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# Enhancement of Indoor Localization Algorithms in Wireless Sensor Networks: A Survey

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**Abstract.** The purpose of this study is to enhance the indoor localization Algorithms in wireless sensor. Localization is one of the critical techniques in wireless sensor networks (WSNs). The implementation of localization can be used to determine object's position in the environments that could be applied both indoor and outdoor with several algorithms to estimates distance such as range-based and range-free. In this paper, the purpose of this study was to comprehensive survey of algorithms to optimize the trade-off between localization performance for an indoor area. Additionally, we discuss the application where the location information is crucial to estimate. The results of these localization algorithms comparison depict that the DV-Hop algorithm is more outstanding to detect the object location an indoor due to hop among sensor nodes rather than other algorithms with maximal range location up to 20 m, while the shortest ranges localization is TOA and TDOA with 60 cm and 90 cm, respectively.

## 1. Introduction

Wireless sensor networks (WSNs) is a set of nodes that could communicate and interact with other nodes, through transmission or received process both source or mobile nodes (their locations still determined) and the anchor nodes (their locations are known) over an unwired network. WSNs has the properties of sense, data processing, and communicating that can be an application in various areas such as target tracking, intrusion detection, energy-efficient routing, wild animal monitoring, underground, deep water, and outer space exploration [1].

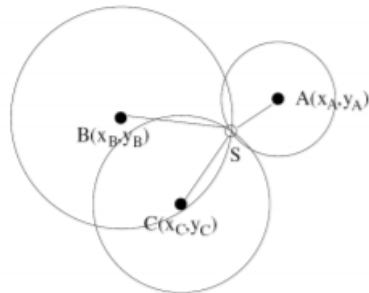
Several challenging issues exist in WSNs. One of the problems is how to obtain location information for sensor nodes and events occurring around the network. Moreover, through this perspective, we categorize the location problem as nodes localization, mobile localization, and location algorithms to enhance the accuracy position. Node localization is processed to determining the coordinates of sensor nodes in both indoor and outdoor environment. Mobile localization is the process of obtaining the coordinates on an event or current target located in the sensor field. The algorithms localization are steps must be passed while the mobile node cooperates and communicates with the sensor networks.

Localization is a technique to estimate the object position through communication medium between anchor nodes and the mobile node. The resulting position is a relative position to the nodes or the

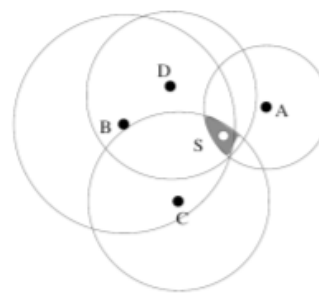


other objects involved in the vicinity. Either to determine using the distance and angle measurements. There are many geometric techniques used for localization such as the following.

- (i) Lateration appears when the distances between nodes are measured for approximate the position.
- (ii) Angulation appears when the measured location estimates through the angle between nodes.
- (iii) Trilateration. The position of the node is estimated by measuring the distance slightly three anchor nodes. Through this technique, the intersection of those circle nodes can be calculated, the result of the intersection would obtain a point position on a mobile node with despite in figure 1.
- (iv) Multilateration. Through this technique, more than three nodes are used to estimate the location of the mobile node as shown in figure 2.
- (v) Triangulation. Through this technique, relatively two angles of the mobile sensor nodes with two anchor nodes are measured to estimate its location. Trigonometric laws such as sine and cosine formulas are used to measure the level of estimate location on the mobile node.



**Figure 1.** Trilateration with three anchor nodes and a mobile node.



**Figure 2.** Multilateration with four anchor nodes and a mobile node.

Many possibilities occur about how to share the computations between sensor nodes and how to select a superior model in determining the localization algorithms as shown in figure 3. As the cornerstone of the model, the localization technique can be widely categories into such sections as centralized and distributed position computation algorithms; range-based and range-free based on the calculated dependencies between actual and expected distances.

### **Figure. 3** Localization Methods Taxonomy

#### *1.1. Centralized localization algorithm*

All measurements are aggregated on a base station (gateway) according to study in centralized localization [2], where the computation is carried out. Furthermore, the results obtained are forwarded to those nodes. The process of sending data within network causes latency, excessive energy consumption, and considerable bandwidth usage. The advantage of this technique is that they are capable of eliminating computation issues in each node. The deficiencies in this scheme are a limitation on the ability to access data correctly as well as inadequately scale. It is more suitable for small-scale networks. Due to the existence of general information, this algorithm is better than other algorithms.

