STOCHASTIC FEATURES OF VBR VIDEO TRAFFIC AND QUEUEING WORKING CONDITIONS: A SIMULATION STUDY USING CHAOTIC MAP GENERATOR

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Abstract The paper presents a simulation study on the impact of LRD and SRD on a simple queueing system and shows that, while for short buffers an analytically tractable SRD model may suffice to capture the long–term loss probability, for systems with large buffers the effect of LRD can be significant. The main contribution of this paper consists in highlighting this evidence through simulations driven by synthetic traces (generated by traditional AR models and LRD Chaotic Map Generator), measured data and shuffled versions of them.

Keywords: Packet Video, Chaotic Map Generator, Short Range Dependence (SRD), Long Range Dependence (LRD).

1. INTRODUCTION

The discovery of long memory characteristics in the traffic generated by new broadband services, such as LAN-to-LAN interconnection, high speed data transport over geographical backbones and VBR video, indicates the self-similar models as promising mathematical tools able to take into account the LRD of real traffics in a parsimonious manner [1]. These long memory properties presented by self-similar processes are indicated like the new burstiness measure: the fractal behaviour of the acquired traces arises from a sort of independence of variations and fluctuations in the activity of sources over several

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time scales. For this reason a definition of burstiness linked to a specific time scale or to the burst length concept is inadequate.

Two kinds of problems come out from these experimental evidences: self-similar queueing performance analysis and discrete event simulation driven by synthetic self-similar traces. They are needed in the design of new traffic management and control schemes [2] which should take into account the actual statistical behaviour of multimedia sources.

The analytical works on queueing systems loaded by LRD arrival processes are restricted to the evaluation of asymptotic relations or bounds for the complementary probability of the queue occupancy with infinite buffer [3][4].

The generation of self-similar traces (see [1] for some generation algorithms), needed in the simulation studies, is much more complex than producing arrivals corresponding to renewal or SRD processes.

Teletraffic researchers are in agree with the strong influence of the long memory features of real traffic on performance of infinite buffer size queueing systems [5]. On the other hand the accuracy of LRD models in operating networks with relatively small buffers is becoming a key debate topic. In this paper we want to emphasise the relevance of the process memory vs. the queueing memory, i.e. the effects of short and long range correlation for different buffer sizes and in different loading conditions. The queueing performance comparison is carried out by means of discrete event simulation considering a single server queue with deterministic service time (simplified model of an ATM network element), fed by videoconference, videophone and entertainment video sequences, whose long memory nature was shown in [6], and by synthetic traces. Traditional self-similar generators, based on statistical methods, are computationally expensive; on the other hand, in this paper we use a fast traffic generator that follows a completely different approach. The generator has been defined developing the idea of producing LRD sequences by means of chaotic deterministic monodimensional systems that were introduced as suitable traffic models in [7]. The model is very simple and can be characterised by few parameters (parsimonious modelling).

In the paper, after a survey of the analysed traces and a description of the Chaotic Map Generator (CMG), we analyse the implication of SRD and LRD on queueing performance. Finally, the main results are collected in the Conclusions.

2. DESCRIPTION OF VBR PACKET VIDEO TRACES

The actual data used to drive the discrete event simulations are obtained by measuring sessions of three different video services: videoconference, videophone and entertainment video. The first one is a videoconference session corresponding to three people in front of a 3-CCD camera, while the second

Table 1.1 Analysed Trace Data

Trace Name	Number of frame	Average (Mbit/s)	Peak/ Mean Ratio	Frame rate (frame/s)	Mean Compr. Ratio
1-Vconf	48496	1.668	4.8	25	39.78
2-Vphone	182353	1.634	8.25	25	56.52
3-"Star Wars"	171000	5.336	2.82	24	8.7

is a long videophone session (a man carrying on a videophone call). These two sequences were produced by a prototype coder described in [8]. The last sequence is an example of entertainment video, namely the movie "Star Wars", corresponding to a frame by frame coding scheme similar to JPEG [9]. Some statistical characteristics of the traces are shown in Table 1.1.

Each sequence corresponding to the number of bytes per frame can be seen as a sample path of a discrete-time second order wide sense stationary process $\{X_n\}_{n\in\mathbb{N}}$ with autocorrelation function $r(k)$ and power spectral density

$$S(f) = \sum_{k=-\infty}^{\infty} r(k)e^{-i2\pi kf}$$

Considering the hyperbolic decay of the autocovariance function of LRD processes

$$r(k) \propto k^{-\beta} \text{ as } k \to \infty$$

and that in the self similar modelling $\beta = 2 - 2H$, we can use the Hurst parameter, H, as a measure of the long memory properties of actual traffics. Among the different methods employed for the estimation of H [1] the so called Variance Time statistic is one of the most widely used; the results of its application to the considered traces are reported in Table 1.2 (see [6] for further details).

