Analysis of the simulation modeling results of flow of negative impacts on adaptive system to ensure the sustainability of communication system

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Abstract. The paper presents results of a simulation of flow possible negative effects on the sustainability perspective system. For the simulation, two variants of organization of adaptive management of the communication system were presented, reviewed 20 different options for process control of the organization. Query parameters and flow parameters of the adaptive sustainability system communication systems were defined.

1. Introduction

The current range of possible negative impacts (NI) on communication systems is becoming wider and more diverse. (For example it is artificial interference in channels, fluctuations, physical damage of various degrees, radio suppression and imposing, attacks on software, etc). In this regard developments of perspective communication systems (CS) are even more often directed to increase in opportunities of the fastest adaptation under operating conditions and increases in resistance to NI. Such problems are largely solved by the use of artificial intelligence models that quickly detect the type of impact and make up scenario of countermeasures to minimize damage.

The article presents the results of simulation of the possible flow of NI on the sustainability perspective system. For the simulation modeling, two options of organizing adaptive control communication system were represented. The first option is focused on the flow requests of negative impacts with three priority levels and one device service in each phase control process to protect the CS. The second option is the opposite of the first, because it includes 9 priority levels (indices) of the input flow and 15 service devices as part of the protection system. To represent these processes as QS (queuing system), the well-known theorem Norton was used [1], according to which individual network elements or portions adaptive sustainability system CS (CS ASS) can be replaced by an equivalent-channel QS with an unlimited queue at the input.

Appropriate schemes for the two originals of CS ASS are presented in Figure 1 and Figure 2. They model mostly such the CS position, which generates random delays of packets of requests about the facts of negative impacts and realizes logical connections with adaptive system providing sustainability. At that on the whole ASS CS is represented as a "black box." Processing of requests is realized by appropriate service devices, which are sections and network elements of the AS CS. In addition, the system includes an additional device-manager, which distributes technical resources and assigns the
order of the message processing. The buffer memory in the QS is ranked by the number of priority. Inquiries about the negative impacts are queued and served in the established priority order. It is assumed that the fragmentation and assembly of messages are outside of the considered model. When the next request comes to the system, the manager must analyze the composition of the queue, determine the type of incoming service messages about the impact, and then he must determine the need to interrupt the current request with a certain priority index. Such organization ASS CS can be described by a mathematical model of type QS open form A / B / 1/3, and A / B / 15/9. Distribution with parameters $\alpha = 3.9$ and $\xi = 0.14$ as well as Erlang distribution, exponential, normal, regular and with parameters $\tau = 0$ [2] - as the statistical laws of the intensity distribution of input flow of requests about negative impacts to simulate CS ASS gamma were taken. A non-priority and relative priority discipline of service is considered for the regular, normal, exponential and erlang laws of distributions, durations of service of flow requests about the negative impacts.

![Figure 1. Equivalent model of a queuing system 1](image1)

![Figure 2. Equivalent model of a queuing system 2](image2)

2. Materials and methods

In order to obtain more reasonable and accurate information about the behavior of the CS ASS and establish patterns of development of the processes occurring in them, 20 different variants of the organization of management processes were considered (Table 1). In this table, the specific value of stay of the request in the system is set based on the data presented in the work [3]. Baseline data for the simulation are presented in tables 2 ÷ 5.

The following parameters were determined in the course of the simulation:

1. Requests flow settings:
   - loading ASS CS with requests of q-priority - $\rho_q$;
   - duration of service requests for all priorities - $\tau_{service}^q$;
   - the length of stay in the system - $\tau_{stay}^q$;
   - the total downtime maintenance devices - $\tau_{downtime}^q$;
   - the duration of waiting for the start of service - $\tau_{waiting}^q$;
   - length of the queue for each priority group $L_q$;
   - variance and coefficient of variation of the residence time in the system;

2. ASS CS parameters:
• total fine of the requests stay in the system - W;
• distribution by parameters CS ASS and function of the fines depending on the total load of the system;
• rational sequence downstream of service requests corresponding to the minimum fine function;
• an equivalent gain in performance for a variety of options for access control process – E;
• evaluation of the accuracy and reliability of the simulation results

