

An adaptive ensemble localization approach for sensor nodes in WSN-IoT

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Abstract

Localization is an essential module for most protocols and applications in Wireless Sensor Networks - Internet of Things (WSN-IoT). Among the well-known approaches available for WSN-IoT localization, the algorithm requires at least one, two, or three beacon nodes-based localization approaches. Many other localization protocols use a small set of beacon nodes for the localization of sensor nodes. However, still, the authors are not able to provide an accurate and reliable approach in the field of WSN-IoT. Thus, this work provides an adaptive ensemble localization approach in WSN-IoT. The proposed approach adaptively uses the concept of available single, two, and three beacons nodes-based localization approaches according to the number of available beacon nodes. By comparing available single, two, or three beacons nodes-based localization approaches the simulation results of the proposed work outperformed in terms of fast convergence rate, less erroneous and higher accuracy with reducing the line of sight problem.

Keywords: WSN-IoT, Range Based, Beacon Node, Localization Accuracy, Convergence Rate, Location Error.

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1. Introduction

In the modern era, the use of IoT led to the creation of smart systems. For the less involvement of humans, the IoT system provides machine-to-machine communication [1][2] facilities. On the other hand, the WSN system performs an essential role in places to collect information. The system is designed for remote area applications where humans have rare physical access. The IoT-based WSN system creates an autonomous smart system for efficiently monitoring the remote area [3][4]. Further assessment of the WSN-IoT-based system involves a variety of continuous information from different sources. It integrates sequentially with the framework of various sensor information processing systems to monitor the executive structures, so the possible areas from remote locations can be achieved [5][6].

Sensor nodes in WSN-IoT can provide a collection of real-time data with timestamps and their location information anywhere and anytime. Data is unusable in a system without a known location, so the localization of the sensor node is an

essential issue for WSN-IoT. Thus, localization poses a significant challenge for WSN-IoT. The localization approaches are classified into two parts, according to range-based localization and range-free localization approaches [7][8]. The range-based location estimation is much precise compared to range free based location estimation in WSN localization [9]. The range-based approaches, for example, as trilateration, triangulation, and multilateration [10]. The range free based [11] approaches, for example, DV-Hop, improved DV-Hop, centroid, Approximate Point-In-Triangulation (APIT). This work provides the critical analysis of currently available work of range-based approaches such as three beacons, two beacons, and one beacon-based approach for localization in WSN. In the presently available localization works are analysis based on the network parameters such as:

- Network density:
The total number of beacon nodes are deployed to sensor nodes localization.
- Computation overhead: It analyzes the total number of packets processed for the of sensor nodes localization

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in the network.

- **Energy consumption:**
The total amount of energy consumption is required to estimate the sensor node location with higher accuracy,
- **Position error:**
The position error is an error, i.e., taken from neighbor reference node for estimation of its sensor node location. If more erroneous reference nodes are involved in the estimate of sensor node location, then less accuracy is achieved by the localization algorithm.
- **Response time:**
The response time is referred to as the convergence rate, which means how much time is taken to meet the target value of networking.
- **Localization Accuracy:**
The error value difference between the actual position and estimated location of sensor nodes is to define how much accuracy is received by the localization algorithm. If lower mean error, then higher location accuracy and higher mean error, then lower localization accuracy.
- **Convergence rate:**
The total number of elapsed time to localized randomly deployed sensor nodes in the networks.

After the critical analysis of existing works in which, most of the researchers focus on localization with a minimum number of beacon nodes or the best selection of beacon nodes, but the least number of researchers are concerned about efficient utilization of available well-known localization approaches in the field of beacon-based localization for the randomly deployed sensor nodes. In randomly deployed sensor nodes scenario, when the sensor nodes are not able to localization itself due to the unavailability of required beacon nodes. Thus, this proposed work based on available beacons-based localization to provides an efficient adaptive ensemble approach of sensor node localization in WSN-IoT. The design approach can provide an efficient adaptive change in its algorithm based upon the received signal at the reference/beacon node of the sensor nodes into the system. The based upon RSSI information received at the beacon node from the sensor nodes, then the beacon nodes will take the decision, which localization approach will be used from the single, two, or three beacons based.

The further part of this work is covered as section 2 provide the literature survey of available vital work in the field of wireless sensor node localization in WSN, section 3 provides the proposed work of ensemble adaptive sensor node localization for random sensor node deployment scenario in the form of flow chart and algorithm, section 4 presents the work analysis of the proposed ensemble adaptive localization approach with their example, section 5 presents the simulation-based analysis of proposed work and comparison analysis with the one, two and three beacon-based localization algorithms and section 6 states the conclusion of the proposed work.

2. Literature Survey

Recurrence Position Estimation (RPE) approach for localization of unknown nodes with the help of at least three beacon nodes in the WSN [12]. This work geometrical problem is solved through a non-linear regression approach and has developed a reliable approach to estimate the location of an unknown node. A designed model was presented, while the deployment of sensor nodes requiring 5% beacons of nodes. The accuracy of this approach is 90% in while estimation of the location of unknown nodes within 3% ranging distance.

