DOI: https://doi.org/10.36910/6775-2524-0560-2023-50-19
UDC 621.396
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OBJECTIVE CONTROL FUNCTIONS OF FANET COMMUNICATION NODES OF LAND-AIR NETWORK

Romaniuk V., Bieliakov R. Objective control functions of FANET communication nodes of land-air network. The analysis and classification of the tasks of managing communication aerial platforms belonging to the FANET class was carried out. Possible control objects and main optimization parameters in air communication networks according to the levels of the OSI reference model are given. A set of target functions of the management of communication air networks is defined, their relationship and the order of use by the network management system when making decisions on the management of node and network resources are determined.
Keywords: objective function, wireless sensor network, monitoring, control system.

Романюк В. А., Бєляков Р. О. Цільові функції управління комунікаційними вузлами FANET наземно-повітряної мережі. Проведено аналіз та класифікацію задач управління комунікаційними аероплатформами, що відносяться до класу FANET. Наведено можливі об'єкти управління та основні параметри оптимізації в повітряних комунікаційних мережах за рівнями еталонної моделі OSI. Визначено множину цільових функцій управління комунікаційними повітряними мережами, визначено їх взаємозв'язок та порядок використання системою управління мережею при прийнятті рішень з управління вузловими та мережевими ресурсами.
Ключові слова: цільова функція, комунікаційна аероплатформа, комунікаційна повітряна мережа, система управління.

Actuality.

FANET (Flying Ad Hoc Network) is a special type of peer-to-peer self-organized network based on unmanned aerial vehicles (UAV) [1]. These networks provide a wide range of tasks for both civil and special applications.

The organization of communication of this type is necessary for the performance of tasks of observation, monitoring, reservation of terrestrial communication networks, etc.

The aerial network consists of a certain number of communication aerial platforms (CAP), which can be located in defined geographical areas to provide wireless sensor network data collection, coverage of the fixed and mobile components of terrestrial communication networks.

Thus, information received by a subscriber of a MANET (VANET) type network is transmitted to special gateways directly or by relaying through intermediate nodes. With different remoteness of subscribers, or if the remoteness of subscribers or the monitoring area is very large, communication aerial platforms can be used as gateways as relay nodes [2].

In the conditions of densely populated cities, different speeds of movement of subscribers, different types of traffic between them, the task of implementing optimal network management solutions can be significantly complicated. The influence of the listed limitations becomes critical, especially in the conditions of conducting modern wars, or during the conduct of active combat operations in the tactical chain of command of troops, which are characterized by various stochastic features - high speeds, uneven acceleration, the trajectory of the movement of combat vehicles, personnel with available means of communication connection, different characteristics of the surrounding environment, different technical capabilities of end devices, etc.

Setting a scientific task.

Under such conditions, a possible way out of the situation is the use of CAPs built according to the Ad-Hoc or MANET (Mobile Ad-Hoc) principle [2], which allows creating a radio network capable of self-organization and adaptation of nodes to operating conditions that cannot be predicted during the design process. Such CAPs, integrated into FANET type air communication network, will function in automatic or semi-automatic mode, and, by their very nature, will act as a connecting link of land-air networks (LAN).

For this, each network node must have a control system (CS) capable of making decisions based on a decentralized principle in order to ensure the specified quality of traffic service that will be transmitted to the LAN [3].

