EXPERIMENTAL RESULTS OF TRAFFIC MODELS FOR BURST DATA AND VOICE SOURCES IN ATM NETWORKS

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Abstract: This paper presents an overview of the existing traffic models for burst data and voice sources in ATM, as well as some experimental results and comments about their implementations. The first paragraph is devoted to burst traffic generated by ON/OFF sources of constant throughput. The Matlab-based scheduler is able to determine the number of ON cells to the number of OFF cells ratio, for every burst, until the transmission process is completed. In the cases of multiple constant bit rate sources or a single source of variable bit rate, the superposition of several independent models previously discussed can be applied. This is method is not useful for voice traffic, possible solutions being offered by Markov-Modulated Poisson process model or by fluid source model. Experiments carried out gave the Matlab-based schedule of ATM cells departure, generated by *S* multiplexed sources.

Key words: *Asynchronous Transfer Mode, Burst Data/Voice Sources, Traffic Models*

I. INTRODUCTION

This paper is based on the theoretical aspects of traffic models for data and voice in ATM, presented at ETc'98 Symposium on Electronics and Telecommunications [1]. This time the aims are related to the experimental results and comments concerning some of these models. In order to maintain the coherence of the presentation, the general description of the algorithms has been included again, knowing that the details could be found in [2]. A brief classification of the models for ATM sources is given within *Table 1.* Note that the paper does not cover topics such as models for video sources or network, which are for further study.

Model	Applications
single ON/OFF source	single data source of constant bit rate for burst traffic
	single voice source for Poisson traffic
superposition of S single ON/OFF sources	single data source of variable bit rate for burst traffic
	S data sources of constant bit rate for burst traffic
	S voice sources for Poisson traffic
MMPP (Markov-Modulated Poisson Process)	S voice sources for Poisson traffic multiple video sources for Poisson traffic
fluid source	S voice sources for Poisson traffic
IPP (Interrupted Poisson Process)	S voice sources for Poisson traffic
	multiple video sources for Poisson traffic
IBP (Interrupted Bernoulli Process)	S voice sources for Poisson traffic

Table 1. Models for ATM burst data and voice sources

II. BURST TRAFFIC MODELS

Let $\dot{D} =$ constant be the throughput within the active state ON (in bps), and $1- p_{ON/OFF}$ be the probability to remain in the this state. Similar, $1- p_{OFF/ON}$ is the probability of staying into the idle state OFF, whilst the throughput is obviously zero in this case. Note that $p_{ON/OFF}$ represents the probability of changing from ON to OFF (β is the source's active/idle changing rate) and $p_{OFF/ON}$ the corresponding value for OFF to ON modification (α is the source's idle/active changing rate).

As a simple Markov process of first order, the current value of the throughput at a given moment *t* is only depending on previous value, at *t-1*

$$p_{OFF} = p_{ON}\, p_{ON/OFF} + p_{OFF}(1 - p_{OFF/ON}) \tag{1}$$

$$p_{ON} = p_{OFF}\, p_{OFF/ON} + p_{ON}(1 - p_{ON/OFF}) \tag{2}$$

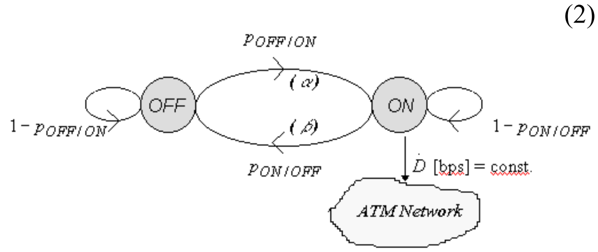

Figure 1. ON/OFF model for one source generating burst traffic at a constant bit rate

From (1) and (2) results

$$p_{ON}\, p_{ON/OFF} = p_{OFF}\, p_{OFF/ON} \tag{3}$$

Knowing that: $p_{ON} + p_{OFF} = 1$ (4)

the system's probability of being in state OFF is given by the equation:

$$p_{OFF} = \frac{p_{ON/OFF}}{p_{OFF/ON} + p_{ON/OFF}} \tag{5}$$

Similar, the probability of being in active state ON is:

$$p_{ON} = \frac{p_{OFF/ON}}{p_{OFF/ON} + p_{ON/OFF}} \tag{6}$$

According to *Figure 1* and to previous results, the average throughput offered by this single source is calculated as follows:

$$\tilde{\dot{D}} = 0 \times p_{OFF} + \dot{D} \times p_{ON} = = \frac{\dot{D}\, p_{OFF/ON}}{p_{OFF/ON} + p_{ON/OFF}} \tag{7}$$

