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Mathematical Model of Operative - Technological Communication - Ip Network Functioning Process under Information Influence Transfers While Transferring a Self-Like Data Flow

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Annotation: In this article, using mathematical modeling of the operation of a network of operational technological communication - IP under informational influences during the transmission of a self-similar data stream, the mathematical expectation of the transmission time of a packet between the corresponding nodes and the distribution function of the time of successful transmission of data packets in a cyber-attack are determined, quick-technological communication in railway transport.

Key words: operational-technological communication, cyber attack, railway transport, stochastic network, mathematical expectation, data packet transmission, queuing system.

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Introduction

An important place in the world is given to the creation of information systems and digital technological networks for the operational management of the operational work of railway transport, which ensures an increase in the level of train safety. In this regard, special attention is paid to improving the network of operational technological communication (OTC) on the railways. In its construction and purpose, it refers to multi-level, hierarchical, regional, technological telecommunication networks [1- 15].

When implementing these problems, in particular, certain results were achieved in the development of OTC systems using the “Internet Protocol” (IP) technology. In carrying out these tasks, an important issue is the modeling of the functioning of the OTC network based on IP technologies in the context of information impacts, a logical-probabilistic model for calculating the reliability of the functioning of the OTC network, and the introduction of OTC systems that increase their performance and reliability.

Today, the requirements for the network of operational and technological communications remain relevant and unexplored to the organization of transportation operations in the railway transport, which is the main one under the conditions of information impacts during transmitting a self-similar data stream.

Problem Solving Concept

To solve the problem of the development of a mathematical model of the process of functioning of the OTC network based on IP-technologies in the conditions of information impact during the transmission of a self-similar data stream, it is necessary to solve the following problem: Let there be a network of operational - technological communication – IP (OTC-IP), in which data packets are transmitted. At the stage of organizing and planning, the exchange of information, transmission routes are determined, each of which in the general case consists of m nodes and $m-1$ sections. The route passes a stream of categorized packets that arrive in a memory buffer of $0<E<\infty$ depending on the class of service (Quality of Service - QoS), packages are assigned relative priorities $i=\overline{1,R}$.

The total packet arrival rate is $\Lambda=\sum_{r=1}^{R}\lambda_r$

where λ_r - packet flow intensity of the r-th priority. The OTC - IP network [16] operates under the conditions of a cyber-attack (SC) of the intruder, each of which violates the P_i; $i=\overline{1,n}$.

If the network is not interrupted, then with probability $1-P_i$ r-priority packets to be transmitted will be successfully transferred to the correspondent in a random time $t_{nep,r}$ determined by a random amount and transmission rate equal to

$t_{nep,r} = \sum_{r=1}^{n-1} \frac{1}{\mu_r}$ where - $\mu_r = R / V_r$ the service intensity of the r-th priority packet, and characterized by the distribution function (DF) $B_r(t)$.

Of the-priority. In the event of a failure of the OTS - IP network is restored in a random time $t_{\text{в}_i}$; $i=\overline{1,n}$ with (DF).

Let there be a network of operational - technological communication - IP (OTC -IP), in which data packets are transmitted. At the stage of organizing and planning the exchange of information, transmission routes are determined, each of which in the general case consists of nodes and sections. A stream of categorized packets is transmitted along the route, which arrive in a volume buffer. Depending on the class of service (Quality of Service (QoS)), packets are assigned relative priorities. In case of a failure of the OTC - IP network is restored in a random time; with FR. recovery time, and the received data packet is retransmitted. The incoming packet stream is characterized by We bull or Pareto distributions. Destructive effects on network elements are possible both during packet transmission and in pauses between them. The number of waiting places is determined by the capacity of the drive [17].

Concept implementation

To implement the concept, it is necessary to determine the mathematical expectation of the transmission time of the packet between the corresponding nodes $\overline{T_h}$ and the distribution function of the time of successful transmission of data packets in spacecraft conditions KA.

Decision:

Let us imagine the process described above in the form of a stochastic network (Fig. 1).

Conditionally, the transfer process is divided into a wait sub process and a direct transfer (service) sub process.The wait process sub process in the transmission queue is characterized by a random wait time with t expectation a DF wait time $\omega(t)$.

The service process is characterized by the average packet $\overline{t_{h_r}}$ transmission time between the respective nodes with the FR service time $\mu_r(t)$.

