UDC 621.398 (045)

R. S. Odarchenko,
S. O. Gnatyuk,
O. P. Tkalich

METHOD OF ROUTING IN UAV WIRELESS NETWORK

Telecommunication systems academic department, National Aviation University
E-mail: odarchenko.r.s@mail.ru

Abstract*—Was proposed improved method for routing group UAVs as of communication channels at what as a metric selected two alternatives: bandwidth or the transfer package. The model of determining effective bandwidth, which is based on using both subchannels using various modulation schemes in the MIMO systems channels. The results of calculations and simulations confirm the high efficiency of the method.*

Index Terms—Routing; method; unmanned aerial vehicles; MIMO system; signal.

I. INTRODUCTION

Currently, it became obvious that unmanned aerial vehicles (UAV) offer many new opportunities, and therefore already widely used for various purposes, both military and civilian. At the same time, for development of modern UAV highlighted some problems that should be solved. One of these problems is the development of modern reliable communication system with UAV for data transmission via radio channel from UAV board and control signals from ground stations.

Modern bandwidth requirements force UAV radiolines developers to seek new approaches for increasing the data rate of multisensor airborne platforms. One of the most effective approaches – use together OFDM and C-OFDM modulation and MIMO systems (Multiple Input Multiple Output). Therefore, further studies will relate to exactly these technologies.

Figure 1 shows a generalized structure UAV communications group, which includes the wireless network between UAV with wireless adapters, ground communication subsystem and satellite navigation systems. Ground segment provides the possibility directly connect the control station to the receiving and transmitting antennas, and the possibility connect remotely using built specifically for these purposes network, or, for example, the Internet. For this scheme a number of problems wasn't fully solved, so this emphasize the relevance of this study.

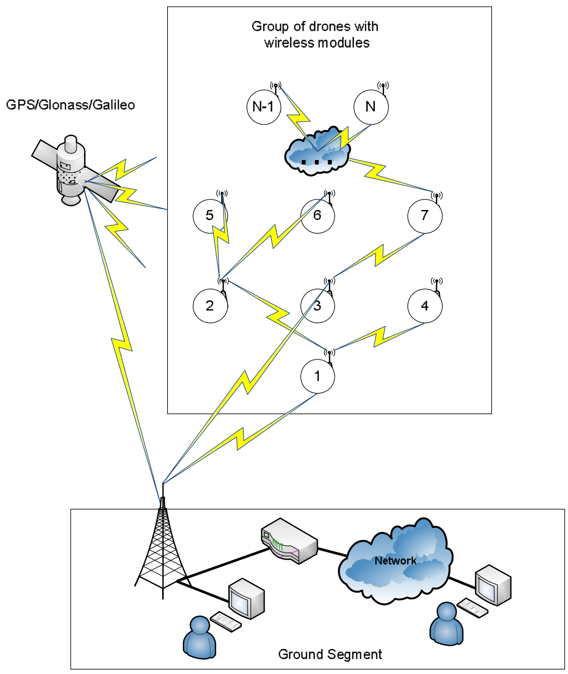

Fig. 1. Generalized structure UAV communications group

Figure 2 shows the general structure of topological relations between UAVs that are in the group. To simplify the model proposed use of only nine aircraft that may have direct connection between themselves and communicate through transit nodes. Therefore, in general, have fully connected topology.

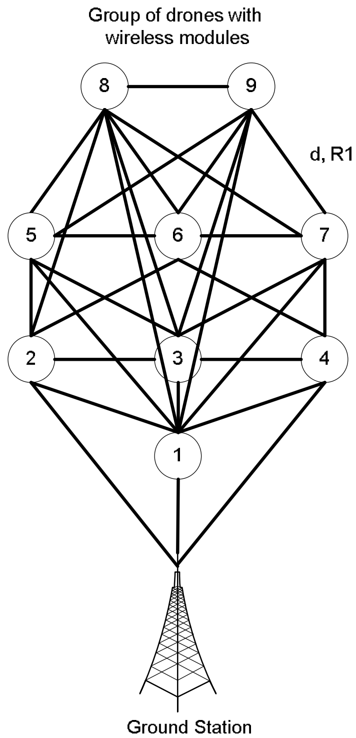

Fig. 2. Wireless communication topology between individual UAV in group

II. THE UAV APPLICATION FEATURES

Using UAVs for patrolling areas and finding people – popular world practice. It became popular in everyday life recent years, with the development of such devices. Modern UAVs can quickly and efficiently fly around area, making it easier to detect violations, saves security forces staff and special tools. These UAVs have to be equipped with special cameras that will provide a clear high-quality transmission of moving images.