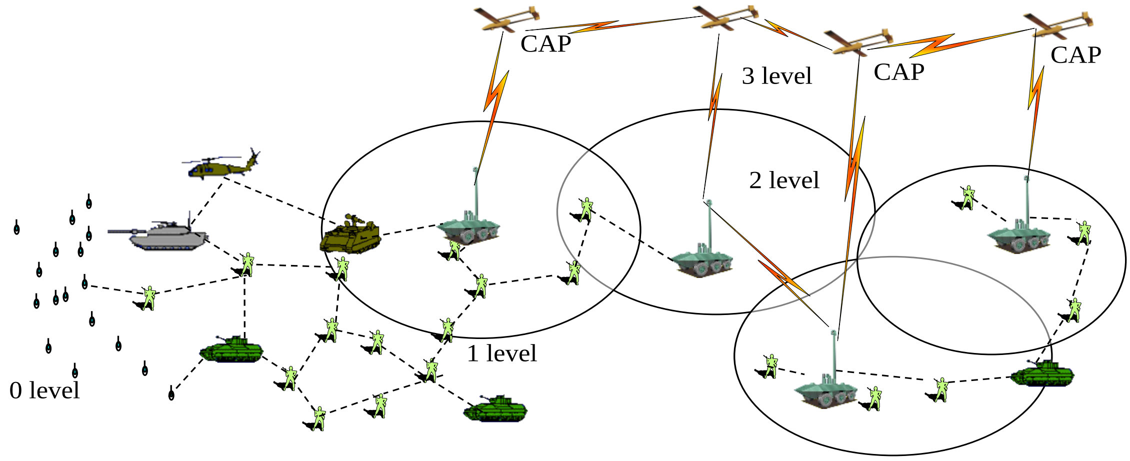

Figure 1. Prospective architecture of a mobile land-air network

The control process in node-type networks is implemented by collecting and analyzing information about the state of the network, after which a control decision is made based on the target control functions depending on the quality requirements and the type of traffic.

It should be noted that the parameters of the nodes of the land component and air nodes are heterogeneous, which complicates the process of selecting target functions, taking into account the target functions of neighboring nodes and the target function of managing the entire LAN (or its zone or level).

In this regard, *the scientific task*, which is solved in this article, consists in determining the set of target functions of the control of the FANET-class CAP, conducting their classification, determining the relationship, features and order of their use by the network management system.

Research analysis.

In the course of previous studies, approaches to the optimization of MANET class radio networks according to one or several indicators were proposed [4-7]. In particular, in [4] it is proposed to manage the energy consumption of batteries, in [5] - to perform multi-criteria optimization of the route taking into account its mobility, in [6] - to optimize the network topology according to several indicators, in [7] - to take into account the type of traffic, etc. However, the unpredictability of the operating conditions of radio networks of the MANET class leads to the need to interpret the fact that the target control functions are not static, but are determined in time depending on the stages and control functions, as well as the state parameters of the control object (objects) (node, radio channel, route, zone, network) and available resources [8].

The purpose of the article is to determine the target functions of managing FANET communication nodes of land-air networks, to determine directions, approaches and methods of their use in the conditions of conducting modern hostilities and performing other special tasks of monitoring and ensuring information exchange.

Presenting main material.

In the general case, the following management tasks exist for the FANET-class spacecraft (Fig. 2):

are implemented at the planning stage (clarification of tasks - aerial reconnaissance, use of spacecraft as mobile sensor nodes, repeaters), study of application conditions, selection of UAV type; deployment (identification of areas/routes, provision of tethering, determination of flight tasks); operational management (support of flight tasks, support of communication tasks by a group of spacecraft or autonomously), i.e. at various stages of LAN management;

provide various functions: changing the trajectory, speed, acceleration of a single UAV or as part of groups, mobile nodes of the land network; determination of target coordinates, UAV energy resource management, etc.); coverage of the monitoring or communication zone (definition of the "responsibility zones" of the CAP, the priority group of subscribers of the land component, the sequence of work, etc.); ensuring the quality of data transmission (routing management, topology management, load management, etc.);

applied to various objects (the entire LAN, a separate area of the land component, the spacecraft network, the direction of information transmission, the route, the radio channel of the spacecraft-land component node), which requires coordination and coordination of target functions;

definition of target functions that may contradict each other;

statements of target functions (mathematical apparatus of clear or fuzzy logic, representation of processes as mass service tasks, methods of describing different types of routing, etc.);

implementation in conditions of high dimensionality of the network and the dynamic nature of its topology change;

formation of a complete interrelated group of indicators for assessing the effectiveness of LAN functioning;

collection of control information about the state of LAN nodes and its elements.

