Simulation-Based Packet Delivery Performance Evaluation with Different Parameters in Flying Ad-Hoc Network (FANET) using AODV and OLSR

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Abstract. The article examines node connectivity as one of the most significant quality characteristics of any information and telecommunication network. The article is aimed to determine FANET parameters providing PDR (Packet Delivery Ratio) more than 90% for the specified area. All results were received on the basis of the experimental study. Imitation modeling based on an ns-2 network simulator was applied as a research method. Characteristics of the network based on the simulation model utilizing the AODV and OLSR routing protocols have been evaluated. The authors studied also the connectivity dependence on such network parameters as the nodes number and the transmission range.

1. Introduction

Unmanned aerial vehicles (UAVs) have been quickly improving and are widely used, while wireless data transmission technologies are also being developed rapidly. All this underlies the appearance of the new communication networks types. One of these communication networks is Flying Ad-Hoc Network – FANET [1].

It attracts specialists’ attention because it is a convenient platform for solving various tasks, mostly related to the territories survey and facilities monitoring (see Fig. 1).

![Figure 1. Example use of FANET in traffic monitoring.](image)

Indeed, FANET represents a decentralized self-organizing network. Its nodes not only provide the link with their neighbors, but they also forward the traffic passing through them.
2. FANET

Recently the world scientific society has been investigating the concept of using a UAVs group to form UAV ad hoc network. This network will be able to perform one or more tasks. FANET started to be researched and deployed intensely in the civilian sector almost at the same time as a mini-UAV separate class was popularized [2]. This class is a multi-rotor system with an electric power unit.

A high level of node mobility is characteristic of FANET; it is well over that of the other self-organizing networks such as MANET (Mobile Ad Hoc Network) and VANET (Vehicular Ad Hoc Networks) (see Fig. 2). Consequently, the network topology changes frequently and rapidly.

![Figure 2. MANET, VANET and FANET.](image)

As for the distances between nodes, in FANET, they are usually greater than in VANET or MANET [3]. Thus, to organize UAVs connectivity, a longer range of communication should be provided, which in its turn will have an effect on the radio channel nature and the equipment choice.

2.1. Network topology

In terms of topology, FANET is a distributed, peer-to-peer and multiply connected network, which nodes connect “on the fly” following the "with each other" principle. It allows high availability to be achieved, while a large number of links between UAVs gives a wide choice of traffic routes inside the network. This topology allows the task completion area to be expanded by data broadcasting, and the maximal broadcasting time to be increased (up to round-the-clock) by successive or gradual UAV replacement [4].

Besides, when one or several UAVs are disabled, intentionally or unintentionally, FANET enables an improved network survivability by rearranging the network topology automatically.

2.2. Routing

The routing protocols utilized in FANET are required to feature the automatic search for the best route (route group) to provide one or several qualitative parameters for the process of data transmission and reception. Thus, one of the major tasks in FANET is to search for the route or the route group among the network nodes. Moreover, such route parameters as connectivity (the route quantity), route length (the number of hops or iterations in the route) and transit nodes share (the network nodes involved in routing), influence the traffic performance in the network [5].

During the investigation, the most widespread and widely used routing protocols in FANET were used on the network level, that is reactive protocol AODV (Ad hoc On-Demand Distance Vector) RFC 3561 and proactive protocol OLSR (Optimized Link-State Routing) RFC 3626 [6].

2.3. AODV

In the reactive protocols, the node looks for the path to the destination point only when it has a packet to deliver. To make a link, the node either uses an existing route or creates a new one based on the data about available channels. AODV protocol adapts quickly to dynamically changing network links [7]. Its overhead costs for data processing and storage and low, and initialization time is short. The sequence number mechanism is used in AODV to delete routing loops. Low, moderately and relatively high mobile nodes can be
manipulated and a mixed type of traffic is supported by this protocol. Dynamic multiply connected routing with possibility of “self-starting” is realized in an AODV algorithm. In AODV, routes to new destinations are received quickly and the routes to inactive nodes are not required to be supported.

