

## Bursty Traffic Simulation by ON - OFF Model

A. Žvironienė, Z. Navickas

Department of Applied Mathematics, Kaunas University of Technology,  
Studentu str. 50, LT-51368 Kaunas, Lithuania, e-mail: Ausra.Zvironiene@ktu.lt

R. Rindzevičius

Department of Telecommunications, Kaunas University of Technology,  
Studentu str. 50, LT-51368 Kaunas, Lithuania; e-mail: Ramutis.Rindzevicius@ktu.lt

### Introduction

The transmission of the voice signals makes a big part of the bandwidth of modern telecommunication systems. Therefore there is searched for the ways to reduce an amount of data needed for voice transmission. It has been ascertained that during the speech the short intervals of speech and silence are repeating alternately. The silence periods present about 60-65% of all speech time [1]. When not transmitting the voice data on silence periods, the part of bandwidth of communication channel is freed. This part of bandwidth can be used for transmission of another data. Improving the existing and creating the new telecommunication systems, it is important to have an exact model of data flow made by voice. Though first research results of the voice active – passive intervals are published in 1965, the investigations of voice signals have been going on. One of the reasons is that the created models are quite different from each other and depending on the usage fields the received results are interpreted differently.

Bursty traffic models are an essential component of performance analyses of telecommunication networks. Good models should be simple, accurate and applicable in both mathematical analysis and computer simulations. There are references [4, 5] that have classified and modeled bursty traffic in a wide variety of situations. Simulations have been used to demonstrate the validity of an analytic bursty traffic models. Internet traffic is very bursty, or equivalently, the ratio of the peak to average data rate is quite high. To handle the bursty traffic the network must be sized to handle the peak load. Most networks today do not attempt to carry the absolute offered peak bursty traffic, but provide some degree of buffering to smooth these peaks out. For this work we assumed that bursty traffic is generated from one source with alternating series of “ON” and “OFF” periods. Both the ON and OFF periods were distributed by different (Poisson, Lognormal, Weibull and others) distributions.

The purpose of paper is to create the simulation model of bursty traffic using the method of automata convolution.

### Description of the model of bursty traffic

We will describe the conjunction of two servicing channels and one servicing channel (Fig. 1), that will generate the bursty traffic.

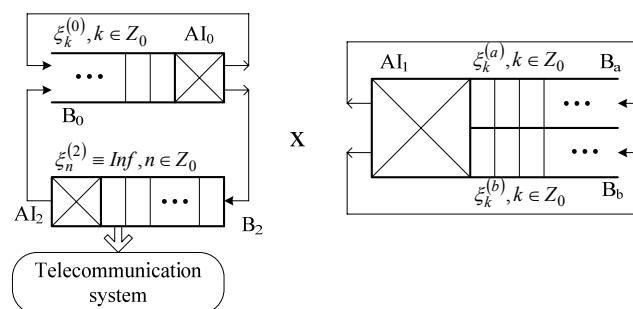


Fig. 1. The conjunction of automata for generation of bursty traffic

Channel  $AI_0$  will generate „the full traffic“  $\xi_n^{(0)}, n \in \mathbb{N}$ ,  $AI_1$  - active ( $\xi_n^{(a)}, n \in \mathbb{N}$ ) and passive ( $\xi_n^{(b)}, n \in \mathbb{N}$ ) windows. In  $AI_1$  channel from buffers  $B_a$  and  $B_b$  arrived packets are served alternately. The servicing time of packet from buffer  $B_a$  will be a random value  $\xi_n^{(a)}$ , together it will be the time of active window, and the servicing time of packet from buffer  $B_b$  -  $\xi_n^{(b)}$  - it will be a time of passive window. The work of  $AI_1$  channel influences a work of channel  $AI_0$  - when an active window is generated (channel  $AI_1$  serves a packet from buffer  $B_a$ ), all in channel  $AI_0$  served packets will get into buffer  $B_2$ ; when a passive window will be generated (channel  $AI_1$  serves a packet from buffer  $B_b$ ), served packets in channel  $AI_0$  will get into buffer  $B_0$ . An infinite time interval will be in channel  $AI_2$ , that is needed to serve a packet  $\xi_n^{(2)} \equiv Inf, n \in \mathbb{N}$ , i.e. the packets that

got into buffer  $B_2$  will stay here. Because we fix the times when packets got into this buffer, thus we get an imitation model of the bursty traffic.

