An improved MPEG behavioral analysis with autonomous parameter-extracting algorithm for strict video applications

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Abstract— **Through detailed analysis of theoretical and real MPEG-compressed video streams, this paper addresses the task of extracting deterministic parameters from such sources in order to provide deterministic service guarantees. We propose and analyze the single-input single-output (SISO) algorithm with quality adjustment to compute the coherent parameters for the XGOP-B deterministic traffic model. Contrary to other proposals, the SISO algorithm leads to a single set of parameters for each input traffic and does not ask for external decisions to perform this stage. Moreover, the accuracy/complexity can be adjusted by a special variable. Our results show that the proposed approach leads to improved accuracy and that the complexity can be decreased by three orders of magnitude.**

I. Introduction

The evolution of computer communication and the development of multimedia techniques have allowed the emergence of applications that require deterministic quality of service (QoS) guarantees from the network. In a deterministic service, all packets of a connection are assured to be delivered within the specified QoS bounds [1], [2], [3], [4], [5], [6], [7], [8]. In order to provide such services, the communication subsystem must be based on an accurate deterministic traffic model that characterizes the source with a minimum set of parameters so as to make an efficient service feasible [3], [9], [10], [11], [12].

The XGOP-B model (*eXtended GOP-Based model*) [9] is a simple and accurate deterministic traffic model for MPEG compressed video streams. MPEG is a standard for video applications and has been widely applied in networked multimedia systems. The XGOP-B model is based on a two-level analysis of MPEG sources, in the frame and group of picture (GOP) levels, and takes advantage of these analysis to yield a specific characterization with fine accuracy [13].

A number of other deterministic traffic models for general variable bit rate (VBR) traffics have been proposed in the literature, e.g. the (σ, ρ) model [12], the $(\vec{\sigma}, \vec{\rho})$ model [3], the discrete $(x_{min}, x_{ave}, I, s_{max})$ model [11], and the D-BIND model [14]. In general circumstances, these models lead to good results. However, they do not consider several MPEG intrinsic properties. Moreover, for most of the models, the procedures to extract parameters from the sources cannot be efficiently performed if the user does not interfere to decide which parameters seem to be the most adequate.

In this paper, we propose and analyze the single-input single-output (SISO) algorithm to compute the traffic parameters for the XGOP-B model. The proposed technique is simple and leads to an accurate characterization at low complexity cost. Furthermore, the required accuracy can be adjusted by a special variable. We show through several analysis the functioning of the SISO algorithm and the improved accuracy obtained for the XGOP-B model.

The following of this paper is organized as follows. Section II introduces the most important concepts for deterministic traffic characterization and presents the XGOP-B model. In section III, the SISO parameter extracting algorithm is detailed and analyzed. Several numerical results and analysis are presented in section IV. Finally, section V concludes this paper.

II. Deterministic Modeling

A deterministic traffic model often makes use of the concept of the traffic constraint function [12]. Consider $\mathcal{G}[t, t+\tau]$ as the number of bits transmitted by the source in the interval $[t, t+\tau]$. A function $\mathcal{F}(\cdot)$ is a traffic constraint function if $\mathcal{G}[t, t+\tau] \leq \mathcal{F}(\tau), t > 0$, i.e., if during any interval of length τ the source does not transmit more than $\mathcal{F}(\delta t)$ bits.

The most accurate traffic constraint function that can be obtained is the empirical envelope [3], defined as $\zeta(\tau) = \sup \mathcal{G}[t, t+\tau], t \geq 0$. However, in practice, representing VBR sources by the empirical envelope may be extremely complex, due to the large number of required parameters. The solution is to choose a simple upper approximation on ζ such that $\mathcal{F}(\tau) \geq \zeta(\tau), \forall \tau$. The most accurate model is the one that minimizes the difference $\mathcal{F}(\tau) - \zeta(\tau)$.

For the (σ, ρ) model, the source is limited to transmit no more than $\sigma + \rho\tau$ bits during an interval of length τ [12]. The $(\vec{\sigma}, \vec{\rho})$ model is an extension of the (σ, ρ) model and defines a two-dimensional array of (σ, ρ), resulting in a piece-wise concave function [3]. The dis-

This work has been supported by CAPES, COFECUB, CNPq, UFRJ, FUJB, PROTEM-CC, REENGE, CNRS, and UVSQ.

crete model uses four parameters to model a traffic, $(x_{min}, x_{ave}, I, s_{max})$, where x_{min} is the minimum interval between two consecutive packet arrivals, x_{ave} is the maximum average interval between two packet arrivals within an interval of length I and s_{max} is the maximum packet size [11]. The D-BIND (*Deterministic Bounding INterval Dependent*) model characterizes a source with the linear piece-wise $R(I)$ function [14]. $R(I)$ corresponds to the maximum transmission rate within an interval I and is parameterized by N pairs $(R_k, I_k), k = 1, 2, ..., N$.

