Distance-Based Distributed Multihop Localization in Mobile Wireless Sensor Networks

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***Abstract*—Localization in wireless sensor networks has been a big challenge for researchers in the past years. Besides physical problems like estimating the distance between two nodes, applicable algorithms are still on the list of open research issues. While single-hop localization with direct connection to fixed anchors is well researched, the localization with fixed anchors over a multi-hop route is still at its beginning. Especially the combination of multi-hop networks and mobile nodes needs further research. In this paper, we present and discuss a refined algorithm and a simulation-based approach regarding the mentioned scenario. Using a five phase structure that pursues a greedy approach, including a refining anchor selection, we investigate and discuss the precision of localization in a mobile environment. To approximate the distance between node and anchor over a multi-hop route, we make use of the mentioned greedy algorithm which fits best for processing multiple distance measurements between nodes. Furthermore, we evaluate different simulation-based experiments with mobile nodes and multi-hop routes.**

***Index Terms*—wireless sensor networks, lateration, mobile localization, radio runtime measuremnt, indoor localization**

I. Introduction

Nowadays, wireless sensor networks (WSNs) are used for different scenarios. They are installed in smart homes for metering and monitoring of enviromental parameters, they are used for ecological enviroment monitoring and they are used for vital parameter monitoring for rescue forces or military purposes. For some of theses scenarios, not only the collected sensor data itself is of interest but also the exact global or relative position *where* the data has been collected.

Gathering this position has been in research focus for years and different approaches exist. While the localization under open air conditions can be done quite simple with mounting Global Positioning System (GPS) receivers onto the nodes, indoor localization is a much more challenging topic. Especially for nodes attached to humans who can freely move inside unknown buildings several problems have to be solved. We need nodes in the network which already know their position and we need a technique to approximate the distance between nodes in order to estimate the position of a sensor node. Immobile nodes with a priori knowledge concerning their postion, are called anchors in this paper. All none anchor nodes are simply called nodes in this paper; they have to calculate their positions using the sensor network localization algorithm distributively.

The major problem of localization in mobile multi-hop networks is the volatile position of nodes while they are in the process of localization, especially when attached to humans or vehicles. This leads to the threefold challenge of our scenario. First, using mobile nodes implies the problem that not all nodes are in range with an anchor during the whole operation. Second, we are not able to calculate a precise position while the node is moving, because the node may continue movement between the needed distance measurements which are called rangings in this paper. The third problem results from problem one and two: To do a localization without having a direct connection to the anchors, the node has to use its neighbors which already could have changed their positions after their last localization.

In this paper, we purpose an algorithm based on a new five phase structure that is applicable for a range-based localization approach in mobile WSNs. The algorithm is usable for multi-hop, infrastructureless WSN deployments and for varying node to node ranging approaches. We introduce a simulation environment which allows the evaluation of current ranging technologies concerning their operational capability and the mentioned problems of mobility and latency during localization. The simulator allows to view the whole network in realtime with a graphical 3D interface.

The main contribution from this paper is twofold:

- We present a distributed multi stage algorithm for indoor localization of mobile sensor nodes and discuss its performance in different scenarios.
- We present a simulation environment to simulate distributed mobile WSN localization algorithms with different parameters and different scenarios in realtime.

Our designated goal is to implement our simulated and evaluated architecture in a real world scenario that inherits the mentioned restrictions. In our current work, we plan to make use of the MSB-A2 sensor node [1] with a 32-bit ARM7TDMI-S based microcontroller in conjunction with chirp technology based NanoLOC modules [2], which use distance calculation via radio signal runtime measurements for the process of ranging.

In Section II we introduce related work, Section III introduces lateration, Section IV presents our localization algorithm and Section V gives an evaluation of our simulated results. We present a conclusion and discuss future work in Section VI.

