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A Novel Optimizing Algorithm for DV based Positioning Methods in ad hoc Networks

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Introduction

Positioning in wireless ad hoc networks plays a major role in the development of geographic aware routing and multicasting protocols that result in new more efficient ways for routing data in multihop networks that span large geographic regions.

Ad hoc network positioning is specific. It is given by network properties and hardware limitations of network devices. The capabilities of individual nodes are very limited and nodes are often powered by batteries only. To conserve energy, collaboration between nodes is required and communication between nodes should be minimized. To achieve these goals nodes in wireless ad hoc networks need to determine a device's context. Since each node has limited power, it is necessary to determine the location of individual sensor nodes without relying on external infrastructure [1, 2]. Therefore the positioning in these networks should meet following criteria:

- self-positioning (positioning does not depend on global infrastructure);
- robust (tolerant of node failures and range errors);
- energy efficient (requires little computation and, especially, communication).

Trilateration as mean for position estimation is utilized in a lot of methods. A new solution which increases positioning accuracy of the methods without additional measurements is proposed in this paper. The proposal will be evaluated on methods based on Distance Vector (DV) protocol: DV-Hop, DV-Distance and DV-Euclidean [3-5].

The most of nodes in ad hoc networks are mobile, therefore it is important to know actual position. Locations of utilized reference nodes play important role from positioning accuracy point of view. Final position estimation is performed by means of data from these surrounding RNs. Therefore it is necessary to select reference nodes, which have suitable positions in respect of localized node. In case that possibility of RN selection exist, it is necessary to consider selection of proper nodes, because of attainable positioning accuracy can be higher more than 10 %.

The methods observed in the paper need three reference nodes for position estimation of localized node. Our solution consists in proposal of algorithm, which selects three from all reference nodes in range [7, 8]. Finally, position of localized node is estimated based on information from the selected nodes.

The rest of the paper is structured as follows. First, investigated positioning methods are briefly discussed. Then, proposal of optimizing algorithm is presented. Simulation model and particular scenarios are described. Last, the obtained results are discussed. The contributions are finally concluded in the conclusion.

Positioning methods

Firstly, principles of investigated methods are explained. Each of the methods has a little bit different basis, but they have one same step in their process. The final position estimation is performed by trilateration [6].

A node with known coordinates is called Reference Node (RN). Otherwise, node which does know own position is referred as Blindfolded Node (BN).

DV-Hop method

This method was named DV-Hop in [5] and Hop-Terrain in [10]. It is the most basic algorithm, and it consists of three phases. First, it employs a classic distance vector exchange so that all nodes in the network determine distances to the reference nodes (in hops). In the second phase, the hop counts are converted into distances. This conversion consists of multiplying the hop count by an average hop distance. The average hop distance between them is derived in following way. When a reference node infers the position of another reference node, the correction for RN [x_i; y_i] is computed

$$c_i = \sum \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} . \left(\sum h_i\right)^{-1}, \quad (1)$$

where [x_i; y_i], [x_j; y_j] – coordinates of RNs i and j; h_i – amount of hops. The average hop distance as correction c_i

is flooded into the network. When an arbitrary blindfolded node received the correction, it may then have estimate distances to three or more reference nodes, in meters, which can be used to perform the trilateration to estimate its own location. The principle of the method is depicted (Fig. 1.).

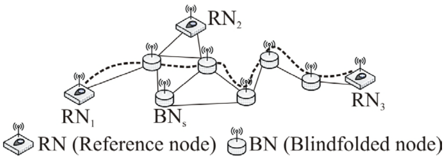

Fig. 1. DV-Hop method

DV-Hop works well in dense and regular topologies, but for sparse or irregular networks the accuracy degrades to the radio range [10].

DV-Distance method

This method is also known as Sum-dist [1]. It is similar to previous method with the difference that distance between neighboring nodes is presented in meters instead of hops. The simplest solution for determining the distance to the reference node is simply adding the ranges encountered at each hop during the network flood. As a metric, the distance vector algorithm is now using the cumulative traveling distance (in meters). Each receiving node adds the measured range to the path length and forwards the message. The propagation range may be measured either by means of received signal strength or by time of arrival. The final result is that each node will have stored the position and minimum path length to at least flood limit RNs.

Described method is more precise than DV-Hop, because not all hops have the same size, but, on the other hand it is sensitive to errors caused by measuring of particular distances between nodes [3].

