Modeling the multichannel systems of a goods delivery provided by the unmanned aerial vehicles

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ABSTRACT

The article describes the systems of goods delivery by the means of the unmanned aerial vehicles. the main goal of this work is the description of the multichannel systems of a goods delivery, that use the unmanned aerial vehicles, especially such their features as the functional differences, the classification, the types and the system's parameters. in addition, authors provide us with the different types of the multichannel systems of a goods delivery that use the unmanned aerial vehicles modeling.

Keywords: UAV, system of goods delivery, system of mass service

1. INTRODUCTION

The bulk of the economical tasks are connected with the systems of the mass service when, from the one side, many asking for some service appears in a moment and, from the other side, satisfying of those asking takes place. The last one depends on creating of the appropriate facilities, tools and logistics' means. All this tasks are solved by the systems of goods and service delivery, which come to satisfy the costumer's orders [1,2,3].

So, the systems of goods delivery (SGD) provide a delivery of the different goods which have been dispatched by a provider to the destination point that have been chosen by a purchaser of these goods.

The main tasks of SGD are:

- defining the channels quantity for goods delivery;

- defining the minimal quantity of means of delivery;

- caring out the calculation of the minimal quantity of the goods'receiving and distributing posts.

There is one channel and multichannel SGD [4], which are differ with the quantity of the means of a goods delivery. The last one can be presented by an unmanned aerial vehicle (UAV). Under this abbreviation one should understand every unmanned aerial vehicle with no pilot (a crew) on the board and projected for solving the tasks which are typical for the unmanned aerial vehicles [5].

The current UAV systems are in the state of the stunning development, which causes the constant expansion of their implementation areas [6,7]. One of these domains can be presented by SGD because in this case UAV implementation can solve the significant bunch of transportation facilities problems [8,9]. The last one is typically presented by the imperfect facilities, the unbearable quality of transportation routes and their overload, a big distance between the receiving and distributing points, the unpredictable expenditure, etc.

So, the goal of this article is the analyzing of SGD that base on UAV, the main functional features of the multichannel SGD that base on UAV and their classification. Also this article provides modeling of the parameters of the different types of SGD that base on UAV according to this classification [10,11,12].

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2. THE FUNCTIONAL SPECIFICITY OF THE MULTICHANNEL SYSTEMS OF A GOODS DELIVERY

SGD divides onto one channel and multichannel systems, so a goods delivery is fulfilled by, in proportion, one or more than one UAV. This article reveals the results of a research of multichannel SGD that base on of UAV. This is important to know the next main flow of their functional specificity that are represented by:

- L_s – the mean quantity of orders, that have been received in a multichannel SGD,
- L_q – the mean quantity of orders, that are currently in line,
- λ – the intensity of orders' income in the multichannel SGD or the mean quantity of orders per a time unit,
- i – the quantity of orders of a goods delivery in the multichannel SGD,
- λ_{ef} – the efficient intensity of the orders' income in the multichannel SGD,
- C – the places' quantity in a queue,
- T_0 – the time of the one order fulfillment.

$$T_0 = T_p / n \, , \tag{1}$$

where T_p – the mean time of one unit of a goods delivery, n – the free of duty UAV quantity;

- μ – the intensity of a service

$$\mu = 1/T_0 \, , \tag{2}$$

- ρ – the summered intensity of a channel's load (the meanquantity of orders that come in per the time of the one order fulfillment)

$$\rho = \frac{\lambda}{\mu} \, , \tag{3}$$

- P_{vidm} – the probability of the service rejection.

$$P_{vidm} = P_N = \frac{\lambda}{\lambda + \mu} \, , \tag{4}$$

The functional specificity L_s and L_q has got from probability P_i (when a multichannel SGD has i orders)[10]. In details:

$$L_s = \sum_{i=1}^{\infty} n P_n \, , \tag{5}$$

$$L_q = \sum_{i=C+1}^{\infty} (n - C) P_n \, . \tag{6}$$

3. THE CLASSIFICATION OF THE MULTICHANNEL SYSTEMS OF A GOODS DELIVERY

There are different ways to classify the multichannel SGD. On the fig. 1 is shown the principal scheme of the multichannel SGD' classifications by the means of the different system's flows.

