Information Support for Monitoring the Parameters of a Self-Organizing Mobile Data Network

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***Abstract*—**The topic of this work is the implementation of routing and clustering algorithms for networks implemented using unmanned aerial vehicles (UAVs). The aim of this work is to model these algorithms and analyze the results. The analysis of the algorithms was carried out in the Matlab software environment. The results obtained have determined the suitability of implementing these algorithms in practice in the industry of wireless networks implemented on UAVs.

***Keywords*—** wireless networks, Dijkstra's algorithm, unmanned aerial vehicle, route modeling, routing, path stability, clustering algorithm, software.

I. Introduction

At present, the development of communication networks is determined by the concept of the Internet of Things [1]. Wireless sensor networks (WSN) are an important part of the Internet of Things. A key feature of such networks is the self-organizing nature of its nodes into local groups [2]. Nodes and groups of nodes can form a network between themselves and transmit data through one or more gateways, then the data is sent to the base station for further processing. The interaction of nodes can be carried out through gateways [9], which are the same network nodes or base stations. Any sensors and actuators located on stationary and mobile objects moving both in 2- and 3-dimensional space can act as such nodes.

Mobile nodes, in addition to performing their basic duties, can act as communication nodes. You can create a flying network, which in turn solves the problem of providing communication to remote and hard-to-reach places.

With the development of radio engineering, the cost and energy efficiency of the elements of radio engineering systems are reduced. This allows the creation of networks based on aircraft capable of performing monitoring and surveillance tasks, as well as providing communication in areas inaccessible to other devices. When organizing data transmission, networks based on UAVs should take into account the density of nodes in order to assess service performance, use effective algorithms to ensure rational routing and reduce the load on each node [6].

The purpose of this scientific work is the development of information support for monitoring the parameters of a self-organizing mobile data transmission network.

The tasks solved in this work:

– development of a method for the location of the UAV, which makes it possible to ensure stable communication at each point of a given area;
– development of a routing method in networks with mobile base stations;
– analysis of the possible influence of various factors on routing in the network and development of an algorithm for finding the most stable one;
– the choice of a clustering algorithm for creating on its basis local networks in the WSN.

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II. LITERATURE ANALYSIS

The widespread introduction of wireless sensor networks and the need to collect information, even in hard-to-reach terrain, have led to the need to consider UAVs or a UAV network as elements of these networks. The work of V.M.Vishnevsky, K.E.Samuylov, V.K.Saryan, S.N. Stepanov, M.A.Shneps, B.S.Gol'dshtein and others are devoted to the study of the location of these networks on a plane. S.N. Stepanov wrote about the distribution of information transmission resources, the distribution of priorities and the analysis of network congestion. Also, Stepanov, together with Iversen, wrote about ways to reduce the amount of computation when calculating models of communication systems with losses, based on ignoring unlikely states and evaluating the characteristics of multithreaded models with a fixed number of repetitions. Buzyukov LB assessed the problems of constructing wireless sensor networks and developed BSS models that allow assessing the connectivity of networks. He also conducted a study of the characteristics of self-organizing wireless networks for various placement methods. Kucheryavyy A.E. dealt with the problems of ensuring the connectivity of wireless sensor network nodes, and also developed a failover clustering algorithm for wireless networks. In particular, he analyzed the evolution of research in the field of wireless sensor networks together with R.V. Kirichkom, A.I. Paramonov, A.V. Prokopyev. EM Akimov developed software that solves the problem of optimizing the BSS topology. S. S. Makhrov proposed a new approach to increasing the efficiency of the functioning of the BSS through the use of artificial intelligence mechanisms of the neural network.

Routing protocols have always been an important task (A.V. Abilov, D.S. Vasiliev), given this, the topic of this article will not lose its relevance in the future. Significant progress has been made in the field of data transmission networks implemented on UAVs and satellites. This new direction is in a state of constant development.

In this area, the following works should be noted: A. E. Kucheryavogo, A. I. Paramonov, R. V. Kirichka, E. A. Kucheryavy, O. I. Shelukhin, S. N. Stepanova, A. K. Erlang, A. Jensen, V. B. Iversen, and P. Kuhn.

