Development of algorithms for processing and transmitting remote sensing data from unmanned aerial vehicles

I P Bolodurina¹,², D I Parfenov¹,²

¹Federal Research Centre of Biological Systems and Agro-technologies of the Russian Academy of Sciences, 29, 9 Yanvarya str., Orenburg, 460000, Russia
²Orenburg State University, 13, Pobedy ave., Orenburg, 460018, Russia

E-mail: ipbolodurina@yandex.ru

Abstract. Currently, various types of robotic systems are used to collect primary data. For example, UAVs can be used to collect various types of melon required for analyzing the effectiveness of agricultural operations and predicting the yield of certain types of crops. The problem of the transfer of information accumulated by the UAV, its analysis and making management decisions remains an urgent task. As a rule, wireless sensor networks are used to transfer data to a UAV, the main problem of which is the low bandwidth of the channel. To improve the efficiency of data transmission over low-speed communication channels and the subsequent processing of the information flows of the UAVs, it is necessary to develop traffic routing methods. As part of the study, an approach has been developed that allows taking into account not only the state of the communication channel at the current time but also to predict its characteristics ahead of time.

1. Introduction
At present, the transition to high-yielding agriculture requires the introduction of smart farming systems in the cultivation of crops. The traditional approach to assessing the state of crops is based primarily on the results of visual inspection, as well as collecting an analysis of a significant amount of heterogeneous data. As a rule, these include local climatic features, cycles of crop changes associated with a change in the phases of crop development, as well as the influence of technological operations of direct action. At the same time, monitoring and processing of data indicators within the framework of existing analog systems of agrotechnology management takes quite a long time, which negatively affects the effectiveness of management decisions made [14]. As a rule, by the time the agricultural operations that are planned as part of the adjustment of the current situation, are being carried out, the studied indicators are greatly changed and the measures are taken to affect the soil environment and the cultivated crop are not sufficiently effective. In addition, as indicators, as a rule, only linear characteristics are used, which do not allow making a sufficiently accurate forecast of future changes. Therefore, the lack of effective digital technologies and intelligent tools aimed at assessing and making decisions in real time leads to an ineffective result. The first is the overrun of resources and reduced efficiency in food production. To reduce the risks of crop production under any climatic conditions and crop rotations adopted it is necessary to promptly assess the state of crops and the environment. As part of this study, a technical solution was developed based on the collection of data on the state of crops using unmanned aerial vehicles. The proposed solution allows you to organize an effective integration of information about the full cycle of crop production by collecting data from IoT devices. Each device collects, locally processes
and transmits data on soil conditions and environmental parameters to the coordination center using wireless communication channels.

As a rule, agricultural land has a large extent and occupies a large area. Therefore, for effective data collection in the framework of this study, an approach based on unmanned monitoring of a given territory using robotic means was proposed. The proposed solution will allow:

1. To carry out proactive intellectual management of the state of crops and the soil environment in real time;
2. To increase the productivity and efficiency of processes of precise cultivation of agricultural crops;
3. To increase the productivity of technological agricultural operations;
4. Reduce the risks of agricultural production;
5. Apply in-depth analytics techniques and information conversion algorithms for effective decision making and organization of interaction between objects of robotic systems.

However, to achieve the goals, it is necessary first of all to solve the problem of directly collecting and routing the received data from the terminal devices to the coordination center. For this purpose, in the framework of this work, FANET (Flying Ad Hoc Network) will be used as the data transmission medium. It represents a special type of peer-to-peer self-organizing network operating using unmanned aerial vehicles (UAVs) [1]. The main problem with routing in such networks is a dynamic space-time change in the current position of intermediate nodes, in the role of which UAVs act. In addition, the rapid change in topology and the movement of network nodes in 3D space impose many additional restrictions. As part of this study, an approach is proposed based on the intelligent routing of traffic on the FANET network, which allows for faster decision-making in smart farming systems.

The structure of the article is as follows. In Section 2, we present a summary of the review of work in this area of research. In section 3, we describe the proposed wireless network model used on the UAV. Section 4 presents an intelligent algorithm for predicting the state of channels, taking into account the current position of the UAV network nodes. Then in Section 5, we present the results of a computational experiment. Section 6 completes the work and presents a plan for further research.

2. Related work
A typical scenario for the use of drones in agriculture is to collect data from ground sensors located in the field. To efficiently collect and transmit data from such nodes, it is necessary to organize traffic routing over the wireless channel. In this case, it is necessary to take into account the peculiarities of interaction with a flying node (UAV). Research on the routing of traffic in wireless networks FANET devoted a lot of research. The main focus today is the solution of problems related to the construction of data transmission channels in an unstable environment with a dynamically changing topology.