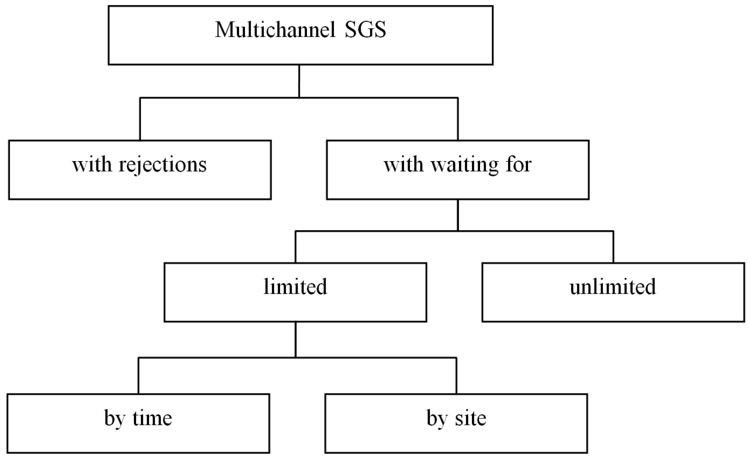

Figure 1. The classification of SGD.

From this picture we can see, that depending on the way of a delivery and the type of goods there are different types of the multichannel SGD [13,14, 27]:

- the multichannel SGD with rejections– when the big quantity of the goods delivery orders come from the source of asking i (a big intensity λ) and the type of goods let us reject some orders' delivery fulfillment;
- the multichannel SGD with waiting – when the big quantity of goods delivery orders come from the source of asking i (intensity λ) and the type of goods do not let us reject some orders' delivery fulfillment. This type of SGD is the most proximate to the real systems because even if the time of a delivery and the waiting lapse does not matter for some type of goods, the order's rejections is not profitable from the commercial point of view [15,16];
- the multichannel SGD with an unlimited waiting time – when waiting and delivery time does not matter for some type of goods (for example, the heavy industry goods);
- the multichannel SGD with limited waiting time – when waiting and delivery time does matter for some type of goods (for example, the food industry goods). This type of SGD is used, when delivery and waiting time influences the total price of an order;
- the multichannel SGD with limited waiting time that is dependable on a site – when a stock of goods, that are waiting for a delivery and are keeping in a queue (for example, the goods with large size), contains their limited quantity;
- the multichannel SGD with limited waiting time dependable on the time and a site or other parameters, when the minimization of delivery time, number or other parameters is important for some type of goods. This type of SGD is typical when waiting and delivery parameters influence the total price of an order [17,18,19, 24, 25, 26].

4. THE MULTICHANNEL SYSTEM OF A GOODS DELIVERY THAT HAS AN OPTION OF A REJECTION

Let presume that a system has N service channels, a flow of the service orders has intensity λ, and service intensity is equal to μ. On fig. 2 is shown the graph of the states of a multichannel SGD that has option of rejection [19, 20, 21, 26].

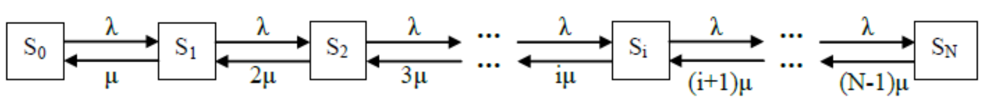

Figure 2. The graph of the states of a multichannel SGD that has option of rejection.

This system has the next states: S_0 –all channels are free; S_1 – one channel is busy, the other $N-1$ channels are free; S_2 – two channels are busy, the other $N-2$ channels are free of service; S_i – i channels are busy, the other $N-i$ channels are free of service; S_N –all channels are busy and an order has got the service rejection.

The probability of the system:

- P_0 – the probability of the state S_0

$$P_0 = \frac{1}{\sum_{i=0}^{N} \frac{\rho^i}{i!}}, \tag{7}$$

- P_i – the probability of the state S_i

$$P_i = \frac{\rho^i}{i!} P_0,\ i = 0,1,2,\dots,N \tag{8}$$

The multichannel SGD that has option of rejection is a group of delivery service stations, which provides the delivery of goods using 50 UAV. Those aerial vehicles can shift one another during the service providing. The income orders have intensity $\lambda = 1$. The mean duration of service is $T_0 = 1{,}6$ hours [21,22].

Under this conditions the meaning of the probability of the channels charge P_i can be defined on the base of formulas (7) and (8) and it reveals her dependency on the total intensity of channels charge ρ and the quantity of goods delivery orders in SGD i, that is shown on fig. 3.

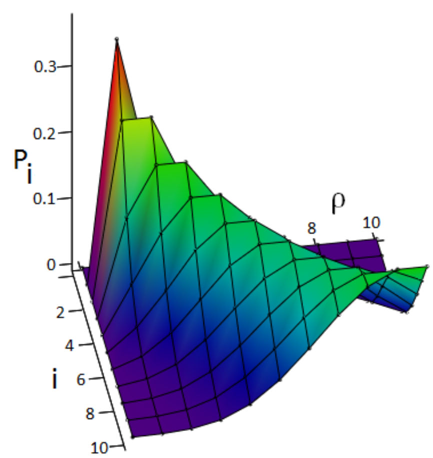

Figure 2. The dependency of the channels charge probability P_i on the total intensity of channels charge ρ and the quantity of a goods delivery orders in SGDi.