### Table 1. Baseline data for simulation 1

| №  | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Type ACSCS | G/E/1/9 | G/M/1/9 | G/R/1/9 | G/N/1/9 | E/E/1/9 | E/M/1/9 | E/R/1/9 | E/N/1/9 | M/E/1/9 | M/M/1/9 |
| The law of distribution of the input flow of requests | Gamma | Erlanga | Exponential |
| α = 3.9; ξ = 0.14; τ = 0 | τ = 1 | τ = 0 | τ = 0 | τ = 0 | τ = 0 | τ = 0 | τ = 0 | τ = 1 | τ = 0 |
| The law of distribution of service duration | Erl | Exp | Reg | Norm | Erl | Exp | Reg | Norm | Erl | Exp |
| τ = 1 | τ = 0 | τ = 0 | τ = 0 | τ = 1 | τ = 0 | τ = 0 | τ = 0 | τ = 1 | τ = 0 |

### Table 2. Baseline data for simulation 2

| Number of priorities, q | Flow settings | Service intensity, λ | Number of service priorities, S |
|-------------------------|---------------|----------------------|---------------------------------|
|                         | p1            | p2                   | p3 |
| 3                       | 0.5           | 0.333                | 0.167                          |
| Specific value of stay in the system | 0.7 |
|                         | a1            | a2                   | a3 |
|                         | 10            | 8                    | 6 |

### Table 3. Baseline data for simulation 3

| Number of priorities, q | The parameters of the requests flow to the security system ACSCS |
|-------------------------|---------------------------------------------------------------|
|                         | p1 | p2 | p3 | p4 | p5 | p6 | p7 | p8 | p9 |
| 9                       | 0.21 | 0.18 | 0.11 | 0.03 | 0.09 | 0.18 | 0.11 | 0.05 | 0.11 |
| The specific value of stay in the system | a1 | a2 | a3 | a4 | a5 | a6 | a7 | a8 | a9 |
|                         | 18 | 16 | 14 | 12 | 10 | 8 | 8 | 4 | 2 |
Table 4. Baseline data for simulation 4

| Number of nodes | Parameters of service devices (service intensity - $\mu$) |
|-----------------|--------------------------------------------------------|
| 15              | 0.1 0.2 0.6 0.8 0.4 0.1 0.1 0.3 0.6 0.3 0.7 0.6 0.1 0.2 0.2 |

Table 5. Baseline data for simulation 5

| Interval modelings $T_M$ | Number of intervals | Allowed service start time $10^9$ | Allowed length of stay $10^9$ | The valid range for idle $10^9$ | The valid range for the service $10^9$ | Allowable specific penalty for staying in the system $10^6$ |
|--------------------------|---------------------|-----------------------------------|------------------------------|----------------------------------|---------------------------------------|----------------------------------------------------------|
| 240                      | 10                  | 10$^9$                            | $10^9$                       | $10^9$                           | $10^9$                                | $10^6$                                                   |

Figure 3. Dependence $\tau_{\text{downtime}} = f(\rho)$ and $\nu = f(\rho)$ for CS ASS $\Gamma/R/1/3$

Figure 4. Dependence $\tau_{\text{downtime}} = f(\rho)$ and $\nu = f(\rho)$ for CS ASS $\Gamma/N/1/3$
Figure 5. Dependence $\tau_{\text{downtime}} = f(\rho)$ and $\nu = f(\rho)$ for CS ASS $\Gamma/M/1/3$

Figure 6. Dependence $\tau_{\text{downtime}} = f(\rho)$ and $\nu = f(\rho)$ for CS ASS $\Gamma/E/1/3$

Figure 7. Dependence $\tau_{\text{downtime}} = f(\rho)$ and $\nu = f(\rho)$ for CS ASS $\Gamma/R/9/15$

