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Experimental Evaluation of Indoor Localization Methods for Industrial IoT Environment

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With the evolution of new technology, GPS brings a lot of revolution in the Localization system but it is not an effective solution in Indoor Environment. This is because of the fact that the signals coming from the satellite are attenuated, absorbed, scattered by the walls, roofs, and other objects. Due to this, lots of errors may arise in the system. To overcome this problem sensor node based localization system is used for mobile IoT domain. Recently, in IoT based system, various sensor nodes have been used in different kinds of localization based applications such as Location-Based Services (LBS) and Proximity-Based Services (PBS). However, such sensor nodes may not be stable in every environment to provide an accurate positioning. Although there are different localization techniques are available to find out the location of any object, but there is a common challenge of finding best localization technique suitable for most of the environment. This work investigates different existing indoor localization methods for its practical suitability in Lab and actual Industrial environment for deployment on IoT nodes. A mobile application has also been developed to implement four state-of-the-art localization techniques for getting the position and calculating its accuracy in different environments. During the experiment, BLE Beacons are used as sensor nodes due to their ease of deployment, lower complexity, lower cost, and higher power consumption. The error in the accuracy of estimated position got calculated in terms of Average Error. According to the experimental result in real environments it has been revealed that the Weighted Centroid Localization technique provides better accuracy in industrial as well as laboratory environment.

Keywords: BLE, GPS, Indoor environment, RSSI, WSN

Introduction

Generally, the indoor localization system is the basic technology to know the human movement in real-time environment with the help of some mobile IoT nodes.[1] Although, the GPS tracking based system is the most commonly used technology to track the location of any object, but it is mainly designed for outdoor environment rather than in indoor environment as positioning system. This is mainly due to the reason that the GPS satellite signal cannot reach inside the buildings.[2] In the indoor positioning system, the detection of human position mainly relies upon Bluetooth, Wi-Fi, or RFID (Radio Frequency Identification) technologies. Irrespective of the technologies used in an indoor positioning based system, the inside structure of a building poses challenges due to the presence of multiple walls, and dynamic environment due to the movement of the multiple people inside the building. These walls and moving persons become the obstacles and interrupt the communication system. In the indoor positioning system, different kinds of techniques can be used to estimate the position of the moving nodes.

For the localization of mobile IoT nodes in Indoor environment, different types of techniques are available in the existing literatures. Based on the measurement method, we can divide the node localization scheme into two broad categories. First is the range-based localization method and second is the range-free localization method. In a range-based localization technique, the actual distance between the nodes is measured to estimate the location. On the other hand, in a range-free localization technique there is no need to find the actual distance between the nodes to estimate the location. In range-based localization, we get better accuracy compared to the range-free localization. However, in range-based localization, a couple of hardware is needed for measuring the real distance between nodes. This also requires extra power supply in comparison to the range-free localization technique. Generally, in range-based localization, there are four different techniques to measure the distance. These are Received Signal Strength Indicator (RSSI), Time of Arrival (TOA),

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Time Difference of Arrival (TDOA), and the Angle of Arrival (AOA). In the Angle of Arrival method, the angle is defined in which the signal has arrived from the sensor nodes where all the sensor nodes are equipped with an array. Due to this, these are prominent in size, cost, and in terms of power consumption. On the other hand, in TOA technique, time synchronization is very much essential for the whole sensor network. In real-time applications, the implementation of time synchronization between unknown nodes and beacon nodes are very difficult. Thus, it can be stated that though this technique is cost-effective but it is very much difficult to deploy the same in real-time applications. In TDOA system, the distance from the sensor node is calculated by using the difference in time of arrival, at the sensor node. The main disadvantage of this technique is that it is not cost-effective and it is very much complex to implement this technique in a real-time system. On the other hand, in the real-time system Received Signal Strength (RSS) is one of the simplest methods to measure the distance. The main advantage of this technique is that it does not require additional hardware for the operation. This technique is very much useful in terms of cost, sensor size, and power consumption.

For the range based localization technique, RSSI ranging can be done with the help of the RF chip, which is an inexpensive and low power technology. The main drawback of this technique is the low value of estimation accuracy.[3]

Related Literatures

The IoT brings a huge revolution in the present day of life. There are lots of challenges and different opportunities for the development of location-based IoT applications. Generally, the low power wireless devices are mostly used for IoT applications. Among them, BLE beacons are the most promising devices due to its compatibility with the other Bluetooth devices such as iPhone and Android smart phone. There are different types of works that have been reported on the indoor localization. In one of the work by Jeon *et al.*[4], the author discusses the survey, challenges, and opportunities provided by BLE beacons for the Internet of Things (IoT) application. The author consolidates the information about the BLE beacon, such as hardware requirements, the software, and the protocols and its applications.

The Wireless Sensor Network (WSN) is the most advanced technology in IoT for the information acquisition and tracking of a target, with the help of a positioning system.[5] This is also very much helpful in monitoring geographical environment, sending location information, and so on.[6] For this purpose, a stable and better accuracy algorithm is needed for better accuracy of the positioning system.[7]

Currently, wireless localization systems are classified into two different categories; viz. distance measurement based localization algorithm and the localization algorithm that does not depend on the distance.[8] There are some positioning algorithms, where we don't need to measure the distance between the target node and anchor node such as the traditional centroid localization algorithm[9], MDS AP algorithm[10], DV-Hop algorithm[11], etc. Generally, these techniques are influenced greatly by different factors of the environment that may cause larger positioning errors.

In one of the work[12] the author proposed the weighted centroid-positioning algorithm to estimate the position using the RSSI (Received Signal Strength Indicator). This algorithm includes the technique to estimate the distance between the anchor node and unknown node as the weight of the centroid localization algorithm by using the RSSI from the anchor nodes for improving the accuracy of the traditional localization algorithm for getting better accuracy in the positioning system. Based on simulation study, it is concluded that this algorithm provides a better result in comparison to the traditional centroid localization algorithm in terms of improved positioning accuracy with minimizing the error in position.

In another work[13] the author discusses different factors that affect the RSSI value with respect to the orientation of the receiver, the distance between the transmitter and the receiver, interference due to the other radio devices, time of detecting the RSS signal, effect of the presence of people and building on RSSI value. In the experiment, it is observed that the RSSI fluctuation is quite significant for single hardware also. In an experiment, it is also proved that at different orientations of the device, there is a mean deviation of around 2 dBm whereas location granularity results into mean fluctuations of 6dBm.

In another publication[14], the author discussed the enhanced time indoor localization technique by using the synchronized TDOA technique. Here the author uses the hybrid RBS-PBS base TDOA technique to find the location in the indoor environment. After the simulation, it is observed by the author that the proposed technique shows better accuracy compared to other commercially available techniques.

In another work[15], the author discusses TOA-based indoor localization by minimizing the non-line-of-sight (NLOS) error of the system. Currently, the NLOS error has a lot of impact on the localization accuracy in indoor localization systems. To solve this problem, the author proposed a TOA-based 3-dimensional indoor localization technique. In this system, the author obtains the node location by using the NLOS error mitigation. Here the system effectively works on both 2D and 3D environments and after the simulation; the author observed that the proposed system shows better accuracy than the other commercially available technique.

