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SYNTHESIS OF DATA COLLECTION METHODS BY TELECOMMUNICATION AIRPLATFORMS IN WIRELESS SENSORS NETWORKS

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Background. Wireless sensor networks using telecommunication airplatforms for monitoring data collection belong to the class of complex, multifunctional, dynamic systems. To increase the efficiency of functioning of this class of networks, it is necessary to develop methods that allow achieving various target functions of network management: increase the time of network functioning, reduce the time of data collection, minimize the resources consumed. An integral part of the wireless sensor network management system is the subsystem of control over data collection from nodes using telecommunication airplatforms. When managing the process of data collection there are scientific tasks: finding the minimum number of points (nodes) of data collection, building the shortest flight routes of these points, defining flight strategies, ensuring the quality of data exchange, increasing the time of network operation. At present, there are no effective methods and algorithms to solve these scientific problems. This article is dedicated to the synthesis of methods that solve these problems.

Objective. The purpose of the paper is development and improvement of monitoring data collection methods from wireless sensor network nodes on the basis of motion and positioning control of telecommunication air platforms.

Methods. The analysis of initial data was performed and the main stages for synthesis of monitoring data collection methods by telecommunication airplatforms in wireless sensory networks were considered. The following mathematical models are proposed: clustering of wireless sensors networks; estimation of network nodes power consumption; time of data collection; quality of monitoring data collection and transmission. The algorithms of search of position and movement of telecommunication airplatforms for achievement of the given control objectives at monitoring data collection are improved. The effectiveness of the proposed methods of monitoring data collection has been assessed.

Results. The results of simulation modeling showed that using the proposed models and algorithms in the implementation of monitoring data collection methods from nodes using telecommunication airplatforms allows: reducing data collection time by 15-20%; increasing network operation time by 10-15%; reducing the required number of telecommunications airplatforms to 15%.

Conclusions. The synthesized methods make it possible to: determine the position and trajectory of telecommunication airplatforms when optimizing various target functions; perform real-time control; plan the trajectory of telecommunication airplatforms; improve the efficiency of algorithmic and mathematical support of network control system.

Keywords: wireless sensor networks; clustering; telecommunication airplatform; monitoring data collection from UAVs.

1. Introduction

Wireless sensor networks (WSNs) have become popular in various areas of use (observation of forest areas, agricultural fields, oil and gas pipelines, borders, battlefield, environmental and meteorological monitoring, search and rescue missions, etc.) including remote (inaccessible) areas in the absence of telecommunications infrastructure [1]. WSN may be designed to operate for several months or even years in hard-to-reach areas. Under such conditions, it is proposed to use telecommunication airplatforms (TA) to collect monitoring data from network nodes

Autonomous sensors nodes monitor certain parameters of objects (environment) of their coverage area, store the received data and wait for their transfer to the telecommunication airplatforms. Telecommunication airplatform flies the sensor nodes along the calculated route, establishes radio communication with them, receives and stores the monitoring data. Upon return to the arrival point, the TA transmits the monitoring data to the corresponding data processing center. Features of this network class are: a significant dimension (hundreds and thousands of nodes), the limited resources of nodes on battery power, processor performance,

memory, transmitter power, radio channel bandwidth, etc. Replacing batteries for a large number of nodes may be impractical or even impossible. Reducing (redistributing) power consumption of the sensor nodes is therefore crucial to increase their operating time. The methods of data collection from the sensor network nodes using TA suggested today do not consider the requirements of different target control functions [1 – 8], peculiarities of specific networks functioning and require further improvement. The purpose of the work is to review the process of data collection methods synthesis from the sensor nodes of WSN with the use of TA in the absence of communication infrastructure.

2. Statement of objective

Let's take a look at the general problem definition [6]. Wireless sensor network contains a certain number (N) of stationary wireless sensor nodes, which are randomly located in a certain territory. Each sensor node consists the following basic elements: sensors for monitoring environmental parameters or objects (acoustic, magnetic, vibration, chemical, temperature, radiation, etc. depending on the purpose of the sensor network), microcomputer, battery, memory, transceiver, positioning system, control system. The network nodes can exchange the data both among themselves (and form connected subnetworks) and with TA to transmit monitoring data to them.

In our case, transmission of the monitoring data from nodes to a fixed gateway is impossible due to the lack of telecommunications infrastructure or limited radio range of nodes. Therefore, data collection from sensor nodes is performed with the help of telecommunication airplatforms equipped with appropriate equipment. Each TA contains the following main elements: flight control system, transceiver, data storage system, data collection control system, implemented as a specialized software.