DV-Euclidean method

DV-Euclidean is positioning method based on real Euclidean distance between BN and RNs. It uses neighboring nodes which know own Euclidean distance to RN.

The principle will be briefly described by means of Fig. 2. At least two nodes (BN_1 and BN_2) are required to determine distance between BN_X and RN. It is necessary to know distances to RN and mutual distance between BN_1 and BN_2. Thus, with the known distances *c*, *d*, and *e*, there are two possible values (r_1 and r_2) for the distance of BN_X to RN. The details of the method can be found in [3-5].

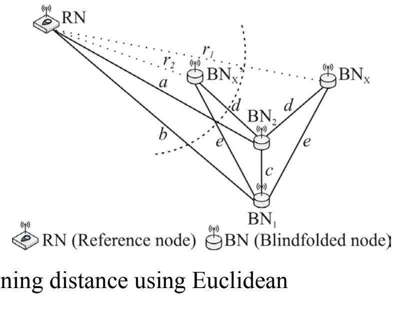

Fig. 2. Determining distance using Euclidean

The advantage of this method is that it provides better accuracy under certain conditions, and there is no correction to be deployed later [5]. If a BN finds out the distance from three RN, it is possible to find the own position by means of trilateration.

Proposal of optimizing algorithm used for positioning methods based on circular trilateration

Positioning methods utilizing trilateration are based on ranging between reference and blindfolded node. The estimated distance is practically always affected by ranging error, therefore is important to select optimal distributed RNs. We focused on positioning methods which used for position estimation three RNs, therefore the proposal is oriented in optimized selection of three RNs.

We assume that given ad hoc network consists of mobile RNs, i.e. there are not fixed beacons. The deployment of reference nodes in the network is random from this point of view.

Optimizing algorithm is based on a few conditions which define the optimal selection of RNs.

Whole process of optimizing algorithm is shown in Fig. 3. The algorithm iterates up to optimal combination of RNs is found. The number of iteration depends on the amount of all RNs in the range of BN, because different combination of three RNs is investigated in each iteration.

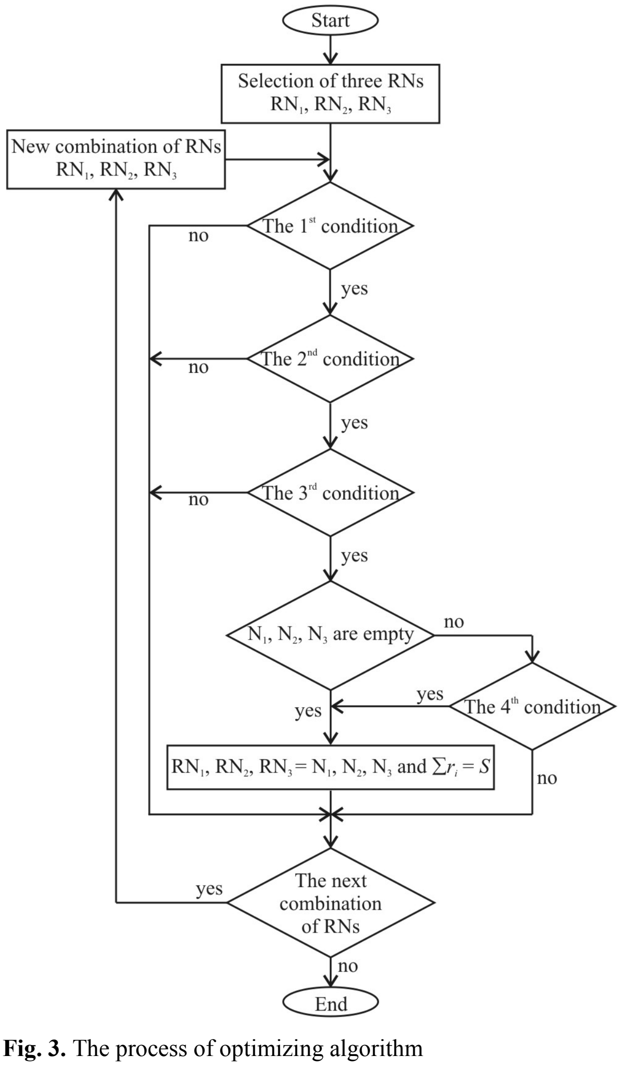

Fig. 3. The process of optimizing algorithm

The optimizing algorithm proposal could be divided into following steps. In the first step, arbitrary three RNs which shape triangle are selected from all reference nodes. They are marked RN_1, RN_2 and RN_3 in Fig. 3 and Fig. 4. The given nodes shape the triangle if **the 1st condition** is fulfilled

$$d_1 > d_2 > d_3 \; and \; d_1 < d_2 + d_3 , \qquad (2)$$

where d_i – mutual distances between RNs (dotted line - triangle side); r_i – radiuses of the circles i = 1, 2, 3.