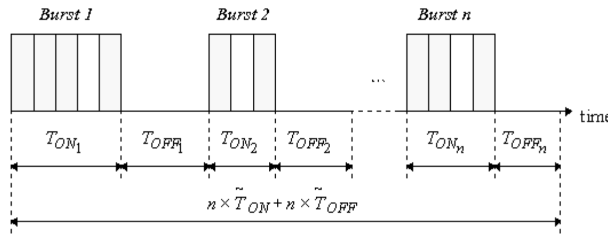

Figure 2. Geometrical distribution of burst traffic

Let suppose now that both active and idle duration are geometrically distributed (not exponential!), with parameters α and β. During ON state the ATM cells are arriving consecutively, at a maximum rate of one per each slot (as in *Figure 2*). Note that some slots may not contain cells, even the source is active. The following suppositions have to be added to previous ones: first, the lengths of bursts are statistically independent and second, there is at least one ATM cell within each active period. On the other hand, it might be possible to have a zero length for the idle period. According to [3], the average length of a single idle period is given by:

$$\tilde{L}_{OFF} = \sum_{k=0}^{\infty} k\alpha(1-\alpha)^k = \frac{1-\alpha}{\alpha} \quad \text{[slots]} \tag{8}$$

and the average length of a burst (i.e., the active period):

$$\tilde{L}_{ON} = \sum_{k=1}^{\infty} k\beta(1-\beta)^{k-1} = \frac{1}{\beta} \quad \text{[slots]} \tag{9}$$

Let us consider now that $424/\dot{D}$ represents the constant duration of one time slot. The source's behavior could be described by burstiness, which is in fact the intensity of the offered traffic:

$$\rho_{offered} = \frac{n \times \tilde{T}_{ON}}{n \times \tilde{T}_{ON} + n \times \tilde{T}_{OFF}} = \frac{n \times \tilde{L}_{ON} \times (424/\dot{D})}{n \times \tilde{L}_{ON} \times (424/\dot{D}) + n \times \tilde{L}_{OFF} \times (424/\dot{D})} = \frac{\tilde{L}_{ON}}{\tilde{L}_{ON} + \tilde{L}_{OFF}} \tag{10}$$

where *n* represents the total number of bursts during the time of observation. From (8) and (9) results:

$$\rho_{offered} = \frac{1/\beta}{1/\beta + (1-\alpha)/\alpha} = \frac{\alpha}{\alpha+\beta-\alpha\beta} \cong \frac{\alpha}{\alpha+\beta} \quad (11)$$

Knowing that $0 \le \rho_{offered} \le 1$, it can be interpreted as the probability that a given input port receives one ATM cell within one time slot.

As an example, let us have a set of 1000 x 1000 images to be retrieved from a video server by a remote terminal. The following parameters are given: resolution of 10^6 pixels, compression rate of 0.25…1 bits/pixel, E1 line (2048 kbps). Supposing a continuous transmission at PBR *(Peak Bit Rate)* and a 48 byte - payload for ATM cells, the necessary time for sending a complete uncompressed image is $[(53/48)\times 10^6]/(2048\times 10^3) = 0.538$ seconds. For 0.25 bits/pixel compression rate, the time decreases at 0.134 seconds. According to *Figure 1*, the average transmission time is $(0.538+0.134)/2 = 0.336$ seconds. Supposing this image is to be used by a human operator, who needs from 5 up to 15 seconds to watch it, the average throughput of the ATM source (considering the single ON/OFF source model of constant bit rate) is calculated as follows. From (8) $n \times \tilde{T}_{OFF} = (5+15)/2 = 10$ s., from (9) $n \times \tilde{T}_{ON} = 0{,}336$ s. $\rho_{offered} = \frac{0.336}{10.336} = 0.032$ and $\dot{D}_{average} = 0.032 \times 2048 \times 10^3 = 66.64$ kbps.

