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Modeling of Data Transfer Process in Wireless Communication Channels

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Abstract: The paper examines the functioning process of wireless communication channel. Queuing system with requests of complex structure and dispatching is used as a mathematic model. The paper provides the algorithm of statistical modelling of the system. The modelling considers the peculiar character where each request consists of a random number of operations with a random continuance.

Keywords: Queuing System, Multiple Demand, Embedded Markov Chain

1. Introduction

Modern development of wireless technologies is closely linked with the implementation of a variety of technical devices in the human activities, facilitating and improving life in various fields. Nowadays any process of information exchange occurs with smartphones, tablets and laptops, which, inter alia, may serve as a multi-purpose dispatch board of automated control systems, under the condition of continuous access to the Internet.

Alterations and innovations in wireless data transmission technologies make it necessary to develop new models for the identification and analysis of the functioning parameters of the modern automated control systems, containing a special structure of data streams.

To study the operation of wireless communication networks many authors consider it appropriate to use the mathematical modeling techniques for obtaining the characteristics of the modeled systems considering all the features of systems. Thus, the mathematical modeling techniques are used in the work [1] for the study and improvement of broadband wireless data transmission technologies. The article analyzes the process of mathematical modeling of wireless telecommunication systems. Presented methods and tools used in the mathematical modeling of multi-antenna systems using a software environment Matlab Simulink, physical and analytical communication channel.

We would like to note that modern researches use not only mathematical modeling for modeling processes that occur in wireless networks when transmitting data. Because the modeling is a theoretical method for describing the real processes in wireless communication channels. So, in the [2] the authors use physical modeling to display the features of the wireless system functioning. The article describes the appropriateness of the choice of a certain frequency for the modeling a wireless system and the composition of the model, the comparative analysis of qualitative and quantitative characteristics of existing wireless systems at certain frequencies was also carried out.

Unlike previous works in the article [3] the authors use simulation modeling to describe wireless technologies. The system model of wireless technologies security was proposed on a level of the structure “system – signal – channel – tract” and its metrological support according to the conception “object – threat – defence”. The software of data encryption procedure for WiMAX systems based on AES standart and C# programming language was developed in limits of the created model.

So, as you can see from the review, various methods of data transmission processes modeling and directly the operation of wireless communication channels is a pressing issue in the modern study of the latest wireless technologies.

2. Queuing Systems with a Stream of Complex Structure Applications

It is advisable to use the mathematical model of a single-channel queuing system (QS) with a stream of complex structure applications in this article for the description of data transmission process through wireless communication channels.

The modelling practice often involves both flows and requests of a more complex nature, which can be observed within the operation of computer and wireless networks as well as satellite and cellular communication systems. For example, as a general principle, one station is not allowed to capture a transmission channel for a long period of time, thus increasing the delay of other stations in computer and wireless networks, using multiple accesses to data transmission medium. In this connection, volume of information from one station is divided into a number of frames to be processed according to certain rules and procedures [4]. Thus the request of complex structure (multiple demand) can be considered.

Several examples of requests of complex structure are considered below.

The functioning of modern radiolocation systems is based on pulse method, i.e., the radar transmits emitting signal only for a very short time, and then it switches to receiving mode to listen to the response, which is reflected from the target, while the emitting pulse is distributed. If the pulse is sent earlier, the response of the previous pulse from distant target can be mixed up with a response of the second pulse from a close target [5]. Thus, there is an overlap of pulses leading to loss of information about the location of a target. By analysing the radiolocation system bandwidth, we can come to the conclusion that such system is processing the request of a complex structure. Thus, the flow of pulses generates flow of multiple demands, where each of them requires a separate processing.

The multiplicity of requests is also observed within the operation of satellite communication systems, particularly in the GPS-system (Global Positioning System). The basic principle underlying the whole GPS system relates to determination of the exact location in two-dimensional space: i.e., signals from at least 4 satellites are to be received to determine three-dimensional coordinates: latitude, longitude and altitude. Determining of GPS-receiver location is based on the measurement of signal delay from several satellites and calculation of geographical coordinates and altitude according to such measurements [6].

Use of queuing systems with flow of complex structure requests can be also observed at modelling the functioning of the "ground-to-air" communication channel during the process of unmanned transport system control.

Ukrainian drone M-7 "Sky Patrol" is designed for aerial photography and mapping, as well as for video surveillance in real time mode. Unmanned Aerial Vehicle (UAV) is controlled remotely by an operator or with on-board software appliances. UAV control can be described through a service system with multiple demands, where every request has a random number of operations with a random duration [7].

