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*Research Article*

# Comparative Study between Two and Three Dimensional Localization Algorithms in WSN

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**Abstract:** Research on Wireless Sensor Networks (WSNs) has recently received much attention as they offer an advantage of monitoring various kinds of environment by sensing physical phenomenon. Many WSN protocols and applications assume the knowledge of geographic location of nodes to report data that is geographically meaningful and services. Locations of nodes can be determined by a number of localization algorithms that may be introducing various types of errors in their estimations. Requirement of applications need feasible localization algorithm with higher accuracy and lower cost. Localization algorithms mostly work on 2-dimensional plane or 3-dimensional plane; in this paper we proposed two localization algorithms in both two and three dimensional planes and compare between them. Where in a 2D plane, the process of localization is less complex and requires less time and energy and provides good accuracy is on terrains and is difficult to localize in harsh terrains, it determines accurate distance by increasing number of nodes and anchor nodes. Using 3-dimensional plane added one extra plane, z plane called as height, to provide more accurate result using height. It can be used in hilly and harsh terrains to provide good accuracy in it.

**Keywords:** Wireless Sensor Network; Localization; Correction Factor; DV-hop; Time of Arrival; Weighted Least Square.

## 1. Introduction

WSNs consist of a large number of sensor nodes spread over a geographical area. A sensor network contained a huge number of nodes, which are distributed either close to the phenomenon or inside it. According to the ways of sensors implementation, we classify the current wireless sensor network localization algorithms in 2D and 3D into several categories such as Range-based vs. Range-free, Centralized vs. Distributed, Anchor-based vs. Anchor-free and Mobile vs. Stationary. Range-based and Range-free localization are the mainly two types of localization algorithms, range-based introduce point-to-point information with anchor node, it provides higher accuracy but it needed continuous update of information and need additional hardware. In their it increases cost and size. Range-free is used where node organize by own self, no additional hardware needed. On comparison range-based provide good accuracy, but it is affected by obstacles and its accuracy is decreases.

The rest of the paper is organized as follows: In the second section, comparison between the present localization algorithms in two dimensional is discussed. The third section refers to comparison between the present localization algorithms in three dimensional. The fourth section, presents our proposed TOADV algorithm in two dimensional. Section five, presents our proposed 3DTOADV algorithm in three dimensional and section six presents the comparison between them. Finally, section seven, introduces our conclusions of this paper.

## 2. Comparison between Localization Algorithms in Two Dimensional

The foundation of numerous localization techniques is the estimation of the physical distance between two sensor nodes. The estimations are obtained through measurements of certain characteristics of the signals exchanged between the sensors, including signal propagation times, signal strengths, or angle of arrival, this technique use additional hardware, which is more expensive, range-based algorithms need to measure precise orientation or distance between neighbor nodes, and use the information for determining the location of nodes such as Time Of Arrival (TOA) [1, 2]. The concept behind it is that the distance between the sender and receiver of a signal can be determined using the measured signal propagation time and the known signal velocity. In [3], Time Difference On Arrival (TDOA) approach uses two signals that travel with different velocities. The receiver is then able to determine its location similar to the TOA approach. In Angle Of Arrival (AOA) approach [4], the direction of signal propagation is determined. The concept behind the Received Signal Strength (RSS) method is that a signal decays with the distance traveled. In [5] triangulation uses the geometric properties of triangles to estimate sensor locations. It refers to the process of calculating a node's position based on measured distances between itself and a number of anchor points with known locations. In iterative and collaborative multilateration once a node has identified its position using the beacon messages from the anchor nodes [5]. It becomes an anchor and broadcasts beacon messages containing its estimated position to other nearby nodes.