An efficient Directed Position Estimation (DPE) for the WSN is constructed with the help of at least two beacon nodes [13] as shown in Figure 1. The presented known direction recursion approach to choose between two known possible solutions, and it also solved the geometric problem. The model introduced a low-density network of unknown node localization in WSN. This work reduces the requirements of three beacon nodes for the estimation of unknown nodes location. It reduces network density deployment, communication overhead, computational error, algorithm complexity, and energy depletion of a node.

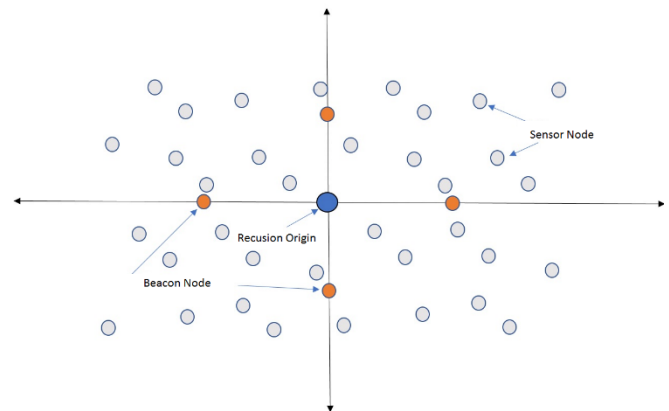


Figure 1. For directed localization recursion using beacon structure

The estimation of the unknown node location is directional through the recursion origin that leads to communication holes. Thus, this problem was solved [14] with the Non-directed Bilateral Position Estimation algorithm (NBPE) presented for WSN with communication holes. This approach for localization provides the omnidirectional (i.e., any 360 ° direction) location estimation for unknown node and also resolves communication holes such as O and C type holes that arise during the localization in WSN. The approach uses the estimation of two possible solutions and the selection of a possible solution based on a common beacon node between two beacon nodes. The NBPE work results have shown that the position error, energy depletion and response time are slightly better than DPE and RPE. The mathematical model for estimation of the two possible solutions for unknown node coordinates are (x_2, y_2) and (x_3, y_3) as shown below:

$$\begin{aligned} (x_2, y_2) &= ((x_1 + L * \cos (\alpha - 30)), (y_1 + L * \sin (\alpha - 30))) \\ (x_3, y_3) &= ((x_1 + L * \cos (\alpha + 30)), (y_1 + L * \sin (\alpha + 30))) \end{aligned}$$

Where L is represented as the distance from sensor nodes 1, 2 and 3 to sensor node 0 as shown in Figure 2.

Single beacon node-based localization of unknown nodes that resolves the need for at least three or two beacon nodes for location determination [15] with the proposed approach, i.e., the computational intelligence-based localization of mobile target nodes with the help of single anchor in WSN. The approach uses the geometric approach in which the centroid of the triangle method is used to find an approximate location of unknown nodes. In general, beacon nodes create six virtual nodes with an angle of 60° around their 360° region using the calculated distance between the beacon and the unknown node (RSSI method). Two virtual nodes are then selected according to the direction of the beacon node for the unknown node and then perform the centroid method to calculate the center point of the three points. The centroid point is the approximate location of unknown nodes and a computational intelligence algorithm is used to estimate the optimal location of the target node. The work also reduced the hardware requirement (like a number of beacon nodes) and the line of sight problem compared to RPE, DPE, NBPE. A very challenging problem of localization of mobile target node in WSN is also solved in the proposal.

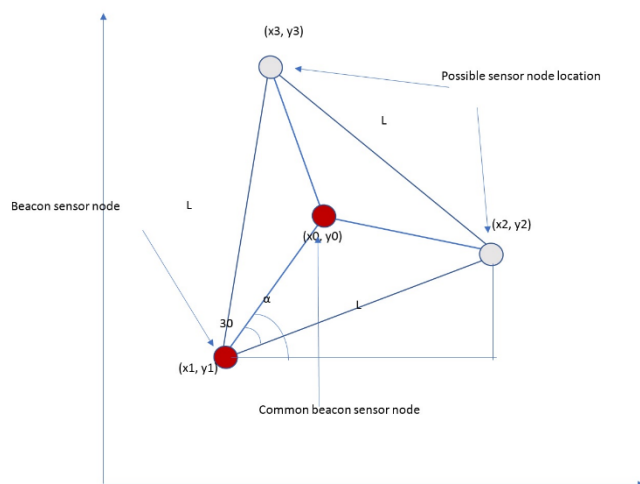


Figure 2. Primary two beacons-based localization structure

The authors [16] and [17] provide a comparative study of various localization techniques in WSNs. This effort helps researchers in the field of geographical routing for the advancement of IoT service to select appropriate localization techniques. Ideas on emerging issues and challenges are critically analyzed in localization approaches with available works. The available works on the basic main idea of the works as well as available network parameters are used to analysis of localization approach performance. The future direction provided by the analysis of available important works in the area of sensor nodes localization in WSN.

