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Procedia Computer Science 151 (2019) 501–510

Procedia Computer Science

www.elsevier.com/locate/procedia

The 10th International Conference on Ambient Systems, Networks and Technologies (ANT)
April 29 - May 2, 2019, Leuven, Belgium

Comparative Study on Range Free Localization Algorithms

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Abstract

Nowadays, determining the exact position of sensor nodes in WSNs is an important factor in many applications. As the need of the localization accuracy varies between the applications, many localization techniques are used in different applications. Hence, node localization becomes one of the fundamental challenges in WSNs. Localization is categorized in two groups: range free and range based. In the range free techniques, localization is related between nodes and topological information of sensor nodes. On the other hand, in range based techniques, it is required to calculate distance between nodes. The scope of this paper is on range free localization. We survey different range free localization techniques and discuss some localization-based applications where the location of these sensor nodes is vital and sensitive. On the second part of the paper, we describe five algorithms namely: Centroid, Amorphous, APIT, DV-Hop and DV-HopMax algorithms. We simulate these algorithms using MATLAB based on different setups. Moreover, we make a comparative study between these localization algorithms based on different performance metrics showing their pros and cons.

Keywords: Localization; Wireless Sensor Network; Range-Free; Range-Based; Anchor Nodes.

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10.1016/j.procs.2019.04.068

1. Introduction

Due to the rapid growth and development of wireless sensor Networks, localization becomes a primary concern. As the reported data event in WSN is meaningful only if its position is known, localization is gaining the attention of researchers around the world. It is not applicable to provision each sensor node with Global Positioning System (GPS) for large network sensors because of power consumption and cost [1]. Wireless Sensor Network is broadly used in different areas such as military applications, industrial applications, medical care, disaster relief, and environmental monitoring [2]. For such applications, we need to find out the position of the data in order to take right decision. The method to determine the position of a node assigned in a network is often considered as localization problem [3].

Distributed localization schemes can be classified into two groups; Range based and Range Free localization technique. Range based localization schemes determine distances between Anchor nodes and Sensor nodes based on inter devices angles or device to device distances then estimates the location using different geometric methods. Position of anchor nodes are known, either using GPS or manual pre-programming during deployment, while Sensor nodes calculate their location with reference to Anchor nodes. The benefit of range based techniques is that it has a high ranging accuracy compared to range free techniques. However, the limitation of these schemes is that they need additional hardware, expensive for large systems and also its deployment is very difficult. Some well-known range based schemes are: Received Signal Strength Indicator (RSSI), Time of Arrival (ToA), Angle of Arrival (AoA), and others [4]. For range free localization techniques, on other hand, no need to determine distances directly; instead it uses hop count between anchor nodes and sensor nodes. Then average distances between hops have been used. Lastly it computes location using geometric methods. Some benefits of these techniques are there is no need for special hardware support, and they are cost efficient, mostly at the expense of the level of accuracy [5]. Common range free localization techniques are Centroid, Amorphous, DV-Hop and DV-HopMax.The comparison between Range Based and Range Free is summarized in Table 1.

Table 1: Comparison between Range Based and Range Free Techniques

Parameters	Range Based Technique	Range Free Technique
Additional Hardware	Needed	Not Needed
Level of Accuracy	High (85%-90%)	Low (70%-75%)
Power Consumption	High	Low
Deployment	Hard	Easy
Robustness	High	Low

The remaining parts of this paper is divided as follows. In section II, we discuss the main points of some previous literature surveys. In section III, we investigate five range free algorithms. Performance analysis for these selected algorithms is described in section IV. Lastly, we conclude our work in section V.

2. Related Work

Various localization algorithms are proposed to address localization issues. There are several metrics that are considered to compare these algorithms. In this paper, we survey different approaches from recent studies in the literature, and try to identify the research gaps that can be addressed in this study. Eva Tuba et al., [6] used, in their paper, a bat algorithm for Range Based Localization to estimate sensor node positions. The algorithm has two stages, first stage; four mobile beacons have been located at the edges of the region where nodes are placed to estimate the coordinates of sensors. Then, in the second stage, the beacons go to their ideal positions with lowest possible distance to sensor nodes. The proposed algorithm is more suitable for regular localization.

