Objective control functions of mobile ad-hoc networks using unmanned aerial vehicles

A. Lisenko
National Technical University of Ukraine
"Kyiv Polytechnic Institute"
Kyiv, Ukraine
lysenko.a.i.1952@gmail.com

A. Romanyuk
Central Research Institute of the armed forces of Ukraine
Kyiv, Ukraine
anton.romaniuk@gmail.com

S. Danylyuk
Central Research Institute of the armed forces of Ukraine
Kyiv, Ukraine
lysenko.a.i.1952@gmail.com

V. Romanyuk
Military Institute of Telecommunications and Information
Kyiv, Ukraine
rom-v-a@yandex.ua

***Abstract* – a new approach to the selection of objective control functions of MANET using UAV, based on the current control functions formation, depending on the traffic type, current situation in the network and available network resources. Decision management task reduced to hierarchical evaluation of alternatives.**

Keywords – wireless sensor networks; unmanned aerial vehicles; control systems.

I. INTRODUCTION

Today unmanned aerial vehicles (UAV) are finding applicationas telecommunication aerial platform (TA) in terrestrial mobile ad-hoc networks(MANET)both civilian and military purposes [1]. For example, TA can be used to establish a communication with geographically removed subscribers or improve the quality of their service. Using TA during flight over sensor networks allows collecting information of themonitoring: about the chemical contaminated radioactive areas,about enemy targetsetc.

The main features of these networks functioning include: dynamic topology, the collective use of radio resources, instability and the presence of mutual radio interference, limitations and heterogeneity of nodes, limited safety through the broadcast nature of radio and others.

All MANET nodes (sensors, mobile nodes, mobile base stations, TA) must quickly adapt to the frequent changes in network topology, traffic, and use of limited network resources effectively. In such conditions, to ensure information exchange with desired quality is impossible without an effective network control system (CS) [2].

II. PROBLEM STATEMENT

It is necessary to define objective control functions set in different MANET with UAVs, do their classification, and define the interconnection, features and the use of MANET control system.

Previously approaches proposed to optimize networks by one or more indicators [3 - 6]. So in [3] proposed to control the batteries power consumption, in [4] proposed multicriterial route optimization with regard to nodes mobility, in [5] proposed the network topology optimizationusing several indicators, in [6] to take into account the traffic typesetc.

A new approach – on the phase of management the objective functions are not static, but are determined over time depending on the phases and management functions and parameters of the object (objects) control (node, channel, route area network) and available resources.

Define the tasks of network control features (Fig. 1):

they are implemented at different phases of network management (planning, deployment or recovery, operational conduct)

they have separate functions: UAV moving, coverage, data transfer can be implemented by different functional subsystems – routing management, topology management, etc.);

different receptors (the whole network, thenetwork area, direction, route, channel, mobile node UAVs);

different mathematical formulation (clear or fuzzy, queuing task, route, etc.);

have high dimension and dynamic character;

difficulty of complete efficiency indicatorsforming;

incomplete and unreliable control information about the network status;

possiblecontradictions;

require coordination (in the nodes, routes, zones throughout the network);

can be implemented at different OSI levels;

most of them depend on each other.

