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Simple Iterative trilateration-based scheme for indoor localization of IoT devices

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Abstract. Indoor localization, as a key enabling technology for Internet of Things (IoT) location-based applications, is one of the primary services in smart automated systems. It is becoming increasingly important and beneficial in many industrial, commercial and public domains. This paper proposes an iterative trilateration technique for localization in indoor IoT environment, as an improvement of baseline trilateration. In our simulations, the iterative trilateration achieves high localization coverage with accurate location estimation compared to baseline trilateration. Additionally, our technique was analyzed considering different parameters like communication range, range error and anchors' fraction in three-dimensional (3D) space under scenarios with and without obstacle. The results show that our iterative trilateration technique is almost resistant to the obstacles in the environment.

Keywords. Internet of Things, indoor localization, iterative trilateration, obstacle

1 Introduction

Nodes localization has been a challenging problem in the last decade, basically from a wireless sensor network (WSN) perspective. The localization problem has been defined as finding node's location in the absence of global positioning system (GPS) signals, which was mapped to indoor environments, where GPS is not available[1][2].

However, although many algorithms have been developed by the research communities worldwide, most of them did not manage to reach commercial success[3]. The main reason behind this is the fact that almost all of them, regardless of their complexity, obtain the internode distances using radio signal strength (RSS) measurements, which are proven to be unreliable in a more complex environments[4]. The fingerprinting (FP) approach, which is based on time consuming process of radio map generation, appeared as a promising solution to overcome RSS issues. Still, FP does not prove to be robust enough to adopt the changes in dynamic environment. This status-quo situation has led to rapid development of new complex methods for localization, which theoretically achieved high localization accuracy, that was never proved in practice. As of May

2017, Google Scholar has indexed more than 10000 scientific articles exclusively dedicated to localization problem in wireless systems.

With the advances in the wireless technology, WSNs have recently evolved toward the IoT, which is defined as a global network of highly efficient and affordable smart devices capable to sense, process and exchange data. Localization, as a key enabling technology for IoT location-based applications, will remain attractive among researchers. In the future, it is expected that IoT devices will be equipped with different interfaces for communication, apart from traditional radio based modules. Additionally, even radio waves can provide more reliable way to obtain distances, like time of arrival (ToA) or time difference of arrival (TDoA), if devices possess additional hardware. This opens room for the researchers to return to the basic concepts of localization and to redesign the simple methods in more complex environments.

The aim of this paper was to investigate the accuracy obtained when simple localization technique is applied in indoor IoT environment. The main assumption in our study is that future IoT devices will bring advances in distance estimation, therefore we do not adopt RSS metrics, but we assume the presence of other, more accurate ranging techniques for distance estimation. The localization technique we implemented is a modification of the well-known trilateration algorithm [5]. We evaluated the algorithm in three-dimensional (3D) space under scenarios with and without obstacle, and our results prove that even simple localization algorithms can provide sufficient localization accuracy.

The rest of this paper is organized as follows. Next section discusses related work from the literature. Section three elaborates implementation details of our algorithm. Section four describes the simulation settings and discusses the results. The paper is concluded in Section five.

2 Related Work

In the WSN research community, different methods for node localization have been developed in the past years. They can be basically divided in range-free and range-based methods, where latest are considered more accurate. They are based on measuring the distances between the nodes in the network, usually estimated using simple RSS[6][7]. Among the techniques used for node localization in 3D space, we can mention Landscape-3D, which utilizes Kalman filter for estimation of nodes location [8] and a particle filtering method for node localization [9], both techniques with similar filtering approach, independent of network density and topology. Another efficient technique is CBLALS, a cluster-based approach which locates nodes by partitioning them in clusters and by correcting intercluster range with the triangle method. This method is proven to be highly efficient in providing accurate locations [10].

Another centralized approach that provides high accuracy in calculating node position is MDS-MAP. Modification of MDS-MAP, known as IMDS, represents an improved version of MDS-MAP for localization in 3D sensor network with higher accuracy. Its mathematical background is based on reducing the compu-

tation complexity by computing distance matrix efficiently, with heuristic approach, which is proven to perform better than Dijkstra or Floyds methods for distance matrix calculation [11] [12].