Range-free algorithms use estimated distance to localize node, Range-free algorithms is used where no additional thing needed. In [6] centroid algorithm, the anchors send out beacon messages which include their position information to neighbor nodes at periodic intervals. A receiver node infers proximity to a collection of anchor nodes. The location of the node is then estimated to be the centroid of the anchor nodes to receive the beacon packets. This algorithm is good but it needs increasing number of anchors. In [7] proposed APIT in which given three anchor nodes, any unknown node can determine its position if it lies inside the triangle composed by the three anchors. In the localization scheme each sensor node performs numerous APT tests with different combination of audible anchor nodes, and infers its location as the center of gravity of the intersection area of all the triangles in which the node lies in. In [8] the authors proposed a distributed algorithm named Virtual Anchor Node-based Localization Algorithm (VANLA), which uses shortest-hop path to upgrade some unknowns' position as virtual anchor nodes with highly accurate. The virtual anchors, as well as the real anchors, will help the other unknown nodes to be localized. In [9] the DV-hop algorithm was proposed, it is based on distance vector. Simplicity, feasibility, cost-effectiveness, and high coverage are the advantages of DV-hop algorithm. It works well in isotropic networks. In DV-hop algorithm, an unknown node determines its minimum hop count from anchor node and then computes its distance from it by multiplying the minimum hop count and average hop distance. Finally, the node estimates its location by using a triangulation scheme or maximum likelihood estimators. Major drawback of DV-hop algorithm is its positioning accuracy. Researchers have proposed many methods to improve location accuracy of DV-hop algorithm; simulation results show that TOA and DV-Hop algorithms are better accuracy than other algorithms in 2D as show in table 1

**Table 1:** Shows the comparison between the localization algorithms in two dimensional

| | **Accuracy** | **Consumed Energy** | **Network overhead** |
|---|---|---|---|
| TOA | High | Low | Low |
| TDOA | High | High | Median |
| AOA | Low | High | High |
| RSS | Median | Median | High |
| Centroid | High | Median | Low |
| APIT | Median | Median | Median |
| DV-hop | High | Low | Low |
| Amorphous | Median | High | High |
| VANLA | Low | High | High |

## 3. Comparison between Localization Algorithms in Three Dimensional

In some real world applications the deployed sensor network operates over a three dimensional area rather than in a two dimensional area. Using 2-dimensional algorithms on a plane the position estimate using point in the plane, where the coordinate are the same as the real position of the surface. Any angle between the ground and the reference plane result may be an error during mapping. But an error can occur when comparing these estimated positions with the real world, because it consists of all three planes. All the strategies that are employed for the localization in 2-D spaces are violated in 3-D spaces, 2-D spaces cannot be directly extended to 3-D just by increasing one parameter. For example, the 2-D localization completely fails in determining the depth of the river bed and other similar sensor network scenarios where the height comes into play. By using a localization system for 3D plane this problem is disappeared completely. In a 2D system, three anchor nodes are required to determine a coordinate system. In a 3D system, four anchor nodes are required.

Range-free and range-based method is defined for localization process in 2D and 3D system such as RSSI, is measuring the signal strength reaching to a received node. It calculates distance using received signal. Main drawback is the power strength is decrease when the node travels at long distance. Power strength is affected from obstacles. It is also fading in distance. Accuracy is affected from it. Good accuracy is in less distance. Advantage is easy to estimate. [14] Proposed Time of arrival (TOA). The anchor uses a packet for sending to other node. Packet contains time when it was transmitted, in there the best clock synchronization needed between the nodes. The distance is calculated between them, i.e. Distance= speed * time, Where time is the difference between two nodes and the packet travelled with the speed of light so it is used here. If synchronization between the nodes is not their then it cannot be useful, TOA is not affected from fading of signal is the most advantage of using it. TDOA, determine the distance using the difference in time between two waves, or one wave with two destinations. Node sends ultrasonic signal and RF at same time. But these two signals will receive to known node with time difference because speed of ultrasound signal is lower than RF signal and calculate the distance as Distance = $\Delta t \times \Delta S$ Where, $\Delta t$ is the difference between receiving and sending signal between two nodes. $\Delta S$ difference in two signal received by other node. $\Delta S = (s_1 \times s_2) = (s_1 - s_2)$, angle measurement, calculation is determined using information about angles instead of distance, to determine the position of an object such as Angle of Arrival (AoA). It determine angle using known reference axis and with signal is send to another node using Omni-direction antenna and position computation, such as Lateration.

