Journal of Applied Research and Technology

www.jart.icat.unam.mx

Journal of Applied Research and Technology 20 (2022) 520-528

Original

Node localization in wireless sensor networks using a dynamic genetic algorithm

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Received 06 27 2020; accepted 03 25 2022
Available 10 31 2022

Abstract: A wireless sensor network is a collection of nodes organized in a cooperative environment. Node localization plays a vital role in many applications. Conventional location detection techniques such as global positioning systems (GPS) and infrared are expensive to find the location node. This paper proposes the use of a genetic algorithm (GA) to learn the environmental impairments within a wireless sensor network with the purpose of localization for data management. In this paper, we have presented an efficient and dynamic Genetic algorithm with help of a received signal strength indicator (RSSI) which gives the optimal node location value with minimal localization error. Our simulation modeled in MATLAB 7.0 shows that the dynamic GA can achieve acceptable node location detection with the aid of three anchors.

The simulation work represents that the proposed optimization method gives an accurate node location estimation value efficiently.

Keywords: Wireless sensor networks, genetic algorithm, received signal strength, optimization

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Peer Review under the responsibility of Universidad Nacional Autónoma de México.

1. Introduction

Wireless sensor systems are utilized in a variety of applications, such as habitat monitoring, military applications, transportation, and health care. The information is gathered, detected, and processed by tiny sensor nodes and maintains an association with neighbor nodes as defined in (Zhang et al., 2014). Which plays an advantageous and proficient role during the localization process? The sensor network describes nodes, it is required the sensor nodes can find their location in different situations. The sensor node location helps the centralized server and efficiently analyses data. Sensor node Location data are essential for remote sensor systems for numerous applications that rely upon the coordinate information of wireless sensor nodes. By considering the route information of distinct nodes in the sensor field as stated, the wireless sensor node coordinates-based information and its query computation conserve the energy of a node (Chen et al., 2013). It also enhances the reliability and accuracy of different applications in WSN as represented in (Kubach & Rothermel, 2001). (Chen et al., 2021) describes the forward energy-efficient clustering and localization centered on the genetic algorithm (ECGAL), in which the residual energy, distance estimation, and coverage connection are developed to form the fitness function. Sink nodes are expected to play a key role in absorbing a large portion of the computational load because they are more accessible and serviceable than any other nodes in the network that are deployed underwater, as indicated by Datta and Dasgupta (2021). This paper proposes an RSSI quantization and genetic algorithm-based localization method is described by Ren et al., (2020).

The localization issue has received impressive consideration in recent years. Subsequently, different node location administrations play a vital role in real-life applications. In the sensor, field to locate an unknown sensor node global positioning system (GPS) plays a vital role. On the other hand, it isn't appropriate to utilize GPS systems in every sensor node considering the sensor field's network size, its computational cost, energy consumption process of sensor nodes. The node location value estimation methods are partitioned into different classes such as self-situating, remote situating, and indirect situating as represented in (Mettouris & Papadopoulos, 2014).

The approach determines the accuracy of sensor field localization during location computation by examining the average location estimation error shown in the localization. The genetic algorithm plays a vital role to analyse the different combinatorial optimization issues and various researchers have attempted to use GAs to take care of issues in computer engineering. Thus, in this paper, a dynamic genetic algorithm is depicted with a specific to assess the accuracy of node localization issues in remote sensor systems. The results of the proposed algorithm represent the optimized location value of an unknown sensor node in the sensor network.

1.1. Node localization problem

Problem representation: - Consider a sensor network where correspondence can be formed between two nodes. In the sensor field, there is an association between anchor and sensor nodes when they are in the corresponding range of data computation as defined in (Redondi et al., 2013). In the sensor network, the nodes have a similar correspondence range 'r', where these nodes are deployed in a two-dimensional plane. Hence, we can define the network graph as the combination of a set of nodes and a set of links as G = (V, E) can be interpreted based on the constraints. Consider sensor nodes a and b in a sensor field and their position values are p_a and p_b, if the two nodes are associated with each other then they are in the communication range, and on the other chance that they are not associated then they are being outside of this range as defined in (Darabos & Todor, 2005). The sensor localization process is essential for various applications. In many cases, the detected information has no value without knowing the exact coordinate data.