In one of the work[16], the author analyzes the localization error in the indoor environment by using the Ultra Wide Band (UWB) measurement. In this system, time information is used in place of RSSI. The efficiency of the algorithm has been evaluated in terms of the cumulative distribution function and root mean square error. After the experiment, it is observed by the author that the linearized least square algorithm shows very poor performance in the Ultra Wide Band base localization technique.

In another work[17], the author discusses the holographic wireless localization technique by using microwave localization technique with reduced bandwidth. The efficiency of the system is verified with respect to the industrial aspect by using the 24 GHz frequency-modulated system. After the experiment, it is observed by the author that the proposed system not only effectively worked but it shows a better result than the classic wireless locating approach.

In one of the paper[18], the author discusses the indoor localization technique by using the indoor knowledge graph. It is one of the important approaches to detect the location by using different information such as the smart phone sensor information and indoor environment structure. The knowledge graph has high data storage, representation, and processing capabilities. This system is very much useful to improve position accuracy. After the experiment, it is observed by the author that the proposed system shows an effective result in different indoor circumstances.

The aforesaid survey shows that the localization using existing state-of-the-art methods are highly prone to the RSSI fluctuation error and thus in turn make the location granularity unstable. This warrants a thorough study of different indoor localization methods for their stability, and accuracy of positioning in different real-time environment like normal building and industrial shop floor setup.

Contributions

In this paper, a survey over range based RSSI localization has been conducted. Although there are different works that have been reported previously but each of those includes one limitation or other. The main contributions of this paper consist of-

1. ***Comparison of RSSI based localization techniques***: In previous work, there are different RSSI based localization techniques that have been proposed. Due to limitation of each it becomes very much difficult to find out which technique is the best one between them for real industrial environment. To overcome this situation, we worked on four best RSSI localization techniques in different environments to know which Localization technique provides better accuracy in Industrial environment.
2. ***Real-time evaluation of the technique***: In previous work, mostly the experiments have been conducted offline using virtual simulation software. Due to inherit limitations of the simulated environment, such experimental result is prone to differ from the result obtained from the real-environment implementation. To address this, the experiment has been conducted in real industrial environment and the results have been presented.
3. ***Development of reliable and secure message base system***: In this work, a secure, reliable, and robust IPv4 based messaging system has been developed for conducting experiments by transmitting the location information of the mobile device to the computer server where the experimental data is further evaluated.

Materials and Methods

Indoor Localization Schemes

Any localization scheme is targeted to reduce the complexity of the system by maintaining the accuracy of the computed coordinates. Since localization is a continuous process, thus a good localization method is also supposed to be an energy-efficient. Four popular indoor localization techniques, which are used for evaluation purpose in this work, have been discussed in this section.

Weighted Centroid Localization (WCL) Algorithm

The concept of the WCL algorithm depends upon the RSSI value received by the target node from the fixed Beacon node placed surrounding it. The position of the Beacon node is the center of the circle in which it is communicating signals. Therefore, it can be stated that the communication distance is the radius of the circle, which can be termed as the distance from the anchor node to the unknown node because of the unknown node intersection part around it with concerning to the traditional centroid algorithm.

In Fig. 1 the method for localization based on WCL algorithm is shown.[12] In this method, the beacon nodes are fixed at different points. The fixed coordinate of the beacon node B_i is represented as (X_i, Y_i) and the estimated coordinate of target node S is (X, Y). Then the weighted centroid can be written as Eqs 1 and 2.

$$X = \frac{\sum_{i=1}^{n} W_i \times X_i}{\sum_{i=1}^{n} W_i} \quad \text{... (1)}$$

$$Y = \frac{\sum_{i=1}^{n} W_i \times Y_i}{\sum_{i=1}^{n} W_i} \quad \text{... (2)}$$

In the above Eqs, W_i represents the weight of the anchor node. The main disadvantage of this technique is if the anchor nodes B_i cannot communicate with the unknown node due to the environmental signal loss then the value of W_i will become 0 and the method fails.

Selection of Weight

Suppose n numbers of anchor nodes are fixed, where the coordinate of the beacon nodes are B_1 (x_1, y_1), B_2 (x_2, y_2), B_3 (x_3, y_3), B_4 (x_4, y_4), ..., B_n (x_n, y_n) and the distance from the unknown node M to the beacons are d_1, d_2, d_3, d_4, ..., d_n. Moreover, the position of M (target node) is X, Y. Let's assume that there are two nodes named B_1 and B_2, where the centroid position of the two nodes is β_{12}(x_{12}, y_{12}) and d_1, d_2 are the estimated distance of the centroid from nodes B_1 and B_2. So according to the formula of centroid, $(x_{12} - x_1)/d_1 = (x_{12} - x_2)/d_2$ and $(y_{12} - y_1)/d_1 = (y_{12} - y_2)/d_2$.

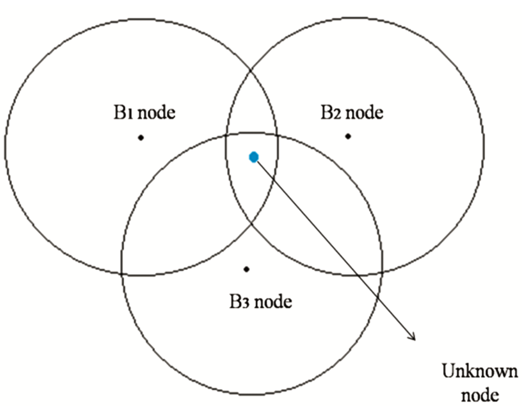

Fig. 1 — Tracking of unknown node using three beacon nodes by WCL method

From the above, Eqs 3 and 4 will give the coordinate of the centroid.

$$X_{12} = \frac{\frac{X_1}{d_1} + \frac{X_2}{d_2}}{\frac{1}{d_1} + \frac{1}{d_2}} \quad \text{... (3)}$$

$$Y_{12} = \frac{\frac{Y_1}{d_1} + \frac{Y_2}{d_2}}{\frac{1}{d_1} + \frac{1}{d_2}} \quad \text{... (4)}$$

The selection of weight indicates the effect of beacon nodes on the target node. Based on Eqs 3 and 4, the position of the node can be calculated using Eqs 5 and 6.

$$X_{1234....n} = \frac{\frac{X_1}{d_1} + \frac{X_2}{d_2} + \frac{X_3}{d_3} + \frac{X_4}{d_4} + ... + \frac{X_n}{d_n}}{\frac{1}{d_1} + \frac{1}{d_2} + \frac{1}{d_3} + \frac{1}{d_4} + ... + \frac{1}{d_n}} \quad \text{... (5)}$$

$$Y_{1234....n} = \frac{\frac{Y_1}{d_1} + \frac{Y_2}{d_2} + \frac{Y_3}{d_3} + \frac{Y_4}{d_4} + ... + \frac{Y_n}{d_n}}{\frac{1}{d_1} + \frac{1}{d_2} + \frac{1}{d_3} + \frac{1}{d_4} + ... + \frac{1}{d_n}} \quad \text{... (6)}$$

And the weight from beacon *i* is computed as Eq. 7.

$$\omega_i = \frac{1}{d_i} \quad \text{... (7)}$$

For the purpose of this work, we placed beacons at different positions of the experimental area (industrial shop floor and lab). To compute the position of the mobile IoT node, we used Eqs 8 and 9 by utilizing RSSI value from three nearest beacons

$$X = \frac{\frac{X_1}{d_1} + \frac{X_2}{d_2} + \frac{X_3}{d_3}}{\frac{1}{d_1} + \frac{1}{d_2} + \frac{1}{d_3}} \quad \text{... (8)}$$

$$\text{And } Y = \frac{\frac{X_1}{d_1} + \frac{X_2}{d_2} + \frac{X_3}{d_3}}{\frac{1}{d_1} + \frac{1}{d_2} + \frac{1}{d_3}} \quad \text{... (9)}$$

Here X_1, X_2, X_3 are the X-axis and Y_1, Y_2, Y_3 are the Y-axis of the three nearest beacon nodes and d_1, d_2, d_3 are the estimated distance from the nearest three beacon nodes to the mobile IoT node (unknown node).