II. Related Work

Localization of nodes in WSNs can be split up into two parts: First, the process of distance estimation or measurement and second, the localization algorithm. There are different approaches for estimating the distance between a node and its neighbors or fixed anchors. Some techniques rely on the calculation of these distances with physical measurements like radio signal runtime, ultrasonic based-measurements or received signal strength indication (RSSI) measurements. Others try to approximate the distance with a hop-count indicator. For mobile WSNs only processes come into consideration which are applicable with a minimum of infrastructure. We focus on methods which can deliver a node to node distance without any infrastructure besides the nodes themselves. [3]

If the distances between nodes are known, there are several aproaches to calculate the position of a node. If the network is only single-hop and the nodes have a direct connection to anchors which know their position (e.g. from GPS), the approach is simply to do a lateration if enough anchors are in range. In multi-hop networks the position can be calculated centrally or distributively [3]. Our approach is to use a distributed approach, because it needs less infrastructure and less network traffic. Nodes knowing their position are able to use this information for additional possibilities like geo-routing.

Comparing to the current state of the art, our approach takes advantage of network dynamics and chaotic node distribution. Moreover, we desire a solution that handles the lateration problem while contact to anchors is not available. The nodes to be localized are allowed to move at different speeds and may change their orientation whenever they want.

Because of the open and previously mentioned problems, typical evaluations in localization scenarios do not focus on the node mobility. The exemplary paper of Langendoen [4] is comparing three localization systems in static WSN scenarios. Their comparison includes a lateration algorithm and concludes that all algorithm do share a common structure while none performs best.

In contrast to single-hop environments, a multi-hop environment has to minimize the error accumulation that may appear in the network as suggested by Savvides in [5]. They optimized the localization by preventing the error accumulation with the usage [3] of a recursive position refinement, in which they did not take node mobility into consideration, as we are going to.

DV-Distance [6] uses rangings to determine the distance to a neighbor and uses lateration over the anchors just as we do. Based on their DV-Hop-Algorithm, they use the first route established to an anchor through the WSN, to establish accumulated distances. This route represents a suboptimal distance between unknown node and anchor. In contrast to this, our approach is to find a shorter route, using the greedy algorithm. Moreover, we evaluate our system with different anchor selection algorithms.

By using the taxonomy of [7], our approach falls into the category of communication based localization and tracking. In order to track or localize a person while moving, this person needs to wear a sensor node with an unique identifier. The environment itself communicates with the nodes by additional anchors with a priori knowledge of their positition as suggested in [4]. The position of a node has to be investigated by rangings between the nodes, possibly worn by humans, and anchors, in order to provide the basis for a lateration-based localization algorithm.

III. Quad Lateration

Our scenario deals with nodes moving around freely, in other words the localization has to cover all three dimensions. In order to calculate a position of a node in a room, we use the principle of lateration which is a well-established technique to approximate the position out of rangings as introduced in [8]. Each ranging describes with its distance the estimated radius to the position of the unallocated node. If we draw a circle around the appropriate measuring node, by using the ranging as the radius, multiple rangings will intersect themselves and define an area where to expect the unlocated node. If 2D-lateration obtains less than three rangings or 3D-lateration less than four rangings, uniquely defined results are impossible due to the problem of flip ambiguity as defined in [9]. To guarantee uniquely defined results due to the 3D lateration algorithm, we specify that exact four rangings are necessary. It is possible to laterate with more than the specified number of rangings by using an overdetermined system of linear equations, with the goal of optimizing the localization. As our mobile scenario has to deal with the problem of undersupplyed number of rangings we abandon to use this approach. Moreover, the approach decreases the speed of the algorithm. Beside this, it is not given that more rangings will result in a better approximation in reality. A more efficient strategy is to find the best rangings out of a given set. Adapted from [8], we define our lateration by the following equations: Where (x_k, y_k), $k \in [1, ..4]$ represent positions of anchors, (x_u, y_u) define unknown positions of the node while the rangings are defined by $r_u, u \in [1, ..4]$:

$$(x_k - x_u)^2 + (y_k - y_u)^2 + (z_k - z_u)^2 = r_k^2, k = 1..4 \quad (1)$$

To solve the system of equations, we transposed in into a general matrix form:

$$x = A^{-1} * b \quad (2)$$

Where

$$A = 2 \begin{bmatrix} x_1 - x_4 & \cdots & z_1 - z_4 \\ \vdots & \ddots & \vdots \\ x_1 - x_2 & \cdots & z_1 - z_2 \end{bmatrix} \quad (3)$$

and

$$b = \begin{bmatrix} (r_4^2 - r_1^2) - (x_4^2 - x_1^2) - (y_4^2 - y_1^2) - (z_4^2 - z_1^2) \\ \vdots \\ (r_2^2 - r_1^2) - (x_2^2 - x_1^2) - (y_4^2 - y_1^2) - (z_2^2 - z_1^2) \end{bmatrix} \quad (4)$$

In order to come closer to a real world environment, the simulation inserts randomly calculated ranging errors within a

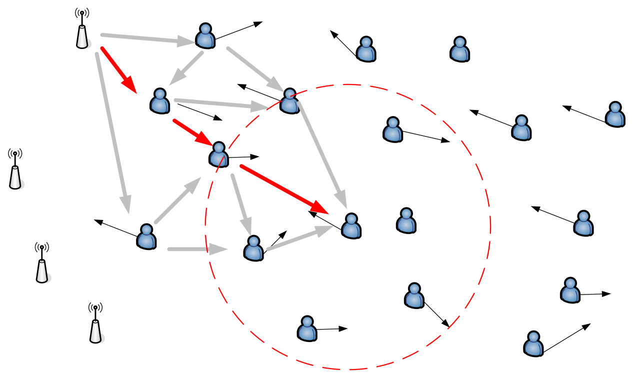

Fig. 1. Choosing the shortest path as anchor distance

fixed range as we desribe in Section V. As described in [3], it is important to interpret effects rising by noisy rangings, hence we need to understand the error propagation characteristics occurring by error-prone range measurements.

IV. Localization Algorithm

Our algorithm reuses the well established three phase architecture as introduced in [4] and extends it to a five phase structure. The five phases are described as follows:

- Phase 1 **aquire neighbor distances -** In this phase a node estimates the distances to all its neighbors with a distance measurement technique. Also, a node has to get the distances from its neighbors to the anchor nodes in this phase. In case of radio runtime measurement this could be done with one radio transmission.
- Phase 2 **calculate anchor distances -** With the aquired data, the node calculates the total distances to all anchors. Probably there will be more than one path to a single anchor which is refined in the next phase.
- Phase 3 **greedy phase -** The node iterates over all distances for each anchor and choses the shortest one and stores it. In all radio runtime based measuremnt systems the calculated distance will be too long and not too short because of reflections and multipath effects. So this simple greedy algorithm chooses the best possible path to the anchor as shown in Figure 1.
- Phase 4 **anchor selection -** The anchor selection phase allows us to choose between different sets of anchor quadruplets; hence the anchor selection is only accessible if more than four different anchors are reachable. These algorithms are exchangeable and we evaluate three anchor selection algorithms afterwards.
- Phase 5 **lateration -** The last phase quad laterates the position of the initiating node with help of the shortest range path to four suitable anchors.

A. Algorithm description - Volume

By using four anchor positions in the $\mathcal{R}^3$, they describe a tetrahedron. Likewise GPS needs to select appropriate satellites, in order be able to locate the unknown position of a node as precise as possible. One simple approach is to use the satellites forming the tetrahedron with the the biggest volume [10]. Inspired by GPS, we adapt their approach and make use of non-collinear anchors forming a tetrahedron with the maximum volume.

B. Algorithm description - nearest Neighbor

Another quite simple approach is to use the four nearest but non-collinear anchors as a lateration basement. This approach is often used in lateration environments and performs well in [4] and [11], moreover, it reduces the possibility to have an obstacle between node and anchor [12].

