METHOD FOR CALCULATING THE EQUIPMENT OF INFORMATION NETWORK BASED ON THE MESSAGE STREAM MODEL

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Abstract: *Usage results of an authors' unified method for calculating the equipment of information network subject to these networks' modern features are reported. This method is based on an authors' model of message streams circulating in convergent network and a model of the information networks' load. It's indicated that usage of the proposed method assures the 18…22% accuracy enhancement of the calculation results. All the reported results are confirmed by the model usage in activity of National Commission for the State Regulation of Communications and Informatization, the methods usage for real design of Ukrainian information networks by "Diprozvyazok" PJSC and the results evaluation by "Ukrtelecom" LLC (Odessa branch).*

Keywords: *information network, load model, information stream, method for calculating the equipment, message stream, distribution function, service node.*

ACM Classification Keywords: *C. Computer Systems Organization – C.2 COMPUTER-COMMUNICATION NETWORKS – C.2.1 Network Architecture and Design; G. Mathematics of Computing – G.3 PROBABILITY AND STATISTICS – Distribution functions, Queueing theory, Stochastic processes.*

"Things imagined by us don't exist in themselves as we imagine them and their interrelations are quite unlike as they are for us."
Peter D. Ouspensky

Introduction

While researching information networks (IN), the information conversion seems to be very important process, delivering nontrivial tasks, which solution demands an applying new approach and up-to-date mathematical methods. Process of information conversion when it's transferring across the IN is the subject of a teletraffic theory (TT) research. For a long time TT represented fundamental tool for telecommunication networks (TN) research. However, analysis of scientists research results of last decades [Leland et al., 1994], [Duffy et al., 1994], [Crovella, Bestravros, 1996], [Giroux, Ganti, 1999], [Borella, Brewster, 1998], [Oliveira et al., 2003], [Ilnickis, 2004], [Min, Ould-Khaoua, 2004], [Stallings, 2002] indicates the impossibility of existing TT tools’ direct usage for the IN synthesis and design at the modern stage of infocommunications development since they don’t match these networks features, aroused last years [Gayvoronska, 2013 (1)]. At that, there are no alternative solutions in most of known publications – there are certain groundworks, but they are particularly dedicated.

One of the factors, which demands review of common approach for the IN synthesis, is fundamental change of view on quality of service (QoS). Previously, all issues of the TN synthesis, design and development were solved in conditions where demand for these networks' services constantly and significantly outdistanced supply. At that the task was to derive the compromise between the QoS characteristics and cost of network design. Quality indicators were normalized by international or national standards, and user had no affect on this process. Such situation continued for decades, but now it has changed radically. A network user became the most important one. User defines necessary services and grade of their rendering quality, which is willing to be paid. A number of authors’ works [Gayvoronska, Britsky, 2016], [Gayvoronska, 2015], [Gayvoronska et al., 2014], [Gayvoronska, 2013 (2)], [Gayvoronska et al., 2012] devoted to analysis of modern situation and users requirements to the IN.

Degree of the IN users satisfaction by rendered information-communications services (ICS) is determined by the QoS. According to the International Telecommunication Union definition, quality of service is totality of characteristics of ICS that bear on their ability to satisfy stated and implied needs of the services user [ITU-T, 2008]. It depends on a network and defines level of user satisfaction when the IN systems are highly loaded. Assurance of necessary quality is determined first by an adequacy of accounting the load characteristics and features of its distribution across the network when designing and operating the IN.

Recent analysis of the quality of real IN functioning pointed that methods used for calculating the network equipment give incorrect values of required number of service nodes (SN) [Gannitsky, 2012]. Therefore, in order to enhance the QoS it’s necessary first to take into account features of the load generated by different information types, co-transmitted across the IN. Thereto it’s necessary to have maximally accurate information about the network load and characteristics of information streams (IS), generating this load. The load parameters and the IS circulating in the TN are subjects of the research of large number of scientists, both in our country and abroad: Kharkevich A.D., Basharin H.P., Roginsky V.M., Lazarev V.G., Livshits B.C., Ionin G.L., Sedol J.J., Ločmelis J.J., Prokofiev V.A., Shneps M.A., Kornyshev Y.N., Duz’ V.I., Chumak N.A., Popovsky V.V., Bezruk V.M. and many others. However, due to the fact that the modern IN can't be directly referred to any of networks models used in existing calculation methods, and taking into account essential changes in the networks' situation on the whole, results of these researches should be clarified and corrected.

The IN design based on reliable initial data and usage of calculation methods, which take into account characteristics of the IS and distribution laws of its basic parameters, provides tangible savings on cost of the IN development and functioning, improves the QoS and network bandwidth on the whole. Consequently, while designing and operating the IN, it's necessary to derive the relationship between the load and network capacity (number of IN equipment) in order to provide the specified QoS. The IN information streams can be transmitted with the usage of all possible data transfer modes (DTM): channel, packet, frame and cell. The transfer mode defines a combination of the methods for switching, multiplexing and packing the information while transmitting across the network. All the DTM are standardized by the ITU and correspond to the first three levels of the open systems interconnection model [Gayvoronska, 2000], and differ in the used multiplexing method: positional (PM) or label (LM), as well as in algorithms for establishing, maintaining and disengaging the connections (physical or logical) [Gayvoronska, 2007 (1)]. The modern IN use all possible DTM simultaneously, so while calculating the network equipment it's necessary to take into account not only the switching method, but a whole totality of parameters, united by the concept of the information transfer mode. Such situation demands a correction of used method for calculating the IN equipment in such a way that the calculations become adequate to the IS model. It means that a selected mathematical model matches a processes in real systems and networks of the information distribution.

Analysis of Existing Methods for Calculating the Information Network Equipment

As it's known from the classical teletraffic theory [Stormer et al., 1971], [Eldin, Lind, 1972], method for calculating the network equipment depends on a structure of service nodes, service discipline and model of information streams, circulating in this network.

Basic works in the queueing theory [Kendall, Stuart, 1961], [Kleinrock, 1975], [Kleinrock, 1964] involve an adopted the five-part descriptor A/B/n/M/N that denotes indicated relationship as follows:

A – the interarrival time distribution;

B – the service time distribution;

n – the number of servers of the queueing system;

M – the system's storage capacity (number of positions for waiting the service start);

N – the size of the customer population (number of load sources).

For a complete specification of a queueing system more information is required and in these cases ITU adopted the six-part notation [ITU, 2005]

A/B/n/M/N/X

where A and B describe arrival process and service time distribution, respectively, of n-server queueing system, M – the total capacity of the system, N – the population size of customers, X – the queueing discipline.

From the first works of the TT founder Erlang A.K. his first and second formulae describing determination of the losses probability in a full-accessible trunk of loss system and the waiting probability (implicit loss) of queuing system, respectively, traditionally involve well known expressions representing a little unity inherent the corresponding mathematical models [Gayvoronska, 2007 (2)]. Works [Sergeev, 1983], [Sergeev, Chekmareva, 1988] show that such homological unity exists and propose a number of formulae with following notations:

E – the threshold value of the service losses;

λ – the rate of the requests (corresponding stream parameter);

$'$ – the loss system indication;

$''$ – the queuing system indication;

ν – the SN number;

^ – indication of the system with re-calls.

Traditional Erlang's first and second formulae

$$P(e<E)=\frac{\lambda^{\nu}/\nu!}{\sum_{i=0}^{\nu}\frac{\lambda_i}{i!}},\ P(e<E)=\frac{1\Big/\left(\frac{\lambda}{\nu}\right)}{1\Big/E+\frac{\lambda}{\nu}\Big/\left(1-\frac{\lambda}{\nu}\right)} \qquad (1,2)$$

can be presented in a generalized form:

for the loss systems

$$E'=\left[1+\sum_{i=0}^{\nu-1}\prod_{j=0}^{i}\frac{\nu-j}{\lambda'}\right]^{-1}, \qquad (3)$$

for the queuing systems

$$E''=\left[1+\left(1-\frac{\lambda''}{\nu}\right)\sum_{i=0}^{\nu-1}\prod_{j=0}^{i}\frac{\nu-j}{\lambda''}\right]^{-1}. \qquad (4)$$

In so doing we suppose that in case of generally distributed IS the service rate is equal to one.

