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METHOD OF OPERATIONAL CALCULATION OF COORDINATES OF INTERMEDIATE ROUTE POINTS OF FLYING INFORMATION ROBOT

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Background. The article describes an operational calculation method of the intermediate points' coordinates of the flying information robot (FIR) route, which collects information from mobile sensors of a mobile wireless sensor network.

Objective. The purpose of the paper is to develop a method that allows building the movement trajectory of the LIR, minimizing the time for collecting information from mobile sensors.

Methods. The quickly calculating method of the route' coordinates of intermediate points involves setting a quasi-mobile mode of sensors movement and the consistent use of algorithms for solving the navigation problem, the clustering problem, and the problem of finding the flying trajectory around information collection points from mobile sensors clusters that formed at the time of the start of collecting information.

Results. A method has been developed that uses the procedures of quantitative calculation of the indicators of the structural-information connectivity of wireless sensor networks with mobile sensors. These indicators take into account the presence of not only a structural connection, but also a guaranteed information exchange between a given sender-destination pair.

Conclusions. The developed method makes it possible to improve the indicators of the structural-information connectivity of wireless sensor networks with mobile sensors: k-connectivity and network bandwidth.

Keywords: *movement trajectory; flying information robot; mobile wireless sensor network; wireless episodic network; unmanned aerial vehicle; connectivity; topology control.*

Introduction

Flying Information Robot (FIR) is an unmanned aerial vehicle (UAV), which is designed to perform information and telecommunication operations.

Depending on the composition of the onboard equipment, the FIR performs the functions of: a flying multi-sensor; storage device; repeater; controller. At the same time, FIR is designed to maintain information interaction of the control center with stationary and mobile subscribers or sensors. The most successful FIR application is in combination with wireless sensor networks (WSN), both stationary wireless sensor networks (SWSN) and mobile wireless sensor network (MWSN) [1, 24, 25].

Mobile wireless sensor network is indispensable in the conditions of absent or destroyed ground infrastructure (regions with difficult terrain or affected by natural disasters or man-made disasters). Typically, MWSN is quickly deployed to organize information interaction between personnel of search and rescue units and (or) law enforcement services. MWSN are wireless local area networks in which nodes (mobile sensors) have the same status (peer-to-peer) and can interact with each other directly in the radio visibility area, or with relaying messages through other nodes, thus forming multi hop networks of arbitrary structure [1]. However, the mobility of the nodes, the unpredictability of the operational landscape, and the limited energy of radio lines lead to instability of connections between nodes and, as a consequence, to the loss of connectivity in the MWSN. In this case, the mobile sensor (MS) connectivity can be provided only within individual clusters [2-8, 23, 24, 25].

We will call such connectivity as MWSN cluster connectivity. According to the physical meaning, the concept of cluster connectivity of MWSN means the ability of maximum number of MSs to communicate with each other during an interval of time sufficient to transfer the required amount of information with the required quality to the mobile sensor, which is selected as the head (information storage device).

It is clear that MWSN cluster connectivity is a function of time [9]. Loss of connectivity can occur as a result of MS movement or lack of electrical energy on board of MS to transmit the required amount of information with the required quality. In the presence of cluster connectivity, one MS (concentrated storage) or their group of MSs (distributed storage) can be used as a storage device. In this case, the choice of both concentrated and distributed storage devices depends on the supply of electrical energy on board of MS and the technical characteristics of the information storage device on board of MS.

But the presence of information in the drive does not mean that it can be transferred to the control center for processing and decision making. In the complex information and telecommunication conditions of an emergency, in which the use of MWSN is planned, a key problem arises: how to transfer the accumulated information to the control center in a timely manner. To solve this problem, it is proposed to use the FIR. The FIR is entrusted with the task of collecting information from information storage devices of individual clusters in a minimum time [1].

Problem Statement

The time for collecting information from the MS using the FIR consists of the time of its movement between the intermediate points of the route and the delay time at the intermediate points of the route for reading information from the MS. We assume that information is read using 5G technology.

Then the time of information reading can be neglected in comparison with the time of mechanical movement of the FIR from one intermediate point of the route to another. Considering that the FIR moves between the intermediate points of the route at the maximum speed, it can be concluded that the best location of the intermediate points of the route will be one that ensures cluster connectivity of the MS and the minimum total distance between these points (Fig. 1).