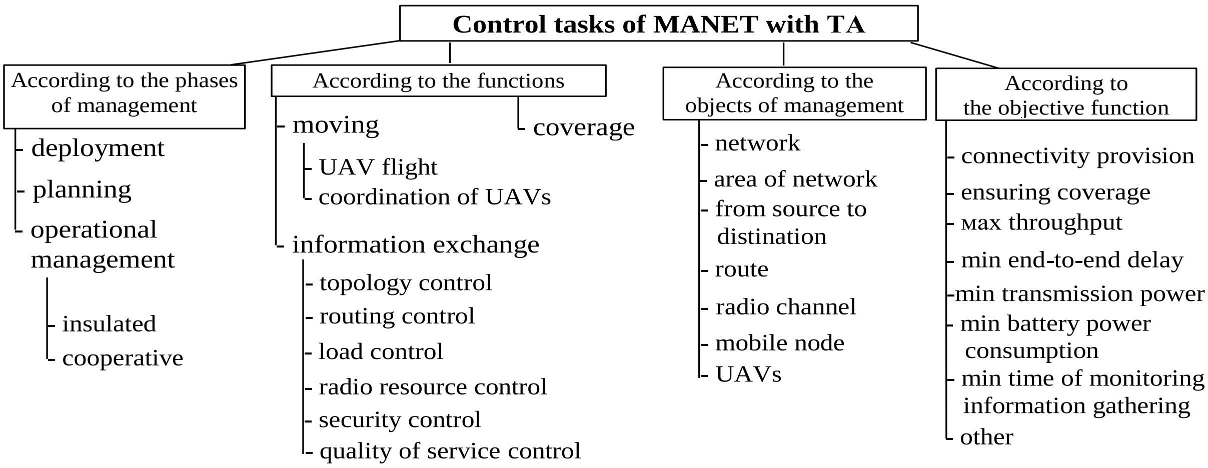

Fig. 1. Classification of tasks MANET control of UAVs

When the network management is mixed (part of functions performed by network control center and the other decentralized – by nodes it is possible to define two groups of interrelated objectives:

network (zonal) – optimization of network or zone communication performance indicators;

user – to achieve a preset transmission quality and operation of the network elements according to necessary direction.

The network (zonal) control objectives include these optimum parameters $C_i = \{C_1, C_2, ..., C_n\}$:

C_1–provide an information exchange with given quality in the mobile network;

C_2 – throughput of the entire network or network zone;

C_3 – transmission power of network nodes, its zone;

C_4 – degree of coverage zone(subscribers, sensors) by network UAVs;

C_5 – structural network reliability (connectivity), its zone;

C_6 – amount of hardware resources (aero platforms);

C_7– the time of operation of the network, its zone UAVs;

C_7 –planning, deployment, recovery network, its zone;

C_8–the volume overheadand so on.

The main constraints are the resources and nodes parameters: batteries, radio bandwidth, range of radio communication, memory, speed of information processing, the parameters of the UAVs and others.

The basic user objectives$C_i$include optimum (limitation) the following parameters(channels, routes from source to destination): throughput,end-to-end delay, transmitter power, batteries energy (energy expenditure) etc.

In the Table 1 shows the possible management objects and main parameters of optimization.

TABLE 1. OBJECT OF INFLUENCEAND ITS COVERAGE

OSI Levels	Management objects	The main parameters of optimization –$C(t)$	Nodal control impacts –$U(t)$
Physical	Radio channels: UAV-UAV, ground node-ground node, ground node-UAV	Throughput, transmission time, battery power consumption, power transmission etc.	Transmission power, antenna beamforming,modulation type, the type of correction code, MIMO parameters, etc.
Date link	Radio channels within radio connectivity	The capacity and the transmission in the channel, battery power consumption, the volume of overheard, etc.	MAC-algorithms, packet sizes and acknowledge, etc.
Network	One or more routes of transmission, topology, flow	The volume of overheard, route options and metrics(time of construction and existence, throughput, end-to-end delay, battery power consumption, etc.).	Routing algorithms, control overhead, topology controlalgorithms
Transport	End-to-end communication	Throughput, timing and variation	Flow control,algorithms of transport layer
Application	Node, neighboring nodes, network zone, the whole network	Throughput, transmission time and its variation, the costs of battery power, transmission safety, time of task implementation, etc.	Algorithms (protocols) transmission, intellectualization and coordination by the OSIlevels, network (zones of the network)

