Method and the device of an estimation of information efficiency of telecommunication systems taking into account information losses

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Abstract. In work on the basis of the deep analysis of approaches to estimation of efficiency of an information exchange of telecommunication systems is offered the method of an estimation on the basis of the generalized indicator – performance coefficient (PC) of transfer of information taking into account losses of information packets. The indicator is specified at network level with use of cybernetic capacity of information losses. The structural scheme of the device with instructions of elements for practical realization of a method is developed. The generalised algorithm providing the analysis and an estimation of information efficiency of telecommunication systems with various structures on the basis of the received method is synthesized. Analytical and imitating modelling of work of algorithm and estimation of information efficiency of telecommunication systems with structures "star" and full connected in the conditions of change of the input traffic taking into account of influence of hindrances is spent. Results of modelling have confirmed working capacity of a method and reliability of estimations received on his basis that can be used at the organisation of complex multi-contour of adaptation.

1. Introduction

For functioning of modern telecommunication systems (TCS) realization of an information exchange in the conditions of the high sharply changing input traffic and influence of various destabilizing factors is characteristic (sets of influences on TCS arising casually or purposely and leading to undesirable changes in work of separate elements and systems as a whole, for example, various hindrances and the errors caused by them at transfer of information, failures of switching nodes (SN), by-effects etc.). One of important features of TCS in such operating mode is presence of losses of information packages (information losses) that must be properly taken into account and, if possible, minimized. Thereupon the problem of reception of an adequate estimation of efficiency of an information exchange (information efficiency) of TCS taking into account information losses and formation of the practical recommendations directed on their decrease, and also increasing and maintenance of the maximum possible values of quality indicators of an information exchange for current operating conditions is actual.

The analysis of classical approaches to estimation of efficiency of an information exchange in TCS [1 – 3] shows that they are under construction on use of separate private parameters and the characteristics which reflect: speed of possibilities of system, a time delay at transfer of information,
statistics of the lost and wrongly transferred packages. Not the exception is represented by the estimations received on the basis of expanded system of QoS-parameters (Quality of Service) [4]. The separate class is represented by estimations that are reduced to finding the probabilistic-temporal characteristics of the system that determine the timeliness and reliability of information transfer [5, 6]. However in received estimations is problematic to allocate factors and the criteria, making the basic impact on final result, including taking into account information losses. Well-known multicriteria and conditionally generalized approaches [7, 8] contain set of the additional parameters which do not have the direct relation to an information exchange, therefore also do not allow unequivocally to define and estimate a role of its concrete characteristics in the chosen generalized system indicator.

In work [9] the alternative method of an estimation of information efficiency of TCS on the basis of the generalized indicator reflecting at network level of property of transfer and storages of the information, of approximation degree of system to optimum characteristics of an information exchange and nevertheless, having accurate physical sense and obvious communication with physical and channel of characteristics of separate elements of system has been offered. For his description is used the model of TCS that reflects the basic system of elements functionally participating in maintenance of an information of exchange, which include: block of information input devices (BIID), block of memory devices (BMD), block of transmission information devices (BTID) и block of information output devices (BIOD).

The essence of the given method of an estimation of information effectiveness of TCS, consists in measurement: an average for the chosen interval of time of total of information in BMD and BTID; average productivity of TCS for the same interval of time; calculation of cybernetic capacity (KW) of TCS; and also in measurement: capacities of buffers BMD and throughputs of communication channels (CC) BTID; calculation of full cybernetic capacity (KW_{full}) of TCS and taking into account the received results in definition of PC of transfer of information of TCS:

\[ \eta = \frac{KW}{KW_{\text{full}}} \cdot 100\% , \]

where KW = N \cdot G_T \text{ - the cybernetic capacity of TCS; } N \text{ - the measured average quantity of information messages in system; } G \text{ - the measured average productivity of TCS; } T \text{ - the chosen time interval of averaging; } KW_{\text{full}} = \sum_{i=1}^{n} \left( N_i \cdot \sum_{k=1}^{s} C_{k,i} \right) \text{ - the full cybernetic capacity of TCS; } N_i \text{ - the measured capacities of each buffer BMD; } \sum_{k=1}^{s} C_{k,i} \text{ - the measured total throughputs of CC BTID of the block for each element of BMD; } n \text{ - quantity of buffers BMD; } s \text{ - number of CC BTID, for service of each } i \text{-th buffer BMD.}

However a lack of the offered method of an estimation is the impossibility of the account of influence of hindrances on an information exchange in TCS, making essential impact on productivity of system and causing information losses.