The paper studies the typical problem of the direct organization of a communication channel between UAVs. In this topology, each driven UAV transmits its data to the main UAV. In turn, the main UAV aggregates the data and transmits them to the ground coordination center. A statistical study of the wireless communication channel between UAVs shows that the number of errors that occur during data transmission is not a constant value. In this case, there is an increase in errors with increasing distance between the UAVs involved in telecommunications interaction. To simulate this behavior of the communication channel, researchers proposed a two-state Markov model to incorporate the effects of fading signals with the Rice distribution [2].

This paper proposes a radio propagation model for FANET [3]. The results obtained are consistent with empirical data. The proposed model estimates the power of the received signal under conditions of multipath propagation, taking into account the effect of signal fading, and is presented as a function of two parameters: the average power value.

Currently, there are quite a few protocols for organizing routing in FANET. One of them is proactive protocol TBRPF (Topology dissemination base on reverse-path forwarding). The advantage of the TBRPF protocol is the ability to pre-construct routes between all network nodes. This allows the decentralized building of logical network topology on each node and forming a local routing table [4]. However, a significant disadvantage of the proactive approach is the redundancy of locally stored information.
The paper proposed a reactive protocol DSR (Dynamic Source Routing) [5]. The DSR protocol is based on the principle of forming routes according to the demand for data transmission channels. Due to the high mobility of nodes in the FANET, maintaining the routing table, as in proactive protocols, is not optimal. To solve this problem, an approach to traffic routing based on the location of network nodes has been developed. The geo-routing protocols meet the basic requirements of FANET. However, studies show low reliability of this type of protocols with a small number of nodes in the network.

On the basis of the well-known proactive OLSR (Optimized Link State Routing Protocol), an international group of scientists has developed a new routing protocol using a directional antenna, called the Directional Optimized Link State Routing Protocol (DOLSR) [6].

One of the most important factors that affect OLSR performance is the choice of multiple MPR (multipoint relay nodes) nodes that have a significant effect on latency. Another variant of the classic remote vector protocol is AODV (Ad-hoc On-Demand Distance Vector) [15]. The protocol builds routing tables on each node of the network to minimize information transfer time between nodes and finds routing paths independently of the use of routes. A number of studies Leonov A.V. and etc. aim to compare the effectiveness of various routing protocols used in FANET. In particular, a comparative analysis of the performance of the AODV and OLSR protocols is carried out using the NS-2 simulator [7]. In another study, the authors modeled the performance of these protocols with respect to network parameters such as packet size, the number of transmitted packets per second, and the number of simultaneously used data transfer sources [8].

Another solution for routing in FANET are hierarchical protocols that have been developed to solve the problem of network scalability. Hybrid routing protocols combine the advantages of reactive and proactive routing protocols that can be used both separately and simultaneously in the same network. The disadvantages of hybrid protocols include the relative complexity of implementation and reduced routing efficiency associated with the need to split the network structure into clusters. One of the most famous hybrid protocols is the Hybrid Wireless Mesh Protocol (HWMP) [9].

One of the main problems in the organization of routing traffic traditional data networks is to ensure the quality of service (QoS) [10]. For FANET wireless networks, this problem is also relevant. To solve this problem in the study [11] proposed to use a number of algorithms based on the use of neural networks. As the criteria for the effectiveness of the proposed solution, the authors point out the following: increasing the speed of distribution of data packets, as well as the delay in obtaining the route. However, a key parameter affecting QoS is network data transfer latency [12].

The FANET network can transmit various types of traffic, including multimedia data, which have specific QoS requirements in terms of bandwidth, delay and / or packet loss. Today, the use of the software-defined network (SDN) concept is one of the effective solutions suitable for this purpose, since it provides visibility of network resources. In their study, the authors propose a routing mechanism for WMSN based on SDN technology, which allows you to predict traffic on the network and configure QoS [13].

FANET applications have many typical limitations, both at the channel and at the network level. Therefore, to organize communication within the group of UAVs, it is necessary to create own and improve existing routing algorithms in order to increase the efficiency of data transmission for FANET networks, taking into account the peculiarities of mobility and node density, topology changes, radio propagation models and localization. The developed routing algorithm should create an effective data transfer route between UAVs, as well as take into account changes not only in the network topology but also in its characteristics.