### The creation of imitation model of the bursty traffic

Here we present how the imitation model of generation of the active and passive windows – “the bursty traffic” – can be described using the convolution of Moore and Mealy automata [4].

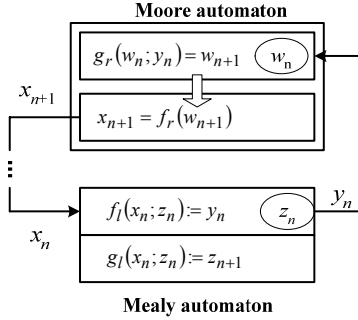


Fig. 2. The convolution of Moore and Mealy automata

The conjunction of Moore and Mealy automata (Fig. 2) is called the convolution of Moore and Mealy automata. Surjections:

$$\begin{cases} g_r : Y \times W \rightarrow W, & f_r : W \rightarrow X, \\ f_l : X \times Z \rightarrow Y, & g_l : X \times Z \rightarrow Z \end{cases} \quad (1)$$

describe the work of this convolution. Here  $W$  – the set of states of Moore automaton,  $X$  – the set of output signals of Moore automaton and input signals of Mealy automaton,  $Y$  – the set of output signals of Mealy automaton and input signals of Moore automaton,  $Z$  – the set of states of the Mealy automaton.

Besides, the convolution of automata starts operating after the initial states  $w_1$  and  $z_0$  are introduced. The implementation of the work of automata convolution can be presented as in Fig. 3:

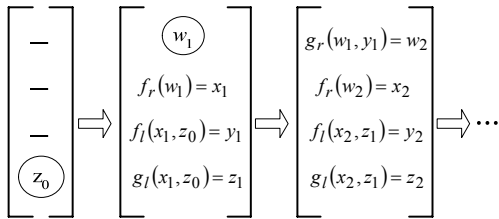


Fig. 3. The implementation of the work of automata convolution

Creating the relations' system, that describes the implementation of the convolution of Moore and Mealy automata, we use the closure of system (i.e. the generation of packets is treated as the work of servicing channel with infinite number of states).

Creating the surjections of automata conjunction (Fig.3) we use the variables:  $t_n$  ( $t_n \geq 0$ ) – „timer“; logical variables:  $v_n^{(i)}$  – ( $v_n^{(i)} = 0, 1$ ,  $i = 0, a, b$ ) – if  $v_n^{(i)} = 1$ , denotes the input of packet into buffer  $B_i$  at time  $t_n$ ;  $\chi_n^{(i)}$

– ( $\chi_n^{(i)} = 0; -1$ ,  $i = 0, a, b$ ) – if  $\chi_n^{(i)} = -1$ , denotes output of the served packet from channel  $AI_i$  (in this case  $\chi_n^{(2)} = 0$ );  $z_n^{(i)}$ ,  $i = 0, a, b$  – the number of packets in buffer  $B_i$  (in our case the number of packets is infinite  $z_n^{(i)} = Inf$ );  $S_n^{(0)}$  – the controlling variable of  $AI_0$  defining the time of packet arrivals;  $S_n^{(1)}$  – the controlling variable of  $AI_1$  defining the changing of active and passive windows at time  $t_n$  ( $S_n^{(0)}, S_n^{(1)} \geq 0$ ).

Then the state of Mealy automaton was described by such vector:

$$z_n = (Inf, Inf, Inf, z_n^{(2)}), \quad z_n \in Z. \quad (2)$$

The state of Moore automaton:

$$w_n = (S_n^{(0)}; S_n^{(1)}; Inf), \quad w_n \in W. \quad (3)$$

The signal of output from Moore – input of Mealy automata:

$$x_n = (t_n; v_n^{(0)}; \chi_n^{(0)}; v_n^{(a)}; v_n^{(b)}; \chi_n^{(1)}; v_n^{(2)}; 0), \quad x_n \in X. \quad (4)$$

The signal of output from Mealy – input of Moore automata:

$$y_n = (t_n; v_n^{(0)}; z_{n-1}^{(0)}; \chi_n^{(0)}; v_n^{(a)}; z_{n-1}^{(a)}; v_n^{(b)}; z_{n-1}^{(b)}; \chi_n^{(1)}; v_n^{(2)}; z_{n-1}^{(2)}; \chi_n^{(2)}), \quad y_n \in Y. \quad (5)$$

The initial states:

$$z_0^{(2)} = 0, \quad w_1 = (\xi_1^{(0)}; \xi_1^{(a)}; Inf), \quad m = j = 1. \quad (6)$$

Note that the third component of vector  $w_n$  always is equal  $Inf$ , because the channel  $AI_2$  doesn't work and only the bursty traffic is garnered in his buffer.

