

Determine the Location of Nodes in Wireless Sensor Network by Using Genetic Algorithm

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Abstract. Wireless sensor networks (WSNs) are widely used in the modern world. An important requirement for the optimal operation of the network is the determination of the location of the sensor nodes. When building the network, various positioning methods are used, providing the necessary level of accuracy in determining the location of the sensor nodes. It makes it possible to adjust the transmission power of the nodes, to determine which sensors should be in standby mode and which ones to be in working mode, and also to determine the best route for transmitting information. The Angle of Arrival (AoA) method is a method of positioning with respect to the location of the mobile station, which is determined by triangulation of received information collected at multiple access points. The Time of Arrival (ToA) method, also known as the telemetry method, provides one-way measurements of the time difference of signal propagation from the exact time the signal is sent by the transmitter and the exact time the signal is received at the receiver. The Time Difference of Arrival (TDoA) method is based on the concept that a mobile station transmits a message that has been received by at least three access points that are synchronized with other access points. Most of these methods involve approximation and/or linearization, which introduce additional errors. In the present work, an algorithm is proposed for calculating the location of the sensor nodes by the ToA method using a genetic algorithm (GA). An objective function is derived, based on the distances from the reference nodes and the mobile sensor node whose location is sought. This objective function is minimized using a GA, resulting in the desired node coordinates. Investigations of the accuracy of determining the location of the sensor nodes at different accuracy of distance measurement have been made.

Keywords: genetic algorithm, node positioning, wireless sensor networks

I. INTRODUCTION

Wireless sensor networks (WSNs) are used in a wide range of applications. A critical requirement for many of these applications is the self-determination of the sensor

nodes location in WSNs [1]. Sensor devices need to be cheap and with low power consumption, which is determined by the fact that sensor networks can be composed of hundreds to thousands of devices. To achieve the desired accuracy for determining the location of each device, various positioning methods are used [2] – [4].

WSNs are used to measure different spatial and/or temporal parameters of some systems or devices. They can measure natural phenomena like temperature, sound, pressure or other non-natural parameters of some objects like coordinates, velocity, etc., and transmit this data via formed network to a given control centre [1]. To obtain information about the relative or absolute coordinates of the searched node, different methods are used [2] – [4].

Some nodes are usually chosen as the ‘reference’ in the analysis of a sensor network. The reference sensor nodes are used to obtain the location of the nearby nodes [4], [5]. The coordinates of the farther nodes are determined, using some nodes that have already self-determined their locations. These late nodes are called ‘main’ further in this paper [6].

Usually, a node associated with the largest number of branches is chosen as a reference node [7], [2] – [4]. Determining the position of main sensor nodes in a network is an important part of solving mobile object positioning tasks. One of the goals of using sensor networks is to eliminate the need for detailed network topology planning, thereby reducing the need for data on the exact location of a particular node when it is deployed in the network [8], [9].

A wireless sensor network is composed of directly connected deployed nodes. Each node can communicate directly with adjacent sensor nodes within its radio range. An ideal case is when the node coverage is a circle [1], [10] – [12].

There are three basic methods that are widely used nowadays. One of them is the Angle of Arrival (AoA)

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method which is a method measuring the angle between direction of received signal and some reference direction or orientation [13]. Another way to implement this method is by measuring the angle between the dumb node and a main node. This technique requires at least three reference or main nodes with known locations to be used. The coordinates of the dumb node are determined by triangulation of received information from main nodes [7], [2] – [4]. This method possesses some disadvantages as deployment of special antennas, the use of more sophisticated and precise hardware, as well as shadowing and multipath fading conditions lead to bigger errors in the estimated position [8], [9]. Because of this, the AoA method is not often used for localization in WSNs.

The second one is the Time Difference of Arrival (TDoA) method which is based on the concept that a mobile sensor receives messages from at least three main or reference sensor nodes. It is necessary to measure time difference between the receiving signals from at least two pairs of sensor nodes (three nodes) [14]. Advantage of this method is that the impact of errors in time difference measurement on the accuracy of mobile sensor positioning is not so critical. Therefore, less complex hardware is required for the measurements. Disadvantage of the method is that the system of hyperbolic equations has to be solved [4], [5].

