Closer to Reality: Simulating Localization Algorithms Considering Defective Observations in Wireless Sensor Networks

Frank Reichenbach[a], Matthias Koch[b], Dirk Timmermann[a]

[a]Institute of Applied Microelectronics and Computer Engineering, Rostock, Germany,
e-mail: {frank.reichenbach,dirk.timmermann}@uni-rostock.de
[b]Institute of Communications Engineering, Rostock, Germany,
e-mail: matthias.koch2@uni-rostock.de

Abstract - The design of energy aware and precise localization algorithms is a challenging task in the realization of Wireless Sensor Networks (WSN). The achievable precision of algorithms strongly depends on the accuracy of the measured observations (e.g. time of signal flight or received signal strength). In reality, observations are highly defective due to different signal propagation effects occurring in the communication channel. Thus, it is important to consider real characteristics of observations as soon as possible in the simulation process. We present a new simulation tool to test localization algorithms under more realistic conditions regarding measured observations. To show the benefits of this tool, we substitute these observations by practically measured received signal strength functions and simulate among other weighted centroid localization and multilateration.

1 Introduction and Problem Statement

The rapid advances in circuit miniaturization have enabled a new generation of tiny wireless devices, which are able to sense the environment (e.g. temperature or humidity) and to transmit gathered data to a sink in a multi-hop manner [1]. With self-configuration and -organization thousands of such sensor nodes form a large wireless sensor network (WSN). To give a typical applicable example, a WSN allows the detection of leakages along an artificial dike or the measuring of critical temperature levels in the wood. Due to the small size of a sensor node, the most limited resource is the available energy. Thus, it is demanded that hardware as well as algorithms are power aware and energy optimized.

After deployment of the sensor network over an area of interest, initially, the sensor nodes have no position information. For several reasons a node's position is very important:

- Measurements without a location, where they were gathered, are generally useless.
- Full covered sensor networks enable energy aware geographic routing.
- Self configuration and self organization are key mechanisms for robustness and can easily be achieved with position information.
- In many applications the position itself is the information of interest.

It is common practice to equip a small number of more powerful sensor nodes, which are called beacons or anchors, with a localization system (e.g. Global Positioning System). These

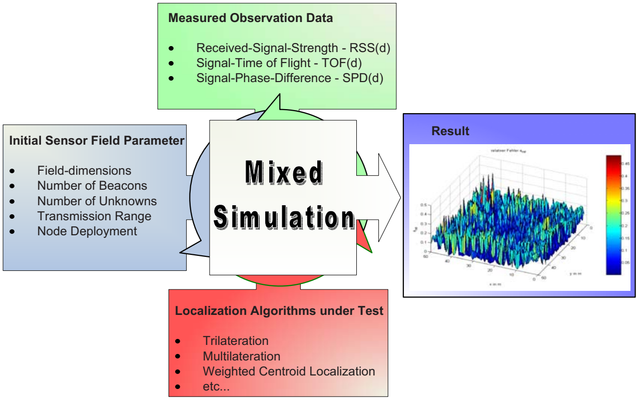

Figure 1: Components of a RiSt simulation; left: initial parameter; bottom: localizations algorithms; top: observations-curves; right: result figure

reference points and the distances to them are used as base of the position estimation for an unknown node. Distances or sometimes angles are determined by measuring observations like the time of signal flight, the received signal strength, the phase difference and angle of arrival. Localization methods for wireless sensor networks can be classified into exact (fine-grained) and approximative (coarse-grained) [2].

In reality, sensor nodes are deployed around natural obstacles and/or a changing environment. Effects like reflection, diffraction, and scattering on obstacles influence the free propagation of signals and thus lead to observation errors at the receiving node [3]. As a result the precisely required distances for the localization are defective. Testing of localization algorithms must consider errors caused by such effects. Commonly used simulators (e.g. NS2, J-Sim, OMNeT++, Shawn) support Radio Propagation Models for the wireless channel. These models assume an attenuation of the signal on the path from the sender to the receiver. At the receiver signal strength is measured for every packet that was sent. The attenuation of the sent signal can be simulated by different physical models [4, 5, 6].

While the "Free Space Model" only considers the signal attenuation without obstacles between the nodes, the "Two-Ray-Ground-Model" considers both the clear path and the ground reflected path. These two models assume an ideal circular propagation of the signal that is not the case in reality due to, e.g., different antenna characteristics. The "Shadowing Model" respects fluctuation using statistical distributions. Principally, these models are only a rough approximation of the natural environment. We demand a tool using defective observations as input and thus enabling more realistic simulations of localization algorithms (see Figure 1). For this reason, we developed RiSt (**R**egarding defect**i**ve ob**S**ervations in simula**t**ions) that allows mixed simulations with gathered observations either to test algorithms for a specific environment and/or a specific sensor node platform.

