Hindawi
Wireless Communications and Mobile Computing
Volume 2023, Article ID 7982038, 11 pages
https://doi.org/10.1155/2023/7982038

Research Article

Lightweight APIT with Bat Optimization with Simulated Annealing Localization for Resource-Constrained Sensor Networks

T. Swarna Latha,[1,2] **K. Bhanu Rekha**,[1,2] **and Alachewn Wubie Ferede**[3]

[1]*Electronics and Communications Engineering, School of Electronics Engineering, Presidency University, Bengaluru, India*
[2]*Electronics and Communications Engineering, SV College of Engineering, Tirupati, India*
[3]*Department of Chemical Engineering, College of Biological and Chemical Engineering, Addis Ababa Science and Technology University, Addis Ababa, Ethiopia*

Correspondence should be addressed to T. Swarna Latha; swarnalatha.tg@svce.edu.in

Received 14 May 2022; Revised 30 July 2022; Accepted 6 August 2022; Published 27 May 2023

Academic Editor: Kalidoss Rajakani

In a wireless sensor network, information processing, and information acquisition, localization technology is the key to making it practically possible application. Approximate Point-in-Triangulation (APIT) is the most widely used localization estimation which has high accuracy in localizing the nodes and ease of deployment of nodes in the real-time environment. Though it has numerous key advantages, some of the drawbacks which make it a little setback in preference are the unevenness in the distribution of nodes. Tracking is more appropriate for mobile sensor nodes than tracking is for static sensor nodes. The two main types of localization algorithms are range-based and range-free techniques. In an indoor setting, the projected range (distance) between an anchor and an unknown node is very inaccurate. By utilizing a large number of already existing access points (APs) in the range-free localization approach, this issue can be overcome to a great extent. The utilization of multisensor data, such as magnetic, inertial, compass, gyroscope, ultrasonic, infrared, visual, and/or odometer, is stressed in recent research to further increase localization accuracy. The tracking system also makes location predictions for the future based on historical location data. To overcome this issue, the proposed localization algorithm of APIT with Bat-SA proves its efficiency. Due to its low localization error, the traditional Bat method is more accurate than APIT. The proposed Bat using the SA algorithm is found to perform better than the traditional APIT algorithm in terms of convergence of computing rate and success rate. In order to mimic the suggested APIT method, it is paired with the Bat-SA localization technique. Simulation evaluation proves the performance efficiency of the proposed algorithm. The performance metrics parameters are latency, node distribution map, positioning error map, and neighbor relationship diagram which are used to evaluate the proposed method.

1. Introduction

A difficult problem in a sizable mobile sensor network is the localization and tracking of wireless sensor nodes. Numerous applications, such as location-based services, network optimization, and environment characterization. The node's position in a 2D/3D space is calculated using localization techniques. Sensing, monitoring, surveillance, and tracking are some of the main uses for the localization techniques, for instance, space applications on the earth and the moon, military surveillance, intruder detection, environment monitoring (such as soil health and temperature), agriculture monitoring, health monitoring (such as smart homes), habitat monitoring, and pollution control. It can be used in locations that are on land, beneath water, or underground. Connectivity and coverage, localization and tracking, data aggregation and latency minimization, privacy and security, time synchronization, MAC protocol and sleep scheduling, cross layer optimization, routing and topology control, and congestion control are some of the various research areas in wireless sensor networks. To provide accurate information on the position of sensor nodes, self-localization has to be implemented in sensor nodes for estimating the position information. In general, global positioning system (GPS) is commonly used in various applications. Because of its high cost, it is not best suited for many high-cost applications. Some of its other drawbacks are difficulty in installation and maintenance costs in some of the peculiar applications. Hence, only a very few sensor nodes in a WSN are equipped with GPS for positioning information, whereas the other nodes in the network need a better self-localization algorithm for the estimation of position information. Many localization algorithms have been proposed by researchers in the recent decade. Based on the mechanisms adopted for estimating the location, the localization techniques are broadly classified into two categories based on the range of node placement range free and range based. In a range-based mechanism, absolute distances along with angle measures are used while calculating the distances such as TDOA, TDA, RSSI, and AOA. The localization based on the range is found to be precise but cost-ineffective, and also, it is mostly applicable for large-scale implementation. Range-free localization is based on network connectivity. Range-free localization depends on the hardware limitation of the implanted sensor nodes. It is found to be cost-effective when compared with range-based applications.

