УДК 621.391
DOI: 10.22213/2413-1172-2021-4-73-79

QoS Analysis of Video Streaming in the UAV Networks with WiFi Standards*

K.E. Korepanov, Master's Degree Student, Kalashnikov ISTU, Izhevsk, Russia
I.A. Kaisina, PhD in Engineering, Kalashnikov ISTU, Izhevsk, Russia
R.E. Shibanov, Master's Degree Student, Kalashnikov ISTU, Izhevsk, Russia
A.V. Abilov, PhD in Engineering, Associate Professor, Kalashnikov ISTU, Izhevsk, Russia
M.A.Lamri, Post-graduate, Kalashnikov ISTU, Izhevsk, Russia

The paper presents the results of simulation of the process of video data transmission from an unmanned aerial vehicle (UAV) to a ground station using the IEEE 802.11 family standards (802.11n, 802.11ac and 802.11ax), with the ability to change modulation indices, coding schemes and data transfer rate in a network simulator NS-3. The aim of the work is to analyze the characteristics of the quality of video data transmission in the UAV network for various Wi-Fi standards, which allows determining the most suitable standard for the transmission of video data in the UAV network, depending on the distances between nodes and the required frequency band.

A scenario is considered in which an unmanned aerial vehicle (UAV) hovering in the air was transmitting a video stream to a ground station, while the distance between nodes increased, and the transmission rate was maintained at the same level close to the transmission rate of the real video stream. The simulation was carried out in several stages for a more detailed study of the dependence of the packet loss of the transmitted data on the change in modulation indices, coding schemes and other parameters. Based on the simulation results, the characteristics of the video data transmission quality were obtained as a relation between the Packet delivery rate (PDR) and distance between nodes for different transmission parameters for each considered standard of the IEEE 802.11 family. Based on the results obtained, conclusions were drawn about the influence of transmission parameters on the quality of service characteristics.

The study was carried out in an open-source network simulator NS-3, which implements build-in libraries that are necessary for high-quality simulation of data streaming transmission and allows you to set a wide range of parameters to obtain realistic results. The results of the work may be of interest to UAV manufacturers when planning missions in which the choice of Wi-Fi standard used as a channel for transmitting video data is crucial.

Keywords: unmanned aerial vehicle, NS-3, Wi-Fi, MCS, data transmission, FANET.

Introduction

Currently, unmanned aerial vehicles (UAVs) are becoming more and more popular and in demand [1]. One of the most important tasks in this area is to provide reliable wireless communication between the UAV and the ground station. In scientific works, communication in self-organizing networks of UAVs (Flying Ad Hoc Networks - FANETs) is considered, but in practice such an application scenario is difficult to implement and requires high costs, therefore, as a rule, a bundle of "one UAV - one ground station" is used [2, 3]. In this scenario, the connection can be made using cellular or satellite communications, wireless networks of Wi-Fi standards, and other methods. In scientific research, the use of standards of the IEEE 802.11 family is often considered due to the low cost and frequent use in microcomputers (for example, Raspberry Pi), which also does not require special expensive equipment or specialized communication channels [4, 5]. Evaluation of the work and study of the parameters of these standards can be carried out in the network simulator NS-3, since it is publicly available and is able during the simulation to produce data close to real scenario [6]. The work focuses on the most common standards of the IEEE 802.11 family, such as 802.11n, 802.11ac, 802.11ax. The NS-3 network simulator is used to study their behavior when changing parameters such as modulation indices, coding schemes, and data rate [7]. The developed programs for the NS-3 network simulator are able to simulate data transmission in a given scenario according to the mentioned Wi-Fi standards, taking into account changes in modulation, network and data flow parameters [8].