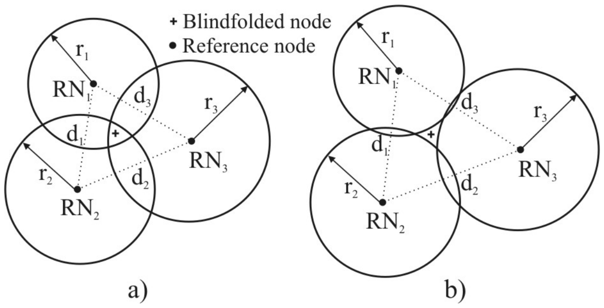

Fig. 4. Optimal situations

The combination of three RNs is known after this step. In the next step, there is investigated if selected RNs have mutual intersections. It is performed as **the 2nd condition**. It is mathematically expressed

$$r_1 + r_2 > d_1 \; and \; r_3 + r_2 > d_2 \; and \; r_1 + r_3 > d_3 , \qquad (3)$$

where d_i – mutual distances between RNs; r_i – radiuses of the circles i = 1, 2, 3. After this step the combination of three RNs which have mutual intersections is known. The intersections are not calculated in this phase.

When RNs shaped to triangle are found, then it is necessary to find out if BN is situated inside of the triangle.

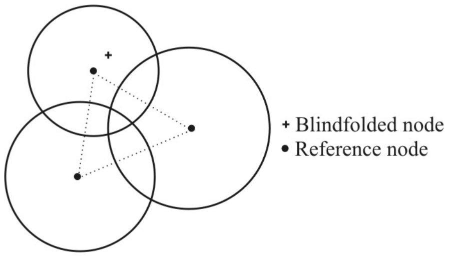

Fig. 5. Unsuitable situations

In case that localized node is not situated in the imaginary triangle, the invalid position estimation could be performed (Fig. 5). It is done as **the 3rd condition**. It is mathematically expressed:

$$\begin{cases} r_1 < d_1 \; and \; r_2 < d_1, \\ r_2 < d_2 \; and \; r_3 < d_2, \\ r_3 < d_3 \; and \; r_1 < d_3, \end{cases} \qquad (4)$$

where d_i – mutual distances between RNs; r_i – radiuses of the circles i = 1, 2, 3.

The positive situations are shown in Fig. 4. In the first case, there is together point (area) which belongs to all three circles, i.e. estimated distances between RNs and BN are longer compare to real distance (Fig. 4, a). On the other hand, there is not together point (area) of all involved circles and estimated distances between RNs and BN are shorter compare to real distance (Fig. 4, b).

After this step, the coordinates of these three nodes are saved into variables N_1, N_2 and N_3. Also a sum of three radiuses corresponds to these circles are saved into variable S.

BN position can be estimated after this iteration, but optimizing algorithm does not know if better combination of RNs is exist. The next RNs combinations are investigated in the next iterations. We assume that mutual distances between RNs are important from positioning accuracy point of view. Particular combinations are compared by mutual distances between RNs. This comparison is done in the next iterations. In the next (i +1) iteration is found another combination of three RNs. It continues up to the third condition is fulfilled and a sum of radiuses S_{i+1} is compared with S. It is **the 4th condition** and mathematically is expressed

$$S_{i+1} < S \, . \qquad (5)$$

This condition investigates if the distances between new RNs are shorter compare to last saved combination. It is done because we assume that BN position estimation by means of nearer RNs is more accurate compare farther RNs. If the 4th condition is fulfilled, the optimizing algorithm found better constellation and saved actual data to variables N and S. When any new combination of RNs is not found, the BN position can be calculated by the data from variables N and S. It is the end of the optimizing algorithm.

Firstly, mutual intersections of three involved circles are calculated. From the six intersections are selected the three nearest, they are called relevant intersections.