The Time of Arrival (ToA) method, also known as the telemetry method, provides one-way measurements of the time difference of signal propagation from the time the signal is sent by the transmitter and the time the signal is received at the receiver [15] – [17]. On the one side, it is easier to linearize the equations, describing the relation between measurements and unknown sensor node coordinates, than in TDoA method. On the other side, this method requires time synchronization between nodes [15], [18]. One possible way is to use a GPS receiver for synchronization. Many applications of WSN, need to know when a given event occurred. In such sensor network, the nodes are accurately synchronized and an algorithm for a sensor node positioning can use this time synchronization [15] – [18].

Communications via Wi-Fi technology is a method widely used for data transfer. In this method, a mobile multifunction device (e.g. smartphone, tablet, laptop; sensor) is connected to a Wi-Fi network over which communications have a limited range and may be affected by interference from other Wi-Fi networks. This method is suitable for mobile devices that operate in a limited range and in areas with a stable Wi-Fi network [1], [19].

The mobile sensor node can be a ground-based unmanned vehicle (rover) whose coordinates can be determined via the WSN. This will allow the WSNs that already exist to be used in different application of rovers [19].

In the present work, an algorithm is proposed for calculating the location of the nodes by the ToA method using a genetic algorithm (GA). An objective function is derived, based on the distances from the reference nodes and the mobile sensor node whose location is sought. This objective function is minimized using a GA, resulting in the desired node coordinates without using any approximation or linearization. Investigations of the accuracy of determining the location of the nodes at

different accuracy of distance measurement have been made.

II. MATERIALS AND METHODS

In this research, the ToA method is utilized to obtain an estimation of a mobile sensor node's coordinates. This method uses the measured distances between the mobile sensor node and some main nodes. The coordinates of main nodes are either exactly known or their estimations are known. In the first stage, the time of arrival of the signal from each main node is measured in the mobile sensor node. Then the time of radio wave propagation between the mobile sensor node and each main node is calculated:

$$\Delta t_i = tr_i - t_i, \quad (1)$$

where: tr_i is the time of receiving of the signal from the i^{th} main node to the mobile sensor node; t_i is the time of signal emitting from the i^{th} main node.

Using (1) the measured distance from the mobile sensor node to the i^{th} main node is obtained by the equation:

$$R_i = c\Delta t_i = D_i + \Delta R_i, \quad (2)$$

where: c is the speed of light; D_i is the true distance; ΔR_i is the measurement error.

The true distance is given by the equation:

$$D_i = \sqrt{(x - x_i)^2 + (y - y_i)^2}, \quad (3)$$

where: x and y are the unknown coordinates of the mobile sensor node; x_i and y_i are the true coordinates of the i^{th} main node.

In the current paper is presented an algorithm which seeks such coordinates x and y that minimize the following objective function:

$$f_{obj} = \sum_{i=1}^N (\sqrt{(x - xm_i)^2 + (y - ym_i)^2} - R_i)^2, \quad (4)$$

where: N is the number of main nodes; i is the main node number; xm_i and ym_i are true or estimated coordinates of main nodes.

The algorithm, proposed in this paper, uses standard GA, included in MATLAB version 2016a, to minimize the formulated objective function (4). The output of the algorithm are the coordinates x and y for which the objective function has minimal value. The proposed algorithm for estimation of the mobile sensor node coordinates is shown in Fig. 1.

First, the surveillance region in which the unknown coordinates will be searched is set. Next, the parameters of GA are set and a random initial population of individuals is created (Generation Zero). The objective function (4) is calculated for each individual. The GA checks if the individual with the minimal objective function value in current generation meets the stopping condition. If it is not fulfilled, the GA creates next generation and the previous two steps are repeated. If the condition is met, then the GA outputs this individual

(coordinates x and y) in current generation for which the objective function value is minimal.

