Functional scheme of the flying sensor networks architecture design

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***Abstract*— The process of flying sensor networks (FSN) construction is quite complicated. To date, there has been developed a number of methods and algorithms of solving separate problems arising in the process of FSN construction, but the process itself is not formalized as a rigid set of rules, algorithms and standards following which would guarantee construction of a FSN satisfying the designer's requirements. Many problems arising on the mentioned stages of FSN design are NP-complete and cannot be formalized and solved by traditional analytical methods due to fuzziness of task formulation, initial data, criteria and restrictions. In most cases one does not need to derive the optimal solution of the design task; usually the task is reduced to obtaining a spectrum of solutions satisfying design criteria and to selection of an optimal one among them, with interactive participation of the designer in the process of decision making. In this work we propose the functional scheme of the FSN architecture design, which can be the basis for a specialized design support system of flying sensor networks.**

***Keyword*— flying sensor networks, architecture construction, design support systems.**

I. INTRODUCTION

FLYING sensor networks (FSNs) is used for monitoring and controlling the arduous zone and the rural area in the last time. The applications can include video dissemination via FSN, military cases. The comparison of different protocols, methods for reducing energy consumption, and data synchronization method are the more investigation areas for FSN [1].

Flying sensor networks include at least two network segments: the ground one and the flying one [2] (for example Fig. 1). The ground segment consists of a set of independent geographically-distributed wireless sensor networks (WSNs). Information from the latter is collected by mobile robots (in most applications by unpiloted flying devices and sometimes

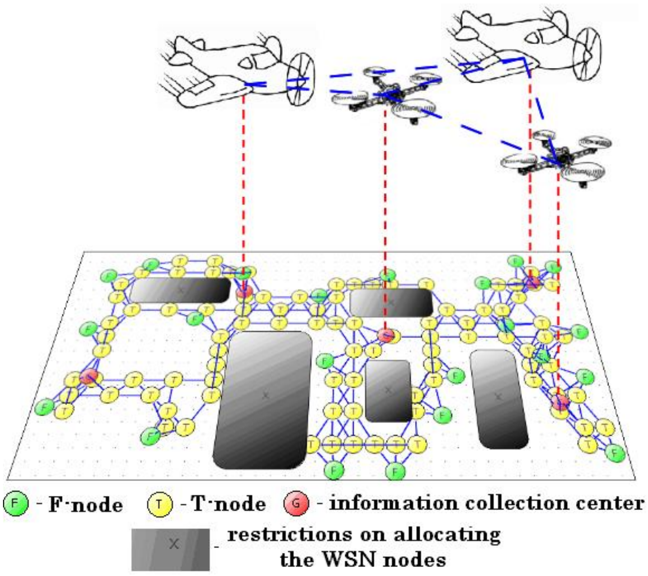

Fig. 1. Example of the flying sensor network

above-ground, above-water and underwater devices). Apart the functions of information collection, mobile robots may perform: work management of the ground WSN; point

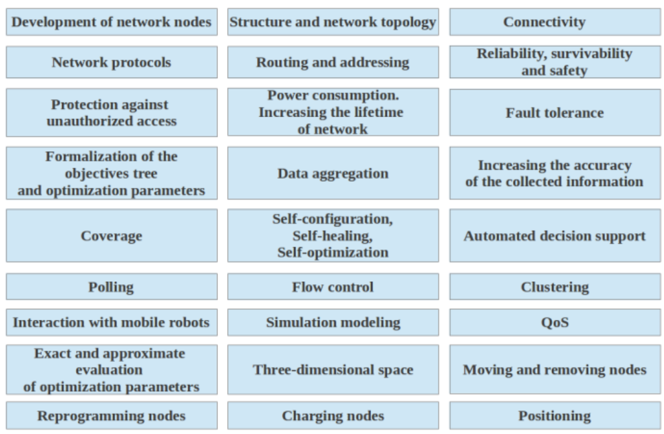

Fig. 2. Several problems arising when constructing the flying sensor network ground structure.

allocation; dissemination over the territory; movement, removal and reprogramming of the WSN nodes; charge and replace of power sources etc.