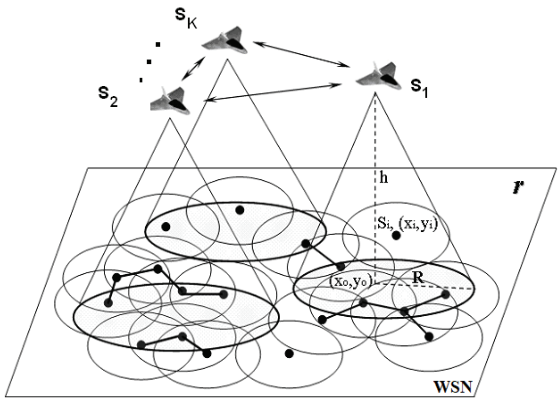

Fig. 1 - An example of a hypothetical trajectory of a flying information robot, providing the minimum time for collecting information from mobile sensors: S_1, S_2, ..., S_K – intermediate points of the FIR route

Currently, trivial methods of collecting information from stationary sensor networks using one or several telecommunication air platforms are known. These methods are based on ensuring the connectivity of the disconnected areas of stationary ground nodes, when the entire stationary network is a single cluster [9-11], or on increasing the connectivity of the ground network [12]. However, no one has yet considered methods of collecting information from MWSN in conditions of cluster connectivity and using one FIR according to the criterion of minimizing the time of flying around all intermediate points of the route (information collection points).

The purpose of this article is development of a method for the operational calculation of coordinates of intermediate points of the route of movement of a FIR. Knowing these points of the route will make it possible to construct a FIR trajectory that minimizes the time for collecting information from mobile sensors.

Problem Solving

To solve the problem, a method is proposed, according to which the scenario of MWSN mobility (called «quasi-mobility») is set. This means that the MSs work in two modes: the first mode is «motion» (MS move in the monitoring area and collect the required information); the second mode is «fading» (MS stops when centralized command from the FIR is sent (or at specified moments of time) to transmit the collected information to the users).

According to the proposed method, in the «movement» mode, the information exchange between the MS and the FIR is not carried out.

According to the proposed method, in the «fading» mode, the FIR on-board computer performs sequential calculations according to three algorithms:

1. Navigation algorithm based on information from the MS, which operate as radio beacons, determine the spatial topology of the MWSN. In this case, the FIR makes special maneuvers (loiters) or «hovers» in the air.
2. Clustering algorithm, using the calculations results of the first algorithm, calculates the coordinates of the points at which the FIR should be located to collect applied (useful) information from the storage media of individual MWSN clusters. The coordinates of these points are programmed route points to be visited by the FIR.
3. Routing algorithm according to the known coordinates of programmed route points determines the trajectory of FIR flight through them. The trajectory is determined using well-known algorithms for solving the «salesman» problem [8].

Algorithms of navigation and routing are already quite deeply worked out today [1]. The clustering algorithm is insufficiently developed. Let's move on to considering it. The computational operations of this algorithm are based on the calculation of indicators of structural and informational connectivity.

Determination of structural and informational connectivity

In general network connectivity is an ability of any pair of nodes to carry out information exchange using intermediate nodes as repeaters [9]. Since information interaction takes place at different levels of the OSI model, then by connectivity we can understand the successful functioning of the protocols of individual levels of OSI model (in narrow sense) or the implementation of conditions and protocols of different levels for guaranteed information exchange between network nodes (in broad sense) [2-14].

At the physical level, between a pair of sender-destination nodes $\{a,b\}, a,b=\overline{1,N}$, where N is the number of MSs in the network, there must be a physical radio channel or a route m_{ab} of serially connected radio channels, characterized by the length of the radio link between each pair of neighboring nodes $d_{ij}, i,j\in m_{ab}, i,j=\overline{1,N}$ or the transmitter power of each route node $p_i, i\in m_{ab}$. If the conditions W_1: $\{d_{ij}\le d^0\ \forall i,j\in m_{ab}$ are met, where d^0, p^0 are the permissible values of the transmission radius (power), we can speak of the presence of a physical connection or structural connectivity of the sender-destination pair $\{a,b\}$.

