ISSN 1392 – 1215 **ELECTRONICS AND ELECTRICAL ENGINEERING** / **ELEKTRONIKA IR ELEKTROTECHNIKA** 2010. No. 9(105)

T 180 TELECOMMUNICATIONS ENGINEERING / TELEKOMUNIKACIJŲ INŽINERIJA

Performance Analysis of Telecommunication System with Feedforward Control Mechanism

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Introduction

The goal of this paper is to analyze processes in an Internet node queueing system with local feedforward control. The proposed analysis method based on Moore and Mealy automata is much simpler and universal than Markov processes applied previously by authors to the analysis of such queueing systems [1, 2, 3]. Feedback and feedforward control is typically used in the telecommunication systems which have time varying transmission parameters. A rich literature exists in the area of data packets transmission process control systems. The majority of them analyze the feedback or feedforward control mechanism to regulate variable data packets transmission parameters, to avoid congestion and overdone delay, and to achieve high data transmission link utilization. The new type of the control system over the Internet allows remote monitoring and control of process plants using for control systems feedback and feedforward actions [8]. The feedforward and backward multirate control mechanism for IP transport network is applied to avoid data link congestion and data packet losses [11]. Two stages bit rate control mechanism must achieve that the originating part sends data at the maximum possible rate to the link [11]. Control algorithms to dynamically adjust bit rate of sender are design to guarantee stable performance measures of data transmission network based on continuous or discrete time feedback [9]. A two-level hierarchy is used for the Internet based control systems with two compensators located at the feedback channel that results the multirate control scheme efficiently reduce the effect of Internet time delay [7, 8]. One possible way to solve problem of network congestion and guarantee the quality of service is to use the feedback control mechanism to adapt the sender output bit rate depending on the transmission link state [6, 10]. Implementation of Moore and Mealy automata in of one channel queueing system simulation allows investigation of processes in a complex system such as telecommunication network [5].

The main goal of the paper is to develop an efficient feedforward control method in data transmission network. This type of control is best deployed in control systems design applications where behavior of the controlled variable is well understood and can be measured at the sender site.

The paper is organized as follows. First section introduces some new approaches to feedback and feedforward mechanisms. Internet adaptive sender bit rate control system architecture is presented in second section. The simulation model based on Moore and Mealy automata are described in third. The simulation results are presented and discussed in fourth section. In last section, we present our conclusions.

Internet node architectures with multirate control mechanisms

The IP based network feedback control scheme that uses a feedback channel to relay measurements, taken at the receiver shown on Fig.1. The feedback channel of Internet often is not suitable for real time data transmission, because cannot guarantee availability and stability of end-to-end delay. We propose the feedforward control mechanism without these disadvantages.

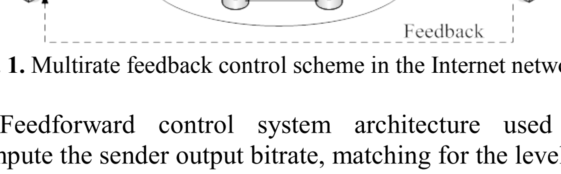

Fig. 1. Multirate feedback control scheme in the Internet network

Feedforward control system architecture used to compute the sender output bitrate, matching for the level of buffer occupancy, is shown in Fig. 2. The buffer occupancy level (threshold) depends on sender output bitrate and Internet link transmission bitrate. In our case, adaptive controlled sender output bitrate depends on buffer threshold. We have fixed three buffer occupancy threshold levels and according to them adaptively changed the sender output bitrate. Such local feedforward control mechanism is rather safe and guarantees the reliable data packet transmission process via Internet.

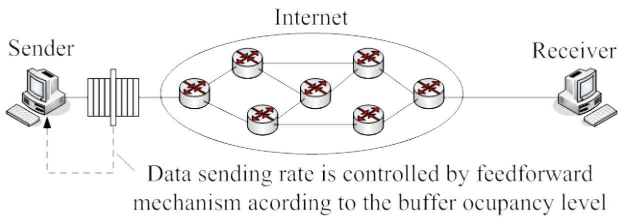

Fig. 2. Multirate feedforward control scheme in the Internet network

Simulation model of Internet network node with local feedforward control mechanism using the convolution of Moore and Mealy automata

The Internet network consists of many interconnected nodes. The data transfer rates in nodes varies depending on their load, failures and traffic variation. The originating network stations must select the data transfer rate and send the lost packets repeatedly. So, in practice, TCP algorithms [4] that receive the needed data by feedback control mechanism from terminating station are used.