Trilateration Localization (TL) Algorithm

The trilateration algorithm is a geometrical algorithm in which three reference nodes perform the localization by calculating the distance to the target node. It is the process of finding the absolute position by calculating the distance with the help of the geometry of the circle (the communication area cover by the beacons).[19] In the TL algorithm, the position estimation of the mobile node is done with the help of the positions (latitude, longitude) of nearby signal towers, the received signal strength and the time to take the signal back from the mobile node to the towers. The trilateration method has also been used for evaluation of its suitability for indoor localization in industrial environment. In this work, we used BLE beacons (in place of cellular tower) for estimating the position of the mobile IoT node. In this process, all the BLE beacons are placed at known coordinates which are transmitting continuous signal. These BLE signals from the beacons are captured by the mobile IoT device (unknown node). Further, the respective RSS value is sensed from three closest beacons.

The working of trilateration algorithm in presence of three beacons is shown in Fig. 2.[(20)]

Assume that there are n numbers of beacon node randomly distributed in the field at a fixed position. The relative location of those beacon nodes are (x_1, y_1), (x_2, y_2), (x_3, y_3),… , (x_n, y_n). And the location of the unknown node is (x, y). Now for three beacons i.e., node 1, node 2 and node 3, the Eqs 10–12 can be solved.

$$(x - x_1)^2 + (y - y_1)^2 = d_1^2 \quad ...(10)$$

$$(x - x_2)^2 + (y - y_2)^2 = d_2^2 \quad ...(11)$$

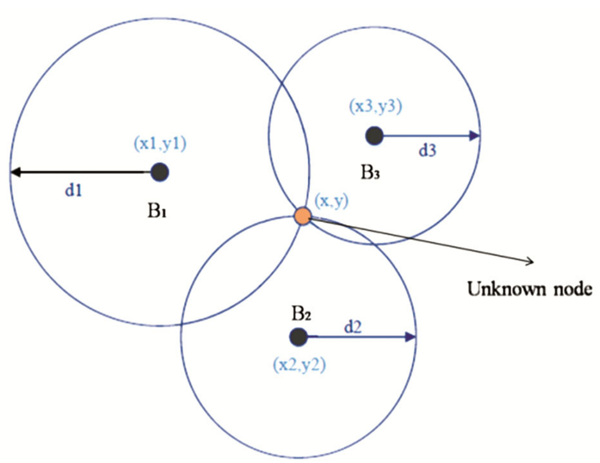

Fig. 2 — Symmetric diagram of Trilateration Algorithm

$$(x - x_3)^2 + (y - y_3)^2 = d_3^2 \quad ...(12)$$

In the above Eqs, d_1, d_2 and d_3 are the distance of the unknown node from beacon node1, node 2, and node 3.

Multilateration Localization (ML) Algorithm

Trilateration is a very convenient and efficient technique for the localization algorithm. But sometimes, this algorithm does not properly work and cannot accurately estimate the position of target node (unknown node) due to the loss of signal between beacon nodes and the unknown node.[19] For this purpose, we also considered using another localization method named Multilateration to evaluate its suitability for use in industrial environment. Multilateration is the surveillance technique based on the measurement of the distance of the node at a known location to the node at an unknown location.

A schematic diagram of the Multilateration algorithm is shown in the following Fig. 3. From the Fig, it can be observed that four beacon nodes are deployed at four different sides, and with the help of these beacon nodes, the position of the unknown node is measured.

Suppose there are four anchor nodes (A_1, A_2, A_3, and A_4) fixed at four different positions of an area of interest. The coordinate of the anchor nodes are A_1 (x_1, y_1),$A_2(x_2, y_2)$, $A_3(x_3, y_3)$, and$A_4(x_4, y_4)$.[21] The estimated distance between the anchor nodes A_1, A_2, A_3, and A_4 and the unknown node (the target node) are $d_1, d_2, d_3 and d_4$ respectively. In this setup, the position (x, y) of the target node can be computed from Eqs 13–16.

$$(x - x_1)^2 + (y - y_1)^2 = d_1^2 \quad ... (13)$$

$$(x - x_2)^2 + (y - y_2)^2 = d_2^2 \quad ... (14)$$

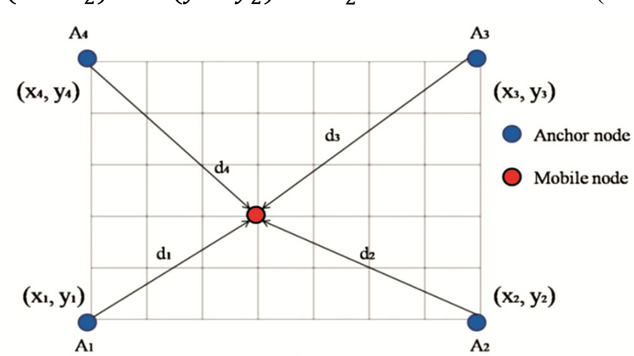

Fig. 3 — Tracking of unknown node using Multilateration Algorithm

$$(x - x_3)^2 + (y - y_3)^2 = d_3^2 \quad \text{... (15)}$$

$$(x - x_4)^2 + (y - y_4)^2 = d_4^2 \quad \text{... (16)}$$

Renewed Centroid (RC) Algorithm

A good node based localization system design for efficient wireless communication is very much critical. In one of the work[21], an advanced version of the centroid localization algorithm has been proposed to solve the problem of low accuracy in localization by using the traditional Centroid algorithm. After the simulation, the author has observed that the proposed scheme provides better results than the traditional centroid algorithm in terms of its accuracy of the computed node location.

The schematic for Renewed centroid algorithm is shown in Fig. 4.

In Fig. 4, the B1(x_{β_1}, y_{β_1}), B2(x_{β_2}, y_{β_2}), B3(x_{β_3}, y_{β_3}),and B4(x_{β_4}, y_{β_4})denote the positions of four beacon nodes 1, 2, 3 and 4 respectively with O as the center.

According to the traditional centroid algorithm, four beacon nodes have been selected for creating an enclosed area to estimate the position of the unknown mobile node. In this condition, Eqs 17 and 18 provides the position of the unknown node.

$$x_i = \left\{\left(x_{\beta_1} + x_{\beta_2} + x_{\beta_3} + x_{\beta_4}\right) \times \frac{1}{4}\right\} \quad \text{... (17)}$$

$$y_i = \left\{\left(y_{\beta_1} + y_{\beta_2} + y_{\beta_3} + y_{\beta_4}\right) \times \frac{1}{4}\right\} \quad \text{... (18)}$$

In the Eqs17 and 18, the coordinated (x_i,y_i) indicates the location of the unknown object. Now according to the geometric relation as shown in Fig. 4, the position of point e, f, g, and h are given by Eqs 19.1–19.8.

