Trilateration and Multilateration Based Localization of Wireless Devices

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***Abstract*—Many new techniques for localization of wireless sensor networks have been developed in the past few decades, the most popular of which is multilateration – a simple technique that determines the position of one node or sensor in space using data collected from other nodes or sensors in the same network. In this paper, we propose a new localization algorithm based on multilateration, named as 'Moving Point Algorithm', which logarithmically searches the space to determine the location of a given node in the sensor network. The simulation of out algorithm shows that it outperforms traditional multilateration by means of localization accuracy and percentage of localized nodes.**

***Index Terms*—Wireless Localization, Multilateration, Localization Algorithm**

I. INTRODUCTION

Localization of wireless devices is a very challenging problem in the research community for many years [1], [2]. Initially it aimed to find the unknown location of wireless devices randomly scattered in the monitoring area, usually for military purposes. With the advances in ICT, the problem was extended by finding the location of various wireless devices, including users' mobile phones in areas where GPS signals are not accurate [3], [4], or livestock tracking [5].

Trilateration is an old technique used to determine the position of one unknown point in space using the a-priory known positions of other points and the distance between these points and the unknown point. In two-dimensional space, at least the positions of three points are required. Around each known point a circle is drawn with a radius equal to the distance between the known point and the unknown point. The intersection of the three circles is the position of the unknown point (Fig. 1). Since this technique uses three points, it is also known as trilateration (not to be confused with triangulation, which uses angles instead of distances).

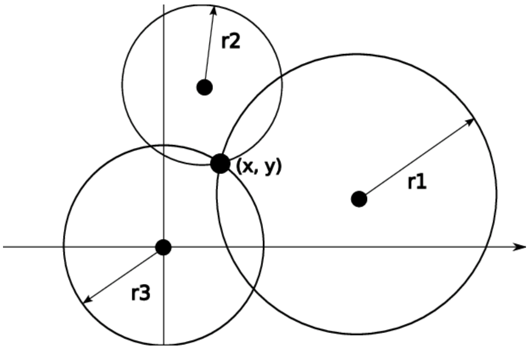

Fig. 1. Geometrical interpretation of trilateration.

In three-dimensional space, the distances describe spheres instead of circles, and since three spheres have two intersection points, we require a fourth known point to determine the position of the unknown point. Since we are now using more than three points, we call the technique multilateration.

The most famous application of multilateration-based positioning systems is the GPS system, which allows us to determine the location of a device by measuring its distance to (at least) three satellites in the orbit. This system is reliable and accurate to a margin of several meters. However, there are cases where this system is insufficient, such as when we need more accurate positioning. Additionally, GPS signals are not available indoors, thus there is a need for pure algorithmic approach.

The positioning method presented in this paper uses an algorithmic approach to the problem as opposed to the mathematical approach of multilateration and gives better results than the basic multilateration technique.

The rest of this paper is organised as follows. The classic approach to localization is given in Section II. In Sections III and IV we describe our new localization algorithms. Simulation results and comparisons are presented in Section V. Finally the paper is concluded in Secion VI.

II. ITERATIVE LOCALIZATION

If the network contains many nodes with a-priori known location (anchor nodes), it can be assumed that all unknown nodes are within the range of at least 3 (in 2D space) or 4 (in 3D space) anchors. In this scenario, all nodes in the network can be localized. But in practice, this is often not true, i.e. there are many nodes which are not in close proximity to the anchor and they cannot be localized. An improvement over the original technique is to use an iterative approach, meaning that the nodes that are already localized can become new anchor nodes [6], [7]. If two nodes that are close to each other and can communicate with each other are "neighbouring" nodes, then the only requirement of this approach is to have a network where each node has at least three (four) neighbours. Still, this improved approach has flaws such as error accumulation with each successive step. Therefore, it is important to measure the quality of the localized anchors. The initial anchors have a weight of 0, the nodes which are localized first have a weight of 1, and all remaining nodes have a weight equal to the weights of all nodes used for their localization increased by 1 [6]–[8]. If more than three (four) anchor-candidates are available for the localization of an unknown node, choosing the best is not always straightforward. Some nodes can be closer, which would minimize the distance measurement error, but others could have a lower anchor-weight and give more accurate measurements.