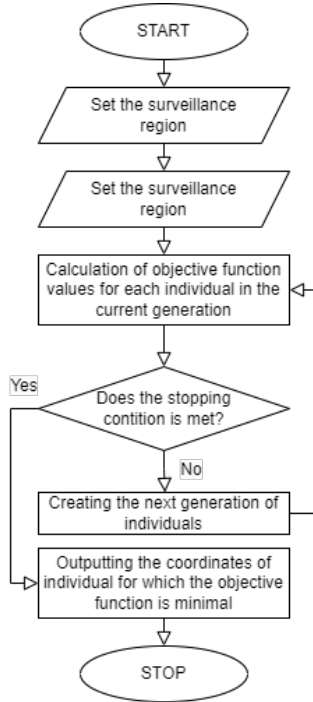


Fig. 1. Algorithm for estimation of mobile sensor node coordinates.

In this article, the rectangular surveillance region is used:

$$\begin{aligned} x_{min} \leq x \leq x_{max} \\ y_{min} \leq y \leq y_{max} \end{aligned} \quad (5)$$

The parameters of GA are as follow:

- population size – 50;
- number of elite individuals – 2;
- number of crossover children – 40;
- number of mutation children – 10;
- stopping condition (6);

$$\frac{1}{50} \sum_{i=n-50}^{n-1} \frac{f_{obj}(i) - f_{obj}(i-1)}{2^{n-i} f_{obj}(i)} < 10^{-6}, \quad (6)$$

where: n is the number of current generation; $f_{obj}(i)$ is the minimal objective function in i^{th} generation.

In fact, the left-hand side of inequality (6) represents the weighted average relative change in the objective function value over the last 50 generations. The population size is chosen after simulations of the algorithm for 30, 50 and 100 individuals in each generation have been done. The rest of the parameters are chosen based on previous studies carried on by the authors using this particular GA. The results obtained in the course of these studies, using the mentioned values of GA parameters, were very good.

The nodes in the WSN are identified by a level, depending on the main nodes, which are used for determination of their coordinates. The first level sensor

nodes determine their coordinates, using only reference nodes as main sensor nodes. The coordinates of reference nodes are exactly known. The second level sensor nodes determine their coordinates, using only first level nodes as main sensor nodes. So, the nodes of given level use only nodes of the previous level to determine their coordinates. For the first level nodes, the true coordinates (x_i, y_i) of reference nodes are used as main nodes coordinates (xm_i, ym_i) in objective function (4). For the higher-level sensor nodes, the estimated coordinates are used in (4). The estimated coordinates of the nodes are obtained during the self-determination of WSN.

Some research results are shown in Section III. It is assumed that the proposed algorithm is used to determine coordinates of main nodes.

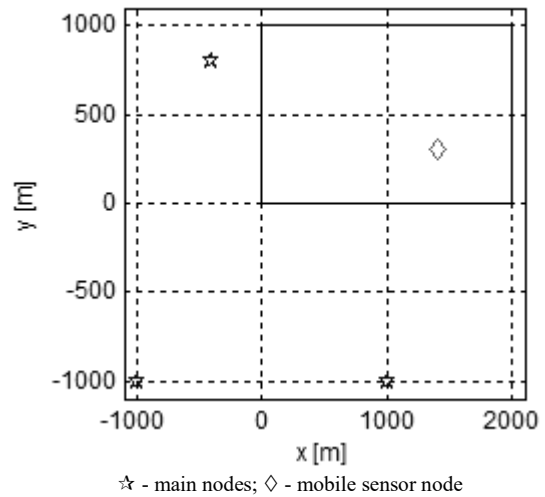
III. RESULTS AND DISCUSSION

The studies are performed at 10 different values of mean squared error (MSE) of the distance measurement. The positioning accuracy of sensor nodes of Level 1 to 5 is evaluated. One thousand simulation of positioning estimation are done for each MSE of the distance measurement and for a given node level.