To avoid considerable data packet loses in network and to guarantee effective transmission link utilization we here propose imitation model which evaluates the possibility to control the data transfer rate based on buffer occupancy level of the originating side.

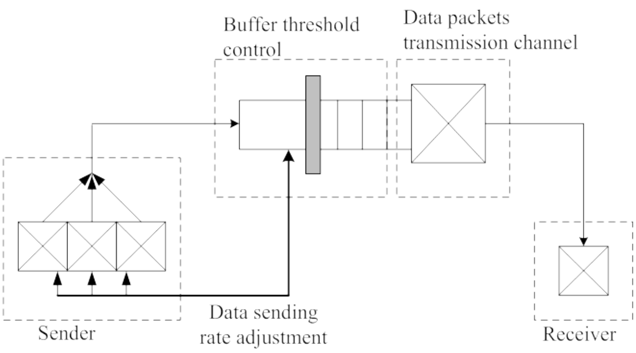

Fig. 3. Internet node data packets transmission bitrate feedforward control model based to the buffer threshold

Combination of Moore and Mealy automata [5] has been used in creation of system feedforward control model (Fig. 3).

The combination of Moore and Mealy automata (Fig.v4) will be called the convolution of them. The following surjections define the work of this convolution:

$$\begin{cases} g_r: \quad Y \times W \to W, \quad f_r: \quad W \to X, \\ f_l: \quad X \times Z \to Y, \quad g_l: \quad X \times Z \to Z. \end{cases} \tag{1}$$

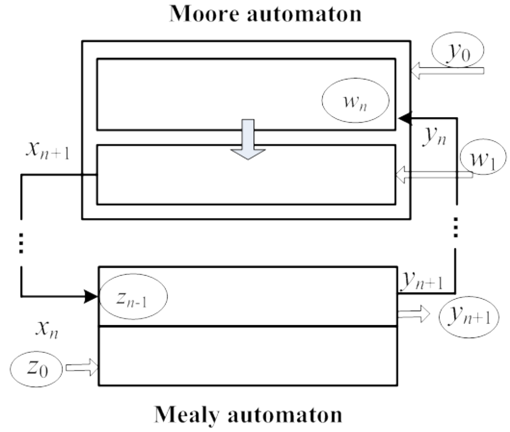

Fig. 4. The convolution of Moore and Mealy automata

The implementation of the convolution of the automata is presented in Fig. 5.

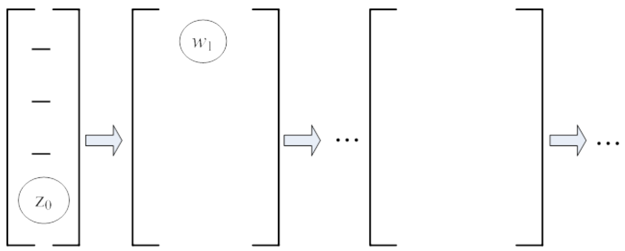

Fig.5. The implementation of the automata convolution

The convolution of the automata begins operating on entering the initial states w_1 and z_0.The virtual servicing system (Fig. 4) is created to imitate the processes in the investigated system (Fig. 3). It is different from the investigated system (Fig. 6), because it is closed and „0-th“ component – data sender with infinite number of packets, being in “0-th's“ buffer, has been placed in it and it generates the data packets for originating station. The “1st“component is for evaluating the data packets transmission over Internet. The Internet is described as data packets transmission system, consisting of finite capacity buffer and transmission channel. This system sends the data packets to data container (the receiver).

In the imitation model (Fig. 6) the data container is refused as the additional device, and the data are directed by feedback to the end of infinite queue in “0-th” component (therefore, they are not served repeatedly).

