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# THE METHOD OF STABILITY PROVIDING IN CONTROL SYSTEMS FOR DELAY AND DISRUPTION-TOLERANT CORPORATE COMPUTER NETWORKS

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*The problem of control stability obtaining in corporate computer networks is considered. The method of stabilization of control systems with data delays of and control signals based on compulsory inserting poles of system function into unit circumference of z-plane is developed. New structure of etalon model for control system comprising of series linear compensating loops of first order is created.*

*Розглянуто задачу забезпечення стійкості управління корпоративними комп'ютерними мережами. Розроблено метод стабілізації системи управління за наявності затримок в даних про сигнали управління, що базується на примусовому введенні полюсів системної функції всередину кола z-площини. Створено нову структуру еталонної моделі, що складається з послідовно сполучених лінійних компенсаційних ланок першого порядку.*

*Рассмотрена задача обеспечения устойчивости управления корпоративными компьютерными сетями. Разработан метод стабилизации системы управления при наличии задержек данных о сигналах управления, базирующийся на принудительном вводе полюсов системной функции внутрь окружности z-плоскости. Создана новая структура эталонной модели, состоящая из последовательно соединенных линейных компенсационных звеньев первого порядка.*

## Statement of purpose

First of all let's give some important terms and definitions. It is common knowledge [1] that corporate network are one of the most popular information and calculating systems for using in large institutions, enterprises, educational organizations etc. As usual, corporate computer network consists of some autonomous segments with connection through high-speed communication lines. The main goal of network operating is observing of guaranteed set of services with conditioned quality (so called quality of service – QoS).

The main problem of network control is maintaining of network in needed organizational and technical state.

So we differentiate the partial problem of network management as implementation of procedures of observing QoS and another partial problem of technical control for providing needed efficiency and technical and exploitation parameters.



Network management is the dissolving of such organization problems:

– regulation of data exchange between neighboring and remote networks;

– prevention of congestions;

– billing and interaction with another network operators/providers;

– security and protection from unauthorized intrusions, providing of data integrity;

– inspection of resources and so on.

This is process with discrete running of some actions for providing of efficient functioning of network.

We may represent this process as finite set of stable states of managed object.

Technical control is continuous process of analysis, prognosis of parameters and state of network units, devices and elements, detection and localization of breaks and malfunctions, specifically such as:

– routing and switching;
– traffic policing and shaping;
– control data flows;
– control parameters of internal and border network gates, transit nodes;
– regulation of activity of network and terminal nodes et al.

Actually we consider the processes of technical control (further – control) as continuous and randomized.

Variations of parameters of controlled equipment are considered as continuous random values as well.

The diagram of control actions for management and control is shown on fig. 1.

This paper is dedicated to providing of stability of control autonomous network segment by means of analysis of parameters and state and prognosis with application of etalon model.

The problem of network control is dissolved under the conditions of incomplete a priori information, and current data about parameters and state of network come to control system with random delay.

There are some papers and documents described so-called delay-tolerant network architecture [2], which includes a hop-by-hop transfer of reliable delivery responsibility and optional end-to-end acknowledgement. It also includes a number of diagnostic and management features.

But the problems of stable and efficient control parameters and state of network as autonomous system do not research. We develop the adaptive control method with application of etalon model of network autonomous segment (AS) as object of control.

This method allows obtaining stable control with desired quality of transient processes under conditions of unknown random delay of information and control data.

### The model of informational and control structure of the network

As we mentioned above, only technical part of control process without human intervention is considered unlike paper [3].