2 Details of RiSt

RiSt[1] was implemented in Matlab 6.5 Rev. 13. Two code versions are supported, running in Matlab or as stand-alone-application under Windows 2000/XP. Simulating with RiSt is based on measured observation values which can be loaded either from .txt- or .mat-files. A simple file format with three files was defined. The first file contains the distance vector, the second file the vector of the observations mean and the third one the vector of the observations standard deviations. After importing these files, RiSt creates an observation-curve out of them. Following, the user specifies the simulation parameter (e.g. field dimensions or number of nodes). Each node must be assigned to one of the imported observation-curves. This allows simulating a real scenario with different beacons and their corresponding transceiver character. Before starting the simulation, an algorithm under test must be selected. Trilateration, Multiple Trilateration with Averaging, Multilateration, and Weighted Centroid Localization (WCL) [7] were already implemented. A simple interface in RiSt makes it easy to access variables and to develop own algorithms. Furthermore, algorithms can be implemented platform independent in ANSI C, allowing an easy adaptation on different sensor node platforms. RiSt outputs the average localization error for all nodes and a figure shows the error distribution over the sensor field.
In the development of RiSt some problems occured. In a normal simulation exact distances are calculated between the unknowns and the beacons. But, in reality defective observations instead of exact distances are measured. Thus, we have to provide observations that can be estimated with the observations-distance-function $o(d)$. One function is shown exemplary in Figure 2a. When estimating an observation two issues have to be considered:

- Observation value o at a specific distance d_k is subject to a statistical distribution with mean and standard deviation
- $o(d_k)$ is defined for some distances ($k = 1 \dots n_{mess}$) only

The first issue can be solved by applying the normal distribution with the specific mean μ_o and standard deviation σ_o at the distance d_k. Therefore, we generate out of that normal-distribution a random observation o.

$$o(d_k) \rightarrow \frac{1}{\sigma_o\sqrt{2\pi}}\, e^{-\frac{1}{2}\left(\frac{d_k-\mu_o}{\sigma_o}\right)^2}$$

The second issue emerges by the fact that in reality in a limited time only a limited number of measurements can be performed. Nevertheless, a continuous function can be achieved by applying a linear interpolation over all observation points including mean and standard deviation. We already applied this in Figure 2a. If no observation exist at a specific distance, this distance it is not considered in the simulation.

After the observations were estimated, the localization starts. The already implemented algorithms use distances between unknowns and beacons and beacon positions as input for a localization procedure. With the observations and the observation-distance curve $o(d_k)$, an approximated distance must be calculated. This process is illustrated in Figure 2b. For a specific observation value the resulting straight line intersect several times at different intervals of the observation-curve. Due to different distances that are possible to choose, we compare the probability-density-functions, that can be computed at every distance point. Exemplary, in

[1]The source code can be retrieved via email from Frank Reichenbach `frank.reichenbach@uni-rostock.de`

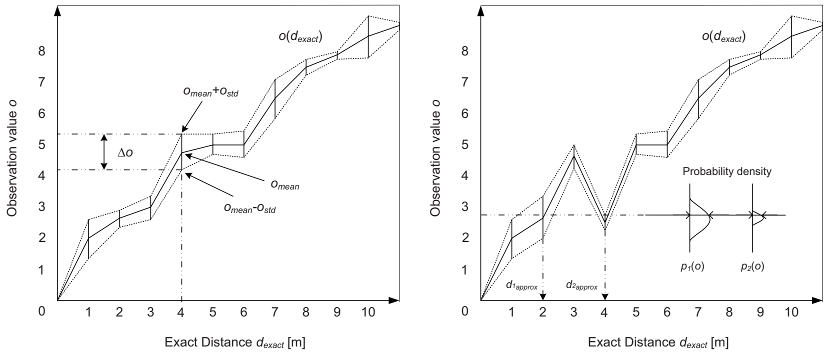

Figure 2: a) Determination of the observation with the interpolated observation-distance-curve b) Estimation of an approximative distance by comparing the different probabilities

Figure 2b the straight line intersects two intervals. In that specific case with $p_1(o) > p_2(o)$ the approximated distance d_{approx} is 2. This approximate distance is used as input for the following localization procedure.

