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ASSESSMENT OF LOAD SELF-SIMILARITY PROPERTIES IN NETWORK STRUCTURES

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Main ratios allowing estimating the influence of self-similar load on the efficiency of network resource use have been obtained. It was shown that the degree of channel loading increases and buffer storage volume in switching nodes decreases in optimal case by minimum criterion of package delay average time.

Introduction

Development of infrastructure of modern communication lines is directed to scaling introduction of high-speed technologies and new telecommunication services on the basis of using information batch communication for traffic formed by applications of different types. The important feature of such networks is mastering new time scales which require solving a number of scientific and practical problems connected with the development of fundamentally new measuring technology for its testing, reviewing the main positions of teletraffic theory directed to calculation of network load. In this case traditional methods of calculating the volume of equipment (especially storage capacitors of switching nodes) based on Markov models result in significant underestimating the degree of loading of existing network resources.

1. State of a question

Numerous investigations of traffic properties of modern telecommunication networks allowed detecting the phenomenon of structural similarity of packet load statistic characteristics at its measuring for different time scale (self-similarity phenomenon). Packet data transmission in digital networks with services integration, local network of the family Ethernet, networks of all-channel signaling, video-transmission with variable velocity in networks using asynchronous transmission method (ATM) and others refer to a number of objects for which similar phenomena are detected. Requirements for storages which are made by classical teletraffic theory are rather strict owing to strong long-term dependence of load in communication channels at transmission of self-similar traffic (characterized by values of Hearst parameter) [1]. At present the opinion is ascertained that if a large self-similar load should be transmitted by network then a presence of storages of higher capacity than it is required by calculations of teletraffic classical theory in switching nodes should be supported. Preliminary analysis showed that at telecommunications optimization by criterion of average time minimum of packet delay at load increase in the network the volume of buffers storage in switching nodes should be decreased that results in reducing time of packet being in the queue that requires, in its turn, application of channels with higher capacity.

2. Problem statement

In telecommunications the traffic is supposed to be planned a priori on the basis of existing probabilistic and prognostic models [2] and on their basis the gravity matrix of network node information flows with estimated data on transmitted volumes of information is obtained along with another ordering information. In these conditions the problem of obtaining reliable information on the volume of the required network resources for achieving the desired values of time-probabilistic characteristics of data volume of network users gains special currency.

In this article the analytic dependences for queuing systems (QS) of two types were obtained. They show the degree of influence of increasing self-similar load on the main network indices. The cases of network load increase were considered:

- only due to traffic self-similarity properties at various values of Hearst index in single-channel QS with a capacity of recall;
- due to increase of load in the network and accounting self-similarity properties of transmitted traffic in multi-channel QS.

To obtain time-probabilistic characteristics of data exchange of network users on the basis of which the models of switching nodes in the form of QS are used and in which packet queues at the input to each channel are arranged into consistent queue the design procedure of network main indices should be changed so that it takes into account the influence of self-similar traffic especially at network overloading. Let us introduce function $f(H)$ where H is the Hearst index to take into account the influence of self-similarity of transmitted traffic on data exchange in the network. At H=0,5 load self-similarity properties are absent. But increasing H to a unit the influence of self-similarity intensifies. It is explained by the fact that at growth of parameter H the inertia of variability of used historical data of network level increases when solving optimization problems. Let us use the approach which is described in [3] to take into account the influence of load self-similarity in the network. Then the intensity of demands entering for service may be presented in the form:

$$\lambda_c = \lambda f(H),$$

where λ is the intensity of demand flow entering for service without self-similarity.

To solve the optimization problem and obtain the results in numerical form the law of variation of function $f(H)$ should be determined. If the linear law of variation of function $f(H)$ of Hearst index H is used and $f(H)$=1 is put at H=0,5, then $f(H)$ may be presented in the form $f(H)=2H$ [2]. Further this law is used for accounting properties of load self-similarity in the network.

3. Problem solution

Solving many network problems the majority of authors confine themselves to examining isolated QS of different types. The obtained results are valid for computing parameters and qualitative indices of data link layers (data link). However, such approach does not allow estimating structural-network parameters and solving the problems of network layer. To solve the problems of network layer the network should be stimulated in the form of multi-channel multisite system which has complicated topological structure and limited coherence.

Solution of network problem in which information flows were optimized in communication lines or communication branch capacities were optimized by criterion of minimum of delay average time $\overline{T}_{зад}$ is of practical interest. Let us use the Little formula to approach the network level solving optimization problem:

$$\overline{T}_{зад} = \frac{1}{\gamma}\sum_{j=1}^{v}\overline{N}_j(F,V), \tag{1}$$

where F, V is the flow of each branch and its conductivity; γ is the total network traffic; N_j is the total amount of demands for service and in queue of channel j; v is the number of network branch.