The distinctive feature of this protocol is the utilization of the recipient sequence number for every cell in the routing table. The sequence number is generated by the recipient itself and, together with the other data, it is sent by the route to the destination node. Sequence numbers usage provides freedom from loops and it does not make programming more complex. When choice should be made between two routes, the node must select the one with the largest sequence number.

2.4. OLSR

Proactive protocols are supposed to provide routing tables on each node, and these tables include routes for reaching any network subscriber. To maintain the data integrity and reliability related to the network structure, the nodes in such protocols exchange control messages. OLSR is a variation of a classical link state routing protocol according to the requirements of ad hoc network [8]. The concept of MultiPoint Relay (MPR) underlies OLSR. This paradigm lowers the transmitted data amount significantly as compared to a traditional broadcast process with each node forwarding the arriving messages to all its neighbors.

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3. Problem statement

The concept of FANET utilization revealed a lot of problems to researchers and scientists. Their solution has been widely investigated by an increasing number of scientific groups recently.

One of the major problems is the loss of connectivity. The connectivity represents the ability to deliver data from the source node to the destination. Mini UAVs can travel with high speed (up to 60 m/s) [9], and during this movements working nodes can be switched off and new ones can be connected. Hence the network topology is prone to fast and frequent variations. So there are the transmitted data delivery routes [10].

The FANET communication nodes area is limited by the antenna parameters, the transmitter and noise powers and other transmitters jamming [11].

3.1. Connectivity

Let us assume that connectivity depends on the distance between nodes, while the node transmission range represents a 2D disk with the radius R and uses omnidirectional antennas having a circular pattern. Two nodes are considered as connected if they can transmit and receive the data from each other directly or via other nodes. Otherwise, the data transfer service is not available between the nodes [12] (see Fig. 3).
The nodes number depends on the specific network purpose, and it is likely to be selected based on the connectivity. However, the network nodes may change their location at the time of operation and break down. Thus, the nodes distribution can be supposed to be random, just like the connectivity [13].

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3.2. Connectivity probability determination

The generalized Erdos-Renyi model allows us to describe the connectivity probability of random graph $G = \{V_n, E\}$. A graph containing nodes $V_n = \{1, ..., n\}$ sets the network model, and an edge between vertices $i$ and $j$ in the graph is specified with probability $p_{ij}$, where $E$ is the random quantity of edges in the graph [14].

Then, the probability space is defined in the following way:

$$G(n, p_{ij}) = \left(\Omega_n, F_n, p_{n,p_{ij}}\right)$$

where:

$$\Omega_n = \{G = G(V_n, E)\},$$
$$F_n = \{G = G(V_n, E)\},$$

$$p_{n,p_{ij}}(G) = \prod_{(i,j) \in E} p_{ij} \prod_{(i,j) \notin E} (1 - p_{ij}).$$

If one captures some graph $G(H_n, p)$, $H_n = \{V_n, E_n\}$, where:

$$p_{ij} = \begin{cases} p, & (i,j) \in E_n \\ 0, & (i,j) \notin E_n \end{cases}$$

$$p_{n,p_{ij}}(G) = p^{[E]}(1 - p)^{[E]}$$

where $[E]$ is mathematical expectation of the edges number in a graph, then for the random graphs described according to this model, there is a known theorem stating that $p = \frac{c \ln n}{n}$, where $c$ is a constant, then for $c < 1$ the graph is almost never connected, and for $c > 1$, it is almost always connected.

In fact, expression $p = \frac{\ln n}{n}$ determines the edge probability threshold. If it is exceeded, the network is connected with a probability higher than 0.5 [15].

For sufficiently large $n$ and $c$, one may estimate the probability of the graph connectivity as:

$$P_{n,p}(G) = 1 - \frac{1}{n}.$$
4. Experiment
Since there are no available real UAVs, and to generate a real FANET scenario requires as much resources as there are people, the network simulator was utilized to perform UAVs movement and to enable communication between them.
The network environment that is maximally close to the real world one must be proposed in the simulation task. Taking this into account, one should try to find real-life scenarios of FANETs utilization. The current section describes the air-to-air scenario that was utilized in the simulations. Next the experimental setup including the parameter setting for ns-2 simulation will be presented [16].

