spatial temporal data. Depending upon the tracked items, tracking environments and the project in question, many different technologies may be in use simultaneously. This leads to a variety of sensors and spatial temporal data without a standardized format, processing or analysis. Motivation: To enable the integration and combination of heterogeneous tracking data so that a useful synthesis of the information involved can be obtained. Prototypical industrial applications include assisting in work flows and providing information. Furthermore, this work enables interdisciplinary scientific tools for the support of experimental scientists by allowing them to collect and process large quantities of moving item data. Background: The idea is based on the tracking of laboratory mice [6] (1st use case) via RFID-technology, weight scale and camera. The aim is to find movement and behavior patterns. In the second use case, service technicians are tracked indoor in an industrial environment via RFID, UWB (Ubisense²), WiFi fingerprints and keystroke sensors to support them in their maintenance work.

3 Related Work
Many applications focus on tracking and localization [3]: AAMPL [7] or Redpin [2] combine different technologies in mobile devices to get precise locations. Opportunistic localization using smart phones with WiFi, GSM, GPS and accelerometers has been developed [8]. The StarTrack framework provides a set of operations to ease the development and deployment of track-based applications [1]. The EnTracked system is based on estimation and prediction of system conditions and mobility to minimize energy consumption and optimize robustness [5]. The location stack is a 6-layer design framework that establishes clearly defined abstractions, building from data to context aware computing [4]. Problems of scalability to large environments and uncertainty due to environmental symmetry have also been considered [9].

² Ubisense homepage latest update 2010-06-02: http://www.ubisense.net/en
4 Implementation

The concept behind the framework is divided into 4 parts, 3 of them are already implemented:

Architecture of the tracking framework: The architecture of the framework consists of four different levels: sensor sources, databases, a processing core and various applications. The framework and its modules have different well-defined internal and external interfaces for the import and export of data. This architecture allows for the integration of different applications.

Modeling of the environment: It is possible to display 3D models of the environment with integrated sensors as one application. The required attributes for a scale invariant 3D modeling of sensors have been taken into consideration. They are used for the extension of a scene graph model with sensor nodes (VRML and Java 3D) and to provide context information. The software allows for the positioning of sensors integrated in the environment to be changed, added or deleted by users. A tracking component allows the display of moving items in the environment.

Sensor fusion: Different levels of instrumentation of the environment and of the tracked items are taken into consideration. The modeling of heterogeneous data sources is necessary, as well as a standardized data model for the gathered data. This enables the framework to integrate various data sources (in this work RFID, UWB (Ubisense), WiFi fingerprinting and keystroke sensors are in use) into the application. The generalized data model determines which data is gathered and stored for positioning and tracking. The data model is easily extensible for more sensor sources. A database schema for the storage of the data has been designed as well as a schema for metadata of tracking technologies. Information about tracked objects can be obtained, and a format has been defined in which data are delivered for further analysis.

5 Conclusions and Outlook

This abstract proposes a tracking framework for moving items based upon heterogeneous data sources. A modular architecture and well defined interfaces make it possible to integrate different applications. In the future, different analysis modules will be established to obtain information: Machine learning will classify patterns without domain knowledge. An expert can add meaning to the patterns and they can be verified in the data. Similarity matching of attribute-labeled related graphs can be used to find predefined patterns (template graphs) in collected data (data graph). Template graphs (designed by a domain expert) can be used to define certain patterns. The aims are to find patterns in movement and behavior, classify observed items and to learn about individual items for the prediction of future behavior.

References

A Fusion Component for location management in mobile devices

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1. Summary and objectives

When indoors, several positioning technologies and systems may coexist (e.g. WiFi, Bluetooth, ZigBee, HF-RFID or bidi codes serving as beacons, cellular networks, etc.); each of them delivering its location estimates with a given accuracy at a given computational cost. In this paper, we describe a Mobile Fusion Component (MFC) -prepared to run in a mobile device- which aims at optimizing the selection of the available positioning systems by handling Quality-of-Location (QoL). The objective of the MFC is to offer the (best) location estimation which fulfills the consumer applications’ QoL needs, at the same time that minimizes resource consumption in the mobile device. Additionally, the MFC will provide seamless hand-off among location technologies and allow the user to establish his own privacy level for location data sharing. The MFC is part of a service-oriented mobile framework which offers ‘Context Acquisition Services anD Reasoning Algorithms’ (CASanDRA Mobile) to accelerate the development of context-aware applications.