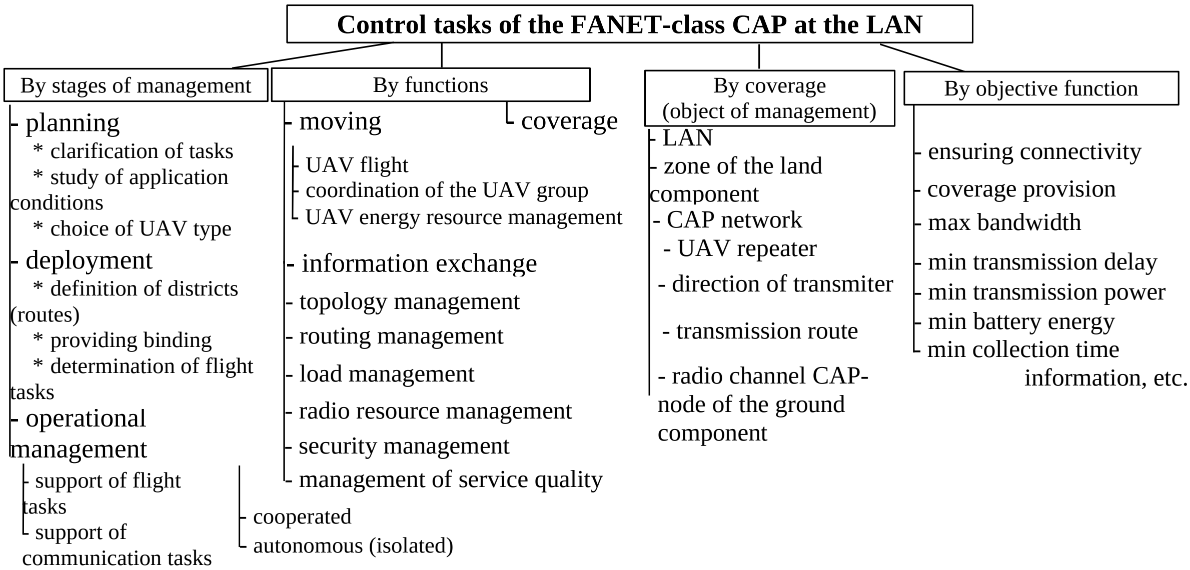

Figure 2. Classification of FANET management tasks with CAP as part of LAN

In modern LANs, management functions are partially performed centrally (by control centers), regardless of the trend of decentralization and self-organization networks (that is, part of the functions are performed by LAN nodes). Therefore, conditionally, management functions can be divided into groups: network (zone) and user goals. Thus, for the first group, it is necessary to achieve optimization of efficiency indicators, for the second, the appropriate quality of information exchange between LAN nodes.

Network (zonal) management goals include the following optimal parameters $C=\{c_j\}, j=\overline{1,J}$: productivity of the entire LAN or its zone; transmission power of network nodes or its zone; degree of coverage of the monitoring and communication zone by communication aerial platforms (mobile or stationary nodes of the land component); structural reliability (connectivity) of LAN and its zones; the number of resources (stationary and mobile nodes, aerial platforms, etc.) that must be used to achieve a certain goal; time of operation of the air network on the spacecraft; the volume of service traffic, which is generated to collect information about the state of the nodes of the land component; time of planning, deployment, restoration of the network on the spacecraft; security settings.

The main limitations are the resources and parameters of the spacecraft: power batteries, bandwidth of radio channels, range of radio communication, memory volumes, speed of information processing by processors, class of used antenna devices (directed/non-directed), etc.

The second group of management goals includes:

optimization of the bandwidth of the LAN node;

message transmission delay time depending on the type of information – $\xi = \overline{1,3}$, where 1 – video, 2 – voice, 3 – data;

transmission power;

specific energy consumption per bit of information;

management of the area of the monitoring/communication area;

network topology adaptation time when reducing the number of CAPs, etc.