Therefore in development of methodology of estimation of information efficiency of TCS the method of an estimation of efficiency of an information exchange taking into account influence of hindrances at physical and channel levels of functioning of system has been developed [10]. The essence of the given method consists that for the chosen interval of time of an operating of TCS besides calculation of PC of transfer of information, total number of single elementary parcels (SEP) is addition defined from which the information packages consist, transferred in system N_{tot} and number
of erroneously received SEP $N_{err}$ at the fixed relation of signal/hindrance and under $N_{err}/N_{tot} \geq 0.1$ is specified value of PC of transfer of information:

$$\eta_{noi} = -\eta \cdot \lg \frac{N_{err}}{N_{tot}},$$

where $\eta_{noi}$ – the PC of transfer of information of TCS taking into account influence of hindrances, $\frac{N_{err}}{N_{tot}} = P_{err}$ – probability of an error of reception of a SEP.

As a lack of the given method it is possible to notice that at definition of an estimation of PC of transfer of information of the influence of hindrances on physical and channel levels of TCS by quantity of erroneously received SEP is considered only without taking into account at network level of system characteristics of information losses and a stream of repeated transfers.

Thus, the purpose of the given work consists in increase of accuracy of an estimation of information effectiveness of TCS by developing a method and the device for definition of capacity of information losses and correction with its help of values of cybernetic capacity of system and PC of transfer of information, and also in development of the practical recommendations providing decrease of losses of information packages and increase of quality indicators of an information exchange in current operating conditions of TCS.

2. Materials and methods

The essence of an offered method consists that for the chosen interval of time ($T$) is measured and calculated cybernetic capacity $KW$ and full cybernetic capacity $KW_{full}$ of system, in addition for this interval of time are measured: average quantity of wrongly accepted packages $N_{wa}$ in BIOD from system, average quantity of not delivered packages $N_{nd}$ in BMD, BIID and BTID, value of intensity of a stream of repeated transfers $\gamma_{rt}$ in BTID, then the general average quantity of information losses (packages) is calculated:

$$N_{los} = N_{wa} + N_{nd}.$$  \hspace{1cm} (3)

Then capacity of information losses is defined

$$KW_{il} = N_{los} \cdot \gamma_{rt}$$ \hspace{1cm} (4)

with its help cybernetic capacity of TCS is specified and there is its “real” value

$$KW_{real} = KW - KW_{il}.$$ \hspace{1cm} (5)

The parameter – PC of transfer of information of TCS taking into account information losses is as a result calculated
Novelty of the offered method consists that he allows to consider in parameter $\eta_{il}$ of the characteristic of information losses of system in the course of transfer of information, i.e. simultaneously to reflect influence of hindrances and as a whole destabilizing of factors on an information exchange in TCS. In expression (4) value $N_{los}$ defines the general average value of the lost packages for the chosen interval of time $T$, and value $\gamma_{rt}$ of intensity of a stream of the repeated transfers which are carried out by system for maintenance of requirements on timeliness and reliability of an information exchange. Thus, the specified value of “real” cybernetic capacity $KW_{real}$ defines information losses of TCS as in the course of storage, and transfer of information. The basic advantage of a received estimation is the accurate physical sense of parameter confirmed with trivial calculations and measurements. Thus the account of losses of packages arising in the course of an information exchange in TCS by additional definition of capacity of information losses of a system, according to known sources [11 - 13] and conducted researches [14], allows essentially to raise accuracy of an estimation of factor. It, in turn, provides timely reaction of system to changes of operating conditions for maintenance of high efficiency of information exchange of TCS, by realization of procedures of complex multi-contour of adaptation in real time [15].

