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Influence of Traffic Prognostic Mechanism on Quality of Adaptive Control of Switchboard

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Abstract

Influence of mechanism of prognostication of package traffic on quality of work of adaptive control system a switchboard is considered. It is shown that in the process of work of the adaptive system there are errors of control that negatively influence on the level of loading of switchboard. It is shown also, that plugging of mechanism of prognostication in the contour of adaptive control allows to bring down the level of system errors and, thus, to provide possibility of increase of loading of switchboard a useful traffic.

Keywords: control system, prognostic mechanism, adaptive control, system errors

1. Introduction

The new adaptive mechanism of step by step discrete control by dynamic redistribution of the throughput of switch equipment between carrying capacities (bandwidths) of its ports offers in [1]. This mechanism adapts in real-time the bandwidths of switchboard ports under the dynamics of changes of intensity of streams of package traffic that come to these ports. But on condition, that the total bandwidth of all ports in any current moment of time does not exceed the carrying capacity of switchboard. Due to work of this mechanism, dynamics of redistributive process almost coincides with the dynamics of traffical trend on ports. It gives a substantial useful effect: a possible loading factor of switch equipment is rised.
During work of adaptive redistributive mechanism there are errors that negatively influence on quality of control. However character of these errors, mechanism of their formation and degree of influence on quality of control in [1] is not investigational. Therefore one of aims within the framework of the real article there is research of mechanism of formation of errors of adaptive control by switchboard bandwidth and character of influence of these errors on quality of control.
The mechanism of redistribution must have high dynamic characteristics, the achievement of that, having regard to high-rate treatment of packages in a modern switch equipment, is a non-trivial task. In particular, in moments of time, when intensity of stream of packages on some port increases quickly, then it is necessary quickly to increase his bandwidth. Other words, it is necessary as possible quicker to distinguish greater part of carrying capacity of switchboard for this port (certainly, due to reduction of parts of carrying capacity, that is distinguished to other ports). And vice versa. It is not difficult to provide for, that under such conditions introduction to the contour of adaptive control of any mechanism of short-term traffic prognostication, that moves up through switchboard ports, can substantially improve efficiency of work of control system. Research of possible influence of such prognostication on reduction of errors of control by switchboard is other aim of the real article.

2. Work of Prognostic Mechanism in Composition of Control System

On **Figure 1** it is shown how the prognostic mechanism is integrated in composition of the system of adaptive redistribution of carrying capacity of package switch device between its ports.
Package streams, that on pic.1 represented by pointers, before to get on input ports of Switch Device (SD) pass through the Measuring Block (MB), that consistently, step by step, in real-time with the beforehand set time interval measures the current values of parameters of these streams, and the results of measuring are sent

on the entrance of Prognostic Block (PB). Foremost, the current values of intensity of package streams are measured on the onesecond intervals I_1, I_2, ..., I_N, where N is an amount of ports in SD. In turn, PB consistently, step by step, takes the results of measuring of values of parameters of packet streams (from MB), produces their treatment thus, to form the sequences of datasets (time rows) that satisfy to the set requirements within the framework of the involved method of prognostication. Except that, the PB will realize the set procedure of prognostication directly, and results of prognosis estimations of values of traffic parameters, which done in the moments of acceptance of control decisions, passes on the entrance of block, which realize functions of forming of control commands (BFK). BFK is integrated in composition of the regulator of redistribution of carrying capacities of switch device ports (*RRCP*) [1]. At the same time in the beginning of every step of control act (on every step of measurements) information about the set sizes of bandwidths of all ports ∇F moves on other entrance of BFK from the unit options (parameters) of ports (UOB), that functions in composition SD. Id est, sizes of bandwidths of all ports are passed from UOB on БФК that set on a previous step of control act. On the basis of this information and got current prognosis estimations of parameters of streams the BFK produces the stream of managing influences (in form corresponding control commands) that is given on the entrance of block of executive mechanisms (EMB). EMB is integrated in composition of the SD. These executive mechanisms of EMB according to the got commands from the BFK carry out the corresponding changes of parameters of SD ports (id est, increase or diminish the sizes of bandwidths of all ports) in UOB of this switchboard. Algorithm of control is chosen, going out the technical requirements of application of equipment. In any case the fast-acting of the adjusting system is co-ordinated with the dynamics of changes in a trend of package traffic.