Queuing system with the limited number M of positions for waiting

$$E''_M = \left[1 + \frac{1 - \frac{\lambda^M}{\nu}}{1 - \left(\frac{\lambda}{\nu}\right)^{M+1}} \sum_{i=0}^{\nu-j} \prod_{j=0}^{i} \frac{\nu - j}{\lambda''} \right]^{-1} . \tag{5}$$

Joint (loss and queuing) service system

$$E''' = \left[1 + \left(1 - \frac{\lambda'''}{\nu}\right) \sum_{i=0}^{\nu-1} \prod_{j=0}^{i} \frac{\nu - j}{\lambda' + \lambda''} \right]^{-1} , \; E'''_M = \left[1 + \frac{1 - \frac{\lambda''}{\nu}}{1 - \left(\frac{\lambda''}{\nu}\right)^{M+1}} \sum_{i=0}^{\nu-1} \prod_{j=0}^{i} \frac{\nu - j}{\lambda' + \lambda''} \right]^{-1} . \tag{6}$$

Loss system, subject to a busyness of the users (degenerate case – only a part of the requests occupy free SN)

$$E'_p = \left[1 + \sum_{i=0}^{\nu-j} \prod_{j=0}^{i} \frac{\nu - j}{\lambda'(1 - p_b)} \right]^{-1} , \tag{7}$$

where p_b – probability of the user's busyness.

System with repeated requests at the isolated trunk which consists of SN

$$E^{\wedge} = \left[1 + \sum_{i=0}^{\nu-j} \prod_{j=0}^{i} \frac{(\nu - j)/\lambda^{\wedge}}{\lambda'(1 - \alpha_d s)} \right]^{-1} , \tag{8}$$

where α_d – user's insistence rate;

s – number of the repeated requests' sources.

System with repeated requests, subject to connection time τ_b, insistence α_p and probability of the user's busyness (the pre-loading system)

$$E^{\wedge} = \left[1 + \sum_{i=0}^{\nu-j} \prod_{j=0}^{i} \lambda^{\wedge} \frac{\frac{\nu - j}{\tau_b + (1 - p_b)}}{1 - \alpha_d s - (1 - s)\alpha_p p_b} \right]^{-1} . \tag{9}$$

System with arbitrary number of arbitrary variants of repeated requests' generating

$$E^{\wedge} = \left[1 + \sum_{i=0}^{v-j} \prod_{j=0}^{i} \frac{\dfrac{v-j}{\lambda(1-p)\ldots}}{1-(x+y+z+\ldots)} \right]^{-1}, \tag{10}$$

$$x = \alpha_z E^{\wedge} \alpha_Q Q;\ \ y = \alpha_d E^{\wedge}(1-Q)p;\ \ z = (1-E^{\wedge}) \cdot \alpha_p p.$$

Joint service system with repeated requests

$$E^{\wedge} = \left[1 + \left(1 - \frac{\lambda''}{v} \right) \sum_{i=0}^{v-1} \prod_{j=0}^{i} \frac{v-j}{\lambda' + \lambda'' / \left(1 - \alpha E^{\wedge}\right)} \right]^{-1}, \tag{11}$$

where α – the rate of the primary requests' source.

Modification of Method for Calculating the Network Equipment, Subject to Probabilistic-temporal Structure of Call Streams in Modern Information Networks

Analysis of the given expressions made in [Gayvoronska, Somsikov, 2008] revealed a unity in the calculation formulae. According to this author offered unified expression generalizing all variants of researched service systems and proved its adequacy for determination of losses probability in the service system

$$E = \left(1 + K \sum_{i=0}^{v-1} \prod_{j=0}^{i} \frac{v-j}{L} \right)^{-1}. \tag{12}$$

That allowed a unification of a method for calculating the network equipment. Depending on the queueing system and discipline only K and L coefficients in (12) should be modified. However the expression doesn't affect third component of the methods for calculating the network resources – a probabilistic-temporal structure of the streams, circulating in the network and arriving for the service. Parameters of the requirements stream have recently changed, so they should be clarified. Application of the calculation method which doesn't match real network streams (their structure) reduces the accuracy of its result [Gayvoronska, 1997]. Underestimated number of SN makes worse the QoS and causes the losses increase, while its overestimated value reduces the network usage efficiency. Therefore further generalization was a unification of the method by introducing the coefficient reflecting a probabilistic-temporal structure of the stream.

The TT existing methods allow calculating only the particular network fragments while for the network as a whole these methods can be applied only like an approximate. Basic formulae for calculating the network equipment, colligating message losses, load and trunks capacity, were obtained under the assumption of Poisson nature of arriving call stream. Analysis of the results of real call streams' measurements in the networks showed that their characteristics deviated significantly from the Poisson distribution model (so-called simplest stream with an infinite number of load sources). Significance of these deviations can be observed by the value of divergence between the moments of the second and higher degrees or the value of divergence between the coefficients of variation, asymmetry and excess [Gayvoronska, 1999]. Due to the fact that the Poisson stream doesn't always match real streams, in the case of the existing information networks it's necessary to select some other distributions allowing modify a shape of the probability density curve loosely enough and provide therefore safe matching the measurements. There are quite a large number of mathematical models describing the characteristics of call streams. However, there is a matter how much do real characteristics of modern networks' call streams match the mathematical models developed up to 90s. And in case of presence of the differences it's necessary to estimate their impact on the modern IN functioning.

In order to solve this problem goodness of fit of the arrival process in real networks at arbitrary time to normal, exponential, log-normal, Poisson, Pareto, Rayleigh, Weibull and other distributions was verified by the Pearson criterion, cf. [Gayvoronska, Gannitsky, 2007], [Gannitsky, 2009]. Real measurements of the researched random variable were obtained by a processing the statistics of call streams of “Ukrtelecom” LLC (Odessa branch) for the 3,5 years (2003, 2004, 2005 and 2006). Total amount of processed data is 100 GB (parent population consists of 711608646 elements in the database). The real arrival process doesn’t match any of previously used models, the call streams are unordinary with aftereffect and can be represented by empirical parameter characterizing the real stream’s nature on the basis of the log-normal distribution, cf. [Gannitsky, 2012]

$$\lambda = \frac{de^{\mu+\delta^2/2}}{3600}, \tag{13}$$

where d – the predicted value of the call stream’s parameter;

μ – the scale parameter of the log-normal distribution;

δ – the shape parameter of the log-normal distribution.

Subject to this, calculation coefficients in (12) for the loss system

$$K = 1,\ L = \frac{de^{\mu+\delta^2/2}}{3600}, \tag{14}$$

for the queuing system with the limited number M of positions for waiting

$$K = \frac{1 - \dfrac{de^{\mu+\delta^2/2}}{3600} \Big/ \nu}{1 - \left(\dfrac{de^{\mu+\delta^2/2}}{3600} \Big/ \nu \right)^{M+1}}, \quad L = \frac{de^{\mu+\delta^2/2}}{3600}. \tag{15}$$

For the other service systems the K and L coefficients are being modified similarly. According to this the unified method for calculating the network equipment, adaptable to the service system and discipline, was further improved by an implementation of the coefficients reflecting the real call stream's nature. So the method's usage can be expanded to the data communication network with the label multiplexing and packet switching. That makes it an adaptable to the switching method and information transfer mode, cf. [Gannitsky, 2012].

Justification of the Message Stream Model Usage for Calculating the Equipment of Information Network

While researching the modern information networks it makes sense to consider the message streams instead the call streams, since a call is only a requirement for the network service in order to transmit the message, and a message – it is an information, transformed into the electromagnetic signals, that should be transferred across the network [Gayvoronska, 2000]. In this connection it isn't enough to consider only the need of the data transfer: it's necessary to know what kind of the information (both from the quantitative and qualitative point of view), what amount of information should be transferred and how, as well as to take into account a number of other parameters of the transmitted information. This is important in terms of the information transformation in time and space. The state-of-the-art analysis reveals that there is still no general theory for the distribution and calculation the quantitative and qualitative indicators of the information streams in the IN [Davydov et al., 1977], [Gayvoronska, 1998], [Gayvoronska, Kalnev, 2001], [Gayvoronska, 2007 (3)]. Thus, in order to represent the IS it's expedient to use the model of message stream, circulating in the network, instead of the call stream model, cf. [Gayvoronska, Solomitsky, 2012 (1)], [Solomitsky, 2013], [Gayvoronska, Solomitsky, 2012 (2)]. Further we denote the message stream as MS to avoid confusion with the call stream (requirements for the service).