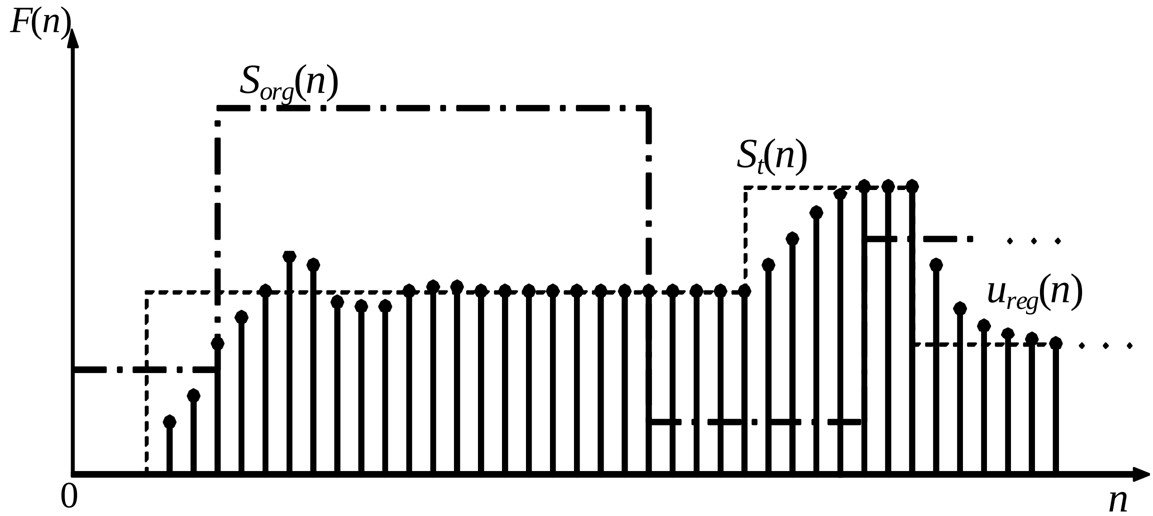


Fig.1. Processes of variation of organizational and technical states of network as control object:
$F(n)$ – functions of state and regulation;
$S_{org}(n)$ – state of management operator;
$S_t(n)$ – state of technical component;
$u_{reg}(n)$ – regulating signal

Information structure of AS under control with etalon model is represented on fig. 2.

This is shown in [3] that the delays of receiving of information about state and parameters of network take place while control process flows. The delays of control data delivery to object of control arise too. Control system is described by discretized differential equation with divergent argument. It's possible to approximate this equation by difference equation of such kind [3]:

$$y_{as}(n) \simeq y_{as}(n-1) + by_{as}(n-k) + u(n-m), \quad (1)$$

where $y_{as}(n)$ is function of object state;

$k$ and $m$ are the delays of state and control signals respectively;

$u(n-m)$ is control signal.

In general case $n \neq m$.

System function of object described by equation (1) is of such kind:

$$H(z) = \frac{z^{-m}}{1 - z^{-1} - bz^{-k}}. \quad (2)$$

Characteristic polynomial of (2) has just specific mode:

$$z^k - z^{k-1} - b = 0. \quad (3)$$

Asymptotic estimates of stability of the systems with characteristic polynomial (3) and domains of stability are calculated in [3]. There was shown that it's necessary to reduce absolute value of feedback coefficient in control loop while increasing of delay of control signals for support of stability of control system.

However, the problem of finding of dependence between feedback coefficient and delay hasn't single valued decision in closed form. Besides, the uncontrolled deviations of dynamic characteristics and deterioration of quality of control have place.

The method of compulsory return of system in stability domain is developed for overcoming of these demerits.

**Developing of the method of support of control system stability**

The roots of the polynomial (3) are the poles of system function (2) on *z*-plane. They have to be in unit circumference of *z*-plane for stability support. So we must permanently inspect position of poles while data delay and/or feedback coefficients vary.

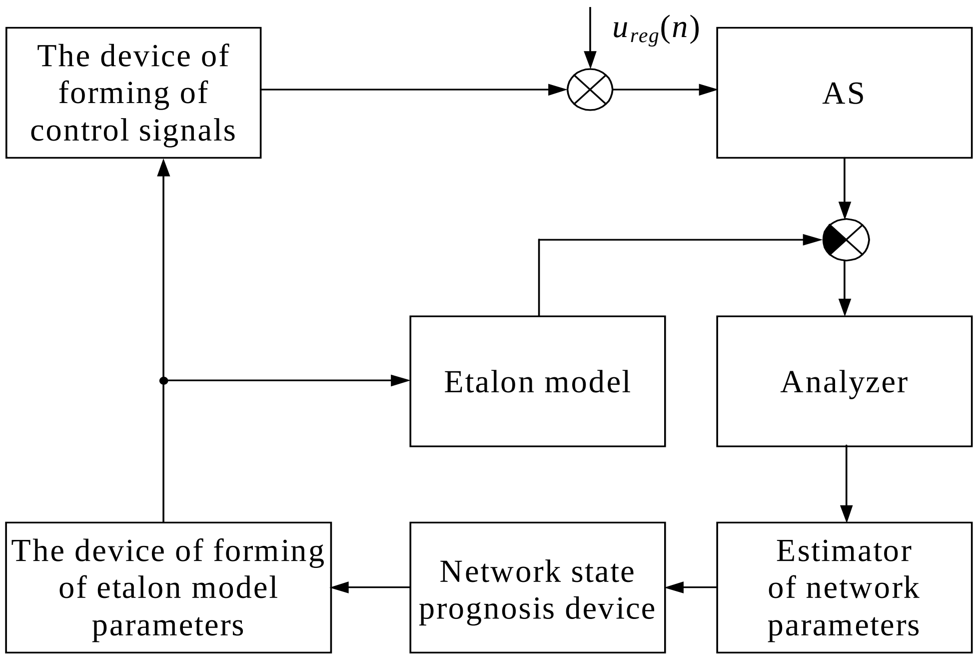


Fig. 2. Information structure of AS adaptive control system with etalon model

The upper estimate of polynomial roots may be obtained on the basic of lemma about module of senior (polynomial) member [4]:

$$r_{\max} \le 1 + \frac{B}{|b_0|}, \qquad (4)$$

where $B$ is maximal module of all coefficients near another members of polynomial;

$b_0$ is coefficient near senior member (in our case coefficient near $z^k$ $b_0 = 1$).

If $|b| < 1$ in considered polynomial (3), then $B = 1$ as the module of coefficient near member $z^{k-1}$. Therefore $r_{\max} \le 2$.

However, estimate (4) is too rough for our problem of stability support. Such upper estimate doesn't give practical way for choice stable roots and obtaining necessary quality of control. So we have to use more precise methods of roots estimation.

Now it's fait accompli general computerization of network equipment. So we may recommend direct calculation of roots by the method of Newton or Lobachevsky. Last method does not need preliminary separation of roots, it gives the estimates of all roots with good accuracy, and the need of cumbersome calculations is not large difficulty for modern specialized processors.

In assumption that problem technically is not critical we give the answer on principal question of choice of sites of new polynomial roots inside unit circumference of *z*-plane.

Let's consider illustrative example of difference equation

$$y(n) = b_1 y(n-1) + b_2 y(n-2) + u(n)$$

with coefficients

$$b_{11} = -0,2, \ b_{12} = -0,8$$

or $b_{21} = -0,2, \ b_{22} = -1,25$.

We make accent that coefficient $b_{22}$ in second set is equal $1/b_{12}$.

System function

$$H(z) = \frac{1}{1 - b_1 z^{-1} - b_2 z^{-2}}.$$

The roots of characteristic polynomial are:

– for first set

$$r_{1,2} \simeq 0,1 \pm j0,89;$$

module $r_{\text{mod}} = 0,8$;

– for second set

$$r_{1,2} \simeq 0,1 \pm j1,12;$$

module $r_{\text{mod}} = 1,25$.

In other words, poles of system function lies inside unit circumference of *z*-plane in first case and they lies outside unit circumference of *z*-plane in second case (fig. 3).

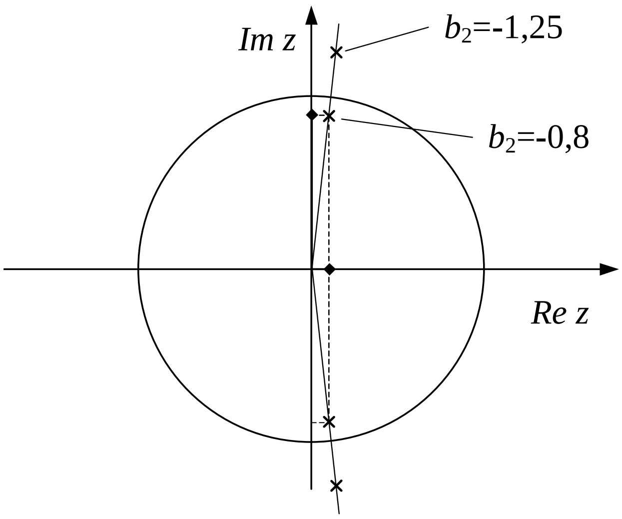


Fig. 3. Configuration of poles

Amplitude-frequency response of this system is

$$H(\omega_n) = \frac{1}{\sqrt{(1 - b_1\cos\omega_n - b_2\cos 2\omega_n)^2 + (b_1\sin\omega_n + b_2\sin 2\omega_n)^2}}$$

where $\omega_n = \omega T_d$ is normalized angle frequency;

$T_d$ is discretization period.

The fig. 4 shows amplitude-frequency responses and pulse responses for both sets of coefficients.

