Innovative Localization Algorithm Using the Line of Intersection Technique in Wireless Sensor Networks

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Abstract

Wireless Sensor Networks consists of a small number of random nodes, which possess lesser memory, fault tolerance, perform multi-functions and have integrated micro sensors. The purpose of the sensor node is to collect, process, compute, store and dispatch information from one node to another node. The process of estimating geometric placement through a message between the localized node and beacon node in the wireless sensor field is termed as localization. Numerous schemes have been implemented to decide the location of a sensor node with utmost accuracy. Generally two types of schemes are present, namely range-based scheme and range-free scheme. In this paper, a range-free based technique is proposed to find the exact locality of the sensor nodes. Proposed algorithm uses a line of Intersection Technique for Localizing Sensor Nodes and brings out accurate locality information when compared with traditional centroid range-free method. The simulation results are demonstrated by comparing the proposed algorithm with a traditional centroid localization algorithm to determine exact geometric placement of sensors.

Keywords: Wireless sensor networks, Line of intersection, Localized node and Beacon node

1 Introduction

Wireless sensor networks are networks of sensors configured to monitor physical conditions and environmental conditions such as the level of pollution, humidity, wind, pressure, temperature and so on. The Sensor network is built using a number of nodes which are connected to one another without wires. The sensor includes a transceiver with an antenna and connection to another antenna for energy source. Localization is a technique that is being used in wireless sensor network to know the exact location of the sensor nodes. Since a sensor holds the number of nodes with GPS connection and such nodes are also expensive, accurate location cannot be provided by them under indoor conditions. The localization is carried out using the beacon node and the blind node. The nodes which can identify its location through GPS or manual method are known as a beacon node. Some node may not know its location, such nodes are blind nodes [1]. Thus, the localization is the way of determining the position of nodes for efficient data and information transformation. These data are transferred from source node to target node so the location of node can be found for problem solving and computation [2]. The main aim is gathering of nodes and exchanging of information between the nodes within a particular area. The exact place of each sensor node is a major research area so an optimized algorithm should be developed to find the current location of the node. The algorithm was found to be low cost, efficient and measurable.

2 Related Work

Singh et al. (2015) conducted a detailed study of the free position algorithm to estimate the position of the sensor node in the Wireless Sensor Networks [3]. The position accuracy of the sensor node is very important it can be identified with the help of beacon node's position information and localization algorithm. The approximate accuracy of the application of the sensor network is sufficient for unclassified location schemes to be considered as substitutes for range-based schemes. Classification of location techniques has been completed and compared to the interval scheme, the cost is lower.

Xie (2017) proposed two weighted centroid algorithms such as Position based on Normal Distribution (PND) and Position based on Network Size (PNS). These algorithms use normal randomness, weights and distance distribution. Both algorithms are more accurate, especially compared to a weighted centroid localization algorithm. Standard deviation and normalized weight are used for estimating the average localization error [4]. The graph is plotted between path-loss, localization error for variable network size

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and PNS has better performance than PND.

Arun et al. (2017) proposed new algorithm called as weighted based centroid localization algorithm. In this algorithm first the distance between the unknown node and beacon node is estimated using RSSI value received. The algorithm is based on Weighted Centroid localization algorithm but it takes intersection points of two beacon node and the average of the two beacon node is taken for evaluation and random way point model is used as a moving object [5]. The results are simulated with the help of three anchor nodes the range of sensor node is varied from 5m to 20m with the scale of 5m. The error value is computed and plotted for the simple WCL algorithm, Modified Static-degree WCL algorithm and Average Weighed Based WCL algorithm. The proposed algorithm reduces average localization error compared to simple WCL and modified static-degree WCL algorithm.

Chen et al. (2012) proposed a localization scheme which is cost effective for wireless sensor networks and proposed method implemented using two anchor nodes and uses bi-alteration technique to estimate the coordinates of unknown nodes and it is low-cost and localization scheme is range-free without any additional sensor and less GPS. Two anchor nodes are used in the bottom right and left corner in square region. The zone is formed by sensor node with the minimum hop count and the estimated location of each unknown sensor is adjusted according to its relative position in the zone. The results of the simulation show that this alteration enhances the location optimization, performance for unknown sensors considerably [6]. Proposed algorithm has improved accuracy, less communication cost and computational complexity are reduced when compared to DV-Hop method and the estimation is suitable for both square and rectangle area.