III. The Moving Point Algorithm

Contrary to the Iterative Multilateration approach, which uses one single calculation for the position of the unknown node based on its distance to the anchor nodes, the Moving Point Algorithm (MPA) uses a logarithmic search of the space the network occupies, and finds the position which best corresponds to the position of the unknown node. The algorithm works as follows.

For the unknown node all potential anchor nodes are identified. Of these, four are selected - the ones closest to the unknown node. Then, the distances to the center of the network are calculated - MPA always begins its search from the center.

In each next step, the 'moving point' makes one step in one of six directions - up, down, left, right, forward or backward. For each of these possible moves, its distance to the anchors is calculated, and the move which results with the minimal difference between its distances and those between the unknown node and the anchors is chosen - in other words, the moving point moves towards the position of the unknown node.

The distance that the moving point crosses with each successive step shrinks until its position overlaps with the position of the unknown node. MPA has internal metrics which can estimate how far the moving point is from the unknown node, and once it has moved sufficiently close, the algorithm ends and the unknown node is localized.

IV. Dynamic Moving Point Algorithm

Unlike the classic Iterative Multilateration, the MPA is capable of using an increased number of anchors for increased precision. We can separately increase the minimum and maximum number of used anchors. Increasing the maximum number of possible anchors reduces the localization error without lowering our localization percentage, up to a certain limit. Increasing the minimum number of required anchors drastically reduces the average localization error, but also reduces the percentage of nodes that can be localized. Fig. 2 shows the localization results of the classic Iterative Multilateration, the basic version of the MPA, as well as several variations of MPA using different minimum and maximum anchors used, in the format MPA (X,Y) where X is the minimum number of anchors that must be used, and Y is the maximum possible number of anchors that can be used. This gives us the option of dynamically choosing the number of anchors we use for each node's localization. The Dynamic Moving Point Algorithm (DMPA) differs from the original by first trying to use as many anchors as possible, and then reducing the number of required anchors in each next iteration if the localization has been unsuccessful.

As a result of that, this algorithm ensures maximum possible localization accuracy for the majority of the unlocalized nodes, while also ensuring maximum overall localization by localizing a small minority of the nodes with lower accuracy.

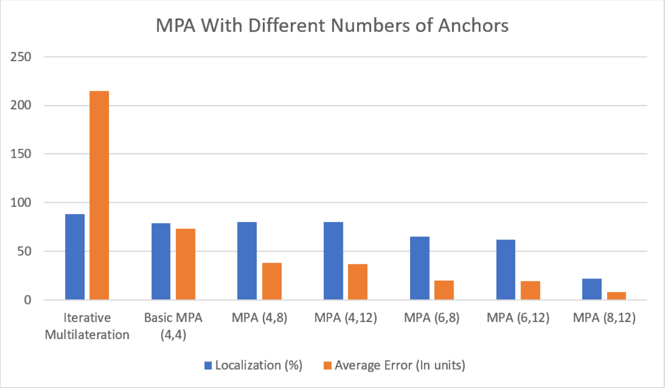

Fig. 2. Evaluation of the percentage of localized nodes and average localization error of Iterative Multilateration, Basic MPA and several variations of MPA.

V. Simulation Results

For the comparison of the three algorithms we simulated sensor network organised as follows:

- 100 nodes are dispersed in a cube with dimensions of 1000 x 1000 x 1000 units with a normal distribution.
- Of these 100 nodes, anchor fraction is in a range of 10 to 50 with an increment step of 10.
- The communication range varies from 100 to 500 units with an increment step of 100.
- The measurement error varies from 5% to 25% with an increment step of 5%.

The computation error is simulated by introducing random variations in the calculated distance between nodes within the specified measurement error limit. These variations follow a normal distribution, meaning the final distance values used to compute the position of the unknown node have a value in a range with the upper limit being the sum of the true distance and the maximum possible error, and the lower limit being the difference between the true distance and the maximum possible error.

The following figures show the number of successfully localized nodes (as a percentage), and the average positional error of the localized nodes (in distance units). The positional error is computed after the algorithms have finished and the node has been localized, as the difference between its localized position and its true position in space.

A. *Evaluating the change of the fraction of initial anchors*

For all algorithms the communication range is set to 300 units, the error rate to 10% and the anchor fraction is evaluated at 10% increments from 10% to 50%.