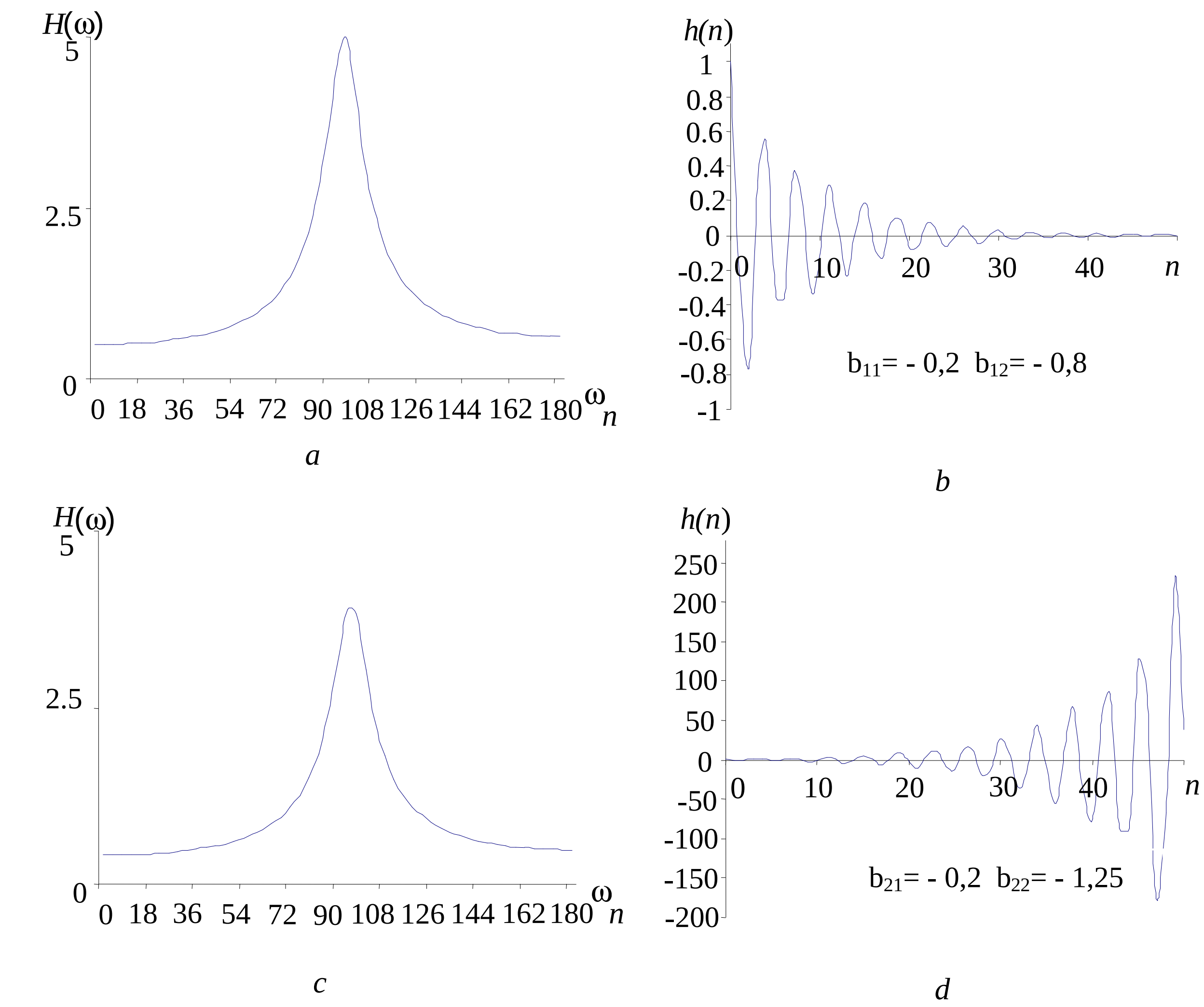


Fig. 4. Amplitude-frequency responses and pulse responses:
*a*, *b* – system stable;
*c*, *d* – system unstable

Pay attention to identity of amplitude-frequency responses both stable, and unstable systems where implied identity of dynamic parameters of considered systems. In other words, parameters of transient processes in both systems are equal, i.e. stable system converges with the same speed as unstable one diverges.

Using this property of digital dynamic systems we can realize compulsory mirror reflection of outside poles inside unit circumference of *z*-plane. Calculating algorithm is the next.

1. Determine the range of equation.
2. Determine feedback coefficient.
3. Calculate equation roots $r_i$, $i=\overline{1,k}$.
4. Find roots modules.
5. If module $r_{\mathrm{mod}}>1$, find reflected root $r_f$:

– for real root

$r_{fi}=1/r_i$;

– for complex root

$r_i=a_i\pm jd_i$

formula for

$$r_{fi}=\frac{a_i}{a_i^2+d_i^2}\pm j\frac{d_i}{a_i^2+d_i^2}.$$

6. If module $r_{\mathrm{mod}}=1$, decrease $r_{fi}=1-\varepsilon$, $\varepsilon\approx 1$.
7. Calculate coefficients of new polynomial with reflected poles inside unit circumference of *z*-plane.