In [4], a hybrid extendible Range Based Distributed Cooperative Approach is proposed, the goal is to examine the impact of MAC on the localization. It is crucial to reduce collisions and retransmissions of packets, which significantly participate saving of energy consumption. To evaluate the performance, authors have varied parameters in order to investigate their effects on the MAC. These parameters include energy consumption, average localization accuracy, average localization time, and the deployment strategy. Authors showed the importance of integration MAC protocol along with the localization algorithm, however, this will minimize the energy consumption and the localization time. However, it needs to come up a localization method with capability of MAC optimizing energy consumption.

In [7], they reduced localization error in WSN, in order to do that, they presented a model called Adaptive Information Estimation Strategy Time of Arrival (AIES-TOA), then they compared with Root Mean Square Standard (RMS-STD), in terms of localization error, Error tolerance, and localization distance error. They showed that the AIEA-TOA outperforms the RMS-STD by 12.64%, 10.62%, and 86.62%, for localization error, error tolerance, and localization distance error respectively. In paper [8] concentrates on enhancing the localization technique that basically relies on Received Signal Strength (RSS). To bear some nugatory errors in the information of node location, a reference beacon node is used. Furthermore, Dixon Approach is employed to eradicate the aberrations of Received Signal Strength Indicator (RSSI) Algorithm. The learning model here is advanced to minimize the ranging error of RSSI and boost the localizing precision adequately. Researchers in [9] proposed a range free localization approach that is used to estimate the positions of nodes. In their work, they improved minimum mean square error that makes easy the computation of the distance between source and destination nodes. Moreover, they considered hop counts between source and destination nodes, and coverage radius. Some features of this approach are high accuracy in determining geographical coordinates, low traffic load, and good performance for both homogeneous and heterogeneous environments. They showed that their approach has good location estimation and minimized traffic load at the same time compared to other existing localizing approaches. In [10] authors introduced a 3D-GAIDV range free localization model for WSN, here a correction factor has been used to modify the average hop size of beacon nodes.

Comparative evaluation of different range free techniques in [11] were carried out. They studied and compared each of these techniques in terms of localization error. The results showed that the presence of inverse proportional relation between the number of nodes and the range value. They also demonstrated the MDS-MAP technique produces better results compared to other existing techniques, even if both number of nodes and the range value are increased. On other hand, the error is less changed for both distance vector hop (DV Hop) and Amarphous techniques. Also, in an effort to solve the localization problem [12] developed a novel range free technique using Genetic Algorithms. The authors calculated a position of unknown node by using Genetic Algorithms (GAs) and traditional DV hop technique. In [13] the authors compared two range free localization algorithms which are Fingerprint and Centroid algorithms using Tmote sky. The authors compared the algorithms in terms of localization accuracy and average error. They showed that fingerprint algorithm has a better performance compared to centroid localization algorithm. In [14], presented an improved version of Distance Vector Hop (DV-Hop) technique, their aim is to save energy by allowing only one beacon node broadcast its position information. When the coordinates are estimated, then the location error is reduced by using ratio position, consequently, location accuracy is improved. The proposed algorithm is compared against two other DV-Hop techniques, the first one is based on last squares and the second is relied on improved particle swarm. The proposed technique performs better in terms of localization accuracy and energy saving.

3. Range Free Algorithms

In this section, we are going to describe four popular range free algorithms (Centroid, DV-Hop, Amorphous and APIT) in details since they are mostly used in the literature reviews:

3.1. Centroid Algorithm

The centroid localization algorithm was proposed by Bulusu as in [15], it is one of the simplest range-free algorithms since it requires only a minimum of computations and little communication expenses comparing with other algorithms. Simply, all unknown nodes calculate their locations as the centroid of all received packets from the beacon nodes within their communication range. Generally, this algorithm is based on a binary information that whether the unknown node is within the communication range or not in order to consider it in the estimated value. However, each beacon node has a circular shape and nodes who are located inside this circle can communicate with them as in Fig.1. Where, there are four beacons with circular range and there is one unknown node, in this figure the estimated location for the beacons is the centroid value.