Patro (2004) proposed algorithm which displays a dynamic Localization calculation. Sensor nodes outline its situation as a centroid of the square successive to getting co-ordinate data from the four signals sitting at the edges of the square. Additionally, sensor contains inbuilt GPS [7]. It utilizes time contrast of landing of radio frequency and ultrasonic signal to evaluate the position. It uses the portable normal for orientation point. Limitation calculation has two stages: Ranging stage and modification stage. Here, the calculation executed can be a decent possibility for wireless applications. It requires framework support of four flexible positions to limit difficult to recognize the sensor node position. It helps in routing and checking data in the node.

3 Localization

Localization is a procedure to figure the areas of remote devices in a system. Wireless Sensor Networks made out of countless hubs that are thickly sent into an area of interests to gauge certain marvels [8]. This makes the establishment of GPS on every sensor hub costly and in addition GPS won't give correct confinement about an indoor domain. Consequently, the essential goal is to decide the area of the objective. Physically designing area reference on every sensor node is additionally impractical on account of a thick system. This offers to ascend to an issue where the sensor hubs must distinguish its present area without utilizing any unique equipment like GPS and without the assistance of manual arrangement [9-10]. The vast majority of the confinement systems are completed with the assistance of stay hub or reference point hub, which knows its present area.

3.1 Range-Based Localization Scheme

Range-Based Localization schemes are reported in calculating the distance between a beacon node and blind node using parameters such as angle, time and signal strength. In this method the locality of sensor node estimation is accurate, but the hardware implementation cost is high.

3.1.1 Angle of Arrival

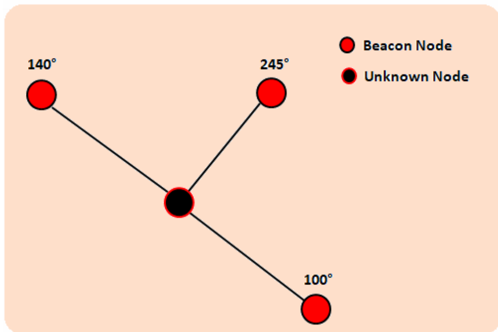

Figure 1. Angle of arrival

Angle of Arrival (AoA) Localization Scheme [11] is based on measuring the angle of the signal received from beacon nodes. Antennas are used to compute the angle of arrival of each signal at the blind nodes. This scheme is inaccurate and this type of measurement is inefficient due to additional hardware cost and size of nodes [12]. This method is not advisable for all kinds of applications because of more cost and less accuracy. Figure 1. shows the angle of arrival.

3.1.2 Time of Arrival

Time of Arrival (ToA) Localization Scheme [13-14] is used to determine the distance between two sensor nodes. In this method the distance between a beacon node and blind node is determined using the formula D=SP*T; where D is the distance between two nodes, SP is the propagation speed of the signal and T is the signal transmission time between beacon node and blind node. Figure 2. Indicates ToA scheme where R_1,

R_2 and R_3 are beacon nodes.

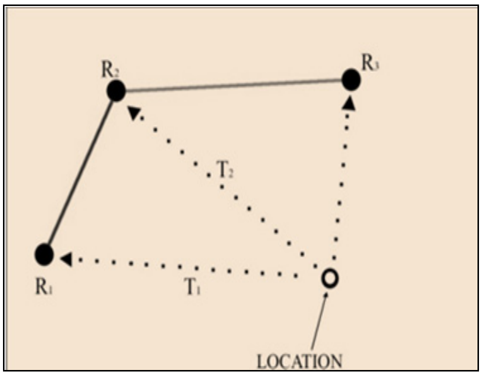

Figure 2. Time of arrival

3.1.3 Time Difference of Arrival

Time Difference of Arrival method determines the time difference between two signals. In this method the beacon nodes should be synchronized and the clock time must be same [15]. In Figure 3. T_1 is the time taken to transmit signal from Anchor2 to unknown node, T_2 is the time taken to transmit signal from Anchor1 to unknown node and T_3 is the time taken to transmit signal from Anchor3 to unknown node. Time difference between Anchor1 and Anchor2 is calculated as $ToDA_{21} = T_2\text{-}T_1$; Time difference between Anchor2 and Anchor3 is calculated as $ToDA_{31} = T_3\text{-}T_1$.