The experiments carried out are trying to determine the departure schedule of ATM cells for a burst traffic. The models have been implemented in Matlab, with the following parameters: $\propto$ (alpha), β (beta), $\dot{D}$ transfer rate, number of bursts.

Experiment 1

First, the number of OFF cells and the number of ON cells versus the number of bursts were studied, as in *Figures 3-5.* By employing a PC network interface card as VIRATAlink (Advanced Telecommunications Modules Ltd., UK), the transfer rate was considered 25.6 Mbps. Due to practical reasons, the maximum number of bursts involved raised to the level of 1750 (if this parameter is chosen 0, there is no other limits to stop the transmission, except when the user information has been sent in its entirety).

For alpha and beta equal to 0.005, the two graphics have almost the same shape, with a maximum of about 22 kcells after 200 bursts, see *Figure 3*. If the number of off-to-on switchings is very low compared to on-to-off switchings, there is a trend to have a continuous stream of very high number of ATM cells with no idle slots, as in *Figure 4.* The opposite case is presented in *Figure 5*, by expecting alpha much greater than beta. The result is a linear increasing of number of ON cells, with almost no OFF cells. Note that although these conclusions were more or less predictable, this implementation is giving an accurate evaluation, which could become relevant for time-dependent applications.

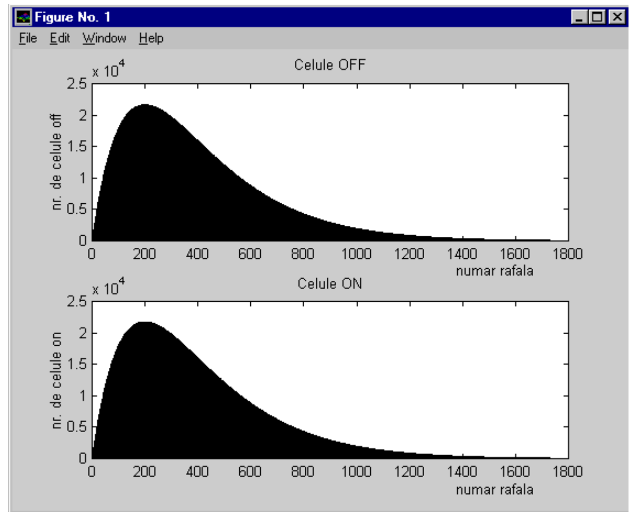

Figure 3. Experiment 1: number of OFF cells, respectively number of ON cells versus number of bursts (for alpha 0.005, beta 0.005, number of bursts 1750, transfer rate 25 Mbps)

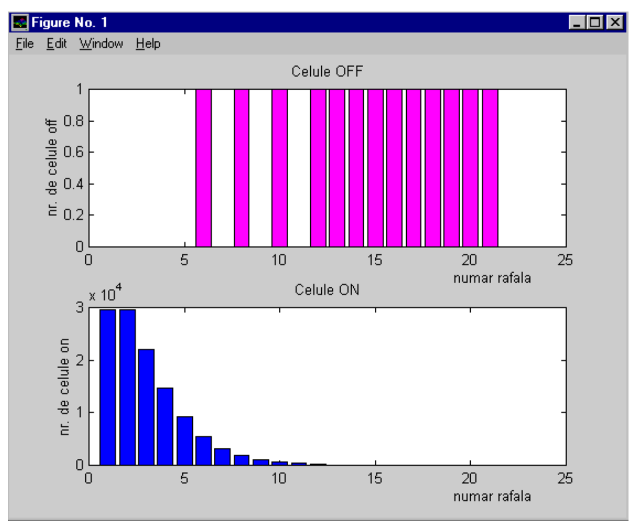

Figure 4. Experiment 1: number of OFF cells, respectively number of ON cells versus number of bursts (for alpha 0.000001, beta 0.5, number of bursts 1750, transfer rate 25 Mbps)