Some of the most commonly used range-free algorithms are DV-hop, Centroid, APIT, and Amorphous. In recent years, several improved APIT algorithms are proposed as an effective localization techniques. A novel PIT algorithm is proposed based on the position of anchor nodes. An algorithm is drawn between the three anchor nodes targeting the target node inside the triangle by judging the COG of the intersection of the selected anchor nodes' coverage area formed within the triangle. An improved APIT algorithm on localization is proposed which determines the proposition of determining the target node if the sum of the areas of the three triangles formed by selecting the target node is found to be greater than the area of the triangle formed by selecting the anchor nodes. If the area of the target node triangle is found to be less than the area of the anchor node triangle, then the target node is said to be outside the triangle. In another modified APIT algorithm, the application area is partitioned into four overlapping and nonoverlapping areas. This is done by deploying four new anchor nodes in the corner of the application area. To reduce the computational complexity, care is taken more in selecting the anchor nodes. By comparing the strength of the received signal strength, each target node can select its own subregion. Then, APIT algorithm is implemented in these selected subregions. Then, the small area and narrow triangle are eliminated. The target node is incorrectly identified as being outside the triangle, per the APIT algorithm's theory. The APIT localization algorithm refers to this issue as an in-to-out error. The anchor nodes' transmitted beacon signal cannot be received due to the unique distribution of the neighboring nodes. As the target node travels towards the neighboring nodes, this occurs at their location, which is simultaneously reduced. In this instance, it is assumed incorrectly that the target node is located inside the triangle. An out-to-in error is the technical term for this error. Node position, data collection, power consumption of the node in real time, node distance and its mobility in the real-time network, accuracy vs. complexity with the increase in network scalability, and propagation error with increased node density are some of the complexities identified in optimizing a WSN. Applications for wireless sensor networks can be found in many different industries. The foundational technology of the WSN is node localization. The distance vector hop (DV-Hop) algorithm is the most often used localization algorithm among the several available localization techniques [1–37].

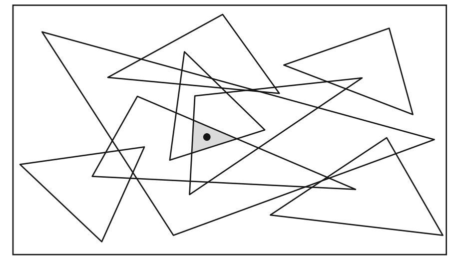

Figure 1: Overview of APIT algorithm.

1.1. APIT Localization Algorithm: An Introduction. APIT is a conventional range-free localization scheme with its own limitations. The basic idea of the APIT algorithm is that position of the anchor nodes is first identified by the target nodes. This is done by the target nodes by the beacon signals that it receives from the anchor nodes. The anchor nodes broadcast these beacon signals. These beacon signals carry various information like the ID of the anchor nodes, their positions, and the power required and consumed for its transmission. The target nodes are those nodes, which try to find their own location, whereas the anchor nodes are those nodes that are equipped with high-power transmitters and localization devices. Among the n anchor nodes, the target nodes choose any three anchor nodes. In the APIT mechanism, the target nodes try to find out their location based on the anchor nodes; it has chosen to form the triangulation area. The target node tries to find out whether it lies within the formed triangulation or not. By trying out all the combinations, the target nodes would form C3 n triangles. COG of the intersection of all the possible triangles formed is found by the target node to find out its estimated position. Figure 1 represents the overview of the triangular area formation of the APIT algorithm.

The theoretical concept used to determine whether the target node lies inside or outside the triangular area is called Point-in-Triangulation (PIT). The working principle of PIT defined as a target node T is considered, and a given TABC is formed which is comprised of three anchor nodes and one target node. There exists a direction along which T moves such that it always stays away from the position of the vertices of the triangle or else close to the vertices. Then, the target node T is said to lie outside the triangle formed; else, it lies inside the triangular area [13].

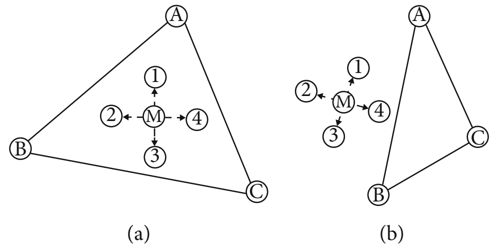

Figure 2: (a) APIT: inside case. (b) APIT: outside case.

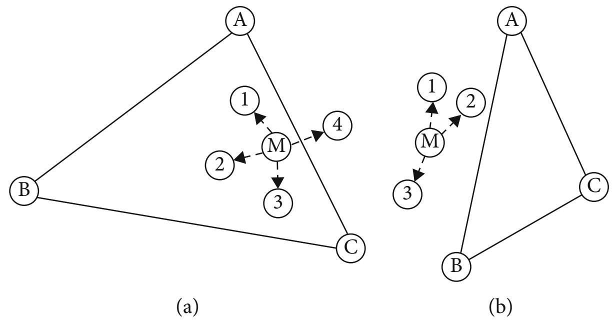

Figure 3: (a) APIT: in-to-out error. (b) APIT: out-to-in error.