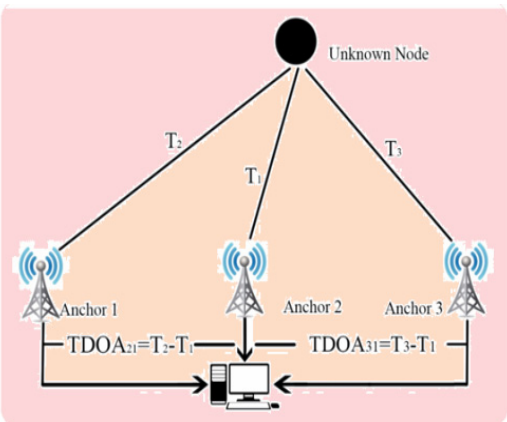

Figure 3. Time difference of arrival

3.1.4 Received Signal Strength Indicator

Received Signal Strength Indicator (RSSI) localization scheme is used to determine location of an unknown node with the help of the signal strength received from the beacon node [16-17]. The received signal strength is high at the beacon node nearest to unknown node. Received signal strength is low which indicates beacon node is far away from unknown node [18]. RSSI is a range-based localization scheme in which the accuracy is good but cost is high because additional hardware is required to measure the strength of the signal send by the beacon node on the receiver side. In Figure 4. Three beacon nodes are present at (x_1, y_1), (x_2, y_2), (x_3, y_3) and unknown node is located at (x, y). The received signal strength is r_1, r_2 and r_3.

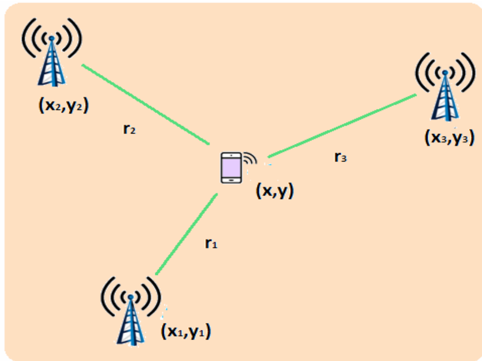

Figure 4. Received signal strength indicator

3.1.5 Comparison of Range Based Localization Techniques

This correlation depends on the limitation parameters like exactness, cost, vitality effectiveness and size of equipment. TDoA procedure gives high precision, though RSSI is limitation to cost. On account of the cost and constraint of the equipment numerous remote sensor systems, applications don't like to utilize range based restriction plans. These systems are sensible for a scalable sensor arrangement. In numerous application's accuracy is adequate; the best cost-effective alternative is range-free schemes of these kinds of applications. There is no need to calculate time difference or angle in Range free applications. To choose the area of sensor nodes these schemes basically sense the remote availability. The below Table 1 gives the comparison of various Range Based Localization algorithms.

Table 1. Comparison of range based algorithms

Scheme	Energy Efficiency	Size of Hardware	Accuracy	Cost
AoA	Medium	Large	Low	High
ToA	Less	Large	Medium	High
TDoA	High	Large	High	Low
RSSI	High	Small	Medium	High

Range-Based localization schemes are used to find the accurate location of sensor nodes. Range-Based Scheme is precise for estimating definite location and it has few disadvantages like more Complexity and implementation Cost is high. In Angle of Arrival and Time of Arrival method the size of hardware is large. In Time of Arrival and RSSI the implementation cost is increased. Range-Free Localization Scheme can be implemented to decrease cost when compared with Range-Based Scheme.