The proof of a technical realisability of an offered method of an estimation of efficiency of information of exchange of TCS, that for its realization are required standard elements of the microelectronics, existing measuring and computer facilities, for example, such as: counters, adders, multipliers, subtractors and dividers, and also the software which basis are elementary mathematical operations [16]. Therefore during researches the device of an estimation of efficiency of an information exchange in TCS taking into account information losses has been received.

The device of an estimation of efficiency of an information exchange of TCS (figure 1) contains:

- the block of 1 calculation of the cybernetic capacity, intended for definition of value of $KW$ (including blocks of measurement of quantity of messages and productivity of TCS);
- the block of 2 calculation of the full cybernetic capacity, intended for definition of value of $KW_{full}$ (including blocks of measurement of capacities of buffers of the BMD and throughputs of the BTID of system);
- the block of 3 managements of the measurements, intended for the task of an interval of time of measurements $T$ and quantity of necessary measurements $n$;
- the block 4.1 of counter of wrongly accepted packages, intended for calculation of quantity of wrongly accepted packages $N_{wa}$;
- the block 4.2 of counter of not delivered packages, intended for calculation of quantity of not delivered packages $N_{nd}$;
- the block 4.3 of counter of repeatedly transferred packages, intended for calculation of quantity of repeatedly transferred packages $N_{rt}$;
- the block 5.1 of divider intended for definition of average quantity of wrongly accepted packages $N_{wa}$ by performance of operation of division of quantity of wrongly accepted packages $N_{wa}$ for the chosen interval of time of measurements $T$ on quantity of measurements $n$;
- the block 5.2 of divider intended for definition of average quantity of not delivered packages $N_{nd}$ by performance of operation of division of quantity of not delivered packages $N_{nd}$ for the chosen interval of time of measurements $T$ on quantity of measurements $n$;
\textbf{Figure 1.} The device of an estimation of efficiency of an information of exchange in TCS taking into account information losses.

- the block 5.3 of divider intended for definition of value of intensity of a stream of repeated transfers $\gamma_{rt}$ by performance of operation of division of quantity of repeatedly transferred packages $N_{rtT}$ for the chosen interval of time of measurements $T$ on size of this interval in seconds;
- the block 6 of adder intended for definition of the general average quantity of information losses (packages) in TCS $N_{los}$ by performance of operation of addition counted up in counters 5.1, 5.2 values of $N_{wa}$, $N_{nd}$, accordingly, according to expression (3);
- the block 7 of multiplier, intended for multiplication of values of the general average quantity of information losses (packages) in system $N_{los}$ and values of intensity of a stream of repeated transfers $\gamma_{rt}$ for the purpose of reception of value of capacity of information losses of TCS $KW_{il}$ according to formula (4);
- the block 8 of subtractor intended for definition of values of "real" cybernetic capacity of TCS $KW_{real}$ by performance of operation of subtraction according to expression (5);
- the block 9 of divider intended for division of values of "real" cybernetic capacity of system $KW_{real}$ on values of full cybernetic capacity $KW_{full}$ for the purpose of receiving on an exit of the
device of value of PC of transfer of information of system taking into account information losses $\eta_d$ according to formula (6).

Device work (figure 1) is carried out as follows. In the block of 3 managements measurements make a choice of an interval of time of measurements $T$ and quantity of necessary measurements $n$ which from the first and second exits of the block stand out in the TCS, being the first and the second device outputs, accordingly.

Then from TCS in counters 4.1, 4.2 and 4.3 the information on wrongly accepted, not delivered and repeatedly transferred packages, accordingly, is arrives. In the counter 4.1 calculation of quantity of wrongly accepted packages $N_{wa_T}$ in the counter 4.2 – quantities of not delivered packages $N_{nd_T}$ in system for the chosen interval of time of measurements $T$ is made. In counters 4.1 and 4.2 quantities of packages $N_{wa_T}$ and $N_{nd_T}$ are routed to the first inputs of dividers 5.1 and 5.2, accordingly, where by performance of operation of division into the quantity of measurements $n$ arriving on the second inputs of dividers from the second exit of the block of management by measurements 3, there are average quantities of wrongly accepted $N_{wa}$ and not delivered packages $N_{nd}$

$$N_{wa} = \frac{N_{wa_T}}{n},$$

$$N_{nd} = \frac{N_{nd_T}}{n}.$$  \hspace{1cm} (7) \hspace{1cm} (8)