In opposition to real-time sensor networks, these networks receive monitoring data with a certain delay and are classified as DTN (Delay Tolerant Networks).

The main stages of the monitoring data collection process using TA are:

1. Collection of data on network status.

At the initial stage, the entire monitoring area is flown by TA and data is collected about the network nodes' parameters (location coordinates, battery energy, volume of monitoring data, etc.), in the future

- data is collected about the network nodes parameters at each round of the flight.

2. Calculation of TA data collection points from the network nodes.

3. Building the flight route by selected data collection points.

4. TA flight along the route and monitoring information exchange at the selected points between nodes and TA.

5. Arrival at the end point and transfer of information from the TA to the monitoring data collection center.

Given: characteristics of wireless sensor network nodes and telecommunication airplatforms:

- number of nodes and their location on the ground; volume of the i -th node monitoring data - V_i ;
- TA amount - $N_{TA} = 1 \dots N_{TA_{giv}}$;
- starting and ending flight point;
- technical and telecommunication characteristics of nodes and telecommunication airplatforms;
- data collection parameter requirements;

Assumptions: each node and TA have their own control systems and interact with each other within the radio communication zone.

Necessary to: to synthesize the method of monitoring data collection, which allows for a specific WSN to determine the number and coordinates of monitoring data collection points of the telecommunication airplatforms, TA movement (positioning) trajectories, data exchange models to meet certain target network control functions: minimizing or limiting the data collection time, maximizing or ensuring the specified network operation time, minimizing or using the specified number of TA.

With resource limitations Ω : nodes (e_i battery energy, transmitter power, etc.), telecommunication airplatforms (time, speed, flight height, memory capacity, etc.), range and speed of exchange in the radio channel, etc.

Pre-determined requirements for monitoring data collection quality parameters: the collection of preset volumes of monitoring data should be performed for a certain period of time.

3. Stages of synthesis of methods for collecting monitoring data using TA

The main stages of data collection method synthesis from network nodes using TA are [7]: analysis of initial data, determination of control method and target control functions, selection of network organization, data collection methods and

determination of the main stages of their functioning, building the TA flight path and flight models

determination (Fig. 1).

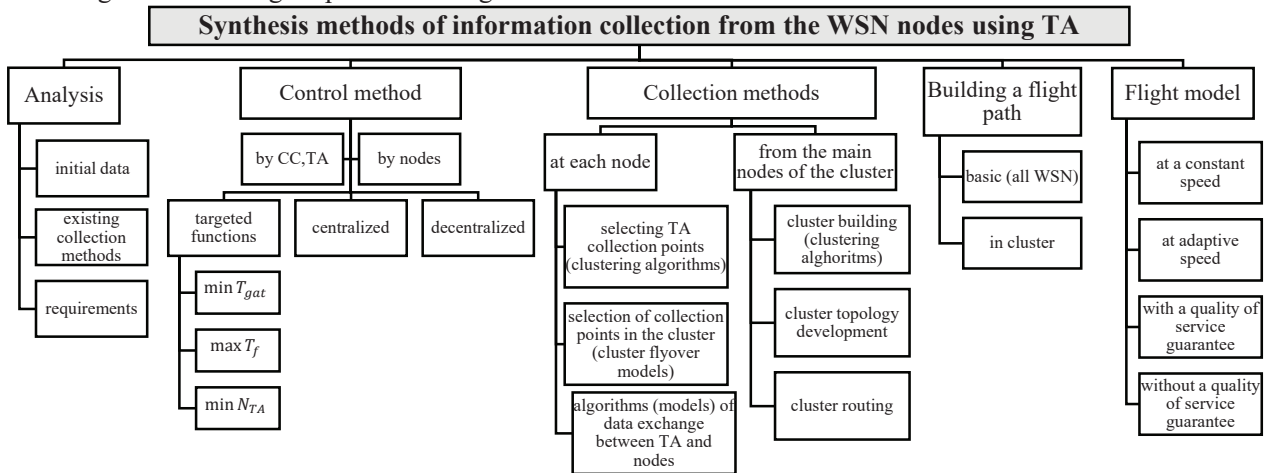


Fig. 1. Stages of synthesis of the monitoring data collection control system

Let's examine each of the stages in more detail.

1. Analysis of initial data, existing methods of data collection using TA, requirements.

The following initial data is analyzed: network characteristics, network nodes characteristics, TA characteristics, data collection quality requirements, monitoring data collection system requirements, cost indicators.