The scheme of determining target functions by the nodal control system. In the table 1 shows the possible control objects and the main optimization parameters. As mentioned above, the unpredictability of the operating conditions of the NPM, the decentralized principle of their management and the availability of various types of information for transmission (video, speech, data) determine the requirements for the control system of each node and the selection of target control functions, taking into account the following factors:

1. The state of the node itself, which is directly determined by a set of its parameters (real bandwidth of radio channels, range of radio connectivity, available neighbors, status of queues, presence, type and magnitude of change in input load, mobility, dynamics of changes in existing connections with neighbors, presence, number and quality of constructed routes, etc.).

Table 1. Management objects and main parameters of LAN optimization

OSI	**Controlling influence of the node**	**Management objects**	**Basic parameters of optimization**
Physical layer	Transmission power (direction), type of modulation, type of correction code, MIMO parameters, etc	Radio channel: CAP-CAP, land node-land node, land node-CAP	Bandwidth, battery power consumption, transmission power, etc
Data Link layer	MAC algorithms and their parameters, sizes of packets and receipts, etc	Radio channels within the radio connectivity of the zone	Bandwidth and transmission time in the channel, battery energy consumption, amount of service information, etc
Network layer	Routing algorithms, queue management algorithms, load management algorithms, topology management algorithms	One or more transmission routes (network area or entire network, respectively), topology, queues, etc	Scope of service information, route parameters (time of construction and existence, quantity, throughput, delivery time, battery energy consumption, etc.), topology
Transport layer	Transport layer exchange algorithms	Communication direction	Data transmission quality parameters in the direction
Application layer	Algorithms (protocols) of application-level information exchange, coordination and intellectualization according to OSI - layers, network zones, the entire network	Node, neighbor nodes, network zone, entire network	Bandwidth, battery power consumption, transmission security, task completion time, etc

2. Node resources are hardware (potential bandwidth of the radio channel, available amount of power battery energy, processor speed, transmitter power, etc.), software resources (control algorithms, control protocols at various OSI levels and functional subsystems, level of intellectualization of control processes, etc.).

3. Each node constantly (actively and/or passively) collects information about the state of: neighboring nodes, routes and directions of transmission, network (zone) and determines (identifies) its state based on a set of indicators [4, 9].

4. The state of the network (determined by the state of nodes, channels, directions, zones and the entire network, availability of resources) and the dynamics of its change.

5. The type of information (traffic), which determines the requirements for transmission quality (transmission time and jitter, number of errors, etc.).

The generalized algorithm for determining target functions by the control system of each node consists of three stages (Fig. 3).

The node constantly analyzes its state and performs its identification.

1. The node constantly collects information about the state of the network and identifies the state of the network (its zone). In the conditions of the impossibility of collecting all information about the state of the network and its rapid aging of the system (that is, incomplete information about the state of networks), it is suggested to use the apparatus of fuzzy logic for the implementation of the identification process [2].

2. The node's decision-making system based on the identified states of the node, the network and

requirements for the quality of information exchange regarding the information that the node has for transmission (Fig. 3):

- defines the current set of optimization parameters - network and user;
- defines management objects (Table 1);
- defines the current target function (functions) of C_{opti} management;
- coordinates it with neighboring nodes (if nodes are of the same rank) or imposes it on subordinate nodes (if it is a network control center);
- selects the controlling influence by stages, coverage, functional subsystem, OSI level.