2. A fusion algorithm for the MFC

The fusion algorithm for the MFC handles a Quality-of-Location [1] tuple which gathers information about the accuracy, availability and freshness of the location estimation provided by the available localization systems. ‘Accuracy’ refers to the mean error in the location estimate; ‘availability’ includes data from the electromagnetic visibility of relevant components of the localization infrastructure (e.g. number of available access points); finally, ‘freshness’ gathers the age of the estimate.

The MFC is dynamically configured to adjust its output to the consumer application’s requirements in terms of QoL. It compares the available location estimates from different sources, provides the application with the estimate that better fits its needs, and initiates or stops sensors to optimize resource consumption. The QoL tuple is provided by the available location systems, together with the location estimate. When different technologies are available, the MFC prioritizes those offering better accuracy whenever the ‘availability’ in terms of visible infrastructure is enough and the estimation is recent enough (‘freshness’) to fulfill the application’s needs.

In order to prototype our MFC, we consider that GPS and Cell-ID positioning are available when outdoors, and the latter also when indoors. Additionally, in closed environments (such as our laboratory), we assume that a deployment of WiFi and Bluetooth access points may be used to locate a mobile device [2] [3]. Moreover, some HF RFID tags will be situated in waypoints to be read from a mobile device. Each of these location systems may offer a given QoL, being the RFID method the most accurate (cms) but offering non-continuous location (event-based) (the full paper will describe the information flow to make the estimator’s choice). Another important issue to consider for the MFC is how to handle hand-offs between localization systems, always guaranteeing seamless transfer and resource consumption optimization. The ‘availability’ information in the QoL parameter is used to start additional sensors and to adjust periodic wake-up of slept sensors.
3. The Fusion Component as part of CASanDRA Mobile architecture.

The Mobile Fusion Component has been designed to work in the architecture of CASanDRA Mobile (Fig. 1) [4], to be offered as a standard feature for the framework. In brief, CASanDRA Mobile is composed by three building blocks - Acquisition Layer, Context Inference Layer and Core System. To implement the MFC, the Acquisition Layer needs to contain five sensors gathering data from communication interfaces (WiFi, Bluetooth, RFID, cellular networks and GPS), while the Context-Inference Layer will host six enablers which process raw data from sensors (localization algorithms). The Fusion Component’s intelligence is bundled in the Location Fusion Enabler (LFE). Additionally, the Core System will provide standard features for development, such as discovery and registry management of new elements. Both ‘sensors’ and ‘enablers’ publish their output data in the middleware through an event manager. Applications run on top of CASanDRA Mobile middleware.

4. Full paper contents

The full paper will go depth in the QoL concept, explaining the relevance of all its elements from the state-of-the-art. The fusion algorithm will be exemplified with cases of use, and the scalability feature will be clearly demonstrated. The performance of the component will be evaluated in terms of energy and memory consumption. Moreover, the full paper will include a detailed description of the MFC in CASanDRA Mobile.

References


Detecting Visibility in Heterogeneous Simulated Environments for Positioning Purposes

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Introduction

In previous research, we elaborated positioning systems based on heterogeneous data, such as GNSS and Wi-Fi, in order to calculate a 3D geographical position of mobile equipments. The results were quite interesting and encouraged us to study a more automatic positioning system with a transparent migration between different environments and equipments, without implementing any additional infrastructure. The aim of the paper is to describe the simulation system through the following steps:

• Simulating a 3D environment with equipments using different technologies of mobile communication.
• Elaborating mobility models towards these environments with a transparent transition between indoors and outdoors.
• Developing and studying the concept of visibility of the equipments using different mathematical and physical methods.
• Applying the previous steps towards a global positioning model taking advantage of telecommunication networks.

Approaches and methods

The term “visibility” means “detection of equipments for a given technology” in our approaches. The visibility is thus defined by different types of methods. For instance, the visibility of two equipments is achieved

• if they are in radio range. The coverage area could differ, according to the real environment.
• if the distance between them is lower than a given distance. This distance is calculated using the Friis Formula, depending on the environment.
• if the signal strength received is inferior to a predetermined threshold.
• by studying the time of signal arrival.
• if the number of hops between them is inferior to a threshold.