To determine the speed of information flow from each camera can be used the table of compression video formats, which shows the maximum speed for a given video quality, image size and number of frames per second.

These flow rates match traffic intensity in the frame above average at compression, which does not create visible artifacts on the image.

Selecting codec streaming (H.264) or single-frame (MJPEG) compression is defined by tasks for camera.

III. DETERMINING THE TOTAL SPEED OF INFORMATION FLOW

The total speed of information flow from all IP-cameras defined as:

$$B = \sum_{i=1}^{n} \sum_{j=1}^{k} V(i, j),$$

where B – the total flow rate of all videocameras; $V(i, j)$ is the speed jth steam from ith videocamera; k is the total number of flows transferred by camera; n is the total number of IP-cameras.

It should be noted, that the total flow rate of all the cameras B is a factor that should not exceed the bandwidth between the coordinators and central earth station A, as shown in topological scheme of data exchange between the UAV and unearthly station (Fig. 3)

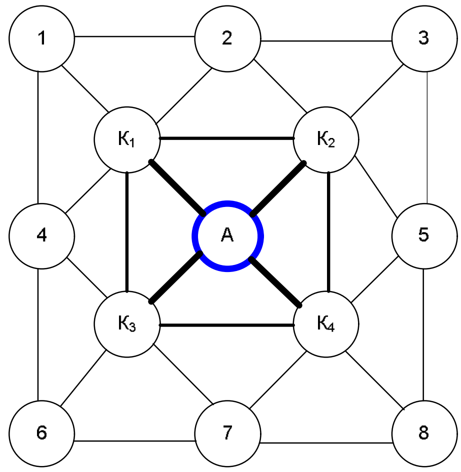

Fig. 3. Mesh network topology (the top of graph UAV): Tops 1, 2, 3, 4, 5, 6,7, 8 is the final UAV; Tops K1, K2, K3, K4 is the coordinating UAVs; Top A is the ground station

This UAV network topology related to the fact that each UAV is responsible for its videosupervision area. However, in this study reviewed only one of the possible options, but in practice can be built different network topology UAV, but the principles of data exchange, limitations and functions of individual units will be stored.

IV. AN IMPROVED METHOD OF ROUTING

To solve this problem assume that the network topology is mesh introduce some network congestion conditions:

– traffic between end and coordinating UAV is constant (normal load);

– traffic between end and coordinating UAV is variable (floating load).

For a more efficient exchange of information between all network nodes UAV is necessary to propose a new routing algorithm. As a metric when calculating optimal routes elect bandwidth - for the video stream and the transmission packet to a neighboring node - for managing service information.

In the first phase of these algorithms must install all possible topological relationships between network nodes. For this purpose neighboring nodes are continuously exchanging service packages from their location, for example, like GPS coordinates. Thus, it will be possible to calculate each moment of time length route between a pair of nodes.

The second step is to calculate the bandwidth between each pair of nodes groups UAV. To do this, apply next model.

Each communication line is a line with MIMO antenna system that will provide increased bandwidth for high quality of users service (low probability of bit errors) in difficult conditions multipath space channel with deep fading signals.

S / N Ratio (SNR) in their subchannels is defined by singular numbers channel matrix H. In the most typical for urban conditions in multipath channel with Relay's fading signals these numbers are random and can vary significantly. Therefore, the probability of bit errors will also be different for different subchannels and energetically weaker subchannels will make the main contribution to the probability of bit errors of entire MIMO-system.