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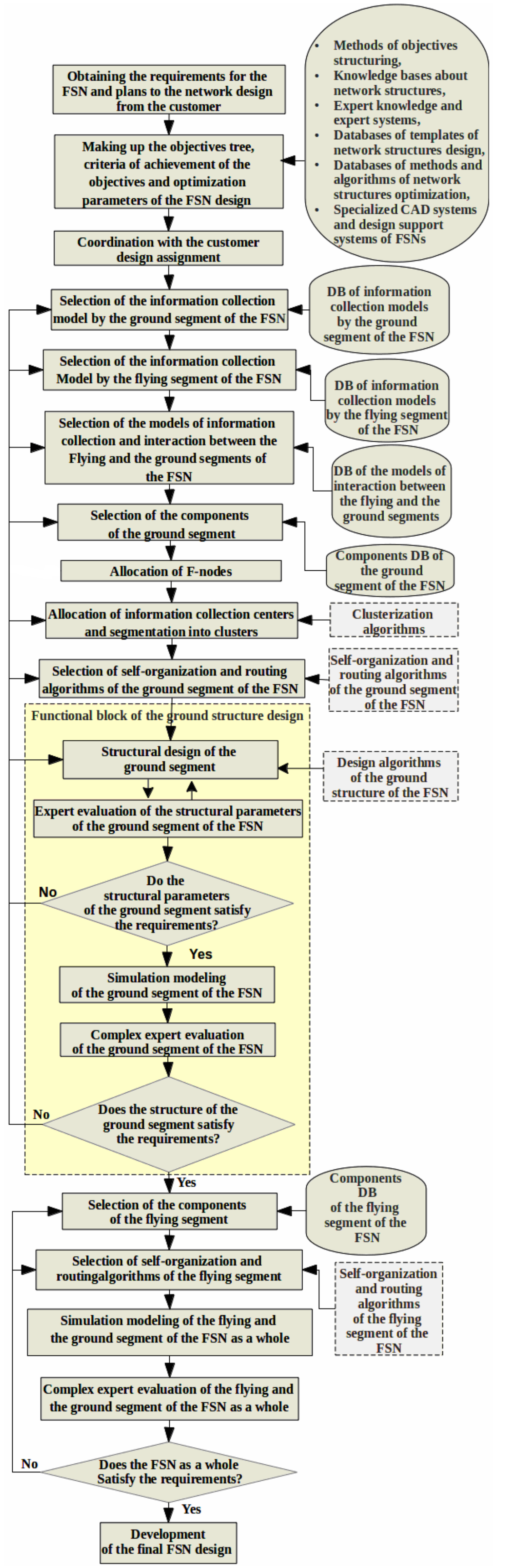

Fig. 3. Functional scheme of the flying sensor networks architecture construction

Construction of the ground segment of FSNs requires solving various complicated problems that relate to different research areas. Some of such problems are given in Fig. 2.

In the work we use a model of the of the ground segment of FSN structure, where on the functional level the following types of nodes can be defined: (1) functional nodes (F-nodes) that collect information in some neighborhood of their location; (2) transit nodes (T-nodes) that manage routing and retransmit the information collected by F-nodes to the information collection centers (ICC) to be utilized further; (3) ICCs that manage the WSN and process information collected by the WSN. In general case there can be multiple ICCs in the WSN, and the information that has arrived into each of them is available to one or multiple users for making decisions and performing certain actions. It means that information received by F-nodes should be retransmitted, with a required degree of reliability, to several ICCs by means of transit nodes allocated within the given object in a certain way.

II. Functional Scheme of the Flying Sensor Networks Architecture Construction

A promising approach to FSN design is use of interactive decision support systems (DSS) [3]. The notion of the DSS arose in the beginning of 70-s.

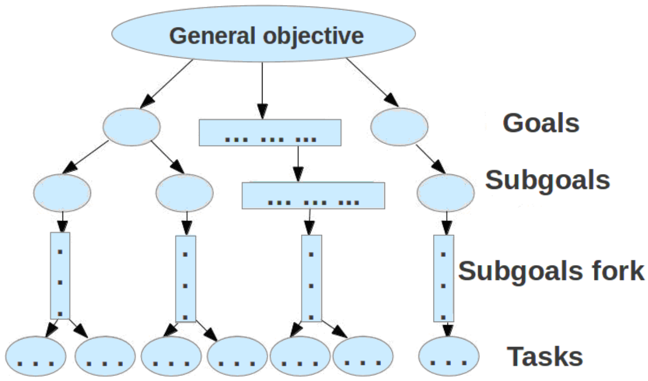

Fig. 4. Objectives tree.