### 1.2. Distributed localization algorithm

In [2] distributed localization, sensor nodes perform the required computation generated by themselves and communicate with each other to gain their locations within the network. Based on distance measurements, the distributed localization conceivable categorized into range based and range free localization technique.

## 2. Methods

In order to determine the indoor localization algorithms within WSNs is highly dependent on a variety of measurement techniques. Several factors affect the location accuracy which makes it difficult to choose appropriate localization algorithms to implemented in specific applications.

### 2.1. Range-based schemes

Range-based schemes are distance estimation and angle estimation-based techniques. The particular techniques are used in range-based schemes are received signal strength (RSS), the angle of arrival (AOA), time difference of arrival (TDOA), and time of arrival (TOA).

**2.1.1. Received Strength Signal (RSS).** The RSS [1] is considered an efficient ranging algorithm. In this case, RSS estimate sensor position without using additional hardware, and there is no significant impact on the local power consumption. However, direct mapping of absolute RSS value to physical distance has many limitations. The radio signal attenuation with an increase of the distance. The propagation of the radio signal may be affected by reflection, diffraction, and scattering. Especially, in indoor environments, such effects may impact the measurement accuracy.

In order to recognize the localization with the reveal reference anchor nodes, which provides the dynamic coefficient for more accurate distance measurements [3]. First, the RSS value can be calculated according to Eq. (1) as follows:

$$RSS = -(10 \cdot \vartheta \cdot \log(d) + A) \quad (1)$$

In which,  $RSS$  is the received signal strength measured by the receiving anchor nodes to the mobile node. As demonstrates, the receiving anchor node is the base station, and the mobile node is the reference anchor node.  $\vartheta$  is the value that assume the environmental conditions (which may change between 1.6 to 6 depend on pathloss exponential). Whereas,  $d$  is the distance between the receiving anchor nodes and mobile node. In this case, the base station and reference anchor node respectively, where the distance is known and  $A$  is the absolute value of RSS for the distance of 1 m.

**2.1.2. Time of Arrival (TOA).** TOA [4] is the one-way propagation time of the signal traveling between a mobile node and an anchor node. As aforementioned that all involve nodes have accurately synchronized the measure of TOA information, and such an identification system is unrequired assuming that two-way propagation in TOA is calculated. The computed TOA is then multiplied along with a known propagation speed, commonly denoted as  $c$ , gives the measured distance between the mobile and the anchors. The measured TOA represents a circle with its center at the anchors, and the mobile must be on the circumference in a two-dimensional (2D) space.

**2.1.3. Time Differential of Arrival (TDOA).** In [5], the conventional Chan algorithm could achieve supposing that entire TDOA be measured, and obtain a specific analytical result. Although, performance would be affected by NLOS environment. Taylor series extension method could conduct. The TDOA information could be obtained through two primary methods such as: first, with include a reduction of arrival time between the sensors to get the difference relative. Furthermore, the second method uses the technique cross-correlation to estimate the TDOA desired.

**2.1.4. The angle of Arrival (AOA).** The AOA measurement algorithm [6] is also known as the bearing measurement or measure the direction of signal arrival. The AOA measurements can be obtained through two techniques namely one derives the anchor antenna's amplitude feedback, and another comes from the mobile antenna's phase feedback. These techniques calculate the angles in which the signal arrive derives the anchor nodes to the mobile sensor node. Furthermore, the region where the mobile node is located in a line having a particular angle from the anchor nodes. Let suppose, to obtain calculation the position of TOA measurement algorithm; it takes at least two anchor nodes. The error of localization could be denoted assuming that there is a modest error of measurement. The accuracy depends on measurements are further complicated and the direction of the antenna by the presence of multipath and shadowing effect in the environment. A multipath component which comes from the transmitted signal may appear as an arrival signal against entirely incomparable direction and consequently causes a vast error in measurement accuracy. Accordingly, the AOA algorithm acquires determinate concern in localization slightly it is used with the large antenna arrays.

## 2.2. Range-free Algorithm

The range-free algorithm created using routing information to estimate the location of the sensor, and ignore the using of range measurement technique. Therefore, that one may estimate the location of the mobile node,

**2.2.1. Approximate Point in Triangulation (APIT).** The idea behind the APIT algorithm [7] is as follows: mobile node monitors the anchor nodes all around and then get the position information of anchor nodes and energy information of received signal energy. Assume that the number of observing anchor nodes is  $N$ , APIT desire to chooses three nodes among the  $N$  anchor nodes every single time and at the moment tests whether the mobile node is in the triangle arranged by selecting anchor nodes or not. The diameter of the estimated area in which a mobile node resides can be reduced to provide accurate location estimates by using a combination of anchor positions. The method utilized to reduce the probable spread in that mobile node consist the point-in-triangulation (PIT) examination. In this method, a mobile node determines itself whether it is inside the triangle conducted by relating these three anchors. APIT repeats this PIT examination equal to different audible anchor triplets before all combination is exhausted, or accuracy required has been reached [8].