To evaluate the matrix H is used the most plausible estimates or estimates based on search minimum mean square error [4] (Fig. 4).

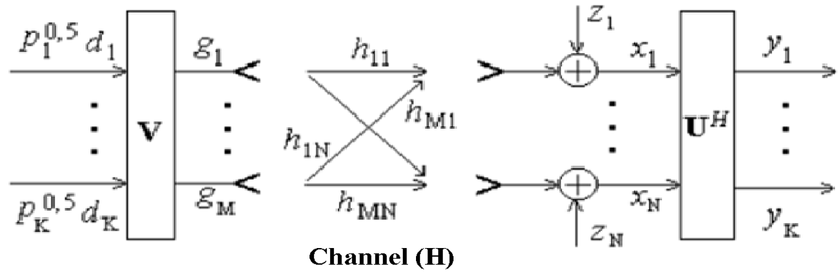

Fig. 4. Formation channels of MIMO-system

At the same time matrix **H** estimated with some error due to the influence of self-noise receivers and changes of the channel between two consecutive assessments. We consider the potential characteristics of MIMO-system matching exactly known matrix **H**.

In this paper proposes to choose MIMO system with configurations ($M \times 2$) and ($2 \times N$) separately. Note that the configuration data is characterized by the fact that they can create one or two their own subchannels.

Note that the eigenvalues λ_i do not change when replacing the transmission antennas on the reception and vice versa. Thus, MIMO-system configurations ($M \times 2$) and ($2 \times N$) are equivalent by bandwidth. Therefore, we assume for concreteness number M transmit antennas arbitrary, and the number of receiving antennas equal to two ($N = 2$).

For this antenna systems configuration speeds on the network can be calculated by equation (1) for each subchannel [11]:

$$R = 10^{\frac{P}{10}} \cdot \frac{1}{kT}, \quad (1)$$

where $P = P_{tr} - (E_b/N_0)_{dB} + G_{tr} + G_{rc} - L - L_{met.cond}$.

In the last equation G_{tr} and G_{rc} are in accordance antenna gain of the transmitter and receiver, dB; P_{tr} is the transmitter capacity, dB; L is the Distribution losses on radio signal, dB. Defined by one of the radio wave propagation models; $L_{met.cond}$ are losses due to absorption of atmospheric gases, hydro meteors, fog, etc., dB.

Thus, $L_{met.cond}$ is determined by the following equation:

$$L_{met.cond} = L_{smog} + L_{rain} + L_{ag},$$

where L_{smog} is the transmitter capacity losses of radio signal in fog, dB; L_{rain} is the loss of signal strength during rain, dB; L_{ag} is the reduction value of radio signal in atmospheric gases.

The required signal / noise ratio $(E_b/N_0)_{dB}$ to ensure the necessary bit error is chosen depending on the type of modulation method. The model for these estimates is presented below.

Density probability ranked eigenvalues λ_1 and $\lambda_2 (\lambda_1 \geq \lambda_2)$ matrix $\mathbf{HH^H}$ presented in [8]. In the case of MIMO-system with configuration ($M \times 2$) have following expressions for calculating integrated distribution functions ranked eigenvalues λ_1 and λ_2 ($\lambda_1 > \lambda_2$) [7]:

$$F_{\lambda_1}(\lambda) = \frac{\gamma(M-1,\lambda)\gamma(M+1,\lambda) - [\gamma(M,\lambda)]^2}{(M-1)!(M-2)!},$$

$$F_{\lambda_2}(\lambda) = \frac{[\Gamma(M-1) - \gamma(M-1,\lambda)][\Gamma(M+1) - \gamma(M+1,\lambda)] - [\Gamma(M) - \gamma(M,\lambda)]^2}{(M-1)!(M-2)!}, \quad (2)$$

where $\Gamma(y)=\int_0^\infty e^{-t}t^{y-1}dt$ is the Gamma function and $\gamma(y,x)=\int_0^x e^{-t}t^{y-1}dt$ is the incomplete gamma function.