Each information message is characterized by a parameters reflecting the required quality of their service by the network e.g. maximum permissible: probability of symbol corruption, mean delay and its variance.

Model of the information message transmitted in the streams

$$\overline{\mathbf{u}_{\vartheta r}^{\Theta}} = (\vartheta, r, \Theta, t),$$

where the information types ϑ depend on the information class ς and together with the network functioning technology define different requirements to the indicators of the quality of messages transfer, priority levels r determine the information urgency, amount of information Θ is determined by the ϑ and ς.

The message stream definition is related to the determination of: number of the messages and amount of the information in the MS, time while the messages are in the network and value of the information in the MS.

Accordingly, the MS analytical model in a generalized form is the set of the following functions.

1. Distribution function of the messages number in the stream at any time.
2. Distribution function of the information content in the stream as a whole.
3. Distribution function of the time while each message of the common sequence (the stream) are in the network.
4. Function of the value of the transmitted information.

Moreover the MS characteristics are affected by the external and intranetwork hampering factors (disturbances, glitches, etc.) arising during the MS transferring across the network in the form of errors and equipment failures which are stochastic too. Thus the MS mathematical model should include models or distribution functions specifying the probabilities of the corresponding stochastic variables E^t.

In general terms, form of the MS model and corresponding certain functions is determined at a concrete time moment at the IN concrete point, which is defined by the vector $x(v, a_k, a_l)$ [Gayvoronska, Solomitsky, 2014],

where v – the information transfer channel or the SN;

a_k, a_l – pair of the nodes between which the researched stream is circulating.

The messages number in the MS in addition to a time depends on the number of the information sources n, the channel bandwidth υ and parameter Ξ characterizing the information receiver and specifying according to the Erlang classification the system structure and the service discipline of the node-information receiver. Form of the distribution function $\Lambda^t(n, \upsilon, \Xi)$ of the messages number in the stream depends on the place in the network, where it's analyzed, which is defined by the vector x.

In order to define the MS types and amount of the information, we used a concept of the user information message (UIM) representing a finite data sequence, formed for the network transmission and having a complete sense content. The UIM is transferred across the network in the form of the data transfer units (DTU): packets, datagrams, frames, cells. There are several types of the MS, which differ in the ratio ξ of the number of elements contained in the information part of the DTU (m_e) and UIM (m_c):

- simple stream, where $m_e = m_c$ and $\xi = m_e/m_c = 1$;
- thinned stream, where $m_e < m_c$ and $\xi = m_e/m_c < 1$;
- complex stream, where $m_e > m_c$ and $\xi = m_e/m_c > 1$.

The distribution function $\mathrm{T}_\rho(c,\Theta,r,q)$ of the time while messages are in the network depends on the number of the messages c, the amount of the information in one message Θ, the integral quality parameter q, determining the delay of the signal transfer, the error rate, the rate of failures and the preset priority r.

The priority is set by the network, so it's considered as the objective characteristic of the information importance/value for the network operator. The information value, as distinct from the priority, defines the subjective information importance to the end users.

The function of the information value for the user is defined as $Q(A,B,W_A,W_B,\varepsilon,\chi,\psi)$,

where A, B – a pair of the corresponding users;

W_A, W_B – the information importance for the user *A* and *B*, respectively;

ε – the timeliness of the information transfer;

χ – preservation of the emotional nuance of the transmitted information;

ψ – preservation of the intonational nuance of the transmitted information.

Generalized model of the message stream is a set of the above expressions

$$MS = \{\, x(v,a_k,a_l),\, \Lambda^t(n,\upsilon,\Xi),\, \Delta^t(c,\Theta),\, \mathrm{T}_\rho(c,\Theta,r,q),\, \mathrm{E}^t,\, Q(A,B,W_A,W_B,\varepsilon,\chi,\psi) \,\},$$
$$v \in V,\, V = \{v_1,\dots,v_b\},\, a_k,a_l,A,B \in N,\, r \in R,\, R = \{r_1,\dots,r_h\}. \qquad (16)$$

At the same time in the most general terms the information transfer process in the IN can be represented as a streams with the intensity $\lambda, \lambda = \lambda(\hbar)$, where in the general case $\hbar$ is a vector whose components are defined by the control algorithms of exchange, multiplexing and switching in the IN as well as by the network structure and its components' structure.

In order to estimate the network capacity for the equipment-assisted QoS it's necessary to develop a model of the network load of the message streams.

Model Development of the Load of the Message Streams in Information Network

The load model of the IN message streams is based on the proposed MS model and takes into account all the possible data transfer modes. The IN load rate is estimated as the sum total of the information content of the stream (label multiplexing) and the time while messages are in the network (positional multiplexing).

The time while message is in the network at the PM for the each type and priority messages consists of the waiting time and service time [Solomitsky, 2014 (1)]

$$\rho_\wp = \omega_\wp + \bar{\tau}_\wp , \qquad (17)$$

where $\omega_\wp$ – the mean value of the waiting time;

$\bar{\tau}_\wp$ – the mean value of the service time.

For the estimation of the mean value of the waiting time and the probability of waiting at the mean service time $\bar{\tau}_\wp$ it's expedient to use approximate formulae, cf. [Kramer, 1975] and [Langenbach-Belz, 1972]

$$\omega_\wp = \overline{\tau_\wp} \frac{A_\wp}{2(1-A_\wp)} \left(\kappa_{A\wp}^2 + \kappa_{H\wp}^2\right) g\left(A_\wp, \kappa_{A\wp}^2, \kappa_{H\wp}^2\right),$$

where $$g\left(A_\wp, \kappa_{A\wp}^2, \kappa_{H\wp}^2\right) = \begin{cases} \exp\left\{ -\dfrac{2(1-A_\wp)}{3A_\wp} \dfrac{(1-\kappa_{A\wp}^2)^2}{\kappa_{A\wp}^2 + \kappa_{H\wp}^2} \right\}, & \kappa_{A\wp} < 1 \\ \exp\left\{ -(1-A_\wp) \dfrac{\kappa_{A\wp}^2 - 1}{\kappa_{A\wp}^2 + 4\kappa_{H\wp}^2} \right\}, & \kappa_{A\wp} \ge 1; \end{cases}$$

$$A_\wp = \frac{\lambda_\wp}{\mu_\wp}, \lambda_\wp = \lambda_{0\wp} + \sum_{j=1}^{N} \lambda_{\wp j} q_{ji}, i = 1,2,\ldots,N, \mu_\wp = \bar{\tau}_\wp^{-1};$$

q_{ji} – transition probability for messages circulating from node *j* to a node *i*;

node 0 represents the outside world of the researched IN;

$\kappa_{A\wp}$ – variation coefficient of the arrival process;

$\kappa_{H\wp}$ – variation coefficient of the service process,

$$W_\wp = A_\wp + \left(\kappa_{A\wp}^2 - 1\right) A_\wp (1 - A_\wp) \begin{cases} \dfrac{1 + \kappa_{A\wp}^2 + A_\wp \kappa_{H\wp}^2}{1 + A_\wp(\kappa_{H\wp}^2 - 1) + A_\wp^2(4\kappa_{A\wp}^2 + \kappa_{H\wp}^2)}, & \kappa_{A\wp}^2 < 1 \\ \dfrac{4A_\wp}{\kappa_{A\wp}^2 + A_\wp^2(4\kappa_{A\wp}^2 + \kappa_{H\wp}^2)}, & \kappa_{A\wp}^2 \ge 1. \end{cases}$$

The information content $\Delta^t(c,\Theta)$ in the MS depends on the messages number c and amount of information in the message.