Today, equipments include multiple sensors, enabling them connections to different kinds of networks (the iPhone is a typical example). Our approach aims at evaluating the possibility to use these multiple data for positioning purposes. The proposed system was simulated with “Matlab”. The paper also gives details on the 3D description of our building and its environment. Then, we developed simulating modules for the different technologies: GPS, Wi-Fi, GSM and Bluetooth. These modules simulate the interactions between networks. The figure below presents the organization chart of the system.
In addition, we implemented different types of mobility models. Several 3D trajectories were designed in order to provide possible realistic situations of mobility. Three of them are described in the paper, using three mobility models: Gaussian, Sinusoidal and Parabolic. Note that the most common model is the Gaussian mobility one. However, it does not take into consideration the 3D changes. For our purposes, we thus elaborated an enhanced 3D Gaussian Mobility Model, fully described in the paper. This step also requires the preparation of different possible paths within buildings and the outdoor environment, simulating user mobility.

Then, we studied the detection of equipments along the paths previously described. Mobile terminals wishing to estimate their positions must then establish a “visibility data collection”. This collection is in the form of a database including all the equipments “seen” by the mobile terminal, as well as their attributes. The collection of the data is carried out for all the equipments. The final database is composed by all these data. This step is needed in order to establish a 3D representation of the geographic relations between equipments.

Results and future works

Simulation results are provided showing the impact of both the visibility pattern and the mobility model chosen on the global connectivity of a mobile terminal. This connectivity will be the foundation of the next step of the complete positioning model under development. Our future works are thus oriented towards the design of this second step of an automatic system, consisting in carrying out positioning algorithms and computations. Note that experimental data are also provided in order to discuss the validity of the various models (visibility and mobility).

Bibliography

Indoor Navigation Integration Platform for Firefighting Purposes

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1 Summary

In Germany about eighteen fire fighters loose their lives and more than 16,000 accidents happen on duty every year. One of the main problems is the orientation inside of complex buildings during operations especially if rooms are full of smoke. Route cards (printed on paper) to find fire detectors in buildings, are means, which often do not meet all requirements with regard to orientation and up-to-datedness. The aim of the presented research project “Context Sensitive Indoor-Emergency-Navigation-System for Complex Buildings” is to develop a solution for response and recovery to support rescuers in finding the shortest way within a complex building. Existing Building Information Models (BIM) are exported and used for displaying plans on mobile devices and for routing purposes. The Indoor Navigation is based on Wireless LAN, Ultra-Wide-Band and Radio Frequency Identification (RFID).

2 Introduction

Within the presented research project – which is funded by the German Federal Ministry of Transport, Building and Urban Affairs – a system using mobile devices and Real-Time Location Systems (RTLS) is developed. Graphs for route calculation generated from BIM-data (Building Information Model) guide fire fighters to the triggered fire detector. Additionally, important information, e. g., about sprinkler systems and dangerous goods, is displayed according to the position of the fire fighter within the building.

Related work in the area of Indoor-Navigation for fire fighters is done by [1], [2], [3] and [4]. These Projects focus mainly on one technology for Position sensing in emergency cases or on communication platforms. The approach presented in this abstract is based on the integration of different existing RTLS, integrating them in a Multi-method-Approach (MMA) and using BIM-Data to generate route graphs to guide fire fighters in buildings.

3 Claimed content in detail

Complex buildings like airports have many different environments and one single indoor positioning system does not work for all environments [5]. Due to this reason three systems have been chosen (see Figure 1). The MMA uses most of the existing technical infrastructure and requires additional navigation infrastructure only where necessary.

Ultra Wide Band (UWB) is appropriate for position sensing in halls. UWB is less influenced by metals and high humidity than other radio communication technologies and is therefore chosen for passenger and baggage halls.

Existing Wireless LAN networks can be used for position sensing in office areas. Wireless LAN is capable of being influenced by human beings walking by or by structural measures. On this account active RFID-tags are added.
Cellars and underground parkings are equipped with active RFID-Tags using the UHF-band (868 MHz). These tags are planned to be placed at central points. As bar antennas of active RFID-tags are small they are suitable for easy handling with mobile devices.