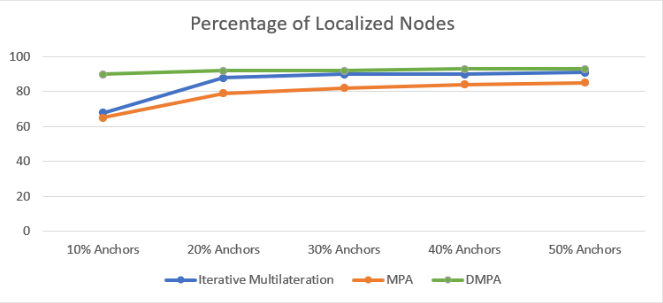

Fig. 3. Percentage of localized nodes for Iterative Multilateration, MPA and DMPA for different anchor fractions

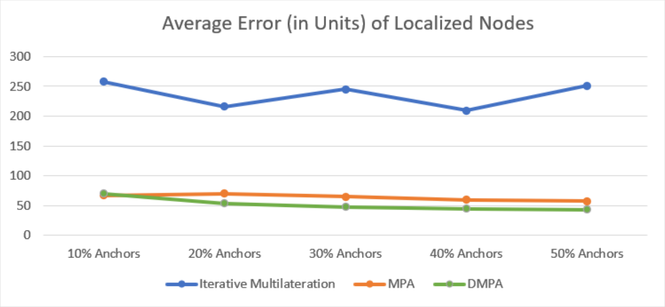

Fig. 4. Average node localization error (in units) for Iterative Multilateration, MPA and DMPA for different anchor fractions

On Fig. 3 and Fig. 4 we can see the results of the comparison of the three algorithms and conclude that DMPA offers slightly better results than the other two algorithms in all scenarios, and significantly better results when we have a small fraction of initial anchor nodes.

B. *Evaluating the change of the communication range*

For all algorithms the fraction of anchors is set to 20%, the error rate to 10% and the communication range is evaluated at 100 unit increments from 100 to 500 units.

On Fig. 5 and Fig. 6 we can see the results of the comparison of the three algorithms and conclude that DMPA can localize a significantly greater number of nodes at lower communication ranges, but with greater average error than the basic MPA. At greater communication ranges, however, it offers a significantly lower error rate.

C. *Evaluating the change of the measurement error*

For all algorithms the communication range is set to 300 units, the anchor fraction to 20% and the measurement error is evaluated at 5% increments from 5% to 25%.

On Fig. 7 and Fig. 8 we can see the results of the comparison of the three algorithms and conclude that both Moving Point Algorithms offer significantly reduced error rates as opposed to Iterative Multilateration.

VI. CONCLUSION

In this paper we propose Moving Point Algorithms (MPA) and its improvement known as Dynamic Moving Point Algorithms (DMPA), as an alternative approach to trilateration technique for localization problem of wireless devices. Both algorithms were simulated in different conditions, such as variable fractions of initial anchor nodes, communication ranges and distance measurement accuracy.

Overall, both algorithms offer significant improvements to the accuracy of the localized nodes compere to the traditional iterative trilateration. Both MPA and DMPA provide a 20 to 80 percent reduction in localization error (more at higher communication ranges). DMPA additionally provides significantly higher localization percentages in sparse networks where communication between nodes is limited.

From the simulation results we can conclude that our algorithmic approach offers significantly more accurate localization than the classical iterative trilateration technique, albeit at the cost of increased processing power and computation time. As future works, we aim to explore the possibilities for algorithms optimizations .

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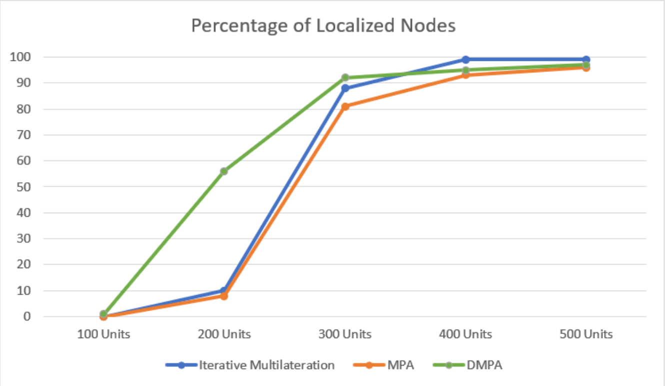

Fig. 5. Percentage of localized nodes for Iterative Multilateration, MPA and DMPA for different communication ranges