WSN is determined by the following characteristics:

- monitoring area, number of sensor nodes placed on it;
- type of monitoring objects (environment), required parameters of data collection about these objects or among them;
- type of data collection system (real time, with a delay);
- the method of monitoring data collection by nodes (on events, periodically, permanently);
- TA data collection method - from each node (flying over each node, flying over the entire monitoring area, flying over certain collecting points) or designated network nodes during its clustering;
- method of sensor nodes installation (delivery) - determined (there is a possibility to install nodes at predetermined locations), random (scattering from the air, delivery by shells, missiles, etc.);
- requirements to the target control functions.

Each node in the network is characterized by the following set of characteristics:

- number of sensor modules performing monitoring;
- operation modes (active - monitoring, data transmission/receiving; passive - sleep);

- intensity and volume of monitoring data;
 - range and model of coverage of each sensor module;
 - initial energy of the node's battery and energy consumption level in the main modes of operation;
 - transmitter power, receiver sensitivity, adopted protocol of channel level information exchange (for example, IEEE 802.11, ZigBee, etc.), which determine the speed and range of transmission in the radio channel;
 - processor performance, memory size, cost;
 - accepted exchange protocols for different layers of the OSI model;
 - control system capabilities (accepted methods and algorithms of monitoring data exchange).
- Each telecommunications airplatform is characterized by:
- UAV type - airplane or rotor type, method and the launch and landing time;
 - weight, time, altitude, flight speed, cost, etc.;
 - characteristics of transceiver, processor, memory, cost, etc.;
 - adopted protocols of exchange with nodes at different layers of the OSI model;
 - control system capabilities (monitoring data collection methods and algorithms).

Data collection control center is characterized by technical characteristics of TA launch and flight control, capabilities of hardware, specialized software that implements the appropriate data collection method.

Requirements to the data collection quality in the TA network are specified: volume of collected data,

time of its collection, the share of collection nodes (from all nodes of the network or its part), etc.

Also, the necessary requirements for the monitoring data collection system are defined: the maximum time of data collection, the minimum time of operation of the network for monitoring (a given number of flights), the maximum number of TA, the cost of equipment and operation, etc.

The analysis of existing methods of data collection of TA [1 – 8] monitoring to meet the

requirements is carried out. And in case of their dissatisfaction, new methods of collection or improvement of existing ones are being developed.

2. Control method and target control functions.

For effective collection process control, it is necessary to create an appropriate control system (CS). CS represents a hierarchical interaction of the network control center, TA control systems and network nodes control systems (Fig. 2).

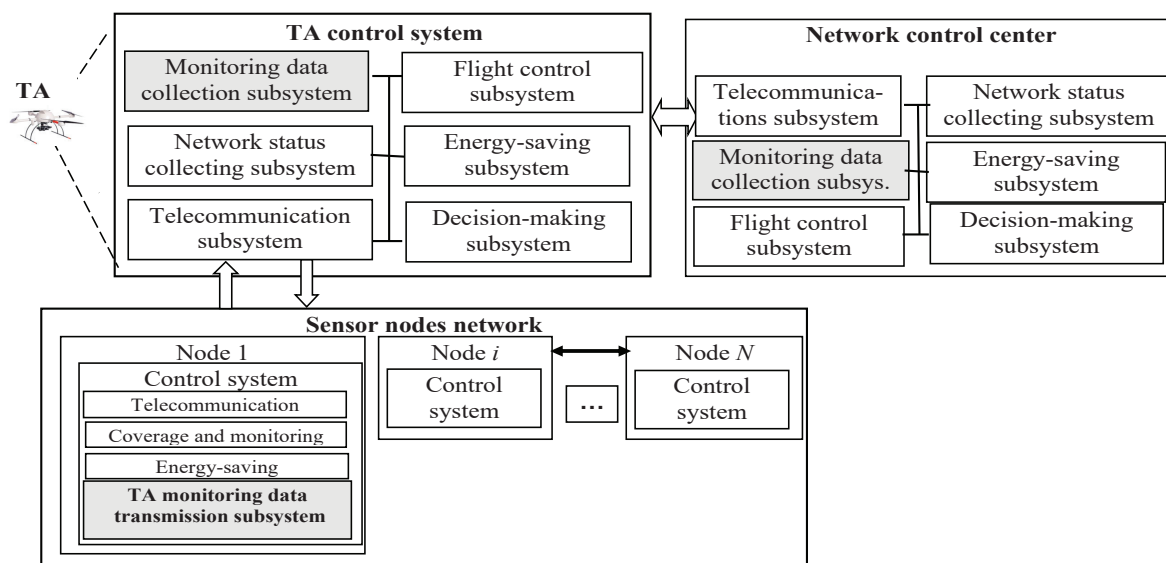


Fig. 2. Functional model of the network control system

Control decisions can be made centrally (control center, TA) or decentralized (network node).