A Lightweight Iterative Positioning (LIP) approach is proposed [18] for WSNs. The approach uses a weighted average moving position obtained from several neighboring sensor nodes for position correction with high accuracy. In addition, the positioning refinement phase uses low duty cycling with high accuracy. The approach minimizes the

effect of neighboring nodes and conserves the energy of sensor nodes. Simulation results suggest that the LIP approach not only improves the network scalability challenge but provides higher accuracy than the robust localization approach.

Proposed an efficient recursion localization (ERL) [19] approach for a reliable reference selection in WSN. The WSN includes an approach for better distribution of reference nodes. The approach excludes the additional costs incurred during the efficient localization of the wireless sensor node compared to the RPE approach. This ERL approach suggests improvements in energy conservation to maximize the lifetime [20][21][22] of the network.

In this section, after presenting several types of literary works well in the area of beacon-based localization of sensor nodes in WSN-IoT. The existing literature suggests that researchers contributed to the selection of the best reference nodes and reduced the number of beacon nodes for the estimation of the location of sensor nodes. The least researchers are bothering about the efficient utilization of existing vital approaches in the field of localization to tackle environmental challenges adaptively. However, this paper tries to provide an efficient ensemble localization approach for WSN-IoT sensor nodes. The proposed approach consists of one, two, or three beacon-based approaches, and its localization approach changes favorably according to the environmental regulation. This approach will be useful for localizing randomly deployed sensor nodes and also solves the line of sight problem in the network.

2.1. Comparison and Discussion

This section provides a critical analysis of the well-known models available for localization of sensor nodes based on network analysis parameters available in WSN, such as network density, computational overhead, the complexity of the algorithm, energy consumption, position error calculation, response time and Accuracy.

At least three beacons nodes-based localization model [12]

- This approach fails when less than three beacons are available.
- Highly dense sensor node network deployment.
- The computational overhead of this approach is high.
- The energy consumption of this approach is moderate.
- The position error and computational error of this approach are high.
- The response time of this approach is low.
- The accuracy of this approach is low.
- The algorithm complexity of this approach is low.

At least two beacons nodes-based localization model [13][14]

- This approach fails when less than two beacons are available.

- Moderate dense sensor node network deployment.
- The complexity of this approach is moderate.
- The energy consumption of this approach is low.
- Position error and computational error of this approach are moderate.
- The response time of this approach is moderate.
- The accuracy of this approach is high.
- The algorithm complexity of this approach is moderate.

At least one beacon nodes-based localization model [15]

- This approach works when at least one beacon node is available.
- Low dense sensor node network deployment.
- The complexity of this approach is high.
- The energy consumption of this approach is high.
- The position error and computational error this approach are high.
- This approach has a higher response time.
- The accuracy of this approach is moderate.
- The algorithm complexity of this approach is high.

The taxonomy of critical analysis vital works in the field of beacon-based localization technique is presented in Table 1 for one beacon, two beacons, and three beacon-based localization approach in WSN.

Table 1. Taxonomy of existing well-known beacon-based localization approaches for sensor nodes

Parameters	One beacon-based localization approaches	Two beacons-based localization approaches	Three beacons-based localization approaches
Available one beacon node	Work	Fail	Fail
Available two beacon nodes	Work	Work	Fail
Available three beacon node	Work	Work	Work
Dense network deployment	Low	Moderate	High
Computational overhead	High	Moderate	Low

After the critical analysis of well-known three works of beacons-based localization in WSN. The existing approaches are given for sensor node localization for the various scenarios of the randomly deployed sensor network, but still not an enormous localization approaches are presented, so we present an adaptive ensemble localization approach with the consideration of all scenarios by one, two and three beacons.

The problem of the statement is to design a good form adaptive ensemble approach for beacons localization for the WSN-IoT system, and it is a motivation to resolve the efficient, reliable, and accurate challenges of localization. Thus, this can also be ensuring that while considering the other localization challenges such as energy depletion, the complexity of an algorithm, overhead communication, position error, network response time, low density of beacon nodes deployment in the random deployment of sensor nodes in various applications of WSN-IoT.

3. Proposed Framework

The localization of sensor nodes with minimal beacon nodes is quite a challenging task for WSN. Commonly used to localize sensor nodes with three beacon nodes (RPE approach). Due to the random deployment of a sensor node in the target area, the probability of the availability of three beacon nodes at some times is low. Therefore, if only two beacon nodes are available, the DPE approach is performed at that location for fast and accurate localization of sensor nodes. The two beacon-based localization approach is complex compared to the three beacon-based localization approaches. A two beacon-based localization approach does not apply if at least two beacon nodes are not available. For example, due to harsh environmental constraints and inefficient sensor nodes deployment strategies, a two beacon-based localization approach is not applicable when only one beacon node is available. A single beacon-based localization approach is more complex than two beacon-based localization approaches. Virtual nodes are deployed around 360 ° with an angle difference of 60 ° at a beacon node for sensor node location estimation. When there is more than one beacon node, then one beacon node based localization approach is not applicable due to the challenges of accuracy and complexity.

Mathematical models are used to calculate one, two or three beacon-based localization approaches:

At least three beacons nodes-based localization model [12]

Consider the data structure for designing the model below, where i relate {1, 2, 3, ..., n} as the sample of nodes in the sensor network.