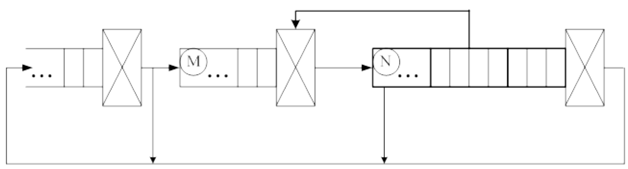

Fig. 6. The imitation model structure of the feedback control mechanism

Such task solution allows all processes to interpret like the convolution of the same three Moore and Mealy automata.

Assume that the “0-th” component (data source) contains some data, the „1st“ component (the sender) generates the data packets (with three data sending rate adjustment options: 1) to increase the rate, 2) keep the same rate, 3) to decrease the data sending rate) and the „2nd“ system component (the receiver) is used to service the packets. The infinite amount of packets wait in the “0-th” component, and the packets served in the „1st“ and „2nd“ components (data transmission channel and receiver) are returned to “0-th” component. If a packet arrives to the „1st“ component and finds it busy (because the capacity M of buffer is finite), it will be lost. In the „1st“ component the packets are served according data transmission rate and are transited to the „2nd“ component. If the buffer of the „2nd“ component is filled till buffer threshold R_1, then sender increases the data packet transmission rate. If the buffer of the „2nd“ component is filled between the thresholds R_1 and R_2, when the sender keeps the same data sending rate. If the buffer in the „2nd“ component approximates to overflow, and the packets are filled from the threshold R_2 to N (N – the amount of states in the buffer of the „2nd“ component), then this device sends a signal to „0-th“ component to decrease the data sending rate.

In the investigated system we have an infinite number of data packets all time. Thus, we create a close service system. It unifies the creation of surjections that describe the operation of such system.

$\left(\xi_n^{(0)}, n \in Z_0\right)$ – the interarrival times between packets of the sender output flow, $\left(\xi_n^{(1)}, n \in Z_0\right)$ – the data transmission rates, $\left(\eta_n, n \in Z_0\right)$ – the data servicing times in the „2nd“ channel, $\left(\overline{\eta}_n, n \in Z_0\right)$ – the controllable servicing times.

The standard variables $S_n^{(k)}, t_n$ are used for the creation of surjections [4]. The logical unitary Heaviside function is used for description of surjections

$$\mathbf{1}(t) = \begin{cases} 0, & t < 0, \\ 1, & t \geq 0. \end{cases} \tag{2}$$

In the bellow conditions meets the symbol Inf, it means $+\infty$.

We introduce the variables for surjections. Let’s suppose that $n \in N$. Then:

- t_n – „timer“ – ($t_0 = 0$, $0 < t_1 < t_2 < \ldots$) - it defines the time, when any event occurs

$$t_n = \min\left(S_n^{(0)}; S_n^{(1)}; S_n^{(2)}\right). \tag{3}$$

- $S_{n+1}^{(k)}, k = 0,1,2$ – the controlled variables, defining the time moment t_{n+1}, when the value t_n is known, $S_{n+1}^{(k)}$ can be equal:
  a) $S_n^{(k)}$ – $\left(0 < S_n^{(k)} < +\infty\right)$ shows that the „k-th“ component will finish to serve the packets;
  b) $t_n + \overline{\eta}_{l_i}$, $i = 1,2$ – the ordinary packet is served;
  c) Inf – the “k-th” component is free.

$$S_{n+1}^{(0)} = S_n^{(0)} + \xi_{l_0}^{(0)} \cdot \mathbf{1}\left(t_n - S_n^{(0)}\right), \tag{4}$$

$$\begin{aligned} S_{n+1}^{(1)} &= S_n^{(1)} \cdot \left(\left(1 - \mathbf{1}\left(t_n - S_n^{(1)}\right)\right) \cdot \left(1 - \mathbf{1}\left(S_n^{(1)} - Inf\right)\right) + \mathbf{1}\left(S_n^{(1)} - Inf\right) \cdot \mathbf{1}\left(-z_n^{(1)}\right)\right) + \\ &+ \left(t_n + \overline{\eta}_{l_1}\right) \cdot \left(\mathbf{1}\left(t_n - S_n^{(1)}\right) \cdot \mathbf{1}\left(z_n^{(1)} - 1\right) + \mathbf{1}\left(S_n^{(1)} - Inf\right) \cdot \mathbf{1}\left(z_n^{(1)} - 1\right)\right) + \\ &+ Inf \cdot \mathbf{1}\left(t_n - S_n^{(1)}\right) \cdot \mathbf{1}\left(-z_n^{(1)}\right), \end{aligned} \tag{5}$$