The node localization data are used in the different routing protocols for the different calculations and administrations. The solution to the localization issue of furnishing nodes with GPS receivers isn't a reasonable alternative because GPS beneficiaries require a pathway from the satellite. Besides GPS computation is costly and consumes more node energy. Hence, in the WSN different localization algorithms are used during the location computation process.

Few nodes layout in the sensor field represented in GPS to find their location using a localization method as defined in (Wang et al., 2007). The node location estimation methods are divided into two types range-based location estimation methods and the second one is range-free. The angled system & absolute distances process used during location computation is described in the range-based method. The range-free technique, on the other hand, relies on hop count numbers to calculate distances between non-anchor nodes and anchor nodes. The different range-based location methods such as received signal strength indicator (RSSI), angle-of-arrival (AoA), time of arrival (ToA), or time difference of arrival (TDoA), etc. In this technique, distance is calculated by using signal strength. The computed distance value can be measured as $d_{ij} = \beta\sqrt{p_i/p_j}$, where p_i and p_j are transmitted and received signal value and β represents as path loss exponent. Hence the distance estimation process of RSSI is not a suitable and accurate one due to some path characteristics. But in the case of the angle of arrival (AOA) technique which requires some directional antenna for its distance estimation process, still, it never gives accuracy in the localization process.

The other issue with the location computation process is that it needs more anchor points to focus on precisely during the localization process in the sensor network. The strategies examined with range-based methods, however, there represent another suitable approach to utilizing associates in unlocalized nodes and specific anchor points. These methods are additionally partitioned into two classifications: local and hop counting techniques. The hop count system assesses the distance values to their neighbor anchor nodes in an efficient manner. The hop count values and with the help of their hop size the anchor node calculates its distance and its position concerning the unknown node. The local technique is used for collecting the position information of the neighbor anchor nodes in the localization process. This research work concentrates on the range-based method.

This remaining part of the paper is composed as follows. Section 2 presents a concise review of the related literature work while section 3 clarifies the GA and its calculation and section 4 clarifies the proposed method. Section 5 explains the simulation and the results and concludes with the future scope describe in 6 respectively.

2. Related work

In Zhang et al. (2012), provide an overview of several localization methodologies as well as a description of the location estimation approach based on the anchor and non-anchor nodes' mobility conditions. A distributed localization method based on angle estimation is represented in (Zhang et al., 2012). In this related work, two antenna anchors are utilized to transmit signals in the sensor network. In the localization process, the angle of information of the radiated waves at each receiving signal strength indication (RSSI) is utilized.

In the network dimension of the WSN, the estimating technique has also increased the number of numerous parallel arrays of antennae. The other advantages of the system are depending on the transmission behavior of the signal. The zero-design structure of the indoor node locator system is defined to locate the associated behavior of nodes in various methods (Azim et al., 2012). In the network field, a synchronization strategy for sensor node localization and association is described (Wu et al., 2012).

There are several approaches to the localization of sensor nodes in a WSN including range-free and range-based algorithms. Because it is more accurate in the location estimate process than the range-free technique, our optimization algorithm is range-based. When compared to other methods, the RSS-based range can be a less expensive option. The node distance value is evaluated using RSSI and an array of directional antennas of a sensor network is defined (Yisheng et al., 2018).