3. The wireless network model
In order to implement an adaptive data routing algorithm in a wireless network, you must first build a model of the network itself. As a rule, a FANET network can be represented as the following set of components:

- a wireless switching node (BDN), as a rule, is a UAV that performs the role of a switch in a traditional data network, whose task is to organize communication channels between neighboring Dorn of this class, data aggregation point, and UAV data collectors (access node);
- a wireless access node (UDN), performs directly the task of collecting and local data processing for subsequent transmission to the data aggregation point;
- wireless data aggregation (BOD), performs the role of a central FANET network router and is responsible for aggregating traffic from all wireless node switching nodes and their transfer to the terrestrial data storage.

The structure of a wireless data transmission network is usually described using a graph, the vertices of which correspond to the network nodes, and the edges - to the spans on which radio communication is possible between the nodes. In the general case, the edges of such a graph are directed, this is due to the non-stationary state of communication between the nodes. However, the overwhelming majority of wireless networks use a mechanism for confirming data transmission, then we can assume that radio communication is possible only if the communication between the nodes is bidirectional. Therefore, when constructing a graph describing a wireless network, we will use undirected edges connecting the nodes.

In the general case, when solving a routing problem, the graph \( G = (V, L) \) is considered:

\[
G = (V, L),
\]

where \( V \) – the set of graph vertices, the number of which is equal to \( N \), and each vertex models a node (UAV, acting as a traffic router); \( L \) is a set of arcs of the graph, each arc models the connection between nodes. The number of arcs of the graph is equal to \( M \).

Each arc of the graph is assigned a certain weight. In the framework of this study, the weight of a graph edge is understood as a consolidated metric expressed in channel delay:

\[
C = [c_{ij}],
\]

where \( c_{ij} \) – “Cost” of packet transmission between nodes \( i \) and \( j \). In this case, we assume that \( c_{ij} = c_{ji} \).

Note that in this case, the delay is a universal parameter that allows evaluating the many characteristics of the communication channel, including from interference and other negative factors affecting the operation of the wireless network.

Under the path \( P \) from the node \( s \) to the node \( d \) through the vertices of the graph \( n_i, i = 1, N \) we mean an ordered set:

\[
P_{sd} = \{s, n_1, n_2, ..., d\}.
\]

Then, to find the shortest path by criterion \( C \), it is necessary to determine the minimum of the following expression:

\[
\min(\sum_{i=1}^{N} \sum_{j=1}^{N} c_{ij}v_{ij})
\]

where \( v_{ij} \) – the proportion of the intensity of the incoming flow between nodes \( i \) and \( j \).

\[
\sum_{j=1}^{N} v_{ij} - \sum_{j \neq i}^{N} v_{ji} = \varphi_i
\]

wherein \( v_{ji} \in \{0,1\} \), \( \varphi_i = \begin{cases} 
1, & \text{if } i = s \\
-1, & \text{if } i = d \\
0, & \text{in all other cases}
\end{cases} \)

The peculiarity of the structure of the graph of a wireless network is the evaluation of the bandwidth on a node or per cluster (by cluster we mean the totality of a given node and all its neighbors with which a given node can establish a connection). Bandwidth resources of a communication channel, in general, can be represented as a set of communication channels for receiving and transmitting, each of which is characterized by a pair of values: bandwidth and a busy flag indicating whether the given channel can be used to receive or transmit data. In addition to the above values, each channel is characterized by the access method parameter, which can take one of the following values: - dedicated channel — this type of communication channel is used for unidirectional data transfer between a pair of nodes, while access to the resources of this channel to all other network nodes is prohibited; - shared channel - this type of communication channel is an analog of a common bus and is intended for omnidirectional data exchange.
between two or more network nodes; - channel of general type - can be used both as a dedicated and as a shared channel.

4. Intelligent data routing algorithm in a wireless FANET network
The main task of routing is finding all possible acyclic paths from source to destination. This is due to the fact that the reliability of wireless connections is much lower than in traditional wired networks. Therefore, ensuring the availability of a backup path in the routing table allows you to quickly redirect traffic. For the intelligent construction of routes, an algorithm has been developed, which is based on the Lee wave algorithm. When searching, the algorithm builds a chain of routes from the source node to the consumer node, choosing the least busy channel. The principle is as follows: of two dependent routes, a route whose length is shorter is considered more efficient. This limitation is based on the following:

1) shorter route length provides less delay in data transmission;
2) routes are by definition dependent, therefore, always for at least one pair of nodes of one route, there is a corresponding pair of nodes of the set of another route, between which there will be at least one node that is not part of the first route. At the same time, it is obvious that since this pair of nodes is in the line of sight, they would need to occupy exactly n logical channels in order to transmit n traffic channels. If there are one or more intermediate nodes between them, it turns out that they will need to occupy at least 2n logical channels. Of these, n channels for transmitting data from the first of a pair of nodes to the initial node of the flow that occurred, and correspondingly n channels for transferring data from the end node of the resulting flow to the second of the pair of nodes.