At the link and network level, guaranteed information exchange is carried out according to the selected multiple access control (MAC) protocol and routing protocol, on the one hand, they are characterized by system parameters, such as the throughput $s\ (m_{ab})$ of the selected data transmission route, and on the other hand, by user parameters, such as the average delay t_d of data packet transmission between the sender-destination pair $\{a,b\}$ (or the number of retransmissions in the route $l(m_{ab})$. Intensity of outgoing flows is defined as $g_{ij}\forall i,j\in m_{ab}$. If the conditions W_2: $\{s(m_{ab})\ge s^0, \overline{t_d}\le t_d^0(l(m_{ab})\le l^0), g_{ij}\le s_{ij}(m_{ab})\}$ are met, we will talk about the presence of a guaranteed information exchange or information connectivity of the sender-destination pair $\{a,b\}$. Note that the presence of information connectivity is possible only if there is structural connectivity.

Then the structural and informational connectivity of the whole network can be determined using the connectivity matrix:

$$[A]=\begin{cases}1, \text{if the conditions are met } W_1 or\ W_2|_{W_1}\\ 0, \text{then}\end{cases}. \quad (1)$$

If the above conditions are fulfilled for all sender-destination pairs $\{a,b\}$ (all matrix elements are equal to 1), then the network will be considered structurally or information ally connected. But this definition of connectivity reflects only the presence of connectivity and does not provide information about the stability of the connectivity of such a network. So, the next step is to quantify an indicator of structural and informational connectivity, which show the degree of network connectivity.

In the case when it is necessary to ensure guaranteed information exchange between each sender-destination pair, the network throughput can be used as a measure of information connectivity. Let’s represent the MWSN in the form of an undirected weighted graph G (N, A), consisting of N vertices (network nodes) and a set of edges (communication channels) A, denoted by a certain weight, for example, expressed by throughput between the corresponding pair of neighbouring nodes $s_{ij}, i,j=\overline{1,N}$ under all other conditions W_1

and W_2. Then the network throughput can be defined as follows [11]:

$$U^T = S(A) = \sum_{i,j=1}^{N\Sigma} \sum_{a,b=1}^{N\Sigma} s_{ij}^{min_{ab}} \quad (2)$$

where $S(A)$ is the network throughput; $s_{ij}^{min_{ab}}$ is the minimum throughput of the channel (edge) that is part of the shortest route m_{ab} between the sender-destination pair $\{a, b\}$, $i, j, a, b = \overline{1, N}$.

The introduction of additional nodes into the network, the role of which can be played by FIR, can significantly increase the above connectivity indicators.

Mathematical Problem Statement

Let the following be given: a set of ground nodes V_i, $i = \overline{1, N}$, where N is the number of ground nodes (MSs) dispersed in a certain area; K is the number of FIRs; R = const is the radius of the service area of each FIR (we assume that they are at the same height H relative to the earth's surface), m; D^0 (P^0) is the radius (power) of the FIR transmission. Each node of the network V_i at time t is described by a set of parameters: location coordinates and speed of movement $(x_i, y_i), S_i, i = \overline{1, N}$; height relative to the earth's surface h (we will assume that h = 0); transmission radius (power) d^0 (p^0); route table of the shortest routes R_i. The connectivity between network nodes at the link level is maintained using the CSMA protocol, and at the network level – by one of the routing protocols [12].

Then the mathematical statement of the problem, the solution of which makes it possible to find a clustering algorithm, can be formulated as follows: to find in real time such a control influence C_x (coordinates of the placement of a set of FIRs in the space $(x_{0j}, y_{0j}, z_{0j}), S_{0j}, j = \overline{1, K}$ that determine the connectivity matrix A^j), which will provide the maximum of the objective function of connectivity determined from expression (2):

$$A^j = arg \max_{C \in W_2} U^T$$

$$W_2 \colon \left\{ \begin{array}{c} d_{ij} \le d^0, D_{ij} \le D^0 \ \forall i, j \in \ldots \\ \ldots \in m_{ab}(p_i \le p^0, P_i \le P^0 \ \forall i \in m_{ab}); \\ s(m_{ab}) \ge s^0; \\ \overline{t_з} \le t_з^0(l(m_{ab}) \le l^0); \\ g_{ij} \le s_{ij}(m_{ab}) \end{array} \right\} \quad (3)$$

Clustering algorithm

Clustering algorithm is intended to find optimal FIR network topology and includes the following steps.