4 Range-Free Localization Scheme

Range-Free Localization Scheme [19-21] is used to determine the location of sensor node which is cost effective, low computational complexity and accuracy is almost same as Range-Based Localization algorithm. In general the Wireless Sensor field consists of three types of nodes. Based on its position information, they are classified as follows: (1) Beacon node (A); (2) Blind node(Unknown node) (B); (3) Estimated node (E). Beacon node (A) is a special kind of node which has its original or exact location before deployment in the sensor field. It is used to convert dumb nodes to estimated nodes that have to settle with the help of localization algorithm.

Anchor node is also known as beacon node. Blind node (B) is a node which doesn't know its location before deployment of nodes in their field. It is also known as Dumb node or Unknown node. Estimated node (E) is a node in which the location is estimated or identified after the execution of localization algorithm with the help of beacon nodes location information. Estimated node is also known as settled node or localized node. Figure 5. Represents simple Wireless Sensor Network setup. In real-world scenario nodes are deployed without knowing its current location information. This is the main reason for location estimation of blind nodes. Estimation can be achieved by implementing a suitable localization estimation algorithm.

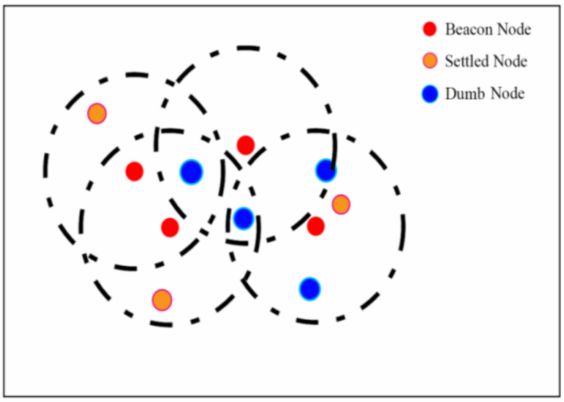

Figure 5. Simple wireless sensor network

4.1 Centroid Localization Scheme

Centroid Localization Scheme is a range-free localization scheme which does not require any additional hardware and exchanging information cost when compared with the Range-Based localization schemes. Localization algorithms are simple and low cost.

The sensor node localizes itself by calculating the centroid of position with the aid of all the nearby beacon nodes [22-24]. The algorithm works as follows: Deploy all sensor nodes in the required wireless sensor field, beacon nodes send its locality information periodically to all other blind nodes, which contains the beacon node id and its 2D locality information {ID, Location info (b(x, y))} which can be obtained with the help of a GPS device.

All blind nodes collect locality information about the nearby beacon node. Now all the blind nodes $b(x_1, y_1)$, $b(x_2, y_2)$, … $b(x_n, y_n)$ are ready to calculate their geographical coordinates with the help of beacon nodes $a(x_1, y_1)$, $a(x_2, y_2)$, ..., $a(x_n, y_n)$ using the centroid formula. In Figure 6. $a(x_1, y_1)$, $a(x_2, y_2)$ and $a(x_3, y_3)$ represent three beacon nodes and location of the blind node b(x, y) can be estimated using the centroid localization scheme. The equation (1) is used to calculate the node b(x, y) position.

$$x = \frac{x_1 + x_2 + x_3}{3}; \quad y = \frac{y_1 + y_2 + y_3}{3} \tag{1}$$

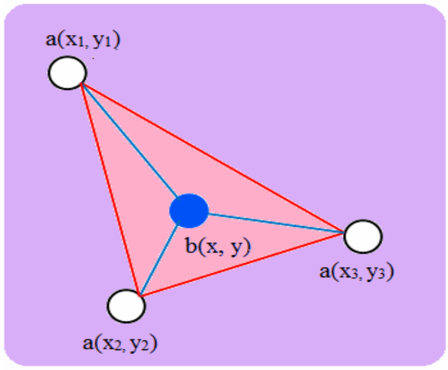

Figure 6. Centroid localization scheme

4.2 Proposed Localization Algorithm

Deploy Sensor nodes in the required Wireless Sensor Field Figure 7. Which contains beacon nodes and unknown nodes. The coordinates of beacon nodes are $a(x_1, y_1)$, $a(x_2, y_2)$ ….. $a(x_4, y_4)$ and the unknown node has the coordinate p(x, y). The beacon node id and its 2D locality information can be obtained with the help of GPS service and or manual entry. The distance between the unknown node and first beacon node is calculated by using the distance formula.

$$D = \sqrt{(x - x_1)^2 + (y - y_1)^2} \tag{2}$$

The value of distance obtained is compared and ranked according. The ranking is done by taking from the smallest value to the largest value.