Formulae of the information content for the three above MS modifications, cf. [Solomitsky, 2014 (2)]

$$P(U_e^1 = c) = \frac{\lambda_{\Sigma\ell}^c}{e^{\lambda_{\Sigma\ell}} c!}, \; c = 0, 1, 2, \ldots, \; M[U_e^1] = D[U_e^1] = \lambda_{\Sigma\ell};$$

$$P(U_e^2 = c) = 1 - \frac{1}{e^{\lambda_{\Sigma\ell} c}} \sum_{i=0}^{\xi-1} \frac{(\lambda_{\Sigma\ell} c)^i}{i!}, M[U_e^2] = \xi / \lambda_{\Sigma\ell}, D[U_e^2] = \xi / \lambda_{\Sigma\ell}{}^2;$$

$$P(U_e^3 = c) = \begin{cases} \dfrac{1}{e^{\lambda_{\Sigma\ell}}}, c = 0 & M[U_e^3] = \lambda_{\Sigma\ell}/\xi, \\ \dfrac{1}{e^{\lambda_{\Sigma\ell}}} \sum\limits_{i=1}^{c} C_{c-1}^{i-1} \dfrac{(\lambda_{\Sigma\ell}\xi)^i (1-\xi)^{c-i}}{i!}, c = 1, 2, \ldots, & D[U_e^3] = \lambda_{\Sigma\ell}(2-\xi)/\xi^2, \end{cases}$$

where U_e – the arrival process of DTU, it depends on a change of amount of information in the UIM and DTU and is determined by a rate of the m_e and m_c values;

$$\lambda_{\Sigma\ell} = \lambda_\ell + s\beta, \lambda_\ell = \alpha n, s = \frac{\dfrac{1}{\nu} \sum\limits_{i=0}^{\nu-1} \prod\limits_{j=0}^{i} \dfrac{\nu - j}{\lambda_\ell} + \left(1 - \dfrac{\lambda_\ell}{\nu}\right) \dfrac{d}{d\lambda_\ell} \left(\sum\limits_{i=0}^{\nu-1} \prod\limits_{j=0}^{i} \dfrac{\nu - j}{\lambda_\ell} \right)}{\left(1 + \left(1 - \dfrac{\lambda_\ell}{\nu}\right) \sum\limits_{i=0}^{\nu-1} \prod\limits_{j=0}^{i} \dfrac{\nu - j}{\lambda_\ell}\right)^2},$$

α, β – rate of the primary and repeated requests' sources, respectively.

The mean value of amount of information in the messages of the stream at the LM

$$\pi_\ell = \begin{cases} M[U_e^1] = \lambda_{\Sigma\ell}, \xi = 1 \\ M[U_e^2] = \xi/\lambda_{\Sigma\ell}, \xi < 1 \\ M[U_e^3] = \lambda_{\Sigma\ell}/\xi, \xi > 1 \end{cases} . \tag{18}$$

We determine the load intensities at the PM and LM for the ϑ^{th} type and r^{th} priority information between nodes k and l by a matrixes $[\lambda_{\vartheta r}^{\ell kl}]$ and $[\lambda_{\vartheta r}^{\wp kl}]$, respectively. So we derived simplified expression for estimating the information type- and priority-averaged time while messages are in the network

$$\rho^{\wp} = \lambda^{-\wp} \sum_{\substack{i \in I_\wp \\ j \in J_\wp}} \lambda_{\vartheta r}^{\wp ij} \rho_{\wp ij}, \; \lambda^{\wp} = \sum_{\substack{i \in I_\wp \\ j \in J_\wp}} \lambda_{\vartheta r}^{\wp ij},$$

and amount of the information in them

$$\pi^{\ell} = \lambda^{-\ell} \sum_{\substack{i \in I_\ell \\ j \in J_\ell}} \lambda_{\vartheta r}^{\ell ij} \pi_{\ell ij} \Theta_{\vartheta}^{\ell ij}, \ \lambda^{\ell} = \sum_{\substack{i \in I_\ell \\ j \in J_\ell}} \lambda_{\vartheta r}^{\ell ij},$$

where $I_\wp, I_\ell, J_\wp, J_\ell$ – set of the information types and priorities at the PM and LM usage, respectively.

The resultant IN load for the concrete DTM, respectively

$$\Lambda^{\wp} = \rho^{\wp} \sum_{r \in R} \sum_{\vartheta \in \Upsilon} MS, \ \Lambda^{\ell} = \pi^{\ell} \sum_{r \in R} \sum_{\vartheta \in \Upsilon} MS. \quad (19), (20)$$

As a result, the unified representation of the load

$$\Lambda^{\Phi} = \lambda^{-\Phi} \sum_{\substack{i \in I_\Phi \\ j \in J_\Phi}} \lambda_{\vartheta r}^{\Phi ij} \rho_{\Phi ij} \pi_{\Phi ij} \Theta_{\vartheta}^{\Phi ij}. \quad (21)$$

This authors load model is determined subject to: a sum of the information messages $\overline{\mathbf{u}_{\vartheta r}^{\Theta}}$ transferring in the streams, the time $\rho^{\wp}$ while the messages are in the network, amount of the information π^{ℓ} in these messages, distribution law of the DTU number in the UIM, priority class at the information transfer, the information value and other parameters which can be specified by the designer.

Modification of the Method for Calculating the Equipment of Information Network Based on the Message Stream Model

The MS load model of the information network is used for evaluation of the parameter λ determining values of the coefficients K and L from (12). So we provide the usage adequacy of the systematized unified method for calculating the network equipment for the IN. Possible variants of service systems used in the researched IN and corresponding modifications of the unified method for calculating the network equipment are given below.

For the loss system (cf. Fig. 1) $K = 1; L = \Lambda^{\wp}$, where the load intensity for the PM is $\Lambda^{\wp} = \rho^{\wp} \sum_{r \in R} \sum_{\vartheta \in \Upsilon} MS$

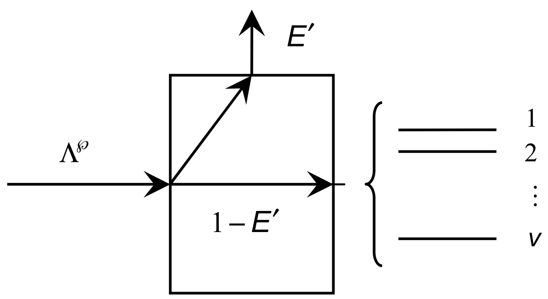

Fig. 1. The loss system

An example of such a system is a service node for voice messages hardwired e.g. by a public switched telephone network (PSTN) or a mobile communication network. The SN is a digital switching system (DSS) of the arbitrary network fragment (cf. Fig. 2) serving the MS load at the channel data transfer mode.

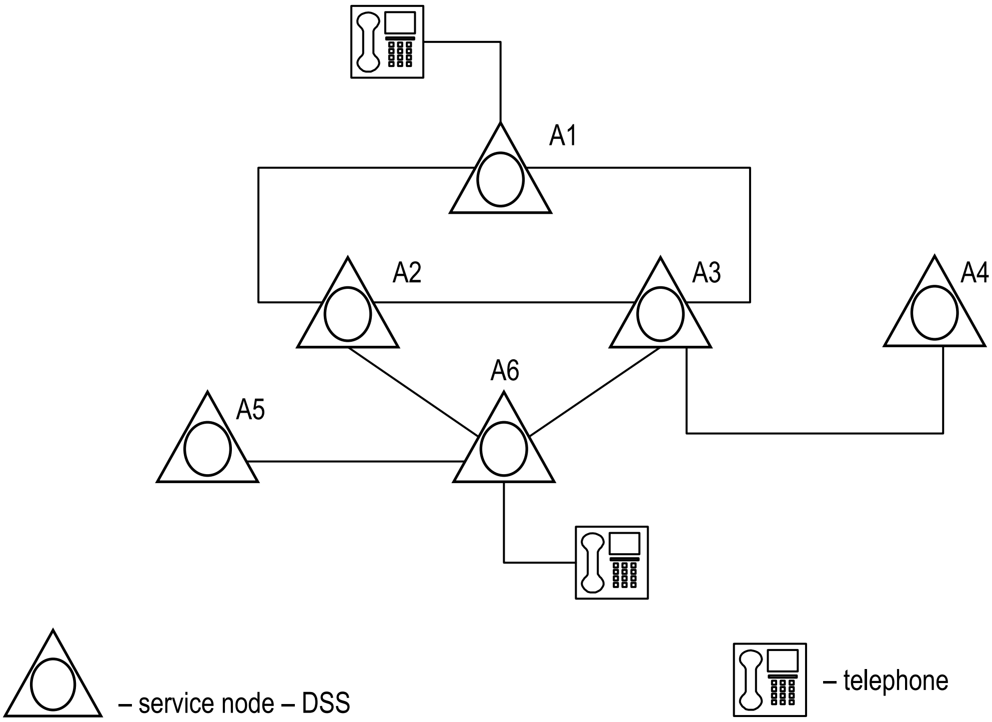

Fig. 2. The PSTN fragment (channel DTM)

For the queuing system with the unrestricted queue (cf. Fig. 3a) $K = 1 - \Lambda^{\ell}/v$; $L = \Lambda^{\ell}$, where the resultant load for the LM is $\Lambda^{\ell} = \pi^{\ell} \sum_{r \in R} \sum_{\vartheta \in \Upsilon} MS$.