C. Algorithm description - brute force selection

Our last algorithm is a brute force algorithm which is only deployable in simulators. This algorithm shows us the theoretically possible precision that could be reached by a lateration based system with an optimized anchor selection. This algorithm simply tries all possible anchor permutations and calculates the relative lateration error and then choses the best permutation.

V. Evaluation

A. Simulation Environment

Due to the lack of well introduced localization simulators for mobile nodes in ad hoc networks, we developed a simulation framework for this purpose. To gain a better understanding of the complex scenarios, we designed a real-time graphical simulation enviroment with a 3D visualization component. The simulator can simulate up to 1000 nodes on a regular PC in realtime and an unlimited number of fixed anchors in a 3D area. The nodes have different movement vectors which can be configured or generated randomly. Each node can have a different radio range and is able to request the distances to his neighbors within radio range. The estimated distances can be inaccurate by a certain percentage. The enviroment has an API for applying different localization algorithms for each node. The environment simulates a volatile, manlike node movement and erroneous radio ranges, whereby the communication between nodes is simplified. Especially the media access and radio characteristics like reflection and absorbtion are not simulated.

B. Experimental Setup

For all simulations we used a $100m * 100m$ playfield with a height of $15m$ to simulate a large building. All nodes move with randomly changing directions and movement speeds which are limited to $2m/s$ to simulate humans with normal walking speed. All nodes start moving on the same spot on the border of the playfield at the same time. In every simulation there are four fixed anchors placed outside the playfield but reachable from every node at the beginning of the simulation. The ranging error is set to 3.33%, while the radio range is set to $30m$. These values where choosen because they fit for the real hardware we are going to use in the second stage of our project.

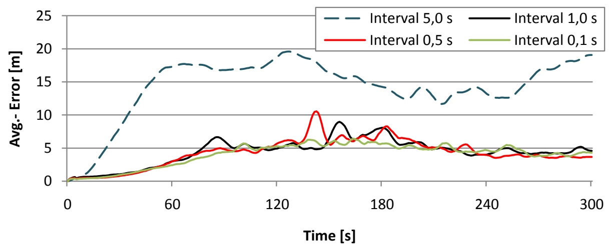

Fig. 2. Comparing average localization error by changing localization intervals. Fixed settings: nearest neighbor anchor selection, 4 anchors and 300 nodes.

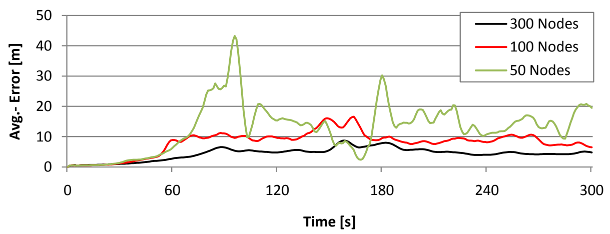

Fig. 3. Comparing average localization error by changing the quantity of nodes. Fixed settings: nearest neighbor anchor selection, 4 anchors and 1 second localization interval.

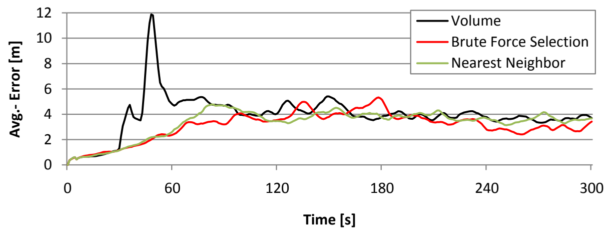

Fig. 4. Comparing average localization error by changing anchor selection algorithms. Fixed settings: 4 anchors, 1 second localization interval and 300 nodes.

C. Results

First, we wanted to analyze if the localization interval has an influence to the average position error which is likely due to the movement speed. But the experiment showed that for the relatively low movement speed of human beings the interval has no big impact which is shown in Figure 2. Only for intervals larger than one second the error begins to increase noticeably. From this observation we conclude that to achieve smaller localization intervals e.g. to save energy, the interval should be compressed so that all localization is done in a one second sub interval of the overall localization interval.