The results are found to be favorable when benchmarked against the Cramer-Rao bound. The efficient localization defined in (Goldoni et al., 2010) used RSS range-based localization methods in low power IEEE 802.15.4 WSN to obtain positioning information. Trilateration, min-max, and greatest likelihood were the algorithms utilized. The problem of localization is NP-hard in general (Saxe, 1980). The location of the sensor node must be evaluated quickly and have a major role, especially in very sensitive applications such as military operations. Stochastic processes have been applied to reduce the computational time to locate sensor nodes. Simulated Annealing (Kannan et al., 2005), Artificial Neural Network (Kannan et al., 2005), Particle Swarm Optimization (Wu et al., 2012), and Ant Colony Optimization (Zhang et al., 2008) are among other approaches that have been used for the localization problem. However, these techniques can easily find the sensor node location. The efficient node localization is represented in a wireless sensor network (Singh & Sharma, 2015) getting stuck in local minima. This is why we have approached the problem using a Genetic Algorithm.

Zhang et al. 2008 and Chen et al., (2018) have proposed the GA for this problem. Zhang et al. 2008 reported a better performance compared to the gradient search localization. When compared to the range-free DV-hop technique, (Chen et al., 2018) demonstrated better performance. However, it's unclear which range-based method was utilized to calculate the Euclidean distance between the unknown node's position and the rest of the network. As previously indicated, we used RSS as a metric to determine the position of each sensor node in the network. (Arya, 2021) recently proposed range-free localization technique under erroneous estimation in wireless sensor networks. (Yu et al., 2021) describes a solution to sensor node localization using Glow-Worm Swarm Optimization Hybridiportzing Positioning Model. Swarm intelligence-based localization in wireless sensor networks. well reported by Akram et al., (2021). A solution to the node localization problem using RSS measurements in WSN is well presented by Wang and Yang (2011). Xu et al. (2011) describe a localization algorithm that uses particle swarm optimization and mobile anchors in sensor networks. There is an obvious improvement in location accuracy and it is robust to interference from the environment.

3. GA approach

The RSS-based method of localization is the strategy we utilized. The RSS from a next-hop sensor node is used to determine the sensor node's position. In our example, we use a one-hop link, in which each of the anchor nodes is directly connected to a sensor node. The signal intensity of the sensor nodes received at each of the anchors is utilized to find the coordinate of the sensor node in the network because the sensor nodes are within the transmission range of each of the anchors. The RSS at the anchor nodes and the transmit power of the sensor nodes have a relationship. This is based on information found in (Singh & Sharma, 2015).

This research work analyses and describes the location estimation issue using a dynamic genetic algorithm with the help of the relating fitness function and genetic operators. Here we describe a basic Genetic algorithm (GA) calculation efficiently. The genetic algorithm calculation is based on the selection and also natural genetics characteristics, which keeps up a constant population size P of the candidate solutions. Every cycle of the operation consists of three important genetic operators such as (reproduction, crossover, and mutation) which generate a new population (offspring). In this system chromosomes are defined in the new generation with populations that are assessed through the estimated value of the fitness, the function is taken into consideration with the help of the cost function. Finally, an efficient population of a candidate solutions arrangement is shaped. In the above depiction, an efficient localization algorithm has described the operation of the sensor network (Alazzam & Almobaideen, 2019). The most effective DV localization algorithm is defined as follows: (Rout et al., 2016). Figure 1 shows a flowchart that outlines the algorithm in detail.

The flow chart of the algorithm is implemented in the following steps:

Step 1. Initialize the sensor field and create an association between nodes in the network.

Step 2. Described and represent self-assertive a population of binary strings in the wireless sensor network.

Stage 3. Utilize arithmetic crossover operation using formula and different crossover operators in the system.

Stage 4. Utilize and analyzed the uniform value of mutation using their formula and mutation operator.

Stage 5. When the localization process is completed in the sensor field, yields the location estimation result. Otherwise, move to Step 2, and compute the position of the unknown sensor node in the sensor field.

4. Proposed method

4.1. General localization method using received signal strength indicator

RSSI-based computation defines signal power measurement during node location estimation. In a sensor network, the RSSI technique plays a vital role to localize the unknown nodes with the help of distance. This technique exceptionally appealing to the computational complexity and cost, precision is its significant downside so precision decrease at the point distance changes.