Table 1.2 Estimation of the Hurst parameter by means of the v-t plot

Trace	Videoconf.	Videophone	"Star Wars"
$\hat{H}$	0.68	0.69	0.78

3. CHAOTIC MAP GENERATOR (CMG) FOR BROADBAND TRAFFIC

Recent measurements carried out in Bellcore have shown that the long memory of real traffic in a LAN interconnection scenario arises as a consequence of network element interactions that can be modelled as heavy tailed ON–OFF processes [10]. According to this physical approach and taking into account that VBR video traffics present equivalent statistical features, we consider a traffic generator obtained by the superposition of independent ON–OFF sources. Each elementary source is modelled by a discrete time monodimensional dynamic system, whose state evolution is described by a chaotic map. The synthetic data are obtained by a two-level quantization, with an adequately chosen threshold c, of the map state $x(n)$ at step n. Several deterministic maps (such as Bernoulli Shift, the Liebovitch Map and the Intermittency Map [7]) have been proposed for traffic traces generation. As far as broadband networks are concerned, a modified version of the Intermittency Map is particularly attractive since it generates sequences exhibiting the characteristics of asymptotic self-similar processes. The deterministic mapping that defines the Intermittency Map is the following:

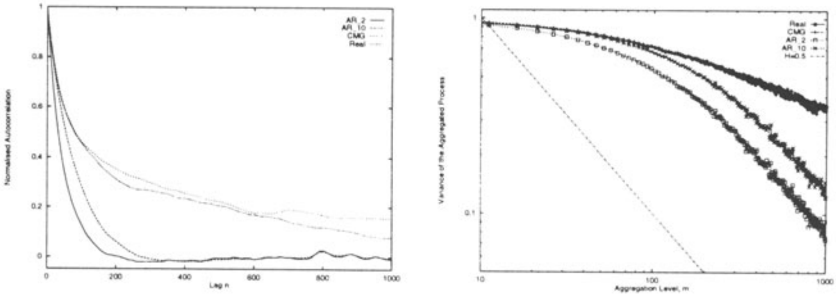
$$x(n+1) = |x(n) + x^z(n)|_{\mathrm{mod}\,1} \tag{1}$$

while the two-state output of the relative ON–OFF model is:

$$y(n) = \begin{cases} 0 & \text{if } 0 < x(n) \leq c \\ k & \text{if } c < x(n) < 1 \end{cases} \tag{2}$$

The output data are generated producing, by means of the map, the number of packets transmitted during each time interval, which can either be empty or contain k packets. The relevant property of the proposed map is that, unlike classical ON–OFF models, the marginal distribution of the OFF period length is heavy tailed [7] for values of c close to zero; the z parameter permits to control the decay of this marginal and the long term decay of the autocorrelation function. This characteristic of the generated sequence makes the model particularly suitable as the basic component of a long memory traffic generator and real traffics can be reproduced by the aggregation of many independent heavy-tailed sources:

$$\begin{cases} x_i(n+1) &= |x_i(n) + x_i^z(n)|_{\mathrm{mod}\,1} \\ y_i(n) &= \begin{cases} 0 & \text{if } 0 < x_i(n) \leq c \\ k & \text{if } c < x_i(n) < 1 \end{cases} \end{cases} \tag{3}$$



(a) Autocorrelation

(b) Variance Time

Figure 1 Comparison among the different "Star Wars"-related sequences

$$y(n) = \sum_{i=1}^{N} y_i(n) \tag{4}$$

where $y_i(n)$ represents the output of the i-th map (with $i = 1, \ldots, N$) at time n and the sum (4) gives the output sequence $y(n)$, representing the number of cells per frame. The fitting of traffic data, described in [11], involves the determination of the four parameters that define the CMG (z, c, k and N) considering the statistical features of the trace itself (mean, variance and autocorrelation function).

The results of the fitting procedure, carried out considering for instance the "Star Wars" trace, highlight that the CMG is unable to reproduce some very pronounced peaks characterising the real trace. However it permits to capture the persistence characteristics of data pattern, eyeballing evidence of the LRD property.