$$\begin{aligned} S_{n+1}^{(2)} &= S_n^{(2)} \cdot \left(\left(1 - \mathbf{1}\left(t_n - S_n^{(1)}\right)\right) \cdot \left(1 - \mathbf{1}\left(S_n^{(1)} - Inf\right)\right) + \mathbf{1}\left(S_n^{(2)} - Inf\right) \cdot \mathbf{1}\left(-z_n^{(2)}\right)\right) + \\ &+ \left(t_n + \xi_{l_2}^{(1)}\right) \cdot \left(\mathbf{1}\left(t_n - S_n^{(2)}\right) \cdot \mathbf{1}\left(z_n^{(2)} - 1\right) + \mathbf{1}\left(S_n^{(2)} - Inf\right) \cdot \mathbf{1}\left(z_n^{(2)} - 1\right)\right) + \\ &+ Inf \cdot \mathbf{1}\left(t_n - S_n^{(2)}\right) \cdot \mathbf{1}\left(-z_n^{(2)}\right), \end{aligned} \tag{6}$$

here $\pm\alpha + Inf = Inf$, $Inf - Inf = 0$, when $|\alpha| < +\infty$.

- $v_n^{(i)}, i = 1,2$ – the varieties of changes in i-th channel:

$$\begin{cases} v_n^{(1)} = \mathbf{1}\left(t_n - S_n^{(0)}\right) - \mathbf{1}\left(t_n - S_n^{(1)}\right), \\ v_n^{(2)} = \mathbf{1}\left(t_n - S_n^{(1)}\right) - \mathbf{1}\left(t_n - S_n^{(2)}\right). \end{cases} \tag{7}$$

- $z_n^{(i)}, i = 0,1,2$ – the number of packets in i-th buffer:

$$z_{n+1}^{(0)} = Inf, \tag{8}$$

$$z_{n+1}^{(1)} = z_n^{(1)} + \mathbf{1}\left(M - z_n^{(1)} - \mathbf{1}\left(t_n - S_n^{(0)}\right) + \mathbf{1}\left(t_n - S_n^{(1)}\right)\right) \cdot v_n^{(1)}, \tag{9}$$

$$z_{n+1}^{(2)} = z_n^{(2)} + \mathbf{1}\left(N - z_n^{(2)} - \mathbf{1}\left(t_n - S_n^{(1)}\right) + \mathbf{1}\left(t_n - S_n^{(2)}\right)\right) \cdot v_n^{(2)}. \tag{10}$$

- $l_i, i = 0,1,2$ - the numbers of packets:

$$l_0 = l_0 + \mathbf{1}\left(S_n^{(0)} - t_n\right), \tag{11}$$

$$l_1 = l_1 + \mathbf{1}\left(S_n^{(1)} - t_n\right), \tag{12}$$

$$l_2 = l_2 + \mathbf{1}\left(S_n^{(2)} - t_n\right). \tag{13}$$

The feedback is described by variable $\overline{\eta}_n$

$$\begin{aligned} \overline{\eta}_n = \eta_n \Big(& k_1 \cdot \mathbf{1}\left(R_1 - z_n^{(2)}\right) + \\ & + k_2 \cdot \mathbf{1}\left(z_n^{(2)} - R_1 - 1\right) \cdot \mathbf{1}\left(R_2 - z_n^{(2)}\right) + \\ & + k_3 \cdot \mathbf{1}\left(z_n^{(2)} - R_2 - 1\right)\Big). \end{aligned} \tag{14}$$

- $N > R_2 > R_1 > 0$, $R_1, R_2 = 1,2,\ldots,N-1$ – the critical values for regimes, $k_1, k_2, k_3 \geq 0$ – the increase (decrease) coefficients of transmission rate.