The studies and problems studied in the works of these authors have made a significant contribution to the development of the field of wireless sensor networks, and the conclusions and developments obtained as a result formed the basis for writing this article.

III.OBJECT, SUBJECT, AND METHODS OF RESEARCH

The object of the research is the processes of creating an optimal structure of a telecommunication network, as well as an algorithm for finding the optimal route. The subjects are: the number of communication nodes, the probability of connectivity, the area of permissible values for the location of drones in space, the load factor and the range of communication nodes.

In studying the tasks set in this work, the following methods were used: analysis and generalization of materials from other related studies, probabilistic-statistical, typologization and simulation.

A. UAV location

Theoretically, it is possible to divide the territory into zones of the same shape without overlapping or gaps by using three regular geometric shapes: a triangle, a square and a hexagon. In the first case, the base stations should be located on the ground in a checkerboard pattern, and in the second - in a square-nested manner. However, the most effective coverage is achieved by hexagonal zones [20]. Since it is the hexagon that almost ideally describes the working area of a digital base station installed in the center of the cell and having an antenna with a circular radiation pattern.

B. Routing method

To solve the routing problem, the most famous algorithms for finding the shortest path in a graph were considered (an abstract mathematical object that is a set of graph vertices and a set of edges, that is, connections between pairs of vertices.)

Due to the fact that Dijkstra's algorithm is the fastest among analogs, and also considering that there is no need to work with edges of negative weight, the choice was made in his favor.

Dijkstra's algorithm finds the distance from one vertex to all the others in a number of operations of the order of n2. All weights are non-negative.

Due to the need to transfer this algorithm to three-dimensional space, the distance between the points will be found by the following formula:

$$R = \sqrt{(x_b - x_a)^2 + (y_b - y_a)^2 + (z_b - z_a)^2}$$

Modification of Dijkstra's algorithm allows adding “checkpoints” to the route. Such points are understood as one or more communication nodes that will be mandatory participants in all routes in the network. You can use these nodes to collect information about M2M (Machine to Machine) device interaction [17]. Using this method affects the network latency.

C. Method of finding the most stable path

One of the problems in the implementation of routing in networks such as FANET (Flying Ad Hoc Network) is the problem of the probability of connectivity failure [12]. This characteristic represents the stability of the connection along this route [16]. Consequently, the desired result is to increase the stability of the connection, and the task of choosing the optimal route is reduced to searching among the set of possible routes, the route (routes) with the maximum probability of connectivity (stability) p = 1-q, where q is the probability of violation of connectivity, determined according to:

$$\max_{\Omega}(p) = \min_{\Omega}(q)$$

If we represent this network as a weighted graph, then this problem is the problem of finding the shortest path (paths) in the graph, while the weight coefficients of the edges (arcs) will be the logarithms of the probability of their connectivity.

$$c_{ij} = -\lg p_{ij}$$

Based on the foregoing, the shortest path will be the route with the minimum sum of the weight coefficients of the edges (arcs):

$$\min_{\Omega}\left(\sum_{i+1}^{n} c_{ij}\right)$$

To solve this problem, Dijkstra's algorithm was used.

The most stable route search method contains the following steps:

1. Formation of initial data. At this stage:
   - The matrix of the initial coordinates of the network nodes is formed $Q = \{(x_i, y_i)\}, i = 1 \ldots m$, where m – number of nodes in the network.
   - For each of the nodes, the degree of mobility relative to the initial coordinates is determined (set) using the standard deviation, i.e. the matrix is defined, $\zeta = \{\sigma_i\}, i = 1 \ldots m$;
   - The radius R is set in which the node can establish communication with other nodes.

2. Calculation of connectivity probabilities: $P = \{p_{ij}\}, i, j = 1..m.\ p_{ij} = F(d_{ij})$, based on R value and standard deviation: $\sigma = \sqrt{\sigma_i^2 + \sigma_j^2}$.
3. Formation of the matrix of weights. Based on the "stability" matrix P, the matrix of the weighting coefficients of the edges is calculated $C = \{c_{ij}\}$, i, j = 1 ... m, where:

$$c_{ij} = \begin{cases} -\lg(p_{ij})\ d_{ij} < R \\ 0\ d_{ij} \qquad \geq R \end{cases}$$

   This matrix is the initial data for the next stage.
4. Finding the shortest path according to Dijkstra's algorithm.