Figure 8. Dependence $\tau_{\text{downtime}} = f(\rho)$ and $\nu = f(\rho)$ for CS ASS $\Gamma/N/9/15$
Figures 3 ÷ 6 and 7 ÷ 10 shows the results of simulation CS ASS control processes in the form of functional dependences of the mean residence time of the requests in the system, the coefficient of variation and the average load time CS input flow requests from three - nine priority groups respectively, for a uniform, normal, exponential and Erlang statistical service laws. The results of calculations are presented for the relative priority service discipline (solid lines) and the simplest non-priority discipline (dashed lines). All graphs number of requests flows meet the established priority for them [5]. From these graphs it follows that the residence time of requests in the system, and also downtime maintenance devices in the composition essentially depends on their load. Thus when loading elements $\rho \leq 0.25$ downtime CS ASS reaches significant values, particularly for the uniform distribution and normal service rate ($\sim 4 \cdot 10^3$). At the same time, with the same load of the protection while staying user requests related to different priority groups about the same for all of their absolute value [6].

Thus, when loading ASS CS $\rho \leq 0.25$ possible to establish any priority for any service disciplines. In the future, with increasing negative impacts of the flow rate of more than 50% of the stay requests increases dramatically, especially for low priority messages. Moreover the requests of the 1st and 2nd types of three priority ASS CS and from the 1st to the 5th to the 9-priority AC is becoming less residence time queries at non-priority the organization of their services. With the onset of overloads of the protection system ($\rho >> 1$), and its further increase, there is a violation of the stationary of the inquiry service process from the queue with the highest value of the index $q$. Despite this, the duration of stay in the system of requests with high priorities index varies in a relatively small range except protection system organized by type of G/M/1/9. This demonstrates the advantage of the relative priority service discipline over non-priority by conserving finite values of the mean residence time in the system, along with a decrease in their absolute values for the most important posts. In this regard, you can restore the stationary ASS CS by completely or partially termination of the service requests of less important requests during the time of the system overload. However, with an increase in the integral part of the system flow applications on the negative impact the share of lower priority messages can lead to a significant increase in the time spent in the system of higher priority requests [7].

The most difficult mode of operation of CS ASS is observed in the case of exponential statistical law of distribution of the service duration. At the same time, the values of the mathematical expectation and
dispersion of the mean residence time are approximately 2 times higher than CS ASS characteristics with a regular service time law. However, this advantage is somewhat reduced due to the fact that all service duration distributions, U variation coefficient substantially exceeds its threshold, i.e., $U \gg 1$.

This indicates that relatively small absolute values $\bar{\tau}_{stay}$ are not a serious guarantee of good quality of the ASS CS management process. Therefore, when designing ASS CS should take into account not only the characteristics of the parameter $\bar{\tau}_{stay}$, but also its variation [8].

3. Results
In general, the comparative analysis of the application in ASS CS of different theoretical distribution laws of duration of service requests of negative impacts (regular, normal, exponential and Erlang) showed that the overall trends in the patterns and behavior of subscriber access networks of the digital communication system (DCS) is maintained. The only difference is in the absolute values of some parameters, tolerances which apart reach 45%. And this, in turn, indicates that the main characteristics of CS ASS parameters behave generally the same with respect to such parameters change as the number of servers, the intensity of the input flow of requests, the intensity of service, queue length, waiting service (capacity of the buffer memory), etc [9].

Table 6. Rational ways of organizing the process of servicing inbound flows of negative impacts

| Statistical distribution | Simulation results | The gamma distribution | Regular distribution |
|--------------------------|--------------------|------------------------|----------------------|
| $\lambda_{input}$        |                    |                        |                      |
| Statistical distribution | $\mu_{survey}$     | Regular | Normal | Exponential | Erlang    | Regular | Normal | Exponential | Erlang |
| The sequence of service  | q=3                | 1-2-3                | 1-2-3 | 2-1-3 | 2-1-3 | 1-2-3 | 1-2-3 | 1-2-3 |                    |
| Fine for staying in the system for q=0 | 230.1 | 258.2 | 274.2 | 241.5 | 149.6 | 181.6 | 206.1 |                    |
| Performance gain, %     | 0                  | 0                    | 14.6 | 16.1 | 0 | 0 | 0 |                    |
| Fine for staying in the system for q=0 | 230.1 | 258.2 | 314.3 | 280.4 | 149.6 | 181.9 | 206.1 |                    |
| Number of search steps  | 3                  | 4                    | 2 | 3 | 3 | 2 | 5 | 3 |                    |
| Q=9                      |                    |                        |                      |
| The sequence of service  |                    | 2-1-3-9-6-7-8 | 2-1-3-9-6-7-5-8-4 | 1-2-3-9-6-7-5-8-4 | 1-2-3-9-6-7-5-9-6 | 1-2-3-9-6-7-5-9-6 | 2-1-3-9-6-7-5-8-4 | 1-2-3-9-6-7-5-4-8 |
| Fine for staying in the system for q=0 | 311.0 | 358.6 | 408.5 | 379.3 | 321.4 | 416.4 | 424.1 |                    |
| Performance gain, %     | 37.7               | 39.6 | 24.9 | 34.2 | 56.5 | 48.1 | 35.5 | 41.4 |                    |
| Fine for staying in the system for q=0 | 428.2 | 500.6 | 510.2 | 509.3 | 502.9 | 616.7 | 514.7 | 561.6 |                    |
| Number of search steps  | 31                 | 27 | 49 | 42 | 24 | 58 | 37 | 47 |                    |