The main stages of the process of FSN design are analysis of the requirements, formation of the objectives tree, development of the structural model of the FSN (structural synthesis), that is, definition of segments and subnetworks, topology design of segments and the network as a whole; development of FSN physical model, that is selection of equipment, protocols and methods of organization of data transmission channels; simulation modeling and FSN optimization.

On the basis of functional flow chart of the WSN construction process [4] in Fig. 3 we propose an extended functional flow chart of FSN architecture construction process, which can be the basis for a design support system of flying sensor networks.

Basing on received designer's requirements to an FSN and the plans on the network development, the objectives tree of FSN design is formed as well as criteria of achievement of the objectives and optimization parameters of the FSN design. A concept of the "objectives tree" was introduced by C. Churchman and R. Ackoff in 1957. An objectives tree is a structured, constructed on the hierarchy principle (distributed into levels, ranged) assembly of project objectives, in which the following ones are emphasized: the general objective ("tree root") and the subgoals of the first, second and consequent levels subject to it ("tree branches"). In Fig. 4 a generalized objectives tree is shown. In leaf nodes of the tree, simple tasks are formed. When designing communication networks, often the simple tasks are the requirements on achieving the specified thresholds of optimization parameters.

Examples of optimization parameters may be: probability of connection between F-nodes and the ICC; coefficient of network readiness; viability parameters (for example, number and fraction of aborted or functioning connections, mathematical expectation and the average fraction of number of died or survived nodes after a virtual attack on the edges or nodes); the total time of network functioning before the moment of its fault; amount of power consumed by the network/nodes in a fixed time interval; time to deliver messages from F-nodes to the ICC; time to deliver messages from the ICC to network nodes in any time moment; time of the network self-recovery after nodes faults; confidence coefficient for the data collected by the network; redundancy coefficient of the transmitted data; coverage area and the density of T-nodes allocation; network protection criteria (for example, network/nodes vulnerability to attacks, average time to dispose of the vulnerability, number of network vulnerabilities, criticality of attacking actions and threats); monetary cost of the network; monetary expenses for network allocation and operation etc.

The objectives tree of FSN design is constructed basing on methods of objectives structuring, knowledge bases about network structures, expert knowledge and expert systems, databases of templates of network structures design, databases of methods and algorithms of network structures optimization, specialized CAD systems and design support systems of FSNs.

For quality evaluation of the network design one can use a generalized indicator that characterizes (in percent) the degree of designer satisfaction of the designed network. One of the methods to produce the generalized indicator collecting in itself all parameters and requirements to the designed FSN is using fuzzy logic and applying confidence coefficients.

After having produced the objectives tree, one develops the assignment for FSN design and coordinates it with the designer. Next, the iteration process of constructing the flying sensor networks architecture is performed. The main steps of the process are given below.

1) Choose an information collection model to be used by the ground segment of the FSN. The functional block of choice of information collection model provides the designer with a list of available-to-use models of information collection together with their usage references. The database related to this block contains the full information about each information collection model (for example, the usage reference, software implementation, simulation model, a list of available-to-use routing algorithms and self-organization, restrictions on model applicability, compatibility with the models of interaction between the flying and the ground segments etc.). After having selected the certain information collection model, the designer uses the FSN design support system so as to set the concrete parameter values of the model. A promising approach is the automatic selection of parameter values of the model from the specified search space (in case the search space is very large and there are no concise algorithms or recommendations on selecting the model parameters, evolution, genetic, bio-inspired and other algorithms may be used to search for approximate solutions in a large space of variants).
2) Choose an information collection model to be used by the flying segment of the FSN. The functional block of this step implements choice of a compatible with Step 1 information collection model to be used by the flying segment of the FSN and operates in a similar way as the functional block of the first step.
3) Choose a model of interaction between the flying and the ground segments, compatible with the models chosen at the first two steps. The functional block of this step provides the designer with a list of available-to-use models of interaction between the segments together with their usage references. The database related to this block contains the full information about each model of interaction between the flying and the ground segments. After having selected the certain interaction model, the designer uses the FSN design support system so as to set the concrete parameter values of the model. As well as on Step 1, the module of automatic selection of model parameters can be used.
4) Choose the components of the ground segment of the FSN to be utilized. The functional block of choosing the FSN components implements the selection from the database of a set of inter-compatible types of utilized nodes on the current iteration. Selection of all compatible nodes is implemented with help of search with restrictions defined by the designer in the nodes database of the ground segment of the FSN. After that, a sorting of the set of compatible nodes is performed on the criteria set by the designer. The design support system of the FSN that implements the functional flowchart (Fig. 2) must either output a usage reference for the certain nodes set for the project, or provide the designer the ability to accomplish the choice themselves. The database related to this block contains the complete information about all available-to-use network nodes.
5) In accordance with the requirements to the FSN, allocate F-nodes at the information collection points and at the points from which it is required to direct the management actions on external objects.
6) Allocate the information collection centers and form the clusters of the ground structure of the FSN (for example Fig. 5). The functional block of segmentation into clusters forms the clusters basing on the clusterization algorithms available in the database, requirements for the