Simulation of data transmission with Wi-Fi

The NS-3 Network Simulator is a discrete event network simulator designed primarily for research and teaching purposes. It has a wide range of software tools for performing simulations of all kinds. In particular, the simulator is able to simulate data

* This research was funded by Russian Foundation for Basic Research (RFBR), grant number 19-29-06076.

transmission using cellular and satellite communication standards, as well as using other wireless communication standards. Many scientific papers present the results of modeling in NS-3 standards of the IEEE 802.11 family, since this simulator covers all standards of this family and allows you to fine-tune the parameters of the communication channel necessary for the implementation of the simulation scenario under the given conditions [9].

The IEEE 802.11 family defines the protocols required for wireless local area networks (WLAN). There are many standards in this family. By far, the most common and modern are 802.11n, 802.11ac, and 802.11ax. With each new generation, there is an improvement in the quality of communication and an increase in the speed of data transmission [10]. The actual physical or channel data rate for each standard is set by parameters such as modulation indices and MCS (Modulation and Coding Scheme) coding scfhemes. In NS-3, MCS is given by a number that is assigned to each modulation option. Each modulation option takes into account the following characteristics [11]:

- type of radio frequency modulation (Type);
- coding rate;
- guard interval (Short Guard Interval);
- the value of the baud rate.

In the NS-3 network simulator, the list of possible modulation indices and MCS coding schemes is defined in the *wifi-phy.h* library, with examples of their correct recording for each standard of the IEEE 802.11 family [12]. All standards of the 802.11 family are defined in the *wifi-standards.h* library and have common parameters that you can configure for various scenarios in order to obtain the most accurate and realistic simulation results, for example: transmitter and receiver power, receiver sensitivity, noise level, transmission channel width , signal frequency, number of antennas, channel number, transmitter and receiver gains, packet sizes and their number during transmission, time interval between packets [13, 14].

Tables 1, 2 and 3 show the parameters set in the NS-3 network simulator to study the characteristics of the data transmission quality according to the standards 802.11n, 802.11ac and 802.11ax.

Table 1. **Parameters for the WiFi 802.11n**

Parameter	TxPower Start, dBm	TxPower End, dBm	RxNoise Figure, dBm	Channel Width, MGHz	Frequency, kGHz	Antennas	Channel number
802.11n 20 MGHz	13	13	7	20	2412	1	9
802.11n 40 MGHz	13	13	7	40	5180	1	9

Table 2. **Parameters for the WiFi 802.11ac**

Parameter	TxPower Start, dBm	TxPower End, dBm	RxNoise Figure, dBm	Channel Width, MGHz	Frequency, kGHz	Antennas	Channel number
802.11n 20 MGHz	13	13	7	80	5210	1	42

Table 3. **Parameters for the WiFi 802.11ax**

Parameter	TxPower Start, dBm	TxPower End, dBm	RxNoise Figure, dBm	Channel Width, MGHz	Frequency, kGHz	Antennas	Channel number
802.11n 20 MGHz	13	13	7	80	5230	1	1

In accordance with the *wifi-phy.h* library, MCS indices are recorded in the NS-3 network simulator with attributes defined for each standard under the *Phy-entity* class. The 802.11n standard uses the HT (High Throughput) attribute - HtMcsN, where N is the MCS index from 0 to 31 [15, 16]. In the course of modernization and improvement of the standards of the 802.11 family in the version 802.11ac, the number of MCS indices was increased, which gives a greater number of connection rates, modulation and coding schemes [17]. 802.11ac MCS indexes are written with the VHT (Very High Throughput) attribute - VhtMcsN, where N is the MCS index [18].

Compared to previous standards, in version 802.11ax a new type of signal modulation appears, which is accompanied by the appearance of more MCS indices. For 802.11ax, indices are written with the attribute HE (High efficiency) - HeMcsN, where N is the MCS index [19]. Table 4 show parameters for all MCS indexes.

Simulation scenario

To simulate the process of data transmission from the UAV to a ground station using different Wi-Fi standards, several programs have been developed for the NS-3 simulator. Figure 1 shows a data transmission scenario where a source node (UAV) and a destination node (ground station) are at some distance D from each other. In the process of transferring data from the source node to the destination node, the distance between them is changed. As the distance increases, data packets are lost at a certain distance and, as a result, image quality deteriorates.