For the queuing system with the restricted queue (M of positions for waiting) $K = \dfrac{1 - \Lambda^{\ell}/v}{1 - \left(\Lambda^{\ell}/v\right)^{M+1}}$; $L = \Lambda^{\ell}$ (cf. Fig. 3b). An example of such a system is a SN of any data communication network (DCN), cf. Fig. 4.

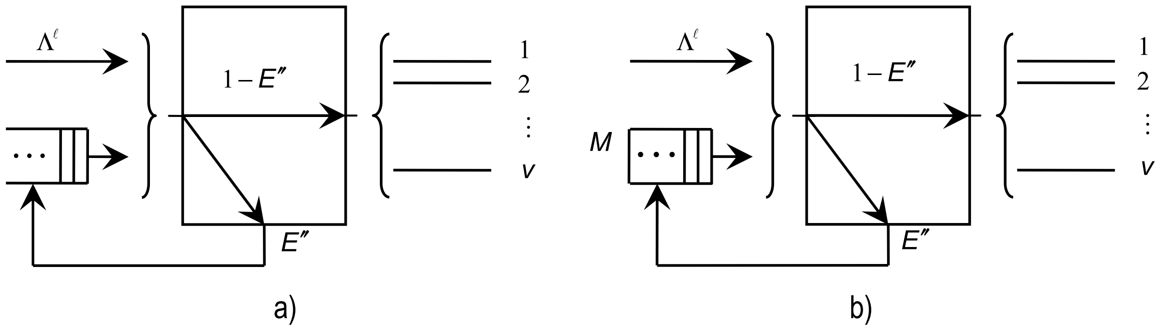

Fig. 3. The queuing system

a) with the unrestricted queue

b) with the restricted queue

The SN is a central switch of the example network fragment (cf. Fig. 4) serving the MS load at the packet DTM.

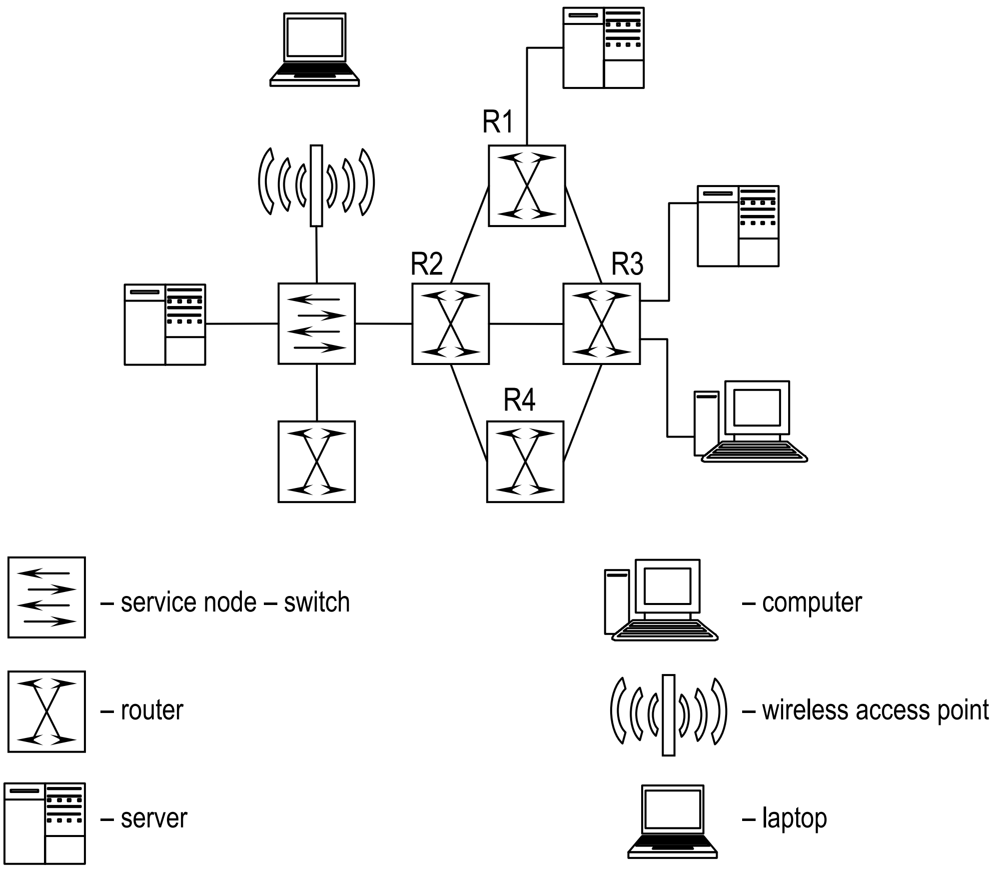

Fig. 4. The DCN fragment

For the joint system $K = \dfrac{1-\Lambda^{\ell}/v}{1-\left(\Lambda^{\ell}/v\right)^{M+1}}$; $L = \Lambda^{\Phi}$, where the resultant load $\Lambda^{\Phi} = \lambda^{-\Phi} \sum_{\substack{i \in I_{\Phi} \\ j \in J_{\Phi}}} \lambda_{\vartheta r}^{\Phi ij} \rho_{\Phi ij} \pi_{\Phi ij} \Theta_{\vartheta}^{\Phi ij}$ includes simultaneous usage of all the DTM (cf. Fig. 5). An example of such a system is a node for servicing the information streams both with losses and queuing (waiting probability – implicit loss).

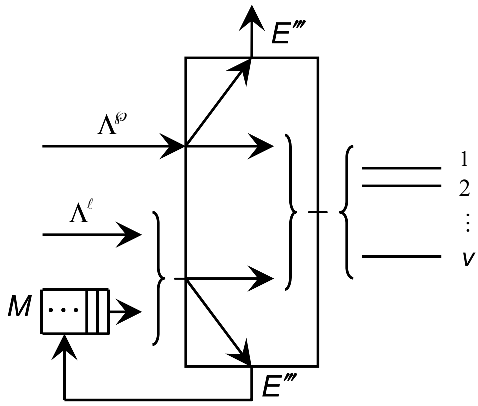

Fig. 5. The joint (loss and queuing)

The SN is an intelligent multifunctional switch of the example network fragment (cf. Fig. 6) serving the MS load of both label and positional multiplexing (packet (frame, cell) and channel DTM, respectively).

