Geometrical Localization Algorithm for Three Dimensional Wireless Sensor Networks

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Abstract The issue of localization has been addressed in many research areas such as vehicle navigation systems, virtual reality systems, user localization in wireless sensor networks (WSNs). In this paper, we have proposed an efficient range-free localization algorithm: Geometrical Localization Algorithm (GLA) for large scale three dimensional WSNs. GLA uses moving anchors to localize static sensors. GLA consists of beacon message selection, circular cross section selection. Three beacon messages are used to compute the center of circular cross section using vector method and perpendicular bisector method. The static sensors are localized with help of the center of circular cross section and geometrical rules for sphere. GLA is simulated in SINALGO software and results have been compared with existing methods namely chord selection and point localization. GLA outperforms both the compared methods in terms of average localization time and beacon overhead.

Keywords Range-free localization · Flying anchor · Geometrical localization algorithm · Vector method · Perpendicular bisector method · Three dimensional wireless sensor networks

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1 Introduction

Wireless Sensor Networks (WSNs) are set of tiny and intelligent sensors which are responsible for their organization, configuration and working in order to provide sensing services assigned to them. The sensors can be deployed randomly or planned ways in the sensing field [1,2]. Recent advancements in wireless communications and electronics technologies have enabled the development of low-cost, low power, and multifunctional sensors that are small in size and communicate in short distances. These cheap and smart wireless enabled sensors which can be deployed in large numbers and provide unprecedented opportunities for various kind of applications. Some of the important modern applications of WSNs are military surveillance, environmental monitoring, habitat monitoring, and structural monitoring etc. [3–6]. In spite of its wide applicability, research in this area has its own challenges. One of the main challenges in WSN is to localize sensors with minimum number of beacon messages that reduces computation time, communication overheads, and energy consumption.

Many of the aforementioned applications require sensors at large scale and locations of these sensors are needed for successful operation of the networks. Deploying large number of sensors at known locations is a difficult task and sometimes practically not possible. One of the solutions to the problem is to deploy sensors in random fashion and compute their locations with the help of few localized sensors. In the literature, many solutions exist for computing the location of sensors in WSNs. These solutions localize sensors in the network while they are at work. However, these solutions suffer from the requirement of large number of beacon messages and localized sensors (anchors).

In this paper, we proposed an efficient range-free localization algorithm: Geometrical Localization Algorithm (GLA) for large scale three dimensional WSNs. GLA uses three beacon messages to compute the location of a sensor. A mathematical model to compute the location of a sensor has been provided by using both vector and perpendicular bisector methods. We have carried out extensive simulations to validate the applicability of GLA. The performance of GLA has been evaluated in terms of average location error, average localization time, and beacon overhead. The simulation results have been compared with existing chord selection method [17] and point localization method [25].

The rest of the paper is organized as follows. We discuss the existing related methods in Sect. 2. Problem statements and proposed algorithm have been presented in Sect. 3. Simulations results are discussed in Sect. 4. Finally we conclude the paper in Sect. 5.

2 Related Works

The researchers have made at attempt to solve the problem of localization commonly in two ways: range free, and range based. Some of the range-based schemes are Time of Arrival (ToA) [7], Time Difference of Arrival (TDoA) [8], Angle of Arrival (AoA) [9], Received Signal Strength Indicator (RSSI) [10]. Various other schemes use Multidimensional Scaling (MDS) [11], radio interferometric measurement (RIM) [12], DV-distance [13], DV-hop[14], etc. to localize the sensor nodes. The range-based techniques are fairly accurate but computationally expensive and require costlier equipment. In range-free localizing techniques, location of a sensor is computed on the basis of information transmitted by nearby anchors or neighboring localized sensors. The range-free localizing techniques are not as accurate as range-based but useful in many of the applications where high localization accuracy is not desired. Moreover, the performance of recently proposed range-free localization techniques is comparable to that of the range based techniques. Range free techniques are inexpensive
compare to the range based techniques [15]. A series of range-free schemes have been developed and some of them are APIT [16], moving anchor [17], three dimensional multi-latitude approach [18], centroid scheme [19], and weighted centroid [20].