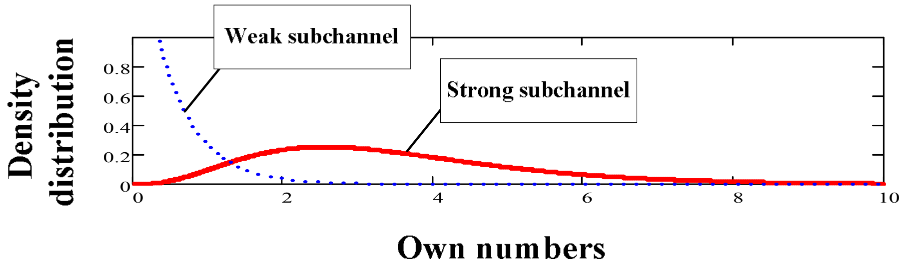

Fig. 5. Density distribution of weak and strong own subchannels

Further will conduct simulations for bit error probabilities in both subchannels for different types of modulation most widely used in modern wireless systems.

Probability of bit error BER_0 in Gaussian noise channel is [9, p. 236]:

$$BER_0(\eta)=0.5[1-\Phi(\sqrt{a\eta})],$$
$$\Phi(x)=\frac{2}{\sqrt{\pi}}\int_0^x \exp(-t^2)dt, \quad (3)$$

where α=2 and α=1 for binary and quadrature phase modulation, respectively.

S / N Ratio in *i*th own subchannel $\eta_i=\beta_i\rho_0\lambda_i$. Due to rationing probability density and parameter $\rho_i=\beta_i\alpha\rho_0$, formula for the probability of bit errors lets present in the form:

$$BER_i=\frac{1}{2}-\frac{1}{2}\int_0^\infty f_i(\lambda)\Phi(\sqrt{\rho_i\lambda})d\lambda,$$

Probability of bit errors P_b for BPSK and QPSK is given in [9]

$$P_b=Q\left(\sqrt{2\gamma_b}\right),$$

where the table function, the value of which is given in [10]:

$$Q(x)=\frac{1}{\sqrt{2\pi}}\int_x^\infty \exp(-\frac{u^2}{2})du,$$

γ_b is the ratio of bit energy E_b to noise spectral density N_0.

For Gaussian channel and receiving via matched filters probability of bit errors modulation K-QAM, where $K=2^k$ and *k* is the even number is determined as follows [9]:

$$BER=\frac{2(1-L^{-1})}{\log_2(L)}Q\left[\sqrt{\frac{3\log_2(L)}{L^2-1}\cdot\frac{2E_b}{N_0}}\right],$$

where $L=\sqrt{K}$ represents the number of amplitude levels in one dimension.

Substituting here expression (1) and conducting the necessary calculations due to the probability of bit errors in a strong (first) and low (second) own channel MIMO-system with an arbitrary number of *M* transmit antennas will have the following graphic dependence (Figs 6 and 7):

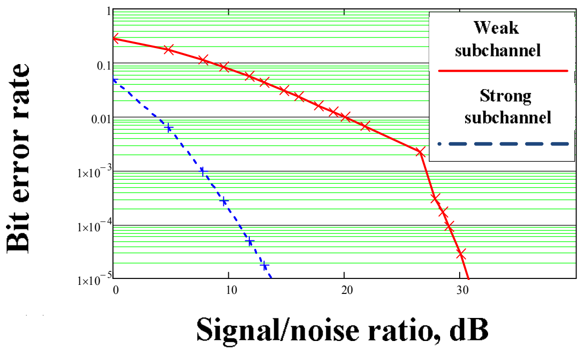

Fig. 6. Logarithmic dependence for bit error probability of signal / noise ratio in the weak and strong own subchannel for modulation QPSK