Choosing a clustering algorithm This approach can be used, for example, to choose the least loaded route, the route with the least losses, determine another stability criterion, etc.

The program implements the ability to search for the least loaded path. The load indicates the size of the queue of processed packets at a certain point in time, and the larger it is, the more loaded the node is considered. The more busy a communication site is, the less preferred it becomes in the final route. It is worth going around such nodes if an increase in hops (hop, that is, a jump, a section between routers) due to a deviation from a geometrically optimal route in the general route will have less effect on the packet processing speed than idleness in the queue of a loaded node.

D. Choosing a clustering algorithm

The main advantages of clustering these networks are energy efficiency, improved network connectivity, efficient topology management, minimizing latency, etc. [5].

When choosing a clustering method, in view of the great variability of possible situations, it is necessary to take into account the possibility of using a centralized and decentralized architecture for building a communication network for a group of UAVs.

The chosen FOREL (Formal Element) algorithm is optimal, due to the low influence of the disadvantages of this algorithm on the operation of the model, as well as the following features:

1. accuracy of minimizing the quality functional (with a successful selection of the radius parameter);
2. simplicity of visualization of clustering results;
3. convergence of the algorithm;
4. highlighting the center of the cluster as one of the results of the algorithm;
5. the ability to test hypotheses of similarity and compactness during the operation of the algorithm.

IV. RESULTS

As a result of the research work, a software product was created that is used to simulate a wireless sensor network within the framework of the assigned tasks.

From the main menu of the program (Figure 1.1) one of 3 operating modes is selected:

1. Route - this menu item is used to simulate routing, and also enables the search for a route by the stability and load parameters.
2. Clustering - this menu item is used to simulate the clustering algorithm.
3. Figures - this menu item is used to model the coverage of the area with the specified figures.

Route and Clustering modes can work in both 2- and 3-dimensional space.

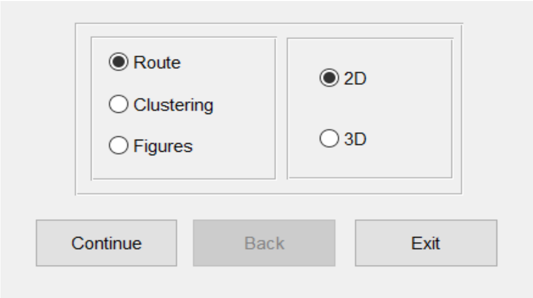


Figure 1 – Program user interface

Figure 2 shows the operation of the routing algorithm. In Figures 2b, 2d, the nodes are randomly assigned load factors. Their size is displayed in color (a darker color indicates a high load of nodes).