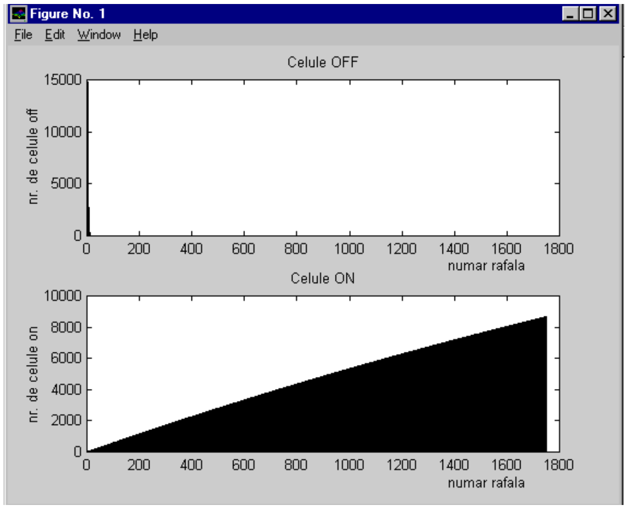

Figure 5. Experiment 1: number of OFF cells, respectively number of ON cells versus number of bursts (for alpha 0.5 , beta 0.0001, number of bursts 1750, transfer rate 25 Mbps)

Experiment 2

Let us suppose now that alpha and beta are constant, whilst the transfer rate is variable (1, 25 or 155 Mbps) and the maximum number of bursts could be 100, 500 or 1750. *Figure 6* gives an interesting result: the file's size to be transmitted as burst traffic has the highest value, of about 5.2 Gb, if beta is equal to 0.002. Due to scaling reasons only, alpha was chosen 0.00001, as the conclusion was that both graphics for the number of OFF cells and the number of ON cells are preserving their shape, no matter the transfer rate is 1 or 155 Mbps. Obviously the scale is different, i.e. the 1750th burst has an ON/OFF cells ratio of 300/40 at 1 Mbps and 50000/6000 at 155 Mbps.

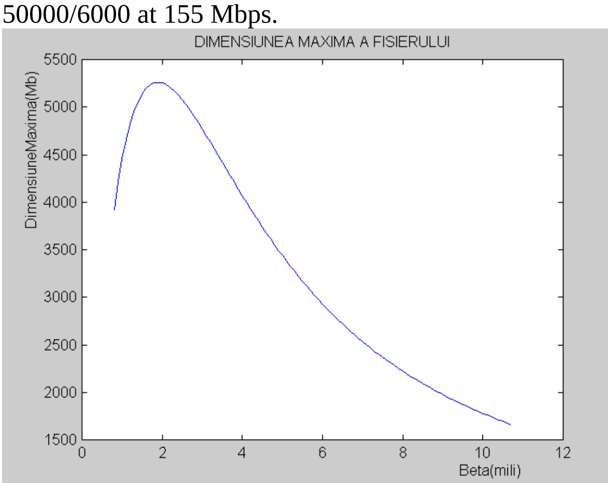

Figure 6. Maximum size of the file that could be transmitted with this model (depending on beta)

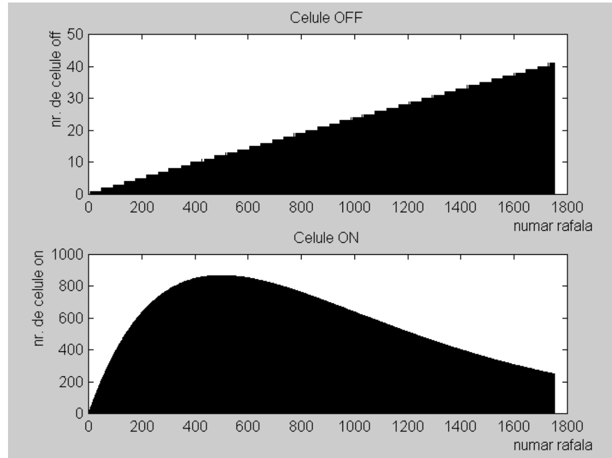

Figure 7. Experiment 2: number of OFF cells, respectively number of ON cells versus number of bursts (for number of bursts 1750, transfer rate 1 Mbps, alpha 0.00001 , beta 0.002)