Further from exits of dividers 5.1 both 5.2, accordingly, value and value stand out on the first and second inputs of the adder 6. In the adder 6 operation of addition (3) of the counted values $N_{wa}$, $N_{nd}$ is carried out, and the received value of the general average quantity of information losses (packages) in system $N_{los}$ arrives on the first input of multiplier 7. In the counter 4.3 calculation of quantity of repeatedly transferred packages $N_{rt_T}$ for an interval of time of measurements $T$ is made. Then the given value gives on the first input of a divider 5.3 where by performance of operation of division into size of an interval of time of measurements $T$ in the seconds, arriving on the second input of a divider 5.3 from the first exit of the block of managements of the measurements 3, the value of intensity of a stream of repeated transfers are found.

$$\gamma_{rt} = \frac{N_{rt_T}}{T},$$  \hspace{1cm} (9)

which goes on the second input multiplier 7.

In multiplier 7 operation of multiplication (4) of value $N_{los}$ on $\gamma_{rt}$, and the received value of capacity of information losses of system $KW_{il}$ is carried out goes on the first input of the subtracting device 8. In the block of 1 calculation of cybernetic capacity on the basis of the input of information arriving from system, by a technique stated in [9] value of cybernetic capacity of system $KW$ which from its output gives on the second input of the subtracting device 8 is defined. In the subtracting device 8, according to expression (5), operation of subtraction from value of cybernetic capacity of TCS $KW$ of value of capacity of information losses of system $KW_{il}$ is carried out and the received value of "real" cybernetic capacity of TCS $KW_{real}$ stands out on the first input of a divider 9. In the block of 2 calculations of full cybernetic capacity on the basis of the input of information arriving from TCS, according to [14] value of full cybernetic capacity of system $KW_{full}$ which from its exit
gives on the second input of a divider 9 is defined. In a divider 9 operation of division of values $KW_{real}$ on the $KW_{full}$ is made, arriving on his inputs therefore the specified value of PC of transfer of information of TCS is defined taking into account information losses $\eta_{il}$ which stands out on the third (basic) exit of the device.

All operations which are carried out in blocks 1 - 9, are simply enough realized, for example, on the basis of digital devices and high-speed microcontrollers [16]. The device can be used at creation new and perfection existing CC, SN, various TCS: the automated control systems, information networks, communication networks with switching of messages, communication networks with switching of packages in the conditions of influence of hindrances.

All operations which are carried out in blocks 1 – 9, are simply enough realized, for example, on the basis of digital devices and high-speed microcontrollers [16]. The device can be used at creation new and perfection of existing channels, knots коммутаторы, various systems: the automated control systems, information and computer networks, communication networks with switching of messages, communication networks with switching of packages in the conditions of influence of hindrances.

3. Results and discussion
The complex algorithm of the decision of a problem has been developed for check of working capacity of the offered method and the device of estimation of information effectiveness of TCS (figure 2) which is software realized in the form of analytical and imitating models of an information exchange in system with structures "star" (figure 3a) and full connection (figure 3b) in the conditions of changes of the input traffic and influence of destabilizing factors (hindrances).

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{complex_algorithm.png}
\caption{Complex algorithm of estimation of information effectiveness of TCS.}
\end{figure}
Programs of analytical models are executed in environments of programming Maple and Delphi 7 on the basis of mathematical apparatus tensor methodology (combining in the uniform decision three spaces of system: static space-structure of the system, two dynamic spaces of information and hindrance of streams), and programs of imitating modelling in GPSS/PC environments and LiteIDE X with use of the classical approach of the theory of systems of mass service (SMS) [17, 18].

Topological models of TCS for the purpose of maintenance of check of a realisability and reliability of functioning of the developed method and the device are generated, therefore are chosen in the simplified base variant from six SN, as two kinds of elementary structures with the minimum and maximum redundancy, accordingly, used at formation of difficult multidimensional topology of TCS, and also for reduction of time of modelling and volumes of made calculations (figure 3).