A. The XGOP-B Model

An MPEG [15] coder produces three frame types: I, P, and B frames. These frames are grouped in a cyclic sequence called GOP (*Group Of Pictures*), which contains an initial I frame and some P and B frames, in conformity with a pre-specified pattern, for instance IBBPBBPBB. Most of MPEG video streams have I frames much larger than P and B frames, which results in information bursts at the beginning of each GOP. Moreover, the average increase rate of the empirical envelope of a MPEG video has divergence points that we call breakpoints (ξ), as shows the example of figure 1.

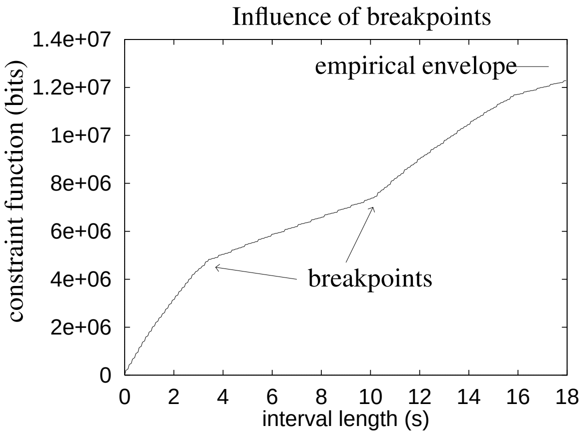


Fig. 1. Influence of breakpoints on the empirical envelope.

The XGOP-B model (*eXtended GOP-Based model*) [9] takes advantage of these two characteristics of MPEG video traffics: the presence of information bursts at the beginning of each GOP, and the breakpoints. For our analysis, consider initially that there are no breakpoints. To adapt to the first property, the XGOP-B model defines two parameters (η, ν). The η factor, called *impulse factor*, models the bursts caused by I-frames. This factor is added to the traffic constraint function at intervals proportional to the GOP size. The GOP size is the number of frames in a GOP. For instance, if the GOP pattern is IBBPBB its size will be 6. The ν factor, named *average factor*, parameterizes the average increase rate of the traffic constraint curve.

In order to capture the breakpoints, the XGOP-B model changes the average inclination of its traffic constraint function at each breakpoint. The empirical envelope is divided in "zones" limited by the breakpoints, as shown in figure 2. We compute then $B+1$ pairs (η_k, ν_k), where B is the number of breakpoints. These pairs, associated with an array of offsets $(\vec{\theta})$ describes the behavior of the traffic constraint function curves within each zone. The final set of traffic parameters is $(\vec{\eta}, \vec{\nu}, \vec{\theta}, \vec{\xi})$ and the correspondent traffic constraint function is given by

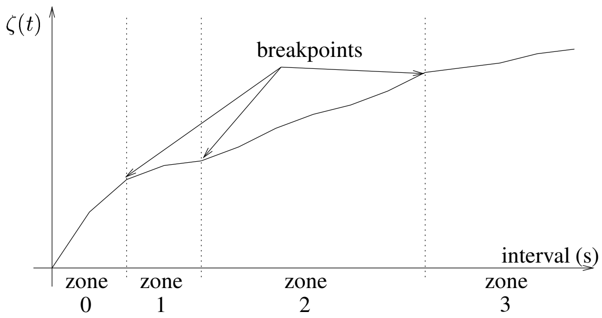


Fig. 2. Empirical envelope subdivided in zones.

$$\mathcal{F}_x(\tau) = \theta_k + \lceil \frac{\delta t + T}{TD} \rceil \eta_k + \nu_k \tau, \qquad \xi_{k-1} \leq \tau < \xi_k, \quad (1)$$

where T is the duration of a frame and D is the GOP size.