Synthesis of CM is a complex task, which is better to be guided by functional subsystems. CS is a set of the main functional subsystems: flight control, telecommunications, monitoring data collection, data collection on network status, energy saving, decision making. Each of these subsystems solves its own control tasks.

The flight control subsystem provides TA flight on the calculated route, with a certain speed and altitude.

Telecommunication subsystem provides data exchange between the nodes and the TA or between the nodes of the network within radio communication.

The data collection subsystem on the state of the network performs the service message exchange between TA-node or node-node containing the information on the state of the network nodes (coordinates, battery energy level, monitoring data volume, time of active and passive modes, etc.).

The energy-saving subsystem makes the transition to energy-saving modes of operation of nodes and TA.

The decision-making subsystem coordinates the work of the subsystems and searches for solutions according to the embedded control algorithms.

The data collection subsystem should ensure the collection of monitoring data from sensor nodes of the TA when achieving certain target management functions. This is the subject of our consideration.

The main target functions of data collection are [6 – 8]: minimizing or limiting the time of data collection, maximizing or providing the specified time of the WSN functioning, minimizing the number of TA, etc.

a) Minimizing or providing a specified time for data collection ($\min T_{gat}$ or $T_{gat} \leq T_{gat\ given}$) with quantity restrictions for TA $N_{TA} \leq N_{TA\ given}$, specified amount of monitoring data $V_{md} \leq V_{md\ given}$ and network functioning uptime. $T_f \leq T_{f\ given}$ [5 – 6].

Time of data collection T_{gat} (1) depends on the flight route length (determined by the number of

clusters designated as data exchange points with TA), TA flight speed, data exchange speed between nodes and TA (depends on MAC-protocol, the distance between them), etc.

$$T_{gat} = \frac{L_{bm}}{v},$$

$$L_{bm} = f(n_{cl}, (x, y, h)_k, t_{flk}, St_k) \quad (1)$$

where $k = 1 \dots n_{cl}$ – network cluster number; L_{bm} – the length of the TA base flight route between the cluster centers; v, h – speed and altitude, $(x, y, h)_k$ – TA positioning coordinates in the cluster, t_{fk} – k -th cluster flight time, St_k – flying strategy of the k -th cluster (determines the order of flying over individual nodes and finding data collection points in the cluster).

b) Maximize or provide a specified time for WSN operation ($maxT_f$ or $T_f \geq T_{fgiv}$) within a given time limit T_{gat} and the volume of V_{md} collected monitoring data, the amount of TA available for use – N_{giv} .

This target function is achieved by reducing the energy consumption of WSN nodes by the following methods [8 - 10]:

- reducing the distance and therefore the transmission power between the two sensor nodes;
- reducing the time nodes stay in active state or increasing sleep mode;
- reducing the amount of service traffic;
- reduction in computational complexity of network management algorithms;
- redistribution of power consumption between nodes by implementing corresponding network control algorithms - coverage algorithms (dividing into independent coverage nodes and drawing up monitoring schedules by sets), algorithms for building and maintaining topology and data transmission routes in clusters [7], algorithms for selecting the main nodes in a cluster (by using energy-dependent metrics);

- when implementing control algorithms at all layers of the OSI model;

In addition, the reduction of energy consumption by the sensor nodes in the cluster can be achieved at the same effort:

- reducing the monitoring radius of the node or the area monitored by the network;
- creating an excessive number of nodes required to cover a given area (object);
- aggregation of transmitted monitoring data from simple nodes to the main node.

c) Minimization of the number of UAVs ($minN$) required to collect data with a given quality, with restrictions on the time of data collection $T_{gat} \leq T_{gatgiv}$, the amount of monitoring data collected $V_{md} \leq V_{mdgiv}$ and operation time of the network $T_f \leq T_{fgiv}$.

It is achieved by dividing WSN into subnetworks and optimization of data collection process in each subnetwork.

The presence of several target management functions leads to the tasks of multi-criteria optimization. In general, its solution will depend on the requirements to the network management system. In a particular case, a task of multi-criteria optimization can be solved using the following methods: main index, lexicographical, additive or multiplicative convolution, concessions, and others.