The Navigation Integration Platform administrates the actual positions of the fire fighters, the organizational structure including work schedules, route graphs for navigation and information on fire protection and building elements. The communication between the mobile devices and a web service of the Navigation Integration Platform can be established by WLAN, GPRS, UMTS or other possibilities for internet access.

4 Conclusion and remarks

A prototype of this system has been tested at the Institute of Numerical Methods and Informatics in Civil Engineering and at the Frankfurt Airport fire brigade training center. The results suggest a distinct improvement of orientation especially in smoke filled areas.

Tests of the different positioning systems (e. g. the Positioning Engine of Ekahau Inc.) showed that the accuracy is satisfactory for a detection of room accuracy. Experiments with active RFID-Tags from Identec Solutions showed that the signal-strength for calculation of distances is not precise enough. For this reason a new system from Identec Solutions (IntelliFind RTLS), which is based on time measurements of signal dispersion, is evaluated for different types of rooms at the moment. The results will be presented in the paper.

5 References

Combined Indoor and Outdoor DOP Criteria helpful to Position and Dimension

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1 Summary
The democratization of wireless networks, combined with the emergence of increasingly autonomous and efficient mobile devices, leads to new services. Positioning services become pervasive. The accuracy is the main criterion applied in the assessment of positioning systems. But high accuracy cannot be guaranteed because it depends on the environment where the user is located and on the positioning systems used (GNSS, GSM or Wi-Fi). To overcome this disadvantage, hybridization or combination is the best solution. In this paper, we first introduce the hybrid dilution of precision criteria that allows the free choice of the system for positioning in indoor and outdoor environments. Secondly and finally, we present an algorithm for combined positioning.

2 Introduction
Recently positioning has become an essential and integral feature of any system of mobility. Indeed, with the appearance of positioning capabilities, applications have emerged and multiplied. Mobile tracking and games are only two of many markets that can benefit from getting positioning information. The bulk supply of positioning is provided by wireless systems such as Global Navigation Satellite System (GNSS), GSM, Wi-Fi, sensors, etc. and their combinations.

Navigation satellite systems can guarantee an overall accuracy of about three meters when the user is in an open area or when the visibility of satellites provides good reception of more than four direct signals with the minimal noise. As soon as we move to a closed environment like an alley or building, the accuracy can decrease significantly. Environments that are well managed by networks, such as Wi-Fi that now prevail in the positioning indoor market, or GSM that has become a repository for assistance applications.

The characteristics and the performances of positioning technologies are defined by the three main dimensions: accuracy, coverage and cost.

The control of those criteria allows increasing the accuracy of the location, ensuring continuity of service and providing better quality of service. Indeed, we need a coefficient that quantifies the quality of these three criteria.

In this paper we first propose different dilution of precision criteria to estimate the accuracy of various positioning systems. Secondly we propose an algorithm for a combined positioning system based on GPS/Galileo and Wi-Fi. Finally, we use an evolutionary algorithm to optimise the combined DOP using the best terrestrial access point positions.
3 Contribution

In order to estimate the accuracy and the coverage in the GNSS domain we tend to use the Geometric Dilution Of Precision (GDOP) to measure the contribution of satellite’s geometry to positioning accuracy. With the emergence of other positioning systems such as GSM, researchers tried to adapt the GDOP to those systems extending it to a more Combined Dilution Of Precision. Gondran et al. provide a geometric indicator for WLAN planning which is based on the study of the covered area by a Basic Service Set (BSS), where a cell relative to an antenna is a set of pixels associated to a given base station.

The first factor we propose is dedicated to WLAN based on signal strength, the number of visible access points and their disposal to assess the accuracy of the computed position.

The second dilution of precision criterion that we present is dedicated to combined positioning systems (indoors and outdoors), which use visible satellites, access points and the visible BTS as indicators. The criterion is differing for hybrid positioning systems.

Unfortunately there is no efficient positioning solution for all situations and environments. For this reason, hybridization or combination appears to be the best solution to overcome the problems of service discontinuity or the lack of positioning in some environments.

Finally, we present a combined positioning system based on GPS and Wi-Fi. We propose to complement the GPS equation system using pseudorange measurements with Signal Strength measurements from 802.11 networks.

4 Results and conclusion

The results of experiments show that the GPS by itself does not guarantee good accuracy regardless of time and environment. Indeed, the values of the indicator reach infinite values when the receiver does not intercept non-noisy signals from GPS, while the contribution of additional data for this indicator leads to better values.

