Exploring different heuristics for WSN localization based on trilateration

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Andrej Jovanov, Robert Stoimenov, Biljana Risteska Stojkoska
Faculty of Computer Science and Engineering
Saints Cyril and Methodius University,
1000 Skopje, Macedonia
{andrej.jovanov, robert.stoimenov}@students.finki.ukim.mk, biljana.stojkoska@finki.ukim.mk

***Abstract*—Localization remains a challenging problem in wireless sensor networks community. There are many algorithms for localization proposed in the literature, ranging from very basic to very complex. Among them, trilateration is one of the oldest and simplest approach, that can be used alone, or as part of more complex pipelines. In this paper we explore two different heuristics that adopt trilateration as a base technique. Our heuristics use distance information together with knowledge about the most appropriate anchors in terms of quality. We show that by improving trilateration with different heuristics, localization error can be significantly reduced, while maintaining low computational cost.**

Keywords—localization; wireless sensor network; trilateration; heuristics

I. Introduction

Localization is still attractive problem in Wireless Sensor Network (WSN) community. Although it is one of the oldest problem defined in WSN, common solutions are very rare, especially for indoor environment. With the flourish of WSN and its seamless integration with Internet of things (IoT) [1], the localization problem has gain even more interest, not only among researcher, but also among entrepreneurs [2].

Most of the algorithms for localization are based on distance measurements. Traditional ranging techniques for distance measurements are based on received signal strength indicator (RSSI), which is proved to be very unreliable method for distance estimation [3]. Therefore, most of the mathematical techniques for localization fail to maintain the same performances under the field conditions. For example, multidimensional scaling technique which is based on very exact mathematical background, although provides very small localization error in simulations, it gives high localization error when evaluated in real environment [4].

In the near future, with the technological advances, we expect new sophisticated ranging techniques that will be embedded in the wireless devices [5]. Having more accurate distance estimation, even basic localization techniques can perform small localization error, maintaining low complexity at the same time.

Therefore, in this paper we investigate very basic technique for localization based on trilateration [6]. To improve the performance of trilateration, we applied iterative approach, which is additionally refined. For refinement, we developed two different heuristics, implement them and evaluate the performances in order to choose the better one. The results from our simulations show that basic techniques for localization, refined with appropriate heuristics, can provide very acceptable localization error.

The rest of this paper is organized as follows. The mathematical and geometrical background of trilateration is given in Section II. In Section III we describe our iterative trilateration together with the two different heuristics for refinement. Simulation settings and results are presented in Section IV. Finally, the paper is concluded in Section V.

II. Trilateration

In this section we will provide a brief mathematical background of trilateration as a technique for localization in wireless sensor network.

Let's assume that a sensor device with unknown location is within the communication range of at least three other sensor devices with apriori known locations, also known as anchor devices. If the three anchors have coordinates $O_1(x_1, y_1)$, $O_2(x_2, y_2)$ and $O_3(x_3, y_3)$ respectively, the unknown device $A(x, y)$ lays in the intersections of the three circles with centers in O_1, O_2 and O_3 (Fig. 1). Using the distance equation assuming that r_i are the distances from the unknown point $A(x, y)$ to the anchor points O_1, O_2, O_3 respectively, we can obtain the coordinates of the unknown:

$$(x-x_1)^2+(y-y_1)^2 = r_1^2$$
$$(x-x_2)^2+(y-y_2)^2 = r_2^2$$
$$(x-x_3)^2+(y-y_3)^2 = r_3^2 \tag{1}$$

After expanding out the squares in each equation, subtracting one from another and solving the system of two equations in two unknowns as given in (2), (3), (4), (5),(6):

$$x^2-2x_1x+{x_1}^2+y^2-2y_1y+{y_1}^2 = r_1^2$$
$$x^2-2x_2x+{x_2}^2+y^2-2y_2y+{y_2}^2 = r_2^2$$
$$x^2-2x_3x+{x_3}^2+y^2-2y_3y+{y_3}^2 = r_3^2 \tag{2}$$

$$(-2x_1 + 2x_2)x + (-2y_1 + 2y_2)y = r_1^2 - r_2^2 - x_1^2 + x_2^2 - y_1^2 + y_2^2$$

$$(-2x_2 + 2x_3)x + (-2y_2 + 2y_3)y = r_2^2 - r_3^2 - x_2^2 + x_3^2 - y_2^2 + y_3^2 \quad (3)$$