In this way for creating the imitation model of such system, it is sufficient to make corresponding surjections  $g_r, f_r, f_l, g_l$ . Calculation relations when  $n = 1, 2, 3, \dots$  are:

$$f_r(w_n) = x_n = (t_n; v_n^{(0)}; \chi_n^{(0)}; v_n^{(a)}; v_n^{(b)}; \chi_n^{(1)}; v_n^{(2)}; 0). \quad (7)$$

The present time is fixed:

$$t_n = \min\{S_n^{(0)}, S_n^{(1)}\}. \quad (8)$$

The time when the packet was served are fixed:

$$\chi_n^{(0)} = -1(S_n^{(1)} - S_n^{(0)}), \quad (9)$$

$$\chi_n^{(1)} = -1(S_n^{(0)} - S_n^{(1)}), \quad (10)$$

$$\chi_n^{(2)} = 0, \quad (11)$$

The time when packet arrives into buffer  $AI_2$  is fixed:

$$v_n^{(2)} = -\chi_n^{(0)} \cdot \frac{1 + (-1)^{m+1}}{2}. \quad (12)$$

$$f_l(x_n, z_{n-1}) = y_n = (t_n; v_n^{(0)}, z_{n-1}^{(0)}, \chi_n^{(0)}; v_n^{(a)}, z_{n-1}^{(a)}, v_n^{(b)}, z_{n-1}^{(b)}, \chi_n^{(1)}; v_n^{(2)}, z_{n-1}^{(2)}, \chi_n^{(2)}), \quad (13)$$

$$g_l(z_{n-1}, x_n) = z_n = (Inf, Inf, Inf, z_n^{(2)}). \quad (14)$$

The number of packets of bursty traffic is calculated:

$$z_n^{(2)} = z_{n-1}^{(2)} + v_n^{(2)}, \quad (15)$$

$$g_r(w_n, y_n) = w_{n+1} = (S_{n+1}^{(0)}; S_{n+1}^{(1)}; Inf), \quad (16)$$

$$j = j - \chi_n^{(0)}, \quad m = m - \chi_n^{(1)}. \quad (17)$$

The time of event occurrence is fixed:

$$S_{n+1}^{(0)} = -\chi_n^{(0)}(t_n + \xi_j^{(0)}) + (1 + \chi_n^{(0)})S_n^{(0)}, \quad (18)$$

$$S_{n+1}^{(1)} = -\chi_n^{(1)} \left( t_n + \xi_{\frac{1+(-1)^m}{4}}^{(a)} + \xi_{\frac{1+(-1)^{m+1}}{4}}^{(b)} \right) + (1 + \chi_n^{(1)})S_n^{(1)}. \quad (19)$$

If a packet arrived from  $B_a$  buffer is served in  $AI_1$  channel, then ‘‘an active window’’ is got; if a packet arrived from  $B_b$  buffer is served in  $AI_1$  channel, then ‘‘a passive window’’ is got.  $v_n^{(2)} = 1$  ( $m$  – an odd number) – at time  $t_n$  a packet arrived into buffer  $B_2$ , if  $v_n^{(2)} = 0$  ( $m$  – an even number) – at time  $t_n$  a packet did not arrive. Note that

$$m \cdot \frac{1+(-1)^m}{4} = \begin{cases} k, & \text{when } m = 2k, \\ 0, & \text{when } m = 2k+1, \end{cases} \quad (20)$$

$$(m+1) \cdot \frac{1+(-1)^{m+1}}{4} = \begin{cases} 0, & \text{when } m = 2k, \\ k+1, & \text{when } m = 2k+1. \end{cases} \quad (21)$$

Note that the formula (19) is original for each system, and other formulas (7-18) are typical. Besides, creating the calculation algorithm the variables, that don't influence on calculation algorithm, were eliminated.