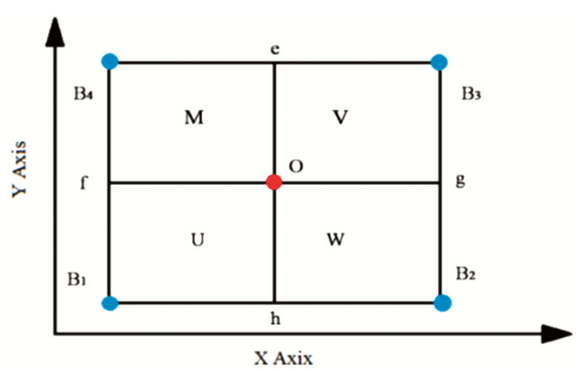

Fig. 4 — Schematic for Renewed centroid algorithm

$$x_e = \frac{1}{2} \times \left(x_{\beta_4} + x_{\beta_3}\right) \quad \text{... (19.1)}$$

$$y_e = \frac{1}{2} \times \left(y_{\beta_4} + y_{\beta_3}\right) \quad \text{... (19.2)}$$

$$x_f = \frac{1}{2} \times \left(x_{\beta_4} + x_{\beta_1}\right) \quad \text{... (19.3)}$$

$$y_f = \frac{1}{2} \times \left(y_{\beta_4} + y_{\beta_1}\right) \quad \text{... (19.4)}$$

$$x_g = \frac{1}{2} \times \left(x_{\beta_3} + x_{\beta_2}\right) \quad \text{... (19.5)}$$

$$y_g = \frac{1}{2} \times \left(y_{\beta_3} + y_{\beta_2}\right) \quad \text{... (19.6)}$$

$$x_h = \frac{1}{2} \times \left(x_{\beta_2} + x_{\beta_1}\right) \quad \text{... (19.7)}$$

$$y_h = \frac{1}{2} \times \left(y_{\beta_2} + y_{\beta_1}\right) \quad \text{... (19.8)}$$

In the same manner, the position of O is computed using Eqs 20.1 and 20.2.

$$x_O = \frac{1}{4} \times \left(x_{\beta_1} + x_{\beta_2} + x_{\beta_3} + x_{\beta_4}\right) \quad \text{... (20.1)}$$

$$y_O = \frac{1}{4} \times \left(y_{\beta_1} + y_{\beta_2} + y_{\beta_3} + y_{\beta_4}\right) \quad \text{...(20.2)}$$

Further to this, the process of finding out the position of the object using the Renewed centroid algorithm is shown in Table 1.

The above process is very much effective in terms of finding out the position of the unknown object but there are some drawbacks to this method as well. Since, the RC method relies upon several conditions, so if any of the given condition fails due to the effect of the environment then it will give a wrong estimated value for the position of the unknown object. Moreover, the above technique is very much effective for a small area but when the area becomes larger, then in that case, the average error of the coordinate of the unknown object may increase. For a small area, the use of four beacons are good enough for getting good accuracy of the position of an unknown node placed inside the area of interest. But in a larger area, there may be a need for deploying more beacons to estimate the position. In this work, we also evaluated RC method in a real industrial environment and compared the result with others.

or our experimental study, we deployed multiple beacon nodes at different places of the industrial environment as shown in Fig. 5. Here B_1, B_2, B_3, B_4, B_5

Table 1 — Process to find out the location of the unknown object using renewed centroid algorithm

Condition for the judgment	Estimation of the region	x axis of the unknown object	y axis of the unknown object
If $\delta_1<\delta_2$, $\delta_1<\delta_3$ and $\delta_1<\delta_4$	In U region	The centroid point of U and can be written as $x_U = \frac{1}{4}\times(x_{\beta_1} + x_h + x_f + x_o)$	The centroid point of U and can be written as $y_U = \frac{1}{4}\times(y_{\beta_1} + y_h + y_f + y_o)$
If $\delta_4<\delta_1$, $\delta_4<\delta_2$ and $\delta_4<\delta_3$	In M region	The centroid point of M and can be written as $x_M = \frac{1}{4}\times(x_{\beta_4} + x_e + x_0 + x_f)$	The centroid point of M and can be written as $y_M = \frac{1}{4}\times(y_{\beta_4} + y_e + y_0 + y_f)$
If $\delta_3<\delta_1$, $\delta_3<\delta_2$ and $\delta_3<\delta_4$	In V region	The centroid point of V and can be written as $x_V = \frac{1}{4}\times(x_{\beta_3} + x_e + x_0 + x_g)$	The centroid point of V and can be written as $y_V = \frac{1}{4}\times(y_{\beta_3} + y_e + y_0 + y_g)$
If $\delta_2<\delta_1$, $\delta_2<\delta_3$ and $\delta_2<\delta_4$	In W region	The centroid point of W and can be written as $x_W = \frac{1}{4}\times(x_{\beta_2} + x_h + x_o + x_g)$	The centroid point of W and can be written as $y_W = \frac{1}{4}\times(y_{\beta_2} + y_h + y_o + y_g)$
If $\delta_1 = \delta_2$, $\delta_1<\delta_3$ and $\delta_1<\delta_4$	In oh region	The middle point of o and h and can be written as $x_{oh} = \frac{1}{2}\times(x_o + x_h)$	The middle point of o and h and can be written as $y_{oh} = \frac{1}{2}\times(y_o + y_h)$
If $\delta_2 = \delta_3$, $\delta_2<\delta_1$ and $\delta_2<\delta_4$	In og region	The middle point of o and g and can be written as $x_{og} = \frac{1}{2}\times(x_o + x_g)$	The middle point of o and g and can be written as $y_{og} = \frac{1}{2}\times(y_o + y_g)$
If $\delta_3 = \delta_4$, $\delta_3<\delta_1$ and $\delta_3<\delta_2$	In oe region	The middle point of o and e and can be written as $x_{oe} = \frac{1}{2}\times(x_o + x_e)$	The middle point of o and e and can be written as $y_{oe} = \frac{1}{2}\times(y_o + y_e)$
If $\delta_4 = \delta_1$, $\delta_4<\delta_2$ and $\delta_4<\delta_3$	In of region	The middle point of o and f and can be written as $x_{of} = \frac{1}{2}\times(x_o + x_f)$	The middle point of o and f and can be written as $y_{of} = \frac{1}{2}\times(y_o + y_f)$

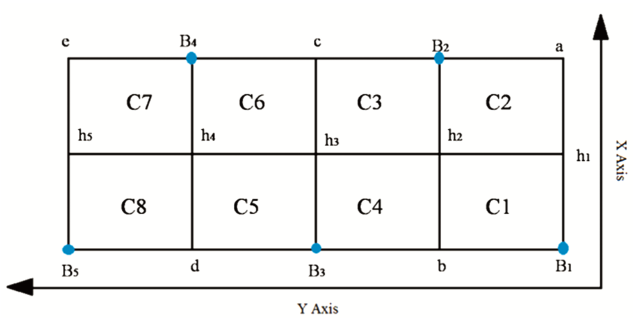

Fig. 5 — Schematic showing deployed layout for evaluating RC algorithm

are the coordinate of five beacons. The estimated coordinates of those Beacons are $(x_{\beta_1}, y_{\beta_1})$, $(x_{\beta_2}, y_{\beta_2})$, $(x_{\beta_3}, y_{\beta_3})$, $(x_{\beta_4}, y_{\beta_4})$ and $(x_{\beta_5}, y_{\beta_5})$ respectively. In addition, the distance from the Beacon nodes to the unknown object are denoted as$\delta_1, \delta_2, \delta_3, \delta_4, \delta_5$. Now, the RC algorithm has been applied and different conditions are formulated as per the recommendation of the RC algorithm and shown as Table 2.

