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Simulation-Based Application of Flying Ad-Hoc Networks with Mac Layer Adaptation

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ABSTRACT

Flying ad-hoc networks (FANET) based on unmanned aerial vehicles (UAVs) are characterized by constant changed of the topology due to the moving of networking nodes. It causes an increased overhead costs for transmission of their coordinates when topology control is being done, or specific geographic routing protocols are being used. In order to reduce such overhead costs, a new approach based on medium access layer (MAC) adaptation is proposed. It evaluates the communication channel parameters, checks the integrity of the received data and manages retransmissions of information packets. Basic carrier sense multiple access/ collision avoidance (CSMA/CA) MAC layer protocol for the application of neuro-fuzzy adaptation have been considered and the types of FANET service messages to be optimized have been described. A flowchart of the new MAC layer neuro-fuzzy adaptation algorithm was shown. Simulation of FANET performance with neuro-fuzzy MAC layer adaptation, as well as classic CSMA/CA protocol, was provided. The simulation showed that the modified MAC protocol reduces the number of lost packets while having a comparable transmission rate and average latency. Thus, the simulation showed the effectiveness of the proposed method of neuro-fuzzy adaptation of the channel level of the UAV network.

Keywords: unmanned aerial vehicle, UAV, flying ad-hoc network, FANET, medium access control, MAC.

INTRODUCTION

The role of unmanned aerial vehicles (UAVs) is increasing every year to provide communications in remote regions and high-risk areas or to monitor the surface during reconnaissance and rescue missions with the transmission of video data and images to the ground station in real time. Today, a complex consisting of one or more UAVs is used for these purposes, each of them transmits information from the on-board camera to the ground control station.

In recent years, research has begun that will allow the use of a ad-hoc networks of UAVs capable of consistently performing one mission. Such devices must transmit data over radio channels using standard technologies. Each node acts as a data source from the camera, which is located on board the UAV, and a repeater, forming a multiconnected network topology. The use of Flying Ad Hoc Networks (FANET) can reduce the cost of technical solutions that will be needed to complete the tasks, allowing to expand the territory by relaying data based on routing and increase the maximum time of their implementation by replacing devices with discharged batteries [1-5]. Such networks can operate in a variety of unexpected situations, while one of the key problems is ensuring the required quality of service.

Improving the quality of service in FANET networks requires the use of competent solutions at various levels of open systems interconnection (OSI) network interaction from the lower physical to the upper application. The role of the channel layer in communication systems, namely the medium access control (MAC) sublayer, is to organize collective access to the radio channel. Accordingly, irrational organization of collective access to the radio channel or filling the network with service requests can reduce the speed of packet transmission in the network or completely stop its operation regardless of other levels. Thus, at the channel network level an algorithm for accessing the environment should be used to ensure efficient use of resources in conditions of constantly changing topology and the number of network nodes [6-11].

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The aim of the work is to develop and study a method of neuro-fuzzy adaptation of the FANET channel layer to improve network performance by controlling the frequency of transmission of service messages.

BASIC MAC LAYER PROTOCOL FOR THE APPLICATION OF NEURO-FUZZY ADAPTATION

The often used CSMA/CA (Carrier Sense Multiple Access/ Collision Avoidance) protocol is promising as a basic MAC-level protocol for the application of neuro-fuzzy adaptation [1]. The use of multiple access method with carrier detection and collision avoidance is extremely important for wireless networks where the detection of collisions of alternative CSMA/CD is unreliable due to the hidden node problem. Before transmitting data, the station sends a special frame, RTS (Ready To Send), which notifies the others that the node is ready to transmit data, as well as the expected duration and destination node. The destination node responds with a CTS (Clear To Send) frame, indicating that it is ready to receive.

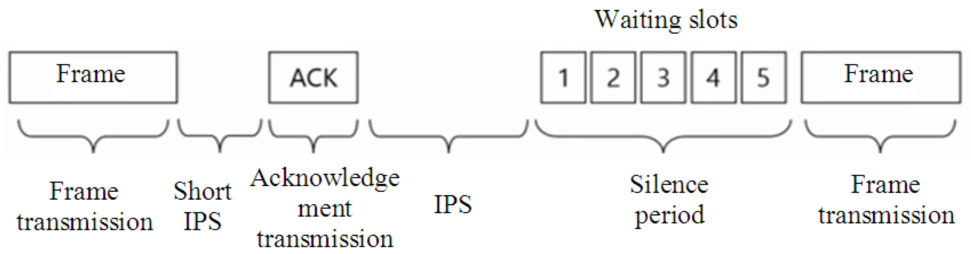

Figure 1. CSMA/CA model

The CSMA/CA model and algorithm (Fig. 1, 2) represent the following sequence of actions: if the channel is free, the subscriber transmits a packet; if the channel is busy, the subscriber postpones transmission taking into account the preset delay and inter-frame sequence gap (IFS) and then repeats the algorithm. Optimization of the algorithm in various operating conditions involves the management of a random delay time, as well as the transmission slot time.