To analyze and compare the results of simulation let us examine, first of all, the well known model of the network where each link is simulated in the form CMO M/M/1/n with a capacity of recall. The generating function of stationary probabilities for such system is determined by the dependence: [3]:

$$P(z) = P_0\frac{\pi(1-z)}{\pi+\delta z - z[h(\lambda-\lambda z)]^{-1}} = P_0 A(z).$$

where: P_0 is the probability of requirement absence in the system;λ is the intensity of input flow of requirements; π is the probability of recall absence; $\delta=1-\pi$ is the probability of call for repeated service;

$$A(z) = \frac{\pi(1-z)}{\pi+\delta z - z[h(\lambda-\lambda z)]^{-1}}.$$

Conversion of Laplace-Stilltiece for exponential of service time distribution has the form:

$$h(s) = \int_0^{\infty}\exp(-st)dx(t) = \frac{\mu}{s+\mu},$$

where: μ is the intensity of call service.

By means of simple conversions we obtain:

$$A(z) = \frac{\pi}{\pi-\rho_0\cdot z} = \frac{1}{1-\rho_c\cdot z} = \sum_{j=0}^{\infty}\rho_c^j\cdot z^j,$$

where $\rho_c^j = \dfrac{\lambda}{\pi\mu}f(H)$ is the coefficient of channel load taking into account self-similarity and capacity of recall.

Therefore, coefficients a^k determining stationary probabilities of being requirements in system k equals to:

$$a_k = [\rho_c]^k,$$

probability of absence of requirements in the system is determined by the expression:

$$P_0 = \sum_{a=0}^{m+1}\rho_c^a, \quad a=\overline{0...m},$$

where m is the total number of demands in the system.

Stationary probabilities of occurrence of requirements in the system k are determined by the expression:

$$P_k = P_0\cdot a_k.$$

Average queue in QS of this type equals to:

$$\overline{N}_a = \frac{1-\rho_c}{1-\rho_c^{m+1}}\sum_{i=1}^{m} i\cdot\rho_c^i, \quad i=\overline{1...m},$$

where ρ_c^i is the degree of loading the channel of i link.

Probability of DoS due to channel and buffer occupancy is determined by the expression:

$$P_{отк} = P_{m+1} = P_0(\rho_c)^{m+1}.$$

Let us determine an average number of demands being in queue:

$$\overline{r} = \rho_c^2 P_0\sum_{a=1}^{m} a\rho_c^{a-1}. \tag{3}$$

Average number of demands being on service equals to:

$$\overline{z} = \rho_c(1-P_0\rho_c^{m+1}). \tag{4}$$

Let us determine an average number of demands being in QS:

$$\overline{N} = \overline{r}+\overline{z}. \tag{5}$$

Substituting values of (3) and (4) into (5) an average number of demands in QS are obtained in the following form:

$$\overline{N} = \rho_c^2 P_0\sum_{\alpha=1}^{m}\alpha\rho_c^{\alpha-1} + \rho_c(1-P_0\rho_c^{m+1}). \tag{6}$$

Let us commit the probability of refusal on this level:

$$P_{отк} \le P_{отк}^{доп}, \tag{7}$$

then:

$$P_{отк}^{доп} = P_0\rho_c^{m+1},$$

whence we find P_0

$$P_0 = \rho_c^{-(m+1)}P_{отк}^{доп}. \tag{8}$$

We obtain:

$$\overline{N} = P_{отк}^{доп}\sum_{\alpha=1}^{m}\alpha\rho_c^{-(m-\alpha)} + \rho_c(1-P_{отк}^{доп}). \tag{9}$$

Expression (9) is valid for each node and each direction of transmission. Therefore, for the network having specified topological structure for arbitrary direction i we have:

$$\overline{N}_i = P_{отк}^{доп}\sum_{\alpha=1}^{m_i}\alpha\rho_{ci}^{-(m_i-\alpha)} + \rho_{ci}(1-P_{отк}^{доп}).$$

Taking into account (9) average delay time (1) in the whole network equals to

$$\widehat{T}_{зад} = \frac{1}{\gamma}\sum_{i=1}^{k}\left[P_{отк}^{доп}\sum_{\alpha=1}^{m_i}\alpha\rho_{ci}^{-(m_i-\alpha)} + \rho_{ci}(1-P_{отк}^{доп})\right]. \quad (10)$$

The results of calculations for presentation of function $f(H)=2H$, carried out by the formula (2), are given in Fig. 1. Fig. 1 determines the dependence of length of average queue of demands $\overline{N}_a$ (axis y) on coefficient of channel loading ρ_c (axis x) for different values of Hearst indices H and probabilities of recall π.