Range-free localization schemes [21–23] are based on two different methodologies. In the first one, a few GPS equipped sensors (known locations) along with a large number of non-GPS equipped sensors (unknown locations) are deployed in a random fashion. The sensors are localized using the GPS equipped sensors [24]. In the second, GPS equipped sensors (anchors) move throughout in the sensing field and broadcast their current locations on specified intervals to localize the sensors (cf. Fig. 1) [17, 25–27]. First method is highly erroneous due to errors propagating from one sensor to another. Whereas, the second method is practically tough but gives better accuracy.

Most of the existing localization schemes that use second method require at least four beacon messages to compute the location of a sensor in Three Dimensional WSNs (3D-WSNs). Similarly, at least three beacon messages are required to find the location of a sensor in two-dimensional WSNs. The higher numbers of beacon messages increase computational time, energy consumption, and communication overheads [28, 29]. Hence, reducing the number of required beacon messages to localize a sensor will improve the performance of the whole process. This paper focuses on the same i.e. reducing the number of beacon messages.

2.1 Existing Localization Algorithms

The existing works, most closely related to the proposed work are Chia-Ho Ou et al. [17] and Vibha et al. [25]. In both the papers, authors have mentioned different methods for calculating the locations of the sensors using anchors and range-free localization techniques. In [17], authors propose a solution for localization based on geometric principle: “a perpendicular line passing through the center of a sphere’s circular cross section also passes through the center of that sphere”. The algorithm developed in this paper can be summarized as follows:

In [25], authors have suggested a localization algorithm based on geometric principle: “if any point is at the surface of sphere then it will satisfy the sphere equation”. This algorithm can be summarized as follows:

In [17], authors have considered chord selection criteria versus points in a plane. Chord selection criteria can be used to avoid beacons. This criterion selects those chords that are built with beacons having angle > 10° between them. Otherwise, it will lead to location of
Localization algorithm by Chia-Ho Ou et al.

1. Select any nonlinear four beacon points \(B_1, B_2, B_3\) and \(B_4\) (cf. Fig. 1)
2. Find any two circular cross sections formed by these four beacon points
3. Find the centre of circles \(C_1\) and \(C_2\)
4. Draw the lines \(L_1\) and \(L_2\) passing through the centre of circles \(C_1\) and \(C_2\) respectively and perpendicular to the corresponding circular cross section.
5. Calculate the intersection point of \(L_1\) and \(L_2\) that is the centre of the sphere i.e. \(S\) and the desired location of the sensor node.

Localization algorithm by Vibha et al.

1. Select any nonlinear four beacon points \(B_1, B_2, B_3\) and \(B_4\)
2. Substitute these four beacon points in equations of sphere to get four equations of spheres
3. Equate these equations to get three different equations
4. Solve these three equations to get the desired center of sphere, which is the desired position of the sensor node.

The center of sphere above or below the actual center. But in our approach occurrences of all coplanar beacons only lead to non-determination of the center. Only one non-coplanar beacon will be sufficient to determine the center effectively. Hence, there is a low probability of discarding any position information obtained through beacon messages.

3 Geometrical Localization Algorithm

3.1 Problem Definition

Localization is a process of computing location of the sensors which are randomly deployed in a WSN. Mathematically, our system environment of 3D-WSN (cf. Fig. 2) can be modeled as multi-hop network and represented by a graph \(G = (V, E)\) where \(V\) is the set of sensors which in turn is a combination of two different sets say \(U\) and \(A\). \(E\) is the wireless communication path among them. The set \(U\) consists of static sensors that do not move. Set \(A\) consists of moving sensors equipped with GPS and hence they know their location. GPS equipped sensors are also known as anchors who broadcast their locations on specified intervals. Let locations of an anchor is represented as \(\{X_a, Y_a, Z_a\}\) and locations of static sensor is represented as \(\{X_u, Y_u, Z_u\}\). We need to compute \(\{X_u, Y_u, Z_u\}\) using location of three anchors.

All static and dynamic sensor nodes have identical sensing ability, computational ability, ability to communicate, and identical communication range \(R\). The connectivity region of each node can be represented by a sphere of radius \(R\), having the sensor node at its centre. The communication range of mobile sensor nodes is assumed not to change drastically during the entire localization process. As soon as any static sensor node comes within its communication range, it will receive the broadcast message. Geometrical theorems which are used to compute the location of the sensor are summarized in the next section.