System Model

This section discusses the network architecture and the basic localization techniques for estimating the position of the IoT node in indoor environment.

Network Architecture

For the experiment in this work, some BLE beacons are set randomly in the place and a mobile device is used as a scanner to scan the signal of BLE Beacons. At the first stage of this architecture, all the BLE beacons are set to continuously send the beacon signal. A mobile device is used to capture the signal strength (RSSI) from each beacon after scanning the surrounding in the mobile device. Secondly, the localization technique implied for getting the location of the mobile device using the RSSI values captured by the mobile device and the position of the corresponding beacons in the mobile device. Finally, the location of the mobile device is sent to the computer server by using TCP/IP. The Fig. 6 shows the Network architecture of the experimental system.

RSSI based Indoor Localization Technique using BLE

In this work, Received Signal Strength (RSS) is used for estimating the location of the device used by the user. Here RSS is the signal power measured by the Received Signal Strength Indicator (RSSI) circuit.[22] The RSSI value is very useful for calculating the distance, which is an important part of the localization algorithm. The advantages of RSSI based localization technique is that it can be easily obtained by low complexity algorithms and can also be easily implemented in the system.[23, 24] The main drawback of this system is that they provide a poor estimation in case of a large distance. In most of the practical cases, the location is acceptable up to three-meter distance.[25]

Table 2 — Process to find the location of unknown object using the renewed centroid algorithm

Condition for the judgment	Estimation of Region	x axis of the unknown object	y axis of the unknown object
If $\delta_1 = \delta_2 = \delta_3$ and $\delta_1 < \delta_4$ and $\delta_1 < \delta_5$	In h_2 region	In the centroid point of B_1, B_2, B_3 and can be written as $x_{h_2} = \frac{1}{3} \times (x_{\beta_1} + x_{\beta_2} + x_{\beta_3})$	In the centroid point of B_1, B_2, B_3 and can be written as $y_{h_2} = \frac{1}{3} \times (y_{\beta_1} + y_{\beta_2} + y_{\beta_3})$
If $\delta_2 = \delta_3 = \delta_4$ and $\delta_2 < \delta_1$ and $\delta_2 < \delta_5$	In h_3 region	In the centroid point of B_2, B_3, B_4 and can be written as $x_{h_3} = \frac{1}{3} \times (x_{\beta_2} + x_{\beta_3} + x_{\beta_4})$	In the centroid point of B_2, B_3, B_4 and can be written as $y_{h_3} = \frac{1}{3} \times (y_{\beta_2} + y_{\beta_3} + y_{\beta_4})$
If $\delta_3 = \delta_4 = \delta_5$ and $\delta_3 < \delta_1$ and $\delta_3 < \delta_2$	In h_4 region	In the centroid point of B_3, B_4, B_5 and can be written as $x_{h_4} = \frac{1}{3} \times (x_{\beta_3} + x_{\beta_4} + x_{\beta_5})$	In the centroid point of B_3, B_4, B_5 and can be written as $y_{h_4} = \frac{1}{3} \times (y_{\beta_3} + y_{\beta_4} + y_{\beta_5})$
If $\delta_1 < \delta_2$, $\delta_1 < \delta_3$, $\delta_1 < \delta_4$ and $\delta_1 < \delta_5$	In C1 region	In the centroid point of C1 and can be written as $x_{C1} = \frac{1}{4} \times (x_{\beta_1} + x_{h_1} + x_{h_2} + x_b)$	In the centroid point of C1 and can be written as $y_{C1} = \frac{1}{4} \times (y_{\beta_1} + y_{h_1} + y_{h_2} + y_b)$
If $\delta_2 < \delta_1$, $\delta_2 < \delta_3$, $\delta_2 < \delta_4$ and $\delta_2 < \delta_5$	In C2 region	In the centroid point of C2 and can be written as $x_{C2} = \frac{1}{4} \times (x_{\beta_2} + x_a + x_{h_1} + x_{h_2})$	In the centroid point of C2 and can be written as $y_{C2} = \frac{1}{4} \times (y_{\beta_2} + y_a + y_{h_1} + y_{h_2})$
And if $\delta_1 < \delta_3$, $\delta_1 < \delta_4$ and $\delta_1 < \delta_5$			
Else	In C3 region	In the centroid point of C3 and can be written as $x_{C3} = \frac{1}{4} \times (x_{\beta_2} + x_c + x_{h_2} + x_{h_3})$	In the centroid point of C3 and can be written as $y_{C3} = \frac{1}{4} \times (y_{\beta_2} + y_c + y_{h_2} + y_{h_3})$
If $\delta_3 < \delta_1$, $\delta_3 < \delta_2$, $\delta_3 < \delta_4$ and $\delta_3 < \delta_5$	In C4 region	In the centroid point of C4 and can be written as $x_{C4} = \frac{1}{4} \times (x_{\beta_3} + x_b + x_{h_2} + x_{h_3})$	In the centroid point of C4 and can be written as $y_{C4} = \frac{1}{4} \times (y_{\beta_3} + y_b + y_{h_2} + y_{h_3})$
And if $\delta_2 < \delta_1$, $\delta_2 < \delta_4$ and $\delta_2 < \delta_5$			
Else	In C5 region	In the centroid point of C5 and can be written as $x_{C5} = \frac{1}{4} \times (x_{\beta_3} + x_d + x_{h_3} + x_{h_4})$	In the centroid point of C5 and can be written as $y_{C5} = \frac{1}{4} \times (y_{\beta_3} + y_d + y_{h_3} + y_{h_4})$
If $\delta_4 < \delta_1$, $\delta_4 < \delta_2$, $\delta_4 < \delta_3$ and $\delta_4 < \delta_5$ And if $\delta_3 < \delta_1$, $\delta_3 < \delta_2$ and $\delta_3 < \delta_5$	In C6 region	In the centroid point of C6 and can be written as $x_{C6} = \frac{1}{4} \times (x_{\beta_4} + x_{h_3} + x_{h_4} + x_c)$	In the centroid point of C6 and can be written as $y_{C6} = \frac{1}{4} \times (y_{\beta_4} + y_{h_3} + y_{h_4} + y_c)$
Else	In C7 region	In the centroid point of C7 and can be written as $x_{C7} = \frac{1}{4} \times (x_{\beta_4} + x_{h_4} + x_{h_5} + x_e)$	In the centroid point of C7 and can be written as $y_{C7} = \frac{1}{4} \times (y_{\beta_4} + y_{h_4} + y_{h_5} + y_e)$
If $\delta_5 < \delta_1$, $\delta_5 < \delta_2$, $\delta_5 < \delta_3$ and $\delta_5 < \delta_4$	In C8 region	In the centroid point of C8 and can be written as $x_{C8} = \frac{1}{4} \times (x_{\beta_5} + x_{h_4} + x_{h_5} + x_d)$	In the centroid point of C8 and can be written as $y_{C8} = \frac{1}{4} \times (y_{\beta_5} + y_{h_4} + y_{h_5} + y_d)$
If $\delta_1 = \delta_2$, $\delta_1 < \delta_3$, $\delta_1 < \delta_4$ and $\delta_1 < \delta_5$	In $h_1 h_2$ region	In the middle point of h_1 and h_2 and can be written as $x_{h_{12}} = \frac{1}{2} \times (x_{h_1} + x_{h_2})$	In the middle point of h_1 and h_2 and can be written as $y_{h_{12}} = \frac{1}{2} \times (y_{h_1} + y_{h_2})$
If $\delta_2 = \delta_3$, $\delta_2 < \delta_1$, $\delta_2 < \delta_4$ and $\delta_2 < \delta_5$	In $h_2 h_3$ region	In the middle point of h_2 and h_3 and can be written as $x_{h_{23}} = \frac{1}{2} \times (x_{h_2} + x_{h_3})$	In the middle point of h_2 and h_3 and can be written as $y_{h_{12}} = \frac{1}{2} \times (y_{h_2} + y_{h_3})$
If $\delta_3 = \delta_4$, $\delta_3 < \delta_1$, $\delta_3 < \delta_2$ and $\delta_3 < \delta_5$	In $h_3 h_4$ region	In the middle point of h_3 and h_4 and can be written as $x_{h_{34}} = \frac{1}{2} \times (x_{h_3} + x_{h_4})$	In the middle point of h_3 and h_4 and can be written as $y_{h_{34}} = \frac{1}{2} \times (y_{h_3} + y_{h_4})$