It follows form Fig. 1 that buffer of large volume should be used for servicing self-similar load in CMO *M/M/1/m* at the same values of channel loading that coincides with the results given in [1].

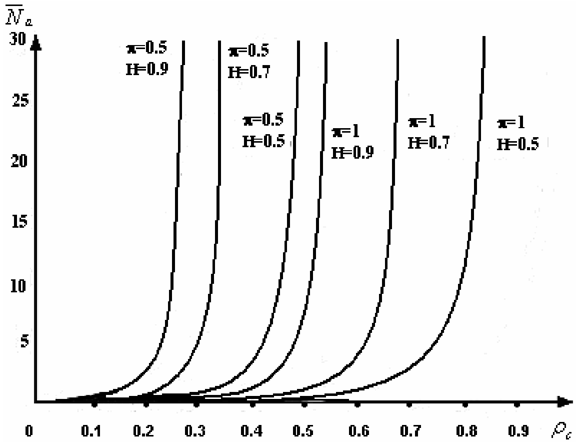

Fig. 1. *Dependence of buffer volume on channel load*

Differentiating (10) by ρ_{ci} and equating the derivative to zero we obtain n equations which allow obtaining coefficients of channel load for each transmitting direction:

$$\frac{\partial \widehat{T}_{зад}}{\partial \rho_{ci}} = 0.$$

Owing to separation property of function $T_{зад}$, let us write down the condition:

$$\frac{\partial \widehat{T}_{зад}}{\partial \rho_{ci}} = \frac{d\overline{N}_i}{d\rho_{ci}} = 0.$$

Differentiation of (10) gives n equations which allow determining optimally coefficients of loading each link:

$$\sum_{a=1}^{m_i}(m_i - a)a\rho_c^{-(m_i-a+1)} = 1 - P_{отк}^{доп}; \quad i = \overline{1,k}. \quad (11)$$

However, according to problem situation the acceptable values are only those of them which meet the condition:

$$P_{отк}^{доп} = \rho_c^{(m+1)}\rho_0 = \rho_c^{(m+1)}[\sum_{\alpha=1}^{m+1}\rho_c^{\alpha}]^{-1}.$$

Let us convert expression (11) to the form ($P_{отк}^{доп}$<<1):

$$P_{отк}^{доп} = \sum_{a=1}^{m_i}(m_i - a)a\rho_c^{-(m_i-a+1)}.$$

Comparing expressions (7) and (11) we obtain:

$$\rho_c^{-1} = \sum_{\alpha=1}^{m_i}[\alpha(m_i-\alpha) - \rho_{c_i}]\rho_{c_i}^{\alpha-1}. \quad (12)$$

Structure containing bundles of channels in each transmitting direction are used in practically implemented topological structures of telecommunications. Therefore, it is reasonable to investigate the influence of self-similar load on the network in which each link is simulated by multi-channel QS with limited queue of the type *M/M/n/m*. For such model an average delay time for the whole network is determined by the expression [3]:

$$T_{зад} = \frac{1}{\gamma}\sum_{i=1}^{k}[P_{i\,отк}^{доп}\sum_{\alpha=1}^{m_i}\alpha\chi_{ci}^{-(m_i-\alpha)} + n_i\chi_{ci}(1-P_{i\,отк}^{доп})].$$

In expression (12) values χ_c are determined from solution of equation:

$$\frac{n_i!}{(n_i\chi_{ci})^n}\sum_{\alpha=0}^{n_i}\frac{(n_i\chi_{ci})^{\alpha}}{\alpha!} = \sum_{\alpha=1}^{m_i}\left[\frac{\alpha(m_i-\alpha)}{n_i} - \chi_{ci}\right]\chi_{ci}^{\alpha-1},$$
$$i = \overline{1...k}, \quad (13)$$

where: $\chi_{ci}=\rho_{ci}/n_i$ is the degree of channel loading in multi-channel QS.

Curves ${}^{np}\chi_c^{onm}=f(m_i,n_i)$ are given in Fig. 2. In Fig. 2 axis χ_c corresponds to the degree of channel loading in multi-channel QS; axis m is the number of places in buffer queue in switching nodes, n is the number of channels.

4. The analysis of the obtained results

The analysis shows that the acceptable values of channel loading degree ${}^{np}\chi_{ci}^{onm}$ does not depend on the required value of probability of refusal and they are the functions of discrete values of channel number (n_i) and a number of places in buffer queue in switching nodes (m_i).