Table 4. **MCS parameters**

MCS index	Spatial stream	Modulation	Coding	802.11n 20 MGHz	802.11n 40 MGHz	802.11ac 80 MGHz	802.11ax 80 MGHz
0	1	BPSK	1/2	6.5	13.5	29.3	36
1	1	QPSK	1/2	13	27	58.5	72.1
2	1	QPSK	3/4	19.5	40.5	87.8	108.1
3	1	16QAM	1/2	26	54	117	144.1
4	1	16QAM	3/4	39	81	175.5	216.2
5	1	64QAM	2/3	52	108	234	288.2
6	1	64QAM	3/4	58.5	124.5	263.3	324.3
7	1	64QAM	5/6	65	135	292.5	360.3

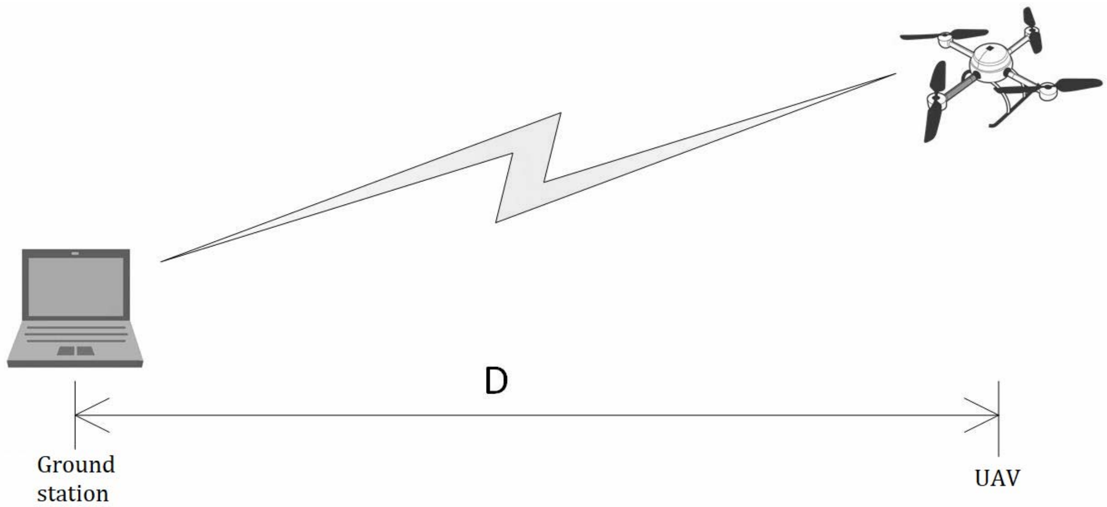

Fig. 1. Scenario of data transmission from one source to ground station

For each WiFi standard, during simulation at different distances between nodes, the Packet-Delivery Rate (PDR) was measured, equal to the ratio of the number of received packets to the number of sent packets (for a sample of measurements - 1000 packets).

$$PDR = \frac{Rx}{Tx}, \quad (1)$$

where Rx - received packets; Tx - sent packets.

The data transfer rate was maintained at the same level for each experiment (≈ 3 Mbit / s). This value corresponds to the approximate real-world FHD video bit rate for more realistic simulation results. To establish the data transfer rate, it is necessary to set a certain interval between packets for each MCS index, which is calculated using the following formula:

$$\text{Interval} = \frac{1 - \left(300 \frac{\text{MaxPackets}}{V_{\max}}\right)}{300}, \quad (2)$$

where $V_{\max}$ is the maximum transmission rate for a given MCS index; MaxPackets - the number of packets sent [20].