4.1. Performance Metric
To estimate the different configurations fitness or quality (tentative solutions), a communication cost function was defined with the use of a wide-spread metric for this area, that is the packet delivery ratio (PDR) [17].
Packet delivery ratio (PDR). Some data packets are generated by an application and delivered by a routing protocol [18]. A data packet is taken as delivered when it is received by the destination node in full and without damages.

\[
PDR = \frac{\sum_{i=1}^{n} \text{receivedCBR}_i}{\sum_{i=1}^{n} \text{sentCBR}_i} \times 100
\] (4)
where \( \text{receivedCBR} \) is all packets received by the receiver successfully, \( \text{sentCBR} \) is all packets produced by the senders.

4.2. Scenario
Following this idea, a FANET sample was generated by mapping an area of 3,600×1,200 m\(^2\) [19]. A rectangular space was chosen to urge the utilization of longer routes between the nodes than possibly occurring in a square space, with the node density being equal.
Air-to-air wireless communications [20]: The communication between the ground base stations and UAVs sets a number of constraints on the transmission ranges. To avoid them, UAVs are able to connect with each other over pure ad hoc architecture. Moreover, one can use such wireless communication when supporting multi-hop communications and different applications whenever the data packet should be transmitted to another node outside of the range. Such topology is applicable in the analysis of the node density effect on the performance.
The radio signal transmission-reception is assumed to be stable, and all UAVs transceivers have identical settings. Under ideal conditions the network nodes are within the line of sight (LOS), that is without obstacles, and without multiple possible paths of signal transmission and refractions [21]. To simulate the Atheros AR9344, the network interface physical radio characteristics for each mobile node were selected, including the receiver sensitivity, the antenna gain and transmission power [22].

4.3. Mobility Model
Being a general-purpose network simulator, ns-2 does not provide a way of direct realistic FANET simulations definition, with the nodes following the UAVs behavior. The Random Waypoint (RWP) model was used for this problem solution to create realistic mobility models (Fig. 4). This model is applied in the majority of simulation scenarios to create multiple movements with straight trajectories. In these scenarios, each node chooses a random destination, then it moves with a random velocity and pause time at the destination. When the pause time ends, a random destination is chosen by the node again with a random velocity and an analogous pause time on the basis of fixed probabilities [23].
A number of UAVs (from 30 to 150) are applied in the simulation with specified UAVs direction/speed changes. During the simulation we considered different levels of UAV density, UAV velocity (between 0 and 60 m/s), and network activity (from 15 to 75 connections).

### 4.4. Traffic Generation Model

In this FANET scenario, a specific data flow representing various possible communications precisely was specified. The data flow model runs from 15 to 75 cycles of the CBR (Constant Bit Rate) network application via UDP source agents built in UAVs, thus interconnection between each other is realized by our mobility model. CBR data packet size is 512 bytes, while the packet rate is 10 packets per second [24]. For future recreation purposes Table 1 includes the other simulation parameters. A fixed data rate was selected because our objective was not to investigate the maximum throughput, but to study the AODV and OLSR abilities to locate and keep routes successfully.

### Table 1. Simulation Parameters In NS-2

| Parameter                | Value                  |
|--------------------------|------------------------|
| Simulation time          | 300 s                  |
| Simulation area          | 3,600×1,200 m²         |
| Number of UAVs           | 30, 50, 100, 150       |
| UAV speed                | 0-60 m/s               |
| Propagation model        | Friis                  |
| Radio frequency          | 2.437 GHz              |
| Channel bandwidth        | 6 Mbps                 |
| Antenna model            | Omni                   |
| Mac protocol             | 802.11g                |
| Transmission range of UAVs | 250, 500, 750, 1000  |
| Routing protocol         | AODV (RFC 3561), OLSR (RFC 3626) |
| Transport protocol       | UDP                    |
| CBR data flow            | 15, 25, 50, 75         |

TCP sources were not applied as TCP offers the network a conforming load, which means it alters times of sending packets based on its evaluation of the network ability to transmit packets. As a result, the protocols differ both in the times of data packet origination performed by its sender and in the node position when the packet is transmitted, thus making a direct comparison between them impossible [20].