In literature [5] the investigations were accomplished only with exponential data flows. But this model lets modeling of the bursty traffic using the various probabilistic distributions or their combinations, accordingly choosing the parameters of distributions and the parameters for extracting of the active and passive windows from ‘‘full’’ traffic (here they will be interpreted as the service of packets).

### Case study

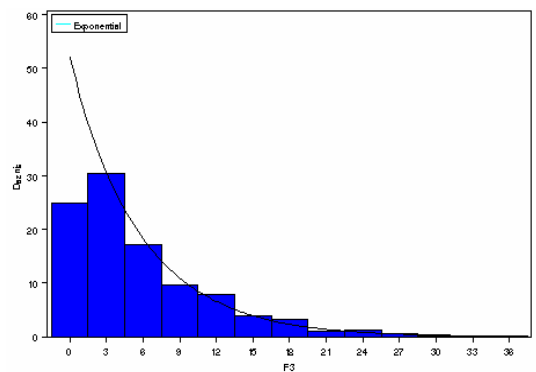
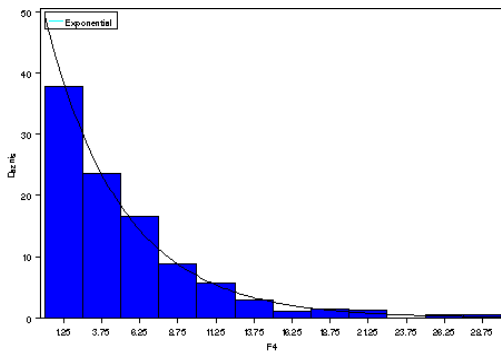
The bursty traffic was received by such model.

Hypotheses about distribution of points were verified using the criterions of compatibility of Chi-square and Kolmogorov and Smirnov that are in programming packets Statgraphics and SAS.

The results in Table 1 and in Fig. 4 show that after the verification of the hypothesis about the belonging of the distributions' points to exponential or lognormal probabilistic distribution, using the criterions of Chi-square and Kolmogorov and Smirnov, this hypothesis is accepted (the statistics  $d_n$  was got smaller than the quantum of distribution  $k_{0.95}$ ).

**Table 1.** Verification of hypotheses (with  $\alpha = 0.05$ )

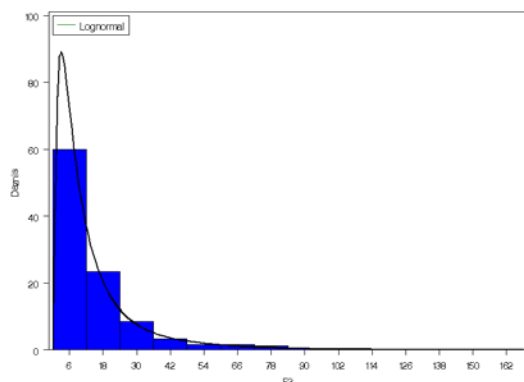
	Traffic – exponential Service -	$m=3$ $\sigma=1.732$	Mean $m$	Standard derivation $\sigma$	Chi-square criterion			Criterion of Kolmogorov and Smirnov	
					Statistics	$k-1$	$\chi^2$ quantum	Statistics	quantum
1.	Weibul		5.0477	5.05613	6.47024	10	19.675	0.03312	0.06675
2.	Paret		5.7688	5.69713	16.0195	11	21.026	0.04467	0.0525
	Traffic – Lognormal Service -	$m=12.182$ $\sigma=255.02$	Mean $m$	Standard derivation $\sigma$	Chi-square criterion			Criterion of Kolmogorov and Smirnov	
	exponential				Statistics	$k-1$	$\chi^2$ quantum	Statistics	quantum
3.	exponential		14.9216	20.525	9.0587	10	19.675	0.01879	0.04987



**Fig. 4.** Histograms of empirical data:

**a)** Location of points got from exponential traffic with  $\Delta t_{\text{exp}} = 3$  and service by Paret\_a with  $a_{\text{par}}^{(a)} = 1.2$  and  $b_{\text{par}}^{(a)} = 2$ , and Paret\_b with  $a_{\text{par}}^{(b)} = 1.3$  and  $b_{\text{par}}^{(b)} = 3$