QoS evaluation of data streaming

Simulation modeling of the video stream transmission process was carried out in 2 stages. For each MCS index with the considered standards of the family with a given transmission interval between packets. During the first stage, an approximate distance between nodes was determined. As a result, a decrease in the PDR packet delivery rate was observed. During the second stage, the segment of the distance was investigated in more detail to obtain a more accurate dependence of the PDR characteristic on the distance between the nodes. The results of PDR measurement at different distances between nodes when 1000 packets were transmitted from source node to destination node are shown in figure 2.

Figure 2 shows the results of measurements in the form of the dependence of the PDR characteristic on the distance (D) between nodes for the 802.11n standard with a bandwidth of 20 MHz with various MCS parameters. The analysis of the most intense section of PDR was carried out by increasing the distance with a 5 meters step from the initial point of the PDR were it was equal to 0.

According to the results in Fig. 2 it is clear that with an increase in MCS, the distance at which a decrease in PDR occurs decreases, which is a consequence of an increase in the maximum data rate with an increase in the MCS index. It is also worth highlighting the sharpness of the decrease in PDR, which becomes larger with each increase in the MCS index. So, for MCS = 0, the PDR begins to decrease at 640 meters and occupies a distance of 95 meters, for MCS = 1, the PDR begins to decrease at 470 meters and occupies an area of 60 meters, and so on.

Figure 3 shows the results of measurements as a relation between PDR characteristic and the distance between nodes for the 802.11n standard, with a bandwidth of 40 MHz with various MCS parameters. The analysis of the PDR reduction in this case was carried out similar to the results for 802.11n at 20 MHz.

The results in Figure 3 show a similar sharp drop in PDR at certain parts of the distance D. But in this case, the decrease in PDR at each MCS index begins at a shorter distance from the ground station, which is explained by the increase in the maximum speed due to the increase in channel width from 20 MHz (Figure 2) up to 40 MHz (Figure 3).