Fig. 2 shows the true geometric position of the main nodes and the mobile sensor node. The rectangular area, shown in Fig. 2, is the surveillance region where the mobile sensor node is expected to be. The true coordinates (x_i, y_i) of the main nodes are:

- $x_1 = -1000 \text{ m}, y_1 = -1000 \text{ m};$
- $x_2 = -400 \text{ m}, y_2 = 800 \text{ m};$
- $x_3 = 1000 \text{ m}, y_3 = -1000 \text{ m}.$

The coordinates of the mobile sensor node are $x = 1400 \text{ m}$ and $y = 300 \text{ m}$.



☆ - main nodes; ◇ - mobile sensor node

Fig. 2. Location of the sensor nodes.

First, the simulations for mobile sensor node of Level 1 at 1 m MSE of the distance measurement $\sigma_d = 1 \text{ m}$ are done. Since in this case the reference nodes are used, the true coordinates of the main sensor nodes are used in the objective function (4).

The distance measurements are simulated, using the following equation:

$$R_i = \sqrt{(x - x_i)^2 + (y - y_i)^2} + \Delta R_i, \quad (7)$$

where: ΔR_i are normally distributed errors with zero mean and variation σ_d^2 .

The proposed algorithm is used to estimate the mobile sensor node's position in each simulation. The errors between the estimated coordinates and the true coordinates of the node are found:

$$\begin{aligned} \Delta x_n &= x - x e_n \\ \Delta y_n &= y - y e_n \end{aligned} \quad (8)$$

where: $\Delta x_n, \Delta y_n$ are the errors in the n^{th} simulation; $x e_n, y e_n$ are the estimated coordinates of the mobile sensor node in n^{th} simulation.

The mean and MSE (σ_x, σ_y) of all 1000, estimated coordinates are obtained and the MSE of the estimated position is calculated:

$$\sigma_{p1} = \sqrt{\sigma_x^2 + \sigma_y^2}, \quad (9)$$

The new simulations for nine other values of σ_d (from 2 m to 10 m) are done and MSEs of the estimated positions are calculated.

In the higher-level mobile sensor node, simulations deviated coordinates instead of the true coordinates of the main nodes are used in the objective function (4):

$$\begin{aligned} x m_i &= x_i + \Delta x_{ki} \\ y m_i &= y_i + \Delta y_{ki} \end{aligned} \quad (10)$$

where: Δx_{ki} and Δy_{ki} are normally distributed errors with zero mean and variation $0.5\sigma_{p(k-1)}^2$; $k = 2 \div 5$ is the mobile sensor node level.

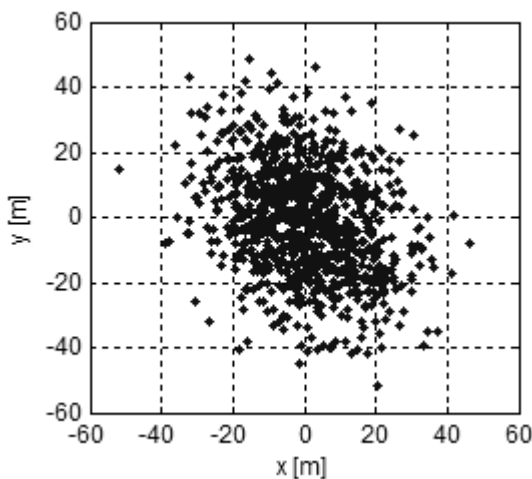


Fig. 3. The errors in estimated position for Level 5 and $\sigma_d = 10$ m.

The errors in estimated mobile sensor node position in the simulations for the node Level 5 and $\sigma_d = 10$ m are shown in Fig. 3. Fig. 3 shows that the errors are grouped around the zero, which points that the estimation of the

mobile sensor node position, using proposed algorithm, is unbiased.