The surjections will be described using the recursion formulas in such order f_r, f_l, g_l, g_r.

$$f_r\left(w_n\right) = x_n, \; x_n = \left(t_n; v_n^{(1)}, v_n^{(2)}\right), \; x_n \in X, \tag{15}$$

$$f_l\left(x_n, z_{n-1}\right) = y_n, \tag{16}$$

$$y_n = \left(t_n; v_n^{(1)}, v_n^{(2)}; z_n^{(1)}, z_n^{(2)}\right), \; y_n \in Y, \tag{17}$$

$$g_l\left(x_n, z_{n-1}\right) = z_n, \; z_n = \left(z_n^{(1)}, z_n^{(2)}\right), \; z_n \in Z, \tag{18}$$

$$g_r\left(w_n, y_n\right) = w_{n+1}, \; w_n = \left(S_n^{(0)}, S_n^{(1)}, S_n^{(2)}\right), \; w_n \in W. \tag{19}$$

Let the initial states of automata system are:

$$l_0 = 0, l_1 = 0, l_2 = 0, \tag{20}$$

$$S_0^{(0)} = 0, S_0^{(1)} = Inf, S_0^{(2)} = Inf, \tag{21}$$

$$z_0^{(1)} = 0, z_0^{(2)} = 0, n = 0. \tag{22}$$

$$\left(\xi_1^{(0)}, Inf, Inf\right) = w_1. \tag{23}$$

All characteristics (for instance, the probability defining how long 1 packet (2 packets, 3 packets, etc.) is in the system, the mean queue size; the mean waiting time in the buffer, etc.) may be calculated from the implementation using values $(n, t_n, z_n), n = 0,1,2,...$, that are calculated by formulas from imitation model (3–23).

Simulation results

The proposed data sending rate control mechanism was modeled in the Mathcad's environment. Its algorithm is given by

$$X := \left| \begin{array}{l} l_0 \leftarrow 0;\quad l_1 \leftarrow 0;\quad l_2 \leftarrow 0;\quad n \leftarrow 0; \\ S_n^{(0)} \leftarrow 0;\quad S_n^{(1)} \leftarrow Inf;\quad S_n^{(2)} \leftarrow Inf; \\ z_n^{(1)} \leftarrow 0; \\ while \quad n \le n\_\max \\ \quad \left| \begin{array}{l} t_n \leftarrow \min(S_n^{(0)}, S_n^{(1)}, S_n^{(2)}); \\ l_0 \leftarrow l_0 + \mathbf{1}(S_n^{(0)} - t_n); \\ l_1 \leftarrow l_1 + \mathbf{1}(S_n^{(1)} - t_n); \\ l_2 \leftarrow l_2 + \mathbf{1}(S_n^{(2)} - t_n); \\ \eta_{l_1} \leftarrow \eta^* \cdot [k_1 \cdot \mathbf{1}(R_1 - z_n^{(2)}) + \\ + k_2 \cdot \mathbf{1}(z_n^{(2)} - R_1 - 1) \cdot \\ \cdot \mathbf{1}(R_2 - z_n^{(2)}) + k_3 \cdot \mathbf{1}(z_n^{(2)} - R_2 - 1)]; \\ \xi_{l_0}^{(0)} \leftarrow \eta_{l_1}; \\ z_{n+1}^{(1)} \leftarrow z_n^{(1)} + \mathbf{1}[M - z_n^{(1)} - \mathbf{1}(t_n - S_n^{(0)}) + \\ + \mathbf{1}(t_n - S_n^{(1)})] \cdot [\mathbf{1}(t_n - S_n^{(0)}) - \mathbf{1}(t_n - S_n^{(1)})]; \\ z_{n+1}^{(2)} \leftarrow z_n^{(2)} + \mathbf{1}[M - z_n^{(2)} - \mathbf{1}(t_n - S_n^{(1)}) + \\ + \mathbf{1}(t_n - S_n^{(2)})] \cdot [\mathbf{1}(t_n - S_n^{(1)}) - \mathbf{1}(t_n - S_n^{(2)})]; \\ S_{n+1}^{(0)} \leftarrow S_n^{(0)} + \xi_{l_0}^{(0)} \cdot \mathbf{1}(t_n - S_n^{(0)}); \\ S_{n+1}^{(1)} \leftarrow S_n^{(1)} \cdot [(1 - \mathbf{1}(t_n - S_n^{(1)})) \cdot \\ \cdot (1 - \mathbf{1}(S_n^{(1)} - Inf)) + \mathbf{1}(S_n^{(1)} - Inf) \cdot \\ \cdot \mathbf{1}(-z_n^{(1)})] + (t_n + \eta_{l_1}) \cdot [\mathbf{1}(t_n - S_n^{(1)}) \cdot \\ \cdot \mathbf{1}(z_n^{(1)} - 1) + \mathbf{1}(S_n^{(1)} - Inf) \cdot \mathbf{1}(z_n^{(1)} - 1)] + \\ + Inf \cdot \mathbf{1}(t_n - S_n^{(1)}) \cdot \mathbf{1}(-z_n^{(1)}); \\ S_{n+1}^{(2)} \leftarrow S_n^{(2)} \cdot [(1 - \mathbf{1}(t_n - S_n^{(2)})) \cdot \\ \cdot (1 - \mathbf{1}(S_n^{(2)} - Inf)) + \mathbf{1}(S_n^{(2)} - Inf) \cdot \\ \cdot \mathbf{1}(-z_n^{(2)})] + (t_n + \xi_{l_2}^{(1)}) \cdot [\mathbf{1}(t_n - S_n^{(2)}) \cdot \\ \cdot \mathbf{1}(z_n^{(2)} - 1) + \mathbf{1}(S_n^{(2)} - Inf) \cdot \mathbf{1}(z_n^{(2)} - 1)] + \\ + Inf \cdot \mathbf{1}(t_n - S_n^{(2)}) \cdot \mathbf{1}(-z_n^{(2)}); \\ n \leftarrow n + 1; \end{array} \right. \\ \text{Rez.:}\quad \{t\}, \{\eta\}, \{\xi^{(0)}\}, \{z^{(1)}\}, \{z^{(2)}\}. \end{array} \right. \tag{24}$$