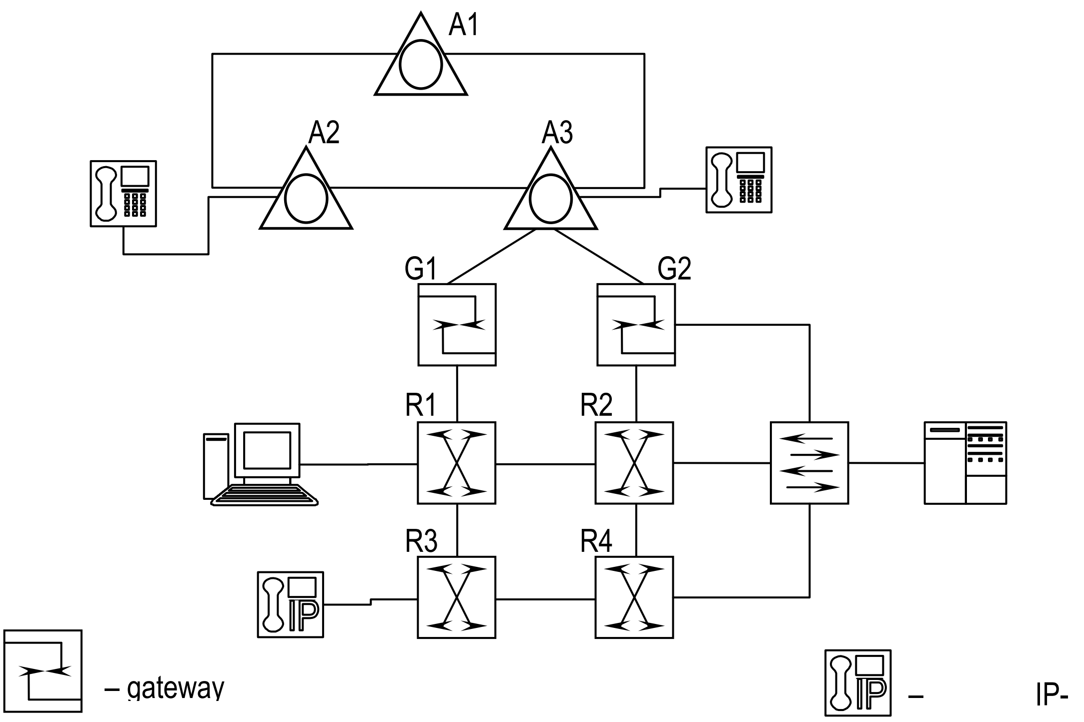

Fig. 6. Convergent network fragment aggregating the PSTN, DCN and VoIP segments

For the loss system, subject to a busyness of the users $K = 1; L = \Lambda^{\wp}(1 - p_b)$, cf. Fig. 7.

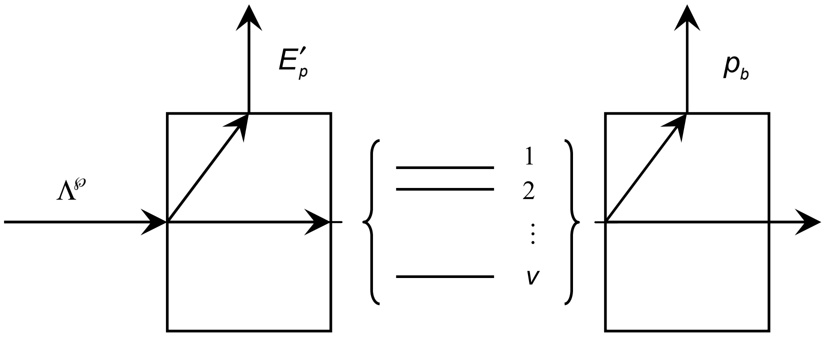

Fig. 7. The loss system subject to a busyness of the users

Model at Fig. 7 can be applied for calculating the SN of the network fragment at Fig. 2 at the channel DTU usage. Expression for the system at Fig. 7 allows consideration of the SN user's busyness probability p_b in comparison with the simplest variant at Fig. 1. For the system with repeated requests at the isolated trunk which consists of SN (cf. Fig. 8) $K = 1$; $L = \Lambda^{\wp} + \Lambda^{\wp\Re}\left(1 - \alpha_d \hat{E}'\right)$, where $\Lambda^{\wp\Re} = \dfrac{d\hat{E}'}{d\Lambda^{\wp}}\beta$.

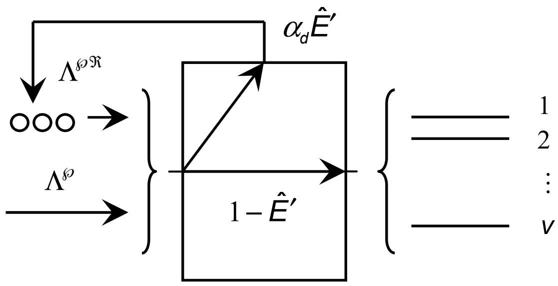

Fig. 8. The system with repeated requests at
the isolated trunk which consists of SN

Strictly speaking, all the SN of the IN should be considered as the systems with repeated requests since while real networks are functioning losses due to the network failures and timeouts leading to the repeated messages' initiation are unavoidable. The total absence of losses (both implicit and explicit) is typical only for ideal networks which are only theoretically valuable. For the system with repeated requests, subject to connection time, insistence and probability of the user's busyness (the preloading system) $K = 1$; $L = \Lambda^{\wp} + \Lambda^{\wp\Re}\dfrac{\tau_b + (1 - p_b)}{1 - \alpha_d\hat{E}' - (1 - \hat{E}')\alpha_p p_b}$, where $\beta \to 0$, cf. Fig. 9.

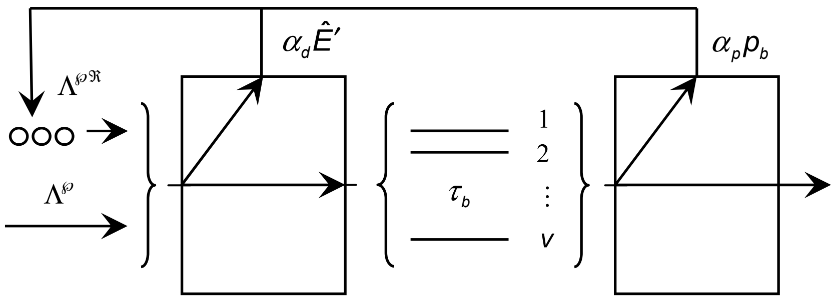

Fig. 9. The system with repeated requests subject to connection time, insistence and probability of the user's busyness (the preloading system)

For the system (cf. Fig. 10) with arbitrary value of arbitrary variants of repeated requests' generating $K = 1$; $L = \Lambda^{\wp} + \Lambda^{\wp\Re} \dfrac{(1-p)\dots}{1-(x+y+z+\dots)}$, $x = \alpha_z E^{\wedge} \alpha_Q Q$, $y = \alpha_d E^{\wedge}(1-Q)p$, $z = (1-E^{\wedge}) \cdot \alpha_p p$, $\beta \to 0$.

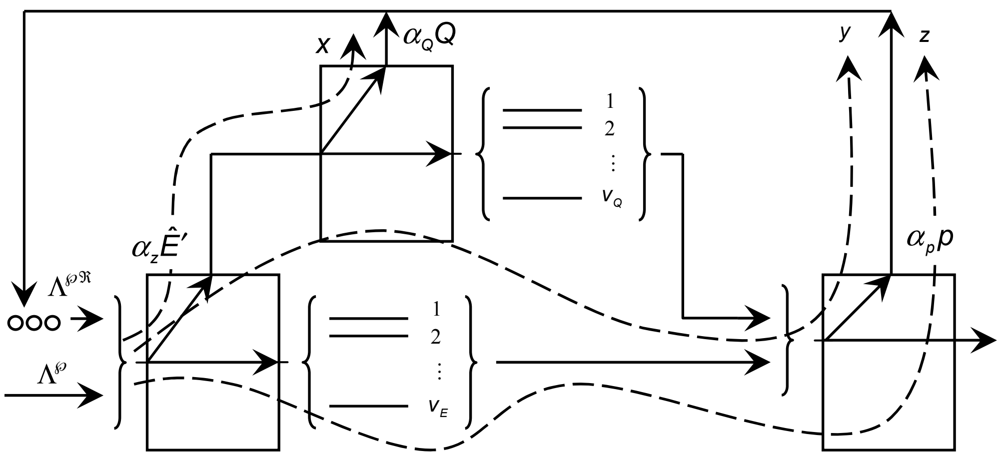

Fig. 10. The system with arbitrary value of arbitrary variants of repeated requests'

For the queuing system (cf. Fig. 11) with the restricted queue and repeated messages $K = \frac{1-\Lambda^{\ell}/v}{1-\left(\Lambda^{\ell}/v\right)^{M+1}}$; $L = \Lambda^{\ell} + \Lambda^{\ell\Re}\left(1-\hat{E}''\right)$, where $\Lambda^{\ell\Re} = \frac{d\hat{E}''}{d\Lambda^{\ell}}\beta$.