- Residual value computation function
Estimated residual value (x, y, z) of unknown node position and follow its calculation model:
residual (x, y, z) =

$$\sum_{i \in reference} \left(\left(\sqrt{((x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2)} \right) - d_i \right)^2$$

- Distance computation function
The unknown node estimates its distance through the reference point and its distance calculation model is as follows:

$$d_i = \left(\left(\sqrt{((x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2)} \right) + \epsilon_i \right)$$

At least two beacons nodes-based localization model [13][14]

Consider the data structure to design the model below, where i belongs to $\{1, 2, 3, \dots, n\}$, as the sample of nodes in the sensor network, $P(i)$ denote the position of sensor nodes i and $K(i)$ refers that the function to calculates the position of the sensor node i .

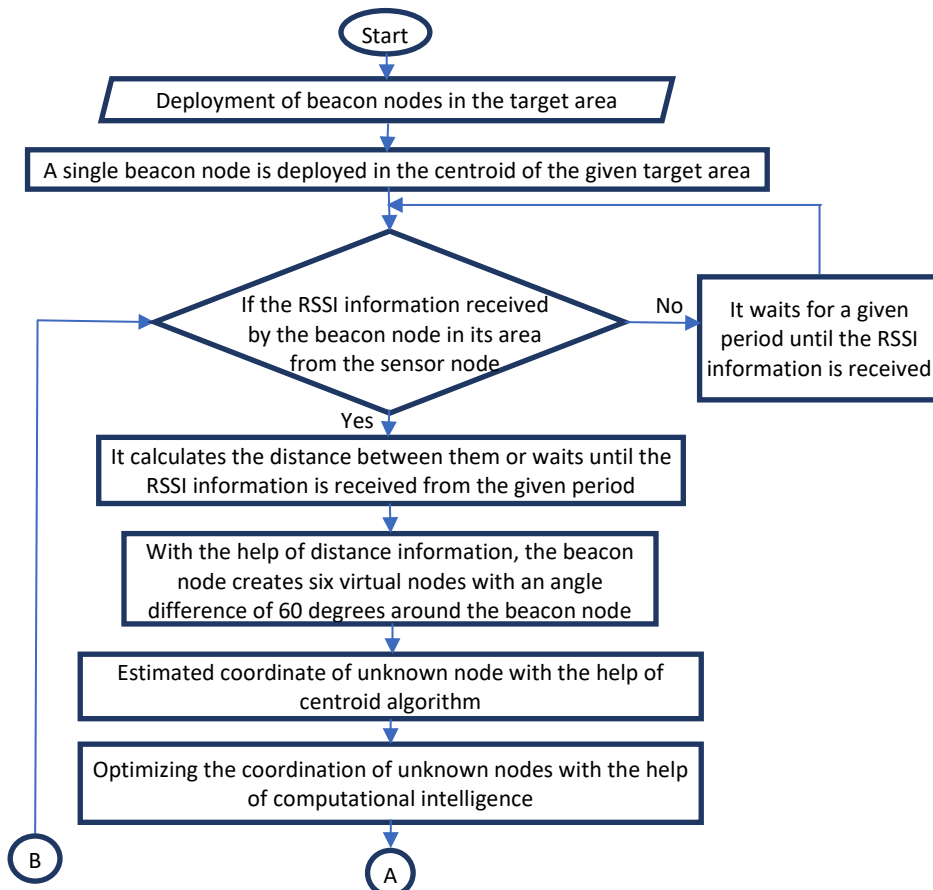
- Error computation function:
Error (i) denotes the function of K for sensor node i , and this model equation is as follows:
 $error(i) = ||P(i) - K(i)||$
- Mean error computation function:
In graph G , $Mean_{error}$ denotes the total average position error of function K for sensor network and its model equation shows as follows:
 $Mean_{error} = \frac{1}{n} \sum_{i=1}^n (||P(i) - K(i)||)$
- Remaining energy computation function:
 $E(i)$ denote the remaining energy of sensor node i , $E_{initial}$ is denoting the initial energy of a sensor node, $E_{used}(i)$ shows depleted energy for localization of sensor node i and its model equation shows as follows:
 $E(i) = E_{initial} - E_{used}(i)$
- Mean remaining energy computation function:
 $Mean_{remaining_energy}$ denote the total remaining energy of the sensor network and its model as follows:
 $Mean_{remaining_energy} = \frac{1}{n} \sum_{i=1}^n E(i)$

- Response time computation function:
 $response_time$ denote the response time for localization sensor networks localization, and it is denoted as $T(n)$
 $response_time = T(n)$

At least one beacon node-based localization model [15]

Consider the data structure for designing the below models, where i relate to $\{1, 2, 3, \dots, n\}$ as the sample of nodes in the sensor network.