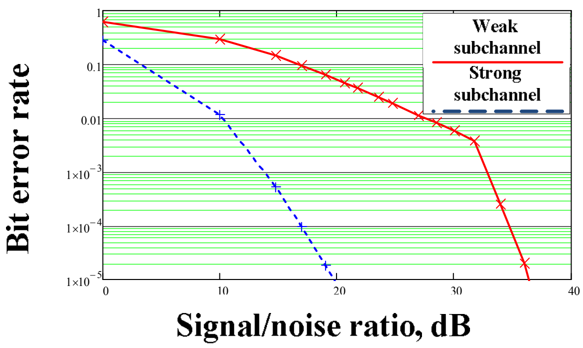

Fig. 7. Logarithmic dependence for bit error probability of signal / noise ratio in the weak and strong own subchannel for modulation QAM-64

Thus, expressing the maximum transfer rate R under certain conditions, gets the value bandwidth *i*th Channel in MIMO system:

$$R_i=10^{\frac{P_i}{10}}\cdot\frac{1}{kT}.$$

The total capacity of MIMO system will be determined:

$$R_{\max} = \sum_{i=1}^{k} R_i,$$

For example, the dependence of data rate from the distance between the transmitter and receiver (Fig. 8).

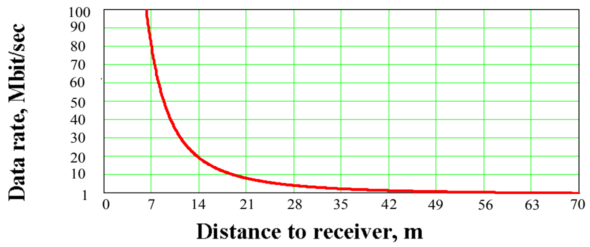

Fig. 8. Dependence of MIMO transmission system data rate in the standard IEEE 802.11n (transmitter power is 17 dBm) from distance

The third stage is the process of determining optimum routes.

To solve the problem under normal load separate Network on data exchange segments under conditions of the load between coordinating UAV and ground station does not exceed the maximum capacity of the channel $R_{13,\,j}$, denote channel bandwidth between end and coordinating UAV C_{Ni}, C_{Nk} – capacity between coordinators, C_{13} – bandwidth from the coordinator to the ground station then necessary fulfill the condition $C_{\max} K_i \succ \sum_{i=1}^{n-p} C_{Ni} \oplus \sum_{k=1}^{p} C_{Nk}$, where $C_{i,j}(K_z)$ related terminal and coordinating UAV. Then get Fig. 9.

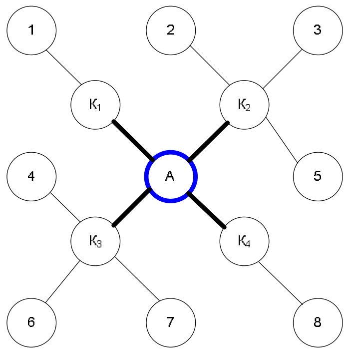

Fig. 9. Segmented topology

According to the algorithm Dijkstra's get shortest route to all the vertices of the graph, namely:

1-K1-A; 2-K2-A; 3-K2-A; 5-K2-A; 4-K3-A; 6-K3-A; 7-K3-A; 8-K4-A.

For second variant $C_{\max} K_i \le \sum_{i=1}^{n-p} C_{Ni} \oplus \sum_{k=1}^{p} C_{Nk}$ in case of exceeding the maximum bandwidth between the terminal station and the coordinator necessary to find another less loaded route. To find such routes may be used routing algorithms analysis of which is presented in [12], [13].

For the second type of traffic i.e. control information for which important condition is efficiency, as an metrics should use the value:

$$c_a = \left[O + \frac{B_t}{r} \right] \frac{1}{1 - e_f},$$

where: O is the constant that defines a channel access, depending on the physical implementation (802.11a, 802.11b); B_t is the number of bits in test package (8192); r is the speed of data transmission in the channel (Mbit / s), which determine algorithm is above; e_f is the probability of occurrence errors in the test package (measured experimentally on packages length B_t) [12].

Assuming that in the packet there are errors independently of each other, the probability of error e_f can be calculated as follows:

$$e_f = 1 - (1 - p_o)^n \approx np_o,$$

where p_o is the probability of occurrence bit errors in transmission; n is the the number of transmitted bits in the package.