To represent the constants in (3), using A, B, C, D, E and F (4), we get (5) and (6).

$$A = (-2x_1 + 2x_2)$$

$$B = (-2y_1 + 2y_2)$$

$$C = r_1^2 - r_2^2 - x_1^2 + x_2^2 - y_1^2 + y_2^2$$

$$D = (-2x_2 + 2x_3)$$

$$E = (-2y_2 + 2y_3)$$

$$F = r_2^2 - r_3^2 - x_2^2 + x_3^2 - y_2^2 + y_3^2 \quad (4)$$

$$Ax + By = C$$

$$Dx + Ey = F \quad (5)$$

$$x = \frac{CE - FB}{EA - BD}$$

$$y = \frac{CD - AF}{BD - AE}$$

(6)

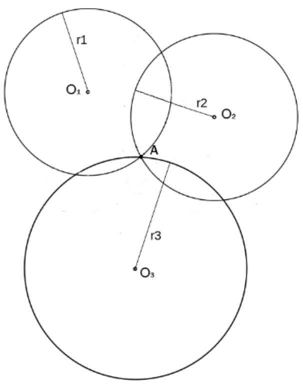

Fig. 1. Geometrical interpretation of trilateration.

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

1. Anchors advertise their location to other sensor devices from the surrounding.

2. Unknown nodes discover all anchors from the surrounding and select three closest anchors.

3. Unknown nodes apply equations (1) – (6) to calculate their coordinates.

III. ITERATIVE TRILATERATION

The main drawback of trilateration is its inability to localize all sensor devices in the network, i.e. only devices that has three anchors in its close proximity would be localized. Even if there is sufficient number of anchors, which are not evenly distributed around the environment, the trilateration will not achieve the desired results. Therefore, trilateration is usually applied as iterative approach. In each consecutive iteration, the sensor devices being previously localized become new anchors. The steps in iterative trilateration are as follows:

1. Anchors advertise their location to other sensor devices from the surrounding.

2. Unknown nodes discover all anchors from the surrounding and select three closest anchors.

3. Unknown nodes apply equations (1) – (6) to calculate their coordinates.

4. Unknown nodes become new anchors. Start step 1 until all nodes become anchors.

In this paper we apply the iterative trilateration approach. Similar approach was previously described and implemented for three-dimensional networks in [7]. In addition to [7], we apply a refinement using two different heuristics (H1 and H2), based on different approaches for choosing the most appropriate three surrounding anchors that will be used to localize the unknown device. Since the unknown device will have many anchors in its surrounding, some of them will be closer, but will have smaller reliability. In order to qualitatively distinguish the anchors, they are assigned a weight, that stands for unreliability. Namely, as new anchors are created in each consecutive iteration, they are supposed to have embedded some localization error.
In the first heuristic H1, the unknown node chooses the closest anchors in order to localize itself. In the second heuristic H2, it uses the most reliable anchors from its surrounding. If we denote the weight of the anchor nodes with $W(A_i)$ respectively, then the weight of the unknown node, after becoming new anchor, will be the sum of the weights of the anchors used for its localization, increased by 1 (7).

$$W(U_n) = W(A_1) + W(A_2) + W(A_3) + 1 \quad (7)$$

The step for each heuristic are described as follows.

H1:

1. Anchors advertise their location to other sensor devices from the surrounding.

2. Unknown nodes discover all anchors from the surrounding and select the five closest anchors.

3. Choose the best three anchors eliminating the possibility for anchors collinearity.

4. Unknown nodes apply equations (1) – (6) to calculate their coordinates.

5. Became a new anchor and go to 1.

H2:

1. Anchors advertise their location to other sensor devices from the surrounding.

2. Unknown nodes discover all anchors from the surrounding and select the five anchors with the smallest weight.

3. Choose the best three anchors eliminating the possibility for anchors collinearity.

4. Unknown nodes apply equations (1) – (7) to calculate their coordinates.

5. Became a new anchor and go to 1.

Since trilateration works only for three non-collinear points, we aim to reduce the possibility to choose three colinear anchors. Therefore, for both heuristics, in Step 2 we select 5 anchors. Then, in step 3, we select the best three anchors, eliminating those anchor combinations that are collinear or near collinear.

IV. SIMULATION RESULTS

To investigate and to compare the performances of proposed heuristics for iterative trilateration, we ran simulations. The parameters of the simulation settings were as follows:

1. Fixed number of sensor devices (*N*=100) deployed randomly with uniform distribution inside a square area (100*r* x 100*r*) where *r* is a unit length distance.