Where the mobile moves from an environment with perfect visibility of the satellites to another with no visible satellites, as it is the case when entering a building (assuming there is at least one visible access point), the hybrid/combined dilution of precision criterion, follows the environmental changes and allows estimating the quality of positioning in both, indoors and outdoors.

The other simulation with a combined positioning system, shows that the combination is more suitable for a positioning system with a high accuracy.

In this paper, we illustrate the trade-off that is to be made by choosing the proper positioning system and the features. First, we introduce the equivalent dilution of precision criterion for each system. Then, we present an algorithm for combined positioning. Finally, we analyse the results obtained from the simulation and the emulation of various scenarios.

5 Bibliography


Generic architectural framework for hybrid positioning

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1 Introduction

A myriad of positioning algorithms [1] have been developed in the last few years. A standalone solution generally does not offer sufficient accuracy in different environments (indoor/outdoor, different type of buildings…). We propose an easy-to-use generic positioning framework, which allows users to plug in a single or multiple positioning algorithms. Multiple algorithms can be active at the same time. A reasoner is used to select the algorithm giving the most accurate position or to intelligently combine the results of multiple algorithms into a more accurate position. Different wireless technologies can be used with this framework. We illustrate the usability of the framework by discussing a hybrid positioning solution.

2 Framework Architecture

The framework is developed in Java and consists of three parts: the positioning server, the web server and the client application.

1. Positioning Server - The positioning server has two functional blocks. The collector is responsible for the retrieval of positioning information gathered by the network infrastructure or mobile unit that is being located. The collector further incorporates an abstraction layer which hides the underlying technology (ZigBee, Wi-Fi, Bluetooth …) from the positioning server. In figure 1, two different approaches for positioning in wireless sensor networks are shown. On the left side, a mobile device broadcasts positioning beacons and the sink node of the WSN forwards the beacons to the collector. On the right side, the infrastructure nodes broadcast beacons and the mobile unit collects and forwards the beacons to the collector. The collector further passes the positioning information to the position calculator, which consists of pluggable positioning algorithms. Multiple positioning algorithms can be active at the same time. A reasoner is used to select the algorithm giving the most accurate position or to intelligently combine the results of multiple algorithms into a more accurate (hybrid) position. Map info can also be taken into account when calculating the position.

2. Web server - The web server can poll the positioning server for the user’s position.
3. **Client** - The client application can either run on a PDA or a central monitoring station. The client communicates with the web server through e.g. Wi-Fi or Ethernet.

Some advantages of the framework:

- Existing PDA applications can use position information by implementing a simple interface allowing the application to request a user’s position from the web server.
- Conversion of relative coordinates to GPS notation is possible. This implies that client applications developed to work outdoor (GPS), can easily use this framework.
- The user of the client application can pinpoint his correct location on the floor plan (for testing purposes). The application then calculates the difference between the estimated and the real position, thus allowing the user to evaluate the algorithm.

### 3 Positioning Solution

We’ve implemented two positioning algorithms, which are described below. The reasoner decides how the results of the different algorithms are combined. The decision making process of the reasoner can also be influenced by other sorts of input, e.g. map information of the building. Finally, we present a hybrid positioning solution.

- **Proximity based solution (figure 2)**: The proximity solution requires a mobile device with a limited wireless range. The resulting position is the centroid of all infrastructure nodes within range of the mobile unit.
- **Weighted-RSSI solution**: In this RSSI-based approach, weights (based on RSSI) are calculated between infrastructure nodes [2]. Using these weights, the position calculator computes the target’s position based on the distance from the target to 3 infrastructure nodes. Triangulation is used to determine the position of the mobile target.
- **Hybrid solution (figure 3)**: The reasoner allows the position calculator to combine the results of different algorithms and other available information. In our hybrid solution information about walls, rooms and doors is used to influence the position estimate.

![Figure 2: Proximity solution (max. error 2.5m)](image)

![Figure 3: Hybrid solution (max. error 2.5m + room accuracy guarantee)](image)

### 4 Conclusion

This framework should significantly reduce the time spent on testing and debugging new positioning algorithms. The proposed hybrid solution has been tested in different real life environments (office, arts center, care home) and results in an average error of 2 meters, with room accuracy guaranteed.