3. Selection the method of TA monitoring data collection.

Depending on the network organization (unclustered or clustered), there are two main ways to collect TA monitoring data from sensor nodes: collection from each node of the network and collection from the main nodes of network clusters (Fig. 3) [7, 8]. Each of them has its own management tasks, its own advantages and disadvantages.

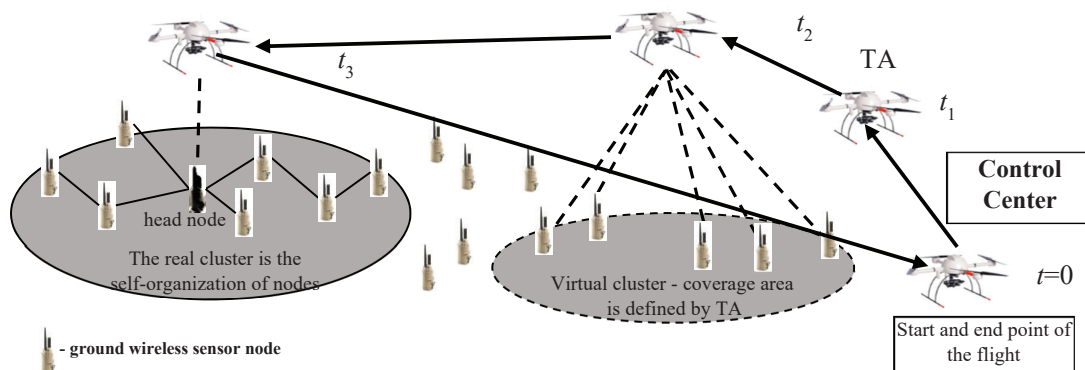


Fig. 3. Illustration of two main methods of data collection

a) *Direct collection of monitoring information from each node of the network by the telecommunication airplatform [7].*

In the simplest case, if there are no optimization tasks, the TA will fly over each node or the entire area of the sensor network. But in this case the time of flight and data collection is significantly increased.

To reduce data collection time, the control center (CC or TA) must calculate the coordinates of data collection points (TA positions in space), which form virtual radio communication clusters covering all nodes of the network. TA flies over the collection points on the calculated trajectory, establishes radio communications with nodes and collects monitoring data. Decision-making on the process of data collection is entrusted to the CC (TA). The node is assigned the functions of establishing radio communication and transfer of monitoring data at the arrival of the TA.

The main advantage of this method is simplicity of algorithms of network nodes functioning during data collection and, accordingly, their cheapness. Disadvantage: high requirements to the TA control system.

In order to minimize (satisfy) the specified time of collection, minimization (or determination of the specified) number of data collection points is performed. This task belongs to the NP-complete class. To solve it, it is proposed to use various heuristic algorithms of clustering. In [5] it is suggested to use the algorithm of mass centers search (places of the largest grouping of nodes). In [7] an algorithm of FOREL (FORMal ELEMENT) cluster analysis with adaptation of the TA coverage area size (R), determined by the TA flight height and radio range, is proposed. Advantages of the FOREL method: its convergence has been proved, it allows

changing the coverage area and obtaining solutions close to the optimal ones.

Another solution [11] to reduce data collection time is to increase the bandwidth of nodes in the cluster due to the ability of channel-level protocols to change the transmission speed depending on the distance between the node and the TA (e.g. 802.11). Therefore, to maximize the throughput between the nodes of the TA and the nodes of its cluster it is proposed to use a mathematical model that allows you to calculate the optimal position of the TA to maximize the throughput of nodes in the cluster depending on their location relative to the TA and the volume of monitoring data. The performed modeling has shown that the total throughput capacity of nodes increased up to 25% depending on the number of nodes in the cluster and their mutual location.

To reduce battery power consumption during the flight of TA, a number of rules for selecting points of TA exchange with the nodes of this cluster are proposed in the clusters at the expense of [9, 10]:

reducing the distance between the nodes and the TA;

flight of TA nodes with critical battery energy at an extremely small distance;

setting the transmission power at the minimum level;

setting the collection points closer to the flight path (Fig. 4a);

cooperative work of some cluster nodes (Fig. 4b). The closest node to the flight path is being searched (node 1 in the figure), which before the TA arrival forms the shortest transmission route (with the metrics transmission power, battery power) from this node to the other nodes, that are further from the TA flight path. In this case, the total transmission power ($R_{3-2} + R_{2-1} + R_{1-TA}$) < ($R_{1-TA} + R_{2-TA} + R_{3-TA}$). However, the cooperative work of the nodes

presupposes implementation of additional algorithms in their control system.