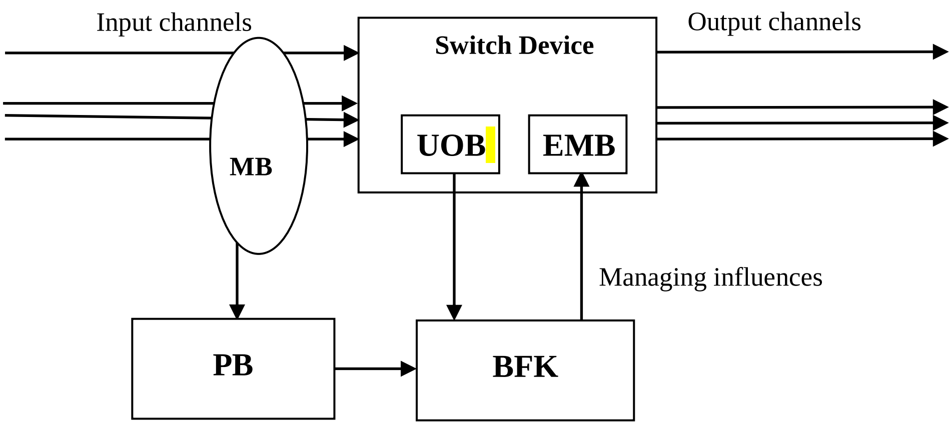


Figure1. Scheme of adaptive control the bandwidths of switch device ports

It should be noted that the PB carries out prognostication not after the current values of intensity of package traffic pulsations, but after its average values $\Gamma`_1$, $\Gamma`_2$, …, $\Gamma`_N$. Id est, at every step prognostication on the basis of a few last points of trend of package stream on each of ports is determined the nearest future point of this trend. Trend is a smooth stream that is formed by averaging of current initial package stream. In practice depending on the certain terms of application SD the coefficient of averaging is elected in a range from 5 to 120 (and anymore). The fivesecond, tensecond, fifteensecond and thirtysecond intervals of averaging are mostly used.

3. Raising of Tasks

Task 1. To ground the criteria of choice of prognostic method for the system of adaptive control by switchboard ports.
Task 2. To define the ways of realization of the chosen method of prognostication.
Task 3. At the terms of absence of prognostical mechanism to investigate the mechanism of control a redistribution with the aim of exposure of possible ways of formation of errors that influence on quality of control. To define the indexes of control quality and character of influence of these errors on quality of management.
Task 4. To investigate the mechanism of adaptive control in the conditions of the use of prognostical mechanism. To define character of influence of prognostication on the indexes of control quality.

4. Distinguish the Errors of Prognostication from the Errors of Adaptive Control

A prognosis mechanism can quite often be mistaken, but if bandwidths of ports is here chosen correctly, then errors in-process adaptive control mechanism will not be. Therefore we use the indexes of quality of prognostication that is directed to on an increase efficiency of functioning of adaptive control mechanisms. Exactly on these indexes we will estimate quality of the chosen algorithms of prognostication.

Index of economy of bandwidths of ports of switchboard E_Δ:

$$E_\Delta = \frac{\sum_{j=1}^{K_\Delta}\sum_{i=1}^{N}\left|\left(W_{i,j} - Wp_{i,j}\right)\right|}{\sum_{j=1}^{K_\Delta}\sum_{i=1}^{N} W_{i,j}}, \qquad (1)$$

where K_Δ - is amount of steps of adaptive control, N - is a common amount of ports, $W_{i,j}$ – is the set bandwidth of i-th port of switchboard on a j-th step of adaptive control on the basis of decision of equalization of Bellman [1] (without the use of mechanism of prognostication); $Wp_{i,j}$ – is the bandwidth of i-th switchboard set on the basis of prognosis on a j-th step of adaptive control.
If during adaptive control prognostication is not executed, then for any i and a j numerator in expression (1) will equal a zero and, thus, in relative units index of economy of bandwidths of ports $E_\Delta = 0$. If prognostication appears on the average successful (from the point of view of economy of bandwidth), then $0 \le E_\Delta \le 1$.
Physically index of economy E_Δ represents the degree of increase of loading of equipment due to the use of block of prognostication in the system of redistribution of carrying capacity of equipment in relation to the level of loading in default of prognostication. It is considered that due to the use of mechanism of prognostication the bandwidth of switchboard is "saved". However the "superfluous" economy of bandwidths of ports can result in the increase of losses of packages. It is therefore necessary to control quality of prognostication on the parameter of losses of packages.