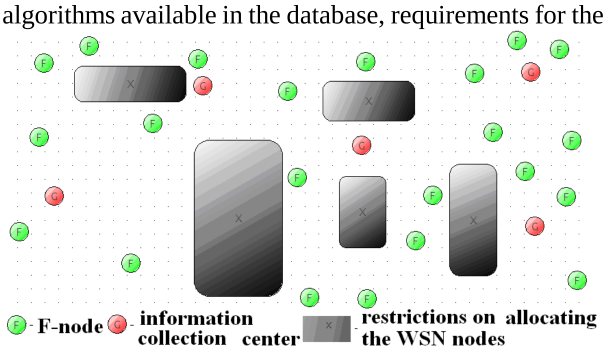

Fig. 5. Example of the information collection centers allocation.

network and the defined F-nodes allocation. It also performs the ICC allocation in such a way that each F-node would be able to connect to at least K ICCs. We suppose that information delivery from an ICC to an end user is performed without any losses or distortions and that the information received by the end user from any F-node is sufficient for them if it comes from at least one of the K ICCs with which the F-node is connected.

7) Choose a self-organization algorithm and a routing algorithm for the ground segment of the FSN (for example [5], [6]). The database related to this block contains the full information about each self-organization and routing algorithm and their simulation model. As well as on Step 1, the module of automatic selection of model parameters can be used.

8) Synthesize the structure of the ground segment of the FSN. The functional block of synthesis of the ground structure of the FSN (FB-SGS-FSN) allocates T-nodes in such a way that the synthesized network structure would satisfy design requirements and goals, that is, would have the “desired properties” for the designer. The initial data of the ground structure synthesis are the following: allocation ant type of F-nodes (Fig. 5); allocation and type of information collection centers (Fig. 5);

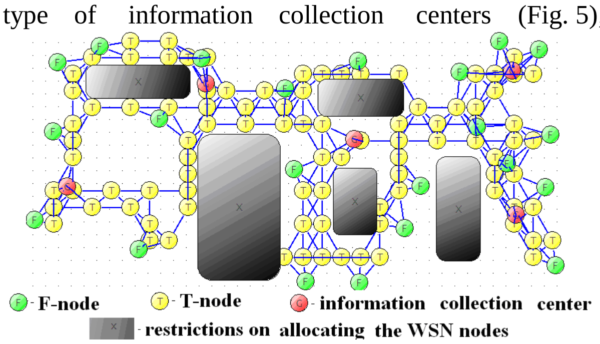

Fig. 6. Example of the designed fault-tolerant ground structure of the FSN (every F-node has at least 3 independent paths to at least 3 ICC)

description of the object at which the ground segment of the FSN is to be located at (the size of the object, its plan, spatial constraints on allocating T-nodes, barriers for electromagnetic waves expansion and characteristics of these barriers; types and characteristics of ready-to-use T-nodes; adopted self-organization and routing algorithms; the model of information collection and interaction between the flying and the ground segments; functional requirements; optimization parameters; the objective functions; exact and approximate functions to calculate network parameters; expert systems; simulation models etc. It is necessary to allocate T-nodes in such way (for example Fig. 6), that the designed ground segment of the FSN would have the «desired properties» assigned by a designer.

Example: Let $q = q(T)$ be the known probability of failure of one ICC in time T. Then the probability of at least one of K ICCs to be operative is calculated in the following manner: $P(Q)=1-q^K$. In case the requirement $P(Q)>=P^*$ is set, where P^* is a defined value, one can define the necessary ICCs number K solving the inequality $1-q^K>=P^*$ for K. In order to allow the information to be delivered from all F-nodes of the network to the end user upon failures of any $(K-1)$ ICCs, one needs to construct (with help of suitable T-nodes allocation) such WSN structure that would assure the defined minimal probability of each F-node to be connected with some K ICCs from the total number of N.