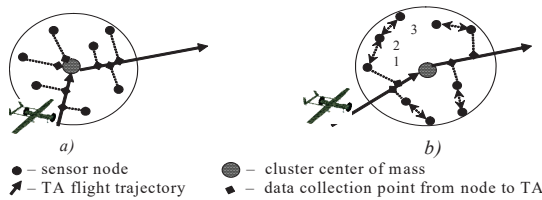


Fig. 4. Illustration of rules to reduce energy consumption when transferring data by cluster nodes to TA

b). *Collecting by TA information in a clustered network* [8] (from the main nodes that store information about monitoring parameters of their network cluster nodes).

Clustering the network is the key to achieving the target control functions of the network. In this way, the network is divided into clusters by a certain algorithm, where the main nodes of clusters are selected [8, 13]. The decision on cluster parameters can be made centrally (CC or TA) or decentralized by network nodes.

The creation of clusters is performed in the self-organization node mode. In each cluster its topology and data transmission routes from monitoring nodes to the main nodes are built. The main nodes collect monitoring data from the nodes of their network cluster to the arrival of the TA. Next, the TA (or network control center) calculates the flight route only to the main nodes, the TA makes the flight and collects monitoring information from them.

There are a number of clustering algorithms (models), aimed at improving the performance of WSN [13]: optimizing the number of clusters, reducing energy consumption of nodes, reducing the delay of data transmission, etc.

The process of building clusters includes the following stages:

a) Calculation of number, size of clusters and rotation period of the main nodes. Optimization of these parameters should ensure implementation of target control functions. Their specific values are determined by the WSN dimension, the area of the monitoring zone, the characteristics of sensor nodes and TA, adopted control algorithms and requirements to the data collection process.

Smaller number of clusters leads to smaller number of main nodes, smaller length of the TA flight route and reduces the time of data collection. However, it increases the diameter of clusters and,

accordingly, increases the time for their organization. In addition, the energy consumption of nodes for service traffic increases, data transmission from simple nodes to the main nodes is carried out on longer routes. To calculate the WSN functioning time, an analytical model has been proposed that considers the nodes energy consumption depending on its functions (monitoring only, monitoring plus routing, monitoring plus the main cluster node) and the monitoring data volume, on the specified network functioning time (or the number of TA data collection rounds) [8].

b) Clusters formation [5, 8, 13]. It is implemented by exchange of service messages between the nodes with the realization of appropriate algorithms for selecting the main nodes of clusters, considering the priority of target network control functions. The algorithm for selecting the main node should include a convolution of metrics: battery energy of the cluster node, signal level in the radio channel node TA, location in the cluster (in the center or on the edges), etc.

c) Construction of cluster topology [14]. It should be performed according to specified target network control functions (e.g., to minimize energy consumption of nodes - construction of energy efficient topology, minimization of transmission time - construction of small diameter topology, etc.).

d) Build and support routes in the cluster from the simple nodes to the main ones by convolution of metrics, which also considers the target management functions transmission power, battery power of nodes, bandwidth and others [15, 16].

The advantages of this method are: reduced flight time and, consequently, reduced time for collecting monitoring information, reduced power consumption of cluster nodes through the use of the main nodes. The disadvantages of this method - it is necessary to synthesize and implement additional algorithms of network management [7, 13]: the network division into clusters, the choice of the main nodes in the clusters and their rotation in the process of functioning, building the topology of the cluster, the organization of the process of building the topology and routes of data transmission from simple nodes to the main nodes, and so on.

Thus, each node in a clustered network must implement an additional set of control algorithms that generate service traffic, i.e. this method requires more powerful processors and significant memory capacity, which significantly increases their cost.

4. Algorithms (models) of exchange between TA and nodes.

Existing protocols (algorithms) of channel level exchange do not consider the specifics of exchange with TA: limited connectivity time due to movement, the possibility of changing the position of TA in space relative to the nodes of the cluster.

Therefore, it is necessary to develop new or modify the existing algorithms of data exchange.

The [12] presents models of transfers between nodes and TA when moving (positioning).

a. The model of ensuring all data amount transmission between the node and the TA.

To ensure that the TA collects the entire volume of data from each node of the cluster is proposed to adapt the speed and altitude of the TA flight based on the required time of radio communication to transmit a given amount of monitoring data. I.e. the TA flight time over the j -th node of T_{prj} should be longer than the transmission time of the given node $T_{prj} \geq T_{prj} = S_{dm} / (s(d, MAC_Protocol))$. The transmission time of the j -th node is determined by the volume of transmitted monitoring data and the transmission speed, which depends on the distance d between the node and the TA and the channel-level MAC protocol used.

b. The model of data exchange between TA and cluster nodes without quality of service [12].