In addition, unmanned aerial vehicles can be used to perform a variety of tasks, which cannot be performed autonomously according to their nature and require a permanent connection (communication line) between the UAV board and ground control centre. Their examples may include the studies in the field of cartography and aerial surveys, examination of the condition of plants in the fields; video surveillance of migration of animals, of human activity, and traffic; security of restricted access facilities; study of atmospheric phenomena and study of air pollution caused by harmful substances, measuring of background radiation or other physical variables with spatial distribution unknown beforehand. It is impossible for such tasks to plan the UAV flight route before its start.

In this case a need occurs to transfer information to both directions in a real time mode: flight control signals and control signals for the equipment as a useful load for UAV shall be transmitted from the ground control facility to UAV and telemetric information on the status of UAV units and the flow of information from the on-board equipment, such as a video cameras, shall be transmitted from UAV to the ground control facility.

If the UAV has several sources of information on the board – for example, the controller of UAV aircraft equipment and several video cameras, the input of the wireless data transmission channel receives the flow of multiple demands, requiring separate processing.

You should also take into account the peculiar features of the radio channel functioning itself. Firstly, a wireless communication channel is regulated by a certain specified protocol, which requires certain auxiliary operations such as adjusting the frequency, synchronization, calibration, test frames, verification of address codes, exchange of encryption keys and others. Thus, the process of connection, maintaining the functioning of the channel itself, its recovery after possible failures adds to the input flow of multiple demands for transmission of useful information the additional requests for transmission of above mentioned service data.

Secondly, the quality of radio communication can be affected with natural and artificial interferences. The likelihood of such effects can be quite high, because the distance of the UAV from ground radio communication station during flight can be quite significant (tens or even hundreds of kilometres). At sufficiently high interference level in wireless systems the data are transmitted with a random delay related to the acknowledgement of receipt. Increase of data volume increases the probability of errors in transmission, thus the repeated transmission of data is possible. Data may be transferred with a break to eliminate the influence of possible long-term interferences.

These examples demonstrate the practical relevance of consideration and research of communication channels of UAV to ground as queuing systems with multiple demands. Overlapping of different signals at a time, probable within operation of the on-board information systems, requires to solve the problem of determining such intensity of flows of complex requests that would not lead to information loss and issues of acceptable or optimal level (in terms of the capacities of data transmission channel) of informational activity of UAV on-board devices, e.g., concerning such an intensity of identification of the location of objects that would not have resulted in the loss of information about their location.

Note that in the classic waiting line theory a request usually involves a servicing during a certain period of time. However, in various technical systems a request involves an execution of some finite sequence of staggered operations. Such situation is specific to systems for processing of information on moving objects. In papers [8-9] studied systems with complex structure requests (multiple demands) involve the execution of n-operations; the paper [10] studies the system, where $n = 2$, such systems we called systems with double requests. It can be considered by convention that the request servicing consists of period for signal reception from some object and response signal transmission period. Both periods can be shifted by operator within certain limits.

We shall also note the importance of the problem of scheduling research in queuing systems. Within the paper [11] E. V. Koba and I. N. Kovalenko consider a single-channel queuing system with Poisson input flow of objects, where each of them consists of several distributed requests requiring scheduling.

It shall be noted that the multiplicity of requests in wireless channels may be associated with subsidiary operations, necessary for communication: adjustment of frequency, synchronization, verification of address codes, text frames, etc. At sufficiently high interference level in wireless systems these data are usually delayed because of acknowledgment of receipt. While the increase of data volume increases the probability of errors in transmission, thus the repeated transmission of data is possible.

3. Statement of the Problem

There is a Poisson flow of similar events, i.e., the initial requests. Each request is accompanied with a random set of pulses (number of pulses and their duration are represented as arbitrarily connected random variables). The term "complex request" will be referred to the set of random pulses generated by certain initial request. The sets of pulses of different complex requests are independent; they do not also depend on the location of the time of the initial request on the timeline.

Thus, the discusses service systems with multiple demands, where each request consists of random number of operations with random duration. Time periods, that are determined by operator for different operations, are executed by one service channel.