- Distance computation function
 d_i denotes as the distance between estimated from the target node position (x_t, y_t) to beacon node position (x, y) and its computation model as follows:
 $d_i = \sqrt{(x_t - x)^2 + (y_t - y)^2}$
- Centroid computation function
The centroid of three points denotes as (x_c, y_c) using beacon node and two virtual nodes are $(xv1, yv2)$, $(xv1, yv2)$ and its computation model as follows:
 $(x_c, y_c) = (((x + xv1 + xv2)/3), (y + yv1 + yv2)/3))$
- Localization error computation function
Localization error is denoting as E_t . It is calculated as an error between the estimated target node coordinate and the actual coordinate of the target node. The error computation model is as follows:
 $E_t = \frac{1}{N_L} \sum \sqrt{((x_e - x_t)^2 + (y_e - y_t)^2)}$



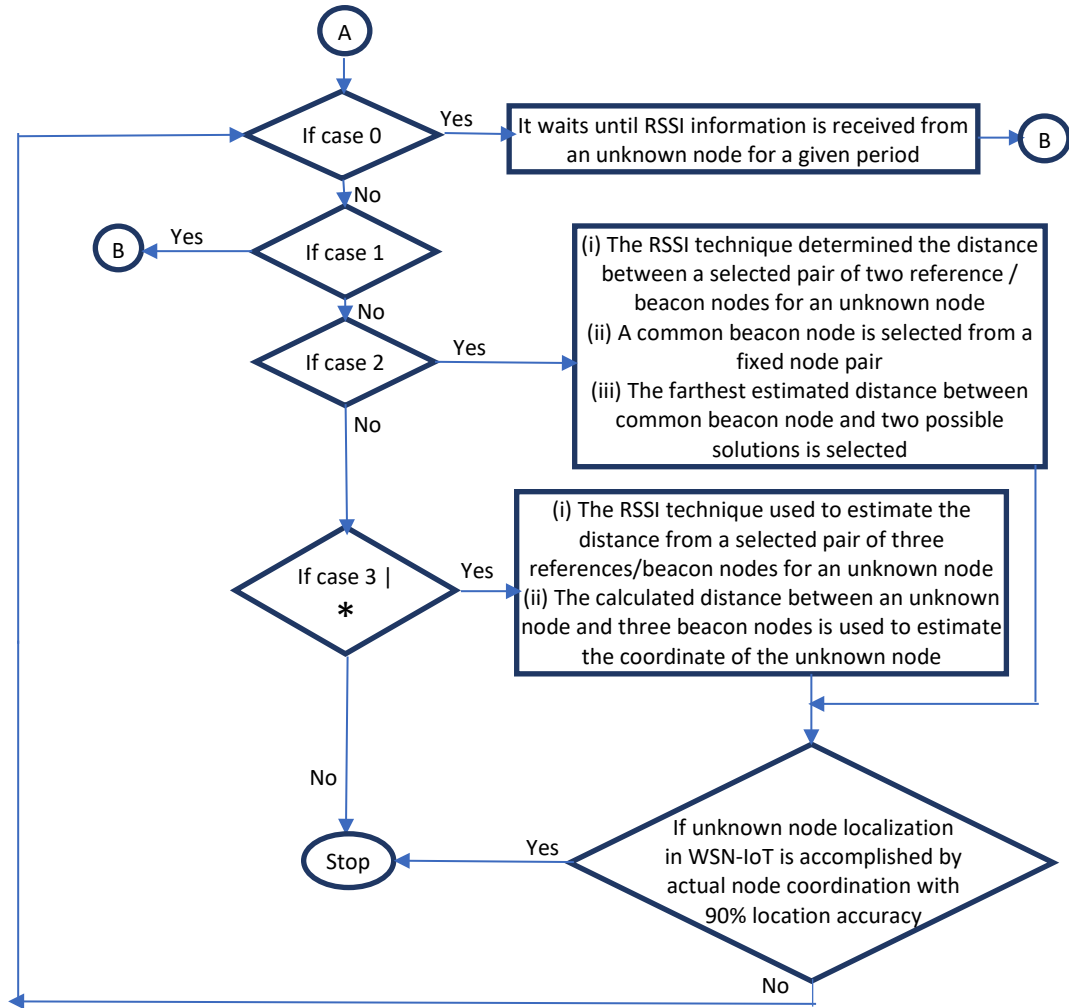


Figure 3. Flowchart of an adaptive ensemble localization approach for WSN-IoT.

3.1. Flow chart for an ensemble adaptive sensor node localization

The proposed flow chart for efficient adaptive localization of the sensor node in WSN-IoT as shown in Figure 3.

3.2. Algorithm for an ensemble adaptive sensor node localization

This proposed algorithm is used to address localization challenges in terms of localization accuracy, convergence rate, energy consumption, and computation overhead and it is performing better in the compared to available approaches for sensor node localization such as single, two or three beacons-based localization. The algorithm for an adaptive ensemble sensor node localization is as follows:

INPUT:

Rec_{area} is rectangle area, l and b are the length and width of the rectangle area, SN_{total} is the total number of sensor nodes, $BN(x, y)$ is an estimated centroid coordinate of

rectangle area, (a, b, c, d) are vertices coordinate of rectangle area, (SN_{deploy}) denote the randomly deployed sensor nodes, x and y is a coordinate value of sensor nodes, i belong to $\{1, 2, 3, \dots, n\}$ as the sample of sensor nodes, BN_{RSSI} denote the received RSSI power of the sensor node at beacon nodes, $RSSI_{received}()$ denote received RSSI signal at sensor nodes, d_i/L is the distance between beacon nodes and sensor nodes, $residual(x, y, z)$ denote the preserved energy of sensor nodes, $((x_1, y_1), (x_2, y_2), (x_3, y_3))$ are beacon nodes coordinates, (x_t, y_t) is coordinate of the target node, (vx_1, vy_1) and (vx_2, vy_2) are virtual nodes.