However, most of the abovementioned algorithms reported results obtained using simulation settings, where range error has been neglected or modeled as a small percentage of the real radio range. In order to improve the localization accuracy, researchers have focused on implementation of refinement, either on optimization or for radio propagation modeling. Recently, many research groups have shifted toward new communication possibilities, like visible light communication or acoustic signals [1]. Those techniques for distance estimation perform better compared to radio range. Therefore, in the future, it is expected that distance measurements will be more accurate compared to RSS-based distances, and even simple localization techniques can perform satisfying localization accuracy.

Trilateration is one of the oldest technique for localization, that has been used for centuries for nautical navigation. It is also the basic technique behind global navigation systems, like GPS, Glonass or Galileo, since its computation is easily implemented without heavy calculation on device side. The main requirement in trilateration is the presence of three (four) referent points for 2D (3D) localization. In modern IoT environment, although there are many IoT devices, not all of them are considered as referent. Therefore, trilateration will not manage to cover all area, i.e. only small fraction of the devices will be localized. In this paper, we propose a simple iterative approach, where each already localized device becomes new anchor device. With respect to previous research, the authors in [13] propose similar iterative approach, but in their simulation setup the range error is neglected. In contrary, we evaluate our approach regarding different range error.

3 Iterative trilateration (ITRL) indoor localization scheme

In this section, the baseline trilateration (TRL) together with the newly proposed iterative TRL (ITRL) modification is described.

3.1 Baseline trilateration (TRL)

It is assumed that an IoT device with unknown location is within the communication range of at least four other IoT devices with apriori known locations, also known as IoT anchor devices. The respective distance to each IoT anchor can be obtained using any of the abovementioned ranging techniques. If the four IoT anchor devices have coordinates $O_1(x_1, y_1, z_1)$, $O_2(x_2, y_2, z_2)$, $O_3(x_3, y_3, z_3)$ and $O_4(x_4, y_4, z_4)$ respectively, the unknown device $A(x_A, y_A, z_A)$ lays in the intersections of the surfaces of the four spheres with centers in O_1 , O_2 , O_3 and O_4 . Using Euclidean geometry, we can obtain the coordinates of the unknown device A by rotating and repositioning the grid for calculation simplification, as given in (1), (2), (3) and (4).

$$\begin{cases} d_1^2 = x_A^2 + y_A^2 + z_A^2 \\ d_2^2 = (x_A - x_2)^2 + y_A^2 + z_A^2 \\ d_3^2 = (x_A - x_3)^2 + (y_A - y_3)^2 + z_A^2 \\ d_4^2 = (x_A - x_4)^2 + (y_A - y_4)^2 + (z_A - z_4)^2 \end{cases} \quad (1)$$

$$x_A = \frac{x_2^2 + d_1^2 - d_2^2}{2 * x_2} \quad (2)$$

$$y_A = \frac{x_3^2 + y_3^2 + d_1^2 - d_3^2 - 2 * x_A * x_3}{2 * y_3} \quad (3)$$

$$z_A = \frac{d_1^2 - d_4^2 + x_4^2 + y_4^2 + z_4^2 - 2 * x_A * x_4 - 2 * y_A * y_4}{2 * z_4} \quad (4)$$

The TRL localization scheme is a distributed approach, since every known IoT device should use all available data from its surrounding to obtain its own location. The algorithm steps are described as follows:

1. Discover all IoT anchors from the surrounding.
2. Select the four closest IoT anchors.
3. Apply equation (2), (3) and (4) to calculate the three unknown coordinates.

The main drawback of TRL is its inability to localize all IoT devices in the network, i.e. only devices that has four anchors in its close proximity would be localized. Therefore, in networks with sparse anchor distribution, only a small fraction of the network will be localized. Even if there is sufficient number of anchors, which are not evenly distributed around the environment, the TRL will not achieve the desired results.

3.2 Iterative trilateration (ITRL)

Iterative trilateration (ITRL) technique expands the baseline TRL by iterating over the network multiple times. In each consecutive iteration, the IoT devices being previously localized become new anchors.

The steps in ITRL algorithm are as follows:

1. Discover all IoT anchors from the surrounding.
2. Select the four most appropriate IoT anchors.
3. Apply equation (2), (3) and (4) to calculate the three unknown coordinates.
4. Advertise your location to other IoT devices from the surrounding that have not yet obtained its location.

The iterative TRL employs two metrics to describe the anchors by terms of quality.

