TRAFFIC MODELS FOR DATA, VOICE AND VIDEO SOURCES IN ATM

Virgil Dobrota, Daniel Zinca

Abstract - **This paper presents an overview of the existing traffic models for data, voice and video sources in ATM. The first paragraph is devoted to bursty traffic of constant throughput, based on classical ON/OFF model. Obviously the superposition of several independent sources gives the method for modelling the variable rate streams. Possible solutions for voice traffic are offered by Markov-Modulated Poisson process model or by fluid source model. Due to different types of correlation between successive frames, the video services are mainly different than voice and data, involving continuous/discrete-state autoregressive Markov and autoregressive moving average process models.**

Index terms - **Asynchronous Transfer Mode, Traffic Models, Data/Voice/Video Sources**

I. INTRODUCTION

This paper presents an overview of the existing traffic models for data, voice and video sources in ATM. The first discussion is devoted to burst traffic of constant throughput, based on classical ON/OFF model. Next paragraphs are dedicated to voice and video sources.

II. BURST TRAFFIC MODELS

Let $\dot{D} = \text{constant}$ (in bps) be the throughput within the active state ON, and $1 - p_{ON/OFF}$ be the probability to remain in 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 $p_{OFF/ON}$ is the corresponding value for OFF to ON modification (α is the idle/active changing rate).

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

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

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

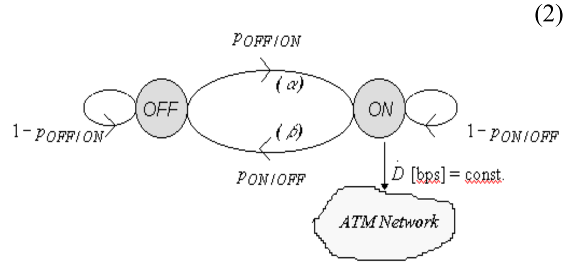

Fig1. ON/OFF model for one source generating burst traffic at a constant bit rate

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 to be 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 to be in active state ON is:

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

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

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

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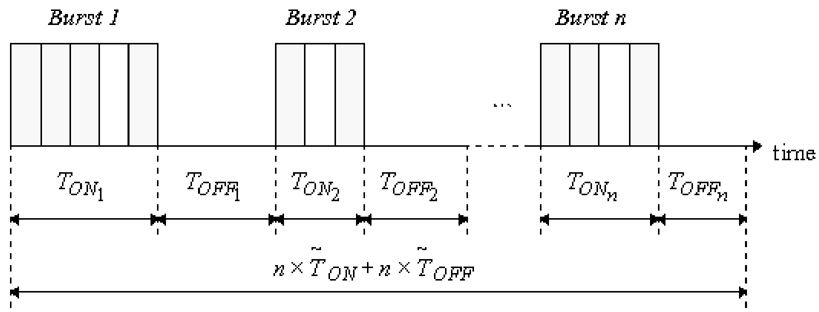

Fig.2. Geometrical distribution of burst traffic

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 Fig.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 [7], the average length of a single idle period is given by:

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

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

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

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:

$$\rho_{offered} = \frac{n \times \tilde{T}_{ON}}{n \times \tilde{T}_{ON} + n \times \tilde{T}_{OFF}} =$$

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

$$= \frac{\tilde{L}_{ON}}{\tilde{L}_{ON} + \tilde{L}_{OFF}}$$

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

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

As $0 \le \rho_{offered} \le 1$, it can be interpreted as the probability that a given input port receives one ATM cell within one time slot. Having the particular case of one Bernoulli source (without memory!), according to [7]:

$$p_{OFF/ON}\big|_{Bernoulli} = 1 - p_{ON/OFF} = \rho_{offered} \qquad (12)$$

$$p_{ON/OFF}\big|_{Bernoulli} = 1 - p_{OFF/ON} = 1 - \rho_{offered} \qquad (13)$$

The average length of a burst for Bernoulli source is:

$$\tilde{L}_{ON}\big|_{Bernoulli} = \frac{1}{p_{ON/OFF}} = \frac{1}{1-\rho_{offered}} \quad \text{[slots]} \qquad (14)$$

Let define now the burstiness factor k_b as the ratio between the average length of a burst over the average length of a burst for Bernoulli source:

$$k_b = \frac{\tilde{L}_{ON}}{\tilde{L}_{ON}\big|_{Bernoulli}} \ge 1 \qquad (15)$$