1. Objective function $f(x)$ is $(x1, x2, \cdots \cdots \cdots x4)^T$
2. Initialize Bat where $(x = 1, 2, 3, \cdots .n)$ and Vi
3. Define the pulse frequency f_i at various Bat population values
4. Initialize rate r_i and loudness A_i
5. While $t <$ maximum number of iterations
6. Adjust frequency and generate new set of solutions
7. Update new velocity and location
8. If rand $> r_i$
9. Select the best solution among the available solution set
10. Generate the local solution around the best solution set
11. End if
12. Generate a new solution by a random fly
13. If rand $< A_i$ and $f(x_i < f(x'))$
14. Accept the new solution
15. Increase the value of r_i and reduce the value of A_i
16. End if
17. Rank the Bat solution and find out the current best solution
18. End while
19. Post process results and its visualization

Pseudocode 1: Bat algorithm.

1.2. Principle of APIT Algorithm. Practically, in a wireless sensor network, sensor nodes are fixed so that there is no random movement, so PIT tests are found to be infeasible in many practical applications. To overcome this issue in the PIT test without the mobility of sensor nodes in the network, APIT is proposed. The basic idea of APIT is that every target node rivals the movement of nodes by comparing the beacon RSSI received from the anchor nodes with respect to its neighbor sensor nodes. These nodes are the adjacent nodes that are also found within the communication range of the target node. Figure 2 shows the identification of the target node within the triangular area as inside the triangle or outside the triangular area as outside the triangle. Figure 2(a) shows the scenario where none of the target node's neighbors are further close or farther from the three anchor nodes of the triangle. When the neighbor nodes move away or closer to all three anchor nodes simultaneously, then the target node is said to lie within the triangle. The neighbor nodes include target nodes as well as the anchor nodes. The next scenario is shown in Figure 2(b) where the target node moves to the position of its neighbor node say node 4, where it is close to the anchor nodes simultaneously; in such cases, the target node assumes that it lies outside the triangulation area.

```
S1 = an initial solution is set
T = an initial temperature is set
REPEAT
REPEAT
S2 = neighbour of the node S1 is identified
UNTIL a criteria is established by the node S2
ΔE = obj( S2 ) – obj( S1)
IF ( ΔE>0 ) THEN // Noe S2 is chosen as better than node S1
S1 = S2
ELSE with probability EXP( ΔE/ T )
S1 = S2
END IF
Decrease T
UNTIL the stop criteria
End
```

Pseudocode 2: Simulated annealing algorithm.

Table 1: Simulation values.

Parameters	Value
Network size	500 ∗ 500 m
SNode's location	Uniform distribution
Node's location	Uniform distribution
Node's initial energy	0.1 J
Super node initial energy	0.5 J
Communication range	90 m
Sensing range	60 m
Number of nodes	300
Number of SNodes	25
Number of target	20
Elect	50 nJ/bit

1.3. Work Motivation of APIT Algorithm. An APIT localization algorithm has the following key advantages:

(i) Less communication overhead

(ii) High localization accuracy

Some of its limitations are as follows:

(i) Dependency on its neighbor nodes

(ii) Impact of the increased network density

(iii) Distribution of nodes in the network

1.4. Miscalculation of APIT Test. In the APIT test of localization basically, there are possibilities of two errors to occur as follows:

(i) In-to-out error

(ii) Out-to-in error

Figure 3(a) shows that the target node *M* actually lies within the triangular area of MABC, but as one of its neighbor nodes lies outside the triangular area and farther from the side AB of the triangle, the target node moves towards the neighbor node as it receives the RSSI of the beacon signals it receives from the anchor nodes gets faded and decreases simultaneously. According to the idea of the APIT algorithm, the target node is wrongly determined as its location lying outside the triangle. This miscalculation is termed an in-to-out error in the APIT localization algorithm.

The other error scenario is shown in Figure 3(b). Actually, the target node *M* lies outside the triangular area. The special distribution of the neighbor nodes leads to the nonreception beacon signal sent by the anchor nodes. This happens at the position of the neighbor nodes which is reduced simultaneously when the target node moves towards them. In this case, it is falsely understood that the target node lies within the triangle. This miscalculation is called an out-to-in error.

Hence from the above study, it is understood that APIT as a standalone algorithm suffers from the effect of increased node density and the distribution of nodes in the network. Hence to improve the efficiency of the APIT algorithm and to overcome the deficiency, this work combines the APIT algorithm with the Bat-SA algorithm which is found to be suitable for all kinds of wireless sensor network topology and varying scales.

1.5. Bat Algorithm. Bat algorithm is a type of metaheuristic searching algorithm. The following rules are the framework of the Bat algorithm:

(i) Echolocation is used to sense the distance of the target

(ii) Signals are transmitted randomly with varying frequency, and it is adjusted automatically to proximity. The pseudocode for the conventional Bat algorithm is given below

1.6. Simulated Annealing Algorithm. The goal of SA algorithm is to start with intense and then reduce the intensity of search. The pseudocode for a basic SA algorithm is given below.