The most rational ways of organization of the process of servicing incoming flows of requests about negative impacts are established. These data are presented in Table 6 and 7, of which it implies that the
message flows for the three-time CS organization ASS in the case of the regular service time and the normal distribution should be handled in the order of their receipt in the system, and for the exponential and Erlang service disciplines in order 2-1-3.

Fine function for these scheduling modes negative impacts flows take the following values, respectively: 230.1; 258.2; 271.3 and 241.5 standard units, and a conditional performance gain ASS CS, respectively, equal to 0; 0; 14.6 and 16.1%. Similarly for 9-priority organization of the CS ASS the average performance gain achieved by introducing rational sequence of service requests of protection system users is equal to 34.1%. It corresponds to the mean value of fine function equals to 473.8.

**Table 7.** Rational ways of organizing the process of servicing inbound flows of negative impacts

|statistical distribution\(\lambda_{\text{input}}\)| The gamma distribution | Regular distribution |
|---|---|---|
|statistical distribution\(\mu_{\text{survey}}\)| Regular | Normal | Exponential | Regular | Normal | Exponential |
| The sequence of service | 1-2-3 | 1-2-3 | 2-1-3 | 2-1-3 | 2-1-3 | 2-1-3 | 1-2-3 | 1-2-3 |
| Fine for staying in the system for \(q\neq0\) | 230.0 | 249.1 | 257.5 | 221.6 | 240.6 | 276.2 | 289.12 | 253.4 |
| Performance gain, % | 0 | 0 | 11.8 | 15.7 | 9.7 | 7.4 | 0 | 0 |
| Fine for staying in the system for \(q=0\) | 230.0 | 249.1 | 287.9 | 256.4 | 263.9 | 295.5 | 289.2 | 253.4 |
| Number of search steps | 2 | 3 | 4 | 6 | \(\frac{1}{3}\) | \(\frac{5}{4}\) | 4 | 4 |

**q=9**

| The sequence of service | 1-2-3-6-9-8-7-3-5 | 1-2-3-5-9-4-7-8-9 | 1-2-3-6-9-7-4-9-5-8 | 2-3-1-5-7-9-6-8-4 | 2-1-3-6-7-9-2-1-3-9-4-8 | 2-1-3-7-5-6-9-5-4 | 1-2-3-7-8-6-9-5-4 |
|---|---|---|---|---|---|---|---|
| Fine for staying in the system for \(q\neq0\) | 369.4 | 375.7 | 403.5 | 396.3 | 423.4 | 501.8 | 537.9 | 440.0 |
| Performance gain, % | 44.6 | 39.2 | 28.1 | 30.6 | 35.4 | 31.6 | 20.1 | 22.9 |
| Fine for staying in the system for \(q=0\) | 534.1 | 522.9 | 516.8 | 517.6 | 573.3 | 660.4 | 646.0 | 540.9 |
| Number of search steps | 44 | 29 | 30 | 53 | 26 | 33 | 45 | 38 |

Thus, changing the way the organization of ASS CS from 3 to 9 priority levels can increase the gain in performance by almost 2.5 times. A further increase in flow index priority requests practically does not change this value by more than 0.1%, so the relative priority discipline service can recommend allowable number of priority levels comprising the integral of the input flow in the range of 8 to 10 [10].