The author integrates into the model such peculiarit operation provisioning for one or another request. If t_n – moment of n-request receipt to service system, then k - operation of such request can be started not earlier than moment: $t_n + U_{nk}$, where U_{nk} – random variables with finite expectation. It is assumed that random vectors $\left(U_{n1}, U_{n2}, ..., U_{nN_n}\right)$ are independent and identically distributed; and $U_{n1} \le U_{n2} \le ... \le U_{nN_n}$.

The operator operating algorithm is described as follows.

The first request operation that came at initial time moment $\left(t_0 = 0\right)$ is located within time interval $\left(U_{01}, U_{01} + Y_{01}\right)$, where Y_{nk} indicates duration of k -operation of n-request.

Operations of n -request are located on axis of time after $\left(n-1\right)$ -request operation is completed. Provided that k - operation of n -request is located after completion of $\left(k-1\right)$ -operation of such request and at the same time after provisioning of given operation, i.e. moment $t_n + U_{nk}$. It means that the operator knows variables U_{nk} and Y_{nk} at the moment t_n of n - multiple demand reception.

4. System Description and Main Relationships

Let's consider service system, in which input flow of requests is recurrent. Request reception moments are: t_n, $n \ge 0$, where $t_0 = 0$, $t_{n+1} = t_n + X_n$, where X_n – are independent random variables with distribution function $A\left(x\right)$; $EX_n = a \in \left(0, \infty\right)$. The request with number n involves execution of N_n operation of O_{nk} duration Y_{nk}, $1 \le k \le N_n$, correspondingly. The location of Y_{nk} variables on axis of time is planned by operator at moment t_n in accordance with the following procedure. Operation O_{nk} takes time interval $U_{nk} = \left(t_n + Z_{nk},\ t_n + Z_{nk} + \Upsilon_{nk}\right)$, where Z_{nk} is chosen on term:

$$Z_{nk} = \min\left(z \ge U_{nk} : \Gamma_{nk} \cap \Gamma_{ml} = \varnothing,\ m < n\ or\ m = n,\ l < k\right)$$

where $U_{nk} \ge 0$ are given variables.

The variable U_{nk} can be interpreted as orientation period for operation O_{nk} : such operation can be started not earlier that the correspondent orientation is completed within time U_{nk}, counted off from moment t_n of request reception. Other interpretations are also possible. In any case: $U_{n1} \le U_{n2} \le ... \le U_{nN_n}$.

Let's mark such system as $\overrightarrow{GI} / \overrightarrow{G} / 1$, i.e. one channel service system with recurrent input flow of the most general type, symbols $\overrightarrow{GI}$ and $\overrightarrow{G}$ mean that the request in the input is multiple, and its full servicing requires plural operations for servicing respectively. Each multiple demand operation requires service channel provisioning.

Let's consider the following probabilistic terms.

1. Random vectors $\left(Y_{n1}, Y_{n2} ..., Y_{nN_n};\ U_{n1}, U_{n2} ..., U_{nN_n}\right)$ are

independent of request input flow, being mutually independent and identically distributed.

2. Random vectors $Y_n = Y_{n1} + Y_{n2} + ... + Y_{nN_n}$ и U_{nN_n} independent and

$$b = E\left(Y_{n1} + Y_{n2} + ... + Y_{nN_n}\right) \le \infty ,$$

$$c = E\left(U_{nN_n}\right) < \infty .$$

Let's enter random variable $W_n = Z_{nN} + Y_n$.

This variable equals the time period from moment t_n to the moment, when the last operation n -request is completed.

5. Boundary Theorems

Theorem 1. In given terms, whereas, in addition to,

$$\frac{b}{a} < 1$$

Sequence (W_n) is stochastically bounded.

Theorem 2. If, in addition to terms of theorem 1, distribution $A(x)$ has density and $A(x) < 1,\ x \ge 0$, then sequence of random vectors (W_n) has boundary distribution, if $n \to \infty$.

6. Theorem Proving

Let's fix some $n \ge 1$ and assume that $W_{n-1} = w > 0$. Two cases are possible: $X_{n-1} + Z_{nN} \le w$ (case A) and $X_{n-1} + Z_{nN} > w$ (case B). In case A servicing of n -request operations will start earlier than moment $t_{n-1} + w$, and all of them will happen successively without gaps. Thus,

$$W_n = w + Y_{n1} + Y_{n2} + ... + Y_{nN_n} - X_{n-1}. \tag{1}$$

In case B we have

$$W_n \le w + U_{nN} + Y_{n1} + Y_{n2} + ... + Y_{nN_n}. \tag{2}$$

From (1) and (2): $E(W_n - w) \le b + E(U_{nN}; B) - E(X_{n-1}; A)$.