Coming back to our discussion about ON/OFF model, a single source of burst traffic could be characterized by two parameters: $\rho_{offered}$ and k_b, whilst the transition probabilities from one state to other are given by the equations:

$$p_{OFF/ON} = \frac{\rho_{offered}}{k_b} = \frac{1}{k_b}\left(\frac{\alpha}{\alpha+\beta}\right) \qquad (16)$$

$$p_{ON/OFF} = \frac{1-\rho_{offered}}{k_b} = \frac{1}{k_b}\left(\frac{\beta}{\alpha+\beta}\right) \qquad (17)$$

Observations:

- $k_b = 1$ corresponds to the ATM network having as an input a Bernoulli source generating random traffic
- $k_b > 1$ corresponds to the ATM network having as an input an ON/OFF source generating burst traffic

- Applying equations (16) and (17) to (7), the average throughput offered by the source is:

$$\tilde{\dot{D}} = \dot{D}\,\rho_{offered} \tag{18}$$

because:

$$\rho_{offered} = \frac{p_{OFF/ON}}{p_{OFF/ON} + p_{ON/OFF}} = p_{ON} \tag{19}$$

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 [5].

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 Markov-Modulated Poisson Process (MMPP) model, as in Fig.3, or by fluid source model, as in Fig.5.

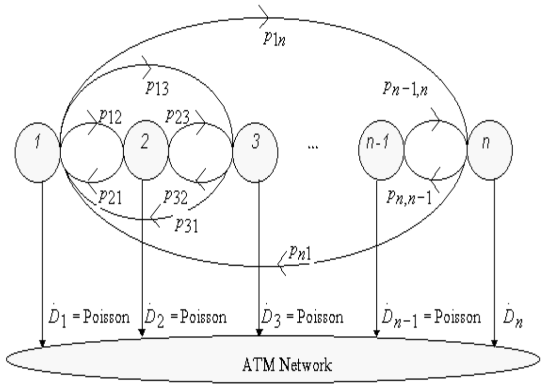

Fig. 3. MMPP model (only possible transitions are displayed)

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:

$$P = [p_1, p_2, \ldots, p_n] \tag{20}$$

satisfying the condition:

$$PM = 0 \tag{21}$$

where M is a $n \times n$ matrix with the structure presented in Fig.4

$$\begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1j} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2j} & \cdots & p_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ p_{i1} & p_{i2} & \cdots & p_{ij} & \cdots & p_{in} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ p_{n1} & p_{n2} & \cdots & p_{nj} & \cdots & p_{nn} \end{bmatrix}$$

Fig.4. Structure of M matrix for MMPP model

The elements of main diagonal are calculated as follows:

$$p_{ii} = -\sum_{\substack{j=1 \\ j \neq i}}^{n} p_{ij} \;, \text{ for } 1 \le i \le n \tag{22}$$

the algorithm being described in details in [5]. 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 [3].

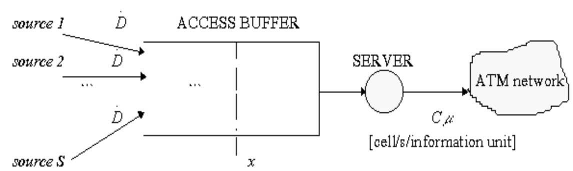

Fig.5. Fluid source model applied to multiplexing of ATM cells

The fluid source model is based on the idea that the during the active period the voice source sends as many cells as the traffic flow is 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:

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

$$= C\mu \qquad \text{[cell/s/unit of information]} \quad (23)$$

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 $1/\mu$:

$$x = \frac{k}{\frac{\dot{D}}{424\mu}} \ \text{[cells/unit of information]} \qquad (24)$$

Now the problem is to find the probability distribution function $F(x)$. If

$$\gamma = \frac{\lambda}{\mu} \qquad (25)$$

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 losing. In [3] it was demonstrated the equation for a single source model:

$$G(x) = 1 - F(x) = \rho \exp[\frac{(1-\rho)(1+\gamma)}{(1-C)}x] \qquad (26)$$

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

$$\rho = \frac{S\lambda}{C(\lambda+\mu)} = \frac{S\gamma}{C(1+\gamma)} < 1 \qquad (27)$$

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

$$P\{k > i\} = P\{x > \frac{424\mu}{\dot{D}} i\} = G(\frac{424\mu}{\dot{D}} i) =$$
$$= \rho \exp[\frac{(1-\rho)(1+\gamma)}{(1-C)} \times \frac{424\mu}{\dot{D}} i] \qquad (28)$$

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.