The final estimation of BN position is defined as the arithmetic mean of the relevant intersections. The estimated coordinates of BN are calculated as follows

$$x_{est} = \frac{1}{K} \sum_{l=1}^{K} x_l \, , \; y_{est} = \frac{1}{K} \sum_{l=1}^{K} y_l \, , \; l = 1, 2, ..., K \, , \qquad (6)$$

where K – the number of relevant intersections. For three circles K = 3.

Simulation model

Simulation model takes into consideration a network of RNs and one BN. The following properties are valid for the model:

- signals from particular nodes are independent to each other;
- all nodes in the model are deployed with omni-directional.

Let $[x_i; y_i]^T$ $i = 1,2…,m$ are coordinates of RNs and $[x_r; y_r]^T$ are coordinates of BN. Positions of particular nodes were generated by uniform distribution on the area 100 x 100 m. In one case, the positions of RNs will be defined fixed, it will be explained below in detail. The results are based on 1000 independent runs.

Radio channel is modeled as AWGN (Additive White Gaussian Noise) channel, i.e. it consists of two parts: path loss and white Gaussian noise. Path loss is modeled by following equation:

$$P_0(\mathrm{dB}) = P_0(\mathrm{dB}) - 10.n_p.\log(d/d_0), \qquad (7)$$

where P_d – the received signal strength at the distance d in dBm; P_0 – the received signal strength at the reference distance d_0. Typically $d_0 = 1$ meter, and P_0 is calculated by the free space path loss formula [1, 9]. The path loss exponent n_p is a function of the environment. The second part, i.e. AWGN has more significant impact on channel properties. Increasing value of AWGN is decreased SNR (Signal to Noise Ratio). The properties of radio channel are directly modified by AWGN and also SNR is affected. The radio range of all devices was defined, i.e. 50 meters.

The positioning accuracy is compared by means of Root Mean Square Error (RMSE)

$$RMSE = \sqrt{(x_r - x_{est})^2 + (y_r - y_{est})^2}\ ,\ [\mathrm{km}], \qquad (8)$$

where $[x_r; y_r]$ – coordinates of true location; $[x_{est}; y_{est}]$ – coordinates of estimated location.

Simulation Results

This chapter analyzes simulation results obtained by particular positioning methods, i.e. DV-Hop, DV-Distance a DV-Euclidean in various simulations. Impact of following parameters on positioning error is investigated:

- selection of three RNs by means of various settings;
- the number of reference nodes in the network;
- distribution of all RNs in the network;
- SNR;
- radio range.

The goal of the first simulation experiment is to define dependency between mutual position of selected RNs and BN. Based on the results will be verified the 4th condition of the proposed optimizing algorithm. Four different settings of RNs distribution will be used for this reason:

1. ideal case - coordinates of used three RNs are fixed [0; 0], [100; 0] a [50; 100];
2. three arbitrary RNs are selected from all RNs and they are used for positioning;
3. final RNs combination is chosen by optimizing algorithm, i.e. RNs with the shortest mutual distance are chosen;
4. final RNs combination is also chosen by optimizing algorithm, but the 4th condition is changed. RNs with the longest mutual distance are chosen.

The other input parameters are SNR = 9 dB, $m = 20$ (amount of RNs) during this simulation. The obtained results are depicted in Table 1. The methods are compared by RMSE and Successful Positioning (SP) [%]. Successful positioning expresses rate with which the positioning method was able to estimate BN position.

Table 1. RMSE and SP vs. RNs distribution

		DV-Hop	DV-Distance	DV-Euclidean
1.	RMSE [m]	18.60	11.25	9.17
	SP [%]	100	100	87.7
2.	RMSE [m]	31.47	23.08	13.40
	SP [%]	100	100	82
3.	RMSE [m]	26.55	19.31	9.28
	SP [%]	100	100	85.7
4.	RMSE [m]	28.31	21.50	10.75
	SP [%]	100	100	85.7

According to obtained results more important facts can be seen. The most accurate results of all methods were obtained in ideal case of RNs distribution (setting No. 1.). On the other hand the biggest positioning error was achieved by setting No. 2, because any optimizing algorithm was not implementing into positioning process and three arbitrary RNs were selected randomly. The setting No. 2 corresponds to basic algorithms proposed in [3-5]. The proposed optimizing algorithm (see Fig. 3) was implementing in settings No. 3 and 4 and it selected optimal constellation of RNs. The more accurate results were obtained in setting No. 3 compare to No. 4, i.e. mutual RNs distance was the shortest. The results achieved by setting No. 4 were also more accurate compare to basic algorithm. The most important fact of the results is that optimizing algorithm improves the quality of the basic algorithms [3-5].