Some comparisons between the proposed algorithm, which uses GA, and one proposed in [1] that uses a least mean square (LMS) algorithm, are made. The obtained MSEs of first level sensor node positioning for the two algorithms are shown in Fig. 4. Fig. 4 shows that the proposed algorithm provides higher accuracy than the LMS algorithm. The improvement in accuracy is observed for all values of MSE of distance measurement.

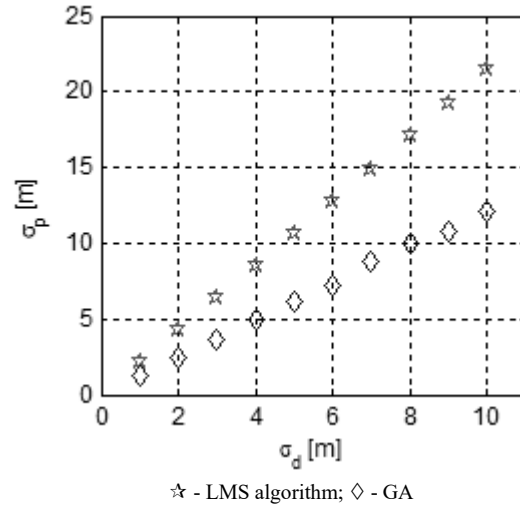


Fig. 4. MSEs of first level sensor node positioning.

The obtained MSEs of third level sensor node positioning for the two algorithms are shown in Fig. 5.

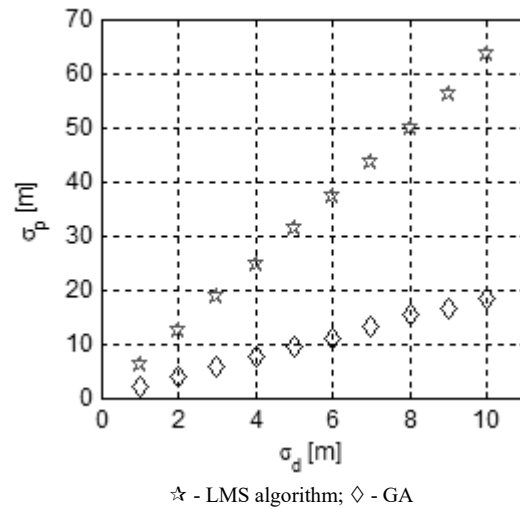


Fig. 5. MSEs of third level sensor node positioning.

Fig. 5 shows that the trends are the same as these in Fig. 4 but the improvement in accuracy of third level node positioning is higher than for first level node positioning.

The obtained MSEs of fifth level sensor node positioning for the two algorithms are shown in Fig. 6. Fig. 6 shows that the improvement in accuracy for fifth level node is significant compared with the first and the third level nodes. The analysis shows that the MSE of node positioning, when the proposed algorithm is used, decreased in comparison with the LSM algorithm 1.70 times for first level node, 2.33 times for second level

node, 3.22 times for third level node, 4.55 times for fourth level node and 6.66 times for fifth level node. It is obvious that the relative improvement of accuracy increases when the level of node is higher.

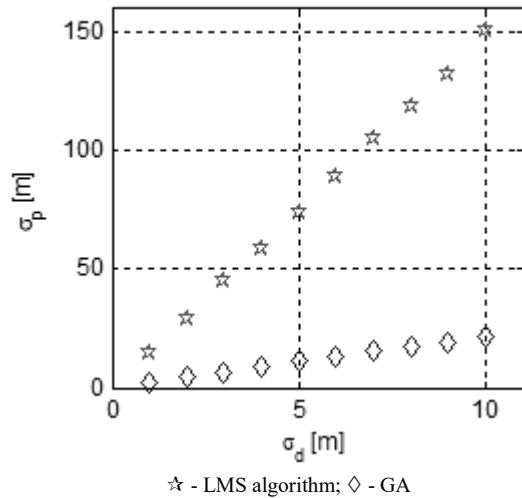


Fig. 6. MSEs of fifth level sensor node positioning.

The graphics of obtained MSEs of node positioning, using proposed algorithm are shown in Fig. 7.