V. Conclusions Acknowledgment

So as a result, in study was proposed improved method for routing group UAVs as of communication channels at what as a metric selected two alternatives: bandwidth – to transfer video data and speed of delivery – for managing information. The model of determining effective bandwidth, which is based on using both subchannels using various modulation schemes in the channels using MIMO systems. An exact expression for calculation system capacity with configurations (M × 2) and (2 × N) under uncorrelated Rayleigh fading signals conditions. The results of calculations and simulations confirm the high efficiency of the method.

References

[1] V. K. Garg IS-95 CDMA and CDMA2000: Cellular/PCS systems implementation. Prentice-Hall, Inc., 2000.

[2] A. A. Maltsev, A. V. Pudeev, and A. E. Rubtsov. "The method of adaptive bit-power apportionment on a subcarrier in OFDM radio communication systems". *Proceedings of the universities. Radiophysics*. 2006. vol. 49, no. 2, pp. 174–184. (Russian).

[3] D. N. Bevan, V. T. Ermolaev, E. A. Mavrychev, and A. G. Flaxman. "Comparative efficiency of cellular communication systems, which use adaptive modulation or coding capacity management". *Proceedings of the universities. Radiophysics*. 2001. vol. 44, no. 12, pp. 1050–1061 (Russian).

[4] V. T.Ermolaev, A. G. Flaxman, and D. N. Lysyakov. "Increasing the capacity of MIMO-radio system with parallel data transmission on its own sub-channels". *Proceedings of the Herald UNN them. N.I. Lobachevsky,* 2010, vol. 3(1), pp. 79–86 (Russian).

[5] Y. Y. Kolyadenko, and A. D. Muslim. "MIMO system capacity research" *Problems of telecommunications*, vol. 1 (1), 2010, pp. 76–82 (Russian).

[6] D. Shen, Z. Pan, K.-K. Wong, and V. O. K. Li. "Effective throughput: a unified benchmark for pilot-aided OFDM/SDMA wireless communication systems". *Proceedings INFOCOM'2003*, 2003 vol. 3. pp. 1603–1613.

[7] V. T. Ermolaev, A. G. Flaxman, and D. N. Lysyakov. "The effectiveness of the spatial separation of users in CDMA-communication systems in Rayleigh fading channel with a frequency dispersion". *Modern problems of statistical physics (Malahovskiy collection).* vol. 5, 2006, pp. 136–148 (Russian).

[8] V. T. Ermolaev, A. G. Flaxman, A. M. Zuev, and D. N. Lysyakov. "The probability of bit errors in MIMO-systems with two private subchannels". *Proceedings of the Herald UNN them. N. I. Lobachevsky*, 2009, vol. 2. pp 55–61 (Russian).

[9] B. Sklar. *Digital Communications. Theoretical bases and practical application*. 2nd corr. Ed. Hardcover. from English, Moscow, Publishing House "Williams", 2003. 1104 p. (Russian).

[10] I. S. Gradshtein, and I. M. Ryzhik. *Tables of integrals, sums, series and products*, Moskow, Nauka, 1971. (Russian).

[11] R. S. Odarchenko, G. F. Konahovych, and M. G. Lutskiy. The standard IEEE 802.11g access point service area determining. Information security, 2010, pp. 107–117. (Ukrainian).

[12] S. M. S. Bari, F. Anwar, and M. H. Masud. "Performance Study of Hybrid Wireless Mesh Protocol (HWMP) for IEEE 802.11s WLAN Mesh Networks". *Proceedings of International Conference on Computer and Communication Engineering (ICCCE 2012)*, 3-5 July 2012, Kuala Lumpur, Malaysia, pp. 103–107.

Received August 17, 2015.