3 Simulating with RiSt

The purpose of this section is to show the correct function of RiSt. Thus, we compared the results obtained by RiSt with the results of a practical localization under the same test conditions. We gathered observation data and we performed a practical location determination with Chipcon's CC1010 Evaluation modules at a frequency of 868 MHz. These modules measure the received signal strength by using the so called Received Signal Strength Indicator (RSSI) which varies in the interval -50 dBm $\leq$ RSSI $\leq$ -110 dBm. It was now possible to replace the introduced abstract observation by this received signal strength indicator.
In the first part of the simulation RSSI-measurements were gathered in the meeting room of our institute. The test setup was stated as followed; we placed one module (sender) at a fixed position in the room. A receiver module was moved on a straight line from 1 cm to 400 cm at a step width of 50 cm. At every step the receiver measured 30 values at an send output power level of -28 dBm. Measurements were taken for four send modules (Ids: 63, 77, 78, 89) and always the same receiver module (Id: 94). These curves are shown in Figure 3a. In all measurements the standard deviation was close to zero. The obtained RSSI-curves now served

Localization Algorithm	Averaged Relative Error [%] with Exact Distances	Averaged Relative Error [%] with Measured Distances
Weighted Centroid L.	7.5535	13.2649
Trilateration	1.0247e-014	10.9035
Multilateration	0.7166e-014	8.4758

Table 1: Comparison of different localization algorithms in RiSt; the averaged localization error is the distance between exact positions and the estimated positions which used measured noisy distances as input

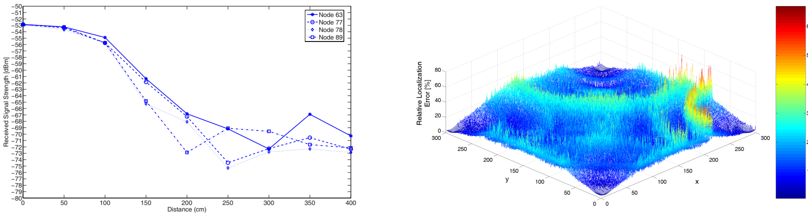

Figure 3: a) Averaged RSSI-curves for all four test nodes in the meeting room of our institute; b) Relative localization error [%] over a sensor field implying premeasured RSS-characteristics; algorithm: WCL, fieldsize: 300×300; beacons 4; testpoints: 300×300

as input for RiSt.
Now, we aimed to test different localization algorithms for a specific test setup in RiSt. Therefore, we defined a test field with the dimension 300×300 and placed the available four beacons at the four corners $B_{63}(x, y) = 1{,}1$; $B_{77}(x, y) = 300, 1$; $B_{78}(x, y) = 1, 300$; $B_{89}(x, y) = 300, 300$ of the square. Normally, many more beacons can be used in RiSt, assuming the characteristic RSSI-curves are equal, which can be the case in outdoor scenarios. Three localization algorithms were run with 300×300 test points. These test points were placed uniformly on a grid ranging from 1 to 300 in both dimensions. RiSt allows choosing between a grid of test points and free placing of only some test points.
The computed averaged localization errors that are the distances between the exact and the estimated positions of the sensor nodes, are shown in Table 1. The errors determined with exact distances are much smaller than the errors determined with noisy input. Moreover, the WCL-algorithm produced the highest error. The multilateration featured higher precision than the trilateration, because four beacons are involved in the localization process, which reduces the input errors. The distribution of the relative error for each test point over the whole test field is shown in Figure 3b, where the positions were estimated with WCL. The test points at the corners produced the smallest error, due to the very close distance to one of the beacons. More details of WCL are discussed in [7].

Furthermore, we showed how close to reality RiSt actually is. For that purpose we built the same test setup as explained above in our meeting room. The four beacons were also placed at the four corners of the 300 cm $\times$ 300 cm field. The sensor node with Id 94 was placed at these 13 different positions: $P(x, y)$=(1,1); (150,1); (299,1); (75,75); (225,75); (1,150); (150,150); (299,150); (75,225); (225,225); (1,299); (150,299); (299,299). At every position the sensor node estimated its position via WCL after measuring the RSSI. In that practical study the averaged relative localization error was 14.7851%. The same simulation in RiSt produced an averaged relative error of 12.8919%. These results are very close together. Nevertheless, they are not exact the same due to two reasons.
The distances used in simulation are obtained by a transformation between exact distances to RSSI-values and back to approximative distances. This transformation contained errors. Secondary, the RSSI-curves used in the simulation were gathered by a measurement on a straight line in the same room. Due to reflections of the signal at the walls the RSSI-characteristics vary at different positions in the room. Nevertheless, the simulations showed that RiSt is applicable to study new algorithms with defective observations.

4 Conclusion

This paper presented RiSt, a more realistic simulation tool to test localization algorithms in wireless sensor networks considering real observation values (e.g. time of signal flight, received signal strength etc.). Common network simulators for wireless sensor networks only support "Radio Propagation Models" that are a rough approximation of the occurring physical effects. We showed in different simulations that RiSt works with different implemented algorithms and practically measured curves of the received signal strength. We finally achieved high conformities under the same test setup between results obtained by RiSt-simulations and results obtained by real localizations using WCL.

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