Instead of the best movement, a random movement is chosen in the SA algorithm. If this chosen movement is

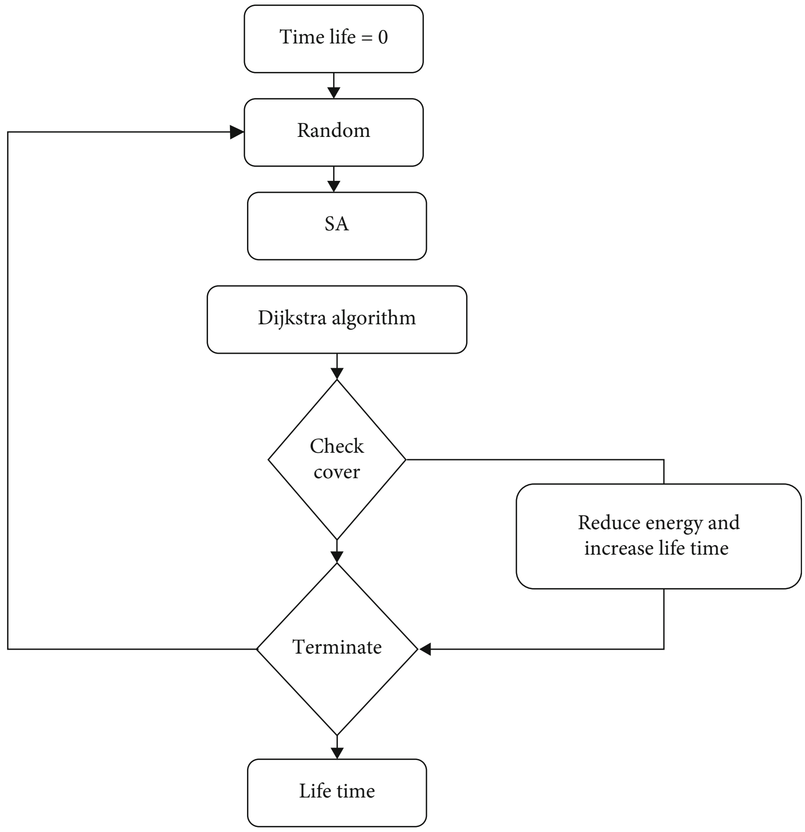

Figure 4: Flowchart for SA algorithm.

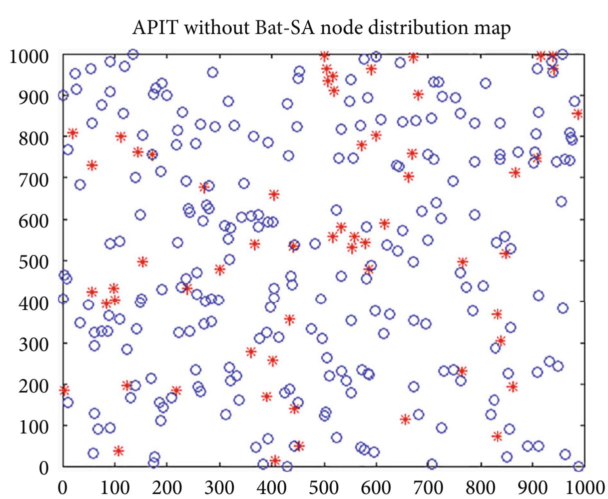

Figure 5: Node distribution map of APIT.

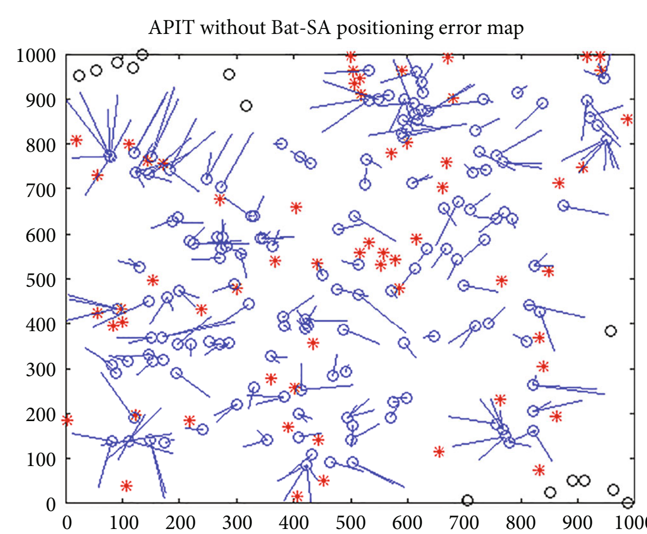

Figure 6: Positioning error map of APIT.

found to improve the search, then it is accepted; else, the probability of movement is taken as 1. This probability is found to reduce with a decrease in temperature. Inappropriate search movements occur with an increase in temperature, and it gets reduced with a reduction in temperature. The value of temperature is multiplied by a coefficient value ranging between 0 and 1. Local optimality problem is encountered with a decrease in temperature. So a value near 1 is chosen say 0.998.