3.2 Computation of Location of the Sensors

In the following section, beacon message selection, vector method and perpendicular bisector methods for computing the location of a sensor have been described.
3.2.1 Beacon Message Selection

In GLA, each moving anchor periodically broadcasts beacon messages consisting of ID, position, and time stamp. Each sensor maintains a set of beacon points and a Visitor List. The beacon point is defined as an end point on the communication sphere of the sensor. The Visitor List consisting of respective IDs and lifetimes of the moving anchors currently passing through the sphere [17].

When a sensor node receives a beacon message from a moving anchor, it checks for an entry of the moving anchor in its Visitor List. If it is missing, the current position of the moving anchor is logged as beacon point, and ID and lifetime of the moving anchor are added to the Visitor List. Otherwise, the beacon message is ignored and lifetime of the anchor is updated. When the lifetime of moving anchor expires, its final beacon message is recorded as a beacon point and the corresponding entry is deleted from the Visitor List. For example, as illustrated in the Fig. 3, an anchor $A$ moves from $(X, Y, Z)$ to $(X', Y', Z')$ broadcasting beacon messages at an interval of $t$, where $t = T_{i+1} - T_i$, and $i = 0, 1, 2, 3 \ldots 8$. The beacon messages at $T_2$ is considered as a beacon point $(A, (X_2, Y_2, Z_2))$ by sensor $S$. Sensor $S$ adds an entry $(A, (X_2, Y_2, Z_2), T_2 + L)$ to its Visitor list, where $L$ is predefined lifetime of the moving anchor having a value larger than beacon interval ($L = a \times t, a > 1$). The life time of anchor $A$ is increased by $L$ when it arrives at $T_3, T_4, T_5$ and $T_6$ respectively. Once anchor $A$ moves out of the communication sphere of sensor $S$, and its life time expire, its beacon message at $T_6$ is logged as a beacon point and sensor $S$ deletes the entry for anchor $A$ from its Visitor List.

3.2.2 Circular Cross Section Selection

In this section, we calculate the center of circular cross section using three non-linear beacon points. Assume that $B_1$, $B_2$, and $B_3$ are three beacons points on the sphere. There exists a
circle with center $C$ which satisfies the points $B_1$, $B_2$, and $B_3$, known as sphere’s circular cross section (cf. Fig. 4). A perpendicular line $L_1$ passing through the center of sphere’s circular cross section will also pass through the center of that sphere. We assume that the sensor $S$ is located at $(X_s, Y_s, Z_s)$ and three beacon points $B_1$, $B_2$, and $B_3$ are located at $(X_1, Y_1, Z_1)$, $(X_2, Y_2, Z_2)$, and $(X_3, Y_3, Z_3)$ respectively. The coordinates of center $C$ of circular cross section is $(X_c, Y_c, Z_c)$.

In the following section, two methods have been proposed to compute coordinates of the center of circular cross section.

(i) Vector Method- The circular cross section of a sphere $S$ is illustrated in Fig. 5. We assume a point $O$ outside the circular cross section and a middle point $P$ on line $B_1$, $B_2$. From triangle $OCP$, we have

$$\overrightarrow{OC} = \overrightarrow{OP} + \overrightarrow{PC}$$

$$\overrightarrow{OC} = \frac{\overrightarrow{OB}_1 + \overrightarrow{OB}_2}{2} + \overrightarrow{PC} = X_c\hat{i} + Y_c\hat{j} + Z_c\hat{k},$$

where $\hat{i}$, $\hat{j}$, and $\hat{k}$ are unit vectors.
We assume that $a$, $b$, $c$ are length of the sides $B_1B_2$, $B_2B_3$, and $B_3B_1$ of the triangle $B_1B_2B_3$ respectively. The values of $a$, $b$, $c$ are given by

$$a = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2 + (Z_2 - Z_1)^2} \quad (3)$$

$$b = \sqrt{(X_3 - X_2)^2 + (Y_3 - Y_2)^2 + (Z_3 - Z_2)^2} \quad (4)$$

$$c = \sqrt{(X_1 - X_3)^2 + (Y_1 - Y_3)^2 + (Z_1 - Z_3)^2} \quad (5)$$

The length of line $PC$ can be expressed as

$$PC = \sqrt{R_c^2 - (a/2)^2} \quad (6)$$

where $R_c$ is the radius of circular cross section equals to $\frac{abc}{4\Delta}$. Where $\Delta$ is the area of triangle $B_1B_2B_3$, can be expressed as

$$\Delta = \frac{1}{2} \left| \overrightarrow{B_1B_2} \times \overrightarrow{B_1B_3} \right| \quad (7)$$