The smallest distance is ranked as one and it is considered to be the first nearest beacon node. Similarly the second, third and fourth are found. Then the midpoint of the first and second beacon nodes are calculated using the formula $(\frac{x_1 + x_2}{2}, \frac{y_1 + y_2}{2})$, then

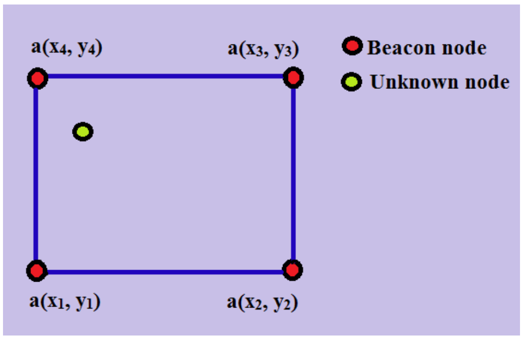

Figure 7. Wireless sensor field

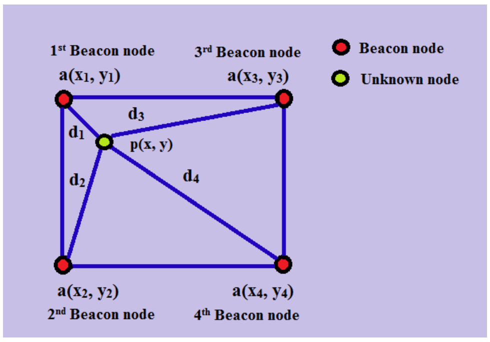

Figure 8. Line of intersection localization scheme

for the first and third beacon node midpoint is calculated and simultaneously for the second and fourth node. The empirical formula is used to find the position of unknown node p(x, y). Line of Intersection Localization Scheme is shown in Figure 8.

4.3 Procedure for Proposed Localization Scheme

Proposed Line of the intersection Localization algorithm takes a number of beacons as an input and the implementation is achieved by below mentioned algorithm, it gives average localization error as an output for unknown node.

• Deploy the sensor nodes randomly in the given sensor field. Find the unknown node location with the help of beacon nodes location. **(1)**
• Compute the distance between first nearest beacon node a(x_1, y_1) and unknown node p(x, y) as follows $$D_1 = \sqrt{(x-x_1)^2 + (y-y_1)^2} \quad \textbf{(2)}$$
• Compute the distance between second nearest beacon node a(x_2, y_2) and unknown node p(x, y) as follows $$D_2 = \sqrt{(x-x_2)^2 + (y-y_2)^2} \quad \textbf{(3)}$$
• Compute the distance between third nearest beacon node a(x_3, y_3) and unknown node p(x, y) as follows $$D_3 = \sqrt{(x-x_3)^2 + (y-y_3)^2} \quad \textbf{(4)}$$
• Compute the distance between fourth nearest beacon node a(x_4, y_4) and unknown node p(x, y) as follows $$D_4 = \sqrt{(x-x_4)^2 + (y-y_4)^2} \quad \textbf{(5)}$$
• Find the intersection of lines passing through the midpoint of first nearest beacon node and second nearest beacon node m_1= (mx_1, my_1) is given by $$m_1 = (\frac{x_1+x_2}{2}, \frac{y_1+y_2}{2}) \quad \textbf{(6)}$$
• Find the intersection of lines passing through the midpoint of first nearest beacon node and third nearest beacon node m_2=(mx_2, my_2) is given by $$m_2 = (\frac{x_1+x_3}{2}, \frac{y_1+y_3}{2}) \quad \textbf{(7)}$$
• Find the intersection of lines passing through the midpoint of second nearest beacon node and fourth nearest beacon node m_3=(mx_3, my_3) is given by $$m_3 = (\frac{x_2+x_4}{2}, \frac{y_2+y_4}{2}) \quad \textbf{(8)}$$