As it is clear from the graph, the less the total intensity of channels charge ρ and the quantity of goods delivery orders in SGD i are, the more probability of channels' full charge is. When the intensity ρ and the orders quantity i increase, the probabilities P_i decreases and the last one softly increases when parameters ρ and i have maximal meaning.

5. THE MULTICHANNEL SYSTEMS OF A GOODS DELIVERY THAT HAVE AN OPTION OF WAITING AND A LIMITED QUEUE'S LENGTH

The multichannel SGD that have an option of waiting and a limited queue's length comprise multichannel SGD that according to up-presented classification (fig. 1) have limited time of waiting for and strict sites of a delivery providing. This originates from the fact that the place of goods storing (a list number) and the time of an orderfulfillment are the crucial parameters of the SGD' concept of "queue". Let's presume that we have C service channels and the number of requests that come in system is limited by N.

This situation can represent as the rejection frequency of a UAV is λ per a time unit. Service speed of a rejection for UAV is μ UAV per a time unit. It is forecasted, that a time when rejection appears and a delivery time are influenced by the Poisson distribution [11, 23, 24, 25, 26, 27].

In this math model the power of an order source fulfillment is limited. It happens in the situation when the all UAV are broken, so the technical source for a delivery providing is over. The graph of states of this SGD is presented on the fig. 4.

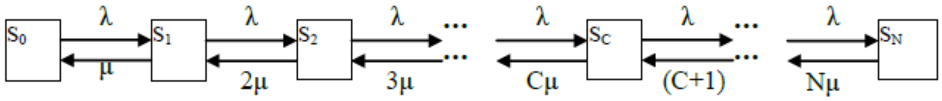

Figure 4. The graph of states of a multichannel SGD that has a time of waiting and limited queue length.

This SGD has the next functional states: S_0 –all channels are free; S_1 –one channel is busy, the other $C-1$ channels are free; S_2 –two channels are busy, the other $C-2$ channels are free; S_C $-C$ channels are busy(all we have for service providing), there is no queue; S_{C+1} $-C$ channels are busy, the queue has only one order; S_N – the all C channels are busy, the queue has $N-C$ orders.

The system's probability:

- P_0 – the probability of the state S_0

$$P_i = \frac{\rho^i}{i!} P_0,\ i = 0,1,2,\ldots,N \tag{9}$$

- P_i – the probability of the state S_i

$$P_i = \begin{cases} \dfrac{\rho^i}{i!} P_0, 0 \le i \le C, \\ \dfrac{\rho^i}{C!\,C^{i-C}} P_0, C \le i \le N. \end{cases} \tag{10}$$

The mean number of orders that the queue has[12]:

$$L_q = \begin{cases} \sum\limits_{i=C}^{N} (i - C) P_i, \dfrac{\rho}{C} \ne 1, \\ \dfrac{\rho^C (N - C)(N - C + 1)}{2C!} P_0, \dfrac{\rho}{C} = 1. \end{cases}, \tag{11}$$

So as no additional order can get in the system with the exceeded capacity of an orders' queue processing, so

$$\lambda_{ef} = (1 - P_N)\lambda\,. \tag{12}$$

The previously marked stations can be imaged like the multichannel lSGD that has waiting time of the orders processing and a limited queue's length. In this circumstance the meaning of channels occupation's probability can be defined on the base of formulas (9) and (10) and his dependency on the total intensity of the channels' load and the goods delivery order's quantity in a SGD are shown on the fig. 5.

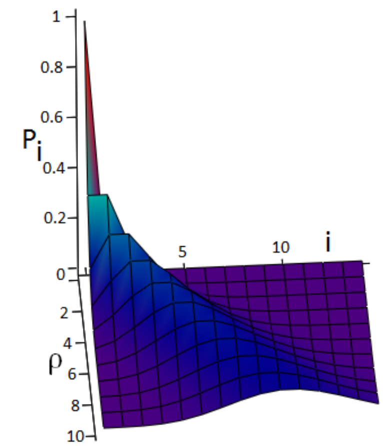

Figure 5. The dependency between the probability of channels occupation P_i and the total intensity of channels occupation ρ and the quantity of delivery orders in a SGD i .