The derivation of the RSS value is calculated as follows:

$$RSS(d) = 10\, n\, log\, \frac{d_0}{d} + A \quad (1)$$

Flowchart of GA:

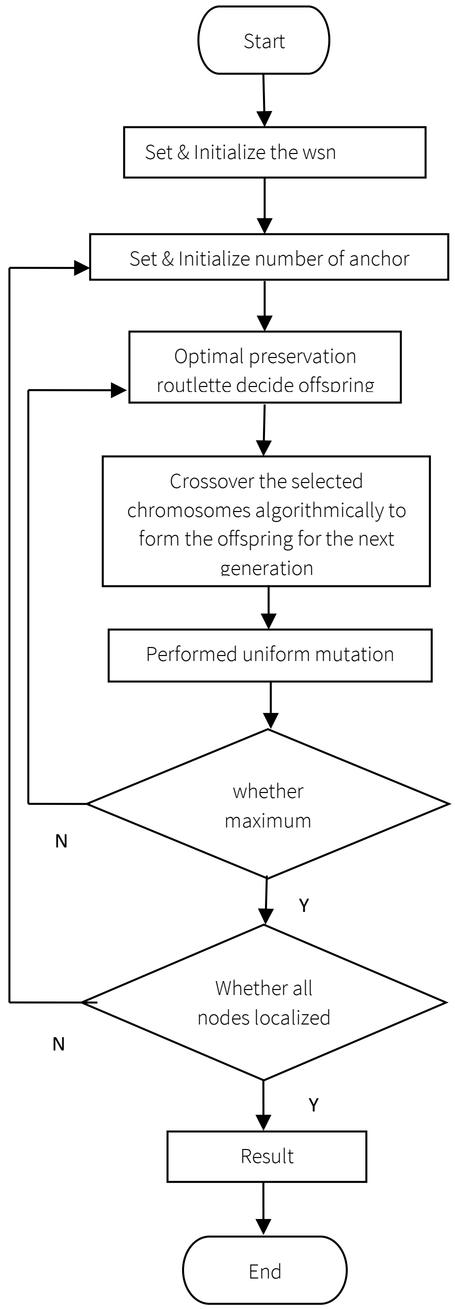

Figure 1. Flowchart of genetic algorithm.

A is the RSS at a distance d_0 from the transmitter, d_0 are the reference distance (usually 1m away from the transmitter) and d is the distance of each sensor node to each anchor. We solve (1) for *d*. We consider that our sensor network has a total of *r* sensors, comprising an anchor node k with known areas and r-k sensor hubs with an obscure area. Since we have r-k sensor positions with unknown coordinates, we move a sensor around in each of the *r-k* positions and capture several readings of each signal strength at each of the *r-k* positions.

Based on the RSS, let the estimated distances of the mobile sensor node from each of the *r-k* positions to the anchor nodes be given by Eq.2.

$$d_i, i = 1 \; to \; r - k \tag{2}$$

If the mobile sensor's absolute location is defined in the grid are(X_i , Y_i), i = 1 to r-k and the positions of the position of anchor nodes represented its value in the network is given by (X_j , Y_j), j = 1 to k, then the Euclidean distance between the mobile sensor node and any of the anchor nodes is given by Eq. 3.

$$D_{ij} = \sqrt{(X_j - X_i)^2 + (Y_j - Y_i)^2} \tag{3}$$

The objective function is primarily to minimize the difference between the actual and estimated distance between the anchor node and the mobile sensor node at each r-k position. Therefore, we can formulate the objective function as given in Eq. 4.

$$\sum_{j=1}^{k} \sum_{i=1}^{r-k} \left(D_{ij} - d_{ij}\right)^2 \tag{4}$$

Crossover

This research work uses an arithmetic crossover operator which describes a linear combination of chromosomes. The most efficient two parent chromosomes are selected randomly for crossover operations such as (x_1, y_1) and (x_2, y_2) . In this operation, it produces two offspring (x_1', y_1') and (x_2', y_2')

$$\begin{cases} x_1' = x_1\beta + x_2(1 - \beta) \\ y_1' = y_1\beta + y_2(1 - \beta) \end{cases} \tag{5}$$

$$\begin{cases} x_2' = x_2\beta + x_1(1 - \beta) \\ y_2' = y_2\beta + y_1(1 - \beta) \end{cases} \tag{6}$$