Range-free Localization Algorithms, It determines using number of hop receive the signal by the sender. The distance between the miss calculated by the number of hop that receive the signal, Academic community has proposed a number of 3-D positioning algorithm in WSN currently, for example, One of the first proposed algorithms for 3d localization is 3D-Landscape [10]. In the first phase, unknown nodes measure a set of distances to mobile (LAs) Location Assistants using RSSI and AOAs. Then nodes used Unscented Kalman filter to determine their own position. Similar algorithm is proposed in [11]. RSSI is used for distance measurements while particle filter for node positioning. Although these methods are independent of network topologies and node densities, the disadvantages is its dependence on mobile anchor that is impossible to be available under some deployments like hostile environments. [12] proposed APIS algorithm, it made the beacon nodes to the center of sphere, and made the distance between beacon nodes to the radius, divided the network to N concentric spheres, determined whether the unknown nodes in the region of these concentric spheres or not, finally find a series of the thinnest spherical shell which contain the unknown nodes, and take the gravity center of these spherical shell's intersection area to be the unknown node' coordinate. But the beacon nodes have a greater impact to positioning accuracy and the coverage. [13]Proposed 3D-MDS algorithm which based on multidimensional scaling, it established a dissimilarity matrix which combined the experience attenuation model of RSS and shortest path, used lightweight matrix decomposition algorithm to locate, then used iterative optimization algorithm to refine the initial position coordinates. The computation and communication capacity of this algorithm are very large, and have a relatively high requirements in the hardware. Simulation results show that TOA and 3D DV-Hop algorithms are better accuracy than other algorithms in 3D as show in table 2.

**Table 2:** Shows the comparison between the localization algorithms in three dimensional

| | Accuracy | Consumed Energy | Network Overhead |
|---|---|---|---|
| TOA | High | Median | Low |
| TDOA | High | High | Median |
| AOA | Low | High | High |
| RSSI | Median | High | High |
| APIS | High | Median | Median |
| 3D Landscape | Median | Median | Median |
| 3D DV-hop | High | Low | Median |
| 3D-MDS | Median | High | High |

## 4. The Proposed TOADV-hop Algorithm in Two Dimensional

In this paper, we compared between the two types of localization algorithms in 2D and found that TOA and DV-hop localization algorithms have better accuracy than other algorithms as show in table 1, so we have proposed an algorithm that integrates TOA and advanced DV-hop. The proposed TOADV algorithm enforces the unknown node which is one hop distance from anchors to calculate its distance from neighbor anchors using TOA method instead of advanced DV-hop method. By this way, the estimate error in network is reduced. In the proposed algorithm, localization error is reduced in three ways. First, the ranging error is reduced by measuring the distance using TOA algorithm for unknown nodes neighboring to anchor nodes and advanced DV-hop for the rest of nodes. Second, error in localization of a node is decreased by solving a system of n equations using Weighted Least Square (WLS) to reduce error. Third, up-gradation in localization of node is suggested to reduce localization error.

## TOADV: TOA-Based Advanced DV-Hop Algorithm:

**The proposed algorithm includes the following six steps:**

**Step 1:** Anchors distribute their localization message to the entire network. This message may include fields such a shop-count, location, and anchor ID. Each node receives this message and stores it in its memory, increases the hop-count by one, and forwards this message to neighbors if the hop-count is less than or equal to the hop-limit; otherwise the message will be killed by the sensor node. Hop-limit is defined as the maximum number of hops that a localization message can be alive. According to the fact that the first message from an anchor includes the shortest hop-length, each node considers only the first message from each anchor and ignores the next messages. If a node receives more than one message from an anchor, the shortest path will be considered, the new message will be ignored and the sensor node forwards the message only.

When a node receives localization messages from 3 anchors, this step will be terminated.

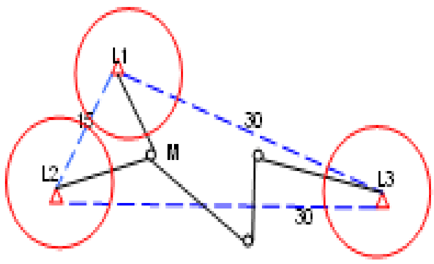


**Figure 1:** An example to illustrate our TOADV.

**Step 2:** Any node that has hop-count equal to one can determine the distance between it and anchor nodes using the measured signal propagation time and the known signal velocity, in Figure 1, node M is one-hop neighbor of nodes L1 and L2, that is, M can receive the packets fromL1 and L2 directly, M will compute the distance from L1 and L2.