Parameter of errors of prognostication E_r:

$$E_r = \frac{k_{error}}{K_\Delta} \cdot 100\% \quad , \tag{2}$$

where K_Δ – is the taken into account amount of steps of adaptive control; k_{error} - is an amount of points in that prognosis bandwidth of port was insufficient. E_r represents the stake of errors that arise up during application of one or another algorithm of prognostication.
Entered higher two indexes (1) and (2) allow to give exhaustive description to the degree of fitness of method of prognostication for the use in composition the system of adaptive control the bandwidths of ports of switchboard. Amount of the taken into account steps of adaptive control of K_Δ determined coming from the temporal interval of T_Δ, on that on one or another reasons it comfortably to execute the estimation of quality of prognostication :

$$T_\Delta = K_\Delta \cdot \tau_\kappa \quad , \tag{3}$$

where τ_κ is an interval between beginning of nearby steps of discretely-adaptive control.

5. We it Admits that there are *N* of Members of Temporal Row in our order

$z(t) \in z_t, z_{t-1}, z_{t-2}, ..., z_{t-N}$. Function of $z^*{}_t(l)$, that gives in the moment of t prognoses for all future moments of forestalling $l = 1, 2, ...$, we will name a forecasting function for the moment of t. It is required to execute the prognosis of this sentinel row with predictor l, id est to find the estimation of value of member of row of z_{t+l}. In other words, it is necessary to find such forecasting function for that mean value of square of rejection of z_{t+l} - $z^*{}_{t+l}$ true from a prognosis value will be the least for every forestaling of l. In addition, it is desirable to specify exactness of prognosis. In particular, to define exactness of prognosis probabilistic limits for both sides from a prognosis value, id est to define a prognosis estimation with the set probability in the set limits.

5.1. Method of prognostication, based on calculations derivative.
This method unbuilds in realization and in calculations, is characterized a high fast-acting, but often exact not enough. In our case exactness of prognosis does not have a decision value. For implementation of prognosis on every step of adaptive control it is enough to use only three last points of temporal row, designing the trend of package traffic. So that, this method is suitable for application at strongly pulsating data.
The algorithm of realization of method, based on calculations derivative, consists of the following:

1) On the current step of adaptive control we take two last points of prognosis of x_{-1} and x_0 and find the first derivative (f_0') of the relatively distinguished value of bandwidth of port for the last step.
2) Take two next to last points of prognosis of x_{-2} and x_{-1} and find the first derivative (f_1') of the relatively distinguished value of bandwidth of port for a next to last step.
3) On the found first derivatives we find a flexon (f_0``) for the last step of control.
4) Size of increase of prognosis value depends on the size of the first derivative of f_0`, and his direction (increase or reduction) from a size of flexon (f_0``), and, consequently, prognosis value of bandwidth of port on the current step of adaptive control determined as

$$x_{prognoz} = \begin{cases} x_0\left(1 + f_0'\right) + prognozConst, \ if \ f_0'' \geq 0 \\ x_0\left(1 - f_0'\right) + prognozConst, \ if \ f_0'' < 0 \end{cases} \quad (4)$$

where $x_{prognoz}$ is a prognosis value of bandwidth of port, x_0 is a current value of bandwidth of port, $prognozContst$ is some constant, characterizing the bulge of approximating function. On the next step of adaptive control procedure of being of prognosis value of bandwidth of port recurs again.

As we see, a calculable chart of prognostication of trend of traffic with the use of derivatives is simple and comfortable in programming, does not require plenty of basic data, that allows to hope on her high fast-acting.

5.2. Method of prognostication with the use of the exponential smoothing out. According to this method [3] a temporal row is smoothed out by self-weighted sliding middle with exponential scales, that allows to execute short-term prognostication.

It is known that the function of x_t in the moment of t can be described by a polynomial

$$x_t = \sum_{i=0}^{p} \frac{a_i}{i!} p^i + \varepsilon_t , \tag{5}$$

where p^i is a derivative from x_t i-th order, ε_t is error of rejection of sum of row from the actual value of x_t .