8. Construct new etalon model for stable control system.

Equation (1) for stabilized system takes on form

$$y_{as}(n) \simeq b_{k-1} y_{as}(n-1) + b_{k-2} y_{as}(n-2) + \ldots + \\ + b_1 y(n-k+1) + b_0 y(n-k) + u(n-m),$$

characteristic polynomial after mirroring of unstable roots into unit circumference of $z$-plane and system function, respectively,

$$z^k + b_{k-1} z^{k-1} + b_{k-2} z^{k-2} + \ldots + b_1 z + b_0 = 0,$$

$$H_{st}(z) = \frac{z^{-m}}{1 + b_{k-1} z^{-1} + b_{k-2} z^{-2} + \ldots + b_1 z^{-k+1} + b_0 z^{-k}}.$$

The values $y(n-2), y(n-3), \ldots, y(n-k+1)$ by definition are unknown, so they are specified according to etalon model, which describes desired behavior of object of control:

$$y(n-l) \simeq b_{n-l+1} y(n-l+1), \quad l = 2, 3, \ldots k-2. \quad (5)$$

Such representation of etalon model actually is similarly to transition to its implicit equivalent [5], comprising of series dynamic first order loops.

The desensitization of model conditioned by simplified representation (5) allows reducing control system sensibility to non-stationarity of object of control and variation of parameters of transmitting processes of control data.

It's even possible obtaining robust control for wide class of non-stationarities, which is especially important for such specific objects with distributed parameters as corporate networks.

In conclusion cite an example of control system with data delay $k = 5$ periods and feedback coefficient $b = 0,4$. Characteristic polynomial is

$$z^5 - z^4 - 0,4 = 0,$$

the set of roots are

$$r_{1,2} = 0,4371 \pm j0,6918;$$

$$r_{3,4} = -0,5349 \pm j0,4619,$$

$$r_5 = 1,1957.$$

Unstable root $r_5$ is real. Reflected root

$$r_{5f} = 0,8363,$$

coefficients of stable characteristic polynomial are

$$b_4 = -0,9406;$$

$$b_3 = 0,0703;$$

$$b_2 = 0,0841;$$

$$b_1 = 0,1005;$$

$$b_0 = -0,2798.$$

Original system pulse response is shown on fig. 5, stabilized system pulse response is shown on fig. 6.

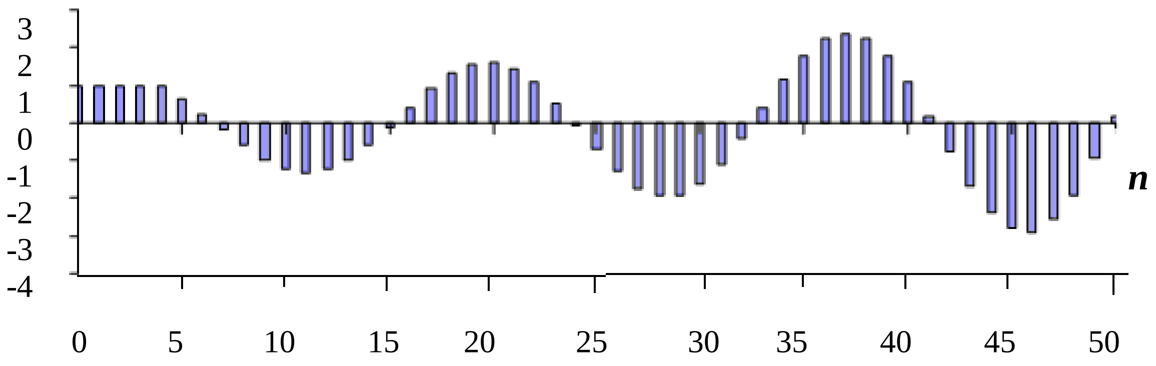


Fig. 5. Pulse response of original unstable control system

Fig. 6. Pulse response of stabilized control system

Thus we can stabilize systems of control of distributed objects with delays in delivery control data and information about object parameters and state. Herewith the quality of control is regulated independently, what is especially important for autonomous segments of corporate computer networks.

## Conclusion

The method of computer networks stable control with random delays of signal and control data is developed. Especially important is implementation of etalon model for analysis and prognosis of delayed data. The method of forming of implicit etalon model equations is proposed. This method is represented rather efficient despite its simplicity.

It's reasonably to continue researches and developments in this area. Influence of estimation and prediction errors on control stability and efficiency is the subject of special interest with organization and exploitation of computer networks.

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