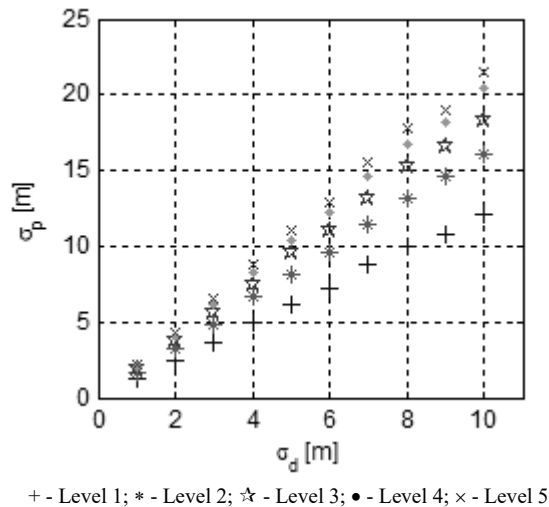


Fig. 7. MSEs of node positioning, using GA.

Fig. 7 shows that the increasing of MSE of positioning is the biggest between Level 1 and Level 2 nodes. The increase in MSE of positioning when moving from a node of a given level to a node of the next level decreases.

The study results for MSE of mobile sensor node positioning are summarized in Table 1 [1]. The analysis of the results in Table 1 shows that the relative sensor node positioning errors σ_{pk}/σ_d can be assumed to be a constant for any given node level. The relative positioning error for first level node is less than 1.25. This points that the accuracy achieved by using the proposed algorithm is high. The MSE of node positioning for Level 5 is less than 1.82 times higher in comparison with Level 1. This proves that the algorithm provides good accuracy even for higher-level sensor nodes.

TABLE 1. MEAN SQUARED ERROR OF SENSOR NODE POSITIONING.

MSE of distance measurement	MSE of mobile sensor node positioning				
	Level 1	Level 2	Level 3	Level 4	Level 5
1 m	1.23	1.65	1.94	2.10	2.20
2 m	2.44	3.26	3.77	4.03	4.30
3 m	3.68	4.89	5.68	6.11	6.55
4 m	4.96	6.66	7.51	8.22	8.78
5 m	6.09	8.17	9.53	10.40	11.04
6 m	7.24	9.53	11.10	11.19	11.91
7 m	8.75	11.50	13.19	14.62	15.60
8 m	10.00	13.21	15.27	16.73	17.74
9 m	10.84	14.58	16.60	18.18	19.00
10 m	11.13	16.03	18.33	20.46	21.43

The results in Table 1 show that there are two ways to ensure that the MSE of positioning is smaller than a predefined value. The first one is to implement better algorithms for distance measurement, but the type of signals, used in WSN, may put limits to their accuracy. The second one is to use the lower-level sensor nodes, which means that more reference nodes have to be placed inside the WSN.

Simulations and studies described in this paper are also done when the population size in GA is 100. The obtained results show that they are not significantly different from the ones discussed in this section. The differences in MSE of the mobile sensor node positioning are less than 5.2%.

IV. CONCLUSIONS

The proposed algorithm uses the ToA method to determine the coordinates of the mobile sensor node. The core of the proposed algorithm is GA, which allows the formulation of an objective function without using approximation and/or linearization. In such way the errors in sensor node positioning are reduced.

The analysis of the research results shows that the proposed algorithm provides much higher accuracy than LMS algorithm. The increase in positioning errors for higher level sensor nodes is relatively small, being less than two times between Level 1 and Level 5 sensor nodes for all values of the MSE in distance measurement. The studies show that it is worth further research to be done for proposed algorithm.

The future studies must include the case when the heights of the nodes in WSNs are not equal, i.e. the coordinate z must be taken into account in the algorithm equations. The impact of the geometry of the main sensor nodes deployment on the positioning accuracy must also be studied. These additional research would give more clarity about conditions and applications in which the proposed algorithm is appropriate for use.

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