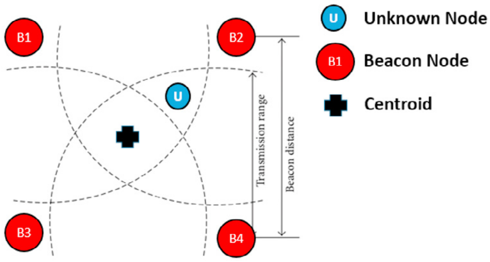


Fig. 1: Nodes representation in the Centroid Algorithm

The pseudo code of this Localization Algorithm is as follows:

Algorithm 1 Centroid Localization Algorithm

Firstly, Receive the location from N neighbour beacon nodes $B_j(x, y)$
Then, Evaluate the location of unknown nodes $C_i(x, y)$ using Centroid Formula
if $N \geq 3$ **then**
    $C_i(x - coordinate) \leftarrow \frac{1}{N}\sum_{i=1}^{N} x_i$ and $C_i(y - coordinate) \leftarrow \frac{1}{N}\sum_{i=1}^{N} y_i$
end if
Last, Same procedure will be repeated for all unknown nodes.

As we mentioned in the beginning, centroid algorithm is a simple algorithm but the accuracy is high comparing with other algorithms and this is due to using the centroid formula. However, the accuracy and the beacon nodes density of the estimate location depend on the type of distribution, more uniform network will increase the localization accuracy.

3.2. DV-Hop Algorithm

Another well-known algorithm from the range free localization group is called DV-Hop algorithm. This algorithm was proposed by Niculescu et al [16] in 2003, it is a distributed hop-by-hop localization algorithm. Mainly, it is based on the distance vector as in the traditional routing algorithms. However, this will give an approximate value for the estimated location for any unknown node within the network by using few number of known location nodes, which are most probably equipped with GPS.

DV-hop algorithm is not using the usual ranging techniques to locate and find the distances of the unknown neighbouring nodes. Simply, each sensor node will calculate its distance based on the minimum hop number and the average distance with respect to the beacon node. After that, the distance can be computed between itself and beacon node by multiplying the minimum hops with the average distance of each hop. At last, each node will estimate its position coordinates using different kind of estimators like, triangulation, maximum likelihood estimators and so on. Particularly, DV-hop algorithm consists of three stages as described in the following detailed manner:

Stage One: Finding the minimum number of hop counts for each node, each beacon node broadcasts a beacon message including his its position coordinates and the hop count which is set to zero at the beginning of transmission. This value will be incremented by other neighbor nodes when they have received and then it will be rebroadcasted again. Therefore, if the beacon or normal node receives the beacon message, it will store the coordinates of the sender node as well as increment the hop count by one. In the meantime, it will initialize a new field called hop size, where this value represents the minimum number of hops between the sender and the node itself. Actually, if the receiver node receives message from the same beacon node, it will first check the hop number and increment it directly, and then compare it with the stored one if it is lesser, it will update its value and rebroadcast it again by the new hop value. Otherwise, it will not even only drop the message but also it will not rebroadcast again to its neighbors. At the end of this stage, all nodes, beacon and normal, will have only the minimum hop counts with respect to every beacon node within the network.

Stage Two: Evaluating the average hop distance; each beacon node evaluates the average distance per hop by using the coordinates that were received from other beacon nodes along with the minimum number of hops needed to reach this beacon; where this value can be estimated by using:

$$HopSize_i = \frac{\sum_{j=1\ \ j\neq i}^{n} \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2}}{\sum_{j=1\ \ j\neq i}^{n} HopCount_{ij}} \tag{1}$$

Where (x_i, y_i) and (x_j, y_j) are the coordinates of the beacon nodes i and j respectively, $HopCount_{ij}$ is the number of hops between i and j, n is the total number of beacon nodes. Then, each beacon node needs to flood this value to other nodes. Once, this value has received by the unknown node, it will store only the first received packet and then send it again to its neighbours. This will assure that most of the nodes receive the value of the nearest beacon node. In the meantime, once the unknown node receives this value and store it, then it will evaluate the distance between itself and the beacon node, where this can be done by using:

$$Distance_{ub} = HopSize_i \times HopValue_{ub} \tag{2}$$

Where $HopSize_i$ is the hop value received by this unknown node from the nearest beacon node i, and $HopValue$ is the minimum hops between the beacon node and this unknown node.

Stage Three: Estimating the location of the unknown node, the unknown node can estimate its location by using triangulation and least mean square estimator along with the evaluated values from stage two.