Consider the intelligent routing algorithm (IDRAWFN) itself. It consists of the following:
1. At the time of sending data, each source node assigns a zero distance to itself, the wave index is 0.
2. As part of the search for a suitable route to the coordination center, the source node extends the wave to all its neighbors and their distance increases by 1 compared to them (the distance to them is 1 span). The source node builds a list of routes, each route is assigned a unique number, and this number, together with the distance from the source node, is associated with the corresponding node by a neighbor. The wave index increases by 1. In this case, when receiving data about the neighbors, the delay in data transmission between the corresponding nodes is estimated. The corresponding routes are added to the list and ranked according to this criterion.
3. If among the neighbors of the source node there is a node that is a coordination center, then the operation of the routing algorithm for finding paths through this direction stops. This route is recorded in the routing table with a metric equal to the current data transfer delay. At the same time, the search for alternative routes continues to establish all possible options to reach a given wireless network node.
4. If there was no consumer node among the neighbors of the source node, then each of the nodes, the length of the route to which is equal to the wave index, tries to spread the wave to its neighbors.
5. If the neighbor of the node propagating the wave has not been included in any of the routes up to this point and meets the requirements for ensuring the specified throughput, then it is assigned an index equal to the wave index +1. The length of the route in which the node that propagated the wave was included is increased by 1 and the number of this route is saved by the newly marked node.
6. If the neighbor of the node propagating the wave already has an index, then a check is carried out on the independence of the routes to which the neighboring node enters and the route of the node propagating the wave. If the routes are independent, then the node-neighbor is additionally marked with an index equal to the index of the wave +1. The length of the route in which the node that propagated the wave was included is increased by 1 and the number of this route is saved by the newly marked node.
7. If the neighbor node turned out to be the focal point, then the resulting route is marked as completed.
8. After all nodes with an index equal to the index of the wave propagate the wave, the index of the wave increases by 1 and everything repeats from point 4.

The operation of the routing algorithm ends in 3 possible ways:
- the focal point is the neighbor of the source node;
- after the next increase in the wave index, it turns out that there is not a single node with such an index;
- the source node limits the maximum index of the wave to a certain value, after reaching which the search stops.

After completion of the search algorithm, the routing protocol must select one of these routes, optimal according to a given criterion. In the case where the length of the route is more than one span, data can be retransmitted.

5. Experimental research

As part of an experimental study of the proposed algorithmic solution, a comparison was made with the most efficient network routing method (AODV). For experimental studies, the OMNeT ++ simulation environment was chosen, which allows simulating the operation of real wireless communication networks. In the OMNeT ++ environment, a network model was created consisting of 30 wireless nodes randomly located on an area of 1500 m x 1500 m, corresponding to a traditional agricultural field. The following characteristics are specified for the FANET network.

| Table 1. Simulation options. |
|-------------------------------|
| Parameter                      | Value  |
| Simulation time                | 300 s  |
| Bitrate                        | 54 Mbps|
| Maximum value of interference  | 50 m   |
| Packet size                    | 500-1400 bit |
| The size of the delay between nodes | 60-500 ms |

For the exchange of data between nodes in a wireless FANET network, a stream of requests has been formed with a random packet size in the range of 500-1400 bit. The time intervals between packets were 500, 750, 1000 ms using the full mesh topology. Each series of experimental studies was performed sequentially for each of the routing protocols.

| Table 2. Simulation results. |
|------------------------------|
| Parameter                   | 500 ms | 750 ms | 1000 ms | Routing protocol |
| Lost packets                |        |        |         |
| 253 (84%)                   | 104 (34%) | 63 (21%) | AODV    | IDRAWFN |
| Response time in the network|        |        |         |
| 430 ms                      | 220 ms | 87 ms  | AODV    |        |
| 380 ms                      | 175 ms | 75 ms  | IDRAWFN |        |
| Performance routing protocols (route/s) | 750 | 1300 | 1800 | AODV |
| 1720 | 2200 | 2500 | IDRAWFN |

As a result of experimental studies of efficiency, it was found that with a low data transfer rate, the AODV routing protocol and the developed intelligent data routing algorithm behave the same. With an
increase in the intensity of the data flow, the proposed algorithm showed a smaller number of lost packets, and also reduced the response time in the network. However, it is worth noting that the simulation results show that as the load on the network increases, the performance of both approaches to finding routes deteriorates.