The steps involved in getting the start of a SA algorithm and its preparation are discussed below.

1.7. Getting Started and Preparation. The problem information is first identified, and the various adjusting parameters are obtained.

(1) An answer near the current answer is identified that satisfies the set criteria

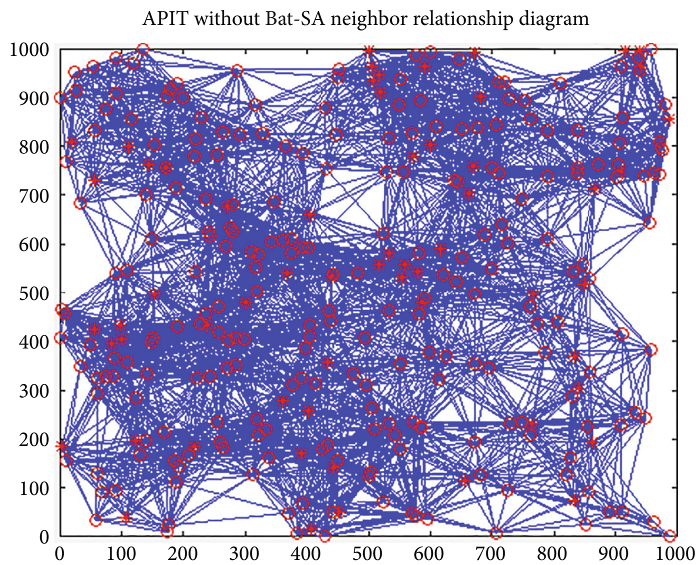

Figure 7: Neighbor relationship diagram of APIT.

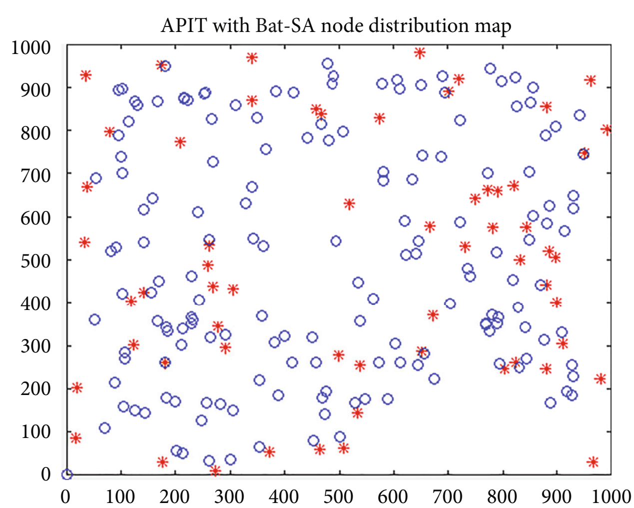

Figure 8: Node distribution map of APIT with Bat-SA.

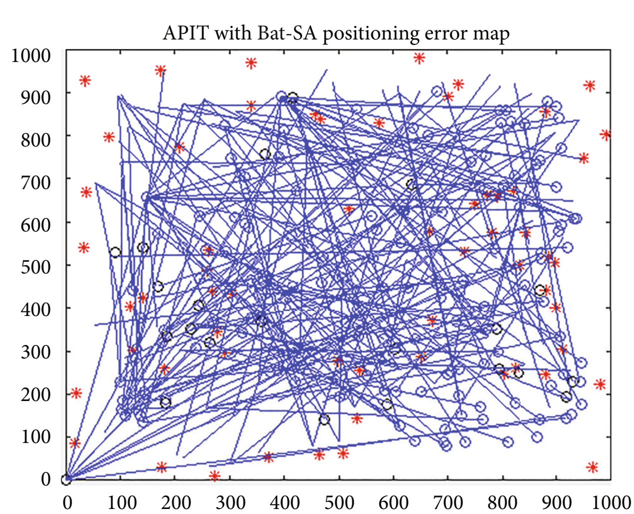

Figure 9: Positioning error map of APIT with Bat-SA.

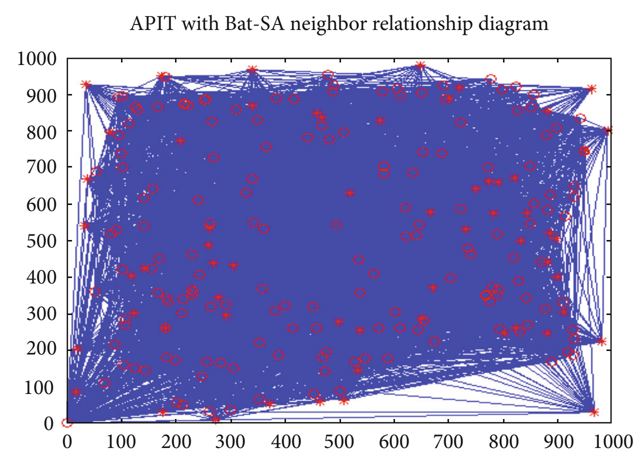

Figure 10: Neighbor relationship diagram of APIT with Bat-SA.