2. Different communication range *R*, from 35*r* to 70*r*, with step 10*r*.

3. Different range error *Er*, modeled as uniform distribution from 5%*R* to 50%*R* with step 10%*R* or 5%*R* for different situations.

4. Different anchor fraction *A*, ranging from 10%*N* to 50%*N* with step 10%*N*.

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

In this section, we investigate iterative trilateration accuracy in open 2D space. We address accuracy as average localization error (*ALE*), which is the average distance between the estimated positions and the real positions of all sensor devices, normalized to the devices communication range. *ALE* is computed using (8).

$$ALE = \frac{\sum distance(pos_i^{calculated} - pos_i^{real})}{(N-A)R} 100\% \qquad (8)$$

The first aim of our simulation was to discover which heuristic is more appropriate for solving localization problem in WSN. Fig. 2, Fig. 3 and Fig. 4 show that heuristic H1 perform better and gives smaller localization error compared with heurist H2 for all simulation configurations.

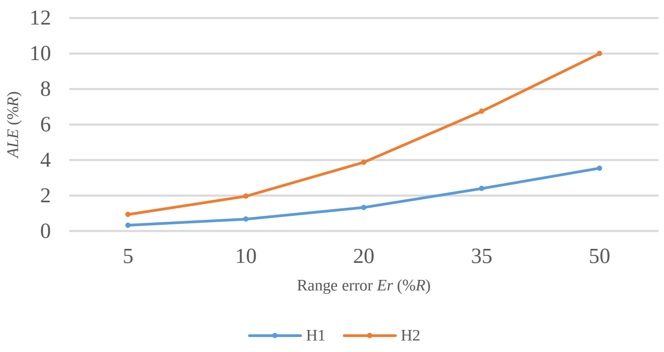

Fig. 2. Evaluation of iterative trilateration, with variable range error *Er*, communication range *R* = 40*r* and anchor fraction *A* = 35.

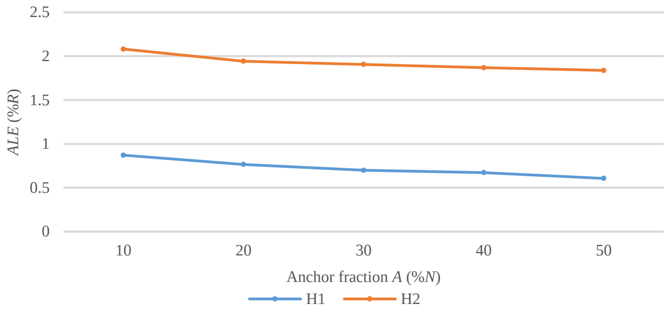

Fig. 3. Evaluation of iterative trilateration, with variable anchor fraction *A*, communication range *R* = 40*r* and range error *Er* = 10%*R*.

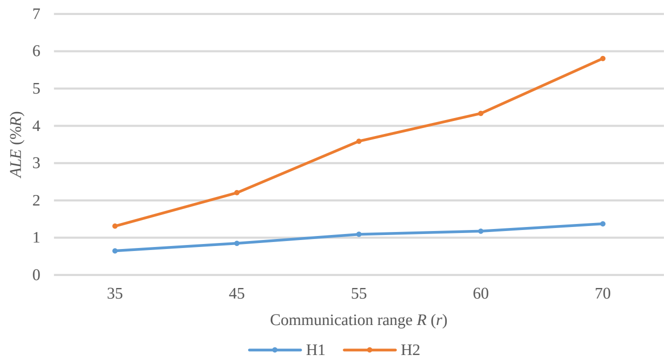

Fig. 4. Evaluation of iterative trilateration, with variable communication range *R*, range error *Er*=10%*R* and anchor fraction *A*=35.

As expected, using more anchor nodes gives slightly smaller localization error. Number of anchors affects the results when the communication range is high (Fig. 5). For small communication range (Fig. 6), there is no evident localization accuracy improvement, especially for small to medium anchor fraction.