### 5 References


A Localization Framework for Wireless Mesh Networks

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1 Summary

Indoor localization is a service that could be provided by many already deployed IEEE 802.11 wireless networks and enable to find people, printers, or rooms in large office buildings without any additional costs. For this, we developed a framework for the study of various localization algorithms in a testbed environment. The Anchor-Free Distributed Localization-Algorithm (AFL) [1] was implemented as a proof of concept. We discuss several problems that arose when an algorithms that has been previously studied only in simulation environments is transferred into a real world scenario. An initial experiment series was run in the DES-Testbed [2], a multi-transceiver mesh network and highlighted many issues due to under-specification or problems that do not arise with abstract models in simulations.

2 Motivation

Localization algorithms can be classified based on many properties. One particular classification considers how many nodes in the network know their physical location. Either all nodes are position-aware, a subset (for example log(n) nodes) knows their coordinates, or in the most extreme case none of them. The last class is known as anchor-free algorithms and is particular interesting for indoor localization using common network devices without specialized hardware; an application scenario where GPS is not available. Although it is only possible to create a relative coordinate system with no relation to geographic positions, several applications already benefit from this. The localization of people, devices, or rooms as well as firefighters and paramedics searching for victims are possible.

For applications in wireless mesh networks (WMNs) there is currently limited support available. We implemented the Localisation Framework for Testbeds (DES-LOFT) that enables the configuration, execution, visualization, and evaluation of experiments. We focus on scenarios where a precision of about 1 to 2 "normal sized" rooms is sufficient. In contrast to some wireless sensor networks or specialized localization systems, we assume that only IEEE 802.11 WLAN transceivers are available and the nodes are sparsely deployed creating a random network with varying node degree.

3 Localization Framework

The Localisation Framework for Testbeds (DES-LOFT) consists of three major parts. The Node Agent is a daemon that runs on the mesh routers that enables the communication between the nodes, network-wide configuration and probing of the current state. A Proxy is run on a gateway node that provides access to all nodes in the network and caches data for subsequent queries to take load off the nodes. As last and depicted in Figure 1, a GUI provides a management interface with a 3D view of the network showing two different
locations of the mesh routers: real and localized position. Currently experiments are mostly run in an interactive-way using the GUI to allow fine granular control. The user can make crucial important decisions for the algorithms under study if a deterministic behavior has to be forced. Fully distributed and autonomous experiments are also possible.

4 The AFL Algorithm in the DES-Testbed

Anchor-Free Distributed Localization-Algorithm (AFL) [1] distinguishes two separate phases: initial fold-free graph embedding and mass-spring based optimization. In the first phase, a coordinate sytem for the network is created. Hop-count is applied as metric to select particular nodes that create the axis. All nodes are then asigned initial positions based on their location in the network topology. In the second phase, the nodes are considered to be connected by springs which apply forces to them. The power of these forces depend on the difference between the measured distances to the neighbors and the distances based on the positions in the coordinate system. The mass-spring algorithm “pushes and pulls” the nodes in the coordinate system to minimize the network-wide force.

We encountered several issues during the implementation based on DES-LOFT. For example, AFL is actually not fully distributed as phase one requires a network coordinator using some election process. Further on, the original coordinate system algorithm can create a distorted coordinate system in some situations which results in poor performance in phase two. In general, a full routing protocol is required as provider of topology information and to achieve a distributed localization. Side-effects of the additional overhead and used link metric have to be considered. We provide modifications to the original AFL specification and propose solutions for open questions that are due to under-specification.

5 Conclusions and Outlook

An initial experiment series in the Distributed Embedded Systems (DES) testbed [2] at the Freie Universität Berlin using three IEEE 802.11 tranceivers per node showed that our modifications can improve the overall performance of AFL. 16 different configurations were considered and evaluated using three metrics. We are certain that by further extension of AFL a sophisticated indoor localization system for common WMN deployments can be provided. DES-LOFT has proved to be a mature basis for the research of localization algorithms in our testbed scenario and other algorithms will be implemented subsequently.

6 References

[1] Priyantha, Balakrishnan, Demaine, Teller; Anchor-free distributed localization in sensor networks; Tech Report #892, April 15, 2003; MIT Laboratory for Computer Science