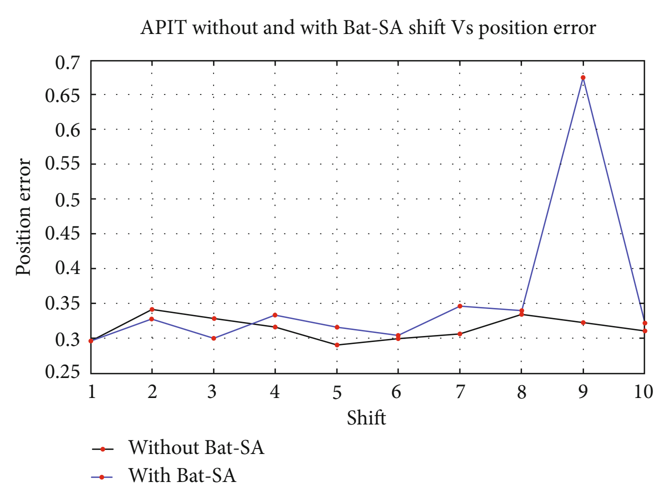

Figure 11: Anchor shift vs. position error of APIT with and without Bat-SA.

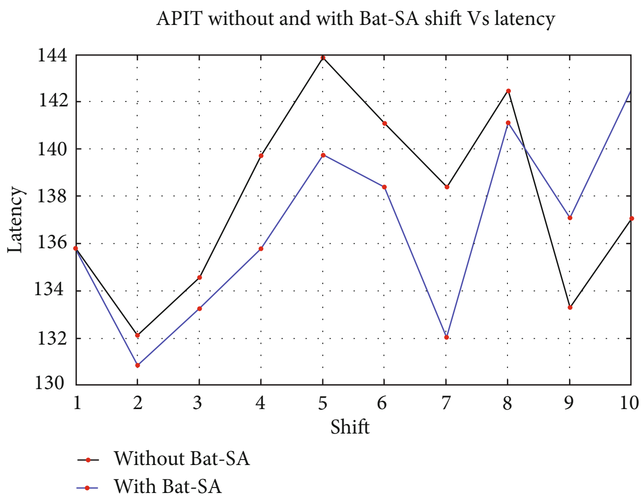

Figure 12: Anchor shift vs. latency of APIT with and without Bat-SA.

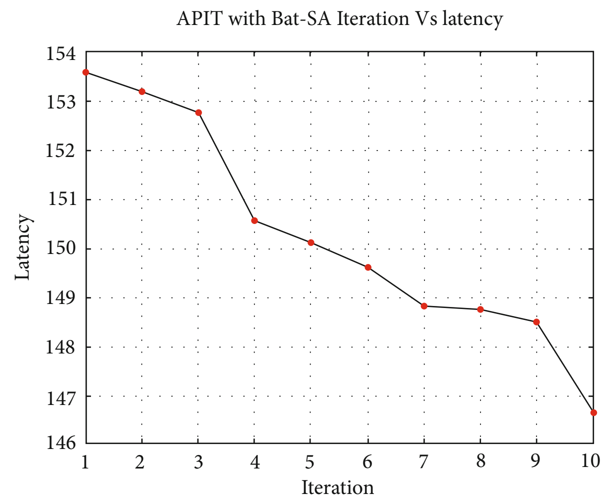

Figure 14: Iteration vs. latency of APIT with Bat-SA.

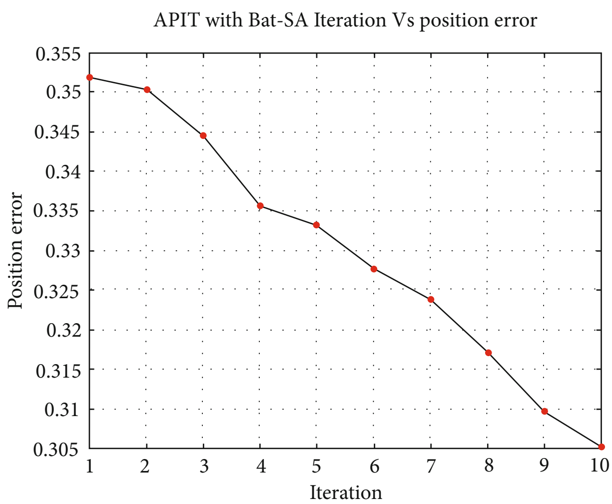

Figure 13: Iteration vs. position error of APIT with Bat-SA.