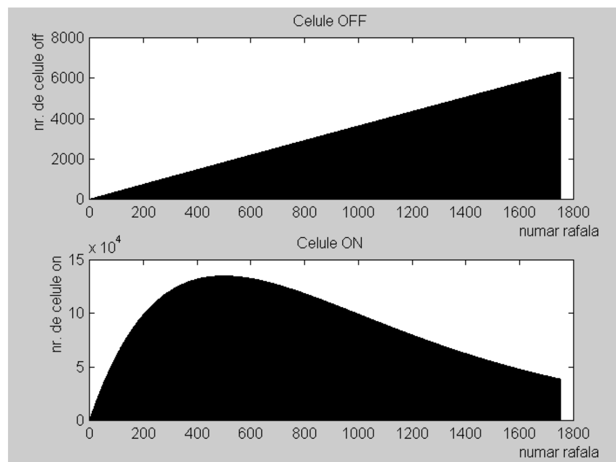

Figure 8. Experiment 2: number of OFF cells, respectively number of ON cells versus number of bursts (for number of bursts 1750, transfer rate 155 Mbps, alpha 0.00001 , beta 0.002)

Conclusions

Figure 9. Test configuration

It is for further study to integrate these results within a test configuration, as in *Figure 9*. The ATM cell generator is sending its information to an ATM network interface card, according to a scheduler, for a given set of parameters {alpha, beta, transfer rate, number of bursts} stored in a file called *param.dat*. The numerical results are offered as an ASCII file, called *Model1.dat*.

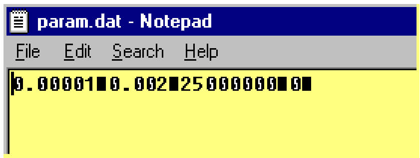

Figure 10. param.dat file: alpha 0.00001, beta 0.002, transfer rate 25 Mbps, number of bursts 0

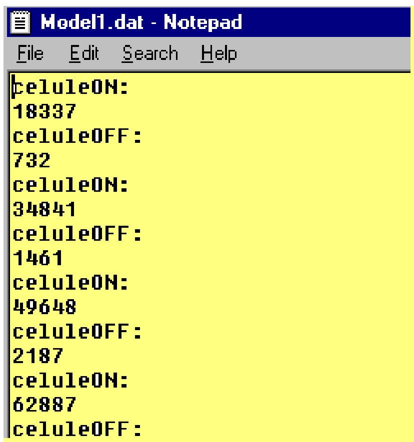

Figure 11. Schedule of ATM cells departure for a burst traffic source, according to Model1.dat file

The models of several ON/OFF sources with constant throughput (by superposition of single sources previously presented), as well as the cases of one or several ON/OFF sources with variable bit rate are discussed in [2].

III. VOICE MODELS

Basically the voice could be transmitted through ATM networks either as CBR traffic (PCM coding at 64 kbps or ADPCM at 32 kbps) with AAL1, either as VBR traffic with AAL2.

A time-assigned speech interpolation technique has been involved, with an active period (talk spurt) of about 0.4 up to 1.2 seconds and a passive period (silent) within a similar range (typically 0.6 up to 1.8 seconds). The arrival of ATM cells could be represented either by a switched Poisson process model, either by IPP *(Interrupted Poisson Process)* or IBP *(Interrupted Bernoulli Process)* [5].

Unless great number of sources, light traffic and small buffering, M/D/1 model is not recommended for multiplexing. Possible solutions are offered by MMPP *(Markov-Modulated Poisson Process)* model, as in *Figure12*, or by fluid source model, as in *Figure 14.*

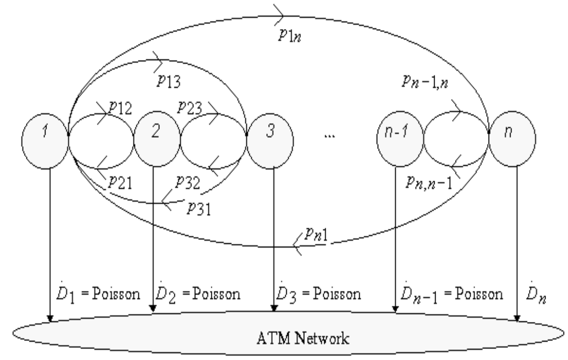

Figure 12. MMPP model
(only possible transitions are displayed)

The MMPP has *n* states, acting in any state *k* as a Markov process, except that the arrival rate λ_k depends on state *k*. All transitions are made according to continuous-time model, but in this case some of them could involve non-adjacent states.