6. Conclusion
Experiments have shown that the proposed data transmission scheme allows transmitting messages with the observance of the specified limits on delay and jitter, and also does not allow exceeding the limit on the capacity of the channel used. Experiments also confirmed that the dynamic selection of data transmission routes does not lead to a significant decrease in network performance even under load.

The main direction of further research is the development of algorithms for the dynamic formation of new routes based on virtual channels using the concept of a software-configured wireless network. The ultimate goal of the work is to create a wireless network technology based on SDN, which provides both real-time data transmission and automatic network reconfiguration when changing the modes of drones functioning, including a sharp increase in network response time and a decrease in its capacity due to equipment failures or enhance background noise.

Acknowledgments
The studies were performed in accordance with the R & D plan for 2019–2020 at the Federal State Scientific Institution «Federal Research Centre of Biological Systems and Agro-technologies of the Russian Academy of Sciences» (# 0761-2019-0004).

References
[1] Khare V R, Wang F Z, Wu S, Deng Y and Thompson C 2008 An Ad-hoc network of unmanned aerial vehicle swarms for search & destroy tasks Proc. of the 2008 4th Int. IEEE Conf. Intelligent Systems (IEEE) pp 665–72
[2] Zhou Y, Li J, Lamont L and Rabbath C 2012 Modeling of packet dropout for UAV wireless communications Proc. of the 2012 Int. Conf. on Computing, Networking and Communications (ICNC) (IEEE) pp 677–82
[3] Abualhaol I Y and Matalghah M M 2006 Outage probability analysis in a cooperative UAVs network over nakagami-m fading channels Proc. of the IEEE Conf. on Vehicular Technol. (IEEE) pp 1–4
[4] Luo D and Zhou J 2011 An Improved Hybrid Location-Based Routing Protocol for Ad Hoc Networks Proc. of the 2011 7th Int. Conf. on Wireless Communications, Networking and Mobile Computing (IEEE) pp 1–4
[5] Mule R and Patil B 2016 Proactive source routing protocol for opportunistic data forwarding in MANETs Proc. of the 2016 Int. Conf. on Automatic Control and Dynamic Optimization Techniques (ICACDOT) (IEEE) pp 227–32
[6] Alshabtat A I, Dong L, Li J and Yang F 2016 Low latency routing algorithm for unmanned aerial vehicles ad-hoc networks Int. J. of Electrical and Computer Engineering 6(1) 48–54
[7] Leonov A V and Litvinov G A 2018 Proactive source routing protocol for opportunistic data forwarding in MANETs Proc. of the 2018 Dynamics of Systems, Mechanisms and Machines (Dynamics) (IEEE) pp 1–6
[8] Leonov A V and Ryabchevsky V O 2018 Performance Evaluation of AODV and OLSR Routing Protocols in Relaying Networks in Organization in Mini-Uavs Based FANET: Simulation-Based Study Proc. of the 2018 Dynamics of Systems, Mechanisms and Machines (Dynamics) (IEEE) pp 1–6
[9] Nataraj A B, Maheshappa H D and Devkatte A 2016 Performance analysis of HWMP protocol for Wireless Mesh networks using NS3 Proc. of the 2016 IEEE Region 10 Conf. (TENCON) (IEEE) pp 1593–8
[10] Bolodurina I and Parfenov D 2019 Development Models and Intelligent Algorithms for Improving the Quality of Service and Security of Multi-cloud Platforms Lecture Notes in Networks and Systems 47 386–94
[11] Sharma V and Srinivasan K 2018 QoS-Aware Routing in Wireless Networks Using Aerial Vehicles J. of Internet Technol. 19(1) 073–89
[12] Bacco M, Ferro E and Gotta A 2014 UAVs in WSNs for agricultural applications: An analysis of the two -ray radio propagation model Proc. of the Sensors (IEEE) pp 130–3
[13] Han L, Sun S, Joo B, Jin X and Han S 2016 QoS-Aware Routing Mechanism in OpenFlow-Enabled Wireless Multimedia Sensor Networks Int. J. of Distributed Sensor Networks 12(7)
[14] Costa F G, Ueyama J, Braun T, Pessin G, Osório F S and Vargas PA 2012 UAVs in WSNs for agricultural applications: An analysis of the two-ray radio propagation model Proc. of the 2012 IEEE Int. Geoscience and Remote Sensing Symp. (IEEE) pp 5045–8
[15] Bekmezci I, Sahingo O K and Temel S 2013 Flying Ad-Hoc Networks (FANETs): A survey Ad Hoc Networks 11 1254–70