As we see on the graph, the less are the total intensity of channels occupation ρ and the quantity of delivery orders i, the more probability is that channels are going to be busy. When the intensity ρ and the orders number i increase meaning the probability P_i decreases under the condition of maximal meaning of ρ and i .

The mean number of orders that are in the queue, L_q can be defined on the base of the formulas (9) – (11) and the dependency between the total intensity of channels load ρ and the quantity of SGD' delivery orders i can be founded out, what is presented on the fig.6.

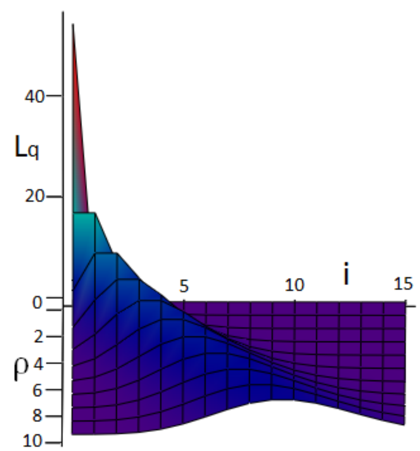

Figure 6. The dependency between the average number of orders that are in a queue L_q and the total intensity of channels load ρ together with the SGD's quantity of the delivery orders i .

As it comes from the graph, the lower total intensity of channels load ρ and the SGD's quantity of delivery orders i are, the higher average number of orders that are in a queue, L_q is. As the total quantity of the system's UAV is 50 units, so the mean number of the fulfilled orders is in proportion to this quantity. As the intensity ρ and the orders quantity i increase, the mean number L_q decreases when parameters ρ and i are maximal.

As it comes from the shown graph, when the lapse of an order fulfillment T_0 increases, the efficient frequency of orders income λ_{ef} increases too, because of in this case the queue has more orders than one that is waiting for fulfillment.

6. CONCLUSION

In this article is presented the analyzing of SGD in case of UAV using, because the popularity of this kind of transportation is booming today, which extends the area of their implementation. The authors make a research of multichannel SGD or such systems, when goods delivery is provided by the means of more than one UAV. The specificity of a UAV is determined by the functional features of this means of transportation and the main of the last one are described in the article.

The classification of multichannel SGD using UAV reveals such SGD's types as the rejection type, the waiting time type; the queue's length limited type and the unlimited time of waiting type.

The authors provide the readers with modeling each SGD's type. In case of multichannel SGD that have an option of rejections, it has come to be clear that the probability of the channel charges beginning from the maximal point under the minimal intensity of channels charges and the minimal SGD's orders quantity decrease with further soft increase under the condition of the maximal intensity and the quantity of orders.

In case of SGD that has an option of waiting time and queue's length limitedtype, the probability of channel charges and the mean number of orders in the queue beginning from maximal points under the minimal intensity of channels charges and the quantity of goods delivery's orders in SGD decreases, when the intensity and quantity of orders are maximal. In addition, in case of this type of SGD the time increasing causes the increase of effective intensity of order's income.

The crucial task during the process of real SGD construction that first of all influences the general costs of transportation systems is the determination of the UAV quantity.

The SGD' income depends on the quantity of fulfilled orders per a delivery and this indicator can decrease in the case of the rejections of orders' fulfillment, in case of the time of order fulfillment increasing and unneeded waiting the orders processing. During the SGD' parameters calculations one should take in account the definition of UAV's quantity so that the total intensity of a channel charge approximates the one grade of a scale. In this case UAV's do not waste the time and the total time of waiting for the fulfilled order is negligible. The multichannel SGD are more attractive for practical realization than one channel transformational systems because this SGD are more flexible, can fulfill more orders per a time unit and more precisely reflect the work of the real systems.

REFERENCES

[1] National Research Council, [Autonomous Vehicles in Support of Naval Operations], National Academies Press, 1-256(2005).

[2] Reg, A., [Unmanned Aircraft Systems: UAVS Design, Development and Deployment], John Wiley & Sons, 1-372(2011).

[3] Mejias, L. Corke, P. and Roberts J., "Field and service robotics: Results of the 9th International Conference," Springer Tracts in Advanced Robotics, vol. 105, Springer, 1-530 (2014).

[4] Baxter, J.W. and Horn, G.S., "Controlling teams of uninhabited air vehicles / Defense industry applications of autonomous agents and multi-agent systems," Whitestein Series in Software Agent Technologies and Autonomic Computing, (97–112)2008.

[5] Kashuba, S.V., Novikov, V.I., Lysenko, O.I. and Alekseeva, I.V., "Optimization of UAV path for wireless sensor network data gathering," Actual Problems of Unmanned Aerial Vehicles Developments (APUAVD), 280-283(2015).