BEGIN:

- 1: $Rec_{area} = l * b$
- 2: $SN_{total} = n$
- 3: $BN(x, y) = \text{centroid}(a, b, c, d)$
- 4: $Rec_{area}(a, b, c, d) = \text{random}(SN_{deploy})$
- 5: for $(i = 0, i < n; i++)$
- 6: do
- 9: $BN_{RSSI} = RSSI_{received}(SN_{RSSI})$

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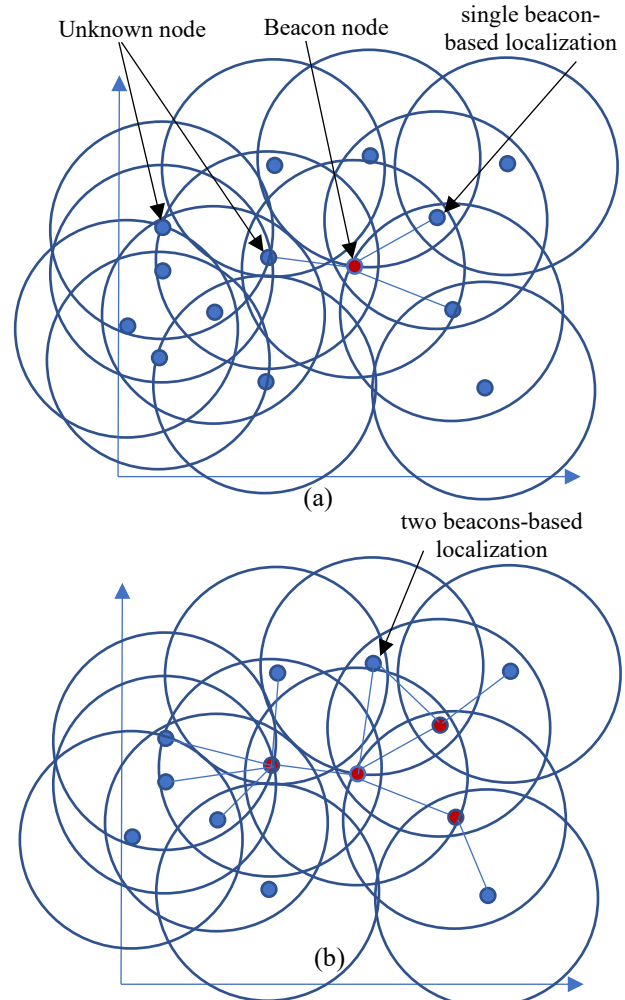
10:  if (BNRSSI == true)
11:    then
12:    else if (BNtotal == three)
13:      then
14:        di =
15:          residual (x, y, z) =
16:            
$$\sum_{i \in \text{reference/ beacon}} \left( \left( \sqrt{((x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2)} \right) + \varepsilon_i \right) - d_i \right)^2$$

17:            Estimate the coordinate (x, y, z) of the
18:            sensor node after the calculated distance
19:            from the three beacons/reference nodes
20:            and its equations are as follows:
21:            (x - x1)2 + (y - y1)2 + (z - z1)2 = d12
22:            (x - x2)2 + (y - y2)2 + (z - z2)2 = d22
23:            (x - x3)2 + (y - y3)2 + (z - z3)2 = d32
24:            else if (BNtotal == two)
25:              then
26:                di =  $\sqrt{((x_t - x)^2 + (y_t - y)^2)}$ 
27:                findCommBeacon (BNtotal)
28:                (x2, y2) = ((x1 + L * cos (α - 30)),
29:                (y1 + L * sin (α - 30)))
30:                (x3, y3) = ((x1 + L * cos (α + 30)),
31:                (y1 + L * sin (α + 30)))
32:                Select the farther distance from a
33:                common beacon node is a valid solution
34:            else if (BNtotal == single)
35:              then
36:                di =  $\sqrt{((x_t - x)^2 + (y_t - y)^2)}$ 
37:                (xc, yc) = (((x + xv1 + xv2)/3), (y + yv1 +
38:                yv2)/3))
39:                Perform computational intelligence
40:                operations to find an optimized solution
41:            else
42:              Wait till RSSI information is received
43:            end if
44:          end for
45:        END
    