The FB-SGS-FSN in its operation process implements calculations of exact and approximate estimates of the structural network parameters, expert evaluation of intermediate results and simulation modeling of network operation. The results of the modeling and structural-parametric estimates of different parameters are passed onto input of the complex expert system of the ground network structure evaluation which is used to calculate the confidence coefficient K_{DSTR} of all designer's requirements for a ground structure of the FSN to be satisfied. In case K_{DSTR} does not satisfy designer's requirements, one should either continue synthesizing the ground structure of the FSN on Step 8, or go to selection of other parameters or models on different levels of the FSN construction (that is, to one of the steps 1-7).

In the paper [4] author proposes various bio-inspired algorithms and the functional flow chart of the multi-agent bio-inspired WSN structure design (Fig. 7).

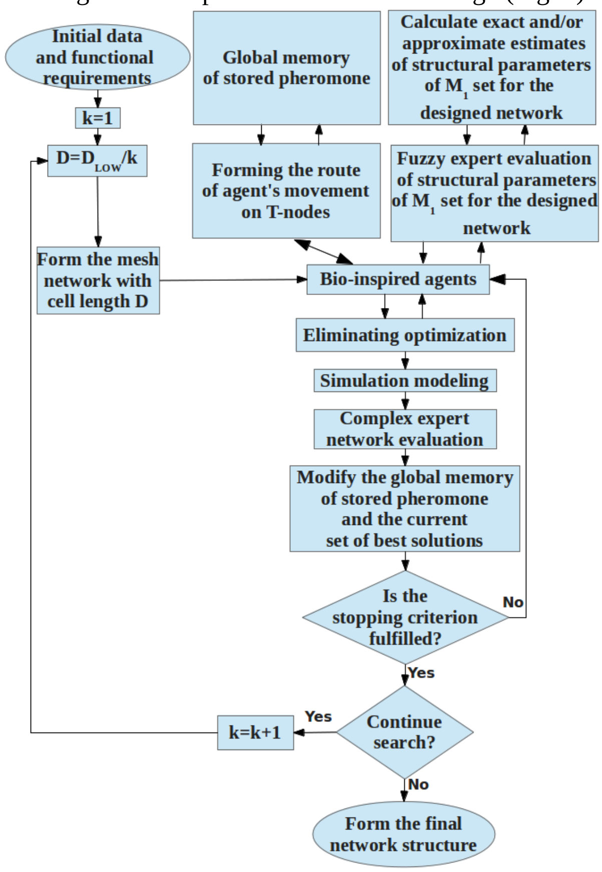

Fig. 7. Functional flow chart of the multi-agent bio-inspired WSN structure design [4].

In recent years, the research area of *Natural Computing* is rapidly developing. It unites mathematical methods in which the principles of natural mechanisms of decision making are embedded [7]. Scientists have developed bio-inspired algorithms (BA) modeling animals behavior for solving various optimization problems that either do not have exact solution, or the solutions search space is vary large and complex constraints of the objective function are present, as well as NP-complete.

The described recommendations on applying BA and the proof in [8] that even the constrained variant of the problem of minimal coverage on plane is NP-complete allow to conclude about the possibility to apply self-organizing bio-inspired algorithms for a self-organizing WSN structure design.

9) Choose the components of the flying segment of the FSN to be utilized. The functional block of choosing the flying segment components operates in a similar way as the functional block of the first step.
10) Choose a self-organization algorithm and a routing algorithm for the flying segment of the FSN (for example [9]). The functional block of the choice of the components of the flying segment operates in a similar way as the functional block of the Step 7.
11) Perform simulation modeling of the FSN operation as a whole. The modeling results and structural-parametric estimates of different parameters are passed onto input of the complex expert system of the FSN evaluation which is used to calculate the confidence coefficient K_{DALL} of all designer's requirements for the FSN architecture to be satisfied. In case K_{DALL} does not satisfy designer's requirements, one should either go to Step 9 or to Step 10.
12) Form the final design of the FSN architecture.

III. Conclusion

In this work we propose the functional scheme of the FSN architecture design, which can be the basis for a specialized design support system of flying sensor networks. Currently, the functional block of the FSN ground structure synthesis is implemented using *Java* programming language. Experimental research has shown the possibility of constructing the FSN ground structure considering various objective functions and optimization parameters.

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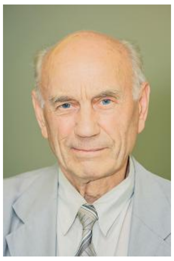

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