It allows, decomposing the function of x_t in the row of Tejlor, to calculate a prognosis value (5) in moment $t + l$. In particular, we have:

$$x_t^* = x_t^{(0)} + l x_t^{(1)} + \frac{l^2}{2!} x_t^{(2)} + \ldots + \frac{l^k}{k!} x_t^{(k)} + \ldots + \frac{l^p}{p!} x_t^{(p)} . \tag{6}$$

R. Brown and R. Meyer [3] proved that every k-th derivative ($k = \overline{0, p}$) of equation (6) can be displayed as a linear combination of exponential moving averages to $(p+1)$ degree:

$$S_t^{(k)}(x) = \alpha S_t^{(k-1)}(x) + (1-\alpha) S_{t-1}^{(k)}(x), \quad k = \overline{1, n} , \tag{7}$$

where

$$S_t^{(1)}(x) = \alpha \sum_{i=0}^{t-1} (1-\alpha)^i x_{t-i} + (1-\alpha)^t x_0 ; \tag{8}$$

α – smoothing parameter ($0 < \alpha < 1$).

From the expressions (7) and (8) follow equation:

$$
\begin{aligned}
S_t^{(1)}(x) &= \alpha x_t + (1-\alpha) S_{t-1}^{(1)}(x), \\
S_t^{(2)}(x) &= \alpha S_t^{(1)}(x) + (1-\alpha) S_{t-1}^{(2)}(x), \\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots , \\
S_t^{(k)}(x) &= \alpha S_t^{(k-1)}(x) + (1-\alpha) S_{t-1}^{(k)}(x), \\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots , \\
S_t^{(n)}(x) &= \alpha S_t^{(n-1)}(x) + (1-\alpha) S_{t-1}^{(n)}(x).
\end{aligned}
\tag{9}
$$

On the basis of equations (9) are computational schemes of prognostication of temporal rows with typical trends.

6. An Analysis of Errors of Adaptive Control is in the Conditions of Absence of Prognostical Mechanism

On Figure 2 lines of I'_1 represents the trend of package stream on first port of the switchboard got as a result of averaging of the measured current values of intensity of this stream on the fivesecond intervals. An overhead chart represents the segment of growing trend, and a lower chart is a segment of handing down trend. As see, a trend has a stepped form, where a height of step is a casual size that depends on the dynamics of changes of trend, and a width of step is a select an administrator interval of averaging. The form of trend is determined by the select mechanism of smoothing of primary traffic. The mechanism of the so-called "bucket of token" is select in this case, that in detail considered in [2]. This mechanism allows to convert the pulsating streams of packages, that come to switchboard ports, in the smoothed out streams of stepped form - just the same, that shown on pic.2. At the end of every fivesecond interval on the basis of results of averaging automatically changes corresponding parameter of mechanism of "bucket of token " (more precisely, generator of token), that results in the saltatory changes of intensity of the smoothed out stream of packages: on the areas of growing trend steps moves upwards, and on the areas of handing down trend steps moves downward. Clear that smoothing properties of conditional "bucket of token " operate only in certain limits: during the too strong splashes of traffic the entrance turns of packages are overfilled and "superfluous" packages are lost.