### 4.5. Experimental Settings

The simulation phase is performed by running an ns–2 simulator (version ns–2.34) based on the UM-OLSR (ver. 1.0 patch) implementation of OLSR. Five separate runs of each optimization method were made on Lenovo ThinkStation P320 SFF with Intel Xeon vPro E3-1245 v6, 16 GB of RAM, and O.S.
Ubuntu Desktop 16.04.3 LTS 64-bit.
A different UAV mobility and interactions are used by each single iteration, based on independent random sources inside each simulation, hence contributing to the generalization of the results.

5. Modelling results

5.1. Packet Delivery Ratio
In the simulation results analysis we obtained the dependencies of the network connectivity providing PDR>90% on the network parameters. Figures 5 and 6 demonstrate simulation modelling results of 30-node network with the UAV transmission range of 250-1000 m with 250 m increments.

![Figure 5. AODV protocol PDR dependence on the transmission range and velocity for 30 nodes.](image-url)
Figure 6. OLSR protocol PDR dependence on the transmission range and velocity for 30 nodes. Figures 7 and 8 show AODV and OLSR protocols PDR dependence on the nodes number, a transmission range and velocity for 50 UAVs with a node transmission range of 250-1000 m in increments.

Figure 7. AODV protocol PDR dependence on the transmission range and velocity for 50 nodes.

Figure 8. OLSR protocol PDR dependence on the transmission range and velocity for 50 nodes. Figures 9 and 10 represent the imitation modeling results for the 100-node network for AODV and OLSR protocols with a UAV coverage radius in the range of 250-1000 m with 250 m increment.
Figure 9. AODV protocol PDR dependence on the transmission range and velocity for 100 nodes.

Figure 10. OLSR protocol PDR dependence on the transmission range and velocity for 100 nodes.

Figures 11 and 12 show PDR dependence on the nodes number, a transmission range and velocity for 150 nodes in AODV and OLSR protocols. The UAV transmission range changes from 250 to 1000 m at 250 m interval.
Figure 11. AODV protocol PDR dependence on the transmission range and velocity for 150 nodes.

Figure 12. OLSR protocol PDR dependence on the transmission range and velocity for 150 nodes.

The results shown in Fig. 7, 8, 9, and 10 demonstrate that with 50 and 100 UAVs, connectivity providing the required PDR level was achieved.

It follows from the data presented in Fig. 7 and 8 that sufficient connectivity probability can be guaranteed by a smaller number of UAVs.

The desired PDR values were achieved with the used simulation settings and network configuration. As the simulation results demonstrate, the transmission range should be $R = 500$ m and UAVs number should be from 50 to 100, to guarantee the required connectivity between nodes. The diagrams in Fig. 9 and 10 demonstrate that a further increase in the nodes number does not improve the quality indicators. Therefore, one may assume there is an optimal UAVs number, as well
as the transmission range for the chosen network topology, data transmission technology and traffic parameters.

5.2. Dropped Packets

There are a number of reasons for packet loss in FANET. Dropped packets represent a significant issue, which can be caused by many factors, e.g. network topology, node mobility, link interferences and network overload.

Dropped Packets: packet loss takes place in a network if one or several packets travelling through a network cannot reach their destination. One may estimate the total number of packets dropped during the transmission as follows:

\[
\text{Dropped Packets} = \sum_{i=1}^{n} \text{SCBR}_i - \sum_{i=1}^{n} \text{RCBR}_i
\]  

(4)

where \( \text{SCBR} \) is Sent Constant Bit Ratio; \( \text{RCBR} \) is Received Constant Bit Ratio.