In a stochastic network are indicated: $\beta_r(s) = \int_0^\infty e^{-st} d[B_r(t)]$

- the Laplace - Steeliest transform, that is, the distribution function of the transmission time of packets of the r-th category of urgency without taking into account the intruders KA spacecraft;

$P_1,\ldots,P_n$ - the likelihood of an intruders influence KA;

$$\delta_i(s)=\int_0^{\infty} e^{-st}d[\Delta_i(t)],\quad i=\overline{1,n}$$ - Laplace

– Steeliest transformation, that is, the distribution function of the network recovery time after the i-th spacecraft *i*-t KA;

$\lambda_{вх}$, $\lambda_{исх}$ - intensity of incoming and outgoing packet flows;

$$\omega_r(s)=\int_0^{\infty} e^{-st}d[W_r(t)]$$ -the Laplace

– Steeliest transform, that is, the distribution function of the transmission time of messages of the r-th category of urgency.

The distribution function of the transmission time of the subprocess of service was obtained [1, 2, 4].

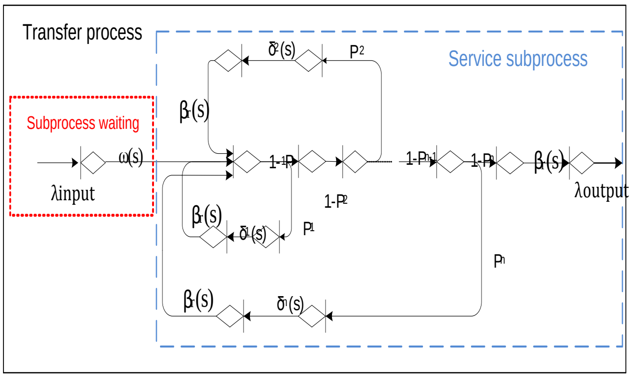

Fig.1. Stochastic transmission process network

$$H_r(t)=\sum_{i=1}^{n}\frac{V(s_{ir})\cdot\left(1-e^{s_{ir}t}\right)}{U'(s_{ir})\cdot(-s_{ir})}\qquad(1)$$
,

Where $$V(s_{ir})=k\beta\left(s_{ir}\right)\left(\overline{d}+\overline{c}+s_{ir}\right)\prod\nolimits_{i=1}^{n}\left(1-P_i\right);$$

$$U'(s_{ir})=\overline{\mathrm{d}}\left[1-\beta\left(s_{ir}\right)\sum_{i=1}^{n}P_i\delta_i\left(s_{ir}\right)\prod_{j=1}^{i-1}\left(1-P_j\right)\right]+\left(\overline{d}+s_{ir}\right)\cdot$$
$$\cdot\left[-\beta'\left(s_{ir}\right)\sum_{i=1}^{n}P_i\delta_i\left(s_{ir}\right)\prod_{j=1}^{i-1}\left(1-P_j\right)-\beta\left(s_{ir}\right)\sum_{i=1}^{n}P_i\delta_i'\left(s_{ir}\right)\prod_{j=1}^{i-1}\left(1-P_j\right)\right]$$

$$\overline{d} = \sum_{i=1}^{n} t_{\text{в}i}^{-1} P_i$$

- the mathematical expectation of the intensity of recovery of the network element after the spacecraft KA;

$$\overline{c} = \sum_{i=1}^{n} t_{\text{рв}i}^{-1} P_i$$

- the mathematical expectation of the intensity of the implementation by the intruder of the spacecraft KA on the network;

$$k = \frac{\overline{d}}{\overline{d} + \overline{c}}$$

- the likelihood of network elements recovering during the retransmission of a packet and the implementation of another KA.

Knowing the distribution function allows you to determine the mathematical expectation and variance:

$$\overline{T}_r = \int_0^{\infty} t d\left[H_r(t)\right] = \sum_{i=1}^{n} \frac{V(s_{ir})}{U'(s_{ir})(s_{ir})^2}; \qquad (2)$$

$$D_r = \int_0^{\infty} (t-T)^2 d\left[H_r(t)\right] = \sum_{i=1}^{n} \frac{2V(s_{ir})}{U'(s_{ir})(s_{ir})^3} - T^2$$

and coefficient of variation of service time $C_{hr} = \frac{\sqrt{D_r}}{T_r}$ (4)

In [2], it was shown that DF (1) can be approximated by an incomplete Gamma

-function, that is, $H_r(t) \approx F_{\gamma r}(t) = \frac{m_r^{\alpha_r}}{\Gamma(\alpha_r)} \int_0^t t^{\alpha_r - 1} \cdot \exp(-m_r t) dt$ (5)

where $m_r = \frac{T_h}{D_h}$; $\alpha_r = \frac{T_h^{\ 2}}{D_h}$ – parameter of scale and shape of an incomplete Gamma - function.