Odarchenko Roman. PhD, Docent.
Telecommunication Systems Department, National Aviation University, Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine (2010).
Research area: Next generation cellular and wireless networks.
Publication: 90.
E-mail: odarchenko.r.s@mail.ru

Gnatyuk Sergiy. PhD, Docent.
Information Security Department, National Aviation University, Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine (2007).
Research area: Information security in telecommunications.
Publication: 110.
E-mail: s.gnatyuk@nau.edu.ua

Tkalich Oleh. PhD, Docent.
Telecommunication Systems Department, National Aviation University, Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine (2001).
Research area: Next generation cellular and wireless networks.
Publication: 100.
E-mail: tkalich@nau.edu.ua

Р. С. Одарченко, **С. О. Гнатюк**, **О. П. Ткаліч. Метод маршрутизації в бездротовій мережі БПЛА**

Запропоновано поліпшений спосіб маршрутизації інформації в каналах зв'язку для груп БПЛА, де в якості метрики запропоновано дві альтернативи: пропускну здатність каналу або час передачі пакету. Модель визначення ефективної смуги пропускання, яка заснована на використанні обох підканалів, для MIMO-системи наведена для різних схем модуляції. Результати розрахунків і моделювання підтверджують високу ефективність запропонованого методу.

Ключові слова: маршрутизація; метод; безпілотні літальні апарати; системи MIMO; сигнал.

Одарченко Роман Сергійович. Кандидат технічних наук. Доцент.
Кафедра телекомунікаційних систем, Національний авіаційний університет, Київ, Україна.
Освіта: Національний авіаційний університет, Київ, Україна (2010).
Напрям наукової діяльності: стільникові та без проводові мережі нових поколінь.
Кількість публікацій: 90.
E-mail: odarchenko.r.s@mail.ru

Ткаліч Олег Петрович. Кандидат технічних наук. Доцент.
Кафедра телекомунікаційних систем, Національний авіаційний університет, Київ, Україна.
Освіта: Національний авіаційний університет, Київ, Україна (2001).
Напрям наукової діяльності: стільникові та без проводові мережі нових поколінь.
Кількість публікацій: 100.
E-mail: tkalich@nau.edu.ua

Гнатюк Сергій Олександрович. Кандидат технічних наук. Доцент.
Кафедра безпеки інформаційних технологій, Національний авіаційний університет, Київ, Україна.
Освіта: Національний авіаційний університет, Київ, Україна (2007).
Напрям наукової діяльності: захист інформації в телекомунікаційних системах.
Кількість публікацій: 110.
E-mail: s.gnatyuk@nau.edu.ua

Р. С. Одарченко, **С. А. Гнатюк**, **О. П. Ткаліч. Метод маршрутизации в беспроводной сети БПЛА**

Предложен улучшенный способ маршрутизации информации в каналах связи для групп БПЛА, где в качестве метрики предложены две альтернативы: пропускная способность канала или время передачи пакета. Модель определения эффективной полосы пропускания, которая основана на использовании обоих подканалов для MIMO-системы, приведена для различных схем модуляции. Результаты расчетов и моделирования подтверждают высокую эффективность предложенного метода.

Ключевые слова: маршрутизация; метод; беспилотные летательные аппараты; системы MIMO; сигнал.

Одарченко Роман Сергеевич. Кандидат технических наук. Доцент.
Кафедра телекоммуникационных систем, Национальный авиационный университет, Киев, Украина.
Образование: Национальный авиационный университет, Киев, Украина (2010).
Направление научной деятельности: сотовые и беспроводные сети новых поколений.
Количество публикаций: 90.
E-mail: odarchenko.r.s@mail.ru

Ткаліч Олег Петрович. Кандидат технічних наук. Доцент.
Кафедра телекоммуникационных систем, Национальный авиационный университет, Киев, Украина.Образование: Национальный авиационный университет, Киев, Украина (2001).
Направление научной деятельности: сотовые и беспроводные сети новых поколений.
Количество публикаций: 100.
E-mail: tkalich@nau.edu.ua

Гнатюк Сергій Олександрович. Кандидат технічних наук. Доцент.
Кафедра безопасности информационных технологий, Национальный авиационный университет, Киев, Украина.
Образование: Национальный авиационный университет, Киев, Украина (2007).
Направление научной деятельности: защита информации в телекоммуникационных системах.
Количество публикаций: 110.
E-mail: s.gnatyuk@nau.edu.ua