To compare the fitting properties of the proposed model with respect to traditional SRD ones, figure 1 presents the autocorrelation functions and the VT plots for the "Star Wars" sequence (similar results are obtained with the other traces), the one of the proposed CMG and those of two Autoregressive models (AR(2) and AR(10) respectively), which were used in the past as suitable models for VBR traffic [12]. It is remarkable that the growth of the AR model order is not particularly relevant since that approach is not able by itself to capture the LRD behaviour in a parsimonious way.

4. SRD & LRD IN VBR VIDEO TRAFFIC

To identify in which cases the LRD of VBR traffic is more critical than short lag correlation in queueing performance, we extended to a finite buffer scenario the approach originally proposed in [5]. In order to consider only the effect of the correlation structure without any influence from the marginal distribution of the model, we produced several traces, some of which maintain only the LRD of the original video sequences while others preserve only their SRD. This was possible by shuffling fixed size blocks of the considered traces. In particular, after subdividing the original data into non overlapping blocks of adequate size, two different procedures can be employed:

- external shuffling: the positions of the blocks are changed preserving the inside sample arrangement. This operation destroys LRD, while maintains SRD;
- internal shuffling: only the sample arrangement inside each block is modified, destroying in this way only SRD.

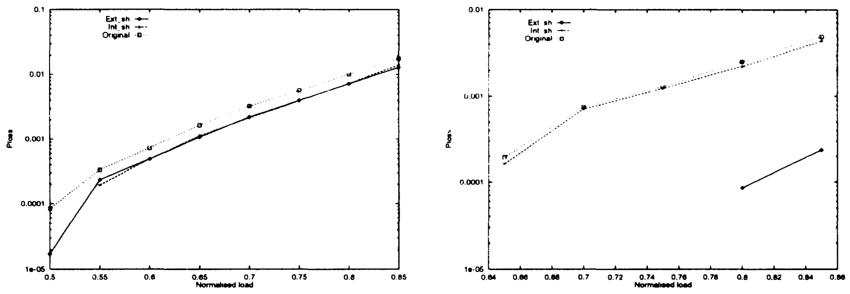
The choice of the block size determines the threshold lag of the correlation structure over which the statistical properties of the original trace are modified or preserved. In order to highlight the difference between LRD and SRD, we have chosen a block size B_s around 100 samples.

5. SIMULATION ANALYSIS OF QUEUEING PERFORMANCE

Our analysis is directed to evaluate, by means of trace driven simulations, the implications that traffic process memory has on performance of a single server queueing system with finite buffer size, N_w, and deterministic service time ($VBR/D/1/N_w$). To highlight the effects of correlation, we considered either two traditional autoregressive (AR) models of different orders (namely 2 and 10), able to fit the autocorrelation function only for relatively short lags, and CMG sequences, that preserve the LRD properties of real traffics. Moreover, as mentioned in the previous section, we shuffled the original data in order to test the effects of other statistics (shuffled sequences preserve the marginal and the chosen term – LRD or SRD – of the autocorrelation structure) on queueing performance.

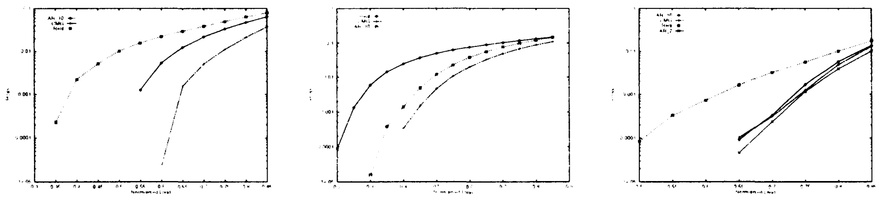
The results are compared in terms of cell loss probability P_L, varying the normalized offered load A_0, i.e. the ratio between the mean arrival rate and the service rate.

Analysing the simulation results, we observe that for relatively short buffers (N_w=5000 cells) the performance of the shuffled data are very close to those obtained with the real trace (see figure 2(a)) in spite of the captured autocorrelation component. A slightly different behaviour can be observed only for low values of A_0 (around 0.5), where no loss is produced by the LRD-preserving trace, while the P_L determined with external shuffling is comparable to the actual value.