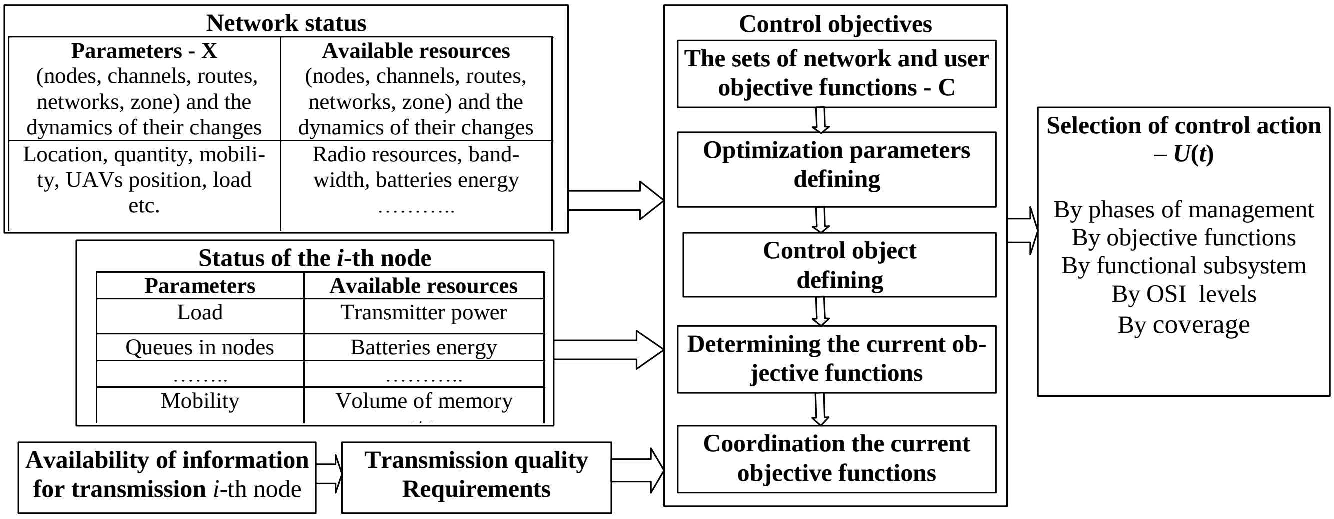

Fig. 2. Scheme of identifying main functions by control system

Availability of necessary information for the transfer requires node to choose main objectives (objective control functions) control that must consider (Fig. 2):

network status (it defined according to channels status, lines, areas and whole network, availability of resources and the dynamics of their changes);

traffictype, which defines requirements for the transmission quality (transmission time and jitter, errors, etc.).

State of node can be described by the following parameters $X(t)$: load, the queue size, neighborsavailability, mobility, available the necessary transmission routes and more. Resources of the nodes are: hardware unit (battery energy, processors speed, transmitter power, etc.), algorithmic or software resources (algorithms or plural control protocols at different levels OSI and functional subsystems), radio resources and more. Each node collects information about the network status and according to aggregate indicators it can determine its status [7].

In general, consideringTable 1, theobjective functioncan be representedas the relationshipof the input variablessetthat describe thestate of thenode andnetwork,and outputvariablesincluding aplurality ofcontrol impactsat each levelof the OSI model:

$$U^*(t) = \arg \underset{U(t)\in\Omega}{opt}\ C_i(X(t), U(t)),$$

$U^*(t)$ – optimalmanagementdecisionsonlevelsoftheOSImodel; Ω – restrictionsonnetworkandnodalresources(transmissionpower;throughput; batteries capacity;transmission delay;the number of nodes, etc.).

A large number ofmanagement tasksat each levelof the OSI model leads to the inability to achieve global optimization of the entire mobile network in the case of decentralized management environment and with presence of contradiction between the optimal node CC awareness and the timeliness of control influences. Thereby, it was proposed in [7] to decompose the main goal of mobile network management to multiple simpler goals. To achieve this, in the design phase of node CS a goal structure (GS) is formed as a graph, where the vertices are goals, and edges are the influences of achieving a goal in a subgoal (Fig. 3).