```

4. Proposed work analysis with the example

This section presents the proposed work analysis of an efficient adaptive ensemble localization approach over the randomly deployed sensor nodes with the consideration of example. Although this random deployment is more suitable for remote location target areas where human physical reachability is very less. Such a random example is taken for the consideration of efficient utilization of one beacon, two beacons or three beacons-based localization approach.

Figure 4 states that how localization approaches, adapted according to the availability of beacon nodes in the target environment. The initially deployed the one beacon node for the computation of the sensor node coordinate in the center of the target area as shown in Figure 4 (a). At the same time, three sensor nodes localized using one beacon node localized approach. In Figure 4 (b) the two-beacon approach is used for localization of one sensor node and one beacon approach is used for localization of four sensor nodes. The three-beacon based localization approach is used for one sensor node coordinate estimation, and another one sensor node estimates its coordinate with using the one beacon localization approach, as shown in Figure 4 (c). Figure 4 (d) shows the localized sensor nodes network after the applied efficient adaptive localization approach.



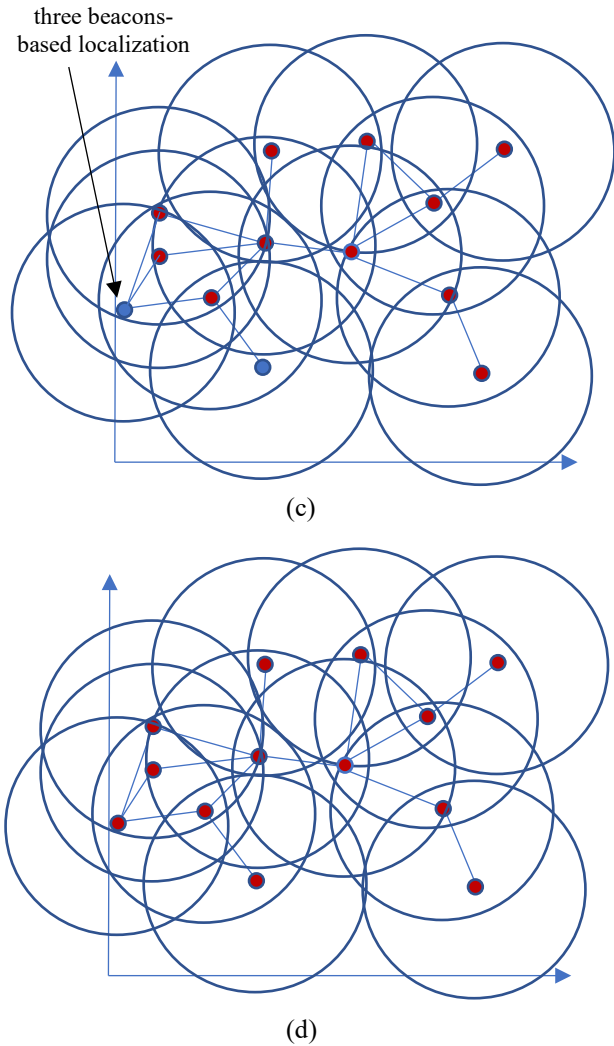


Figure 4. (a) Initial one beacon-based localization, (b) One and two beacon-based localization, (c) One and three beacon-based localization, (d) Localized sensor network

5. Simulation Results and Analysis

The performance analysis of the proposed approach is presented with a comparative analysis of single [15], two [13][14], and three [12] beacon-based localization approaches. The performance was analyzed using Matlab [23] on a PC with an Intel Core i7 processor, 3.40 GHz CPU and 4 GB of RAM.

5.1. Simulation Scenario

In the simulation configuration, the communication range of the sensor node is set at 25 m. The sensor nodes are randomly distributed over a target area of 100 x 100 m². The network model considered free space path loss and fading, RSSI measurement technique, and multihop propagation technique for localization of sensor nodes. The

10% standard deviation is taken to simulate noise in the distance estimation phase using the RSSI measurement technique.

5.2. Performance Evaluation Criteria

Performance evaluation of the proposed work based on localization accuracy, convergence rate, computational overhead, and energy consumption. The suggested work results are compared with single, two, and three beacon-based localization techniques.

Localization Accuracy

Localization accuracy is analyzed by measuring the error rate, i.e., the average difference between the actual coordinate value and the estimated coordinate value of the sensor nodes in the network. If the error rate is low, then high accuracy is achieved by the localization algorithm.

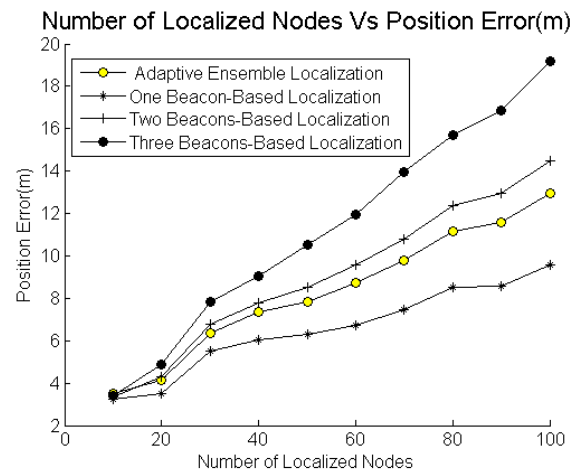


Figure 5. Number of localized nodes vs position error (meter)

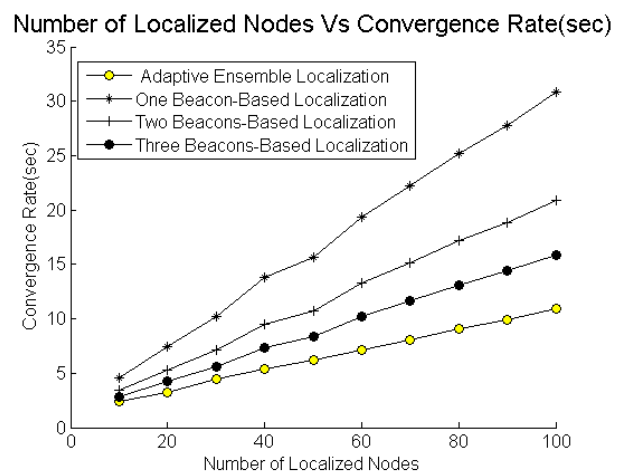


Figure 6. Number of localized nodes vs convergence rate (second)