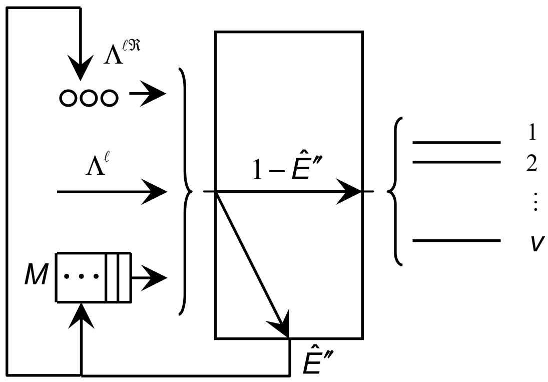

Fig. 11. The queuing system with the restricted queue and repeated messages

For the joint system with the repeated messages $K = \frac{1-\Lambda^{\ell}/v}{1-\left(\Lambda^{\ell}/v\right)^{M+1}}$; $L = \Lambda^{\Phi} + \frac{\Lambda^{\Phi\Re}}{1-\alpha\hat{E}'''}$, where

$\Lambda^{\Phi\Re} = \frac{d\hat{E}'''}{d\Lambda^{\Phi}}\beta$, $\beta \to 0$.

On the basis of the actual situation at the modern IN it's expedient to research the SN supporting simultaneously the packet, channel, frame and/or cell DTM of the MS load as the joint service system with the messages requiring retransmission.

Proposed representation of the unified method for calculating the network equipment can be used for estimation of any system with any service discipline of the message streams. At the same time proposed approach causes an adaptability of the method for calculating the network equipment to the DTM in the researched IN.

Results of the Developed Method Application for the Network Equipment Calculating at the Information Network Design

In order to evaluate an efficiency of the proposed method for calculating the network equipment we compared several possible methods for calculating the information network's fragment (cf. Fig. 12).

This is a converged fragment; it is aggregate of segments of the several networks: PSTN, DCN, the CATV and VoIP network. Additionally the fragment aggregates the PSTN segments with the ADSL/VDSL technologies’ usage and CATV based on the DOCSIS standard. The analyzed network fragment consists of 46 transit nodes, of which 12 are hardwired as the digital switching system, 21 – as the router, 8 are functioning as the gateway between the network segments, 5 are implementing the Softswitch system.

All the calculations are based on the assumption of a stationary mode of the network functioning. The initial data are based on the real Ukrainian networks’ values of users number, intensity of information sources, information types and classes, used at the design by the “Ukrainian State Institute for the Design and Development of the Information-communication Infrastructure “Diprozvyazok”. Mentioned parameters’ values correspond to the aggregated segments’ features which are typical specially for such networks.

We compared the usage results of four methods (M1…M4) for calculating the network SN. **M1** is based on the Erlang’s first formula which was base until the last time for all the Ukrainian design organizations (including the “Diprozvyazok”). **M2** takes into account a possibility of the requirements' repeated service due to the rejects (explicit loss) or waiting in excess of the allowed time (implicit loss). **M3** is theoretically possible calculation for the joint service system, subject to repeated messages and the MS aggregated nature, based on the Erlang’s first formula. **M4** is based on the authors’ unified calculation method for the joint system with the messages requiring retransmission.

These methods were applied subject to the features of the equipment functioning at the researched network fragment’s nodes. We give analysis of the methods usage results for calculating the transit node (S3) hardwired by the Softswitch equipment (it’s marked out by bold lines at the Fig. 12). This node services the MS load of the packet DTM as well as realizes the joint service of aggregated load of the cell, channel and frame DTM. This load arrives from the seven network segments (PSTN, DCN, VoIP, CATV, PSTN with ADSL and VDSL, CATV with DOCSIS, the telephone and data transfer networks’ hybrid segment) by the five routes via routers R6, R7, R12, R13, R17. The DCN segments load arrives to the Softswitch (S3) via routers (R6) and (R13), the PSTN voice load – via gateway (G3) and router (R7), the load from the DCN, CATV (including the DOCSIS CATV) and the telephone and data transfer networks’ hybrid segments – via router (R12). Generally the node, servicing the corresponding MS, is the queuing system with the restricted queue.

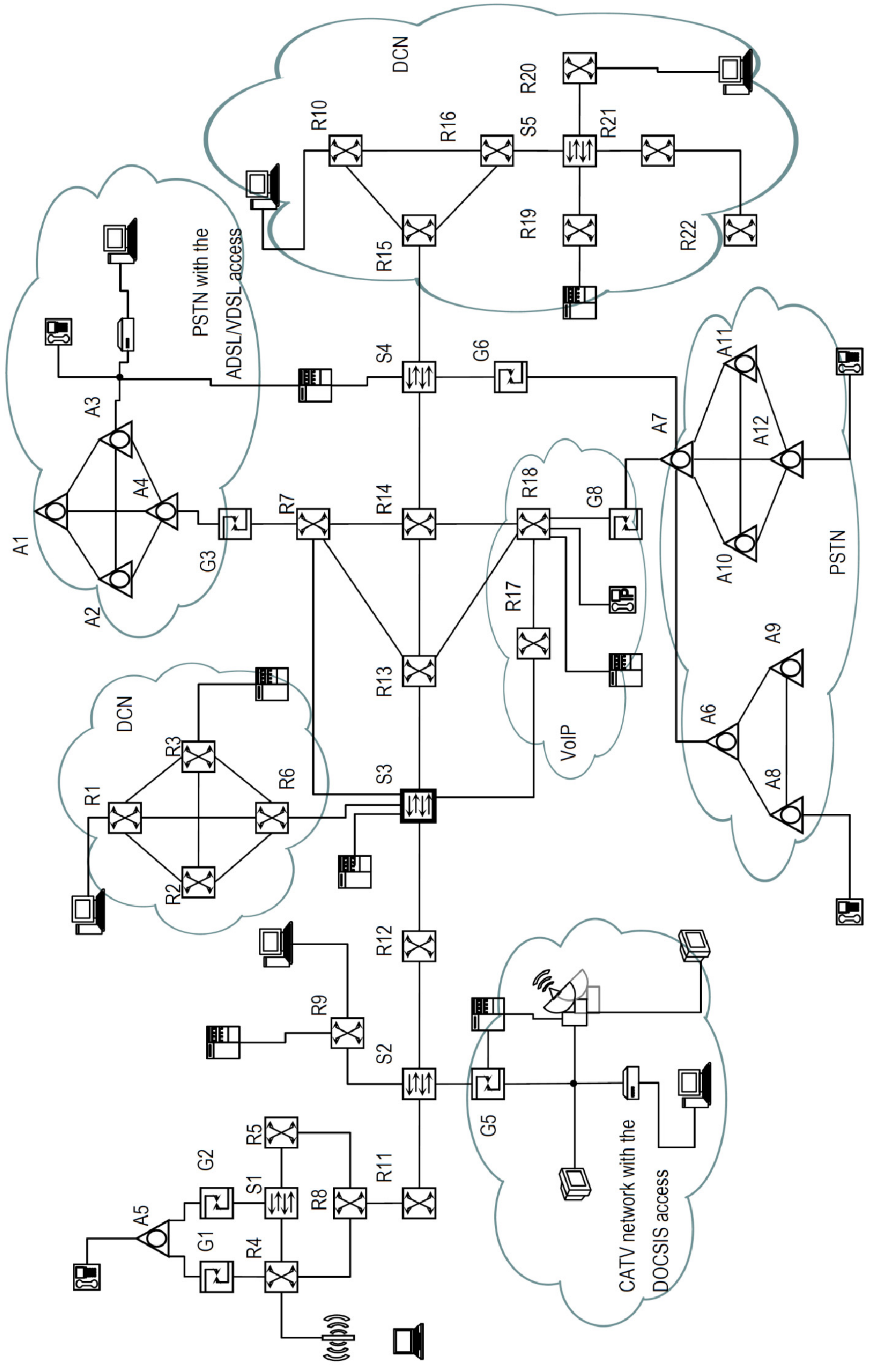

Fig. 12. The convergent network fragment (aggregation of the PSTN, DCN, the CATV and VoIP network)

The calculation results of the S3 service node for the transit load of aggregated MS via the five mentioned above routes (routers) are shown in Fig. 13. The histogram's first row represents the result of calculating the SN number at the M1 usage. The value is 60474 SNs. Deficiency of this method is caused by a non consideration of the messages re-arrival, characteristically for the real service systems' functioning. This leads to increase of the losses and the QoS degradation correspondingly. So the histogram's second row represents the calculation result according to the M2. The result of consideration of the messages requiring retransmission is 67731 SNs. This is more than the M1 result for 12%. The histogram's third row represents the result of calculating the SN as the joint service system, subject to the repeated messages and aggregated nature of the MS. The value of usage of the M3, based on the Erlang's first formula, is 47412 SNs.