**b)** Location of points got from exponential traffic with  $\Delta t_{\text{exp}} = 3$  and service by Weibul\_a with  $\alpha_{\text{veib}}^{(a)} = 0.5$  and  $s_{\text{veib}}^{(a)} = 3$ , and Weibul\_b with  $\alpha_{\text{veib}}^{(b)} = 2$  ir  $s_{\text{veib}}^{(b)} = 2$



c) Location of points got from lognormal traffic with  $m = 2$  ir  $\sigma = 1$ , and the service by exponential with  $\Delta t^{(a)} = 8$ ,  $\Delta t^{(b)} = 2$

The experiments showed that the traffic is not exponential in the common case. For instance, choosing the corresponding parameters to eliminate “the silence windows” from “the full traffic”, exponential bursty traffic can be received from exponential traffic, but in most cases the another distribution is received. So it’s expedient to investigate this traffic.

Executing the statistical researches with programs SAS and Statgraphics and establishing the traffic parameters, later this traffic may be successfully applied for the telecommunication networks modeling.

## Conclusions

The generation methodology of the bursty traffic has been created using the special combination of convolutions of Moore and Mealy automata.

The experiments showed that this traffic significantly differs from “the full traffic” by its properties. Choosing

the corresponding parameters to eliminate “the silence windows” from “the full traffic”, the exponential or Weibull bursty traffic can be received from exponential traffic, lognormal bursty traffic – from lognormal “full traffic”, etc.

The bursty traffic model presented here is provocative, but should be regarded as only speculative because it relies on the results of a simple model, extended with some quite strong assumptions.

To improve this analysis, it would be desirable to consider alternative models of bursty traffic and simulate a variety of bursty traffic models.

## References

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2. **Arvidsson Å., Harris R.** Analysis of the accuracy of bursty traffic models // *Proceedings of First International Conference On Telecommunication System Modelling and Analysis*. – Nashville, Tennessee, U.S.A, 1993. – P. 206–211.
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**A. Žvioniene, Z. Navickas, R. Rindzevicius.** *Bursty Traffic Simulation by ON - OFF Model // Electronics and Electrical Engineering*. – Kaunas: Technologija, 2006. – No. 6(70). – P. 65–68.

The proposed generation methodology of the bursty traffic has been created using the special combination of convolutions of Moore and Mealy automata. This model permits modeling of the bursty traffic using the various probabilistic distributions or their combinations. Executing the statistical researches with programs SAS and Statgraphics and establishing the traffic parameters, later this traffic may be successfully applied for the telecommunication networks modeling. Il. 4, bibl. 5 (in English; summaries in English, Russian and Lithuanian).

**A. Жвиронене, З. Навицкас, Р. Риндзевичюс.** *Анализ пульсирующего трафика используя ON – OFF модель // Электроника и электротехника*. – Каунас: Технология, 2006. – № 6(70). – С. 65–68.

Методология имитирования пульсирующего трафика была создана используя специальную комбинацию свертки автоматов Мура и Милля. Это имитирование позволяет использовать разные вероятностные распределения или их комбинации. При этом можно провести статистические исследования с программами SAS и Statgraphics и установить параметры трафика, позже этот трафик можно успешно использовать для моделирования телекоммуникационных сетей в целом. Ил. 4, библи. 5 (на английском языке; рефераты на английском, русском и литовском яз.).

**A.Žvioniene, Z.Navickas, R.Rindzevicius.** *Pliūpsninio srauto ON - OFF modelio analizė // Elektronika ir elektrotechnika*. – Kaunas: Technologija, 2006. – Nr. 6(70). – P. 65 – 68.

Pasiūlyta „pertrauktojo“ srauto generavimo metodika, sukurta naudojant specialų Muro ir Milio automatų sąsūkų darinį. Šis modelis įgalina modeliuoti pertrauktąjį srautą įėjimo paraiškų srautams imant įvairius atsitiktinius skirstinius ar jų mišinius. Atlikus šio srauto statistinius tyrimus programomis SAS ir Statgraphics ir nusistatčius srauto parametrus, vėliau jį galima panaudoti atliekant telekomunikacinių tinklų tyrimus. Il. 4, bibl. 5 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

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