**Step 3:** If any anchor receives a localization message from an anchor, it will calculate the average hop length (AHL). For example, in Figure 1, we have 3 anchors L1, L2, and L3. The distance from L1 to L2 is 15m, from L2 to L3 is 30 m, and from L1 to L3 is 30 m. The hop-count from L1 to L2 is 2, from L2 to L3 is 4, and from L1 to L3 is 4. Each anchor calculates its own AHL as follows:

$$AHL(L1) = (15 + 30) / (2 + 4) = 7.5$$
$$AHL(L2) = (15 + 30) / (2 + 4) = 7.5$$
$$AHL(L3) = (30 + 30) / (4 + 4) = 7.5$$

**Step 4:** Each anchor distributes the AHL to the entire network. Each anchor considers that the first received AHL comes from the nearest anchor. For example, in Figure 1, node M, the first received AHL from L1and L2 is 7.5, so the distance from anchors to M is calculated by multiplying the minimum hop number and the average distance of each hop.

$$d_{p,i} = HopSize_i \times h_{p,i} \quad (1)$$

Where $h_{p,i}$ is the number of hops between unknown node p and anchor$_i$ and HopSize$_i$ is the hop-size of anchor.

$$n - L1 = 7.5 * 1 = 7.5$$
$$n - L2 = 7.5 * 1 = 7.5$$
$$n - L3 = 7.5 * 3 = 22.5$$

**Step 5:** After obtaining these distances, system of n equations will be used to localize M (in the example, the actual distance is 10, but the estimate distance is 7.5) using the DV-hop algorithm. It is obvious that the error reaches twice of the actual distance. After using the system of n equations, the estimate position of M will be detected from actual position. There is a straight-line between M and L1, L2 but the DV-hop uses curvilinear average distance instead of straight-line distance. The proposed TOADV algorithm calculates the distance from other anchors by using average distance per hop which has known before M will figure out the distance to L3 as 7.5*3=22.5. Then M can locate itself by the system of n equations using 10, 10 and 22.5 instead of 7.5, 7.5 and 22.5.

**Step 6:** We use a new method to solve the system of n equations to locate the unknown node using n anchor nodes, which is completely different from the model used in DV-hop algorithm. Let (x, y) be the coordinates of unknown node p. The coordinates of anchor node is $(x_i,y_i)$. Let denotes the distance between p and anchor. Thelocation of p will be estimated by solving the following system of equations:

(2)

Where is measured by Eq. 1, it contains error due to error in hop-size. If both sides of the Eq. 2 are squared to estimate (x, y), the error in increases rapidly. Therefore, to reduce the inherent error in , we subtract the last equation from first n − 1 equation, we get a system of n − 1equationsasfollows:

Then,by squaring both sides and simplifying Eq. 3, we get:

Where *k* , for i = 1; 2; 3, …, n writing in the matrix form *QZ*= *H*, where *Q*, *H*, and *Z* are given by Eqs. 5, 6, and 7 respectively as follows:

$$Q = \begin{bmatrix} -2(x_1+x_n) & -2(y_1+y_n) & 1 \\ -2(x_2+x_n) & -2(y_2+y_n) & 1 \\ \dots & \dots & \dots \\ -2(x_{n-1}+x_n) & -2(y_{n-1}+y_n) & 1 \end{bmatrix} \quad (5)$$

$$H = \begin{bmatrix} d_1^2 + d_n^2 - (E_1+E_n) \\ d_2^2 + d_n^2 - (E_2+E_n) \\ \dots\dots \\ d_{n-1}^2 + d_n^2 - (E_{n-1}+E_n) \end{bmatrix} \quad (6)$$

$$Z = \begin{bmatrix} x \\ y \\ k \end{bmatrix} \quad (7)$$

To improve the location accuracy, we solve it using WLS method. By applying WLS, we have:

(8)

Where W is the weight matrix for the minimum number of hops from unknown node to anchors. For an unknown node p, it can be obtained by Eq. 9.