Service messages can be generated either by a ground station or by a UAV. Managing the frequency of transmission of service messages will improve the performance of the FANET by reducing overhead costs. The frequency of transmission of service messages under favorable conditions of network operation can be reduced, which will lead to an increase in the proportion of useful traffic and, accordingly, the efficiency of the network as a whole. The types of FANET service messages to be optimized are:

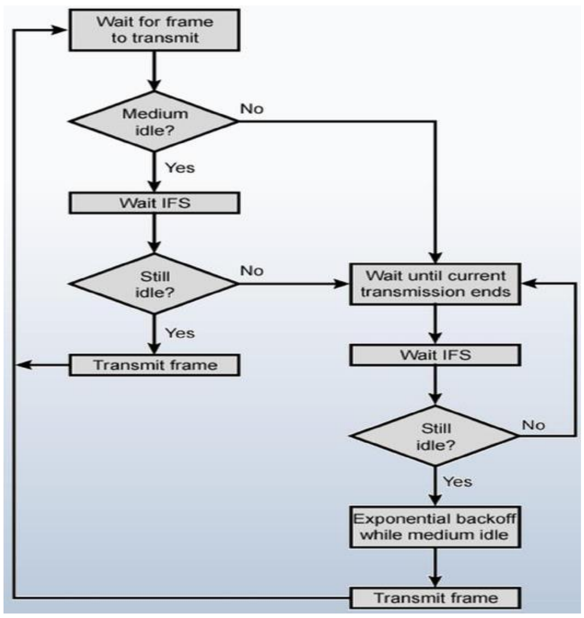

Figure 2. CSMA/CA algorithm flowchart

1) a message containing the serial number of the UAV and broadcast by the access point. This message is not addressed, requires the UAV to respond, as mentioned above;

2) messages-responses of the UAV, serving to confirm the performance of any actions (about the coincidence of data when checking access rights, about the acceptance of the previously sent messages, and so on, about disconnecting from the transmission channel). The messages are addressed and do not require a response.

3) video traffic messages: are informational messages, targeted, that do not require any kind of response, the source of such messages can only be a UAV. Errors are allowed in this type of messages, since the error of receiving a few milliseconds of a video stream will affect the user's visual perception to a small extent. Therefore, there is no need for mandatory verification of the integrity of the received message;

4) informational messages: these include user requests for the provision of services. They are directed to the access point (they are addressable), which by redirecting them to the UAV and, based on the response received from it, forms a response to the user about the provision or non-provision of the service.

Also, information messages include messages containing commands for controlling the video and kinematics of the UAV. Such messages are addressed and must have a high degree of error protection, that is, have a guarantee of delivery by the recipient, that is, the UAV. The guarantee of delivery of control commands is achieved by using an automatic retransmission request (ARQ). The source of information messages is also a UAV, which transmits the necessary telemetry data to them. The integrity of service and information messages is checked by including a 12-bit cyclic redundant code (CRC) field in their composition.

THE PRINCIPLE OF NEURO-FUZZY ADAPTATION OF THE CHANNEL LEVEL

The developed block diagram of the neuro-fuzzy adaptation algorithm of the channel layer has a complex internal architecture with the interaction of various elements, both with the neural network and with each other (Fig. 3). The data source model is set by the signal conversion model in the channel and the transceiver paths of network nodes at the physical network level [12,13]. The process of functioning of a neuro-fuzzy system consists of a set of clock cycles, which are counted at elementary intervals. Data transmission is carried out taking into account the physical and channel layers of the OSI model in packets, the duration of which, with centralized access to the data transmission medium, is considered predetermined. This allows us to consider the process of data transmission over the network synchronous with the duration T_F. The duration T_F denotes the smallest total multiple of the time intervals for data delivery either along all routes, or within a single communication channel, taking into account the physical and channel layers, as well as delays in accessing the data transmission medium. The process of managing data flows is conditionally divided into the following components:

The optimal set of Nopt routes is determined using the routing function F based on neuro-fuzzy analysis [14,15]. The load A_{net} on the network arising from the delivery of the required amount of data I_{max} is calculated as a fraction of the time interval for the formation of the information vector T_I occupied for the delivery of data I_{max} using a set of routes N_{gmax} calculated by analogy with the optimal route N_{opt}

$$A_{net} = \frac{T_F}{T_I} \bullet \sum_{g=1}^{G} N_{g\max} \tag{1}$$

1) choosing the transmission route;

2) changing the delay interval when sending a data packet;

3) destruction of the package, provided that it is damaged or intended for this node and has reached the target;

4) transfer the packet to the next node.