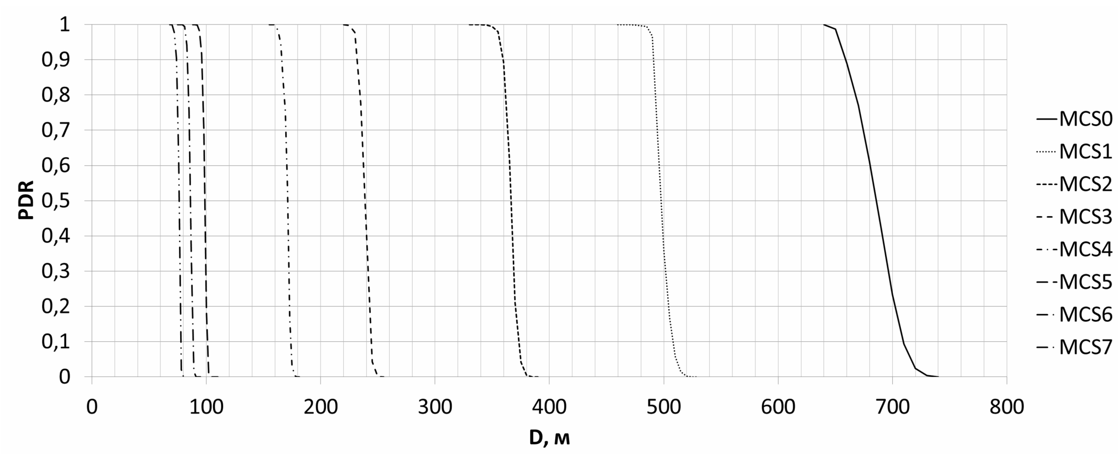

Fig. 2. PDR for 802.11n at 20MGHz, MCS 0-7

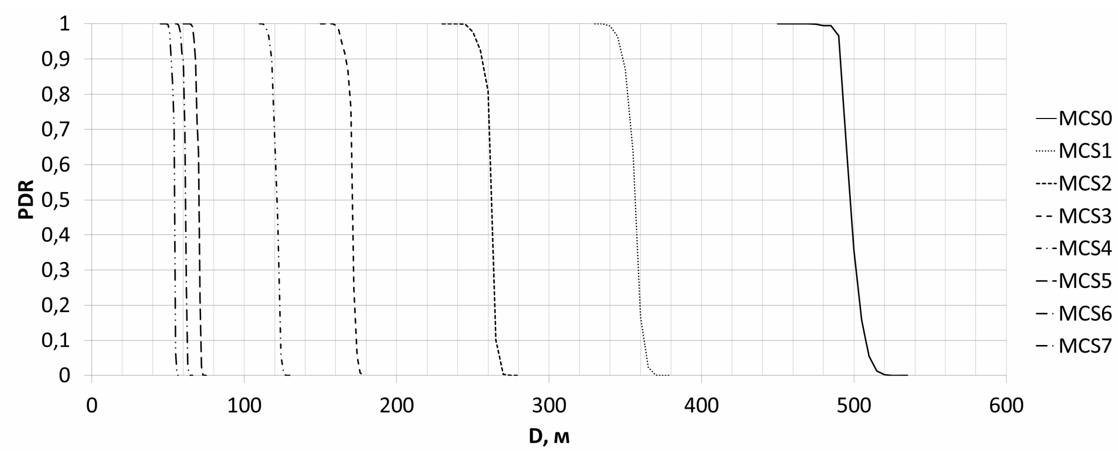

Fig. 3. PDR for 802.11n at 40MGHz, MCS 0-7

Figure 4 shows the results of assessing the quality of data transmission for the 802.11ac standard. In this case, the analysis of the dependence of PDR on distance was carried out with a step of 2 m, since due to an increase in the maximum data transfer rates in the standard under consideration, the PDR reduction sections occupy even narrower sections of the distance.

The results in Figure 4 are similar to the previous ones in form. But the decrease in PDR begins closer to the ground station, which is due to the greater bandwidth, in contrast to the 802.11n standard, and the increase in the maximum speeds in the 802.11ac standard. The results of the study of the characteristics of the data transmission quality for the 802.11ax standard are presented in Figure 5. The analysis of the PDR reduction sections was carried out similarly to the 802.11ac standard.

The results in Figure 5 are slightly different from those in Figure 4 due to the same 80 MHz bandwidth for both 802.11ax and 802.11ac.