Where β is a random number in the range of [0, 1]

Mutation

The mutation operator plays out an irregular move of the neighbor in the populace's possible locale. An individual (x,y) is picked for mutation, at that point the new arrange (x', y') is characterized as follow:

$$\cos(\theta) \geq 0$$

$$\begin{cases} x' = x + |x_{max} - x| \times \cos(\theta) \\ y' = y + |y_{max} - y| \times sin(\theta) \end{cases} \tag{7}$$

$$\cos(\theta) < 0$$

$$\begin{cases} x' = x + |x_{min} - x| \times \cos(\theta) \\ y' = y + |y_{min} - y| \times sin(\theta) \end{cases} \tag{8}$$

Where $x_{min}, x_{max}, y_{min}, y_{max}$ the RSSI upper and lower signal transmission range of are coordinates, $0 \epsilon [0, 2\pi]$ is an angle randomly produced during signal transmission between anchor and sensor nodes. The proposed method gives the optimal result of the localization process using RSSI.

4.2. Proposed algorithm

The proposed algorithm is described as follows:

Step 1: Set N number of anchor nodes random in the network, which transmits their coordinate value along with node power level during the localization process.

Step 2: Estimate the approximation distance value from a selected number of anchor nodes in equation (1) using the signal strength of anchor nodes. After the distancing estimation process is completed, and then it computes the coordinate value of the unknown sensor node.

Step 3: Once the distance measurement process is completed, and then use the genetic algorithm to compute the unknown node position value so it limits the objective function operation using equation 4.

5. Simulation and results

The assessment of the proposed work is simulated in various situations and configurations. The simulation was done in MATLAB 7.0 to determine the location of the wireless device using the genetic algorithm. *The generation of the Data* Experiment was carried out in a chamber free from wireless interference. A 5m-by-5m grid was created with coordinates ranging from [0, 1], [0, 2] to [5, 5]. The RSS captured in each of the coordinates in the grid points were fed into the GA as input. A Spectrum Analyzer was used to measure the RSS at each of the three anchor nodes. Because RSS is susceptible to attenuation and reflection, we captured 10 readings per coordinate per testing period over 10 test periods.

We averaged the RSS values per coordinate per one test period and used it to determine the behavior of the RSS with distance; this is to ascertain the amount of signal interference in the chambers. Figure 2 shows the graph of the captured RSS against distance averaged over one test period. Figure 2 shows a decrease in RSS with increasing distance except three out of the twenty-five points in the grid. The readings obtained at each of these three points were consistent over several test periods. We conjecture that there is a deflection or reflection at these points as a result of the obstructing steel elements present at the specific points. Since Figure 2 shows a relatively acceptable RSS behavior with distance.

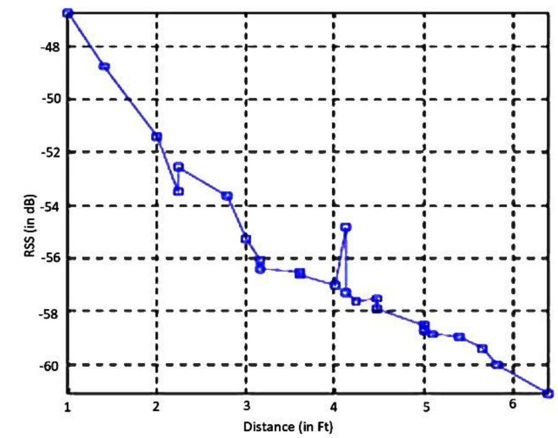

Figure 2. Average RSS vs. distance.