Where $W_{P,i}$ is the weight of the unknown node p for $i^{th}$ anchor. It is defined by Eq. 10

$$W_{p,i} = \frac{1}{h_{pi,}} \quad (10)$$

Where is the minimum number of hops between p and anchor i. If an anchor is at more hops away from the unknown node, its distance from the unknown node will contain more error due to error in hop-size and as such will have a lower weight. Therefore, weight for an unknown node to anchor is taken as the inverse of the minimum number of hops between them. Using Eq. 8, the unknown node obtains its location (x, y) and also gets the value of k.

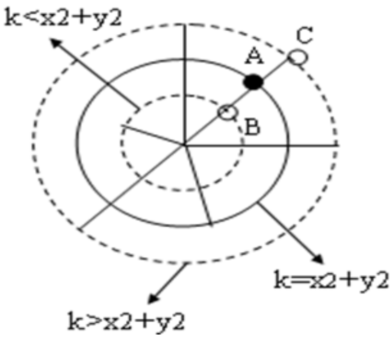


**Figure 2:** Estimated location of unknown node.

Due to error in , the coordinates (x; y) of theunknown node does not satisfy $k = x^2+y^2$ of Eq. 4. If $k < x^2+y^2$, where x and y are estimated coordinates of unknown node, a better estimation of the position of the unknown node may be B and if $k > x^2+y^2$, the position of the unknown node may be C, as shown in Fig. 2. In Fig. 2, A shows the unknown node's location (x, y) estimated by Eq. 8. Therefore, by using the value of k, the unknown node's location (x, y) is upgraded.

## Performance Evaluation:

We evaluate the performance of the proposed algorithm regarding to DV-hop and advanced DV-hop algorithms with the network simulation parameters shown in table 3.

**Table 3:** Network Simulation Parameters

| Parameter | Value |
|---|---|
| Number of nodes | 100 |
| Network dimensions | 100 m×100 m |
| Hop-count | 0 |
| Data packet size | 5000 bits |
| Communication radius | 15 m |

It can be observed that as the total number of nodes increases in the region, the ratio of anchor nodes increases or communication range increases. As a result, the average number of neighbors for each node increases and thus the network becomes well connected. This improves the chances that the unknown nodes lie on the line joining anchor pairs, then, TOA distance can be used in more unknown nodes, the average hop-size of the anchor nodes becomes more accurate, and the estimated distance between anchor node and unknown node turns into closer to its actual distance. Therefore, location error of the algorithm decreases with increasing number of unknown nodes, i.e., the TOADV algorithm has lesser localization error as shown in figures 3, 4, 5.