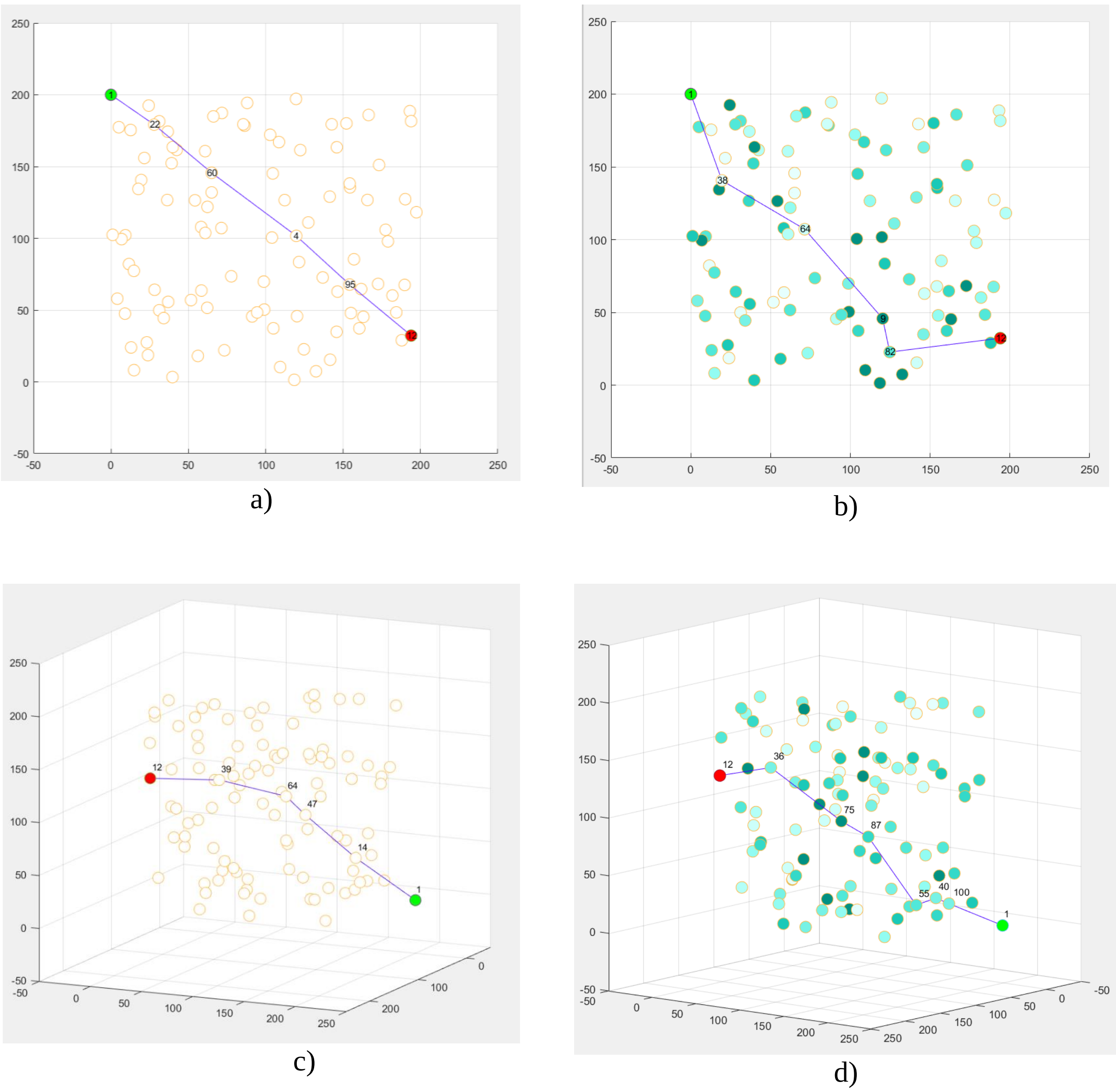


Figure 2 – Route example: a, c)without workload of nodes; b, d)with workload of nodes

The results obtained during the simulation confirm that the load on the node directly affects the routing (the route deviates from the geometrically optimal one).

Figure 3 shows examples of simulation results and the use of the above method to find the most "stable" route in a network of 100 nodes randomly located in a 200x200 m square, with a node communication radius of 80 m. Figure 3a shows the shortest route found by the criterion for the minimum total path length. Figures 3b-f show the paths found by the criterion of maximum stability for various values of the standard deviation.