**2.2.2. Distance Vector-Hop.** The main idea of the DV-Hop algorithm is to determine the estimated distance between two nodes by multiplying average hop distance with some hops between them. The DV-Hop consists of three phases. In the first phase, each anchor sends its location information and hop count value (initially set to 0) in the form of a packet to its neighbor nodes. Later the nodes that receive the packet desire to send the given packet to its neighboring nodes after increasing hop count value by 1. In such a way, the entire nodes in the network acquire the minimum value of hop count against each anchor nodes and location information of every single anchor in the form of hop count table.

The second phase involves calculation of average distance in a hop (AvgHopDistance) over the whole anchor adopting the eq. (2) and transmitting the information to entire nodes in the network.

$$AvgHopDistance_i = \frac{\sum_{i=1}^m \sum_{i \neq j} \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2}}{\sum_{i=1}^m \sum_{i \neq j} h_{ji}} \quad (2)$$

Where  $m$  is the total number of anchors in the given network,  $i$  is the identity of each anchor,  $h_{ji}$  is the minimum number of hop counts between anchor  $i$  and anchor  $j$ ,  $(x_i, y_i)$  and  $(x_j, y_j)$  correspond to coordinates of anchor  $i$  and  $j$ , and  $AvgHopDistance_i$  is the average distance of a hop computed by

anchor  $i$ . Then, each mobile node  $u$  computes the estimated distance from the anchor node  $i$  using eq. (3)

$$d_{ui} = AvgHopDistance_i \times h_{ui} \quad (3)$$

After obtained the distance of an anchor, in the last phase, the mobile node determines its location utilized multilateration method. The multilateration method employs a least-squares technique that runs as follows:

Let the coordinates of mobile node  $u$  and anchor  $A_i$  be  $(x_u, y_u)$  and  $(x_i, y_i)$ . Then, the following system of the equation can be derived by:

$$\left. \begin{aligned} (X_u - X_1)^2 + (Y_u - Y_1)^2 &= d_{u1}^2 \\ (X_u - X_2)^2 + (Y_u - Y_2)^2 &= d_{u2}^2 \\ &\vdots \\ (X_u - X_m)^2 + (Y_u - Y_m)^2 &= d_{um}^2 \end{aligned} \right\} \quad (4)$$

Eq. (4) can be transformed into Eq. (5).

$$\left. \begin{aligned} x_1^2 - x_m^2 + y_1^2 - y_m^2 - d_{u1}^2 - d_{um}^2 &= 2 \times x_u \times (x_1 - x_m) + 2 \times y_u \times (y_1 - y_m) \\ x_2^2 - x_m^2 + y_2^2 - y_m^2 - d_{u2}^2 - d_{um}^2 &= 2 \times x_u \times (x_2 - x_m) + 2 \times y_u \times (y_2 - y_m) \\ &\vdots \\ x_{m-1}^2 - x_m^2 + y_{m-1}^2 - y_m^2 - d_{u(m-1)}^2 - d_{um}^2 &= 2 \times x_u \times (x_{m-1} - x_m) + 2 \times y_u \times (y_{m-1} - y_m) \end{aligned} \right\} \quad (5)$$

Eq. (5) can be written into matrix Eq. (6) as follows:

$$\begin{aligned} &AX_u = B; \\ \text{Where;} \\ A &= 2 \times \begin{bmatrix} X_1 - X_m & Y_1 - Y_m \\ X_2 - X_m & Y_2 - Y_m \\ \vdots & \vdots \\ X_{m-1} - X_m & Y_{m-1} - Y_m \end{bmatrix}, X_u = \begin{bmatrix} x_u \\ y_u \end{bmatrix}, \text{ and } B = \begin{bmatrix} x_1^2 - x_m^2 + y_1^2 - y_m^2 - d_{u1}^2 - d_{um}^2 \\ x_2^2 - x_m^2 + y_2^2 - y_m^2 - d_{u2}^2 - d_{um}^2 \\ \vdots \\ x_{m-1}^2 - x_m^2 + y_{m-1}^2 - y_m^2 - d_{u(m-1)}^2 - d_{um}^2 \end{bmatrix} \end{aligned} \quad (6)$$

The Eq. (6) can be converted to Eq. (7) as follows:

$$X_u = (A^T A)^{-1} A^T B \quad (7)$$

The Eq. (7) is solved to find the coordinates of the mobile node by using the least square method.