Comparison of particular positioning methods is also very interesting. The most accurate results were obtained by DV-Euclidean. Nevertheless, the method was not always able to estimate BN position. This phenomenon is caused that this method is more sensitive to inaccurate RN-BN distance estimation compare to other observed methods. On the other hand, the most inaccurate results were obtained by "basic" DV-Hop method. But this method with DV-Distance always localized BN.

According to shown results, we decided to define the 4th condition for optimizing algorithm. It means that RNs with the shortest mutual distance will be always chosen.

In the following simulation, impact of the number of all RNs in the modeled ad hoc network on positioning accuracy is compared. SNR is again 9 dB. The obtained results are shown in Fig. 6 and Table 2.

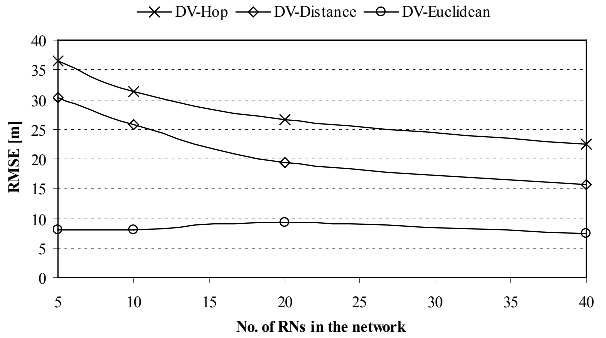

Fig. 6. RMSE vs. No. of all reference nodes in the network

The most accurate results were obtained by DV-Euclidean method. This method has approx. same results for the various number of RNs. But on the other hand, successful positioning fall down with the decreasing of the number of RNs. It is caused by the following effect. In case when optimized solution of three RNs was not found, BN position was not determined and parameter SP was set to 0. We decided to use only optimized solution, but position could be also estimated without it.

Table 2. SP vs. the No. of RNs

No. of RNs	DV-Hop	DV-Distance	DV-Euclidean
	Successful Positioning [%]		
5	94.8	94.3	0
10	99.7	99	29.3
20	100	100	85.7
40	100	100	94.5

The increasing of the RNs number means exponentially descending of positioning accuracy in case of DV-Hop and DV-Distance method. Successful positioning again depends on the No. of RNs, but the impact is much less compare to DV-Euclidean. If we assumed longer radio range of the nodes, successful positioning was increased.

The impact of the radio range on RMSE and SP in case of DV-Euclidean is investigated in the next simulation. Twenty RNs were randomly situated on the observed area. The obtained dependency is shown in the following figure.

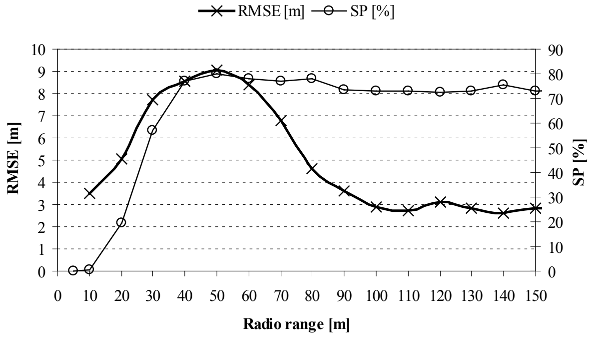

Fig. 7. RMSE vs. radio range

From the results is evident that radio range of nodes has influence on positioning accuracy. The SP increases up to radio range = 40 m, with the next increasing the SP is constant. In those cases when radio range is bigger than 40 m, the observed area is enough covered by signals from RNs and it causes this effect. It means that SP = 80 % is limit of optimizing algorithm implemented on the method and the given number of nodes. SP should increase with the RNs number increasing. From positioning accuracy point if view, the maximum of the method is 2.7 m for these conditions.

Finally, the influence of radio channel quality on positioning accuracy is observed.

According to Fig. 8 can be noted that DV-Hop method is not sensitive on change of radio channel properties, because the method does not utilize parameters of radio channel for distance estimation in whole positioning process. On the other hand, DV-Distance and DV-Euclidean are dependent on the radio channel quality, because distances between particular nodes are estimated based on received signal strength. The more stabile conditions in radio channel means less positioning error. The DV-Distance and DV-Euclidean have very similar dependency on SNR. The obtained results confirm that DV-Euclidean method is the most accurate of investigated methods.