In a wireless ns-2 model, packets are dropped due to several reasons. Data in Table II explain these reasons [25].

| MAC LAYER | Explanation of Packet Drop |
|-----------|----------------------------|
| COL       | Collusion                  |
| DUP       | Duplicate                  |
| ERR       | MAC Error                  |
| STA       | MAC State invalid          |
| BSY       | MAC Busy                   |
| RET       | Retry Count Exceed         |

| ROUTER LAYER | Explanation of Packet Drop |
|--------------|----------------------------|
| LOOP         | Loop on Route              |
| TOUT         | Time Out                   |
| IFQ          | Interface Queue Full       |
| ARP          | ARP Queue Full             |
| OUT          | Outside Subnet             |
| CBK          | Call Back                  |
| TTL          | Time to Live               |
| NRTE         | No Route Exceed            |

| GENERAL |
|---------|
| END     | Simulation End             |

Figures 13, 14, 15, and 16 illustrate the congestion that occurs due to the buffer overload at the Interface Queue (IFQ) level for 50 and 100 UAVs.
Figure 13. Dropped packets for 50 nodes of AODV protocol.

Figure 14. Dropped packets for 50 nodes of OLSR protocol.
The node becomes a bottleneck when the packets arriving at the node have a higher rate than it can transmit. If this is the case, a large number of packets are dropped at the IFQ buffer, which leads to a throughput reduction. An overload control mechanism is needed to solve the issue. The flow rate must be adjusted to reduce the excess packets number and to control the network overload for reducing the packet losses and improving network performance.

Figures 13, 14, 15, and 16 demonstrate the absence of the packets dropped due to the ERR, STA, BSY, TOUT and OUT, and drops due to the COL are few in number.

Even though in most cases packets are dropped because of Callback (CBK) and No Route Exceed (NRTE), dropped packets appear on the MAC layer if after the 7th attempt of RTS (Request To Send)
it receives no CTS (Clear To Send) message. In such case, the MAC layer activates the router layer because RTS RET signifies that the destination node is unavailable, which in its turn means that a break is on the previously found route to destination. If this is the case, the router layer can drop all packets in its queue. In the ns-2 simulation trace file, it is called as CBK. In addition, the route layer does not send packets anymore, and the route establishment procedure is initiated.

Even if the node begins the route establishment procedure, there are still some neighboring nodes able to send packets directed to a broken link to this node. When such packet arrives at the node, it may be dropped because there is no route. This is called NRTE.

The queries from Link layer arrive at the Address Resolution Protocol (ARP) module that translates the hardware addresses into the network one. If the hardware address for destination exists in ARP, it is recorded into the MAC header of the packet. Elseways, an ARP query is transmitted, and the packet is temporarily moved to cache. Every unknown destination hardware address has a buffer for a single packet. If ARP receives additional packets to the same destination, the packet that has been buffered before is dropped. When the hardware address for the packet's next hop is known, the packet is put into the interface queue.

Each packet has a TTL value (according to RFC 791 [26] / RFC 1812 [27]). If the waiting time is longer than TTL, the packet will expire. As the nodes number in the entire system increases, contention is higher for a model based on contention, resulting in more dropped packets. In the proposed model, when the nodes number rises, the packet waiting time rises too since the slot number is fixed. More dropped packets result, because the TTL value of packet expires (see Fig. 14, 16).

6. Conclusion
FANET is the initial step towards cost-effective self-organizing networks. FANET Imitation modeling in the ns-2 simulator, undertaken for the present research, demonstrated OLSR protocol operability. Connectivity has several definitions, and their common element is that two nodes are called connected if there is some criterion above the threshold. The authors defined the connectivity in FANETs in terms of quality of service (QoS) metric, namely, packet delivery ratio.

The simulation results showed that FANET connectivity with PDR>90% is achieved when the nodes number is 50 and 100, while their transmission range is 500 m.

The factor affecting UAV ad hoc network connectivity was experimentally proven to be the nodes number distributed over the area and their transmission range.

However, there is also a need to rework the model to make it closer to the real network. This can be achieved by setting "background" relevant traffic from other nodes, taking into account administrative traffic, not related to routing, utilizing real video files as generated video traffic, and so on.

It seems useful to introduce routing protocols, more modern and adapted for FANET, in a simulation model.

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