Each equation of the system (13) is the function of the variable χ_{ci}. It gives the possibility to determine the acceptable optimal values ${}^{np}\chi_{ci}^{onm}$ for network links independently on each other:

$${}^{np}\chi_{ci}^{onm} = \frac{\lambda_i}{n_i\mu_i} = \frac{L\lambda_i}{n_iL\mu_i} = \frac{F_i}{V_in_i} = f(m_i, n_i),$$

where L is the fixed packet length (ATM cell); F_i is the sum flow at the input of i link; V_i is the capacity of each channel in the direction i.

Optimization by χ_{ci} allows varying the values V_i and n_i depending on the type of transmitted traffic according to the loading matrix giving any channel set to a user by his demand with variable width of bit transmission rate forming virtual channel with variable capacity independently on the required probability of refuse. In this case an average packet time delivery is minimal. Solution of equations (13) is simplified for isotropic network in which the acceptable degree of channel loading does not depend on transmitting direction. Omitting index i at parameter χ_c we obtain:

$${}^{np}\chi_c^{onm} = \frac{F_i}{V_in_i} = f(m_i, n_i).$$

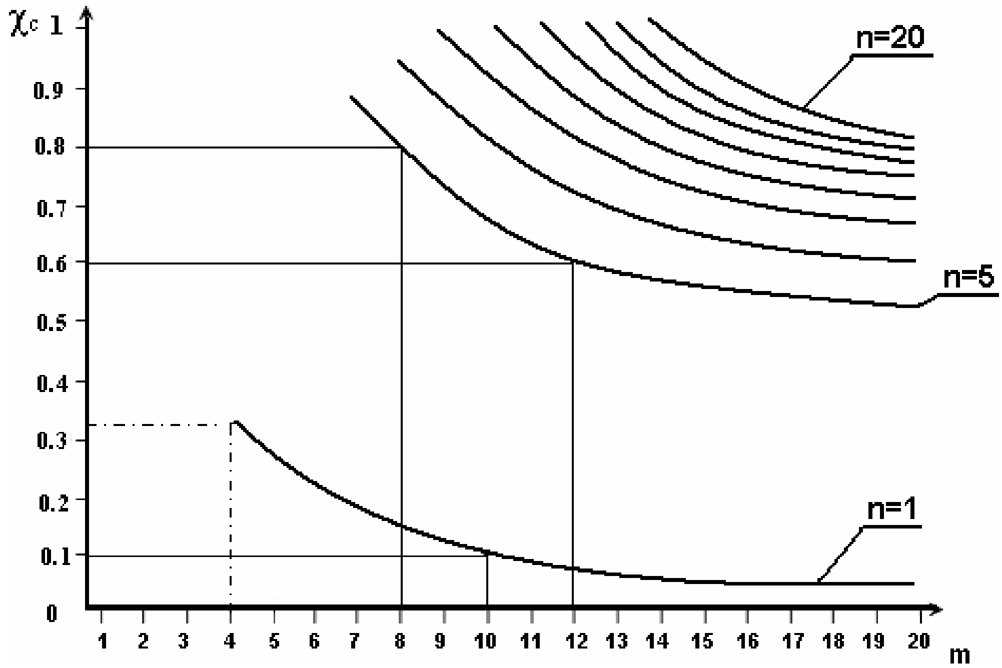

Fig. 2. *Dependence of coefficient of channel loading on buffer volume*

To take into account self-similar load in isotropic network it is enough to multiply the value of coefficient of channel load χ_c by the value $2H$. As the Hearst index is changed in the range of H=0,7...0,9 then the value χ_c should be multiplied by this coefficient having chosen its appropriate value. The analysis of the curves shows that increasing the degree of network channel load the volume of buffer storage of switching nodes decreases. Optimal values ρ_c gives minimum to functional (10). They are obtained by computation from equations (12) (optimum condition) for single-channel QS with the capacity of recall and have upper bound ρ_c=0,328. The buffer volume m=4 (Fig. 2) corresponds to this value of channel load (n=1). Increase of buffer volume results in decrease of channel load degree. For example, at m=10 we obtain χ_c=0,1.

This confirms the supposition made earlier about the fact that increasing self-similar load in the network and for minimization of average delay time the buffer volume of switching nodes should be decreased increasing the degree of channel load.

In the network having several channels in each transmitting direction this tendency is saved. For example, at channel number n=5 (Fig. 2) at load increase from value χ_1=0,6 to χ_2=0,8, the equation (12), a number of places in the queue decreases in one and a half time (from 12 to 8). This result confirms the supposition made earlier.

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