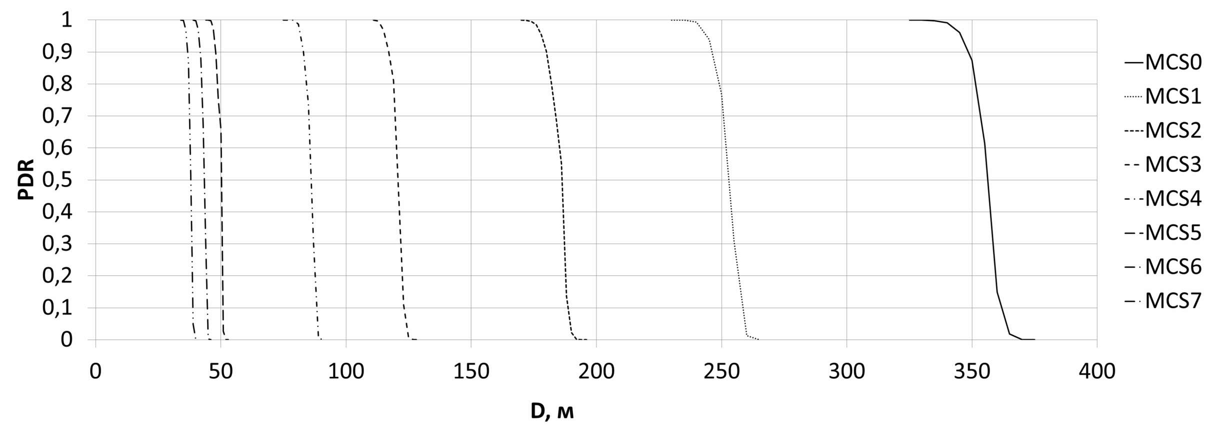

Fig. 4. PDR for 802.11ac at 80MGHz, MCS 0-7

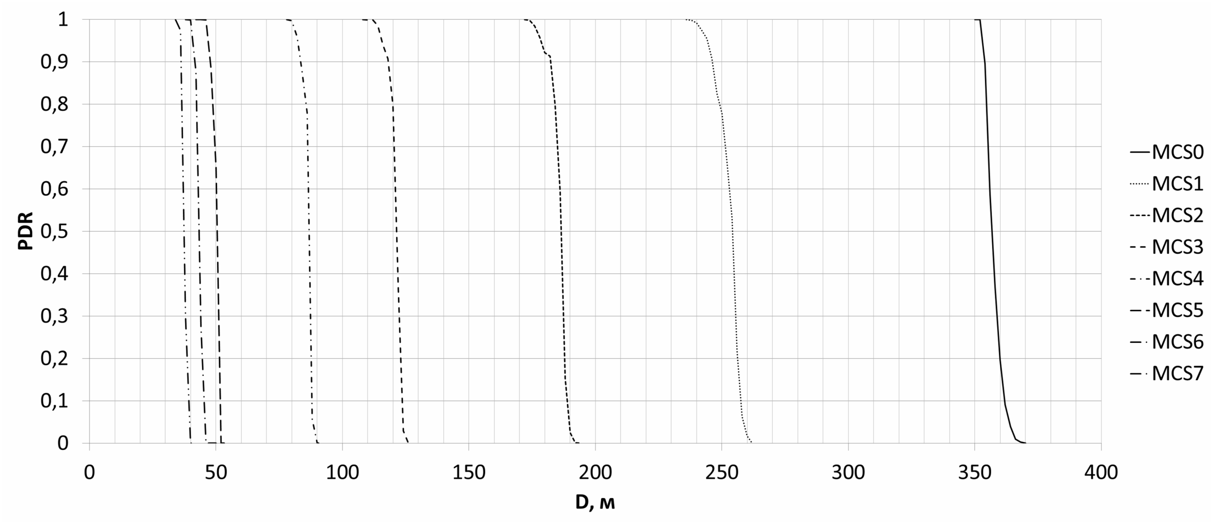

Fig. 5. PDR for 802.11ax at 80MGHz, MCS 0-7

The obtained numerical characteristics of the quality of transmitted data, allows for different Wi-Fi standards in a UAV network to determine the most suitable standard depending on the distances between nodes and the required frequency band.

Conclusion

Computer programs have been developed for simulating the process of transmitting video data from an UAV to a ground station in an NS-3 network simulator environment using the IEEE 802.11 family standards (802.11n, 802.11ac and 802.11ax). The programs allow to change modulation indices, coding schemes and data rates. Based on the results of simulation modeling, the influence of changes in the MCS index on PDR was investigated for all 802.11 proposed standards. So, for the studied Wi-Fi standards with the minimum index MCS = 0, the distance at which the PDR decrease occurs varies from about 350 to 750 meters, while for MCS = 7 this value is in the range from about 30 to 70 meters. This indicates a significant impact of the used Wi-Fi standard on the range of stable transmission of data streaming.

Obviously, as MCS grows, the distance at which stable streaming is provided decreases, while more modern Wi-Fi standards have a shorter distance compared to previous standards. This can be explained by an increase in the maximum data rate due to more advanced communication protocols, modulation types and coding schemes. As the data transfer rate increases, external interference and data loss have a greater impact on the transmission quality. As a result, the distance at which the recipient is able to fully receive and process data decreases. This decreasing will lead to packet loss decreases from its part. The results obtained make it possible to determine the most suitable standard depending on the distances between nodes and the required frequency band and will be useful in the future for creating new algorithms for transmitting streaming data in UAV networks, designed to improve the quality of communication and reduce the loss of transmitted data.