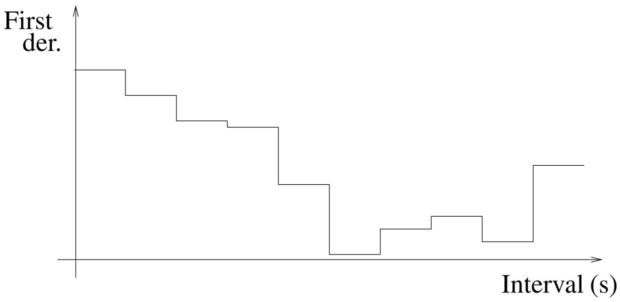
III. Single-Input Single-Output Parameter Extracting Algorithm

For the majority of the models proposed in the literature, the computation of the traffic parameters requires user interaction, which may result in a non-optimized characterization. For example, for the (σ, ρ) model it is quite difficult to choose the best values for σ and ρ in order to obtain a high accurate modeling, since different values can be selected for the same traffic source. If the algorithm leads to a single set of parameters, the accuracy of the characterization does not depend on the users to choose the most appropriate parameters.

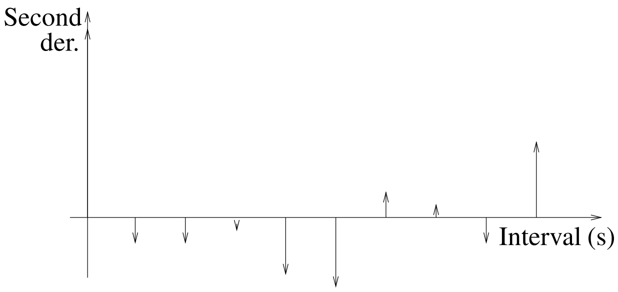
The XGOP-B model defines a structure of parameters that leads to a unique characterization for each traffic source. For this reason, the parameter extracting algorithm is referred as the Single-Input Single-Output Parameter Extracting Algorithm. As the results will show, the algorithm is quite simple and results in high accuracy.

A. Determining the Breakpoints

The SISO parameter extracting algorithm comprises two main steps: the reckoning of breakpoints and the computation of the effective parameters. The first step is to develop a mathematical procedure to identify the breakpoints. First, we define a function that corresponds to the successive inclinations of the empirical envelope. This function stores the transmission rate of the source per time unit. These inclinations are calculated at intervals proportional to the GOP size, resulting in the *first derivative function* (figure 3(a)). Based on this function, we calculate a discrete representation of the non-zero variations of the first derivative function, which results in the *second derivative function*, as shown in figure 3(b).



(a) First derivative function.



(b) Second derivative function.

Fig. 3. Derivative functions.

It must be distinguished among the points plotted in figure 3(b) the ones to be identified as breakpoints. This identification is performed according to the amount of accuracy required by the user. If a large number of points are chosen, more accurate is the the model, since a greater number of parameters are determined. On the other hand, if fewer points are selected, the model is simpler but less accurate. For this purpose the parameter extracting algorithm defines a variable β called QoM (Quality of Model) which is the key to the determination of the breakpoints. The algorithm is performed in conformity with the following propositions:

Proposition 1: Given an inclination, a breakpoint ξ is identified if this inclination varies, negatively or positively, of a factor β, with $\beta > 0$.

Proposition 2: A breakpoint ξ is identified if the sum of an uninterrupted sequence of second derivatives varies, negatively or positively, with regard to the first inclination of this sequence, of a factor β, with $\beta > 0$.

B. Computing the Parameters

As shown in section II-A, for each zone bounded by two breakpoints, the XGOP-B model defines a set of three parameters: the impulse factor η, which corresponds to impulse information; the average factor ν, that models the average increase rate; and the θ parameter, which corresponds to the offset of the curve. In this section we present the method to extract parameters for the first zone, but it can be easily extended to the other zones by simple translation of the x-y axis.

The basic input to the algorithm is the $\zeta[\cdot]$ array, which is a discrete representation of the empirical envelope. In this array, $\zeta[n], n \geq 0$, is the value of the empirical envelope for the interval equivalent to nT, where T is the duration of a frame. In the array, the entries correspondent to the impulses (I frames) are

$$n^k_{imp} = 1 + kD, \quad 0 \leq k \leq \left\lfloor \frac{(M-1)}{D} \right\rfloor, \tag{2}$$

where M is the last position of the array (i.e., the last value in the zone) and D is the GOP size. The value of η is then calculated as $\eta = \max\{n^k_{imp}\}$, which is equivalent to the worst-case impulse within the zone.