In the previous research it was shown, that in an uncertain environment, where a MANETs function, to describe a situation and make a management decision by the subsystems of nodal CS it is advisable to use the methods of fuzzy logic [2]. Therefore, the goal structure (Fig. 3) can be mathematically interpreted as a list of fuzzy management objectives of different levels $L_1, ..., L_k$, that are connected by:

$$\begin{aligned}\mathrm{GS} = \{&C_1, R_{2m_{(1)}}\{C_{21}, C_{22}, ..., C_{2m_{(2)}}\},\\ &R_{3m_{(2)}}\{C_{31}, C_{32}, ..., C_{3m_{(3)}}\}, ...,\\ &R_{km_{(k)}}\{C_{k1}, C_{k2}, ..., C_{km_{(k)}}\}\},\end{aligned} \tag{1}$$

whereC_1 – global goal of the network CS, that is determined by the master node; C_{il}, $i = \overline{1,k}$, $l = \overline{1, m_{(i)}}$ – l-th subgoal of i-th level of the goal structure, that is determined by the metaagent of the corresponding node CS; R_{ij}, $i = \overline{1,k}$, $j = \overline{1, m_{(i-1)}}$ – fuzzy relationship between the lax advantage of the objects on the i-th level over every object at the upper i-1 level.

If R_{ij} describes the relationship only between the subgoals of neighboring levels, we should talk about a goal tree, otherwise the goal structure degenerates to a network.

Let the goal system consist of k levels and every L_i level $i = \overline{1,k}$ consists of m_i objects (for first level $m_1 = 1$):

$$L_i = \{C_{i1}, C_{i2}, ..., C_{im_{(i)}}\}.$$

Goal structure (Fig. 3) can be described as a multiple of levels L_i:

$$\text{GS} = \bigcup_{i=1}^{k} L_i = \bigcup_{i=1}^{k}\bigcup_{l=1}^{m_i} C_{il} \ .$$

As seen on Fig. 3, different elements of the goal structure are united under a global goal C_1, that can be described as a information exchange quality of service in the network. As mentioned before, a binary fuzzy relationship of a lax advantage R_{ij} is used to describe the relationship between global goal and lower level goals, that is given by a membership function $\mu_{R_{ij}}(C_{il}, C_{ir})$, $i = \overline{2,k}$, $j = \overline{1, m_{(i-1)}}$, $l, r = \overline{1, m_i}$.

It should be noted, that depending on the hierarchy layer (Fig. 3) there can be two types of relationship:

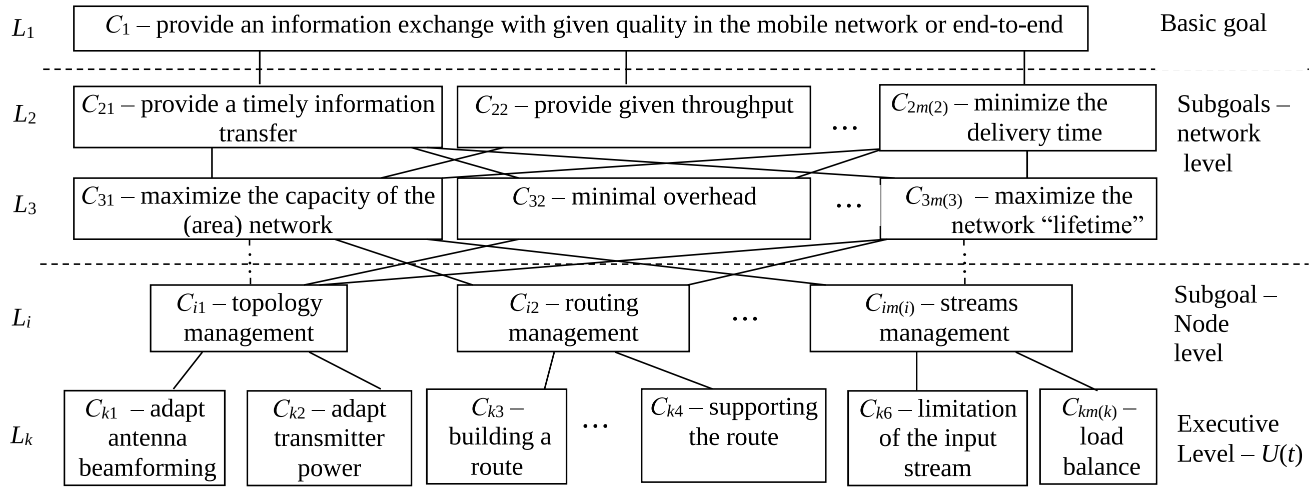

Fig. 3. Fragment of the goal structure of the network CS

„goal – subgoal” relationship – appear between the elements of the network and node layers (between master node and subordinate nodes of a mobile network or its area) and create a goalforming part of the GS;

„subgoal – means to reach the goal” relationship – appear between elements of the node layer (master node CS) and the elements of the executive layer (corresponding functional subsystems) and create an implementing part of the GS.

And so, beginning with the second hierarchy layer (1), at every i-th layer there are as many fuzzy relationship of advantage R_{ij} as there are objects at i–1 level of GS. In the general case, these relationships can be described as a matrix:

$$R_{ij} = \begin{vmatrix} 1 & \mu(C_{i1}, C_{i2}) \ \dots & \mu(C_{i1}, C_{im_{(i)}}) \\ \dots & 1 & \dots \\ \mu(C_{im_{(i)}}, C_{il}) & \dots & 1 \end{vmatrix},$$

where $\mu_{R_{ij}}(C_{il}, C_{ir}) \in [0;1]$, $i = \overline{2,k}$, $j = \overline{1, m_{(i-1)}}$, $l, r = \overline{1, m_i}$.

As a result, tasks of decision making of the network CS are reduced to receiving of the priority vector of the lower layer elements in relationship to the global goal – the element of the first layer. To cope with this task in [8] it is proposed to use a weighting procedure of the hierarchy analysis method or fuzzy relationship convolution algorithm.

III. Conclusions

Thus, a classification of objective functions of the MANET using UAVs is made. A new approach to the objective functions formation in radio networks is offered: each node determines the current objective function depending on the traffic type, the network situation and available network resources. The task of MANET objective function decision-making is reduced to a hierarchical objective evaluation of alternatives.

IV. References

[1] Bekmezci I., Sahingo O, Temel S.Flying. Ad-Hoc Networks (FANETs): A survey // Ad Hoc Networks , 05/2013; 11(3):1254 – 1270.

[2] Minochkin A., Romanyuk V. Control System of Mobile Ad-hoc Networks // In Proc. of In-ternational Conference Modern Problems of Radio Engineering, Telecommunications and Computer Science (TCSET 2008), Lviv, 2008. – pp. 414 – 415.

[3] Olascuaga-Cabrera J.G., Lopez-Mellado E., Mendez-Vazquez. A multi-objective PSO strategy for energy-efficient ad-hoc networking // IEEE Cybernetics Systems, Man (SMC) Conference, 2011.

[4] Babaei H., Romoozi M. Multi Objective AODV Based On a Realistic Mobility Model // IJCSI International Journal of Computer Science Issues, Vol. 7, Issue 3, No 3, May 2010.

[5] Banner R., Orda A. Multi-Objective Topology Control in Wireless Networks // In Proc. IEEE INFOCOM, 2008.

[6] Selvi R., Rajaram R. Muliple-objective optimization of multimedia packet scheduling for ad hoc networks through hybridized genetic algorithm // The International Journal of Multimedia & Its Applications (IJMA), Vol.3, No.3, August 2011.,

[7] Zhuk P., Romanyuk V., Sova O., Bunin S. Intellectual Mobile Ad Hoc Networks // In Proc. of International Conference Modern Problems of Radio Engineering, Telecommunications and Computer Science (TCSET 2012), Lviv, 2012. – p. 238.

[8] Blumin S. Methods of decision making in anuncertain environment / Blumin S., Shuikova I.– Lipetsk: LEGI, 2001. – 138 p.