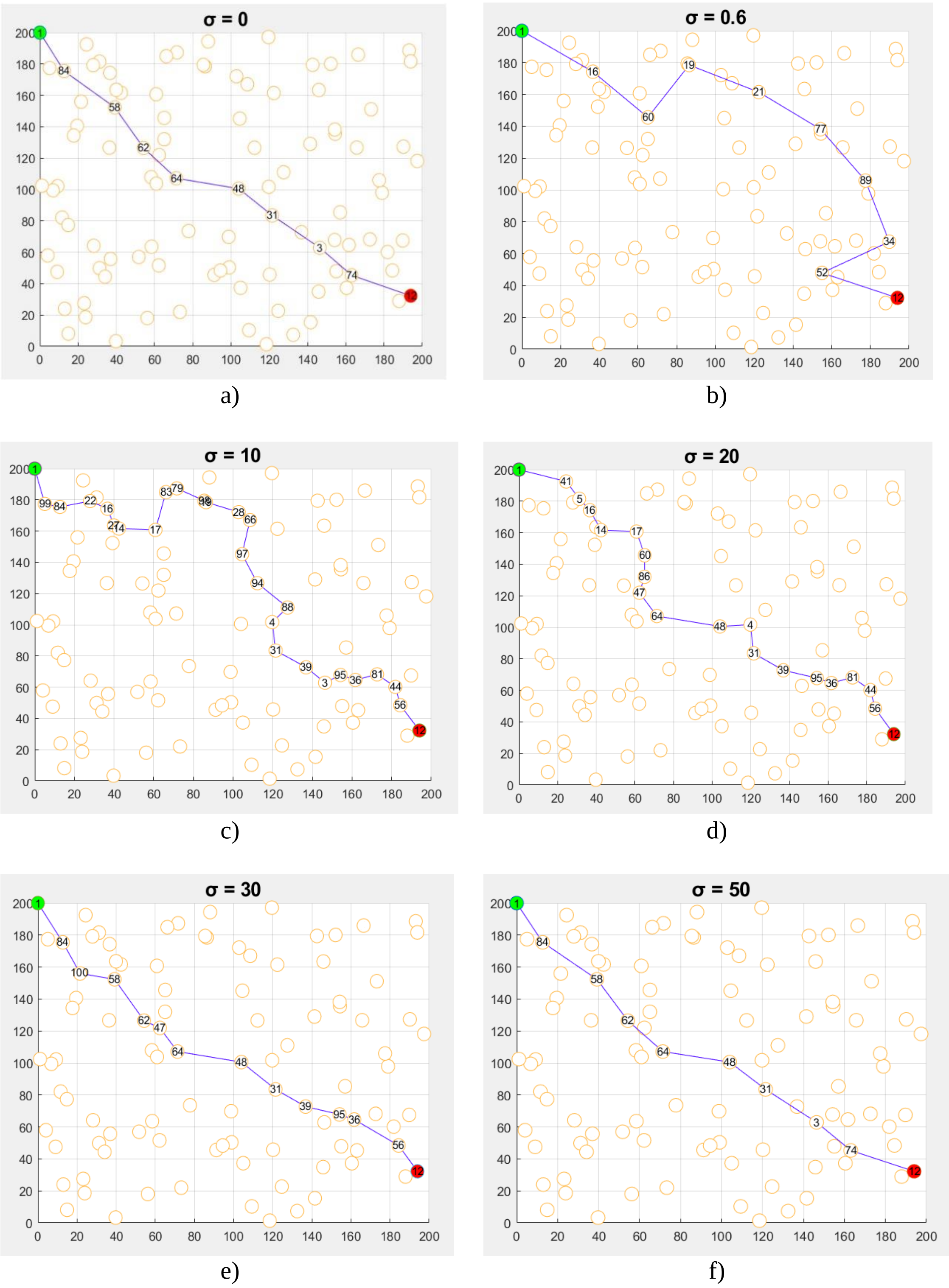
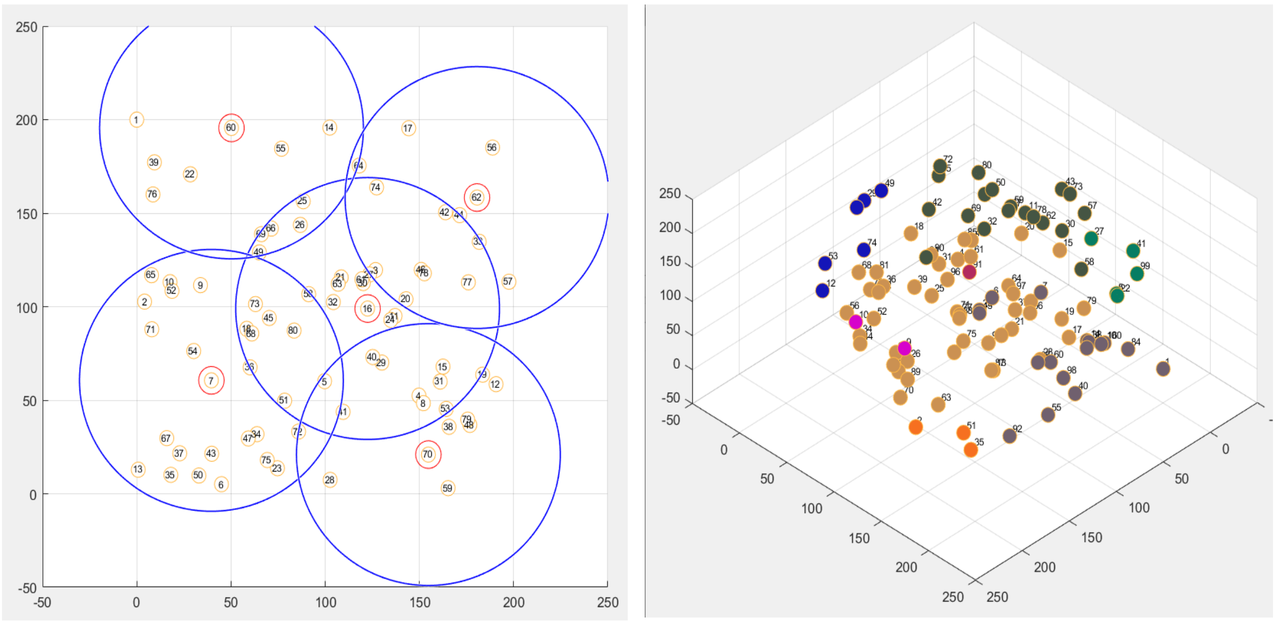