• Calculate using empirical formula for coordinates x and y of unknown node is given by The x coordinate value of unknown node is: $$\boldsymbol{x} = \frac{\boldsymbol{x}_1(\frac{y_3+y_4-2y_2}{x_3+x_4-2y_2}) - \frac{1}{2}(\frac{y_2-y_3}{x_2-x_3})(x_1+x_3) - \frac{1}{2}(y_1-y_3)}{(\frac{y_3+y_4-2y_2}{x_3+x_4-2y_2}) - (\frac{y_2-y_3}{x_2-x_3})} \quad \textbf{(9)}$$
• The y coordinate value of unknown node is: $$\boldsymbol{y} = \frac{\boldsymbol{y}_1(\frac{x_3+x_4-2y_2}{y_3+y_4-2y_2}) - \frac{1}{2}(\frac{x_2-x_3}{y_2-y_3})(y_1+y_3) - \frac{1}{2}(x_1-x_3)}{(\frac{x_3+x_4-2y_2}{y_3+y_4-2y_2}) - (\frac{x_2-x_3}{y_2-y_3})} \quad \textbf{(10)}$$
• Find the average localization error for all unknown nodes with the help of beacon nodes location information.

5 Simulation

This paper simulates the range-free localization algorithm for both centroid localization algorithm and proposed localization algorithm. Here the wireless sensor field is of size 100 m x 100 m with 50 unknown nodes are randomly deployed, 4 beacon nodes are deployed at the 4 corners of the Wireless Sensor field. The communication range of beacon nodes is 60 m.

In Centroid localization, the unknown nodes receive beacon messages within the range of their communication. The nodes, then estimate their position by taking the average of all the beacon positions using centroid localization formula and take the resulting centroid as their estimated position. The resulting localization error simulation using centroid algorithm is shown in Figure 9. Which shows the estimated error of the unknown nodes location, error is high, accuracy is less and the elapsed time to find the location of unknown node is also high.

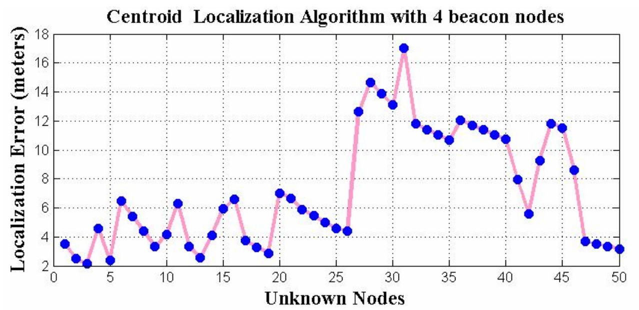

Figure 9. Graph plotted for centroid localization algorithm

In this work, the line of intersection of the midpoint algorithm is used to compute the location of unknown node. In proposed localization the beacon nodes first communicate with each other and the distance of each beacon node and unknown node is calculated then the mid points are found, finally the localization error is estimated by using empirical formula. Simulation reports the resulting localization error using proposed algorithm is shown in Figure 10. Where the localization error is minimized, the accuracy is high and the time taken to find the unknown node position is also less when compared with centroid algorithm.