The main advantages of DV-Hop algorithm are being simple, less complexity, and low-cost (i.e., no need for ranging techniques). On the other hand, it may suffer from low accuracy, especially when we have a small network. This can be explained if we have a pair of nodes with same hop distance value from all beacon nodes, so, we will get the same estimated location while this is not acceptable in the reality since they might be apart from each other. Therefore, most of the researches after 2003 tried to improve the localization accuracy regardless how many beacon and unknown node in the network and the distances between them.

3.3. Amorphous Algorithm

The Amorphous Localization algorithm [17], proposed independently from DV-Hop, it is similar to DV-Hop algorithm, and the idea is to calculate the hop distance between two nodes instead of the linear distance between them. Mainly, amorphous algorithm consists of the following three steps:

Step One: Calculate the Minimum Hop from the Unknown Node to the Beacon Node, every beacon node sends messages to the unknown nodes by flooding method. The minimum hop from the unknown node i to the beacon node k is calculated by using following formula:

$$S_{(i,k)} = \frac{\sum j \in nbrs\,(i)\, h_{(j,k)} + h_{(i,k)}}{|nbrs\,(i)| + 1} - 0.5 \tag{3}$$

where $S(i,k)$ is the minimum hop from the unknown node i to the beacon node k; $h(j,k)$ is the integer hop from the unknown node j to the beacon node k; $h(i,k)$ is the integer hop from the unknown node i to the beacon node k; $nbr(i)$ is the neighbour nodes around the unknown node i; $|nbr(i)|$is the number of the neighbour nodes around the unknown node i.

Step Two: Calculate the Distance from the Unknown Node to the Beacon Node, the average distance of one hop is calculated by using this formula:

$$HopSize = r\left(1 + e^{-n_{local}} - \int_{-1}^{1} e^{-(n_{local}/\pi)(arcos\ t - t\ \sqrt{1-t^2})}\,dt\right) \tag{4}$$

Where r is the wireless range of the node and $nlocal$ is the average connectivity of the network. Formula (5) is used to calculate the distance d from the unknown node to the beacon node on the basis of the average distance of one hop and the minimum hop from the unknown node to the beacon node.

$$d = HopSize_i \times S_{(i,k)} \tag{5}$$

Step Three: adopt the Least Squares Method to Locate, when the estimated distances from the unknown node to three or more than three beacon nodes have been obtained, the location of the unknown node can be calculated by using same calculations mentioned in DV-Hop algorithm for least square estimation.

3.4. APIT (Approximate Point in Triangle) Algorithm

APIT (Approximate Point in Triangle) is the free-range approach [18]. APIT requires a heterogeneous network of sensing devices where a small percentage of these devices (percentages vary depending on network and node density) are equipped with high-powered transmitters and location information obtained via GPS or some other mechanism. We refer to these location-equipped devices as anchors. In this approach as we can see in Fig.2 the whole area of the network divided into triangular between anchors. Inside or outside of every triangle has a node which is allows a node to narrow down the area in which it can potentially reside. By utilizing combinations of anchor positions, the diameter of the estimated area in which a node resides can be reduced, in order to provide a good location estimate and satisfactory accuracy.

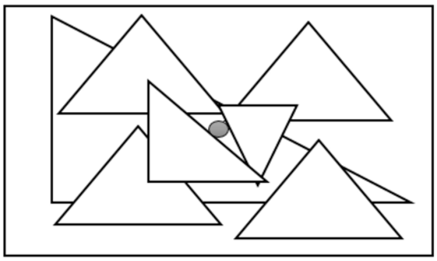


Fig. 2: Area-based APIT Algorithm Overview

The hypothetical method used to narrow down the possible area in which a target node resides is called the Point-In-Triangulation Test (PIT). In this test, a node chooses three anchors from all noticeable anchors (anchors from which a beacon was received) and tests whether it is inside the triangle formed by connecting these three anchors. APIT repeats this PIT test with different noticeable anchor combinations until all combinations are exhausted or the required accuracy is achieved. At this point, APIT calculates the center of gravity (COG) of the intersection of all of the triangles in which a node resides to determine its estimated position. The basic pseudo code for APIT algorithm as follows:

3.5. DV-HopMax Algorithm

Shahzad et al. [19] proposed an extended technique of the DV-Hop called DV-HopMax for both anisotropic and isotropic networks. Authors in this paper introduced a new parameter called MaxHop, the value of this parameter depends on the characteristics of the network topology in order to improve the accuracy of the whole network. The concept of this algorithm is very simple, it only follows the same steps of the DV-Hop with minor modifications. Where, the main difference that the hop count is limited by a threshold value and it will not forward the received

Algorithm 2 APIT Algorithm

1: Receive location beacons (X_i, Y_i) from N anchors.
2: InsideSet = Φ // the set of triangles in which I reside
3: **For** (each triangle $T_i \in (\binom{N}{3})$ triangles) {
4: **If** (Point-In-Triangle-Test (T_i) == TRUE)
5: InsideSet = InsideSet ∪ { T_i }
6: **If** (accuracy(InsideSet) > enough) break; } /* Center of gravity (COG) calculation */
7: Estimated Position = COG ($\cap T_i \in$ InsideSet);

packet if the value is larger than this value. So, the unknown node will neglect the information from the beacon nodes, if the hop count is more than MaxHop. Since the distance estimation of some nodes especially that are not helping or even deforming the accuracy; this will produce some errors in the estimation and increase the delay factor and this is not suitable for most of the Internet of Things (IoT) applications. They found that MaxHop value is between 5-12 hop count, and this will give a good result for different topologies and anisotropic factors. This value can be adjusted based on the needs such as, desired accuracy, power consumption and convergence time. It is clear from their results that the convergence time, localization accuracy, computational overheads and energy consumption either in isotropic or anisotropic networks have been improved comparing with other similar algorithms. Since these factors either accuracy or convergence time depends on the Max-Hop value, however, this value is varied based on the network topology.

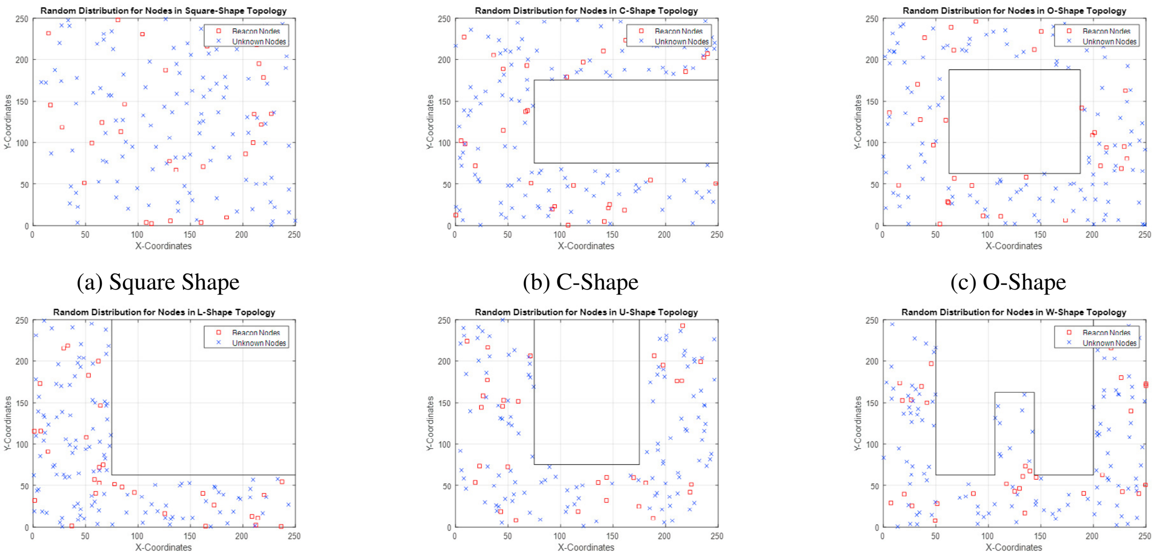
4. Performance Analysis

In our simulation, we change different parameters to study the effect on the overall performance of the selected range-free localization algorithms as follow:

Beacon Density: This parameter represents the number of beacons that is within range of a node and are used to estimate its location as well as the error value. However, more beacon nodes will improve the accuracy but will increase the overall cost. The number of beacons is between 10-45 nodes and 20% of total number of nodes when we will change the node density.
Node Density: This parameter defines as the number of beacons and unknown nodes in the communication range. This number is between 100-500 nodes.
Topology Model: Two common distribution strategies are investigated, where unknown and beacon nodes are distributed either in a uniform or random way with different shapes such as, square, C-shape, W-shape, U-shape, L-shape, and O-shape.
We simulate different algorithms under different topologies and parameters like, radio range configuration, beacon node density, and unknown node density. Fig.3 shows these topologies for only one single run. However, in order to achieve 95% confidence interval, we run the simulation for this experiment fifty times and reported the average results for varying beacon and total nodes. Parameters settings are shown in Table 2.