1. The first metric is anchor weight that stands for unreliability. Namely, as new anchors are created in each consecutive iteration, newly anchors are supposed to have embedded some localization error. Therefore, we assign weight "0" to the initial anchor, and weight "1" to the anchors obtained after the first iteration. For each additional iteration, the weight of the newly generated anchor is calculated as a sum of the weights of the anchors that participated in its creation, i.e. $\text{new_weight} = \text{sum}(\text{anchors_weights}) + 1$.
2. The second metric is the proximity of the anchors to the unlocalized device.

In this iterative procedure, the unknown IoT device will have many anchors in its surrounding. Some of them will be closer, but will have smaller reliability. Therefore, it is challenging to choose the most appropriate four surrounding anchors that will be used to localize the unknown device.

4 Simulation results

To investigate and to compare the performances of baseline TRL and our newly proposed ITRL, we ran simulations. The parameters of the simulation settings were as follows:

1. Fixed number of IoT devices ($N=190$) deployed randomly with normal distribution inside a cubic area ($200r \times 200r \times 200r$, where r is a unit length distance).
2. Different communication range R , from $30r$ to $70r$, with step $10r$.
3. Different range error E_r , modeled as uniform distribution from $5\%R$ to $25\%R$ with step $5\%R$.
4. Different anchor fraction A , ranging from $10\%N$ to $40\%N$.

The results for each scenario represent an average over 30 trials.

4.1 Comparison of Baseline TRL and ITRL

It is expected that ITRL algorithm would achieve better results by means of localization coverage compared to baseline TRL technique. Localization coverage is defined as the ratio of the localized devices to the total devices.

The obtained results in Fig. 1(a) show that the basic TRL algorithm is outperformed by the ITRL approach when simulating with variable communication range, however, the iterative approach provides 65.43% localization coverage for low communication range, which is not the perfect solution. We can notice that when increasing the range, the localization coverage gets very close to 100%. On the other side, on Fig. 1(b) we can see that communication range error doesn't have a huge impact on overall localization coverage, for both algorithms, as we get less curvature for both plots. Fig. 1(c) shows the relationship between the localization coverage and the initial number of anchor nodes, for both approaches. Again, the iterative method outperforms the baseline method.

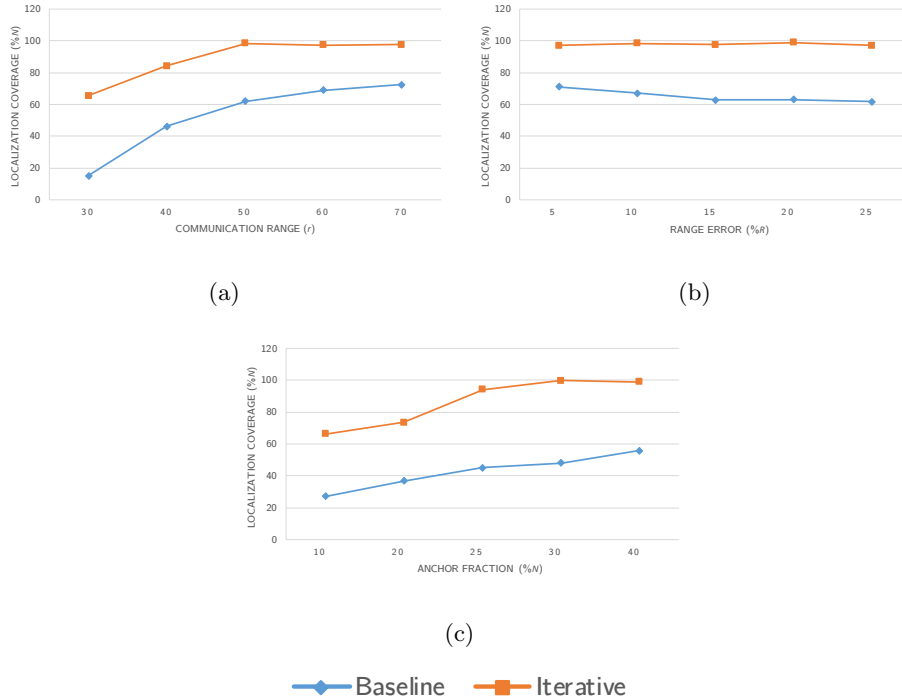


Fig. 1: Comparison of localization coverage for baseline TRL and ITRL approaches, for (a) variable communication range, $E_r=10\%R$, $A=30\%N$ (b) variable range error, $R=50r$, $A=30\%N$ and (c) variable anchor fraction, $R=50r$, $E_r=10\%R$.