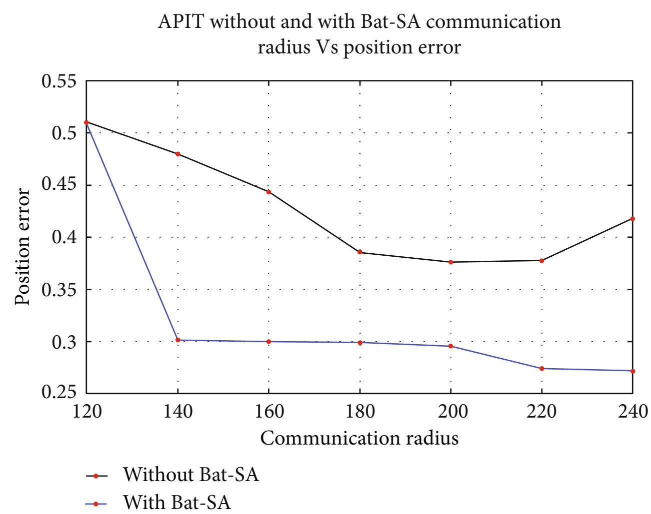

Figure 15: Communication radius vs. position error of APIT without and with Bat-SA.

(2) Answer obtained is evaluated

(a) If the newly identified neighbor is better than the existing one, go to NA (new answer)

(b) The probability > random number, go to NA else step 1

(3) Update the problem parameters and algorithm. Go to step 1

In the first step, the number of sensors needs to be identified for the user. As a request is raised by a user, a binary path solution is randomly generated. In the SA algorithm, an optimized path solution is created from the primary path. Two indexes are randomly chosen for a neighbor node. The indexes represent sensor nodes that are prone to change. Dijkstra's algorithm is used for identifying the relay nodes in identifying the path between the BS and the destination node. The overall energy optimization of the nodes of the path established is reduced, thereby adding a value of 1 to the network lifetime. The loop is continued until the desired value of optimization is reached. Table 1 shows the values used for the simulation of the network. Figure 4 shows the flowchart of simulate annealing algorithm.

1.8. Proposed Bat with Simulated Annealing Algorithm. Some of the complexities identified in optimizing WSN are as follows:

(i) Node position

(ii) Data collection

(iii) Power consumption of node, i.e., real time

(iv) Node distance and its mobility in real-time network

(v) Accuracy vs. complexity with the increase in network scalability

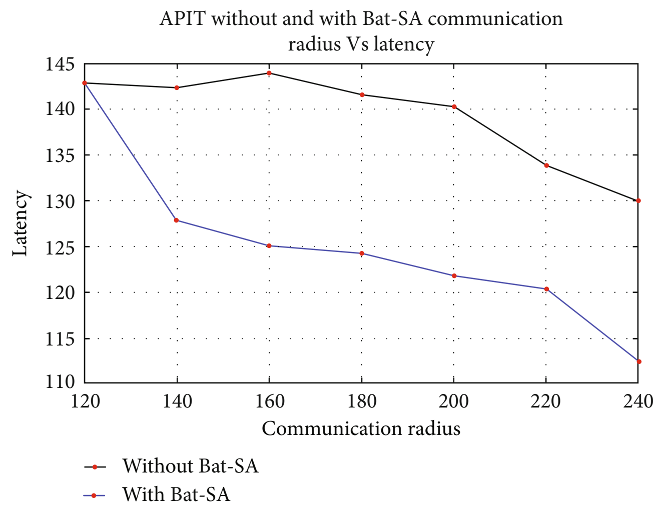

Figure 16: Communication radius vs. latency of APIT without and with Bat-SA.

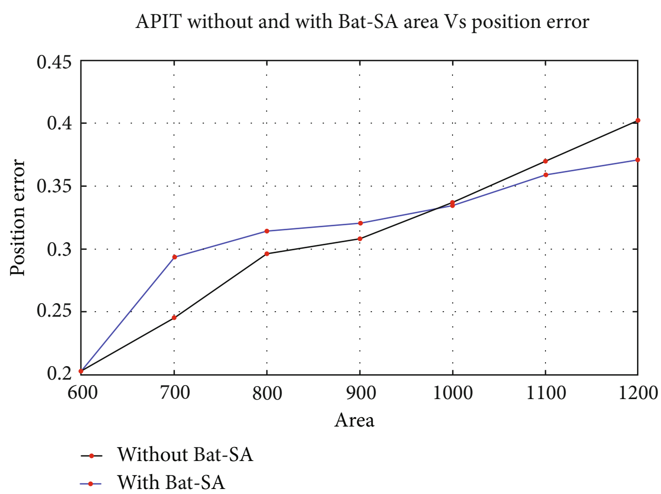

Figure 17: Comparison of area vs. position error of APIT without and with Bat-SA.

(vi) Propagation error with increased node density

1.9. Overall Working Principle of APIT with Bat-SA Algorithm. PIT tests are discovered to be impractical in many practical applications because sensor nodes in a wireless sensor network are fixed to prevent random movement. APIT is suggested as a solution to this problem in the PIT test without the network's sensor nodes being mobile. The fundamental tenet of APIT is that each target node compares its movement to neighboring sensor nodes by comparing the beacon RSSI it receives from the anchor nodes. These nodes are the neighboring nodes that are also present within the target node's communication range. A particular kind of metaheuristic search method is the Bat algorithm. The Bat algorithm's foundation is comprised of the following rules: target distance is detected via echolocation, and signals are randomly delivered at varied frequencies, and they are automatically adjusted for closeness. The SA algorithm seeks to increase search intensity initially before reducing it.