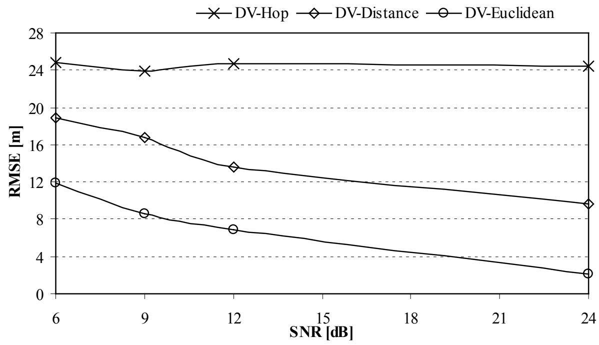

Fig. 8. RMSE vs. SNR

Conclusion

The goal of this paper is a suggestion of an optimizing algorithm for selection of reference nodes used for mobile positioning based on trilateration in wireless ad hoc networks. The proposed algorithm is extension of basic positioning methods. We implemented it into three methods DV-Hop, DV-Distance and DV-Euclidean.

The function of algorithm was verified by simulation model. According to the reached results we can conclude that the positioning accuracy is higher with optimizing algorithm compare to obtained accuracy without it. The proposed algorithm brings more accurate results with all observed methods. We assume that it could be implemented in all positioning methods based on circular trilateration.

Acknowledgments

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The optimizing algorithm for selection of reference nodes used in mobile positioning based on trilateration in wireless ad hoc networks is proposed in the paper. Position of reference nodes plays important role from positioning accuracy point of view. In case, that there is possibility to select some reference nodes from all it is useful do it. Therefore, there will be selected reference nodes which position is optimal in respect of localized blindfolded node. The properties and function of proposed algorithm are verified by means of simulation model of wireless ad hoc network. The following positioning methods DV-Hop, DV-Distance a DV-Euclidean are implemented into simulation model, because final position estimation of these methods is based on circular trilateration. More accurate results were achieved by implementation of proposed algorithm compare with the basic algorithms. Ill. 8, bibl. 10, tabl. 2 (in English; abstracts in English, Russian and Lithuanian).

П. Брида, Ю. Махай, Я. Дуга. Новый оптимизированный алгоритм для DV методов локализации в ad hoc сетях // Электроника и электротехника. – Каунас: Технология, 2010. – № 1(97). – С. 33–38.

В данной статье предложен оптимизированный алгоритм для выбора опорных узлов, который используется при методах локализации основанных на трилатерации в беспроводных ad hoc сетях. Расположение опорных узлов играет очень важную роль с точки зрения точности локализации. В случае, когда опорные узлы можно выбирать, выгодно осуществить выбор таких узлов, позиции которых являются оптимальными учитывая позицию локализированного узла и применяемый метод. В модели применены методы локализации DV-Hop, DV-Distance a DV-Euclidean, поскольку в случае этих методов конечная оценка позиции реализуется посредством круговой трилатерации. При применении предложенного алгоритма были получены более точные результаты по сравнению с исходным алгоритмом. Ил. 8, библ. 10, табл. 2 (на английском языке; рефераты на английском, русском и литовском яз.).

P. Brida, J. Machaj, J. Duha. Naujo optimizavimo algoritmo tyrimas taikant nuotolinių vektorių padėties nustatymo metodus tiesioginiuose bevieliuose tinkluose // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 1(97). – P. 33–38.

Padėties nustatymo mazgai naudojami optimizuojant algoritmus bei trišaliuose tiesioginiuose bevieliuose tinkluose mobilių įrenginių padėčiai nustatyti. Padėties nustatymo mazgai atlieka svarbų vaidmenį įvertinant padėties tikslumą. Jei yra galimybė, siūloma pasirinkti keletą padėties nustatymo mazgų. Tokiu atveju bus atrinktas optimalus mazgas. Siūlomo algoritmo savybės ir funkcijos patikrintos atliekant tiesioginio bevielio tinklo modeliavimą. Modeliuojant įvertinti DV-Hop, DV-Distance ir DV-Euclidean padėties nustatymo metodai. Il. 8, bibl. 10, lent. 2 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

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