The remaining modules and processes are the external environment.

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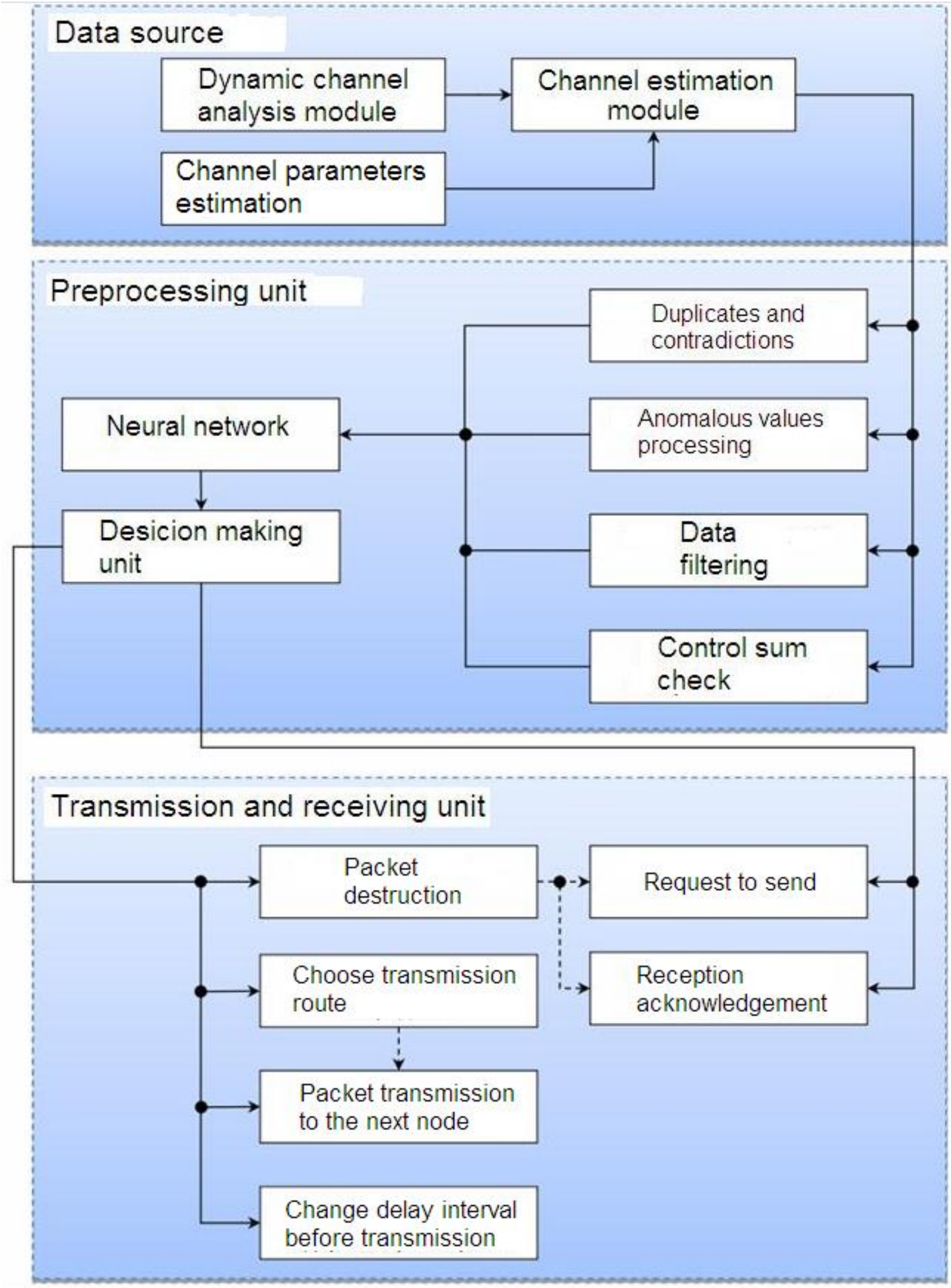

Figure 2. Block diagram of the neuro-fuzzy adaptation algorithm of the channel level