Figure 3 – Examples of route selection: a) σ=0 m b) σ=0.6 m c) σ=10 m; d) σ=20 m e) σ=30 m f) σ=50 m

The examples show that with an increase in the standard deviation (σ) of nodes from their initial position in the path found by the criterion of maximum stability, the number of transit sections increases. This is because the "stable" path search algorithm prefers "short" sections, since they provide a higher probability of connectivity than "long" sections. However, with a further increase in the standard deviation, after reaching a certain value, the opposite process occurs (on figures 3e, 3f). This is explained by the fact that at large values of σ (when the standard deviation has a value close to the radius of the node's connection), the reliability of the sections is so low that when assessing the stability of the entire route, their number dominates.

Thus, we can conclude that the choice of a route based on the stability criterion makes sense when the mobility of network nodes relative to their initial positions is relatively small, i.e. the standard deviation of their positions at least does not exceed the node's link radius. Otherwise, the search result will be close to the route search result by the criterion of the minimum number of transits.



a) b)

Figure 4 - Clustering variations: a) two-dimensional space b) three-dimensional space

The simulation results (Fig. 4) show the effectiveness of the FOREL method, and are also the basis for the further development of FANET network management methods.

V. Conclusions

This paper presents a software product that simulates organization and routing in wireless sensor networks with mobile nodes.

To solve the problem of routing this network, the most versatile algorithm was selected and implemented, with the highest performance among analogs. The developed algorithm allows to explore networks with different parameters of communication nodes, such as: number, range, workload and distribution in space. Also, the algorithm can take into account the mobility of nodes and, when using it, choose the optimal route based on the criterion of the stability of the connection.

Simulation modeling was carried out, as a result of which some features of construction and routing in this type of networks were revealed.

One of the main prerequisites for use can be considered the universality of these networks, as well as their ability to increase the network bandwidth, which is very beneficial when holding mass events. And also due to the speed of deployment of these networks and the low influence of the terrain factor, their use becomes effective in emergency situations and in hard-to-reach areas. Thus, it can be concluded that the use of these networks is promising in the future.

The resulting software product can be useful in scientific research related to modeling the processes occurring when using networks such as FANET and their analysis. Also, this software can be used in the educational process of various educational institutions.

Methods for organizing networks with mobile nodes are currently being developed to take advantage of clustering.

