

Software-Defined Architecture for Flying Ubiquitous Sensor Networking

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Abstract— The paper describes a flying ubiquitous sensor network (FUSN) and the method of interaction UAV network (flying segment) and the terrestrial segment. It is shown that the main problem of the interaction is a significant difference between the motion characteristics of the objects of terrestrial and flying segments of FUSN. It is caused by the fact that the sensor node can be in communications range of the UAV flying segment for a limited time. It is proposed to use the additional nodes that perform the routing control function (role SDN controllers). When placing the nodes on UAVs, there are the additional options of the network structure and condition monitoring of communication channels, the localization of its components, assessing the characteristics of movement, getting forecasts of network structure changes. Organizations of flying ubiquitous sensor network, which is based on SDN architecture, improves its resistance to changes in the structure, reduces the amount of routing traffic due to its location within the same management cluster.

Keywords— FUSN, SDN, WSN, UAV

I. INTRODUCTION

Using wireless technology enables to implement self-organizing communication network, providing interaction of elements of the automated systems which have a certain freedom of movement in space. The most important problem of the organization of such networks is the necessity to implement quite complex and demanding their configuration management algorithms. These algorithms must monitor the network elements and definition of the network configuration. Changing network structure makes it necessary to exchange service data to search for data delivery routes. Volatility or stability of the network structure depends, primarily, on the nature of the movement of objects, and ultimately on the purpose of the system and the problems to be solved it [1]-[5]. When building a homogeneous system, i.e., one in which all objects have the same features and characteristics of the motion, the network communication parameters are selected based on these characteristics and parameters. When choosing parameters, usually the aim is to obtain the most stable network structure, i.e., minimizing the work on the reorganization of the network. In many practical applications, this goal is achievable if certain restrictions on the relative movement of elements are available.

The development of the construction of UAV technology and robotic devices leads to the development of methods for

their use and management systems built on their base [6]. For example, to solve a number of problems it is advisable to use multiple robots or UAVs. Self-organizing network [7], [8] can be used to solve problems of group management and interaction between devices formed transceivers placed on such devices. The structure of the network depends on the relative location of the device and may vary in time when you change the relative position of elements of the system. Changing network structure makes it necessary to exchange service data to search for data delivery routes. Volatility or stability of the network structure depends primarily on the character of motion of objects, and ultimately on the purpose of the system and the problems to be solved it. When building a homogeneous system, i.e., one in which all objects have the same features and characteristics of the motion, the network communication parameters are selected based on these characteristics and parameters. When choosing parameters, usually the aim is to obtain the most stable network structure, i.e., minimizing the work on the reorganization of the network. In many practical applications, this goal is achievable if certain restrictions on the relative movement of elements are available. As the UAV in a network, and a terrestrial network robotic system move relative cell system may be limited by the choice of certain rules of motion and these rules may be similar for all the elements. However, the interaction of two or more systems, i.e. in a heterogeneous system, for example, the interaction of UAV systems and robotic ground system have problems building a unified network because of the substantial difference characteristics of their movement. To ensure such cooperation, sufficient stability of the heterogeneous structure of the network should be ensured. This objective can be achieved by selection of the relative motion rules of the elements of different networks.

In connection with the introduction of 5G (IMT-2020) networks, one of the most urgent tasks will be to ensure the guaranteed coverage for high-speed access of various Internet of Things applications, such as Tactile Internet.

II. FORMULATION OF THE PROBLEM

Tasks group interaction UAVs and the terrestrial segment can be very diverse. In this paper we restrict ourselves to the tasks such as data collection with elements of the terrestrial segment, terrestrial segment software connectivity network, providing interaction of elements of air and terrestrial

segments. The main problem of the interaction is a significant difference between the characteristics of motion of the objects of terrestrial and flying segments. Typically, the ground network element can be in the range of a segment member of the air for a limited time.

III. NETWORK MANAGEMENT (SDN ARCHITECTURE)

As is known, Software-Defined Network (SDN) is a data transmission network, where resource control layer is separated from the data link layer. Open Flow protocol is the most common mechanism providing interaction between control layer and data link layer [9], [10].