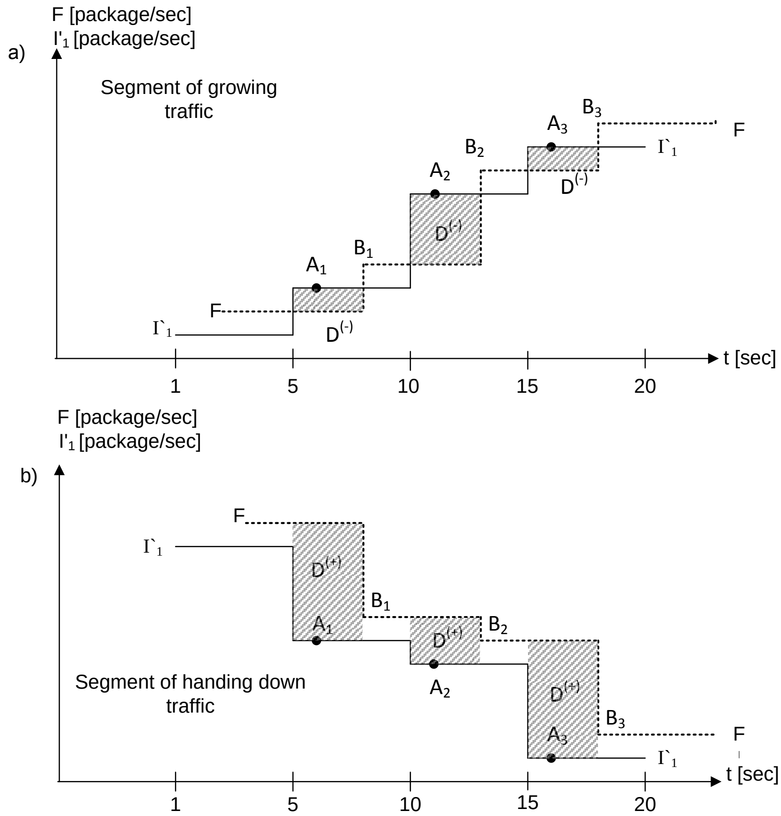


Figure 2. Formation of errors of adaptive control is without prognostication

The adaptive control mechanism of package redistribution must change the SD bandwidth synchronously with changes and proportionally to the changes of trend. Discrete character of changes of trend stipulates discreteness of control. The bandwidth, that is distinguished to the first port, on Figure 2 mark the line of F. As see, the line of F repeats after a form the line of I'_1, however with a certain delay. The size of delay is conditioned, mainly, by the fast-acting of control mechanism (as at every step of control time is needed on processing of data, that come to the BFK, and on work of executive mechanisms of EMB). Except that, the line of F passes some higher than line of I'_1. Distance on a height between these lines is stipulated by the accepted supply in relation to unexceeding of the distinguished bandwidth of port by a trend. On Figure 2 durations of work of control mechanism are determined distance between points A and B. In particular, on an interval between fifth and tenth seconds duration of work of control mechanism is determined by a time interval between the points of A_1 and B_1, on an interval between tenth and fifteenth seconds - time interval between the points of A_2 and B_2 et cetera. Thus will notice: in order to avoid an ambiguousness in the

Shows of UOB what passes the set values of bandwidths of ports to the BFK), the moments of beginning of work of control mechanism (points of A_1, A_2, A_3) are some displaced in relation to beginning of steps of line of I'_1.
Will consider work of control mechanism on the segment of growing trend. As see, there are time intervals in this case, when the line of F is subjacent, than line of I'_1. (On Figure 3 they are black-out). On these intervals intensity of the smoothed out stream of packages exceeds the size of bandwidth distinguished for port. Id est, as a result of underestimation of necessary bandwidth of port, done on the previous step of control process, there was a deficit of bandwidth on the current step of control, that resulted in a loss the determined amount of packages. Such the errors of adaptive control will name the errors of underestimation of bandwidth $D^{(-)}$. As a counterbalance to the errors $D^{(-)}$, will enter the index of errors of overvalue of bandwidth of port $D^{(+)}$, that contacts with the situation of surplus grant of bandwidth to certain port, when the distinguished bandwidth exceeds intensity of the smoothed out stream of packages.
As results of analysis of work of control mechanism on the segments of growing trend, next conclusions are done:

1) at any terms there can be only errors of underestimation of bandwidth $D^{(-)}$ on the segments of growing trend;
2) errors of overvalue of bandwidth $D^{(+)}$ on the segments of growing trend do not arise up under any circumstances;
3) index of errors $D^{(-)}$ increase proportionally to the increase of height and (or) width of step in a trend (id est, proportionally to the increase of jumps in a trend and (or) reduction to the fast-acting of control mechanism);
4) at terms, when the size of jumps in a trend less than distance between the lines of I'_1 and F, errors of control as $D^{(-)}$ or $D^{(+)}$ does not arise up in general.

Will consider work of control mechanism on the segment of handing down trend (see a lower chart on Figure 2). As see, there are not time intervals in this case, when the line of F is subjacent, than line of I'_1. It testifies to absence of errors as $D^{(-)}$. On any areas of handing down trend intensity of the smoothed out stream of packages does not exceed the bandwidth distinguished for port. However as a result of delay of moments of changes of bandwidth of port in relation to the changes of trend of the smoothed out stream of packages there are areas (on pic.2 they are black-out), where difference in levels between the lines of I'_1 and F is more than a supply is accepted in relation to unexceeding of the distinguished bandwidth of port by a trend. Thus, there are errors of overvalue of bandwidth $D^{(+)}$ on these areas, that negatively influence on the level of work-load of port.