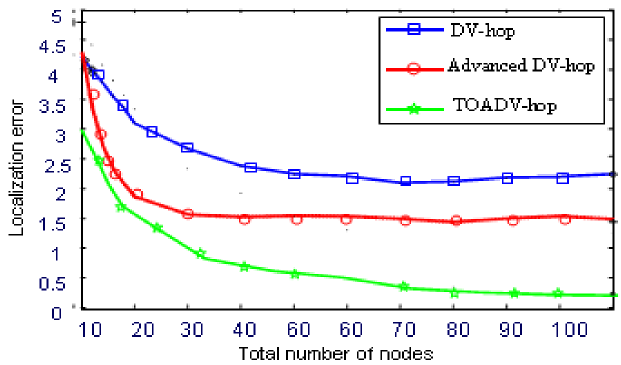


**Figure 3:** Total number of nodes versus localization error

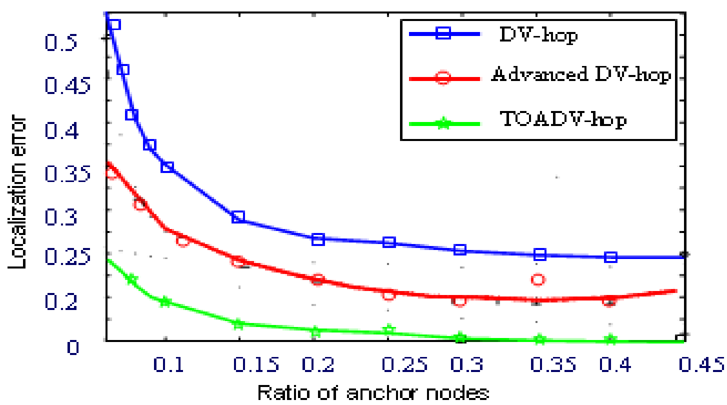


**Figure 4:** Ratio of anchor nodes versus localization error

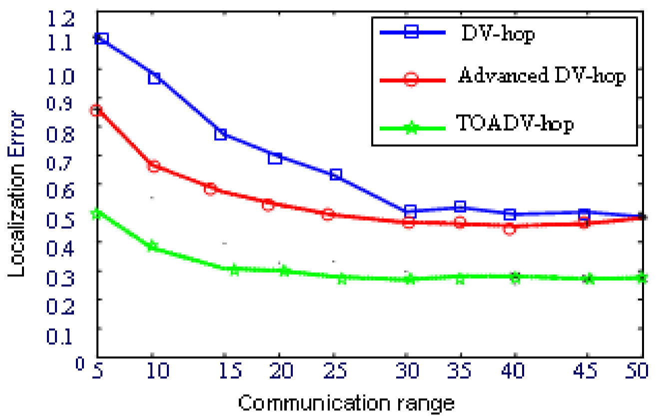


**Figure 5:** Communication range versus localization error

Simulation results show that the performance of the proposed algorithm is better than DV-Hop algorithm and Advanced DV-Hop algorithm as show in Table 4:

**Table 4:** Shows the comparison between our proposed algorithm, Advanced DV-hop and DV-hop in two dimensional

| | **TOADV-hop** | **Advanced DV-hop** | **DV-hop** |
|---|---|---|---|
| Accuracy | Fair | Good | Good |
| Consumed Energy | Small | Large | Largest |
| Network overhead | Smallest | Large | Largest |

## 5. Proposed 3DTOADV-hop Algorithm in Three Dimensional

Our proposed 3D TOADV-Hop algorithm, is mainly expanded the traditional TOADV-Hop algorithm into 3-D space, and on this basis to positioning by those way of introducing the mobile agents, using the mean square error and normalized weighted to deal with the average jump distance, determining the effectiveness of beacon nodes which involved in positioning, and depending on the situation using total least squares method, translation coordinate method and draw circle method for positioning, and improved the aspects of the communication, the positioning accuracy and so on, to ensure that this algorithm can locate the vast majority of the unknown nodes in the entire network successful.

We evaluate the performance of the proposed algorithm regarding to 3D DV-hop and APIS algorithms as show in Figure 6 and 7, in the case of R is 20 and 30, the positioning accuracy of three algorithms is rise by increasing the number of beacon nodes, when the beacon nodes' number is more than 30, the positioning accuracy gradually stabilize. The average positioning error of 3D TOADV-Hop and the APIS algorithm is lower than the 3D DV-Hop algorithm, although in the Figure 7, when the beacon nodes is 10, the 3D TOADV-Hop algorithm' positioning accuracy is slightly lower than the APIS algorithm, with the increasing of the beacon nodes' number, the 3D TOADV-Hop algorithm' average positioning error is smaller, number of message decreased, coverage increased as show in figures 8, 9, 10, 11 and the positioning accuracy curve is more stable.