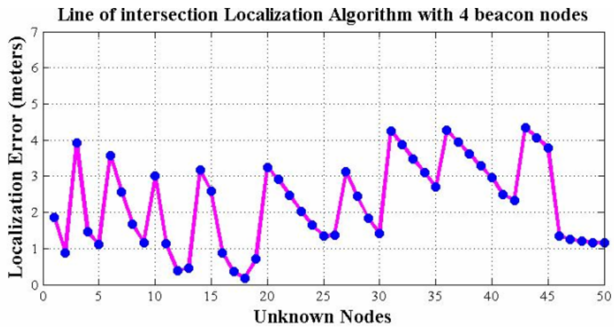

Figure 10. Graph plotted for line of intersection localization algorithm

Simulation Comparison

Sensor node localization algorithms are implemented for wireless sensor network in which the error is optimized. The comparison of centroid localization algorithm and the line of intersection algorithm are represented in Figure 11. The value of the localization error for each node is approximately decreased after applying the line of intersection algorithm, there by sensor nodes positioning accuracy gets improved, by finding the midpoints of two nearby beacon nodes from unknown node is found lower than a centroid localization algorithm.

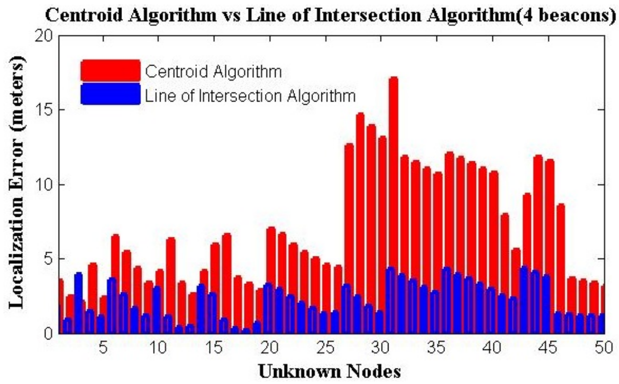

Figure 11. Comparison between centroid algorithm and proposed localization algorithm

Table 2 reports the computed outcome obtained by using Centroid Localization Algorithm and Line of intersect Localization Algorithm which shows that minimum error is decreased by 1.443, the average error is decreased by 4.701 and the maximum error is decreased by 13.055.

Table 2. Simulation result of different localization scheme's

Localization Scheme	Minimum Error (m)	Average Error (m)	Maximum Error (m)
Centroid Localization Algorithm	2.023	6.7355	17.2636
Line of intersect Localization Algorithm	0.5805	2.0345	4.2087

The elapsed time difference for both the algorithm is also found and the values are indicated in Table 3. As a result, using centroid localization 2.7856 seconds is been consumed and using proposed localization 2.4662 seconds are being consumed. Thus the Proposed Localization algorithm is found to be the most efficient one.

Table 3. Elapsed time for centroid and proposed localization algorithm

Localization Algorithm	Elapsed Time
Centroid Localization Algorithm	2.7856 seconds
Line of intersect Localization Algorithm	2.4662 seconds

Table 4. Indicates the overall performance evaluation of different localization schemes. Using Centroid Localization Scheme Computational Complexity is low and Time complexity is high when compared to Line of intersection method. The position accuracy of node plays vital role in many wireless sensor applications. The line of intersection of midpoints of the nearest beacon is more accurate and suitable for Two-dimensional applications which are highly dependent on position accuracy.

Table 4. Overall performance evaluation

Localization Scheme	Position Accuracy	Computational Complexity	Time Complexity
Centroid Localization Algorithm	Less	Low	High
Line of intersect Localization Algorithm	High	Medium	Low

6 Conclusion

Line of intersection localization algorithm and centroid algorithm is implemented in this paper. The centroid localization algorithm is one of the traditional methods for range free localization Scheme. The line of intersection localization algorithm is the advanced method which produces more accuracy than the centroid localization algorithm. The basic concepts and steps for performing line of intersection algorithm have been discussed in detail. The error possibilities for both methods are simulated and plotted in the graph. As a result, the two schematic graphs are compared which depicts that the line of intersection algorithm is more efficient than the existing scheme with less error probability. Hence the efficiency of line of intersection algorithm is proved experimentally. The Range-Based is less cost effective, whereas the line of intersection algorithm is cost effective and high scalability. All the efforts are taken to improve the performance and to develop techniques to work on a large scale of applications. In the future, the proposed localization algorithm can be applied for three-dimensional space. In summary, the identification of the exact location of sensor node plays a major role in many real-time research areas and it can be achieved with the help of the proposed innovative method.

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