The average increase rate of the empirical envelope is calculated as follows. The parameter ν is initially set to the slope of the straight line between $\mathcal{F}(0) = \eta_0$ and $\zeta[D]$ for an interval of $(D-1)$ frame periods (figure 4(a)),

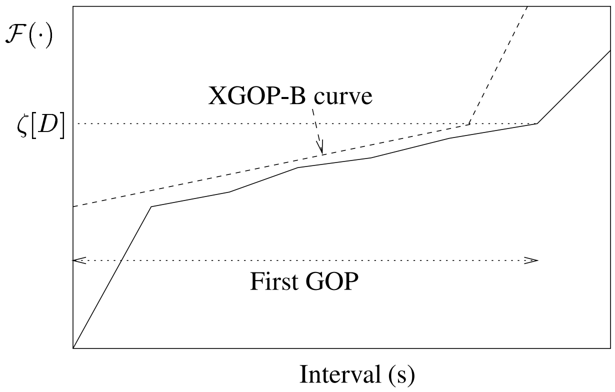
$$\nu = \frac{\zeta[D] - \mathcal{F}(0)}{(D-1)}. \tag{3}$$

Note that this does not guarantee that this curve is a deterministic characterization of the source. It must be assured that the difference $\mathcal{F}_x(\tau) - \zeta(\tau)$ is positive $\forall \tau$. Figure 4(b) shows an example where this requirement is not satisfied. To eliminate this possibility, the algorithm performs a loop that checks the traffic constraint function for each $\tau = kT$, where $0 < k < M$. To illustrate this procedure, consider the first GOP of the function, i.e., the curve between $\zeta[0]$ and $\zeta[D]$. For each $0 \leq p \leq D$, if $(\mathcal{F}_x(\tau) - \zeta(\tau)) < 0$ then a new ν is computed through the following pseudo-code:

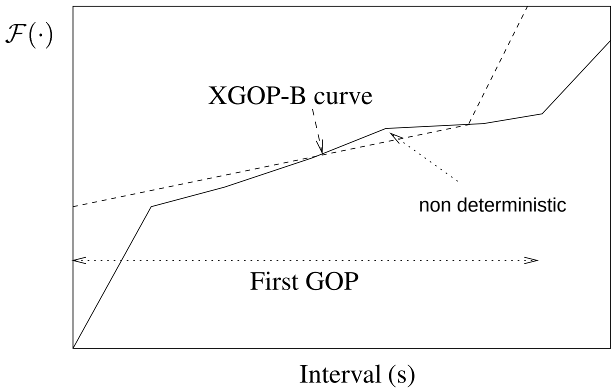
for $p = D$ downto 0
  if $((\mathcal{F}_x(pT) - \zeta[p]) < 0)$ then
    $\nu = \frac{\zeta[pT] - \mathcal{F}(0)}{p}$

It is not necessary to change the parameter η since the adjustment of ν is sufficient to keep the traffic constraint curve totally deterministic. The next step is to calculate the proper offset values for each zone. Since the first point of the traffic constraint function in each zone[1] is known, and considering that η and ν have already been computed, θ is obtained directly from

[1]For a zone limited by ξ_{k-1} and ξ_k, the first point is given by $\mathcal{F}_x(\xi_{k-1}T) = \zeta[\xi_k]$.



(a)



(b)

Fig. 4. (a) Deterministic and (b) non deterministic characterization.

$$\theta_k = \mathcal{F}_x(\xi_{k-1}T) - \left\lceil \frac{(\xi_{k-1}T) + T}{TD} \right\rceil \eta_k - \\ -\nu_k(\xi_{k-1}T). \qquad (4)$$

IV. Results

We have simulated the SISO algorithm with actual M-PEG video traces [16]. These video streams were coded from films, sportive events and TV shows.

In the first part of this section, the tradeoffs between the quality adjustment given by the β factor and the numbers of breakpoints is evaluated. This must be estimated since the number of traffic parameters is proportional to the number of breakpoints. By adjusting the value of the β, this tradeoff is controlled. Figure 5 shows the effect of β on the number of breakpoints for four video traces. At the time of the admission control, the source can send this information to the network together with the respective levels of accuracy. The admission control mechanism then uses these values to decide if the connection should be accept or not.