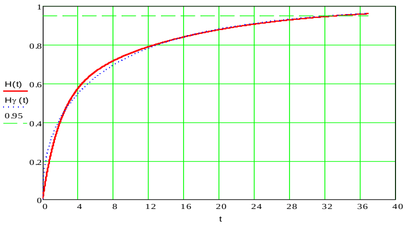

Fig. 2. Approximation of RF transmission time of incomplete Gamma - function

The error of such an approximation does not exceed 10%, as illustrated in Fig. 2.Thus, with an accuracy sufficient for engineering calculations, picture DF $H_r(t)$ the Laplace – Steeliest image of a DF can be definitely defined as an image of an incomplete Gamma function, i.e.

$$h_{\gamma_r}(s) = \left(\frac{m_r}{m_r + s} \right)^{\alpha_r} \qquad (6)$$

This allows us to represent the process of packet transmission in the form of an enlarged stochastic network (Fig. 3) with an equivalent function *Q(s)*:

$$Q_r(s) = \omega_r(s) h_{\gamma r}(s) \cdot$$

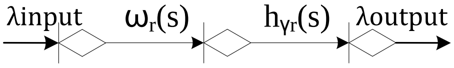

Fig. 3. Enlarged stochastic transmission process network

In determining ωr(s) we will proceed from the following well-known statements:
- a queuing system (QS) with a finite and infinite buffer at low packet loss rates (less than 10-3) has the equivalence property [18];

- on the basis of the "law of conservation of work accumulated in the queue", the work accumulated in the priority queue is constant and equal to the accumulated work in a non-priority QS with a total load;

- the length of the queue for service (transmission), and hence the waiting time in the queue does not depend on the time of delivery of packets and time of service.

Based on the results of [18], expressions for determining: - the first moment, i.e. the average waiting time for serving packets of the r-th priority:

$$\overline{T_{\omega r}} = \begin{cases} \overline{T}^{*}_{\omega r}, r = 1; \\ \frac{\Lambda_r}{\lambda_r} \left(\overline{T}^{*}_{\omega r} - \frac{\Lambda_{r-1}}{\Lambda_r} \overline{T}^{*}_{\omega r-1} \right), r = \overline{2, R} \end{cases},$$

where the average waiting time for servicing packets without priorities, taking into account the variability of the distributions of time between packet arrivals and service time

$$\overline{T}^{*}_{\omega r} = \frac{\rho_r - \rho_r^{K+2}}{1 - \rho_r^{K+2}} \frac{1 - (K+1)\rho_r^{K} + K\rho_r^{K+1}}{\mu_r (1-\rho_r)(1-\rho_r^{K+1})} \frac{C_\omega + C_{hr}}{2}$$

$\rho_r = \lambda_r \overline{T}_r; \overline{T}_r -$ mathematical expectation of packet transmission time in spacecraft conditions KA with a rare subsequent input stream [19, 20].

In turn, the variance of the latency is

$$D_{\omega}=\begin{cases} M_{2\omega r}-\left(\overline{T_r}\right)^2, r=1; \\ \left(\left(\frac{\lambda_i}{\Lambda}\right)^3\left[M_{2\omega r}-\sum_{i=1}^{r-1}\left(\frac{\lambda_i}{\Lambda}\right)^3 M_{2\omega r-1}\right]\right)- \end{cases} \tag{8}$$

where: - the second moment of waiting time without taking into account priorities

$$M_{2\omega r-1}=\left(\frac{C_{\omega}{}^2+C_{hr}{}^2}{2}\right)^2\times\frac{\rho_r-\rho_R{}^{K+2}}{1-\rho_R{}^{K+2}}\times$$

- coefficient of variation of time between packet

$$\times\frac{2(1-\rho_r{}^K)+K\rho_r{}^K(1-\rho_r)\left[\rho_r(K+1)-K-3\right]}{(1-\rho_r)^2(1-\rho_r{}^{K+1})}\times\sum_{i=1}^{n}\frac{2V(s_{ir})}{U'(s_{ir})(s_{ir})^2}$$

arrivals and packet $C_{\omega r}$ service (transmission) time C_{hr}.

It is proposed to approximate the DF, the waiting time for an incomplete Gamma function, which is in good agreement with the results published in [19, 20].