1.10. Simulation of the Proposed APIT with Bat-SA Algorithm. MATLAB simulation tool is used for the proposed work. The network area considered is a 1000 m radius. In a conventional APIT algorithm, the error in obtaining the position of the neighbor nodes and latency is increased.

The performance metrics parameters are considered, and the results are obtained by using APIT and the proposed Bat with SA algorithms. Figure 5 shows the node distribution map of APIT without the Bat-SA algorithm.

Figure 6 shows the positioning error map of the APIT algorithm without the Bat-SA algorithm.

Figure 7 shows the neighbor relationship diagram obtained for the APIT localization algorithm.

Figure 8 shows the node distribution map for the proposed APIT with the BSA-SA algorithm. The nodes in the network are more evenly distributed than the node distribution done by the APIT algorithm.

Figure 9 shows the positioning error map obtained by using the proposed APIT with the Bat-SA localization algorithm. Less positioning error occurred when the proposed

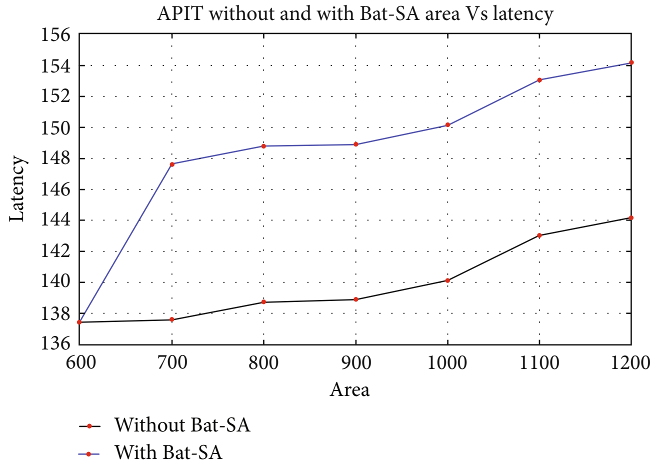

Figure 18: Comparison of area vs. latency of APIT without and with Bat-SA.

APIT with Bat-SA localization algorithm is used. The proposed algorithm achieves less node positioning error when compared with the conventional APIT localization algorithm.

Figure 10 shows the neighbor relation diagram obtained for APIT with the Bat-SA algorithm. From the diagram obtained through simulation of the proposed algorithm, it is proved that the relationship among the neighbor nodes is well established than the neighbor relationship attained through the APIT localization algorithm.

Figure 11 shows the shift vs. position error of APIT with and without the Bat-SA algorithm.

Figure 12 shows the comparative result of anchor shift vs. latency of APIT with and without the Bat-SA algorithm. Latency is found to be comparatively less in APIT with Bat-SA than in APIT without the Bat-SA algorithm.

Simulation result of the APIT with Bat-SA algorithm for positioning error of nodes is performed for various iterations, and the result obtained is shown in Figure 13. It is found that the positioning error gets reduced as the number of iterations gets increased. Latency is also decreased for APIT with the Bat-SA algorithm with increased iterations, and the result obtained is shown in Figure 14.

Simulation is performed for communication radius against position error for APIT without and with the Bat-SA algorithm. Figure 15 shows that the positioning error is found to be less in the case of APIT with the Bat-SA algorithm.

Figure 16 shows the comparison of communication radius against latency for APIT without and with the Bat-SA algorithm. The results show that APIT with Bat-SA algorithm proves to be efficient for its significantly reduced latency against the increase in communication radius.

Figure 17 shows the simulation results for area vs. position error of APIT without and with the Bat-SA algorithm.

Figure 18 shows the simulation results for area vs. latency of APIT without and with the Bat-SA algorithm. From the result, it is proved that APIT outperforms the function of APIT without the Bat-SA algorithm in the case of area vs. latency parameter check.

2. Conclusion and Future Work

The conventional Bat algorithm than APIT has good accuracy since it provides minimal localization error. The convergence of the computing rate and the success rate of the proposed Bat with the SA algorithm is found to have better performance than the conventional APIT algorithm. Hence, the proposed algorithm of APIT is combined with the Bat-SA localization algorithm and is simulated. From the simulated results obtained, it is proved that the computing time is also reduced with an increase in the scalability of the network area. The position error and latency are also decreased than the conventional APIT localization algorithm. The relationship among the nodes is also more well established than in the APIT algorithm. The simulation also shows the consistency of the proposed algorithm. Thus, the overall system performance is increased, and the localization of WSN is significantly optimized by using the proposed APIT with Bat-SA algorithm.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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