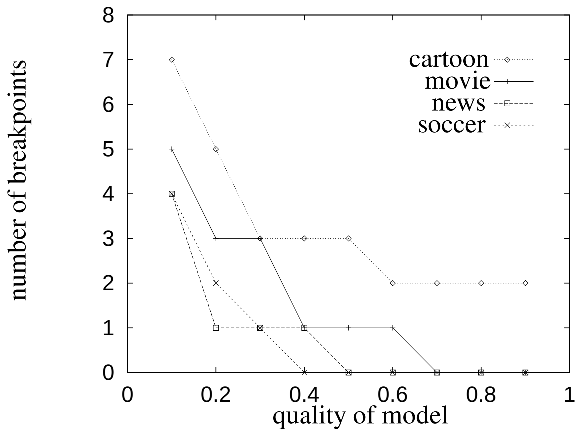


Fig. 5. How β affects on the number of breakpoints.

Table I presents a quantitative comparison of the number of parameters for the XGOP-B and D-BIND models. We have compared the XGOP-B with the D-BIND model since the D-BIND model is the only one that leads to levels of accuracy compatible with the XGOP-B model. Comparing the complexity of two models that do not lead to the same levels of accuracy might be unfair.

TABLE I

Complexity in terms of number of parameters.

	D-BIND	XGOP-B
Movie	28	20
News	16	16
Soccer1	26	16

In [14], the authors suggest for the D-BIND model a number of (R, I) pairs between 4 and 8. In order to compare the models in a similar basis, we have chosen the number of parameters that led to the same level of accuracy. If we had used the suggested values, we would have not been able to fairly compare the models, since the D-BIND model would have not achieved the same level of accuracy of the XGOP-B model. The results show that, for example, to perform admission control, the XGOP-B model leads to reduced complexity, due to the small number of traffic parameters.

We have also compared the models in terms of the Modeling Approach Loss (MAL). MAL indicates how much a traffic constraint function diverges from the empirical envelope. For each traffic constraint curve, the respective MAL is obtained from the difference of the area under the traffic constraint curve ($S_{\mathcal{F}}$) and the area under the curve given by the empirical envelope (S_ζ), which corresponds to

$$MAL = \left(\frac{S_{\mathcal{F}}}{S_\zeta} - 1\right) 100\%. \qquad (5)$$

It should be observed that the smaller is the value of

TABLE II

MODELING APPROACH LOSS FOR EACH MODEL.

	Modeling Approach Loss (%)				
Video	(σ, ρ)	$(\vec{\sigma}, \vec{\rho})$	Discrete	D-BIND	XGOP-B
1. bond	44.02	2.16	31.75	1.48	0.41
2. lambs	30.56	3.42	20.31	2.23	1.63
3. movie	6.96	1.55	76.96	1.49	1.61
4. news	7.44	2.56	33.67	2.47	1.58
5. soccer	7.21	2.20	39.58	1.53	1.22
6. video	6.79	5.42	13.49	5.18	1.93

MAL, more accurate is the function. In the particular case where MAL = 0%, the two curves meet and the maximum accuracy is obtained, since the empirical envelope is the most precise function.

Table II shows the results for the analyzed video traces. For the discrete model, the algorithm performed with the interval equivalent to one GOP size, i.e., $I = 540ms$. For the XGOP-B model, the QoM is $\beta = 1\%$. The results show the high accurate characterization obtained by the XGOP-B model and prove that the XGOP-B model really captures the intrinsic properties of MPEG video sources. This is translated in modeling approach loss that are in some cases up to 70% lower than the best result obtained by the other models.

The methodology studied in this paper is applied to stored video traffics. This means that the global complexity must be estimated by the number of parameters *vs* accuracy and by the traffic constraint function complexity. The complexity of the parameter extracting algorithm is not considered since this algorithm is not performed in real-time. The proposed methodology results in weak complexity because of the reduced number of traffic parameters for higher levels of accuracy.

V. CONCLUSIONS

We proposed in this paper the Single-Input Single-Output algorithm to extract deterministic parameters from MPEG compressed video traffics. Contrary to other proposals, we have shown that, as this algorithm performs automatically, we have always only one set of traffic parameters for each input traffic. We showed that it is important to obtain an accurate characterization without the user's intervention on what parameters are the most adequate. The simulation analysis performed over different MPEG video traces proved that the XGOP-B model achieves lower inter-model distance from the most accurate characterization, which is quantified by calculating the achievable modeling approach loss (MAL). Furthermore, by the adjustment of a special variable, we can control the number of parameters. The numerical results showed that the proposed methodology achieves a high modeling accuracy with a reduced number of parameters if compared to the most accurate traffic models proposed in the literature.

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