SIMULATION OF FANET PERFORMANCE WITH NEURO-FUZZY CHANNEL LEVEL ADAPTATION

The proposed algorithm of neuro-fuzzy adaptation of the channel layer was used to simulate the performance of a specific UAV network configuration. The maximum number of network nodes was assumed to be 20, the network size is a square with a side of 10 km, the bitrate is 1 Mbit/s, the power of the UAV transmitting device is 0.05 W, the threshold receiving power is minus 95 dB, the data packet size is 512 bytes. The simulation was performed in the OPNET Modeler 14.5 environment. The comparison of the basic CSMA/CA protocol and the developed CSMA/CA protocol based on neuro-fuzzy adaptation was performed. At the network level, in each case, the Geographic Routing Protocol (GRP) was used.

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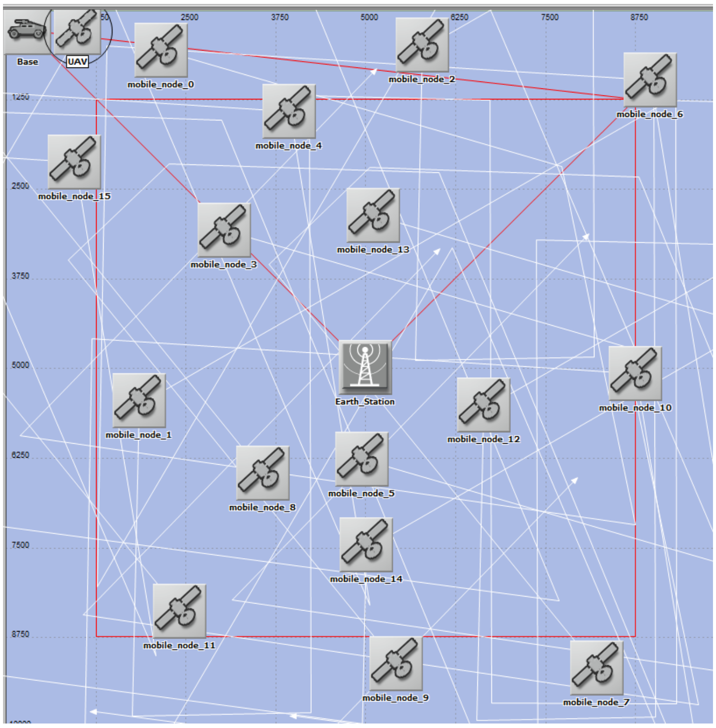

Figure 3. Simulated FANET configuration (network size is 10x10 km, in the center is a ground base station, in the upper left corner is the main UAV, other nodes are additional UAVs that create a load on the network)

Each additional UAV moved along a random trajectory at the same height and speed as the main one (Fig. 4). It should also be noted that in this case, each additional UAV transmitted packets of information to another UAV in this network, with the exception of the base station and the simulated UAV. It is worth noting that the results of this simulation are radically different from the simulation of ideal UAV flight conditions due to the presence of transit traffic passing through both the base station and the main UAV we are interested in. The simulation results when receiving packets by a ground base station from a UAV are presented in Table 1 (the maximum packet transmission rate was normalized to 1 packet per second).

Table 1. FANET performance when receiving packets by a ground base station from a UAV

Characteristic	Basic CSMA/CA	Developed Protocol
Maximum speed, pack./s	1	1
Average speed, pack./s	0.381	0.407
Minimum speed, pack./s	0.056	0.111
Maximum delay, with	0.259	0.206
Average delay, with	0.111	0.104
Minimum delay, with	0.013	0.013
Packages lost, pcs.	44	44
Maximum number of transit packages, pcs.	112	173
Average number of transit packages, pcs.	58.68	66.40
Minimum number of transit packages, pcs.	14	13

CONCLUSION

The proposed method for managing the performance of the FANET network with neuro-fuzzy adaptation of the channel layer allows for dynamic analysis of the communication channel, checking the integrity of the received data and managing retransmissions of information packets and service messages. During the simulation, with a minimum number of nodes with a working and non-working ground station, a huge number of packets were lost, but at the same time there was a minimum packet delay. During the simulation, when additional UAVs are added, the situation changes. There was minimal data packet loss and delay both when the ground station was running and when the ground station was disconnected. From all of the above, it can be concluded that in the FANET configuration considered, the developed algorithm has an advantage over the basic CSMA/CA protocol when modeling with a large number of nodes, it has not a bad transmission speed, average latency and the smallest number of lost packets. Thus, the simulation showed the effectiveness of the proposed method of neuro-fuzzy adaptation of the channel level of the UAV network.

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