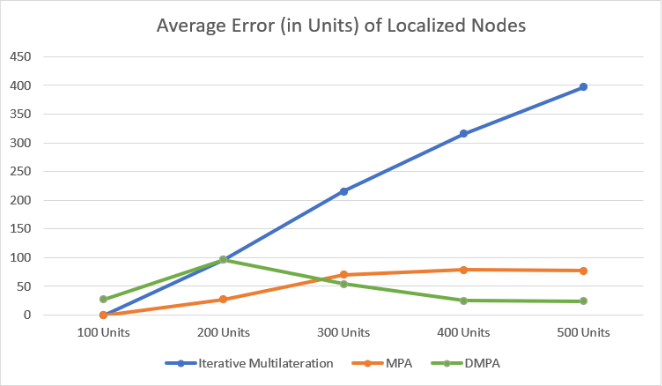

Fig. 6. Average node localization error (in units) for Iterative Multilateration, MPA and DMPA for different communication ranges

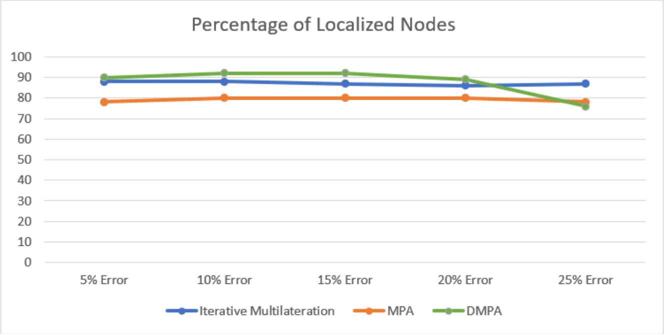

Fig. 7. Percentage of localized nodes for Iterative Multilateration, MPA and DMPA for different measurement errors

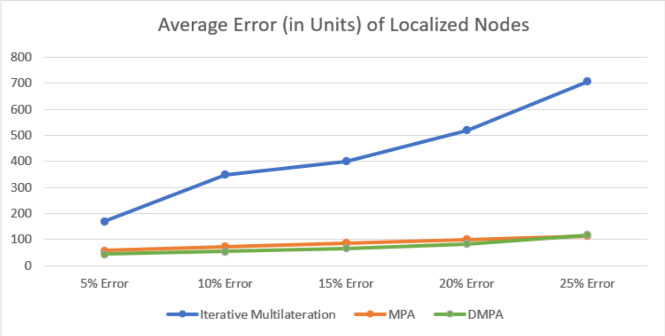

Fig. 8. Average node localization error (in units) for Iterative Multilateration, MPA and DMPA for different measurement errors

REFERENCES

[1] Yanying Gu, Anthony Lo and Ignas Niemegeers, “A survey of indoor positioning systems for wireless personal networks”, in IEEE Communications Surveys & Tutorials, vol. 11, no. 1, pp. 13-32, First Quarter 2009. Doi: 10.1109/SURV. 2009.090103

[2] Zahid Farid, Rosdiadee Nordin and Mahamod Ismail. 2013. “Recent Advances in Wireless Indoor Localization Techniques and System.” Journal of Computer Networks and Communications 2013: 1-12.

[3] Biljana Risteska Stojkoska, Ivana Kosovic Nizetic and Tomislav Jagusht. A Survey of Indoor Localization Techniques for Smartphones, ICT Innovations 2016, Web Proceedings, ISSN 1865:0929, pp. 11-22, 2016

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

[5] Biljana Risteska Stojkoska, Dijana Capeska-Bogatinoska, Gerhard Scheepers and Reza Malekian, “Real-time internet of things architecture for wireless livestock tracking”, in Telfor Journal, 2018

[6] Biljana Risteska Stojkoska 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

[7] Andrej Jovanov, Robert Stoimenov and Biljana Risteska Stojkoska. “Exploring different heuristics for WSN localization based on trilateration”, CIIT 2018, Web Proceedings

[8] Matsna Nuraini Rahman, MT Ir Ahmad Tri Hanuranto and STMT Ratna Mayasari. ”Trilateration and iterative multilateration algorithm for localization schemes on wireless sensor network.” In 2017 international conference on control, electronics, renewable energy and communications (ICCREC), pp. 88-92. IEEE, 2017.