The GA parameters are as follows:

Population size is 100, Number of generations is 100, Crossover rate is 0.6, and Mutation rate is 0.01. The Average Error which shows the difference between the GA predicted results and the expected ones is shown in Figure 3 below. We can see that the error decreases with an increase in the number of generations. At around the 33rd generation, the GA had found a good solution for less than 0.01. This is a practically acceptable result. Figure 4 describes the efficient node coordinate computation process during localization. But Figure 5 describes the optimization of location computation concerning programming objective functions which gives a new dimension to the node localization process. But Figure 6 describes the optimization of location computation concerning node localization error in different scenarios.

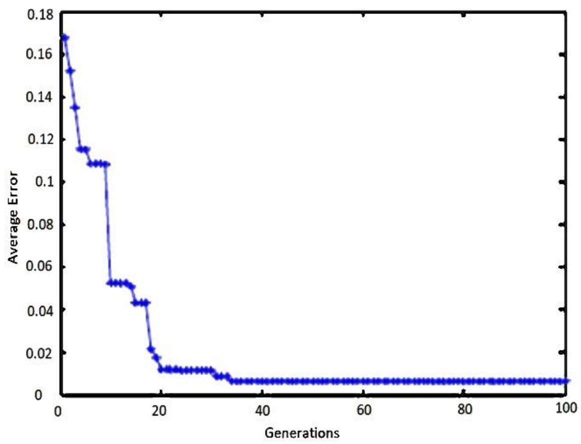

Figure 3. Average errors for target nodes per generation.

During the unknown node localization process, the accuracy of the proposed method depends on the network configuration parameter is described in Table 1. Also, the comparison result of the proposed method is layout in Table 2 in the terms of % average localization error with respect to time in second.

In case of optimization of location computation concerning average node localization error in different scenarios with RSS, AOA, and the proposed method in different time slices in the sensor field describes the optimization of location (Figure 7). The time slices define the performance of location computation.

Network Configuration in situation 2 to the assessment of the proposed algorithm for the node localization process is described in Table 3. The accuracy and the performance value of the proposed method are compared with other existing methods are represented in Table 4.

Figure 8 shows the optimization of location computation concerning RSS, AOA, and the proposed method in its average node localization error value in their different time slices. This comparison defines the proposed method gives efficient value to the location estimation process.

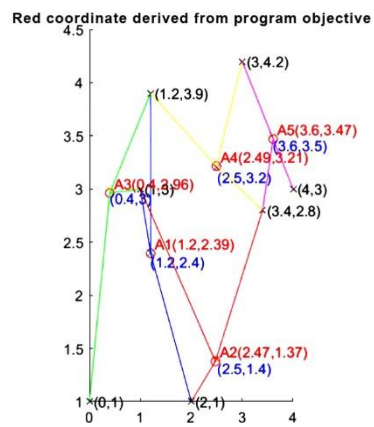

Figure 4. Node location computations using dynamic GA.

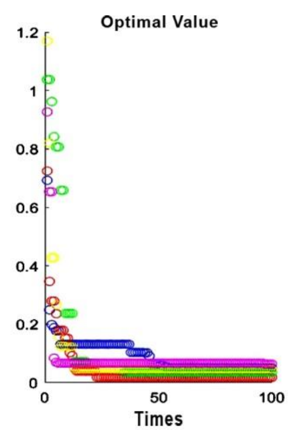

Figure 5. Optimization of node location computation using dynamic GA.

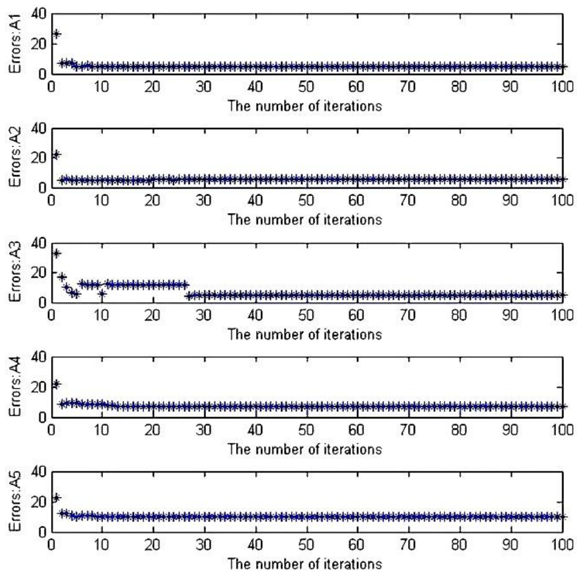

Figure 6. Optimization of localization processes and error minimization using different iterations.