[6] Harrison, G.J., "Unmanned Aircraft Systems (UAS): Manufacturing Trends," Congressional Research Service. CRS Report for Congress, 30-37(2013).

[7] Lee J., Huang R., Vaughn A., Xiao X., Hedrick J.K., Zennaro M. and Sengupta, R., "Strategies of path-planning for a UAV to track a ground vehicle <http://c3uv.berkeley.edu/papers/Lee_ains03.pdf> (25 September 2008).

[8] Yang, X., Koziel, S. and Leifsson, L., "Computational optimization, modelling and simulation: Past, present and future," Procedia Computer Science, 29(0), 754-758(2014).
[9] Corke, P., [Robotics, Vision and Control: Fundamental Algorithms in MATLAB], Springer Science & Business Media, 73, 1-530(2011).
[10] Fahlstrom, P., Gleason, T., [Introduction to UAV Systems. Aerospace Series], John Wiley & Sons, 1-312(2012).
[11] Amigoni F., Caglioti V., "An information-based exploration strategy for environment mapping with mobile robots," Robotics and Autonomous Systems, 58 (5), 684-699 (2010).
[12] Cover, H., Choudhury, S., Scherer, S.. Singh. S., "Sparse tangential network (SPARTAN): Motion planning for micro aerial vehicles," International Conference on Robotics and Automation, 23-29(2013).
[13] Agrawal. M., Konolige, K., "Real-time localization in outdoor environments using stereo vision and inexpensive GPS,"18th International Conference on Pattern Recognition ICPR, 3(1), 1063-1068(2006).
[14] Burgard W., Derr A., Fox D., Cremers, A. B., "Integrating global position estimation and position tracking for mobile robots: the dynamic Markov localization approach," Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems, 2(1), 730-735(1998).
[15] Kvyetnyy, R., Maslii, R., Harmash, V. and Bogach I., "Object detection in images with low light condition," Proc. SPIE 10445, 104-112(2017).
[16] Kvyetnyy, R., Sofina, O. and Olesenko, A., "Method of image texture segmentation using Laws' energy measures," Proc. SPIE 10445, 145-153 (2017).
[17] Kvyetnyy, R.N., Sofina, O.Y. and Lozun, A.V., "Modification of fractal coding algorithm by a combination of modern technologies and parallel computations," Proc. SPIE 9816, 98-114 (2015).
[18] Zabolotna, N.I., Pavlov, S.V., Radchenko, K.O., "Diagnostic efficiency of Mueller - matrix polarization reconstruction system of the phase structure of liver tisssue," Proc. SPIE 9816, 161-169(2015).
[19] Vyatkin, S.I., Romanyuk, A.N., Gotra, Z.Y., "Offsetting, relations and blending with perturbation functions," Proc. SPIE 10445, 104-112(2017).
[20] Wojcik, W., Komada, P., Cieszczyk, S., "ECTL application for carbon monoxide measurements," Proc. SPIE 5958 145-153(2005).
[21] Wojcik, W., Lach, Z. and Smolarz, A., " Power supply via optical fibre in home telematic networks," Przeglad Elektrotechniczny, 84(3), 277-279(2008).
[22] Avrunin, O.G., Tymkovych, M.Y., Pavlov, S.V., Timchik, S.V., Kisała P., "Classification of CT-brain slices based on local histograms," Proc. SPIE 9816, 86-92(2015).
[23] Romanyuk, O.N., Pavlov, S.V., Melnyk, O.V., Romanyuk, S.O., Smolarz A., "Method of anti-aliasing with the use of the new pixel model," Proc. SPIE 9816, 981617, 120-126(2015).
[24] Romanyuk, S. O., Pavlov, S. V., Melnyk, O. V., "New method to control color intensity for antialiasing," International Siberian Conference on Control and Communications (SIBCON), 21-23 May, 20-24(2015).
[25] Nasilowski, T., Skorupski, K., Makara, M., Statkiewicz-Barabach, G., Mergo, P., Marc, P., Jaroszewicz, L. "Very high polarimetric sensitivity to strain of second order mode of highly birefringent microstructured fibre," Proc. of SPIE, Vol. 7753, 77533O (2011).
[26] Sawicki, D., Kotyra, A., Akhmetova, A., Imanbek, B. and Suleymenov, A. "Wykorzystanie metod optycznych do klasyfikacji stanu procesu współspalania pyłu węglowego i biomasy, " Rocznik Ochrona Środowiska, 18, 404–415(2016).
[27] Sawicki, D. and Kotyra, A., "Porównanie wybranych metod wyznaczania obszaru płomienia w wizyjnym systemie diagnostycznym, "Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska, 4, 14-17(2013).