IV. VIDEO MODELS

Video services are mainly different than voice and data services due to different types of correlation between successive frames. Let define the correlation coefficient as a measure of linearity between the quantity of information *x(n)* included in frame *n* and the quantity of information $x(n+1)$ from frame $n+1$:

$$-1 \le C(t) = \frac{\widetilde{[x(n)-\tilde{x}(n)][x(n+t)-\tilde{x}(n)]}}{\sigma^2\{x(n)\}} \le 1 \qquad (29)$$

where: $\tilde{x}(n)$ represents the first order moment or the average (expected) value and $\sigma^2\{x(n)\}$ is the variance. *C(t)* is in fact the ratio of covariance of *x(n)* and *x(n+t)* over the variance of *x(n)*.

Observations:

- $C(t) > 0$ is a positive correlation between *x(n)* and *x(n+t)*, meaning that both variables are varying (increase or decrease) in the same manner.

- $C(t) = 1$ is the highest rate of linearity (positive correlation).

- $C(t) = 0$ shows that both random variables are not correlated.

- $C(t) < 0$ is a negative correlation between *x(n)* and *x(n+t)*, meaning that both variables are varying in inverse manner (one increases while the other one decreases).

- $C(t) = -1$ is the highest rate of linearity (negative correlation)

The throughput of compressed images has 100-150 frame period of peaks, requiring high peak bit rate channel (even the average rate could be relatively modest).

A possible solution is to replace the VBR traffic by CBR, the main disadvantage being that the resulting quality of service is not constant at all. Continuous-state auto-regressive, uni- and bi-dimensional discrete-state Markov and auto-regressive moving average process models are discussed for single video source, whilst the multiplexing of several independent sources could be described again by MMPP or fluid source models.

In this paper the uni-dimensional discrete-state Markov model for a single video source is discussed only. Interested readers could find an extended presentation in [5].

Let suppose [$\dot{D}_{\min}$, $\dot{D}_{\max}$] is the interval of transfer rate values provided by a video source. Applying a N-level uniform quantization, the step is

$$\Delta = (\dot{D}_{\max} - \dot{D}_{\min}) / N \qquad (30)$$

As each quantization level is associated to a state, the transfer rate for state *i* is

$$\dot{D}_i = \dot{D}_{\min} + i\Delta\ ,\ 0 \le i \le N \tag{31}$$

The transition rate between state *i* and an adjacent state is defined as in [1]:

$$\begin{aligned} p_{i,i+1} &= (N-i)\alpha && \text{for } 0 \le i \le N-1 \\ p_{i,i-1} &= i\beta && \text{for } 0 \le i \le N \\ p_{i,i} &= 0 && \text{in other cases} \end{aligned} \tag{32}$$

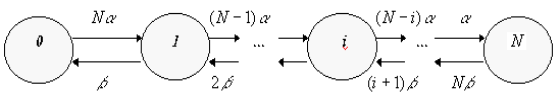

Fig.6. Uni-dimensional discrete-state Markov model for a single video source

Parameter N is chosen according to the expected granularity. A higher value of N assures a more accurate model, but also increases its complexity. Let p_i be the probability that a Markov process is in state *i*, determined from the equation:

$$p_i(N-i)\alpha = p_{i+1}(i+1)\beta \qquad \text{for } 0 \le i \le N-1 \tag{33}$$

But $$\sum_{i=0}^{N} p_i = 1 \tag{34}$$

and it results:

$$p_i = \frac{N!}{(N-i)!\,i!}\left(\frac{\alpha}{\alpha+\beta}\right)^i \left(\frac{\beta}{\alpha+\beta}\right)^{N-i} \tag{35}$$

for $0 \le i \le N-1$. Parameters Δ, α and β are determined from relation

$$\tilde{(\dot{D})} = \sum_{i=0}^{N} p_i \dot{D}_i = N\Delta \frac{\alpha}{\alpha+\beta} \tag{36}$$

whilst the variance (in fact correlation coefficient for $t = 0$) and the correlation coefficient are calculated as follows:

$$\sigma^2(\dot{D}) = C(0) = N\Delta^2 \left(\frac{\alpha}{\alpha+\beta}\right)\left(\frac{\beta}{\alpha+\beta}\right) \tag{37}$$

$$C(t) = C(0)\exp[-(\alpha+\beta)t] \tag{38}$$

V. CONCLUSIONS

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

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