**2.2.3. Centroid.** The centroid localization algorithm [9] was considered by Nirupama Busulu, John Heidmann, and Deborah Estrin. This algorithm consists of two phases. In the first phase, all anchor nodes transmit their location information in the form of a packet to mobile nodes that come under threshold domain. While in the second phase, each mobile node  $u$  determines its locations  $(x_u, y_u)$  by handling the arithmetic average of the whole coordinates that are within span threshold of the mobile node. This is described using Eq. (8).



$$x_u = \frac{\sum_{i=1}^m x_i}{m}, y_u = \frac{\sum_{i=1}^m y_i}{m} \quad (8)$$

Where  $(x_i, y_i)$  are the coordinates of anchor node  $i$  and  $m$  is the total count of anchor nodes that are within threshold span domain of mobile node  $u$ . This algorithm is slight to implement, nevertheless does not deliver the correct result as well as require a complicated method to determine threshold value.

**2.2.4. Gradient Algorithm.** In [10] the authors describe an algorithm for organizing a global coordinate system from local information. In this approach, ad-hoc sensor nodes are randomly distributed in a two-dimensional plane and each sensor communications with nearby sensors within a fixed distance  $r$ , where  $r$  is plenty smaller than the dimension of the plane. In their algorithm, they assume that some set of sensors as “seed” sensors which are identical to sensors in capabilities except that they are programmed with their global position.

**2.2.5. Multi-Dimensional Scaling (MDS).** Initial a useful mathematical algorithm based on a subjective view of data, named as multidimensional scaling (MSD) [11]. The concept of MDS is straightforward. Let there are  $n$  randomly distributed sensor nodes, for which distance between each connection of sensor nodes is known, then to estimate the position of mobile node multidimensional scaling using the law of cosines and linear algebra which help in the reconstruction of the relative positions of the sensor nodes by pairwise distances. The algorithm can be carried out with the assist of an algorithm which has four steps as follows:

Step 1: Aggregate information around ranging data from the sensor network and built a distance matrix  $X$ , where  $x_{ij}$  is the range in the middle of node  $i$  and  $j$ .

Step 2: Accomplish an algorithm for determining the shortest line, for instance, Dijkstra, Floyd, etc. on  $X$  to establish a complete matrix of inter-node distance  $R$ .

Step 3: Run a conventional metric MDS on  $X$  to find estimated node positions  $P$ .

Step 4: Transform the solution metric  $P$  into global coordinate by using several of the anchor nodes.

**2.2.6. Probability Grid.** In [12] the controlled deployment of the sensor nodes in the sensor field, in which the nodes are deployed into a grid topology, and where the unit length of the grid is known to the whole nodes in the sensor network. In other respect, the localization error may arise from an incorrect positioning in the grid of a sensor node, due to information loss, collisions and incorrect estimation of the Euclidian distance for one hop.

### 3. Results and discussion

Table 1 shows the performance comparison of different localization algorithms. Each localization serves a different purpose whether implement in the indoor or outdoor environment. Besides, the number of anchor nodes produces less the localization error due to a fixed position. Therefore, enhanced the location accuracy of the mobile node. In the dense indoor environment, the location error tends to increase due to a high of impaired propagation such as multipath, fading, shadowing as well as obstacles that appear from furniture in the room. This can be controlled by making the sensor network dense.

**Table 1.** Enhancement performance of indoor localization algorithms.

Localization Algorithm	Indoor Range Accuracy
<b>Range- Based</b>	
RSSI	4 to 8 m
TDOA	90 cm
TOA	65 cm to 0.9 m
AOA	1 to 6 m
<b>Range-Free</b>	
APIT	3 to 14 m
DV-Hop	10 to 20 m
Centroid	3 to 5 m
Gradient (GIFT)	3.6 m
MDS-MAP	15 m
Probability Grid	15 m

In the table describes that the DV-Hop algorithm in the range-free method can reach the object position as far as 20 meters farther than other algorithms. This is because the algorithm takes advantage of the hop on each sensor nodes to the destination node so that it takes less energy. On the other hand, it is seen that the shortest distance range is TOA and TDOA with 65 cm and 90 cm respectively. The distance is due to this algorithm relies on send time and receive time between nodes.

#### 4. Conclusion

This paper covered the enhancement of different indoor localization techniques used and their computing problems. The scalability of indoor range accuracy within range free approach is better than range-based approach due to connectivity among sensor nodes reachable a long distance. The indoor localization technique offers the reducing of deployment cost in wireless sensor networks. Currently, there is a trade-off between the accuracy and localization algorithms to determine object position. In the future work, the security and energy issues will be further considered in indoor wireless sensor network localization.

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