Let *P* be a row vector including all *n* probabilities of the system's states:

$$P = [p_1, p_2, \ldots, p_n] \qquad (12)$$

satisfying the condition: $PM = 0$ (13)

where *M* is a $n \times n$ matrix with the structure presented in *Figure 13.*

p_{11}	p_{12}	...	p_{1j}	...	p_{1n}
p_{21}	p_{22}	...	p_{2j}	...	p_{2n}
...	...	...	...	...	...
p_{i1}	p_{i2}	...	p_{ij}	...	p_{in}
...	...	...	...	...	...
p_{n1}	p_{n2}	...	p_{nj}	...	p_{nn}

Figure 13. Structure of M matrix for MMPP model

The elements of main diagonal are calculated as follows:

$$p_{ii} = -\sum_{\substack{j=1 \\ j \neq i}}^{n} p_{ij} \text{ , for } 1 \le i \le n \qquad (14)$$

the algorithm being described in details in [2]. While the source is in active period *(talk spurt),* the voice cells (packets) are sent according to Poisson distribution. M. Schwartz appreciated that this model could not guarantee better results for simulations, being rather suitable for video sources.

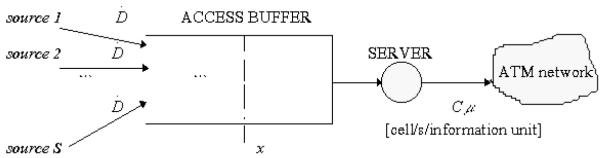

Figure 14. Fluid source model applied to multiplexing of ATM cells

The fluid source model is based on the idea that the during the active period the voice source sends so many cells that the traffic flow looks continuous, being compared with a fluid. Knowing that the throughput is $\dot{D}$, in [bps], or $\dot{D}/424$, in [cells/s], the conclusion is that the source will contribute with one information unit $\dot{D}/(424\mu)$ at every activation. The server's average throughput is calculated as follows:

$$\tilde{\dot{D}} = \frac{C\dot{D}}{\dfrac{\dot{D}}{424\mu}} = 424C\mu \text{ [bps/unit of information]}$$

$$= C\mu \qquad \text{[cell/s/unit of information]} \quad (15)$$

Suppose k represents the state of the access buffer (i.e., the number of ATM cells at a given moment), let x be a random continuous variable representing the number of cells arriving during active period $1/\mu$:

$$x = \frac{k}{\dfrac{\dot{D}}{424\mu}} \text{ [cells/unit of information]} \qquad (16)$$

Now the problem is to find the probability distribution function $F(x)$. If $\gamma = \dfrac{\lambda}{\mu}$ (17)

it is more suitable to determine the complementary function $G(x) = 1 - F(x)$, which related to the probability that the buffer occupancy is greater than *x*. It is also called *survivor function* because it is used to evaluate the probability of loses. In [4] it was demonstrated the equation for a single source model:

$$G(x) = 1 - F(x) = \rho \exp[\frac{(1-\rho)(1+\gamma)}{(1-C)}x] \qquad (18)$$

where the intensity of offered traffic (with $S = 1$) is:

$$\rho = \frac{S\lambda}{C(\lambda+\mu)} = \frac{S\gamma}{C(1+\gamma)} < 1 \qquad (19)$$

The result will be now converted from units of information into cells, as the probability of having the buffer occupancy greater than the threshold *i*

$$P\{k > i\} = P\{x > \frac{424\mu}{\dot{D}} i\} = G(\frac{424\mu}{\dot{D}} i) =$$
$$= \rho \exp[\frac{(1-\rho)(1+\gamma)}{(1-C)} \times \frac{424\mu}{\dot{D}} i] \qquad (20)$$

Obviously the higher the transfer rate $\dot{D}$ is (for a given capacity of the server), the higher the probability of losing will be, due to the limited buffer.

Experiment 3

The ATM cells generator from *Figure 9* will supply Poisson traffic, obtained as in fluid source model by multiplexing *S* voice sources. Three types of graphics versus time are of great interest: probability p_k of having *k* active sources, sum of p_k, sum of $k\,p_k$.