![Figure 3. Structural models of investigated TCS.](image)

As the initial data and restrictions at modelling following values of the basic system of indicators and parameters of an information exchange were used:

1. Total of cybernetic elements of TCS $n_{kib\_el}$, CC $n_k$ and SN $n_{usl}$, including, having an information input of stream $n_{usl\_xx}$ and giving out his on output a system $n_{usl\_vis}$.

2. Restriction on a time delay $T_{adm}$, throughputs of intranetwork CC $C_{kan}$ and the channels providing delivery of the information from system $C_{vis}$, length of a package $L_{pak}$.

3. Arrays (vectors in analytical tensor of models) an input stream $\gamma_{in}$: information $\gamma^b$ and hindrance $\gamma^c$ of the traffic, accordingly, providing an operating mode of TCS with intermediate storage of the information in BMD of SN.

4. Interval of change intensity of input and hindrance of streams $\gamma^{b\_shaga}$ and $\gamma^{c\_shaga}$, accordingly.

5. Capacities of BMD $n_b$ and channel capacities $n_c$ in number of packages for mutually independent single-channel of systems and a primitive of network of tensor orthogonal model

6. Value of probability of an error $P_{err}$, for the account of influence of hindrances on an information of exchange in imitating model of TCS.

7. Tensors the transformations $A^\alpha_x$, $A^\beta_a$, $C^{\alpha}_\beta$, providing formation of connected structures of TCS from a primitive network of single-channel of systems in analytical tensor of model [19].

Results of work of models in the form of schedules of dependence of factor from the input traffic are presented on figure 4.
For the purpose of maintenance of identical loading of investigated structural models of TCS modelling was made in topology "star" at change of intensity of the input traffic with step $\Delta \gamma_{\text{in}} = 100 \text{ kbit/s}$, and for topology "full connected" – $\Delta \gamma_{\text{in}} = 200 \text{ kbit/s}$, accordingly. Results of work of analytical tensor orthogonal of model of an information exchange in TCS taking into account destabilizing factors (including hindrances) are presented in figure 4a, imitating modelling in the environment of LiteIDE X by multithreading programming on the basis of the classical approach of the theory of SMS – on figure 4b.

Modelling was spent for three casual arrays (vectors) of the input information of traffic $\gamma_{\text{in init}} = \gamma^b \{p, i_{\text{in}}\}_0 = (30...60) \text{ pack/s}$ without influence of hindrances, and at modelling of the influence hindrance of traffic $^{\text{in}} \gamma^m$ in TCS – $\gamma_{\text{in init}} = (15...30) \text{ pack/s}$.

Received on their basis of dependences $\eta(\gamma_{\text{in}}) = \eta(\gamma^b \{k, i_{\text{in}}\})$, $\eta_{\text{noi}}(\gamma_{\text{in}}) = \eta_{\text{noi}}(\gamma^b \{k, i_{\text{in}}\})$ and $\eta_{\text{noi}}(\gamma_{\text{in}}) = \eta_{\text{noi}}(\gamma^b \{k, i_{\text{in}}\})$, were averaged on three realizations of function of information efficiency for each of investigated structures of TCS. For the purpose of definition of the full data about behavior of a network in each realization of change of an input stream $\gamma_{\text{in init}}$ were carried out during 30 iterations with the values of a step of change of intensity of the traffic specified above.

For the comparative analysis of dependence of each of investigated structures of TCS (continuous lines) are placed in uniform system of co-ordinates with results of modeling providing the account of influence of hindrances at channel level by an indicator of a noise stability $S$ (dashed lines) and with results, received on the basis of the developed method of an estimation of information efficiency at the system approach at network level of functioning of TCS (dash-dotted lines).

At researches of functions of efficiency $\eta(\gamma_{\text{in}})$, $\eta_{\text{noi}}(\gamma_{\text{in}})$, $\eta_{\text{noi}}(\gamma_{\text{in}})$ and a finding of area of high information effectiveness of TCS similar test intervals of change of the input traffic, as in the imitating models, defined by threshold value of PC of transfer of information $\eta_{\text{orig}}$ are chosen.