Table 2: Parameters Setting

Type	Value
Covered Area	2D- 250m x 250m
Nodes	150 nodes
Anchor Nodes	20% of Nodes
GPS Error	Zero
Radio Range	100m
Distribution/Topology	Random/[Square, C, L, U, O, W]-Shape
Simulation Runs	Repeated 50 times
MaxHop	6 hops



(a) Square Shape (b) C-Shape (c) O-Shape

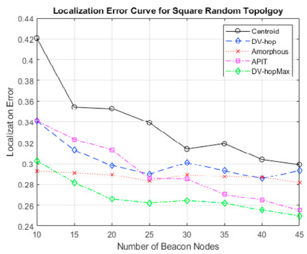
(d) L-Shape (e) U-Shape (f) W-Shape

Fig. 3: Topologies (Square-Shape, C-Shape, O-Shape, L-Shape, U-Shape, and W-Shape)

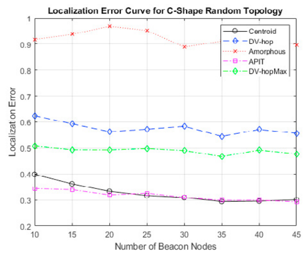
Fig.4 shows the localization error of all five algorithms for all topologies when the number of Beacon is varying from 10-45 beacon nodes. Overall, it shows that the average localization error decreases as the number of Beacon increases. It can be observed from also that the APIT and DV-HopMax algorithms perform the best in term of localization error when the number of Beacon is varying for most topologies comparing to the DV-Hop, Centroid and Amorphous algorithms. It can be notified that the localization error of APIT and DV-HopMax algorithms for all topologies between (0.3-0.35) when the number of beacons is only 10 while the localization error of APIT and DV-HopMax algorithms for all topologies is about (0.25-0.26) when number of beacons is 45. However, it is very important to note that the different algorithms show different behaviours based on the topology type. For example, the centroid scheme performs worse than the DV-Hop and Amorphous algorithms in square and O-shape random topologies. In contrast, the centroid scheme performs better than the DV-Hop and Amorphous algorithms in C-shape, L-shape, U-shape and W-shape random topologies.

Fig.5 demonstrates the localization error of DV-HopMax, APIT, DV-Hop, Centroid and Amorphous algorithms for all topologies by setting the beacon nodes to be 20% of the total nodes and changing the number of nodes from 100-500 nodes. In general, it illustrates that the average localization error decreases as the number of neighbours increases. As we can see from Fig.5 the DV-HopMax and APIT algorithms are robust to varying node density, and produce good results as long as the neighbour density increases and it achieves the best in term of localization error when the number of nodes is changing for square topology comparing to other three localization algorithms. It shows also that the localization error of DV-HopMax and APIT algorithms for most topologies is about (0.25-0.30) when number of nodes is only 100 while the localization error of these algorithms for same topologies is about (0.2-0.27) when number of nodes is 500. However, it is very important to note that the different algorithms show different performances based on topology type. For instant, the centroid produce good results than the DV-Hop, DV-HopMax and Amorphous algorithms in C-shape, L-shape, U-shape and W-shape random topologies as long as the neighbour density increases. Whereas, DV-Hop and Amorphous algorithms performs better than the centroid algorithm in square and O-shape random topologies.

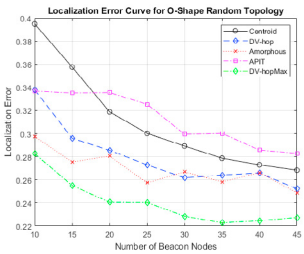
The comparison between the simulated range free localization algorithms for the square shape is summarized as in Table 3. DV-HopMax is the best in terms of the accuracy and has less error value comparing with other techniques.