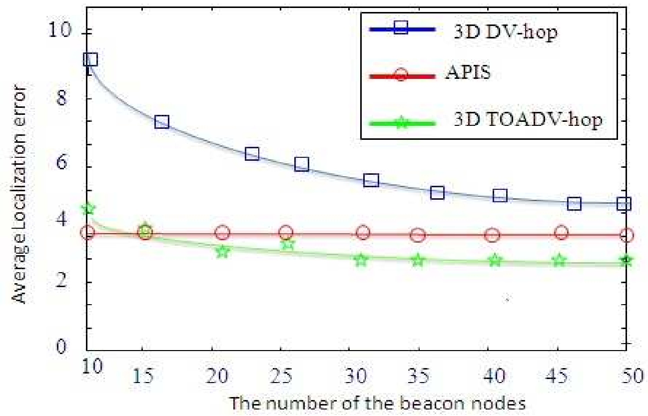


**Figure 6:** The average positioning error of the three algorithms for the different number of the beacon nodes (R=20)

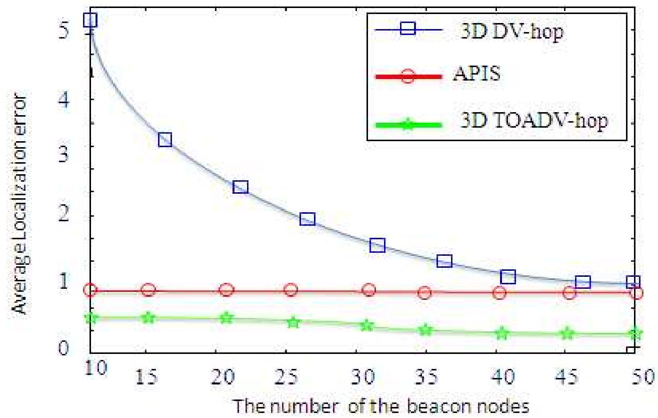


**Figure 7:** The average positioning error of the three algorithms for the different number of the beacon nodes (R=30)

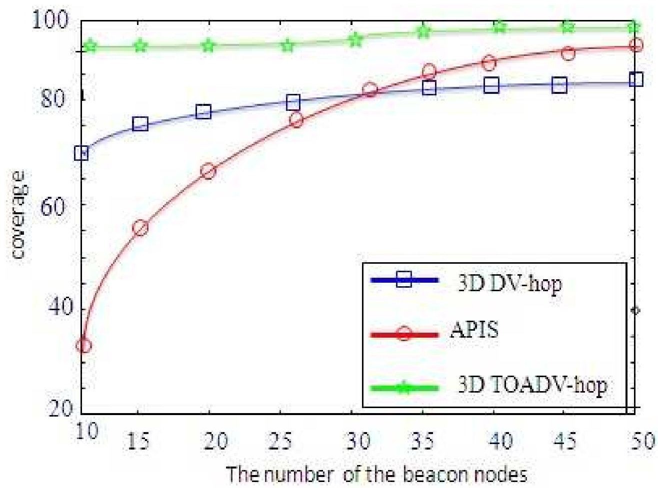


**Figure 8:** The positioning coverage of the three algorithms for the different number of the beacon nodes (R=20)

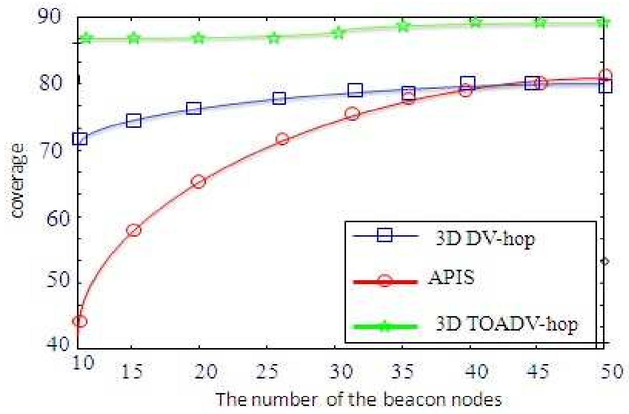


**Figure 9:** The positioning coverage of the three algorithms for the different number of the beacon nodes (R=30)

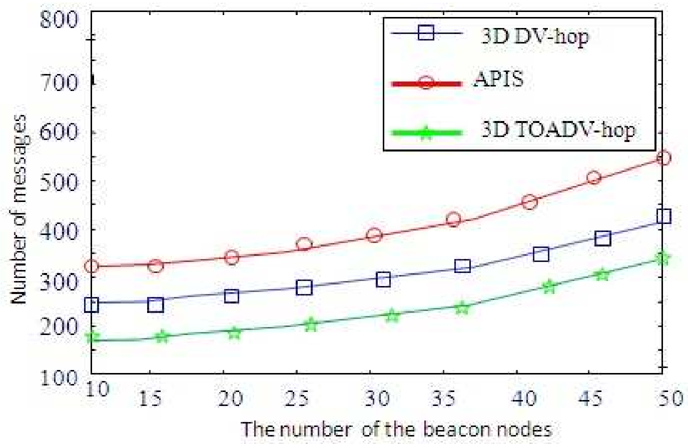


**Figure 10:** The number of messages of the three algorithms for the different number of the beacon nodes (R=20)

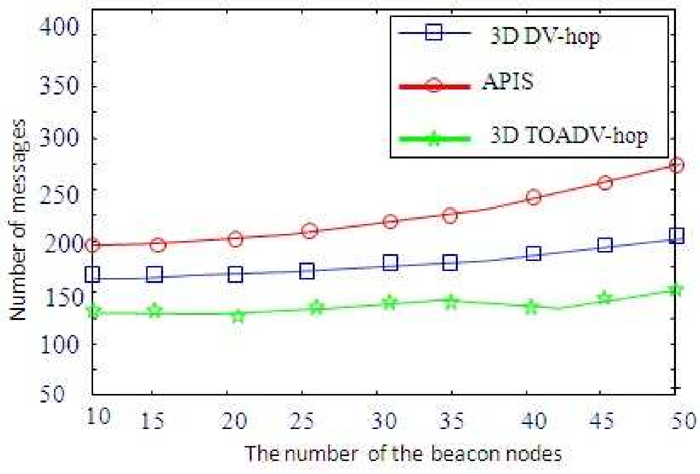


**Figure 11:** The number of messages of the three algorithms for the different number of the beacon nodes (R=30)

The simulation results show that 3D TOADV-Hop algorithm can not only maintain the advantages of the DV-Hop algorithm, but also showed some advantages in the positioning accuracy, energy consumption and coverage, especially in the larger space which exists a lot of obstacles, and can adapt the requirements of the low-cost and low-power as show in Table 5.

**Table 5:** Shows the Comparison between the Proposed Algorithm, APIS and 3D DV-hop in Three Dimensional

| | **3D TOADV-hop** | **APIS** | **3D DV-hop** |
|---|---|---|---|
| Accuracy | Fair | Good | Good |
| Consumed Energy | Small | Large | Largest |
| Coverage | Fair | Good | Good |