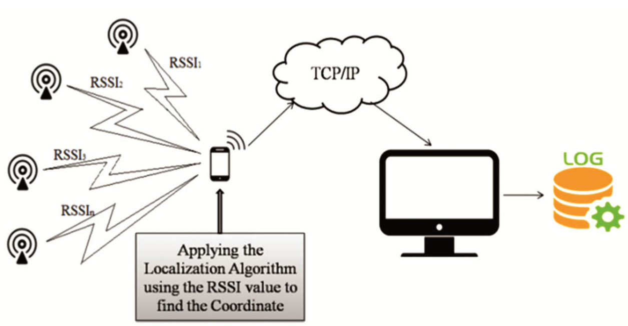

Fig. 6 — Network Architecture

Transmission Model of Wireless Signal

During the process of transmission, the RSSI converts the loss according to the intensity of the transmitted signal. In the indoor localization system, the RSSI based signal propagation model has been simplified in terms of cost, requirement of location accuracy, and other factors and expressed |as Eq. 21.

$$\mathrm{RSSI(d)} = -10n \times \log_{10}(d) + \mathrm{RSSI(d_0)} \quad \ldots (21)$$

Here, RSSI(d) is the RSSI value at a distance d, d is the distance between the beacon node and unknown node; RSSI(d_0) is the RSSI value at a distance of one meter in dBm; n = environmental factor whose range varies between 2 to 4.

Data Transmission

In this work, we used Client-Server architecture for the data transmission. The system architecture of the Client/Server system has been discussed in this section.

System Architecture of Client/Server system

The basic structure of the Client/Server (C/S) system totally depends upon the distribution of the task-level applications.[26] The general architecture of the C/S system is described in Fig. 7. To exchange the information between client-side and server-side communication software used for example TCP/IP. The main purpose of using this software is to provide a basic structure for the applications. In C/S system, the designing of the client-side user interface is one of the important factors. The main benefits of the C/S system are that it can be easily handled, quick response, and very much flexible.

Setup for Indoor Localization

In this experiment, different devices are configured for doing the entire experiment perfectly. BLE enabled Beacon is configured to transmit the signal at a regular time interval, the Mobile device is set to receive the BLE signal and estimate the position and then send the estimated position data along with the Id of the nearest detected Beacon to the computer server.

A. Working Procedure of BLE Beacon

BLE (Bluetooth Low Energy) is an advanced technique for wireless sensor networks designed for short-range wireless communication. It is very much helpful to communicate with each other. BLE data transfer is one-way communication. For example, a BLE Beacon sends a packet of data at a fixed time interval, and this packet of data detected by the mobile application, preinstalled in the Mobile device. For saving energy and transfer the data at a high rate the entire BLE communication framework consists of 40 frequency channels. Out of those, there are three primary channels (advertisement channels) and the remaining are secondary channels (data channels). Now a day's most of the smart-phone and tablets support BLE (From Android 4.3 to the latest version of Android, for Apple iPhone 4 to the latest version of Apple set). Classical Bluetooth is used for the continuous streaming of data such as headphones. On the other hand, BLE is used for the periodic transfer of data for this, the energy consumption in BLE is lower than the classical Bluetooth. Due to its energy efficient properties, BLE beacons are mostly used in different types of IoT applications such as activity sensing, proximity detection, indoor localization, etc. The symmetric diagram of the BLE Beacon signal transmission is given in Fig. 8.

Localization using BLE beacon

In this work, we selected BLE beacons for the indoor localization due to its practical use. Wi-Fi can also be used as an alternative of BLE beacons for indoor localization but WiFi has some drawbacks. WiFi access points (AP) are inflexible to deploy, APs are mainly meant to cover the signal and not used specifically for localization, also the power consumption of Wi-Fi is comparatively higher and thus doesn't provide a power efficient way for deploying the localization system. There are also some other technologies available for localization such as RFID, infrared and ultra-wideband. However, in these technologies, a dedicated reader is needed to operate the system which makes the system complicated for the common public to properly utilize this service.

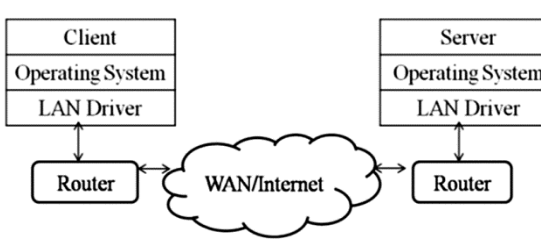

Fig. 7 — Routing figure of Client Server architecture

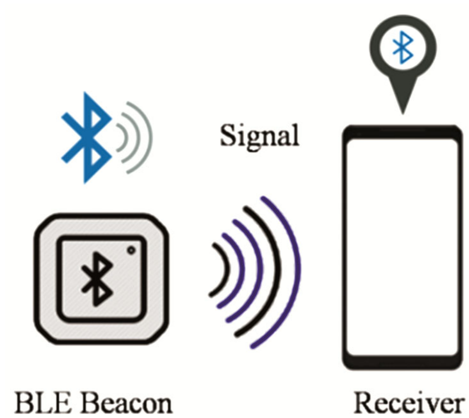

Fig. 8 — Signal Transmission by BLE Beacon

Client Side

For implementing the client side system, we used Android based smart phone as a client terminal to locate its position using the BLE Beacons fixed at different positions. During the first stage, an application for the localization scheme is designed in Android Studio, which will detect the BLE beacon signal nearby using Bluetooth technology. The mobile node based client app is set to read the RSSI value of the nearby Beacons and apply the localization scheme based on those RSSI values to find its own indoor position. The android app is designed to display the received beacon data on the screen and simultaneously send the same to the computer server. The mobile application serves as the element between the mobile device and the user. The main aim of this application is to provide the user with an easy solution to track its own location in an unknown indoor environment. The most important feature of this app is that it displays its own coordinate instantly without any delay.