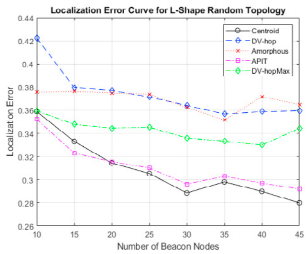
(a) Square Shape



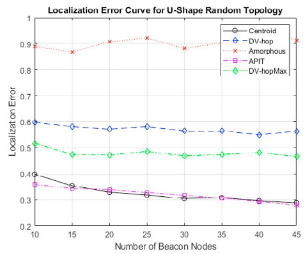
(b) C-Shape



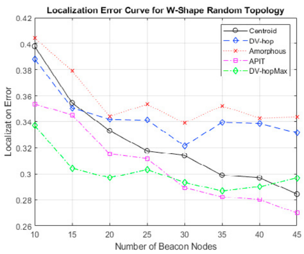
(c) O-Shape



(d) L-Shape

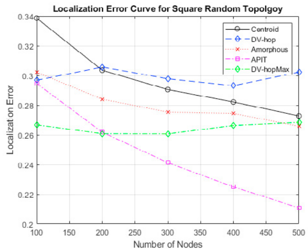


(e) U-Shape

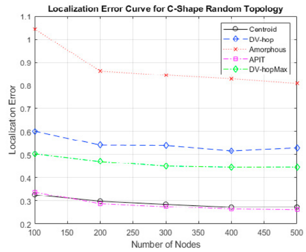


(f) W-Shape

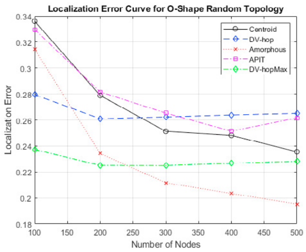
Fig. 4: Localization Error for different number of Beacon nodes



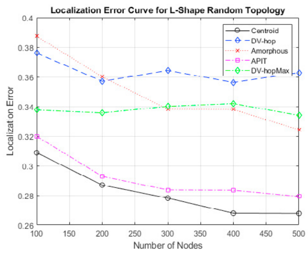
(a) Square Shape



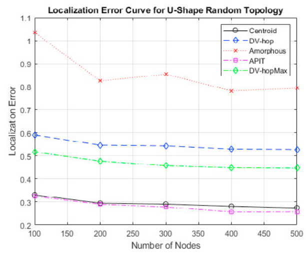
(b) C-Shape



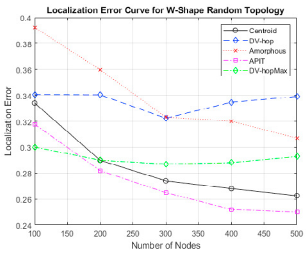
(c) O-Shape



(d) L-Shape



(e) U-Shape



(f) W-Shape

Fig. 5: Localization Error for different number of nodes

Table 3: Comparison between all algorithms

Parameter	Centroid	DV-Hop	Amorphous	APIT	DV-HopMax
Accuracy	Fair	Average	Average	Good	Good
Classified	Proximity	Network-Connectivity	Network-Connectivity	Proximity	Network-Connectivity
HW Size	Low	Low	Low	Medium	Low
Overhead	Low	High	High	Medium	Lowest
Cost	Low	High	High	Low	Low
Scalability	Yes	No	No	Yes	Yes

5. Conclusion

In this paper we reviewed different range free localization algorithms. We compared the localization performance of Centroid, Amorphous, APIT, DV-Hop and DV-HopMax range free algorithms in different topologies. Depending on the topology, localization protocols have different accuracy performances. For instance, the centroid scheme performs worse than the DV-Hop and Amorphous algorithms in square and O-shape random topologies. In contrast, the centroid scheme outperforms both of the DV-Hop and Amorphous algorithms in C-shape, L-shape, U-shape and W-shape random topologies. However, DV-HopMax technique reduces the computational overhead and the overall cost of the network compared with all algorithms.

Acknowledgements

We are thankful to King Fahd University of Petroleum and Minerals (KFUPM), Saudi Arabia for providing the necessary lab equipment and setup for experimentation. We would also like to thank Acadia University and Natural Sciences and Engineering Research Council (NSERC) of Canada for funding this research.

References

[1] J. Desai and U. Tureli, "Evaluating Performance of Various Localization Algorithms in Wireless and Sensor Networks," 2007 IEEE 18th International Symposium on Personal, Indoor and Mobile Radio Communications, Athens, 2007, pp. 1-5.