Typically, WSN is based on principles of ad hoc network in which each of the nodes (part or nodes) can be a source or receiver of messages and the transit node. In this case, the network is determined by the functioning of the protocols of choice roles of nodes and routing protocols. A routing in such a network requires a significant investment of resources for transmission of service traffic, moreover, the amount of these costs depends on the nature of the traffic, and the stability of the structure of the network, depending on the characteristics of the motion of its elements and the impact of the network environment. To improve network resource utilization in a variety of configurations under different routing algorithms are designed to be subdivided into proactive and reactive [7]. Proactive protocols require relatively rare detailed procedures for data collection from the network elements and the construction of routing rules, which then are used for maintenance traffic. Reactive protocols accomplish the work to find a route in the event of the need for data delivery. The first ones are advantageous to use on a relatively stable network structure and the second otherwise. In any case, the instability of the structure leads to increase in the share of service traffic, reduce bandwidth and quality of service. The main reason for this is the need to collect data from the network elements and work to find delivery routes. When using proactive protocols, work to find the routes assigned to one of the network nodes functioning as a gateway (coordinator), by using reactive protocols it is running nodes that act as routers. In both cases, the routers perform their functions on the basis of routing data stored in its memory. WSN nodes resources are limited, primarily because of the need to save energy, supply of which is limited by the capacity of autonomous non-renewable source. The quality of operation of the network depends on the properties of the selected route. The quality of wireless links between nodes is highly influenced by the number of transits (hops) in the routes [2].

Analysis of the route selection process and traffic service shows that the main problem of WSN and the ad hoc network, in general, is the lack of sufficiently reliable configuration data, which leads to the cost of network resources.

The articles [11]-[13] take up the issues of SDN application in dynamic aerial wireless environments. The paper [11] proposes that network may be formed by mounting the data plane or the OpenFlow switches on the UAVs and the control facility on a centralized ground controller or distributed

control on UAVs. The proposed solution in [12] opens opportunities for both operators and UAV service providers in terms of networking management for large-scale air control of UAV swarm. The SDN-approach to maximizing aerial network availability by proactive prediction and mitigation of network disruptions is shown in the paper [13].

The aim of this work is the choice of method, providing cost reduction of resources required to service the possible introduction of service traffic node (or nodes) having substantially more computing resources, sufficient reliable data on the network configuration and a relatively large area of communication. Placing in the open network (outside) the controller as part of the UAV may be used as such a node. Software-defined architecture for Flying Ubiquitous Sensor Networking presented on Figure 1.

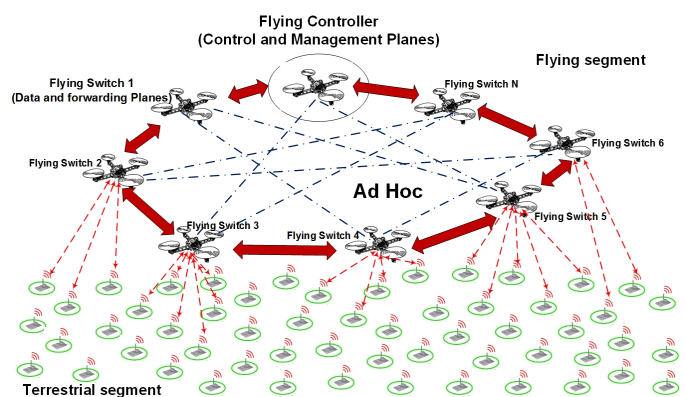


Figure 1. Interaction of flying and terrestrial segments of FUSN

Using UAVs makes it relatively easy to implement a number of features that were hard feasible for self-organizing network. It functions such as: the study of network structure (determination of the geographical coordinates of its nodes and getting them to channel quality information with neighbouring nodes), a significant expansion of range with nodes [14], a potentially bigger (fills), reserve energy enables a sufficient amount of computation for determine the network configuration and definition of traffic routing rules. This functionality enables to make up for the lack of information about the network configuration, use the methods of construction of routes based on the coordinate data of nodes, routes to reduce the length of service for the traffic channels and unload terrestrial component the self-organizing network (Figure 2).