(a) N_w = 5000 cells (b) N_w = 50000 cells

Figure 2 Effects of internal and external shuffling over P_L

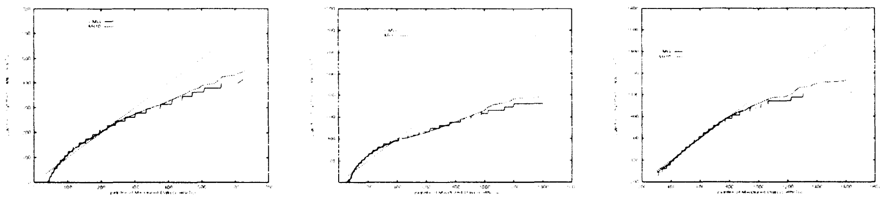


(a) VConf (b) Vphone (c) StarWars

Figure 3 P_L Comparison: LRD vs. SRD models (N_w = 5000 cells)

In figure 3 the comparison is extended to the mentioned synthetic traces for the three test sequences: the performance obtained with all the different models (characterised by gaussian marginals) is very similar, but quite different from the real curves, whose distributions present heavier tails than the empirical distribution of synthetic sequences (for "Star Wars", see [9]). This is confirmed by figure 4, which presents the Q-Q plots for the CMG and AR(10) synthetic data fitting the three considered sequences. The Q-Q plot is a goodness-of-fit test for the marginal distribution of a data set and it is obtained representing the quantile of the distribution model under examination vs. the quantile of the empirical distribution of considered data [13]. In our case, we substitute the distribution model with the empirical distribution of the synthetic traces in order to take into account the differences from the theoretical model introduced by the setting of all negative samples to zero.

The P_L analysis for N_w = 5000 points out the poor influence of the long-term autocorrelation structure for short buffers and highlights the relevance of other statistics, like marginal distribution of the cell rate.



(a) VConf (b) Vphone (c) StarWars

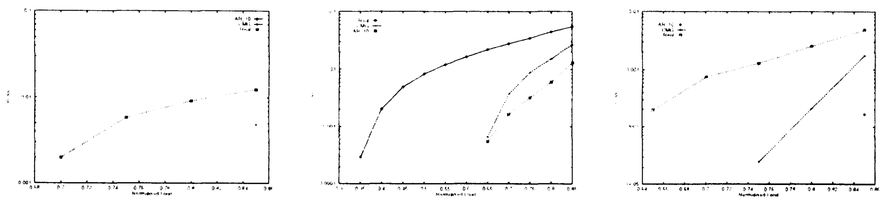
Figure 4 Q-Q Plots for the CMG and AR(10) synthetic data for the considered sequences

Increasing the buffer size (N_w=50000 cells), the performance with SRD traces goes away from the real one, while that of LRD data draws near (see figure 2(b)). In particular we have observed that long term correlation provokes a dramatic decrease in queueing performance as soon as the offered load exceeds a given threshold (no losses are observed for $A_0 < 0.65$).

The comparison of P_L for the original trace, the CMG and the AR models (see figure 5) points out that, as buffer size grows, only the CMG generator permits to estimate reasonable P_L values (at least for traces *b* and *c*), although even the latter seems to be less critical than the original data (compare the curves in figure 2(b) and 5(c)), because of the marginal distributions that have not been considered in the fitting procedure.

For sake of simplicity, we have considered the AR(2) model only for the "Star Wars" trace, observing no loss over the whole range of normalised loads. The AR(10) traces provoke losses only for $A_0 \geq 0.85$ for trace *c* and no loss for all normalised load values for trace *a*.

The simulations confirm that in case of short buffers, also traditional models could be a correct approach in simple queueing performance evaluation, while LRD must be taken into account in case of longer buffers.



(a) VConf (b) Vphone (c) StarWars

Figure 5 P_L Comparison: LRD vs. SRD models (N_w = 50000 cells)

6. CONCLUSIONS

The goal of this paper is to show, by means of simulation studies, the implications of LRD and SRD on queueing performance considering finite buffer systems. The modelling of VBR video traces using self-similar processes implies a more complicated analytical evaluation of the queueing behaviour. Unlike the case of Markovian modelling approaches used to design networks with narrowband services, closed-form results have not been obtained yet. At the state of the art, few bound approximations, involving complicated mathematical tools, such as Large Deviations Theory [3], were presented only for infinite buffers.

From this study we deduce that in case of short buffer systems it is not needed to consider long term correlation because the queueing behaviour is mainly determined by the short term correlation structure of ingoing traffic, while in case of long memory queueing systems we have to take into account the LRD of the input traces.

This result is particularly relevent since in the real network environment the trend is toward the use of short buffers (around some thousands of cells), especially when real-time services, such as the transport of VBR video information (i.e. videoconference and videophone services) in a broadband network, are involved.

Moreover, irrespective of the buffer size, a relevant role is also played by the marginal distribution. This is confirmed by the different results obtained with shuffled traces, with the same marginals of the original data, and synthetically generated sequences, characterised by gaussian distribution: only the first case gives a queueing behaviour very close to the actual one (if the above rule for the correlation structure is matched).

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