[2] T. Arampatzis, J. Lygeros and S. Manesis, "A Survey of Applications of Wireless Sensors and Wireless Sensor Networks," Proceedings of the 2005 IEEE International Symposium on, Mediterrean Conference on Control and Automation Intelligent Control, 2005., Limassol, 2005, pp. 719-724.

[3] Mekelleche, Fatiha and Hafid Haffaf. "Classification and Comparison of Range-Based Localization Techniques in Wireless Sensor Networks." JCM 12 (2017): 221-227.

[4] S. Pandey, S. Varma, "A range based localization system in multihop wireless sensor networks: A distributed cooperative approach", Wireless Pers. Commun., vol. 86, no. 2, pp. 615-634, 2016.

[5] S. P. Singh, S. C. Sharma, "Range free localization techniques in wireless sensor networks: A review", Proc. Comput. Sci., vol. 57, pp. 7-16, 2015.

[6] Eva Tuba, Milan Tuba, and Dana Simian. 2016. Range Based Wireless Sensor Node Localization Using Bat Algorithm. In Proceedings of the 13th ACM Symposium on Performance Evaluation of Wireless Ad Hoc, Sensor, & Ubiquitous Networks (PE-WASUN '16). ACM, New York, NY, USA, 41-44.

[7] Thimmaiah, Sudha H. and Mahadevan. "A Range Based Localization Error Minimization Technique for Wireless Sensor Network." (2017).

[8] W. J. Feng, X. W. Bi, R. Jiang, "A novel adaptive cooperative location algorithm for wireless sensor networks", Int. J. Autom. Comput., vol. 9, no. 5, pp. 539-544, 2012.

[9] Y. Ahmadi, N. Neda and R. Ghazizadeh, "Range Free Localization in Wireless Sensor Networks for Homogeneous and Non-Homogeneous Environment," in IEEE Sensors Journal, vol. 16, no. 22, pp. 8018-8026, Nov.15, 2016.

[10] Gaurav Sharma, Ashok Kumar, "Improved range-free localization for three-dimensional wireless sensor networks using genetic algorithm," Computers & Electrical Engineering, Volume 72, 2018, Pages 808-827, ISSN 0045-7906.

[11] Prashar D, Jyoti K, Kumar D. "A comparison of distributed range free localization algorithms in wireless sensor networks." Indian Journal of Science and Technology. 2016 Jul; 9(28):1–5.

[12] Najeh, Tawfik, Hichem Sassi, and Noureddine Liouane. "A Novel Range Free Localization Algorithm in Wireless Sensor Networks Based on Connectivity and Genetic Algorithms." International Journal of Wireless Information Networks 25.1 (2018): 88-97.

[13] Shahra, Essa Q., Tarek R. Sheltami, and Elhadi M. Shakshuki. "Comparative study of fingerprint and centroid localization protocol using cooja." Procedia Computer Science 98 (2016): 16-23.

[14] Yamei, Li. "An improved DV-hop localization algorithm based on energy-saving non-ranging optimization." Journal of Networks 9.11 (2014).

[15] N. Bulusu, J. Heidemann, and D. Estrin, "GPS-less low-cost outdoor localization for very small devices," IEEE Personal Communications, vol. 7, no. 5, pp. 28–34, 2000.

[16] D. Niculescu, and B. Nath. "DV based positioning in ad hoc networks." Telecommunication Systems, Vol. 22, no.1-4, pp.267-280, 2003.

[17] Nagpal, R., Shrobe, H., and Bachrach, J. (2003). Organizing a global coordinate system from local information on an ad hoc sensor network. In Information processing in sensor networks (pp. 333-348). Springer, Berlin, Heidelberg.

[18] He, T., Huang, C., Blum, B. M., Stankovic, J. A., and Abdelzaher, T. (2003, September). Range-free localization schemes for large scale sensor networks. In Proceedings of the 9th annual international conference on Mobile computing and networking (pp. 81-95). ACM.

[19] F. Shahzad, T. R. Sheltami, and E. M. Shakshuki, "DV-maxHop: A fast and accurate range-free localization algorithm for anisotropic wireless networks," IEEE Trans. Mobile Comput., vol. 16, no. 9, pp. 2494–2505, Sep. 2017.