The analysis of results of modeling, in characteristic points of the received dependences, allows to speak about working capacity of the received models, and also reliability of estimations of efficiency of an information exchange in TCS on the basis of the presented approaches to the account of influence of destabilizing factors on functioning of system. The data of calculations of the basic network of parameters of investigated topologies of TCS testifies to similar character of behavior in the course of an information exchange at changes of useful loading and hindrance of conditions. Thus estimations of information efficiency in tensor orthogonal model and imitating model of TCS differ no more than on 3 %, and an interval of pass-bands – on size of an order 1 Mbit/s. As a whole it is visible that reduction of the maximum value of PC of transfer of information $\eta_{\text{max}}$ and narrowing of a
pass-band of TCS $\Pi_f(\eta_{\text{noi}})$ at change of parameters of a noise stability (values $P_{\text{err}}$) at channel level and a variation of parameters hindrance of the traffic at network level ($\gamma_{\text{noi}} = \gamma^*$) is observed. The TCS with topology "star" is most strongly subject to the given changes for which reduction of a maximum of PC $\eta_{\text{max}} = 37.8\%$ is observed, accordingly, on 11.3 % at the account of hindrances at channel level ($\eta_{\text{noi}} = 26.5\%$) and on 14.6 % at the system approach ($\eta_{\text{dil}} = 23.2\%$). Thus also the area of information effectiveness of TCS that is defined by considerable reduction of a pass-band on the input traffic for the set threshold level of PC of transfer of information $\eta_{\text{tirg}} = 10\%$ is narrowed: $\Pi_f(\eta_{\text{noi}})_{\text{noi}}$ on 2.3 Mbit/s and $\Pi_f(\eta_{\text{noi}})_{\text{dil}}$ on 7.1 Mbit/s. By results of modeling it is visible that in all range of researches on the input traffic full connected structure provides high indicators of an information exchange ($\eta_{\text{max}} = 50.5\%, \ \eta_{\text{noi}} = 35\%, \ \eta_{\text{dil}} = 29.5\%$) and stability of functioning $\Pi_f(\eta_{\text{noi}})_{\text{dil}} = 6.5 Mbit/s$ at change of the input traffic and hindrances influences largely. Application of the developed method of an estimation of information effectiveness of TCS taking into account information losses provides more exact account of influence of destabilizing factors on an information exchange in system that allows to predict functioning of system at changes of the traffic and hindrance of conditions for development of the practical recommendations directed on minimization of losses of information packages, increase and maintenance at demanded level of indicators of an information exchange ($\eta_{\text{dil}}, \ \Pi_f(\eta_{\text{noi}})_{\text{dil}} \rightarrow \text{max}$).

4. Conclusion

Thus, it is possible to consider the work purpose reached. The developed method and the device of an estimation of information effectiveness of TCS taking into account losses of packages provide increase of accuracy of an estimation of quality of an information exchange on the basis of definition of capacity of information losses of system and correction with his help of values of cybernetic capacity and PC of transfer of information. The models received on the basis of an offered method for TCS with various topologies allow to consider influence of destabilizing factors on efficiency of an information exchange at network level. The constructed dependences reflect adequate estimations of PC of transfer of information and define the best operating conditions of TCS at simultaneous change of information and hindrance of traffic. Results of imitating and analytical modelling have shown working capacity of an offered method and reliability of received estimations of PC taking into account information losses at influence of hindrances on quality of an information exchange that also proves to be true their conformity to character of functioning of real systems in similar conditions. The given approach is offered to be used at the organization of algorithms and procedures of complex multi-contour of adaptation of TCS in real time to changing conditions of an information exchange and hindrance of conditions that will allow to provide increase (maintenance) of information efficiency and stability of system.

Following the results of work, being based on results of the spent researches, concrete practical recommendations about increase of quality indicators of an information exchange and application of variants of structural construction of TCS depending on values of the basic network of parameters, characteristics of the input traffic and influence of destabilizing factors can be generated. The finding of quasioptimum operating conditions of TCS can be realized on the basis of conciliatory proposals on maintenance of demanded efficiency of an information exchange and a choice of topology of system.

Acknowledgments

Researches are executed with financial support of the Ministry of a science and higher education of the Russian Federation within the limits of Action within the limits of Agreement 14.577.21.0284 from June, 18th, 2019. The unique identifier of project RFMEFI57717X0284.
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