The area of triangle $B_1B_2B_3$ can also be represented as

$$\Delta = \frac{1}{2} \sqrt{\Delta_x^2 + \Delta_y^2 + \Delta_z^2} \quad (8)$$

where

$$\Delta_x = (Y_2 - Y_1)(Z_3 - Z_1) - (Z_2 - Z_1)(Y_3 - Y_1) \quad (9)$$

$$\Delta_y = (Z_3 - Z_1)(X_2 - X_1) - (X_3 - X_1)(Z_2 - Z_1) \quad (10)$$

$$\Delta_z = (X_2 - X_1)(Y_3 - Y_1) - (Y_2 - Y_1)(X_3 - X_1) \quad (11)$$

The unit vector in the direction of $PC$ can be given as

$$\hat{PC} = \frac{\hat{N} \times \overrightarrow{B_1B_2}}{||\hat{N} \times \overrightarrow{B_1B_2}||} = d_1\hat{i} + d_2\hat{j} + d_3\hat{k} \quad (12)$$
where \( \vec{N} \) is a normal vector and \( d_1, d_2, \) and \( d_3 \) are scalar quantities. The vector \( \vec{N} \) can be expressed as
\[
\vec{N} = \vec{B}_1\vec{B}_2 \times \vec{B}_1\vec{B}_3 = (N_x, N_y, N_z)
\]  
(13)
where \( N_x = \Delta_x, N_y = \Delta_y, \) and \( N_z = \Delta_z. \) The value of scalar quantities \( d_1, d_2, \) and \( d_3 \) is given by
\[
d_1 = \frac{N_x(Z_2-Z_1)-N_z(Y_2-Y_1)}{m} \\
d_2 = \frac{N_x(X_2-X_1)-N_z(Z_2-Z_1)}{m} \\
d_3 = \frac{N_x(Y_2-Y_1)-N_z(X_2-X_1)}{m}
\]  
(14)
The value of \( m \) can be expressed as
\[
m = \sqrt{N_y(Z_2-Z_1)-N_z(Y_2-Y_1)^2+N_x(X_2-X_1)-N_z(Z_2-Z_1)^2+N_x(Y_2-Y_1)-N_z(X_2-X_1)^2}
\]  
(15)
Finally, using Eq. (2), the coordinates \( (X_c, Y_c, Z_c) \) of the center of the circular cross section, can be expressed
\[
X_c = \frac{X_1+X_2}{2} + d_1 \times PC \\
Y_c = \frac{Y_1+Y_2}{2} + d_2 \times PC \\
Z_c = \frac{Z_1+Z_2}{2} + d_3 \times PC
\]  
(16)
In the next section, alternative method for the same has been proposed.

(ii) **Perpendicular Bisector Method** Consider the circular cross section shown in Fig. 6. The normal vector \( \vec{L}_1 \) to the perpendicular bisector \( L_1 \) of the chord vector \( B_1B_3 \) can be generated by the cross product of vector \( \vec{N} \) and \( \vec{B}_1\vec{B}_3. \) We have
\[
\vec{L}_1 = \vec{N} \times \vec{B}_1\vec{B}_3 = (l, m, n)
\]  
(17)
Similarly,
\[
\vec{L}_2 = \vec{N} \times \vec{B}_3\vec{B}_2 = (p, q, r)
\]  
(18)
Equations of the straight line \( L_1 \) can be written as
\[
\frac{x - a_1}{l} = \frac{y - b_1}{m} = \frac{z - c_1}{n} = t_1
\]  
(19)

Similarly we have equation of \( L_2 \) as
\[
\frac{x - a_2}{p} = \frac{y - b_2}{q} = \frac{z - c_2}{r} = t_2
\]  
(20)

where, \((a_1, b_1, c_1)\) and \((a_2, b_2, c_2)\) are the mid points of \( B_1B_3 \) and \( B_2B_3 \) respectively and \( l, m, n \) and \( p, q, r \) are the direction cosine of lines \( L_1 \) and \( L_2 \). From the conjecture which states that the perpendicular bisector of any chord passes through the center of the circular cross section or in other words, the intersection point of \( L_1 \) and \( L_2 \) is the center of the circular cross section. Therefore, coordinates of the center of the circular cross section can be expressed as
\[
\begin{align*}
X_c &= l \times t_1 + \frac{X_1 + X_3}{2} \\
Y_c &= m \times t_1 + \frac{Y_1 + Y_3}{2} \\
Z_c &= n \times t_1 + \frac{Z_1 + Z_3}{2}
\end{align*}
\]  
(21)