The data sending rate is selected by multiplying the particular value of η^* by k_1, k_2 or k_3 coefficients, which are selected by the buffer occupancy level $z_n^{(2)}$ according to the buffer thresholds R_1 and R_2.

Two cases of data sending rate control were modeled:

1) The value η^* is constant (for example, it is equal to the mean value of data transmission channel rate).The simulation results are shown in Fig. 7 and Fig. 9;

2) The value η^* is equal to the $\eta_{l_1 - 1}$ (the previous data sending rate is used to select the current data sending rate) The simulation results are shown in Fig. 8, Fig. 10 and Fig. 11.

To evaluate how the feedforward mechanism selects the data sending rate when the data transmission rate in the channel changes, we used the following data channel rate model

$$R(t) := \left| \begin{array}{lll} 256kbps, & if & t < t_1, \\ 512kbps, & if & t_1 \le t < t_2, \\ 256kbps, & if & t_2 \le t < t_3, \\ 512kbps, & if & t_3 \le t < t_4, \\ 256kbps, & if & t_4 \le t. \end{array} \right. \tag{25}$$

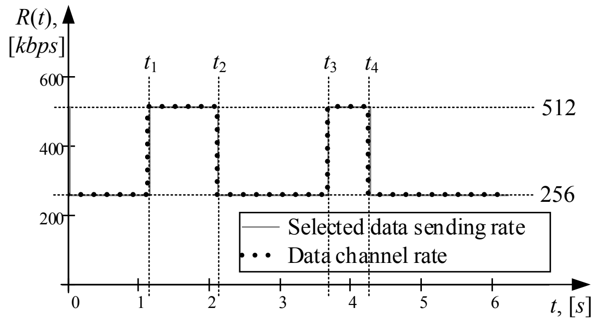

Fig. 7. The simulation results in the first case of feedforward control mechanism (when η^*=1/512kbps, R_1=5, R_2=10, N=15, M=10, k_1=0.5, k_2=1, k_3=2)