Step 1. Collecting information about the initial network topology and entering the initial data:

- parameters of ground nodes: N, (x_i, y_i), $S_i, i = \overline{1, N}$ and previously derived FIRs: (x_{0j}, y_{0j}, z_{0j}), $S_{0j}, j = \overline{1, K}$ (obtained, for example, via GPS);
- parameters limits in W_2;
- number of FIRs per operation K;
- parameters of MAC and routing protocols.

The above parameters and their limitations determine the initial MWSN topology without the use of FIR $A^j, j = \overline{1, K}$, where j = 0 is the number of the iteration of the solution search (the ordinal number of FIR).

Step 2. Structural connectivity analysis (validation if conditions W_1 are met).

Step 3. Collecting information about the functioning of the network (matrix of the shortest routes
R_i). The collection of this information can be carried out at the planning stage in the presence of FIRs (via a communication channel with the control center) or at the deployment stage by «reading» data from any ground MWSN node (through the functioning of one of the routing protocols [21]).

Step 4. Analysing the presence of information connectivity:

1. Calculation of the network functioning parameters $g_{ij}, s(m_{ab}), \overline{t_з}(l(m_{ab}))$ according to [21].
2. Checking the fulfilment of restrictions W_2. If the conditions are met, then go to step 6, otherwise go to step 5.

Step 5. Execution of the following algorithm to ensure information connectivity:

1. Selection of problematic edges (for which the condition $s(m_{ab}) \ge s^0$ or $g_{ij} \le s_{ij}(m_{ab})$ is not met) and / or problem routes (for which the condition $\overline{t_з} \le t_з^0(l(m_{ab}) \le l^0)$ is not met).
2. Search for new solutions (topology using the current FIR)A^{j+1} that provide coverage of as many problem areas of the network as possible. To reduce the complexity of the search, one can use centroid or lattice initialization, which are discussed in detail in [8].

3. Construction of routing tables $R_i(A^{j+1})$ determined by the flow's matrix and the accepted routing method. Redistribution of flows g_{ij} according to $R_i(A^{j+1})$. Calculation of parameterss$(m_{ab}), \overline{t_3}(l(m_{ab}))$ for existing sender-destination pairs.
4. Check that the conditions W_2 for A^{j+1}. In case of execution (or coverage of the maximum number of problem areas of the network) the FIR is put to the specified position (deployment stage) and adaptation of MAC protocol parameters to real operating conditions is done according to the procedures specified in [15] (operational control stage).
5. Validation of the presence of a hardware resource (FIR). If it is present ($j < K$), go to Step 1, otherwise FINISH.

If all FIRs are withdrawn then each of them periodically at the stage of operational control executes the above scheme to check the need to change its position (in this case, all network nodes are considered fixed at a given time). Moreover, the period between control algorithm executions should be long enough to build routes and transmit a minimum amount of data along them, and at the same time, small enough so that the network topology does not change significantly.

Simulation of Mobile Wireless Sensor Network Functioning Using Proposed Algorithm

The proposed algorithm was implemented on the basis of the Maple environment. For its implementation, the following initial data were used: the number of MSs N = 8, 12 or 16, which were randomly placed on the surface within the area of deployment $r \leq 10^6$ m^2. Allowable values of MS and FIR parameters: d^0= 100 m, D^0= 300 m, R = 200 m, s^0= 0.9, l^0 = 5. The number of FIRs per operation was K = 5. To simplify the calculations, it was assumed that the average load of each MS $\overline{g_i}$ = 5. The packet length was L = 1000 bits. The frequency bandwidth for each channel of the network (MS-MS, FIR-MS, FIR-FIR) was Δf = 300 kHz. BPSK was used as carrier modulation. At the link level MS-MS, flexible CSMA protocol was used, in the FIR-MS (FIR-FIR) channels CSMA protocol with the use of adaptive redundancy was used [15-22]. Dijkstra's algorithm was used to calculate the shortest routes. The number of retransmissions was used as the route metric U^T.