References

1. Khorov E.A tutorial on IEEE 802.11 ax high efficiency WLANs. *IEEE Communications Surveys & Tutorials*, 2018, vol. 21, no. 1, pp. 197-216.

2. Vikulov A.S., Paramonov A.I. [Traffic analysis in a wireless access network of the IEEE 802.11 standard]. *Trudy uchebnykh zavedenii svyazi*, 2017, vol. 3, no. 3. pp. 21-27 (in Russ.).

3. Vikulov A.S., Paramonov A.I. [Model of the OFDM channel in the problem of assessing the efficiency of the IEEE 802.11 network]. *Infokommunikatsionnye tekhnologii*, 2018, vol. 16, no. 3, pp. 290-297 (in Russ.).

4. Chriki A. FANET: Communication, mobility models and security issues. *Computer Networks*, 2019, vol. 163, p. 106877.

5. Bujari A., Palazzi C.E., Ronzani D. FANET application scenarios and mobility models. *Proc. of the 3rd Workshop on Micro Aerial Vehicle Networks, Systems and Applications*, 2017, pp. 43-46.

6. Srivastava A., Prakash J. Future FANET with application and enabling techniques: Anatomization and sustainability issues. *Computer Science Review*, 2021, vol. 39, pp. 100359.

7. Crow B.P. IEEE 802.11 wireless local area networks. *IEEE Communications magazine*, 1997, vol. 35, no. 9, pp. 116-126.

8. Carneiro G. NS-3: Network Simulator 3. *UTM Lab Meeting April*, 2020, vol. 20, pp. 4-5.

9. Belan V.A., Shakir M.M., Khomenok M.Yu. [Modeling the Manet network in the NS-3 simulator]. *Telekommunikatsii: seti i tekhnologii, algebraicheskoe kodirovanie i bezopasnost' dannykh*. BGUIR, 2018, pp. 20-26 (in Russ.).

10. Shipitsin S.P., Kavalerov M.V. [Features of modeling the urban environment in the network simulator NS-3]. *Avtomatizirovannye sistemy upravleniya i informatsionnye tekhnologii*, 2018, pp. 265-269 (in Russ.).

11. Belan V.A., Shakir M.M., Khomenok M.Yu. [Simulation in the NS-3 simulator of the MANET network based on the routing protocols AODV and DSDV]. *Kodirovanie i tsifrovaya obrabotka signalov v infokommunikatsiyakh*. BGUIR, 2019, pp. 123-128 (in Russ.).

12. Zabarin M.A., Ponomarchuk Yu.V. [Analysis of the simulation capabilities of wireless sensor networks in the Kozha simulator]. *Nauchno-tekhnicheskoe i ekonomicheskoe sotrudnichestvo stran ATR v XXI veke*, 2019, vol. 2, pp. 27-31 (in Russ.).

13. Kuleshov S.V., Zaitseva A.A., Shal'nev I.O. [An approach to implementing a distributed system of virtual machines for self-organizing networks]. *Informatsionno-upravlyayushchie sistemy*, 2019, no. 5 (102), pp. 30-37 (in Russ.). DOI: 10.31799/1684-8853-2019-5-30-37.

14. Chernega V.S. [Evaluation of the throughput at the channel and transport layers of 802.11 n networks operating in infrastructure mode]. *26-ya Mezhdunarodnaya Krymskaya konferentsiya «SVCh-tekhnika i telekommunikatsionnye tekhnologii» (KryMiKo'2016) (Sevastopol', 4 sentyabrya 2016 g.)* [26th International Crimean Conference "Microwave Technology and Telecommunication Technologies" (Critique'2016) (Sevastopol, September 4, 2016)], pp. 394-400 (in Russ.).

15. Masiukiewicz A. Throughput comparison between the new HEW 802.11 ax standard and 802.11 n/ac standards in selected distance windows. *International J. of Electronics and Telecommunications*, 2019, vol. 65, no. 1, pp. 79-84.