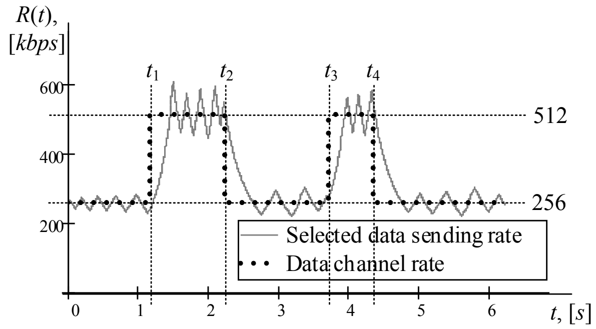

Fig. 8. The simulation results in the second case of feedforward control mechanism (when R_1=1, R_2=2, N=3, M=10, k_1=0.99, k_2=1, k_3=1.01)

It is obvious, that the closer the selected data sending rate to the data transmission rate of the channel – the better efficiency of the channel's throughput utilization.

In the first case the efficiency was achieved much better (the selected data sending rate matches for the data channel bitrate), because the channel transmission rate changes only to in the fixed 256 kbps and 512 kbps boundaries, which are ideal for the selected η^*, k_1, k_2 and k_3 values.

The Fig. 9 shows what happens when the 1st case scenario is used, but the selected value η^*=1/384 kbps with the coefficients k_1, k_2 and k_3 doesn't match the values 256 kbps and 512 kbps.

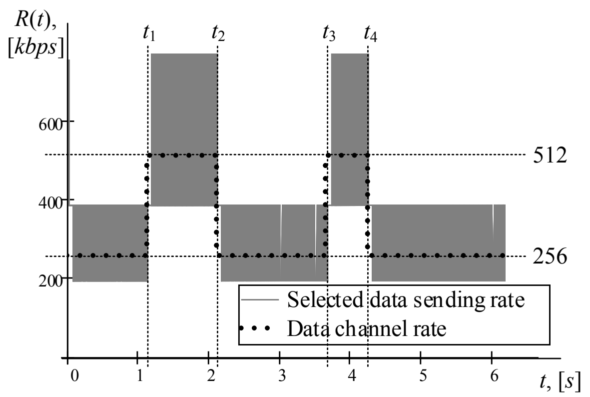

Fig. 9. The simulation results in the first case of feedback control mechanism (η^*=1/384 kbps, R_1=5, R_2=10, N=15, M=10, k_1=0.5, k_2=1, k_3=2)

Therefore, in a general case, the adaptive (second) data sending rate control mechanism may prove better.

It is illustrated in the Fig. 10 and Fig. 11 how the selected data sending rate depends on the different values of k_1, k_2, k_3, R_1, R_2 and N.

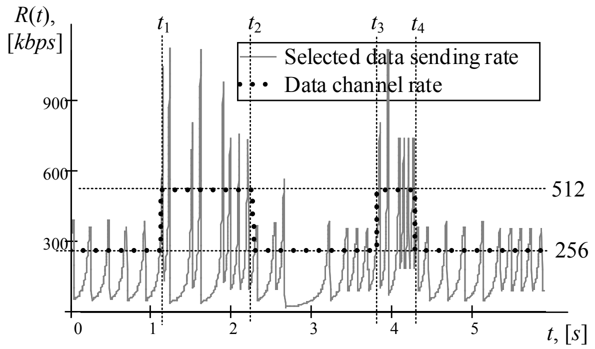

Fig. 10. The simulation results in the second case of feedback control mechanism (R_1=2, R_2=4, N=6, M=10, k_1=0.95, k_2=1, k_3=2)

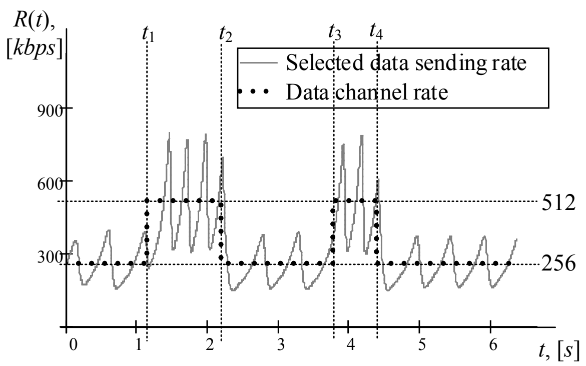

Fig. 11. The simulation results in the second case of feedback control mechanism (R_1=4, R_2=6, N=8, M=10, k_1=0.99, k_2=1, k_3=1.05)

As can be seen the selection method of optimal data sending rate control values could be chosen as the task for future works, because inappropriate selection of the values decreases the data channel rate usage efficiency significantly.