4.2 Evaluation the ITRL performances

In this section, we investigate ITRL accuracy in open 3D space and in 3D space with a fixed obstacle. We address accuracy as average localization error (ALE), which is the average distance between the estimated positions and the real positions of all IoT devices, normalized to the devices communication range. ALE is computed using (5).

$$ALE = \frac{\sum distance(pos_i^{calculated} - pos_i^{real})}{N \times R} \times 100\% \quad (5)$$

The network parameters are set as follows: 60 anchors, 10% range error and $50r$ communication range. We tested the algorithm on a grid with and without obstacle, where the obstacle is represented with a cube with size $40r \times 40r \times 40r$.

The iterative technique was tested on a network with the above described parameters, with and without obstacle. We decided to test the algorithm with an obstacle because of the fact that even when two nodes are within the communication range of each other, they cannot communicate if there is an obstacle standing between them. Therefore, we expect reduction in efficiency of the algorithm when adding an obstacle, as the number of anchors within the communication range of a node decreases.

According to the obtained results, we notice slight difference on the average localization error between simulations with and without obstacle. As we expected, the simulations proved that the ITRL performs better in 3D space without obstacle, by producing lower ALE , that varies from $5\%R$ up to $25\%R$.

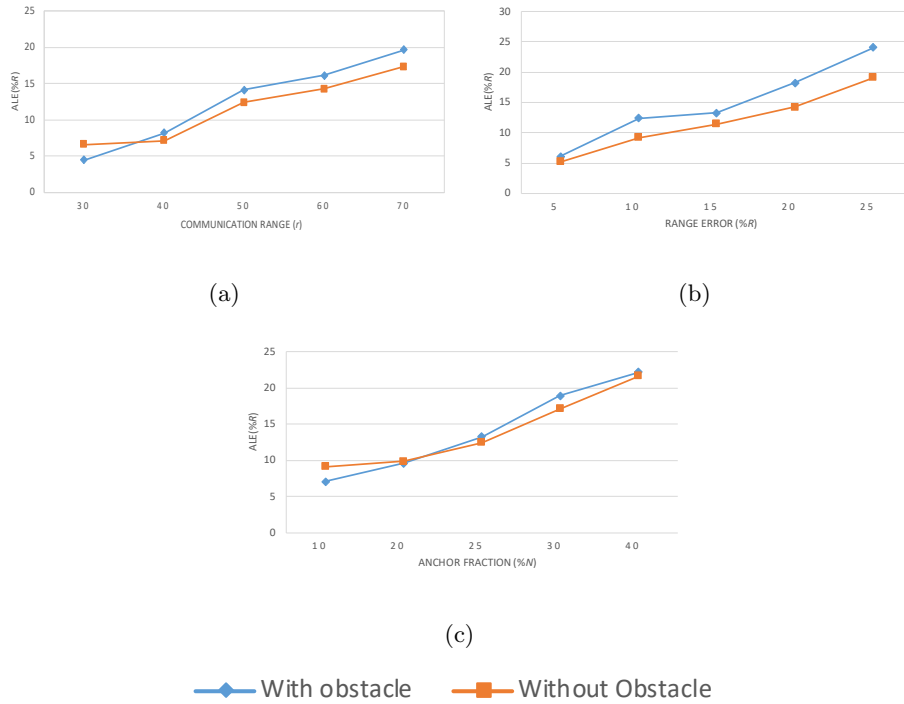


Fig. 2: Evaluation of ITRL in environment with and without obstacle, with respect to (a) variable communication range, $E_r=10\%R$, $A=30\%N$ (b) variable range error, $R=50r$, $A=30\%N$ and (c) variable anchor fraction, $R=50r$, $E_r=10\%R$.

5 Conclusion

In this paper we propose an iterative trilateration-based scheme for localization of IoT devices in indoor environment, as an improvement of the baseline trilateration technique. We simulated both algorithms, considering different parameters like communication range, range error and anchors' fraction and compared the results to prove that the ITRL technique outperforms baseline technique in terms of localization coverage. Additionally, we tested the ITRL scheme in 3D environment with and without obstacle placed at random location, and compared the results regarding average localization error. In contrary to other techniques from the literature, which fall to work well in environment with obstacles, ITRL performs almost equally good as in the environment without obstacle. As for future work, we suggest that researchers should experimentally evaluate simple localization techniques using different means of communication, like visible light or acoustic signals.

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