We have $a = E(X_{n-1}) = E(X_{n-1}; A) + E(X_{n-1}; B)$. If $w \to \infty$ the last summand represents a convergent integral reminder, where

$$-E(X_{n-1}; A) = -a + o(1),\ w \to \infty. \tag{3}$$

Similarly

$$E(U_{nN}; B) \le E(X_{n-1} + U_{nN}; B) = o(1),\ w \to \infty. \tag{4}$$

If a reminder of coincident line from (3) and (4)

$$E(W_n - W_{n-1} \mid W_{n-1} = w) = b - a + o(1),\ w \to \infty, \tag{5}$$

i.e. by reason of $\frac{b}{a} \le 1$, within boundaries we have negative number.

From (1) and (2) we have

$$E(W_n - W_{n-1}) \le E(U_{nN}) + E(Y_{n1} + Y_{n2} + ... + Y_{nN}) \le c + b \tag{6}$$

On the basis of relationships (5) and (6), theorems 1 and 2 are easy to prove using theorem 1 from §20 of monography [12].

7. Monte-Carlo Algorithm

Let's mark through W_{nk} the time from moment t_n to moment of completion of k -operation of n -request, if $N_n \ge k$; assume that $W_{nk} = 0$ in opposite case. It is easy to prove that on terms of theorem 1 the ergodic mean exists

$$W_k = \lim_{n \to \infty} \frac{1}{n}\left(W_{1k} + W_{2k} + ... + W_{nk}\right), \tag{7}$$

where it is meant a probability convergence. Thus, W_{nk} can be by all means correctly approximated by pre-boundary value of right part (7). As random vectors $(W_{n1}, W_{n2}, ...)$ create homogeneous Markov chain then they can be calculated using Monte-Carlo algorithm. For this purpose it is sufficient to implement recurrent relationships that satisfy these values.

For initial values $(n = 0)$ we have the following formulas:

$$W_{01} = \begin{cases} U_{01} + Y_{01},\ if\ N_0 > 0, \\ 0,\ if\ N_0 = 0. \end{cases} \tag{8}$$

If $k > 1$ we have

$$W_{0k} = \begin{cases} \max\left(W_{0,k-1}, U_{0k}\right) + Y_{0k},\ if\ N_0 \ge k, \\ 0,\ if\ N_0 < k. \end{cases} \tag{9}$$

If $n > 0$ we have the following formulas:

$$W_{n1} = \begin{cases} \max\left(W_{n-1,N-1} - t_n + t_{n+1},\ U_{n1}\right) + Y_{n1},\ if\ N_n > 0, \\ 0,\ if\ N_n = 0. \end{cases} \tag{10}$$

Moreover, if $k > 1$, we have:

$$W_{nk} = \begin{cases} \max\left(W_{n,k-1}, U_{nk}\right) + Y_{nk},\ if\ N_n \ge k, \\ 0,\ if\ N_n < k. \end{cases} \tag{11}$$

As the result formulas (8-11) provide the possibility to use the mention Markov chain by means of Monte-Carlo algorithm, that significantly eases the study of system $\overrightarrow{GI} / \overrightarrow{G} / 1$.

8. Conclusions

Provided algorithm of statistical modelling can be applied for further research of servicing system with multiple demands stream taking into account time of preparation of servicing of the channel. Indices of actual processes occurring within the research of operating of the wireless communication channel can be determined for this system at various principles of distribution of receipt of plural signals from a single source of information; thus not being always possible to make it analytically.

It shall be mentioned that scientists have studied system $GI/G/1$, i.e., single-channel queuing system with recurrent input flow of the most general form, where the request in the input flow is not a multiple one, and therefore its complete processing does not require a full maintenance operations set. Thus in papers [13-14], for queuing systems with return of $GI/G/1$, with a common distribution function of request in orbit and FCFS discipline of servicing, E. V. Koba derived condition of existence of ergodic distribution of corresponding Markov chain for two cases, specifically: when the time distribution function in orbit is lattice and when it is continuous. The method of embedded Markov chains is applied to obtain the results. The authors of the article [15] study the discretely-timed, single-channel service system with repeated calls at the general, periodically dependent on the number of request, discrete distributions of intervals of requests receipt, time of servicing and cycle in orbit. There is accepted the discipline of service in sequence. There is derived the sufficient condition for ergodicity of embedded Markov chain.

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