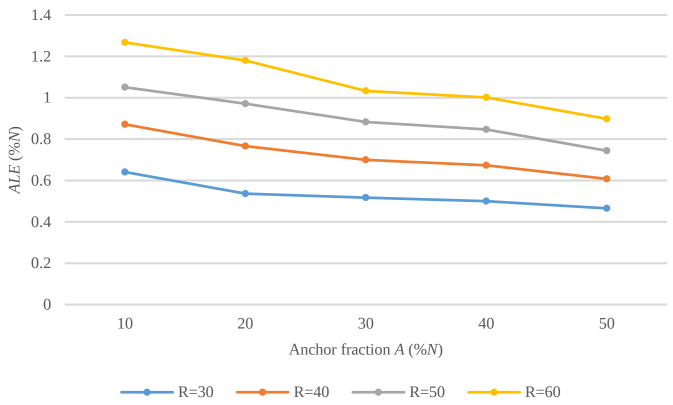

Fig. 5. Evaluation of iterative trilateration, with variable anchor fraction *A*, communication range *R* and range error *Er*=10%*R*.

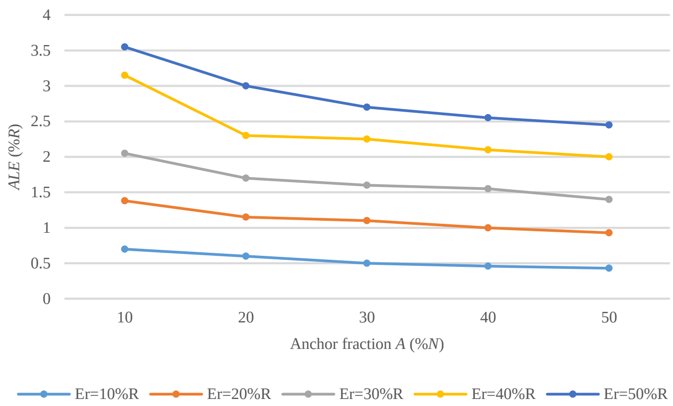

Fig. 6. Evaluation of iterative trilateration, with variable anchor fraction *A*, range error *Er* and communication range *R*=30*r*.

Range error E_r has great impact on localization error. As E_r increases, H1 deteriorates (Fig. 7 and Fig. 8).

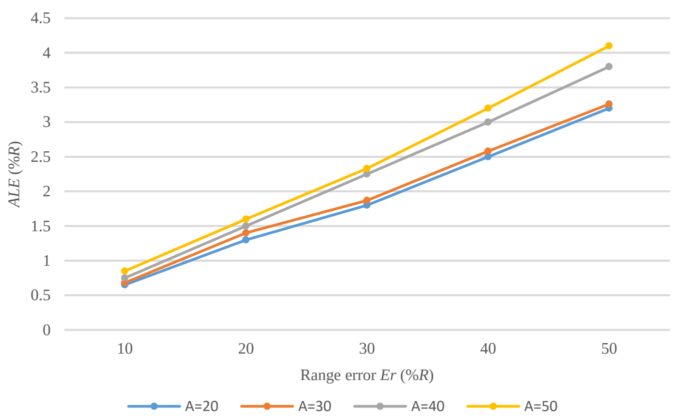

Fig. 7. Evaluation of iterative trilateration, with variable range error *Er*, anchor fraction *A* and communication range *R*=40*r*.

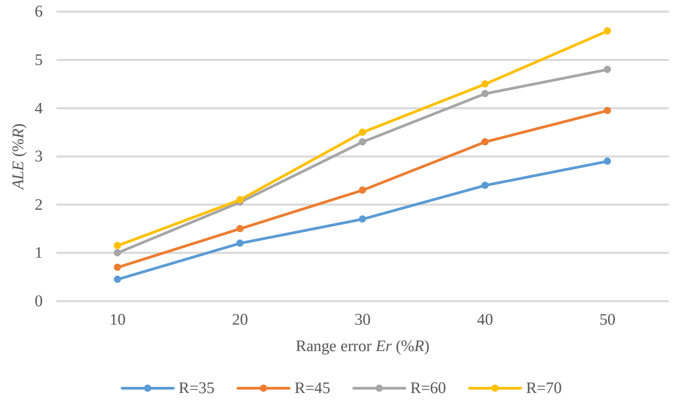

Fig. 8. Evaluation of iterative trilateration, with variable range error *Er*, anchor fraction *A*= 40%N and communication range *R*.

Fig. 9 shows evaluation of iterative H1 trilateration, for different communication range *R*, different range error *Er* and anchor fraction of 20 nodes. Fig. 10 shows the results of H1, for different communication range R, different anchor fraction A and range error *Er*=10%*R*. As can be seen from the figures, in both cases, H1 performs smaller estimation error for smaller *R*. The reason is that *Er* increases with R, and *Er* greatly affects the localization error.