Using the proposed algorithms for placing a set of VLIRs, it was obtained: 1) chart of the dependence of the indicator of structural and informational connectivity (network throughput) on the coordinates of the location of one FIR (Fig. 2); 2) chart of the dependence of network throughput U^T on FIRs number K in case of different MS number N and different size of MS deployment area r (Fig. 3).

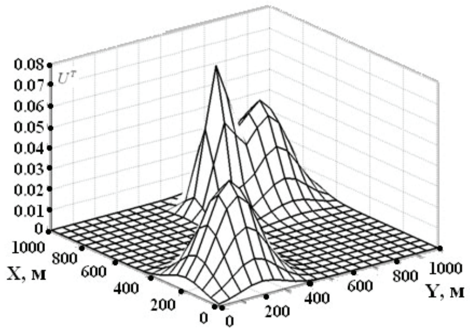

Fig. 2 - The dependence of network throughput on the coordinates of the location of one FIR

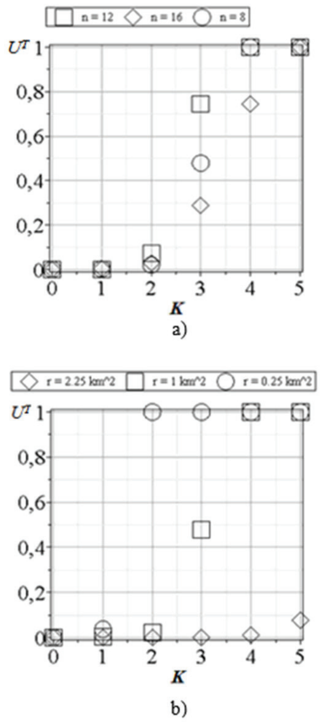

Fig. 3 - The dependence of network throughput on FIR number

Analysing Fig. 2, we can see that the throughput has a global and several local maxima. The maximum value of throughput (when using one FIR) is indicated on the graphs with a star, and the minimum value (without using FIR) is indicated with a diamond. So, for example, when the FIR is placed at the global maximum point with coordinates (302, 261), the throughput reaches its maximum value. In this case, the use of one FIR increases the network throughput in 2-3 times.

Analysing Fig. 3, we can see that the connectivity (throughput) can be increased by applying several FIRs. The effectiveness of using a set of FIR depends on the number of MS nodes in the network and the size of the MS deployment area. With a larger number of MSs or with a smaller deployment area of MSs, the throughput will be greater for a given number of FIRs, since the MSs will have stronger connectivity with each other. FIRs should be used until the specified level of connectivity (throughput) is reached.

Conclusions

The article describes a method for the operational calculation of the coordinates of intermediate points of the route of movement of a flying information robot (FIR), which collects information from mobile sensors of a mobile wireless sensor network (MWSN). Knowing these points of the route allows constructing a FIR trajectory that minimizes the time for collecting information from mobile sensors.

The method of real time calculation of the coordinates of intermediate points of the route involves the sequential use of algorithms for solving the navigation problem, clustering problem and the problem of finding the trajectory of flying around the points of information collection from clusters of mobile sensors that were formed at the time of the start of information collection.

To solve the clustering problem, a special algorithm has been developed in the article that uses procedures for the quantitative calculation of indicators of the structural and informational connectivity of wireless sensor networks with mobile sensors. These indicators take into account the presence of not only a structural connection, but also a guaranteed information exchange between a given sender-addressee pair. To quantify the degree of structural and informational connectivity of wireless sensor networks with mobile sensors, two indicators were proposed: k-connectivity and network bandwidth.

An algorithm for controlling the topology of a network of flying information robots (FIR) has been developed to improve the indicators of the structural and informational connectivity of wireless sensor networks with mobile sensors. This algorithm is based on the use of an adaptive algorithm for optimal placement of a separate telecommunication aero platform in space.

The use of heuristic techniques for specifying the initial conditions (first approximation) can significantly reduce the complexity of finding a quasi-optimal solution to the FIR placement problem and increase the probability of hitting the global maximum in terms of quantitative indicators of structural and informational connectivity.

The results of the simulation experiment indicate the effectiveness of the proposed algorithms. The use of at least one FIR makes it possible to increase the network throughput in 2-3 times. The use of the FIR group makes it possible to increase the indicators of structural and informational connectivity by an order of magnitude.