Therefore, the image of the FR according to Laplace – Steeliest

$$\omega_r(s)=\begin{cases} \left(\frac{\omega_r}{\omega_r+s}\right)^{\beta_r} \\ \frac{\Lambda_r}{\lambda_r}\left(\left(\frac{\omega_r}{\omega_r+s}\right)-\frac{\Lambda_{r-1}}{\Lambda_r}\left(\frac{\omega_r}{\omega_{r-1}+s}\right)^{\beta_{r-1}}\right) r=\overline{2,R} \end{cases} \tag{9}$$

where: $\omega_r=\frac{\overline{T_{\omega r}}}{D_{\omega}}$; $\beta_r=\frac{\left(\overline{T_{\omega r}}\right)^2}{D_{\omega}}$

- parameter of the scale and shape of the Gamma - distribution. Thus, the equivalent function of the stochastic network (see Fig.2) takes the form and FR delay time (transmission process)

where: $F_r(t)=\frac{\chi^{\varepsilon_r}}{\Gamma(\varepsilon_r)}\int_0^t x^{\varepsilon_{r-1}}\exp(-x\chi_r)dx$; (10)

$$\chi_r=\frac{T_{\omega r}+\overline{T_r}}{D_{\omega r}+D_r};\quad \varepsilon_r=\frac{\left(T_{\omega r}+\overline{T_r}\right)^2}{D_{\omega r}+D_r}. \tag{11}$$

The probability of packet loss of different priorities is

$$P_{K+1}=\frac{\rho-\rho^{K/C^2+2}}{1-\rho^{K/C^2+2}}\frac{1-\rho}{1-\rho^{K/C^2+1}}\rho^{K/C^2} \tag{12}$$

$$C_{\omega\Pi}{}^{2}=\left(\frac{\phi^{2}{}_{\max_r}\phi^{\alpha_r}{}_{\min_r}-\phi^{\alpha_r}{}_{\max_r}\phi^{2}{}_{\min_r}}{2-\alpha_r}-\frac{\alpha_r\left(\phi_{\max_r}\phi^{\alpha_r}{}_{\min_r}-\phi^{\alpha_r}{}_{\max_r}\phi_{\min_r}\right)^{2}}{(1-\alpha_r)^{2}\left(\phi^{\alpha_r}{}_{\max_r}-\phi^{\alpha_r}{}_{\min_r}\right)}\right)\times$$
$$\times\frac{(1-\alpha_r)^{2}\left(\phi^{\alpha_r}{}_{\max_r}-\phi^{\alpha_r}{}_{\min_r}\right)}{\alpha_r\left(\phi_{\max_r}\phi^{\alpha_r}{}_{\min_r}-\phi^{\alpha_r}{}_{\max_r}\phi_{\min_r}\right)^{2}} \quad . \qquad (13)$$

To establish the DF of the delay time, it is necessary to determine the coefficient of variation of the incoming stream, $C_{\omega r}$ (13) which substantially depends on the type of distribution model for the duration of time intervals between packets in the Pareto incoming stream: while Weibul distribution,

$$C_{\omega B}=\sqrt{\frac{\Gamma\left(1+\frac{2}{\alpha_r}\right)}{\Gamma^{2}\left(1+\frac{1}{\alpha_r}\right)}-1}, \qquad (14)$$

where: $\Gamma(*)$-Gamma is a function.

The incoming stream, which in the general case is self-similar, is characterized by a H - Hurst coefficient. The expressions for calculating the coefficient substantially depend on the parameter

$$\alpha_r=\begin{cases}3-2Hw, npu\, 0\le Hw\le 0,51;\\ -\frac{1}{9}Ln\frac{Hw-0.51}{1.2}, npu\, 0,51\prec Hw\le 0,6;\\ -\frac{1}{19}Ln\frac{Hw1-0.57}{4.1} npu\, 0,6\le Hw\le 1;\end{cases}$$

α_r - the Weibul or Pareto distribution form.
(15)

- in the Pareto distribution, the parameter α_r defined by expression $\alpha_r=H^{-(1/0,8)}$.

Based on the results of simulation in [8, 9], an empirical formula was obtained for calculating the Hurst coefficient: for the Weibull distribution, the Hurst coefficientα_r is determined by the expression $Hw=1.2\exp(-9\alpha_r)+0.51$, where: α_r - Weibul distribution parameter numerically equal.

Conclusions

Thus, all the required quantities necessary for calculating the distribution function are established. From the calculation it follows that the developed model provides non-contradictory logic results. In the context of spacecraft implementation, the role of the effectiveness of the mechanism for organizing information security of the OTC network based on IP technologies, which characterizes the working time after the spacecraft in the model, substantially increases.

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