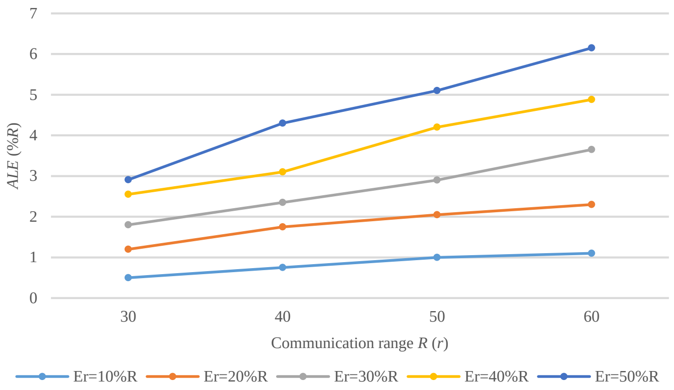

Fig. 9. Relationship between *ALE* and *R* for different *Er*.

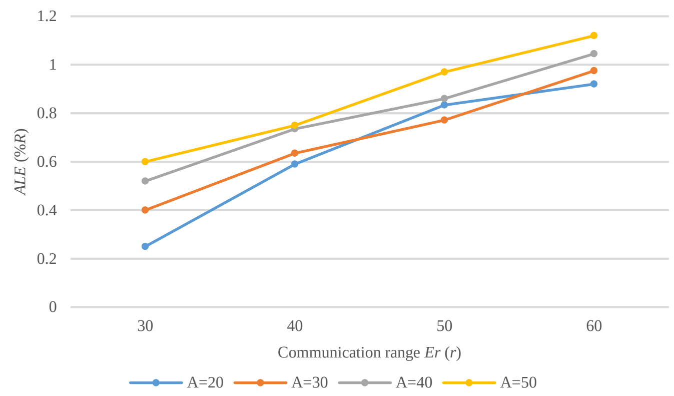

Fig. 10. Relationship between *ALE* and *R* for different *A*.

V. Conclusion

In this paper we explore two different heuristics that adopt trilateration as a base technique. Our heuristics use distance information together with knowledge about the most appropriate anchors in terms of quality. We show that by improving trilateration with different heuristics, localization error can be significantly reduced, while maintaining low computational cost. For future work, we will investigate the behavior of our approach in three dimensional networks in order to compare the results with [7].

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References

[1] Shit, Rathin Chandra, Suraj Sharma, Deepak Puthal, and Albert Y. Zomaya. "Location of Things (LoT): A Review and Taxonomy of Sensors Localization in IoT Infrastructure." IEEE Communications Surveys & Tutorials (2018).

[2] Stojkoska, Biljana Risteska, Ivana Nizetic Kosovic, and Tomislav Jagušt. "A Survey of Indoor Localization Techniques for Smartphones." In th International Conference ICT Innovations 2016. 2016.

[3] Parameswaran, Ambili Thottam, Mohammad Iftekhar Husain, and Shambhu Upadhyaya. "Is RSSI a reliable parameter in sensor localization algorithms: An experimental study." In Field failure data analysis workshop (F2DA09), vol. 5. IEEE, 2009.

[4] Stojkoska, Biljana Risteska, Ivana Nižetić Kosović, and Tomislav Jagušt. "How much can we trust RSSI for the IoT indoor location-based services?." In Proceedings of the 25th International Conference on Software, Telecommunications and Computer Networks (SoftCOM,'17), Split, Croatia. 2017.

[5] Brena, Ramon F., Juan Pablo García-Vázquez, Carlos E. Galván-Tejada, David Muñoz-Rodriguez, Cesar Vargas-Rosales, and James Fangmeyer. "Evolution of indoor positioning technologies: A survey." Journal of Sensors 2017 (2017).

[6] Zhou, Zhong, Jun-Hong Cui, and Shengli Zhou. "Localization for large-scale underwater sensor networks," Networking 2007. Ad hoc and sensor networks, wireless networks, next generation internet, pp. 108-119, 2007.

[7] Stojkoska, Biljana Risteska, and Nasi Jofce. "Simple Iterative trilateration-based scheme for indoor localization of IoT devices.", ICT Innovations 2017, Web Proceedings, ISSN 1865-0937, pp. 121—129.