Conclusion and future work

In this paper, we have made an attempt to explore control theory in designing feedforward adaptive sender output bitrate local control mechanism based on output buffer occupancy level. We argued that the proposed bitrate control mechanism is applicable to Internet technologies - the realization is simpler, data packet transmission is safer in comparison with the classical feedback output bitrate control scheme. We derive local control algorithm too dynamically or determine adjust output bitrate of sender. The system simulation model is implemented using the convolution of Moore and Mealy automata.

The output buffer threshold feedforward control mechanism may be used in the practical real-time data transmission systems to ensure the non-critical packet transmission delay and to optimize the data transmission channel bandwidth usage.

The key component of the proposed feedforward sender output bit rate control mechanism is the way to compute the sender transmission bit rate matching with level of output buffer occupancy.

The focus of our future work is to investigate the two levels feedforward/feedbackward output bit rate control mechanism for multirate control scheme which efficiently reduces the effect of Internet network variable delay for data packets transmission performance measures.

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Received 2010 04 17

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The proposed feedforward adaptive bitrate control method has advantages over feedback control scheme. Advantages of the method were demonstrated by means of simulation. Delayed feedback signal from long paths in IP network causes excessive queue growth and data packet loss. Adaptive local feedforward sender output bit rate control mechanism removes IP network delay impact to data packets transmission performance measures. The key component of the proposed feedforward sender output bit rate control mechanism is the way to compute the sender transmission bit rate matching with level of output buffer occupancy. Investigated bit rate control mechanism is based on generating feedback signal when the queue length in the output buffer exceeds the defined occupancy thresholds. The bit rate controller works according to a feedback signal, adaptively reducing or increasing sender output bit rate and keeps the system within an acceptable range of performance avoiding transmission link of congestion. Simulation model of proposed feedforward bit rate control mechanism based on Moore and Mealy automata is simple and universe. We carried out simulations to verify our proposed feedforward bit rate control mechanism and evaluate an effectiveness of our solution. Ill. 11, bibl. 11 (in English; abstracts in English and Lithuanian).

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Pasiūlytas tiesioginis adaptyvus duomenų perdavimo spartos valdymo metodas turi pranašumų, palyginti su grįžtamojo ryšio valdymo schema. Šie pranašumai atsispindi modeliavimo rezultatuose. Dėl grįžtamojo ryšio signalo vėlinimo ilgose interneto tinklo linijose atsiranda nemažų perdavimo buferiuose svyravimų ir duomenų paketų nuostolių. Adaptyvus vietinis tiesioginis duomenų perdavimo spartos valdymo mechanizmas pašalina IP tinklo vėlinimo įtaką duomenų paketų perdavimo kokybės rodikliams. Pagrindinė pasiūlyto adaptyvaus vietinio tiesioginio duomenų perdavimo spartos valdymo mechanizmo idėja yra duomenų perdavimo spartos parinkimas atsižvelgiant į duomenų perdavimo buferio užpildymo lygį. Tiriamojo siųstuvo duomenų perdavimo spartos valdymo mechanizmo veikimas pagrįstas grįžtamuoju signalu, gaunamu iš duomenų siuntimo buferio, ir jo reikšmė priklauso nuo buferio užpildymo slenksčių. Duomenų paketų perdavimo spartos reguliatorius didina arba mažina bitų perdavimo spartą priklausomai nuo grįžtamojo signalo reikšmės ir kartu palaiko pageidautiną duomenų paketų perdavimo tinklu kokybę ir išvengia perdavimo grandies perkrovos. Imitacinis mechanizmo modelis remiasi Muro ir Milio automatais ir yra universalus ir palyginti paprastas. Modeliavimo metu gauti rezultatai patvirtino mūsų priimtų sprendimų efektyvumą. Il. 11, bibl. 11 (anglų kalba; santraukos anglų ir lietuvių k.).