The comparative analysis of the fine function values and the corresponding values of the residence time of the queries in the system allows setting practically important law, which is the ratio of length of
stay in a penalty per unit of time of stay in the Messaging devices CS ASS located in the order of non-decreasing:

\[
\frac{\tau_{\text{stay}}_{j-1}}{a_{j-1}} \leq \frac{\tau_{\text{stay}}}{a_j}
\]  

(1)

Separately, the authors studied the effect of different theoretical inquiries service time distribution laws of the negative impacts on the ways of organizing the sequence of processing in accordance with and set priorities. As a result, it was found that a change in the nature of service CS ASS from negative impacts in general does not have a significant impact on the general order of prioritization and sequence of message flow processing. More strikingly, this dependence is shown for regular and exponential size distribution. In other cases, this effect is negligible. All this allows considerably simplifying the procedures control the work of ASS CS as small error inquiries about the negative impacts of the queue can be selected without taking into account the features of their service in the system [11].

Figure 11. Graphs of functions \( W = f(\rho) \) and \( E_w = f(\rho) \) for 3 priority CS ASS

Figure 12. Graphs of functions \( W = f(\rho) \) and \( E_w = f(\rho) \) for 9 priority CS ASS

In general, the processes of simulation to find the most efficient options for system management organizations of the ASS and the corresponding fine function \( W(X) \) required an average of 39-step of the simulation algorithm. The solution of the problem by exhaustive search would require a \( 9! = 362800 \) computing functions.

A basic understanding of the laws governing the behavior of the mean value of the fine \( W(X) \) for the stay in the system, as well as an equivalent gain in performance \( E_w \) CS ASS depending on the download requests of the users provide graphs shown in Figures 11 and 12.

These figures use the same notations as in Figures 3 ÷ 10. Analysis of the graphs allows quantifying the relative merits of the application the priority of message flows of service discipline the negative impact to non-priority discipline, depending on the system loading. For example, for 3-priority ASS CS when it is loaded in the range of the maximum gain in productivity reaches 29%. At the same loading of 9 priority ASS CS equivalent gain already will be 63%.

However, if the system is underloaded \( (\rho \leq 0,25) \), the service discipline in the natural order of priority becomes comparable or even exceeds the performance relative priority discipline for ASS CS type \( G/R/1/9 \) and \( \Gamma/E/1/3 \). Therefore, when a large load ASS CS or its overload can be recommended...
service discipline with relative priorities, and when underload – the simplest discipline in the natural order of messages received.

Thus it detects the assertion of the necessity of applications of the CS methods for adaptive switching of the data packets. In turn, this helps to clarify some of the requirements for the organization of the functioning of processes elements ASS CS, in particular use of adaptive strategies for process control scheduling data flows.

Thus, for example, if while in a certain number of queries negative impacts are received, there is a sequence of priorities, which ensures the complete absence of violations of the terms of stay in ASS CS for a corresponding value of fine for their violation, then according to the rule (3.17), flow of requests can be ordered in a way that will minimize the mean duration of their stay in the system until the completion of service and receipt of the final results. This allows applying a recursive method of constructing the most efficient strategy to service the requirements of CS protection from negative impacts, starting with the last request.

For this they received the totality of the system of the negative impacts of requests will need to choose those for which the total duration of stay does not exceed the deadlines for their implementation. Of those requests, satisfying this condition, one is selected with the highest ratio of the length of stay in a fine per unit time spent in the system and secured the last place on the overall consistency of service. Then, the process is repeated, resulting in the now selects penultimate request and so on.

4. Conclusion
Recursively all the maintenance schedule of the process can be made. However, it must be taken into account that the case of non-simultaneous receipt of requests required each time to solve the problem of obtaining the rules for choosing the optimal time interval adjustment of a schedule.

5. Acknowledgments
Expressing gratitude for the invaluable help in this work, as well as to develop into quality issues of information security and communication systems Ruzheynikov Valery Nikovaevich. He had many scientific papers and worked in Military Academy of Strategic Missile Forces of Peter the Great. He raised and trained a large number of engineers.

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