Table 1. Network configuration in situation 1 for the assessment of the proposed algorithm.

Properties	Value
Width	100m
Height	100m
Length	100m
Number of anchor nodes	3
Error in distance cal. (%)	4
Error in angle cal.(%d)	4
GA population size	65
Maximum Iterations	100

Table 2. Comparison of the proposed algorithm with an existing method in scenario 1.

Methods	X	Y	Z	% Error	Time (Sec)
Original	39.6847	7.9456	70.6512	0	0
RSS	13.2718	20.4489	79.3377	27.6735	33.3486
AOA	64.2835	1.982	59.1086	28.9845	35.8705
Proposed	39.1322	16.9874	86.3986	16.7895	53.5913

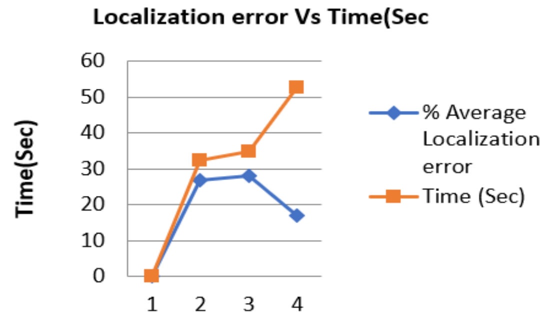

Figure 7. Average localization error vs time (sec).

Table 3. Network configuration in situation 2 for the assessment of the proposed algorithm.

Properties	Value
Width	100m
Height	100m
Length	100m
Number of anchor nodes	4
Error in distance cal. (%)	4
Error in angle cal.(%d)	4
GA population size	65
Maximum Iterations	100

Table 4. Comparison of the proposed algorithm with the existing method in scenario 2.

Methods	X	Y	Z	% error	Time (Sec)
Original	59.9749	32.7322	32.754	0	0
RSS	55.4658	34.3655	35.857	5.7574	30.6547
AOA	59.7549	31.8645	32.54376	1.4704	29.7546
Proposed	59.3622	32.4744	30.53696	1.5358	47.8428

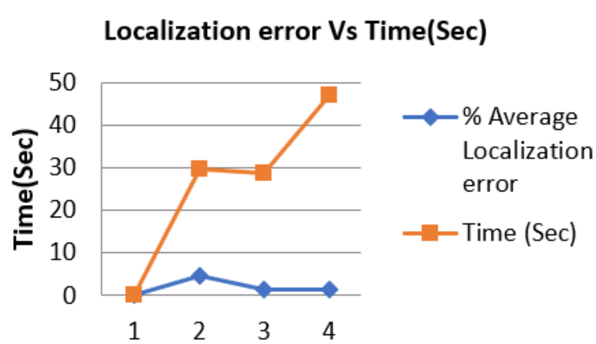

Figure 8. Average localization error vs Time (sec).

6. Conclusions and future work

This research work presents a simulation of wireless sensor network node localization using the GA. We utilized the signal quality portable sensor node to assess the facilities of the sensor node location value in the sensor field grid point. The test was carried out in a chamber free from any other wireless signals apart from the signals from the mobile sensor node.

The GA calculation was permitted to run for 100 generations giving the worthy result of less than one percent normal error in a brief timeframe. This is useful for pragmatic reasons in a remote sensor network.

Conflict of interest

The authors do not have any type of conflict of interest to declare.

Funding

The authors did not receive any sponsorship to carry out the research reported in the present manuscript.

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