The experiments were done for 10 sources (C=6), respectively 20 sources (C=14). *mPk* represents the mean value of p_k calculated by the Matlab-based simulator, and *mKpk* is the notation for the mean value of $k\,p_k$.

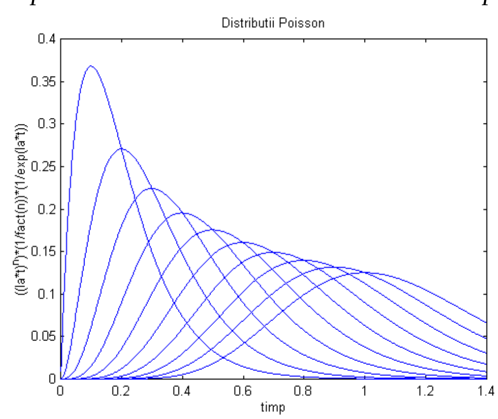

Figure 13. Experiment 3.: p_k vs. time, for 10 sources

S=10; mPk=0.6861; mKpk=3.6749; max=6.

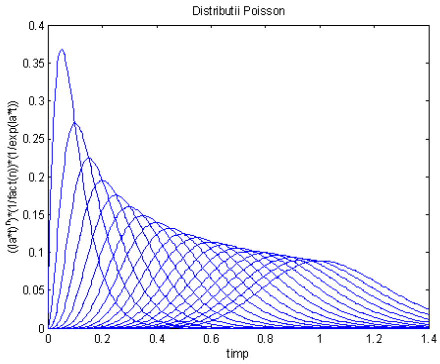

Figure 14. Experiment 3: p_k vs. time, for 20 sources

S=20; mPk=0.7080; mKpk=7.3792; max=14.

Figures 15-16 show the sum of p_k, for *k=1,2,…S.* Note that a value of almost 1 has an important significance: it means there is at least one active source in the system, because $p_0 \to 0$.

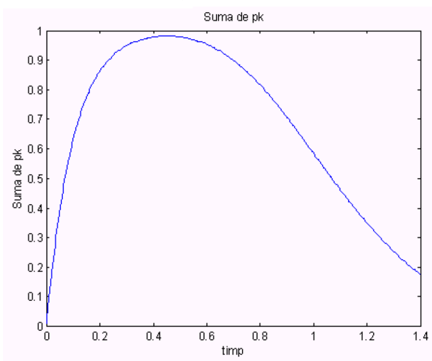

Figure 15. Experiment 3: sum of p_k vs. time, for 10 sources

S=10; mPk=0.6861; mKpk=3.6749; max=6.

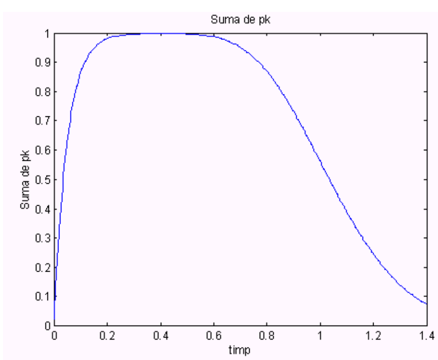

Figure 16. Experiment 3: sum of p_k vs. time, for 20 sources

S=20; mPk=0.7080; mKpk=7.3792; max=14.

The last two graphics have a major importance, as the mean value of the sum of $k\,p_k$ represents the average number of active sources in the system, for a given configuration and a given ratio between talk spurt and silent period.

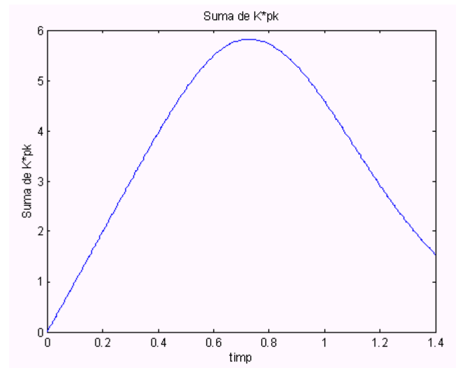

Figure 17. Experiment 3: sum of $k\,p_k$ vs. time, for 10 sources

S=10; mPk=0.6861; mKpk=3.6749; max=6.