The localization accuracy of the adaptive ensemble approach is superior to one beacon, and two based localization approaches, as shown in Figure 5. The position error may increase when the number of physical nodes interactions is increasing for sensor node localization. Therefore, the adaptive localization approach provides higher accuracy at lower convergence rates than other beacon-based localization approaches.

Convergence Rate

The total number of computation times required for localized randomly deployed sensor nodes in the network is known as the convergence rate. Figure 6 shows that the convergence rate of a very high rate compared to all localization approaches due to low overhead calculation.

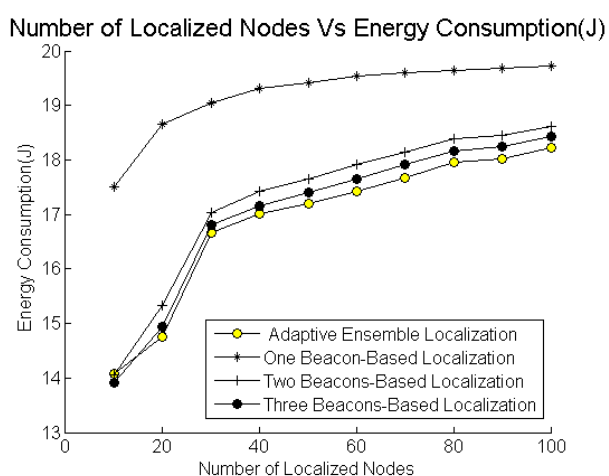


Figure 7. Number of localized nodes vs energy consumption (joule)

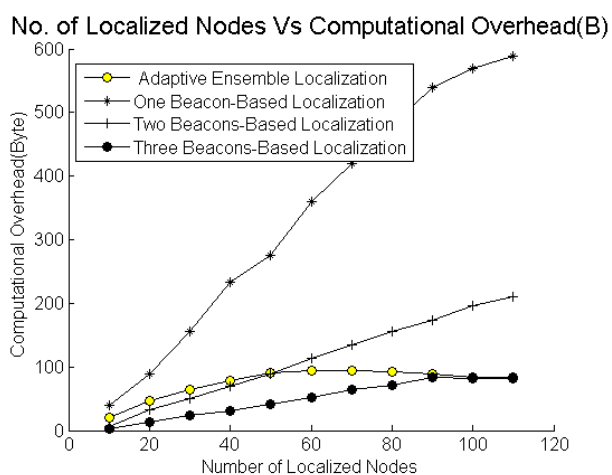


Figure 8. Number of localized nodes vs computational overhead (byte)

Energy Consumption

Total energy consumption of the sensor by the localization nodes of the localized sensor node in the network. Figure 7 shows that a beacon-based localization approach consumed a larger amount of energy than all localization approaches. The proposed approach has an adaptive nature to provide efficient use of energy resources of sensor nodes.

Computational Overhead

The total number of communication packets is processed for the localization of the sensor node in the network known as computational overhead. Figure 8 states that the computational overhead of a single anchor is higher than all localization approaches due to additional virtual node computations. The adaptive ensemble localization approach uses one, two or three beacon-based approaches according to their availability. Initially, the localization process starts with a deployed beacon node in the center of the target area, and then the localization process begins. Therefore, the initial stage of computation overhead is higher than that of two and three beacon-based localization approaches. Depend upon the number of beacon nodes availability of the two or three beacon-based localization approach is selected. The computational overhead degrades gradually at the phase of localized sensor nodes density are increased as shown in Figure 8.

6. Conclusion

Localization became a challenging task for WSN-IoT to provide efficient and reliable monitoring of real-time systems. Without the location of sensor nodes, the information gathered is of less importance. In the context of indoor applications where GPS technology is not capable of working efficiently, a range-based localization approach plays an important role. The proposed adaptive ensemble localization approach is designed for WSN-IoT using single beacons, two beacons, and three beacon-based localization approaches. The adaptive localization approach changes according to the number of available beacon sensor nodes. The simulation results and analysis section have shown that the proposed approach presenting the eminent performance over to three other approaches of sensor node localization to provide the fast convergence with higher accuracy, and it also balanced the network resources.

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