where \( t_1 \) can be calculated as
\[
t_1 = \frac{p\left(\frac{Y_1 + Y_3}{2} - \frac{Y_3 + Y_2}{2}\right) - q\left(\frac{X_1 + X_3}{2} - \frac{X_3 + X_2}{2}\right)}{(q \times l) - (p \times m)}
\]  
(22)

3.2.3 Localizing Sensor \( S \)

In this section, the process of finding the coordinates of sensor \( S \) has been described (cf. Fig. 4). The equation of the line \( L_1 \) passing through the center \( C(X_c, Y_c, Z_c) \) of the circular cross section and perpendicular to the circular cross section i.e. in the direction of \( \vec{N} \), can be expressed as
\[
\frac{x - X_c}{N_x} = \frac{y - Y_c}{N_y} = \frac{z - Z_c}{N_z} = t
\]  
(23)

By using geometrical rule, the line passing through center of circular cross section of the sphere and perpendicular to the circular cross section will also pass through the center of the sphere. Thus, the coordinates \((X_s, Y_s, Z_s)\) of the center of the sphere \( S \) satisfies the equation of line \( L_1 \). We have
\[
\frac{x_s - X_c}{N_x} = \frac{y_s - Y_c}{N_y} = \frac{z_s - Z_c}{N_z} = t
\]  
(24)

The communication range of sensor \( S \) i.e. equation of sphere \( S \) can be given as
\[
(X - X_s)^2 + (Y - Y_s)^2 + (Z - Z_s)^2 = R^2
\]  
(25)

Beacons are selected within the spherical range of the sensor \( S \), therefore coordinate of the beacons \( B_1(X_1, Y_1, Z_1), B_2(X_2, Y_2, Z_2) \) and \( B_3(X_3, Y_3, Z_3) \) will satisfy the equation (25), we have
\[
(X_1 - X_s)^2 + (Y_1 - Y_s)^2 + (Z_1 - Z_s)^2 = (X_2 - X_s)^2 + (Y_2 - Y_s)^2 + (Z_2 - Z_s)^2
\]  
(26)
\[
(X_1 - X_s)^2 + (Y_1 - Y_s)^2 + (Z_1 - Z_s)^2 = (X_3 - X_s)^2 + (Y_3 - Y_s)^2 + (Z_3 - Z_s)^2
\]  
(27)
On solving the Eqs. (24), (26) and (27), we get the coordinates of the center of the sphere $S$ as

\[
\begin{align*}
X_s &= t \times N_x + X_c \\
Y_s &= t \times N_y + Y_c \\
Z_s &= t \times N_z + Z_c
\end{align*}
\]

where $t$ is can be expressed as

\[
t = \frac{(X_1^2 + Y_1^2 + Z_1^2) - (X_2^2 + Y_2^2 + Z_2^2) - 2(X_1 - X_2)X_c - 2(Y_1 - Y_2)Y_c - 2(Z_1 - Z_2)Z_c}{2(X_1 - X_2)N_x + 2(Y_1 - Y_2)N_y + 2(Z_1 - Z_2)N_z}
\]

### 3.3 The Algorithm

The above discussed mathematical formulation for localizing the sensors has been summarized in nutshell by the following algorithm.

**Algorithm-1: GLA**

1. Select any nonlinear three beacon points $B_1(X_1, Y_1, Z_1)$, $B_2(X_2, Y_2, Z_2)$ and $B_3(X_3, Y_3, Z_3)$ on the sphere $S$.
2. Find a circular cross section from joining all the three chosen beacons points.
3. Compute the coordinates $(X_c, Y_c, Z_c)$ of the center of the circular cross section by using either vector method or perpendicular bisector method.
4. Find the equation of line $L_1$ passing through $(X_c, Y_c, Z_c)$ and perpendicular to the circular cross section i.e. (23).
5. Substitute the coordinates $(X_s, Y_s, Z_s)$ of the center of the sphere $S$ in the equation of line $L_1$ (23) to get equation (24).
6. Substitute the coordinates of the beacons $B_1$, $B_2$ and $B_3$ in the equation of sphere (25) to get the Eqs. (26) and (27).
7. Determine the coordinates $(X_s, Y_s, Z_s)$ by solving the Eqs. (24),(26), and (27).