Usage of the existing methods for a designing the IN converged segments leads to the significant overstatement of the SNs number, cf. Fig. 13. It's caused by the fact that these methods are based on the load which has additive nature in terms of the arrival information streams. I.e. the SN number is being calculated separately for each IS generating the load. But the load is being jointly served by the researched node. However derived results are adding and their sum determines necessary number of the SN. Actually the SN is the joint service system of a pre-aggregated MS. This fact should be considered in the calculation method. That's why the M4 result (cf. Fig. 13 fourth row) is the most accurate among the compared methods. The value is 37929 SNs (in spite the fact that it joint to the messages requiring retransmission, cf. Fig. 14). It's lower by 20% than the best theoretically possible result (i.e. the M3, subject to the load aggregation, which isn't being considered at the real design) and by 44% than the M2 result subject to the re-service. The 20% accuracy enhancement of the result, provided by the authors' method usage, effects a saving of 9483 SNs, the 44% accuracy enhancement of the result – 29802 SNs.

The authors' method usage specially for the joint service systems of the aggregated load generated by the heterogeneous information streams both at the channel and packet DTM is the best evidence of its adequacy and expedience. All the results given in this paper are documented by National Commission for the State Regulation of Communications and Informatization, “Diprozvyazok” PJSC, “Ukrtelecom” LLC (Odessa branch).

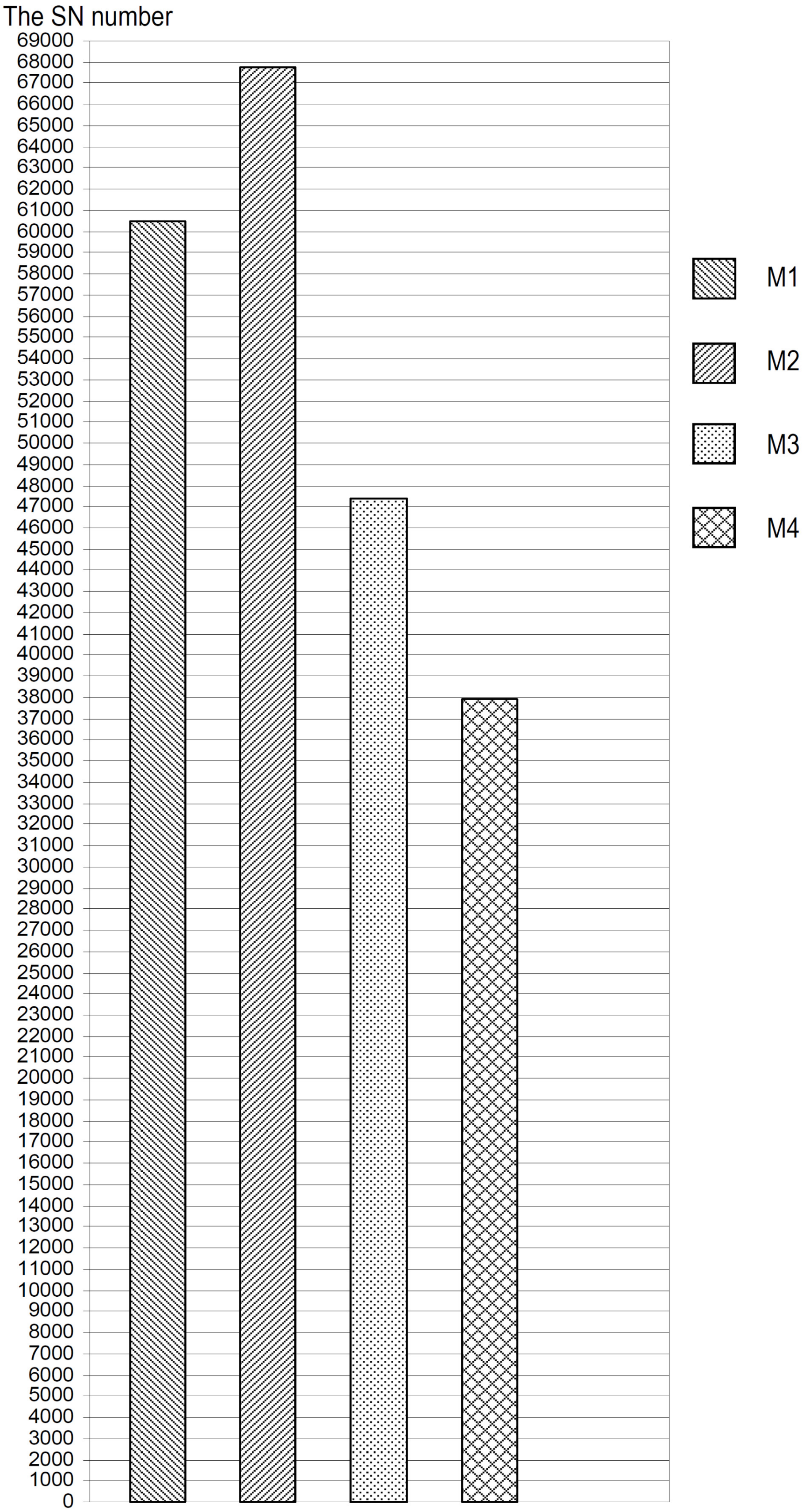

Fig. 13. The calculation results of the Softswitch (S3) service system

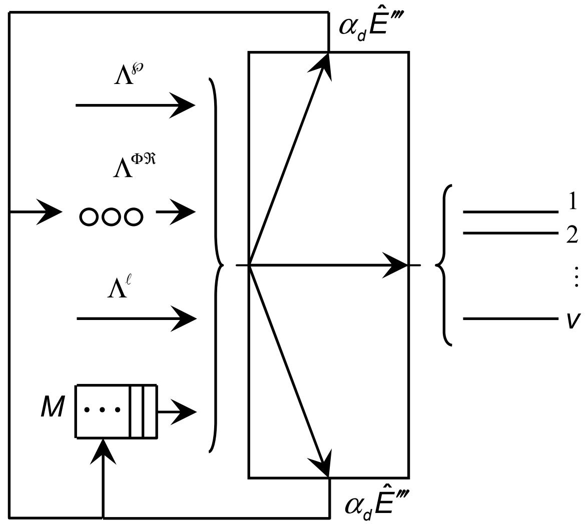

Fig. 14. The joint service system of the messages requiring retransmission

Conclusion

The developed unified method for calculating the network equipment capacity is an adaptable to the service system structure and discipline as well as to the data transfer mode which is being used in the network.

The method is improved with introduction of the coefficients, reproducing the real information stream's nature and in this way expanding its adequacy and sphere of application by means of specification of a used stream model.

An usage necessity of the message stream model instead of the call stream model is justified for the modern convergent information network. Such a model allows adequate consideration of features of the probabilistic-temporal structure of the information streams at the load intensity estimation and the QoS determination.

The developed load model is used for modification of the unified method for calculating the network equipment to any service system and discipline at all the data transfer modes, subject to parameters of the message streams circulating in the network. These parameters consist of the distribution functions of: number of the messages both in time and space, amount of the information in the message stream, time while the messages are in the network and value of the information, as well as the QoS parameters (a maximum permissible probability of symbol corruption, mean delay and its variance, etc.).

The developed method for calculating the equipment of information networks based on the message stream model assures the 18…22% accuracy enhancement of the results and so extends accuracy of the network design on the whole. The implementation results of the developed methods and models to the real design of Ukrainian information networks are verification which confirms their reliability.

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