To increase the probability of data transmission, it is proposed to set a priority in the service of nodes located at a distance from the TA. For example, controlling the sequence of nodes access to the channel using the protocol IEEE 802.11 DCF is performed by dynamically changing the competition window $cw_{min} < cw < cw_{max}$; ($cw_{min} = 32$, $cw_{max} = 1024$). After the node is busy, it waits for the DIFS period and enters the competition period. The delay time (*backoff_interval*) is chosen within the competition window, measured by slots and determined by the expression $t_{bf} = rand[0, 2^r cw_{min}] \times t_r$, $0 \leq r \leq m$, where t_r is the duration of the competition window slot, $rand$ - a random number, which is equally selected in the range $[0, cw_{min} \times 2r]$, $[x]$ - the largest integer, which is less or equal to x , r and m - gear priority, $0 \leq r \leq m$, $r = f(R)$, R - the distance between the node and TA.

5. Building the trajectory of data collection points flight.

Calculation of TA flight trajectory is performed in two stages. At the first stage, the CC calculates the

basic flight path between the centers (main nodes) of clusters at the same altitude (actually, the task of finding the shortest route). In the second stage, the basic flight trajectory in clusters is corrected in accordance with the adopted rules for selecting data exchange points to achieve certain target functions. Many researches have been devoted to the criteria for selecting nodes in a cluster to ensure the exchange with TA, directed to the achievement of certain target functions [7, 10]. For example: to find the nearest nodes to shorten the route of TA movement; to establish a minimum range communication with nodes that have minimal battery energy; to select nodes in the "center of mass" of the cluster, etc.

Reduction of the flight path length decreases the time of data collection and TA energy consumption, but increased the energy consumption of nodes due to the increased distance in the radio channel node-TA.

The flight height of the TA determines the distance between the TA and nodes, i.e. the size of the virtual radioconnectivity cluster between the TA and nodes. Increasing altitude leads to an increase in: fuel consumption (energy) of the TA; energy consumption of the nodes for the transmission process due to increasing distance; reduction of the coverage area and the number of nodes with radio communication with the TA. And vice versa. Therefore, the flight altitude should be optimized considering the target network control functions and limitations on its resources, the quality of exchange requirements [7, 8]. Besides, ground nodes can be in a radiocommunication zone with TA only for a limited time, therefore it is necessary to have time to transmit TA monitoring data from many nodes located in a radiocommunication zone. The exchange depends on the transmission speed, the number of information sources and the channel level protocol accepted.

In works [1 - 8] the task of searching the flight route is defined as the task of a salesman - to find the shortest route of TA movement when visiting the given set of data collection points. The task belongs to the NP-complete class. The number of algorithm iterations increases significantly when the network dimension increases. There are a lot of algorithms (methods) to solve it: full search, linear integer programming, branches and boundaries, greedy heuristic, genetic, etc., which are known to be the best way to solve the problem.

The choice of a particular route search algorithm will be determined by the WSN dimension and computational limits of the CC (TA).

6. TA flight model.

The main flight models are:

- a. The basic simplest model. Flight with the same constant speed in a cluster and between clusters.
 - b. Flight of TA with the same constant speed sufficient for cluster maintenance and with increased speed between clusters.
 - c. Flight with adaptive speed in clusters.
 - d. Flight with guaranteed service of cluster nodes
- Flight with adaptive speed in clusters.

Modelling of developed data collection algorithms (models) [7, 8] for networks of 100, 200 and 300 nodes is shown. The results of simulation modeling showed that the use of synthesized methods allows: reducing the time of data collection by 15-20%; increasing the time of network operation by 10-15%; reducing to 15% the required number of telecommunications airplatforms.

4. CONCLUSION

The article describes the stages of synthesis of methods to control the process of collecting monitoring data from the nodes of the WSN using TA, which allows implementing various network control functions: minimizing network life time, reducing data collection time, minimizing the number of TA. Using specific clustering algorithms, data collection methods, cluster flyover strategies, data exchange models will be determined by the characteristics of the network, network nodes and TA, as well as the requirements to the quality of data collection. The proposed approaches can be used in a special software system of data collection management in the WSN using the TA.