The second experiment analyzed the impact of the network density. As shown in Figure 3, the node count has a much bigger influence than the localization interval on the average position error. A node count below 50 leads to too many nodes having no connection to a sufficent number of neighbors to perform the lateration.

Finally, we wanted to know the effect of the algorithm to choose the anchors. So we placed another four anchors around the area and ran different algorithms to choose the best four of them. Figure 4 shows that our nearest neighbour algorithm is very close to the optimal algorithm in its effect to the average position error. In the diagramm it looks like that it is sometimes even better than the brute force algorithm which can be traced back to the fact, that there are some calculations in the simulator which are affected by randomness e.g. distance error. The volume algorithm performed as good as the nearest neighbor algorithm but because of its more complex implementation we propose the nearest neighbor algorithm as the best algorithm. The increase of the anchors resulted in a noticeable decrease of the average error which should be observed in future work. It is not clear if the decrease is a result of the better position of the chosen anchors or simply an effect of the obeservation that the average hop count from a node to a anchor was also decreased by placing more anchors.

VI. Conclusion & Future Work

We propose our five stage localization algorithm as a next step to achieve precise indoor localization for multi-hop mobile networks. The algorithm performs good in dense networks with an acceptable refresh rate. In future work, we will concentrate on implementig the algorithm on real sensor nodes and evaluating localization precision with a real radio layer. Further, we will research on adding an applicable QoS component that enables a local estimation for the position error.

References

[1] M. Baar, H. Will, B. Blywis, T. Hillebrandt, A. Liers, G. Wittenburg, and J. Schiller, "The scatterweb msb-a2 platform for wireless sensor networks," Freie Universitt Berlin, Tech. Rep., 2008.

[2] N. T. GmbH, "nanoloc trx transceiver (na5tr1)," 2000.

[3] G. Mao, B. Fidan, and B. D. O. Anderson, "Wireless sensor network localization techniques," *Comput. Netw.*, vol. 51, no. 10, pp. 2529–2553, 2007.

[4] K. Langendoen and N. Reijers, "Distributed localization in wireless sensor networks: a quantitative comparison," *Comput. Netw.*, vol. 43, no. 4, pp. 499–518, 2003.

[5] A. Savvides, H. Park, and M. B. Srivastava, "The n-hop multilateration primitive for node localization problems," *Mob. Netw. Appl.*, vol. 8, no. 4, pp. 443–451, 2003.

[6] D. N. And, "Ad hoc positioning system (aps)," 2001.

[7] E. D. Manley, H. Al Nahas, and J. S. Deogun, "Localization and tracking in sensor systems," in *SUTC '06: Proceedings of the IEEE International Conference on Sensor Networks, Ubiquitous, and Trustworthy Computing - Vol 2 - Workshops*. Washington, DC, USA: IEEE Computer Society, 2006, pp. 237–242.

[8] H. Karl and A. Willig, *Protocols and Architectures for Wireless Sensor Networks*. John Wiley & Sons, 2005.

[9] A. A. Kannan, B. Fidan, and G. Mao, "Robust distributed sensor network localization based on analysis of flip ambiguities." in *GLOBECOM*. IEEE, 2008, pp. 6–11. [Online]. Available: http://dblp.uni-trier.de/db/conf/globecom/globecom2008.html#KannanFM08

[10] S. H. Dong, "A closed-form formula for gps gdop computation," 2007.

[11] P. K. Sahoo, I.-S. Hwang, and S.-Y. Lin, "A distributed localization scheme for wireless sensor networks," in *Mobility '08: Proceedings of the International Conference on Mobile Technology, Applications, and Systems*. New York, NY, USA: ACM, 2008, pp. 1–7.

[12] A. A. Yi Shang, Hongchi Shi, "Performance tradeoffs of localization methods in ad-hoc sensor networks," 2004.