On results the analysis of work of control mechanism on the segments of handing down trend, next conclusions are done:

1) at any terms there can be only errors of overvalue of bandwidth $D^{(+)}$ on the segments of handing down trend;
2) errors of underestimation of bandwidth $D^{(-)}$ on the segments of handing down trend do not arise up under any circumstances;
3) index of errors $D^{(+)}$ increase proportionally to the increase of height and (or) width of step in a trend (id est, proportionally to the increase of jumps in a trend and (or) reduction to the fast-acting of control mechanism);
4) at terms, when the size of jumps in a trend less than distance between the curves of I'_1 and F, errors of control as $D^{(-)}$ or $D^{(+)}$ does not arise up practically.

It follows to underline that errors of underestimation as $D^{(-)}$ in the mechanism of control is obviously undesirable, as they result in the losses of packages. In the same time by the errors of overvalue as $D^{(+)}$ it maybe to scorn at the decision of most operating tasks, as they only unimportant worsen the level of work-load of port. Unfortunately, both types of errors carry system character, that it is related to the inertance to the process of control. These errors it is impossible fully to remove. However them it maybe to decrease and, even, convert one type of errors into other. In the context of adaptive control interest presents possibility of transformation of errors as $D^{(-)}$ in errors as $D^{(+)}$. Such possibility arises up, if in the contour of control system by the redistribution of bandwidths of ports of SD to include the mechanism of prognostication of trend.

7. An Analysis of Errors of Adaptive Control is in the Conditions of the use of Prognostical Mechanism

A size of errors (both $D^{(-)}$ and $D^{(+)}$) is proportional to the areas of black-out rectangles that is represented on Figure 2. Clear:, to decrease errors of control, it is necessary to accomplish actions that result in reduction of areas of these rectangles. The heights of rectangles it maybe to decrease, if to increase the interval of averaging of primary traffic. However such action will result in the increase of delays of packages in the entrance turns of switchboard ports , that in many cases - extremely undesirable. Width of rectangles it maybe to decrease, if to increase the fast-acting of the automatic system of adjusting (so that distance, for example, between the points of A_1 and B_1 was less). However such it maybe to do only to the certain limits, as to this system inhere eventual inertance.

Another method of reduction of areas of black-out rectangles is offered by the use procedure of prognostication at every step of control process. Must be get prognosis of the nearest future point of trend, where this trend must saltatory change. In practice it is important to decrease the errors of underestimation of bandwidth $D^{(-)}$, that, as specified already, can arise up only on the segments of growing trend. Therefore for explanations of effect of reduction of errors of underestimation due to the use of prognostical mechanism will consider the segment of growing trend that consists of three steps (see Figure 3).

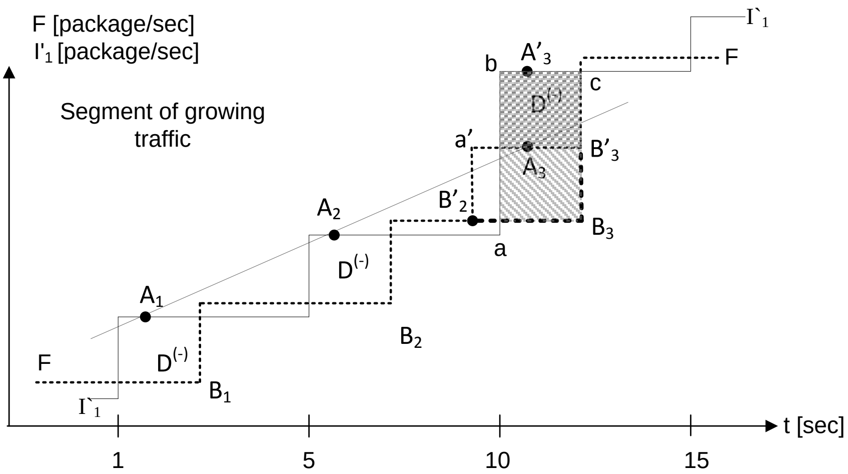


Figure 3. An effect of reduction of errors of underestimation of bandwidth of port is as a result of the use of prognostical mechanism