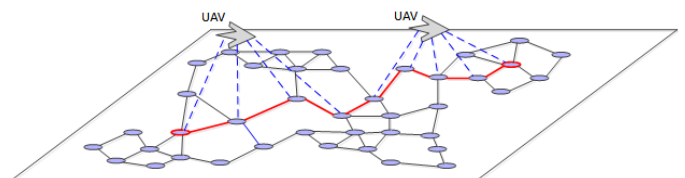


Figure 2. Interaction of flying and terrestrial segments of FUSN

Thus, the use of UAVs, enables the removal of the network elements of the data collection functions and determining the routing rules in the communications centre, located on the

UAV. Of course, in the case of unavailability of network nodes, the network must be capable of independent operation.

The above architecture of network control repeats the SDN architecture discussed in [15], [16], in which the network nodes are the switches and the controller as part of the UAV - Network Management SDN-Controller.

Operation of the controller algorithm can determine (composed UAV) as follows:

1. Data acquisition via a network communication node UAV. Data collection nodes coordinates are calculated, the data is requested from the network node channel quality with the neighbouring nodes.

2. Analysis of the logical structure of the network and the quality of its functioning. If the functioning of the quality criteria are met then, go to claim 6, or claim 3.

3. Calculation of traffic routing policies between network nodes. Construction of the logical network structure and the definition of the role of nodes.

4. Control Data Transfer ties and change (formation of) its logical structure of the network.

5. Routing rules data transmission network nodes act as a router.

6. Waiting for and receiving requests from network routing rules nodes search and transmission of routing nodes, go to claim 1.

The algorithm assumes that the controller is a part of the UAV performs continuous monitoring of configuration and network status, in the case of changes that lead to a decrease in performance indicators, he decides to change the configuration and transfer it implements the control commands corresponding nodes.

Network nodes that perform routing functions, network traffic service in accordance with those obtained from a controller packet routing rules. If the node cannot find the corresponding rule for routing the received packet, it makes a request to the controller (UAV). After receiving a response, the node uses the resulting rule for incoming service package. Getting the right is saved in the node routing rules table for a while. Limited time of storage routing rules can reduce the cost of memory and CPU time of the router. We believe that the router's connection area with a drone much longer communication range with ground nodes, so the route has only one plot (without transit). In the case where the UAV controller is unavailable, the routing is performed using reactive protocol.

Then the share of traffic served by using reactive protocols will depend on the connection between the router and the network UAV controller. The use of multiple UAVs (group) in the presence of channels of communication between them, enables to organize the functioning of the network of a sufficiently large scale, while avoiding routing traffic growth and high performance requirements of the router (network nodes).

We make the assumption that the network nodes form a Poisson field, the network is connected, each of the network nodes can perform backhaul functions, and nodes can transmit data in random directions, i.e., between any pair of nodes in

both directions. Then, assuming that the package delivery network is the shortest path between the nodes (containing the minimum number of transits) [14], [17], [18], we can say that the traffic between nodes i and j pass an average of k nodes, where k the average length of any shortest path (including transit).

For the model of a random graph, the average length of the shortest path can be roughly estimated as:

$$k \approx \frac{\lg n}{\lg c}, \quad (1)$$

where $c = pn$, p - the probability of the existence of edges of a graph that describes the network.

For wireless communications p can be determined as a proportion of the neighboring nodes in the area of an arbitrary communication node. If the communication area node is a circle of radius R , and network coverage area is S , then

$$p = \frac{\pi R^2}{S} \quad (2)$$

We believe that the total number of routes in the network is equal to the number of possible directions of data transfer between nodes, that $n(n-1)$, where n number of network nodes. Since the route, on average, contains k nodes, then the probability that an arbitrary node is a transit node in any of the routes is equal to k/n . The probability that node r is selected as a transit time will be determined by the binomial distribution

$$p_r = C_{n(n-1)}^r \left(\frac{k}{n} \right)^r \left(1 - \frac{k}{n} \right)^{n(n-1)-r}. \quad (3)$$

Then, the average number of routes in which an arbitrary node participates equally

$$\bar{r} = (n-1)k. \quad (4)$$

Node traffic intensity is equal

$$a = a_0 \bar{r} = a_0 (n-1)k \quad (5)$$

where a_0 - the intensity of the traffic produced by one node on the network.