The article shows that the criterion of structural connectivity cannot fully characterize the reliability of the connection. This criterion does not take into account the characteristics of the algorithms for the functioning of the network: multiple access protocol, the algorithm for processing applications at network nodes, routing protocol, channel capacity, etc. Therefore, the article proposes to use the criterion of structural and informational connectivity and the criterion of informational connectivity to assess network reliability. These criteria characterize the quality of service of requests in conditions of unreliable elements.

The article shows that the combination of these criteria makes it possible to fully determine the structural reliability of the network as a whole.

These criteria make it possible to assess the reliability of a mobile wireless sensor network in the face of rapid changes in its structure. These criteria are applicable to assess the reliability of the MWSN under the conditions of the deterministic and stochastic development of its structure.

The article shows that the flying information robot either hovers or flies in a circle with a minimum radius around the point of its optimal placement. Before moving to the next point of the route, the adaptive adjustment of the data transmission routes and the load of the channels is carried out.

Operational control of equipment flying information robots means adapting transmitter power, multiple access protocols, routing, etc. to the real conditions of functioning. The rate of adaptation depends on the rate of change in the network topology.

If there are several flying information robots, they can be used to increase structural and informational connectivity (reliability). The flying information robot should be placed in such a way as to cover (link) as many nodes of the network as possible.

If it is not possible to connect even a pair of given nodes due to the small size of the flying information robot's coverage area, then the flying information robot must be placed in such a way as to connect one of the given nodes with as many other network nodes as possible. All subsequent flying information robots should be placed in such a way as to link the previous flying information robot with as many other network nodes as possible.

The increase in the number of flying information robot should be continued until the specified structural and informational connectivity (reliability) is achieved or the specified hardware resource of the flying information robot ends.

References

1. Lysenko, O., Romaniuk, A., Zhuk, O., Romaniuk, V., Increasing the efficiency of data gathering in clustered wireless sensor networks using UAV, in: Information and Telecommunication Sciences, volume 1, 2020, pp.102 – 107.

2. Imad Jawhar, Nader Mohamed, Jameela Al-Jarood, UAV-based data communication in wireless sensor networks: Models and Strategies, International Conference on Unmanned Aircraft Systems (ICUAS), 2015.

3. Huseyin Okcu, Mujdat Soyturk, Distributed Clustering Approach for UAV Integrated Wireless Sensor Networks, in:International Journal of Ad Hoc and Ubiquitous Computing, volume15, 2014, pp.106 – 120.

4. Asim Zeb, A. K. M. Muzahidul Islam, Mahdi Zareei, Ishtiak Mamoon, Nafees Mansoor, Sabariah Baharun, Yoshiaki Katayama, Shozo Komaki, Clustering Analysis in Wireless Sensor Networks: The Ambit of Performance Metrics and Schemes Taxonomy, in: International Journal of Distributed Sensor Networks, 2016.

5. Tony Ducrocq, Michaël Hauspie, Nathalie Mitton, Balancing Energy Consumption in Clustered Wireless Sensor Networks ISRN Sensor Networks, 2013, http://dx.doi.org/10.1155/2013/314732.

6. Bakhtin, A., Development of methods of connectivity and quality of service in mobile ad hoc networks with retransmission: Abstract. dis. Candidate for the degree. tech. Science: special. 05.12.13Systems, networks and telecommunications device, 2009.

7. Ilchenko, M., Telecommunication systems based on high-rise aeroplatform, NaukovaDumka, 2008.

8. Lysenko, O., Valuiskyi, S., The method of optimal control of network topology by the criterion of improving connectivity of wireless ad-hocnetworks, Management systems, navigation and communication, volume2(14), 2010, pp. 218 – 224.

9. Minochkin, A., Romaniuk, V., Objectives of the unmanned aerial vehicles network topology of military communication networks mobile component, Collected Works of VITI"KPI", volume2,2005, pp. 83–90.

10. Chandrashekar, J., Dekhordi, K., Baras M., Providing full connectivity in large ad-hoc networks by dynamic placement of aerial platforms. In Proceedings of IEEE MILCOM'04, volume2,2004, pp. 1429 – 1436.