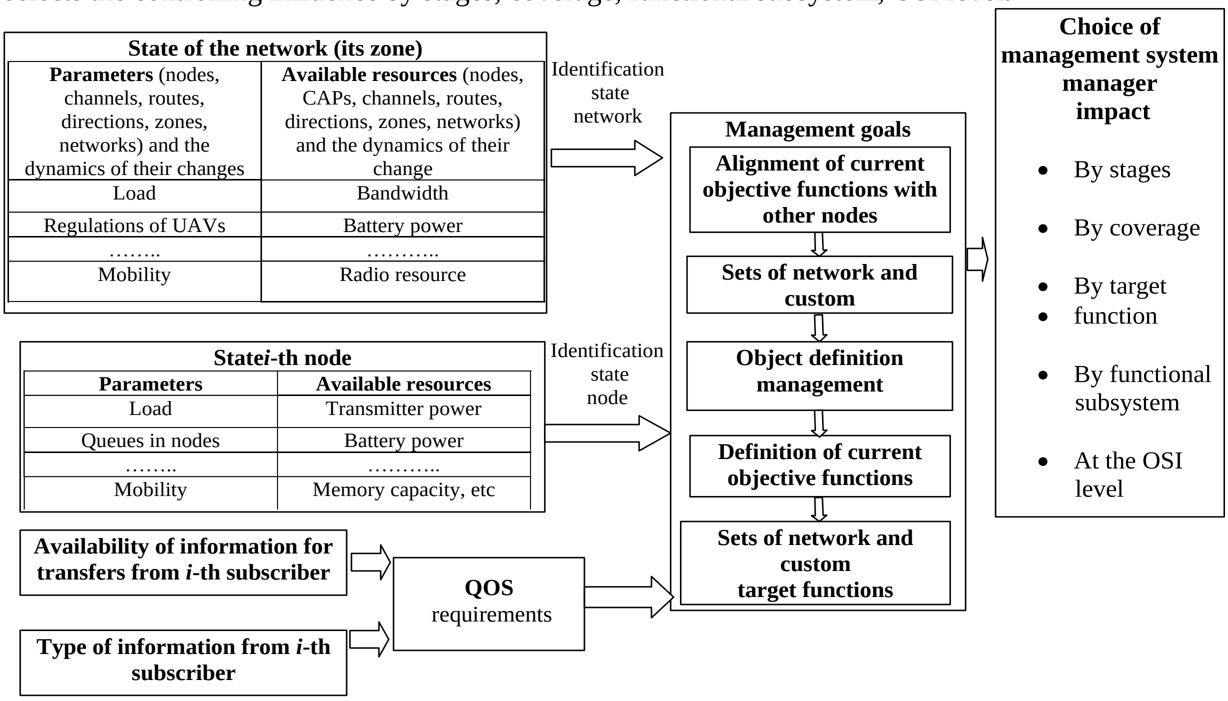

Figure 3. Scheme of determining target functions by the nodal control system

In [2], the interdependence of the goals, as well as their hierarchical nature, the decomposition of the global goal of network management into functions, each of which is divided into tasks and implemented at the OSI levels, is carried out. The goal is to obtain the priority vector of the elements of the lower level of the hierarchy in relation to the goal - the element of the first level using the method of analysis of hierarchies or the method of convolution of fuzzy relations.

Target structure (TS) of LAN management:

$$TS \to H = \{C_1, R_{1m_{(1)}}\{C_{21}, C_{22}, \ldots, C_{2m_{(2)}}\}, R_{2m_{(2)}}\{C_{31}, C_{32}, \ldots, C_{3m_{(3)}}\}, \ldots, R_{km_{(k)}}\{C_{k1}, C_{k2}, \ldots, C_{km_{(k)}}\}\},$$

where C_1 – main control target, $C_{im_{(i)}}$ – $m_{(i)}$-th subtarget i-th level in TS, $i = 1\ldots k$, R – set of relations on a subgoal structure. The proposed construction of the hierarchy of the process of choosing alternatives and the comparison of decisions at each level of the hierarchy based on the normalization of the received evaluations of the alternatives (using the weighting procedure of the method of analysis of hierarchies or the method of convolution of fuzzy relations).

Conclusions and prospects for further research.

As a result of the research, it was established that the task of making a decision on network management (choice of management methods) is reduced to the task of hierarchical targeted dynamic evaluation of alternatives with unclear initial data.

Thus, the classification of the target functions of managing tactical radio networks with communication aerial platforms has been carried out. A new approach to the formation of management objective functions in these radio networks is proposed: each node determines the current objective function in time depending on the type of traffic, the situation on the network and the available network resources. The task of making a decision regarding the choice of the target function of radio network management is reduced to a hierarchical target evaluation of alternatives.

Given the incompleteness and inaccuracy of information about the state of the land-air communication network, the complex use of fuzzy logic apparatus and neural networks is proposed for the implementation of the presented scheme of formation of target control functions. In the course of further research, methods of coordinating the target functions of LAN nodes will be developed.

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