In this experiment, we used Samsung Galaxy J7 Nxt as an android device to localize the moving node. This device has the operating system of Android 7.0 and 2 GB RAM.

Server Side

For the purpose of indoor localization experiment, there is a need for the computer device on the server-side to track the moving node and store that information. For this, a windows based application has been developed on the server-side using NetBeans 8.2. This server-side application is meant to receive all the data sent by the mobile application and save those data in a CSV file. For the computer server, we used a computer that has the operating system Windows 8.1, Intel Core i5 3.30 GHz processor, 16 GB RAM for experimenting fluently.

The screenshots of the developed client and server applications used for the indoor localization experiments are shown in Fig. 9.

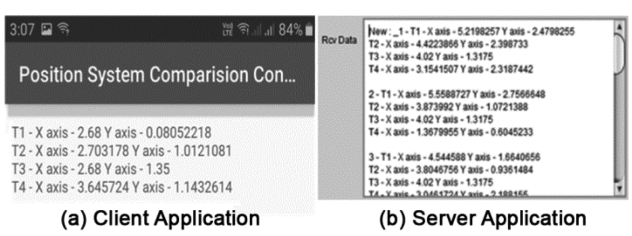

Fig. 9 — Localization application (a) Client (b) Server Application

Developed mobile app is capable of displaying its own indoor positioning based on different deployed localization methods and then sends the same to the server side application in real-time. In the information window, theterm T1 (Technique 1) indicates Trilateration localization algorithm, T2 (Technique 2) indicates Weighted Centroid localization algorithm, T3 (Technique 3) indicates Renewed Centroid localization algorithm and T4 (Technique 4) indicates Multilateration localization algorithm.

Algorithm for Localization Process Experiments:

Input:

1. Configure BLE Beacons throughout the area.
2. BLE Beacons transmitting signals continuously at a fixed time interval.
3. Trigger the Mobile Application.
4. **for** time = 1 : t
5. **for** Beacon = 1 : n
6. Read the BLE Beacon predefined in the Mobile Application.
7. Calculate the RSSI value for each Beacon.
8. Calculate the distance from the Beacon node to Unknown node for each Beacon by using Eq. (21). Compare those values to find out the nearest Beacon nodes.
9. **end for**
10. Applying localization technique, based on the distance calculated by the help of Eq. (21).
11. Calculate the position of the unknown node and send that data to the Server Computer by using TCP/IP.
12. **end for**

Output:

13. Run the Windows Form to receive the data.
14. **for** time = 1 : t
15. Receive all the data send by the Mobile Application.
16. Store all the value of the coordinate in CSV Format.
17. **end for**
18. Calculate the Average Error by using the Eq. (22) for each coordinate to know the accuracy for each coordinate
19. Create plot based on that information.

Four different kinds of localization techniques are used namely Trilateration Algorithm[19,20,27], Weighted Centroid Algorithm[28], Renewed Centroid Algorithm[21] and Multilateration Algorithm[21, 29] to find out the best scheme for estimating the position in industrial and living room environments.

To track the unknown object, here the localization technique applied based on BLE Beacons by using the Bluetooth technology where the experimental result evaluation is done by calculating the Average Error of the estimated coordinate with the help of Eq. 22.

$$E = \sqrt{(x - x')^2 + (y - y')^2} \quad \ldots (22)$$

Here (x, y) is the actual coordinate of the unknown node and (x', y') is the estimated coordinate by using the localization algorithm and E is the Average Error of the estimated coordinate.

Experimental Sites

The experiment is conducted in both Industrial and Lab Room Environment to compare the techniques in both environments and find out the best technique in different circumstances. At the first stage, all the BLE Beacons are placed at different positions in both Industrial and Room locations. Following the same, the mobile application is used to track the position of the node. The layout design of BLE configuration in different indoor environments has beenshown in Fig. 10.

In Fig. 10, B1, B2, B3, B4, and B5 are the beacon nodes, configured and placed in the industrial environment, and P1, P2, P3, P4, and P5 are the data collection point from where we collected the data to know the accuracy of the position using different localization techniques.

All the BLE beacons are placed at different positions and after that, the mobile application is triggered to track the position of the mobile node by using the different localization techniques and send the localization data to the computer server for logging and analysis. We moved the mobile node and position that at five different positions to know the accuracy of the computed locations inside the indoor environment.

Fig. 10 — Experimental Sites (a) Industrial workshop and (b) Lab room

Results and Discussion

Tables 3–5 show the actual and estimated position of the unknown mobile node using different localization techniques.

The result obtained in Table 5 is plotted using bar graph for better comparison. The plots of average errors at different positions in Industrial as well as room environment are shown in Fig. 11. From Fig. 11, it can be observed that at different positions we get different values of average error due to the presence of multiple obstacles (such as type of machinery, wall, etc.), distortion, noise, and other environmental factors, etc.

These physical objects and environmental factors affect the localization process. From Table 5, it can also be observed that when compared with the Renewed Centroid Algorithm and Multilateration Algorithm, the Weighted Centroid Algorithm and the

Table 3 — Data collected in industrial Environment

Unknown Node Position	Actual Data Collection Points		Position estimation using Trilateration Algorithm		Position estimation using Weighted Centroid Algorithm		Position estimation using Renewed Centroid Algorithm		Position estimation using Multilateration Algorithm	
	X Axis	Y Axis	X Axis	Y Axis	X Axis	Y Axis	X Axis	Y Axis	X Axis	Y Axis
P1	4	4.6	3.091	7.424	4.6702	7.3676	6.4088	6.5104	5.1550	10.4236
P2	7.9	13.5	7.8322	14.8587	5.7654	14.2372	3.5728	11.7500	5.4114	14.8540
P3	4	15	7.8815	15.0862	6.1534	15.4747	3.9075	17.4764	5.4590	15.1571
P4	7.5	21.5	3.0220	22.4759	4.5945	22.4120	6.8474	22.0192	5.1659	19.3601
P5	4	25	3.0334	22.8087	4.1628	23.7797	5.6379	26.2500	5.2107	19.6443

Table 4 — Data collected in Room Environment

	Actual Data Collection Points		Position estimation using Trilateration Algorithm		Position estimation using Weighted Centroid Algorithm		Position estimation using Renewed Centroid Algorithm		Position estimation using Multilateration Algorithm	
	X Axis	Y Axis	X Axis	Y Axis	X Axis	Y Axis	X Axis	Y Axis	X Axis	Y Axis
P1	.93	4.26	1.8194	4.8381	2.1565	4.3606	1.8760	4.1145	4.4109	5.5953
P2	2.15	1.8	1.9249	1.5714	2.3650	1.2790	2.0100	1.3681	3.6661	1.7332
P3	3.14	3.34	4.2856	2.6700	3.7567	2.5444	3.4840	1.8850	4.8223	4.5895
P4	4.06	1.89	3.8908	1.4456	3.5244	1.1884	3.8860	1.3207	2.9805	0.8987
P5	4.82	.90	5.5231	2.3758	4.8696	0.4365	4.0200	1.3175	4.3359	2.3085