## 6. Comparison between the Proposed Algorithms in the Two and Three Dimensional

Where TOADV-hop algorithm in a 2D plane, the process of localization is less complex and requires less time and energy and provides good accuracy, it determines accurate distance by increasing number of nodes and anchor nodes. Using TOADV-hop algorithm in 3D plane, it provides more accurate result using height and it can be used in hilly and harsh terrains to provide good accuracy in it. By comparing this algorithm, we found that TOADV-hop localization algorithm have better accuracy in 3D than in two dimensional as show in Table 6.

**Table 6:** Shows the comparison between the proposed algorithms in the two and the three dimensional

| | **Accuracy** | **Consumed Energy** | **Coverage** |
|---|---|---|---|
| 3D TOADV-hop | Fair | Good | Good |
| TOADV-hop | Good | Small | Small |

## 7. Conclusions

In this paper we have carried out a comparative study between the two and three dimensional localization algorithms present on the literature, we have also presented two proposed algorithms. The first algorithm integrates TOA and advanced DV-hop. The proposed TOADV algorithm makes the unknown node which is one hop distance from anchors to calculate its distance from neighbor anchors using TOA method instead of advanced DV-hop method. By this way, the estimate error in network is eliminated. The experimental results proved the validity of our method. The second algorithm extended the TOADV-Hop algorithm from 2-D to 3-D successfully, and improved the aspects of the communication, the positioning accuracy and so on, to ensure that this algorithm can locate the vast majority of the unknown nodes in the entire network successful. The simulation results show that 3D TOADV-Hop algorithm can not only maintain the advantages of the DV-Hop algorithm, but also showed some advantages in the positioning accuracy, energy consumption and coverage, especially in the larger space which exists a lot of obstacles, and can adapt the requirements of the low-cost and low-power.

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