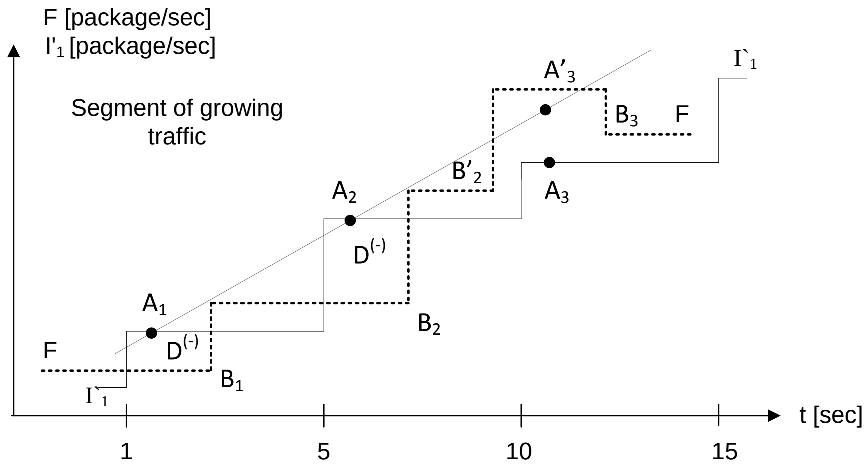
By the points of A_1, A_2, A_3 mark the moments of beginning of steps of control process. In these moments from UOB on BFK value of bandwidths of ports set on a previous step are passed. By the points of B_1, B_2, B_3 mark the moments of completion of steps of control process. In these moments the executive mechanisms of EMB end the process of increase or reduction bandwidths of switchboard ports. Black-out areas of three rectangles are on Figure 3 illustrate the sizes of errors of underestimation $D^{(-)}$ in relation to three current steps of control process. In particular, the size of error of underestimation on the third control step at the terms of absence of prognostication is determined by an area rectangle of aʙᴄB_3.

Will show, how prognostication can decrease the error of underestimation on the third step of control. For this purpose will use the simplest mechanism of linear prognosis, id est on the basis of data in relation to two points of trend of A_1 and A_2 will define the prognosis estimation of height of the third step, that will designate as A'_3. Knowing the coordinates of two points, it is undifficult to build a line that passes through these points. Clear that a prognosis point of A'_3 must be on this line. Knowing a prognosis point yet then that, when the next jump of trend will take place, it maybe to modify a control algorithm thus, that immediately in front of this jump (on Figure 3 - in the point of B'_2) to change the bandwidth of port to the size of A'_3. Then the size of error of underestimation on the third control step will be determined by an area rectangle of a'ʙᴄB'_3. As see, the area of this rectangle less than than area of rectangle of aʙᴄB_3 subject to condition, if an error of prognosis will be not to exceed the height of step of trend.

Thus, improvement of control mechanism in direction of reduction of errors as $D^{(-)}$ consists in that at every step of prognostication on the basis of a few last points of trend of stream of packages is determined the nearest future point of this trend. This point is perceived by the adjusting system as a value of bandwidth of port that must be set immediately in front of the nearest future jump of trend. The less error of prognosis the less error of underestimation of port bandwidth.

If to apply the above-mentioned mechanism to the handing down areas of trend, then it maybe to ascertain, that on occasion have worsening, but errors of overvalue $D^{(+)}$ in practice most cases do not have substantial. If it not so, then the mechanism of prognostication it follows to disconnect on the handing down areas of trend.

The attractive feature of the use of prognostication on the growing segments of traffic is existence of effect of transformation of errors of underestimation $D^{(-)}$ in errors of overvalues $D^{(+)}$, that, as specified already, usually does not have a substantial value. Possibly, that a prognosis value of height of the third step is on Figure 3 it appeared more than A_3. Then line A'_3 B'_3 passed higher the lines of bc, that would mean disappearance of error of underestimation and appearance of error of overvalue. This situation is represented on Figure 4.



Pic.4. Effect of transformation of error as $D^{(-)}$ in the error of type $D^{(+)}$

Conclusions

1) Work of the system of adaptive redistribution of carrying capacity of switchboard between its ports is accompanied by the origin of system errors of control process that leads, in one cases, to the increase to the level of losses of packages, and in other, to the decline to the load of switchboard by an useful traffic.

2) At the decision of most operating tasks more important is a task of reduction of system errors of control process that is related to the losses of packages. This task

it is suggested to decide by introduction to the contour of adaptive control the mechanism of prognostication of trend of package traffic.
3) The mechanism of prognostication allows to decrease, and at certain terms and to remove errors that result in the losses of packages.

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