REFERENCES

[1] IoT Platform Companies Landscape 2019/2020 https://iot-analytics.com/iot-platform-companies-landscape-2020/

[2] Махмуд О.А., Анализ трафика интернет вещей. подходы к моделированию / Махмуд О.А., Парамонов А.И. // В сборнике: Интернет вещей и 5G INTHITEN 2017, 2017 г.

[3] Бузюков Л.Б., Проблемы построения беспроводных сенсорных сетей / Бузюков Л.Б., Окунева Д.В., Парамонов А.И. // Труды учебных заведений связи. 2017. Т. 3. № 1. С. 5-12.

[4] Tang S. An Analytical Traffic Flow Model for Cluster-Based Wireless Sensor Networks / Tang S. // 1st International Simposium on Wireless Pervasive Computing, 2006.

[5] Хуссейн О.А., Анализ кластеризации D2D-устройств в сетях пятого поколения / Хуссейн О.А., Парамонов А.И., Кучерявый А.Е. //

[6] Электросвязь. 2018. № 9. С. 32-38

[7] Парамонов А.И., Чинь Б.Х. // Актуальные проблемы инфотелекоммуникаций в науке и образовании (АПИНО 2017) Сборник научных статей . Под редакцией С.В. Бачевского. 2017. С. 514-519.

[8] Paramonov, A. Clustering Optimization for Out-of-Band D2D Communications / A. Paramonov, O. Hussain, K. Samouylov, A. Koucheryavy, R. Kirichek, Y. Koucheryavy // Wireless Communications and Mobile Computing. — 2017. — T.

[9] 2017. — Paper ID 6747052.

[10] S. Andreev, J. Hosek, T. Olsson et al., “A unifying perspective on proximity-based cellular-assisted mobile social networking,” IEEE Communications Magazine, vol. 54, no. 4, pp. 108–116, 2016.

[11] Рекомендация Y.2062 Структура связи "объект-объект" при организации повсеместно распространенных сетей в сетях последующих поколений. Сектор стандартизации электросвязи МСЭ, Женева 2012 г.

[12] Футахи А., Беспроводные сенсорные сети с мобильными временными головными узлами / Футахи А., Парамонов А.И. // Электросвязь. 2016. № 9. С. 48-54.

[13] Парамонов А.И., Чинь Б.Х. // Актуальные проблемы инфотелекоммуникаций в науке и образовании (АПИНО 2017) Сборник научных статей . Под редакцией С.В. Бачевского. 2017. С. 514-519.

[14] Bekmezci, O. K. Sahingoz, S. Temel., Flying Ad-Hoc Networks (FANETs): A Survey, Ad Hoc Networks, 2013, Vol. 11, № 3, pp. 1254–1270.

[15] Парамонов А.И., Исследование параметров маршрутов в самоорганизующихся сетях связи / Чинь Б.Х., Парамонов А.И. // Информационные технологии и телекоммуникации. 2016. Т. 4. № 4. С. 81-88.

[16] Дуйнова Ю.А., Исследование оптимальных условий достижения консенсуса в мультиагентных системах / Ю.А. Дуйнова, Н.И. Лущик, С.И. Половеня // Системы синхронизации обработки сигналов в инфокоммуникациях «Синхроинфо-2018» : материалы 45 Междунар. Науч.-техн. конф., Минск, РБ, 4-5 июля 2018 г. № 43613 официальном перечне IEEE

[17] Нуриллоев И.Н., Модель связности для беспроводных сенсорных сетей / Нуриллоев И.Н., Парамонов А.И. // В сборнике: 71-я Всероссийская научно-техническая конференция, посвященная Дню радио Труды конференции. 2016. С. 176-177.

[18] Кучерявый А.Е., Обеспечение связности беспроводных сенсорных узлов гетерогенной сети /Кучерявый А.Е., Нуриллоев И.Н., Парамонов А.И., Прокопьев А.В.//Информационные технологии и телекоммуникации. 2015. Т. 3. № 1. С. 115-122.

[19] Asadi, A. A survey on device-to-device communication in cellular networks / A. Asadi, Q. Wang, V. Mancuso // IEEE Communications Surveys Tutorials. – 2014. – № 99. – P. 279- 288