In such a way, when data routing rules of service node (useful) traffic, on the average, are at $\bar{r}$ times greater than its own traffic.

If the network has one node acting as a gateway, and its useful traffic communication nodes produced only directed to the node, the number of possible directions of communication is equal to $(n-1)$. Then the average number of routes that involved an arbitrary node in the network and the average intensity of serviced site traffic, according to (2) and (3) are defined as

$$\bar{r}_G = \frac{n-1}{n} k, \quad (6)$$

$$a_G = a_0 \frac{n-1}{n} k. \quad (7)$$

For sufficiently large node n participates in average about routes k , where k arbitrary average length of the route in the network. The use of reactive routing protocols associated with the need to service a large volume of service traffic, produced by broadcast messages in route finding. If the route of delivery unknown sender node package, there is a need for route search. While the search, the broadcast messages are generated, which are accepted by all neighboring nodes, which in turn re-send similar messages to their neighbors nodes, until the limit is reached the number of hops in the route. Necessity of broadcast data due to the lack of network configuration is assumed that each of the nodes may be equally probable route of the desired element. The number of messages transmitted is not less than the number of nodes in the communication area of nodes included in the route. If the network is large enough, the distribution of broadcast messages will occur radially from the source node, and the required number of hops on which will spread the message will be equal to the expected number of hops in the desired route, Figure 2.

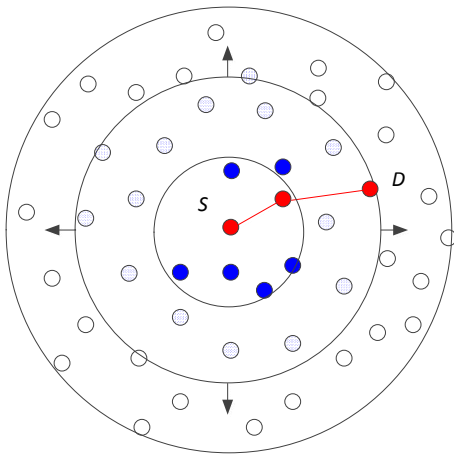


Figure 3. Distribution of service messages when searching for a route

Thus, the number of messages is generated from the quadratic dependence of the average length of the desired route. After finding the route, information about it is stored and used when sending the next packet. The need arises repetition path when changing the network configuration search procedure (in case of unsuccessful attempts to deliver the packet) or after the network configuration is stored and the interval between packets does not exceed a specified time interval, the route searching procedure is performed only in the case where it is unknown.

It is clear that with such a network according to actual scale should be limited so that the average length of the route does not exceed a few (units) hops. This greatly limits its possibilities.

When using proactive protocol data delivered according to predetermined routes that do not require resource costs for route search procedure.

However, if you select the route to use some prior information about the network configuration, the network nodes can be ranked according to the probability of their belonging to the desired route. When searching for a route guide service packages primarily nodes having the highest probability to enter the route. This requires the availability of a method of evaluating the probability for each of the network nodes. For the construction of such methods can be used data from a network configuration by using its monitoring UAV. For example, the empirical probability of belonging to a route can be calculated on the basis of data on their coordinates in proportion to the degree of proximity to the line connecting the source node and the destination node, or on the basis of solutions k shortest paths search problem (algorithm Jena [19]).

IV. CONCLUSIONS

1. The operation of the wireless ad hoc network is much dependent on the movement characteristics of nodes and their relative placement. Existing routing protocols developed for such networks take into account these circumstances. However, when the structure of the network nodes and the traffic characteristics are not stable, the existing routing protocols require nodes considerable amount of resources and bandwidth, which limits practicable scale network.

2. The additional nodes, the routing management (role SDN controllers) can be used to solve the problem of self-organizing network with unstable structure. When you place the nodes on UAVs, there are the additional options of the monitoring network structure and its status.

3. Use the control node (SDN controllers) as part of the UAV enables to monitor the status of network function channels, localization of its components, the characteristics of motion estimation, receive predictions of the network structure changes.

4. The use of the process of building a network increases its resistance to changes in the structure, reduces the amount of routing traffic due to its location within the same management cluster (UAV communication zone).

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