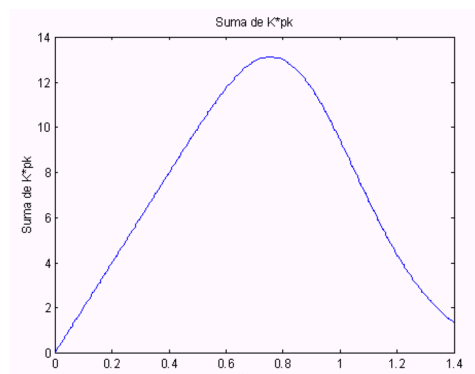

Figure 18. Experiment 3: sum of $k\,p_k$ vs. time, for 20 sources

S=20; mPk=0.7080; mKpk=7.3792; max=14.

Experiment 4

The aims of this experiment is to determine the influence of the average time of talk spurt, when the silent period is constant. Similar, the talk spurt is kept constant, whilst the silent period is decreasing within its normal range.

Following the results of both experiment 3 and experiment 4, Matlab-based simulator is able to generate the departure schedule for each ATM cell.

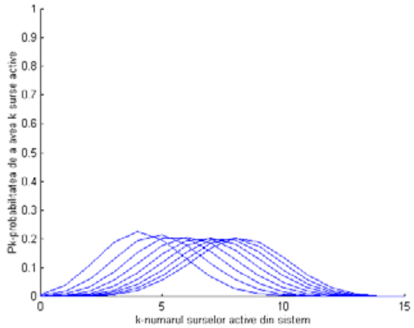

Figure 19. Experiment 4: probability p_k vs. number of active sources k, for S=15 sources of constant bit rate, average time of silent period T0=1/λ=1 second and average time of talk spurt T1=1/μ varying within the range 0.4 … 1.2 seconds

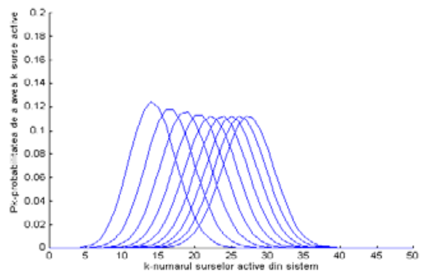

Figure 20. Experiment 4: probability p_k vs. number of active sources k, for S=50 sources of constant bit rate, average time of silent period T0=1/λ=1 second and average time of talk spurt T1=1/μ varying within the range 0.4 … 1.2 seconds

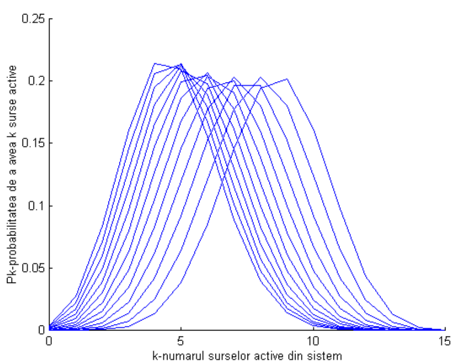

Figure 21. Experiment 4.: probability p_k vs. number of active sources k, for S=15 sources of constant bit rate, average time of talk spurt T1=1/μ=0.4 seconds and average time of silent period T0=1/λ decreasing within the range 0.6… 1.8 seconds

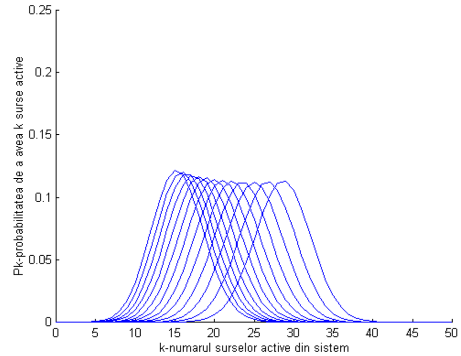

Figure 22. Experiment 4: p_k vs. k, for S=50 sources of constant bit rate, T1=1/μ =0.4 seconds and T0=1/λ decreasing within the range 0.6… 1.8 seconds

IV. CONCLUSIONS

This article covers the authors' experience in modelling different types of ATM traffic, including burst data and voice, with significant impact in practice for simulating and evaluating the performances of the existing and future broadband networks. It is for further study the models for video sources and for the network behaviour.

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