Table 5 — Average error comparison using different localization technique in industrial and room environment

Unknown Node Position	Average Error Comparison in Industrial Environment				Average Error Comparison in Room Environment			
	Technique 1	Technique 2	Technique 3	Technique 4	Technique 1	Technique 2	Technique 3	Technique 4
P1	2.9798	3.0547	4.7906	5.9597	2.4329	1.4829	0.9596	4.1161
P2	1.3632	2.3372	5.2215	4.3589	0.5500	0.6578	1.1654	2.1901
P3	3.8848	2.2703	4.2757	3.8319	1.8134	1.2061	2.1597	2.3752
P4	4.5852	3.1059	4.1967	3.2592	1.3970	1.0929	0.6647	2.3539
P5	2.4035	1.5131	2.9610	5.5424	2.0571	0.5955	0.9024	1.9070

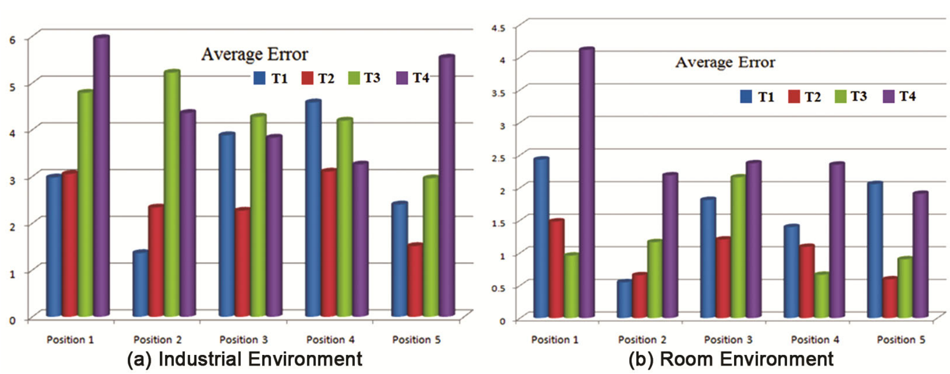

Fig. 11 — Average Error at different position using different Localization Technique in (a) Industrial environment and (b) Room environment

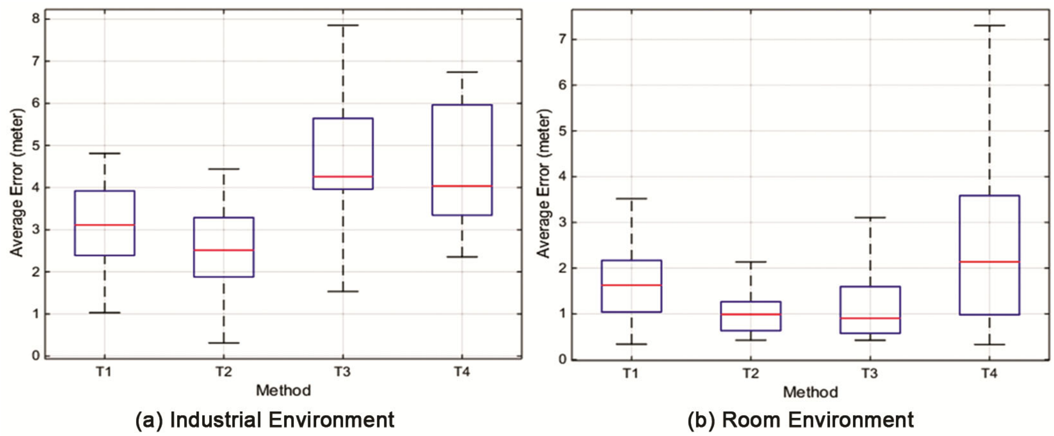

Fig. 12 —Average Error using different Localization Technique in (a) Industrial Environment and (b) Room Environment

Trilateration Algorithm provide the better estimated value for the position of the mobile node.

Further, the obtained position data are also used to study the variability of the Average Error for each localization techniques. The variability study is made to understand the stability of the estimated position for different localization techniques. The Average Error observed using different localization techniques is shown in Fig. 12. From Fig. 12, it can also be stated that for the industrial environment, the Average Error obtained using the Trilateration Algorithm is well within 3.1 meters, however same appeared within 2.5 meters when Weighted Centroid Algorithm is used. On the other hand, for the Renewed Centroid Algorithm, the value of Average Error comes within 4.3 meters whereas the same is within 4 meters for the Multilateration Algorithm. While in the room environment, the Average Error of around 1.5 meters has been observed in the case of Trilateration Algorithm, however for Weighted Centroid Algorithm the same value comes within 1 meter. It can also be observed that the Renewed Centroid Algorithm also perform at par with Weighted Centroid Algorithm in room environment but the range of the Average Error in the former case is larger than that of in Weighted Centroid Algorithm. Further, the analysis of the Multilateration Algorithm demonstrated the moderate Average Error i.e., within 2.1 meters. From the above observations, it can be stated that the localization accuracy highly depends upon the environment where the beacons and mobile nodes need to be deployed. Our experiments proved that the interference due to multiple industrial machineries and signals has adverse effects on the indoor localization accuracy irrespective of the applied localization technique.

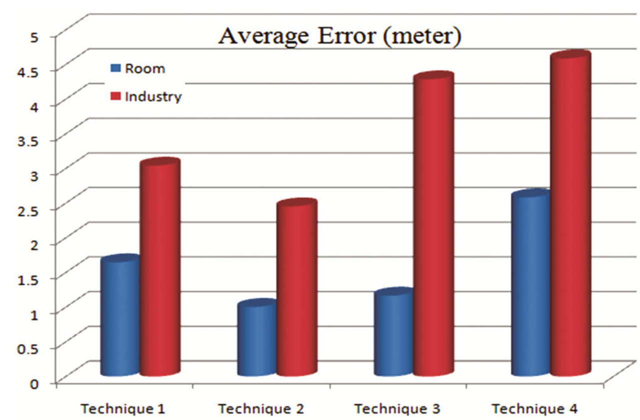

Fig. 13 — Comparison of different Localization Technique in Room and Industrial Environment

Furthermore, to find out the best localization technique in both the environments (i.e., room and industrial) for indoor localization systems, a bar graph of all the previously mentioned localization techniques have been plotted as shown in Fig. 13.

From Fig. 13, it can be concluded that the Weighted Centroid localization technique provides the best localization accuracy among all the four techniques in both industrial as well as room environment.

Conclusions

Indoor localization of IoT node in industrial environmental is imperative for implementation of any location based applications. In this work, four different range based localization techniques have been implemented on the mobile IoT node. After conducting extensive experiments in real environment, it is observed that the Weighted Centroid Localization

Algorithm provides the best position accuracy with better stability both in industrial and room environment. From the experimental results, it is also concluded that the indoor localization of IoT node is getting adversely affected in industrial environment possibly due to presence of multiple interferences in BLE signals from different machineries and large structures. In future, we will be working towards minimizing the effect of industrial environmental interferences on indoor localization technique that will further help in obtaining better localization accuracy of the IoT node even in indoor industrial environment.

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