### 4 Performance Analysis

In this section, we evaluate the performance of ELA via simulation in terms of average location error, average localization time and beacon overhead. We have simulated GLA and compared the results with existing localization methods as in [17] and [25].

#### 4.1 Simulation Environment

GLA is simulated using Simulator for Networking Algorithm (SINALGO) which provides simulation framework for 3D-WSNs algorithm. Simulations are performed in a sensing field of volume of $1,000 \times 1,000 \times 1,000$ m$^3$. The number of static sensors deployed in sensing filed is 3,000. The number of anchors used are 1, 2, 3, 4, and 5 % of total number of deployed static sensors. Anchors move following the random waypoint method and random direction walk. We have assumed that all the sensors have same transmission range. The transmission range used in the simulation is 30m. The number of beacon messages generated by anchors varies from 0 to 18,000. The beacon messages are generated following the Poisson distribution.
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4.2 Performance Matrices

The following metrics have been used to evaluate the performance of GLA.

Average Location Error This metric is the average distance between the estimated location \((X_e, Y_e, Z_e)\) and the actual location \((X_i, Y_i, Z_i)\) of all the sensor nodes. This is computed as

\[
\text{Error}_{ALE} = \frac{\sum \sqrt{(X_e - X_i)^2 + (Y_e - Y_i)^2 + (Z_e - Z_i)^2}}{\text{Total no of sensor nodes}}
\]

Average Localization Time The average time taken for all the sensor nodes to compute their locations. It is given as

\[
\text{Time}_{ALT} = \frac{\sum \text{Localization time for each sensor nodes}}{\text{Total no of sensor nodes}}
\]

Beacon Overhead This is the average number of beacon messages broadcasted by moving anchors during the total localization time. It is given as

\[
\text{Over head}_{BO} = \frac{\text{Total number of beacon messages}}{\text{Total number of moving anchors}}
\]

4.3 Results Analysis

The results of simulations for localizing sensors with respect to localization time are shown in Fig. 7. We observed that as the number of sensors increases, the localization time for both methods also increases. But rate of increment in localization time for GLA is less as compared to point method. This is due to the fact that GLA uses less number of beacon messages resulting in lower computation time. Thus, GLA performs significantly better than the point method.

The results in Fig. 8 show the impact of number of flying anchors on localization time. It clearly reveals that with the increasing number of flying anchors, the average localization time decreases for all the three methods. Further, it is observed that GLA localized sensors
faster as compared to Point method and Chord selection method. This due to the fact that GLA uses lesser number of flying anchors which ultimately reduces required number of beacons messages to localize the whole network.

The Fig. 9 shows the results between the number of flying anchors versus average number of beacons for GLA and the two methods. It is observed that with the increasing number of flying anchors, the average number of beacon message decreases for all the three methods. Further, it is observed that GLA requires less number of beacon messages to localize sensors as compared to Point method and Chord selection method. This is due to the fact that in GLA, only one non-coplanar beacon will be sufficient to determine the center of circular cross
section effectively. Hence, there is a low probability of discarding any location information obtained through beacon messages which reduces the number beacon messages required to localize sensors.

Finally, we observed that the average localization error obtained through simulation for GLA is same as discussed in [17]. All other parameters such as chord selection, circular cross section selection, radio range and moving anchor velocity which potentially affects the accuracy of the localization process, will have the similar effect.

5 Conclusion and Future Work

The range-free geometrical localization algorithm for 3D-WSNs presented in this paper, localize the sensors with the help of anchors. Similar existing approaches use at least four known locations to localize one sensor whereas in GLA, only three known locations are required without compromising the accuracy. The ability of GLA for localizing sensors using only three known locations not only saves computations time, energy, but also reduces the number of anchors required to be deployed. The simulation results confirm that GLA localized sensors faster as compared to Point method and Chord selection method. Additionally, GLA requires less number of beacon messages as well as less number of anchors to localize sensors. In the future research, authors will explore the idea of utilizing the already localized sensors’ locations in GLA to improve the performance of localizations process.

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