11. Basu, P., Redi, J., Shurbanov, V., Coordinated Flocking of UAVs for Improved Connectivity of Mobile Ground Nodes, in: Proceedings of IEEE MILCOM'04, volume.3,2004, pp. 1628 - 1634.

12. Han, Z., Swindlehurst, A., Liu, K., Smart deployment / movement of unmanned air vehicle to improve connectivity in MANET, in:Proceedings IEEE Wireless Commun. network conference, volume1,2006, pp. 252 - 257.

13. Popovsky V., Mathematical foundations of the theory of telecommunication systems, LLC "Smith", 2006.

14. Ilchenko M., Bunin, S., Voyter, A., Mobile radio networks with packet switching, NaukovaDumka, 2003.

15. Romaniuk A., The UAV monitoring data collection management tasks in wireless sensor networks. Collection of scientific papers MITI, volume2, 2018, pp. 103 – 112.

16. Romaniuk A., Method of the date collecting in wireless sensor networks with unmanned aerial vehicles, Collection of scientific papers MITI, 2018, volume, pp. 90 – 99.

17. Romaniuk V., Zhuk O., Tkachenko D., Power management in wireless sensor networks. Bulletin of NTU "KhPI", Series: Mechanical-technological systems and complexes, Kharkov: NTU "KhPI", volume20, 2017, pp. 53 – 59.

18. Zagorujko N., Prikladnye metody analiza dannyh i znanij, Novosibirsk:IM SO RAN, 1999.

19. Safwan Alfattani, Wael Jaafar, Halim Yanikomeroglu, AbbasYongacoglu, Multi-UAV Data Collection Framework for Wireless Sensor Networks, 2019, Retrieved from https://arxiv.org/pdf/1910.10792.pdf.

20. Minochkin, A., Romaniuk, V., Topology management of mobile radio networks, Zv'yazok, volume2,2003, pp. 28-33.

21. Minochkin, A., Romaniuk, V., Routing protocols in mobile radio networks, Zv'yazok, volume1,2001, pp. 31 - 36.
22. Minochkin, A., Romaniuk, V., Analytical modelling of automated radio networks, Collected Works of KVIUZ, volume 1,2001, pp. 88 –94.
23. Sergiyenko O., Flores-Fuentes, W., Mercorelli, P., Machine vision and navigation, Springer Nature Switzerland, 2020.
24. Asim Zeb, A. K. M., Muzahidul, Islam, Mahdi, Zareei, and others, Clustering analysis in wireless sensor networks: The ambit of performance metrics and schemes taxonomy, International Journal of Distributed Sensor Networks, 2016.
25. Huseyin, Okcu, Mujdat, Soyturk, Distributed clustering approach for UAV integrated wireless sensor networks. International Journal of Ad Hoc and Ubiquitous Computing, 2014.

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Метод оперативного обчислення координат проміжних пунктів маршруту руху літаючого інформаційного робота

Проблематика. У статті викладено метод оперативного обчислення координат проміжних пунктів маршруту руху літаючого інформаційного робота (ЛІР), який збирає інформацію з мобільних сенсорів мобільної бездротової сенсорної мережі.

Мета. Розробити метод, який дозволяє побудувати траєкторію руху ЛІР, яка мінімізує час збору інформації з мобільних сенсорів.

Методи. Метод оперативного обчислення координат проміжних пунктів маршруту передбачає встановлення квазімобільного режиму руху сенсорів та послідовне використання алгоритмів розв'язання навігаційної задачі, задачі кластеризації та задачі пошуку траєкторії обльоту пунктів збору інформації з кластерів мобільних сенсорів, що сформувалися на момент початку збору інформації.

Результати. Розроблено метод, який використовує процедури кількісного обчислення показників структурно-інформаційної зв'язності бездротових сенсорних мереж з мобільними сенсорами. Ці показники враховують наявність не тільки структурного з'єднання, а й гарантованого інформаційного обміну між заданою парою відправник-адресат.

Висновки. Розроблений метод дозволяє покращити показники структурно-інформаційної зв'язності бездротових сенсорних мереж з мобільними сенсорами: k-зв'язність та пропускну спроможність мережі.

Ключові слова: *траєкторія руху; літаючий інформаційний робот; мобільні бездротові сенсорні мережі; бездротові епізодичні мережі; безпілотні літальні апарати; зв'язність; управління топологією.*