16. Titov K.D., Lipatov A.O., Zavalishina O.N. [Evaluation of the noise immunity of the IEEE 802.11n communication system under the influence of interference, taking into account the structure of the transmitted data packet]. *Teoriya i tekhnika radiosvyazi*, 2019, no. 4, pp. 95-107 (in Russ.).

17. Vikulov A.S. [Efficiency of channel use and a method for optimizing the number of frames in the A-MSDU block for the IEEE 802.11 ac network]. *Radiotekhnicheskie i telekommunikatsionnye sistemy*, 2018, no. 4, pp. 21-31 (in Russ.).

18. Rochim A.F. Performance comparison of wireless protocol IEEE 802.11ax vs 802.11ac. 2020 International Conference on Smart Technology and Applications (ICoSTA). IEEE, 2020, pp. 1-5.

19. Bankov D. OFDMA uplink scheduling in IEEE 802.11 ax networks. 2018 IEEE International Conference on Communications (ICC). IEEE, 2018, pp. 1-6.

20. Sevryukova E.A. [Simulation modeling of the environmental monitoring system]. *Izvestiya vysshikh uchebnykh zavedenii. Elektronika*, 2019, vol. 24, no. 5, pp. 521-529 (in Russ.).

Сравнение стандартов Wi-Fi при передаче данных с борта БПЛ к наземной станции в NS-3

К. Э. Корепанов, магистрант, ИжГТУ имени М. Т. Калашникова, Ижевск, Россия
И. А. Кайсина, кандидат технических наук, ИжГТУ имени М. Т. Калашникова, Ижевск, Россия
Р. Э. Шибанов, магистрант, ИжГТУ имени М. Т. Калашникова, Ижевск, Россия
А. В. Абилов, кандидат технических наук, доцент, ИжГТУ имени М. Т. Калашникова, Ижевск, Россия
М. А. Ламри, аспирант, ИжГТУ имени М. Т. Калашникова, Ижевск, Россия

Представлено описание работы программ для проведения имитационного моделирования процесса передачи видеоданных с борта БПЛА к наземной станции с использованием стандартов семейства IEEE 802.11 (802.11n, 802.11ac и 802.11ax) с возможностью изменения индексов модуляции, схем кодирования и скорости передачи данных.

Рассмотрен сценарий, в котором зависший в воздухе беспилотный летательный аппарат передает поток видеоданных на наземную станцию, при этом расстояние между узлами увеличивается, а скорость передачи поддерживается на одном уровне, близком к скорости передачи реального видеопотока.

Моделирование проводилось в несколько этапов для более детального изучения зависимости потери пакетов передаваемых данных от изменения индексов модуляции, схем кодирования и других параметров. По результатам моделирования было получено несколько графиков, отображающих влияние увеличения расстояния на коэффициент доставки пакетов (Packet-Delivery Rate – PDR) при изменении вышеперечисленных параметров при каждом рассматриваемом стандарте семейства IEEE 802.11. На основе полученных результатов были сделаны выводы о влиянии рассматриваемых параметров на передачу данных и выделены перспективные вопросы, в решении которых будут полезны полученные результаты.

Исследование проводилось в сетевом симуляторе с отрытым исходным кодом NS-3, который имеет необходимые библиотеки для проведения качественного моделирования передачи данных и позволяет задавать широкий спектр параметров для получения реалистичных результатов. Результаты работы могут быть интересны производителям БПЛА при планировании миссий, в которых в качестве канала для передачи видеоданных используется Wi-Fi.

Ключевые слова: беспилотный летательный аппарат, NS-3, Wi-Fi, MCS, передача данных, FANET.

Получено 18.10.2021

For Citation

Korepanov K.E., Kaisina I.A., Shibanov R.E., Abilov A.V., Lamri M.A. QoS Analysis of Video Streaming in the UAV Networks with WiFi Standards. *Vestnik IzhGTU imeni M.T. Kalashnikova*, 2021, vol. 24, no. 4, pp. 73-79. DOI: 10.22213/2413-1172-2021-4-73-79.