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Синтез методів збору даних телекомунікаційними аероплатформами у безпроводових сенсорних мережах

Проблематика. Безпроводові сенсорні мережі із використанням телекомунікаційних аероплатформ відносяться до класу складних, багатофункціональних, динамічних систем. Для підвищення їх технічної ефективності необхідно розробити методи керування, які б дозволили збільшити час функціонування сенсорної мережі, зменшити час збору даних, зменшити витрати ресурсів. Важливою складовою частиною такої безпроводової сенсорної мережі є система керування збором даних моніторингу. Під час керування системою збору даних моніторингу із використанням телекомунікаційних аероплатформ виникають наукові задачі: відшукування мінімальної кількості вузлів збору даних; побудови оптимального маршруту збору даних із підтримкою необхідної якості їх передавання. Зараз відсутні ефективні методи розв’язання цих наукових задач. Тому саме синтезу методів розв’язання наукових задач керування збором даних і присвячена ця стаття.

Мета досліджень. Розробка і вдосконалення методів збору даних з вузлів безпроводової сенсорної мережі із використанням телекомунікаційних аероплатформ.

Методика реалізації. Проаналізовані задачі керування безпроводовими сенсорними мережами із телекомунікаційними аероплатформами. Синтезовані методи та алгоритми моніторингу. Побудовані математичні моделі: кластеризації безпроводових сенсорних мереж; оцінки енерговитрат вузлів мережі; часу збору даних; якості збору і передачі даних моніторингу. Удосконалено методи пошуку положення та керування рухом телекомунікаційних аероплатформ. Виконана оцінка ефективності запропонованих методів.

Результати досліджень. Результати імітаційного моделювання показали, що використання синтезованих методів дозволяє: зменшити час збору інформації на 15-20 %; збільшити час функціонування мережі на 10-15 %; зменшити необхідну кількість аероплатформ на 10%.

Висновки. Синтезовані методи дозволяють: визначити положення та траєкторію руху телекомунікаційної аероплатформи при оптимізації різних цільових функцій; виконати керування системою збору даних у реальному часі; підвищити ефективність алгоритмічного забезпечення системи керування функціонуванням безпроводової сенсорної мережі.

Ключові слова: безпроводова сенсорна мережа; кластеризація; телекомунікаційна аероплатформа; збір даних моніторингу.

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Проблематика. Беспроводные сенсорные сети с использованием телекоммуникационных аэроплатформ, относятся к классу сложных, многофункциональных, динамических систем. Для повышения технической эффективности этих беспроводных сетей необходимо разработать методы увеличения времени функционирования сетей, уменьшения времени сбора данных, минимизации расходуемых ресурсов. Составной частью беспроводной сенсорной сети является подсистема управления сбором данных с узлов с использованием телекоммуникационных аэроплатформ. При управлении процессом сбора данных возникают научные задачи: нахождения минимального количества точек (узлов) сбора данных, построения кратчайших маршрутов облета этих точек, определений стратегий облета, обеспечения качества обмена данными, увеличения времени функционирования сети. В настоящее время отсутствуют эффективные методы и алгоритмы для решения этих научных задач. Синтезу методов, которые решают данные задачи посвящена данная статья.

Цель исследований. Разработка и совершенствование методов сбора данных с узлов беспроводных сенсорных сетей с управлением перемещением и позиционированием телекоммуникационных аэроплатформ.

Методика реализации. Проанализированы задачи управления беспроводными сенсорными сетями с телекоммуникационными аэроплатформами. Синтезированы методы и алгоритмы сбора данных мониторинга телекоммуникационными аэроплатформами. Предложены математические модели: кластеризации беспроводных

сенсорных сетей; оценки энергозатрат затрат узлов; времени сбора данных; качества сбора и передачи данных мониторинга. Усовершенствованы алгоритмы поиска положения и перемещения телекоммуникационных аэроплатформ для достижения заданных целей управления при сборе данных мониторинга. Оценена эффективность предложенных методов сбора данных мониторинга.

Результаты исследований. Результаты имитационного моделирования показали, что использование синтезированных методов позволяет: уменьшает время сбора данных на 15-20%; увеличить время функционирования сети на 10-15%; уменьшить на 15% необходимое количество телекоммуникационных аэроплатформ.

Выводы. Синтезированные методы позволяют: определять положение и траекторию движения телекоммуникационных аэроплатформ при оптимизации различных целевых функций; осуществлять управление в режиме реального времени; оперативно планировать траекторию перемещения телекоммуникационных аэроплатформ; повысить эффективность алгоритмического и математического обеспечения системы управления сетью.

Ключевые слова: беспроводные сенсорные сети; кластеризация; сбор данных мониторинга с БПЛА; эффективность.