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ORIGINAL ARTICLE

Self-similarity and stationarity of increments in VBR video

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Abstract As self-similarity trail is being detected in many types of traffic, and the Markovian models failing to represent some statistical behaviors, the tools being used for traffic testing are still complex. Our study here is related to VBR video. Its self-similarity and long-range dependence aspects will be tested using a wavelet-based tool. As the test tool requires stationarity of the increments of the traces, a novel testing technique will be suggested for this aim. Then, the degree of self-similarity will be related to both the traces time scale and its statistical measures of spreading.

1. Introduction

The pervasive ubiquitous support of multimedia traffic over communication networks, including the Internet and wireless mobile networks, imposed very stringent requirements on the coding schemes used to generate these types of traffic and led to many developments in related areas. Consequently, very complex features and characteristics of the generated traffic. Thus, many advanced techniques in motion estimation, such as multiple reference frames, variable block sizes, and quarter pixel resolution have been implemented in the new H.264/MPEG-4 AVC standard. A very high computational complexity has been engendered, which led to many research works to optimize it. The use of the stationarity characteristic has been the key element in most of them. Using spatial homogeneity and temporal stationarity of video objects, a decision algorithm has been proposed in Wu and Al (2005), while a selective multiple reference frame motion estimation that uses the stationary property has been suggested in Tsui et al. (2010).

In many instances, however, stationarity is not necessary, only stationarity of increments is sufficient. For instance, the authors in Wendt and Abry (2007) propose a new bootstrap-based technique to differentiate between non-Gaussian finite variance self-similar processes with stationary increments and multi-fractal processes. The goal of our study here goes along these lines. We will propose a correlation-based test for the existence of stationarity of increments in video traffic characterized by some form of self-similarity.

Accurately modeling such traffic has become a crucial part of many research groups. Initially, it was concluded that the simple Markov Modulated Poisson Process (MMPP) models inadequate for the representation of such traffic (Garret and Willinger, 1994; Ryu and Elwalid, 1996; Pruthi et al., 1999) were far from adequate. Even relatively more complex models, that assumed short-term correlation, have failed as well. The repercussions of such findings on the performance and analysis of current data networks have been very drastic. For instance, it was reported very early (Park and Willinger, 2000), that the existence of self-similarity and ubiquitous heavy-tailed

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phenomena in networked systems will have a drastic effect on traffic modeling, queueing-based performance analysis, and traffic control.

In this paper, a tool proposed by Leland et al. (1994) will be used to test a couple of representative VBR video traces for self-similarity trail. Since the tool requires the stationarity of increments in the trace frame sequences, a very efficient tool has been proposed, implemented, and tested on the used traces. All results were conclusive and in harmony with the preset assumptions.

The rest of the paper is organized as follows. In Section 2, the characteristics of VBR video and the models that have been used will be given along with a description of the video traces to be used in this study. In Section 3, some conventional testing techniques will be presented, along with the wavelet-based technique to be used in this work. Then, in Section 4, some novel feasiblity tests will be developed to check the stationarity of the increments of the considered traffic sequences. In Section 5, the stationarity test will be first applied, followed by tests on the effects of the used number of vanishing moments in the test tool, and lastly, by the results obtained when applying the test tool to estimate the self-similarity trail in the video traces, along with a look at any possible correlations with the spreading parameters of the traces. The conclusions will be included in Section 6.

2. VBR video traffic

2.1. Characteristics

The main factors affecting the complexity of multimedia traffic may be classified into three main categories:

- *Inherent aspects*: This takes care of the fact that the movements that may be recorded, for instance in a video sequence, have in general some common aspects that may be translated into some sort of short and long-term correlation between successive frames.
- *Compression and coding*: The techniques being used take advantage of the previously listed inherent aspects. They take advantage of both the spatial and temporal correlations in the scene and the frames.
- *Traffic shapers*: In some networks, some quality of service (QoS) is provided. The user has to abide by certain traffic constraints which will be enforced through special traffic shapers. Although, this will not add to the correlation aspects of the traffic, it will add to its complexity.

2.2. Modeling

Due to the cumulative effects of these technological advances, modeling video traffic has become a tedious and complicated task. Mathematical models of video sources tried to keep pace with these advances. The developed models may be classified into two categories. Markovian (or Embedded Morkovian) models, which is based on the memory-less property, and takes into consideration only the short-term correlation properties. Examples include Markov Modulated Poisson Process model (Heffes and Lucantoni, 1986), Markov Modulated Fluid model (Anick et al., 1982), Versatile Markovian Arrival Process model (Neuts, 1989), Memory Markov Chain model (Rose, 1999), and D-BIND model (Knightly and Zhang, 1997).

The second category includes long-range correlation models, which tries to capture a peculiar behavior found in certain processes where the autocorrelation function decays to zero at a rate slower than the exponential function. Examples include F-ARIMA (fractional autoregressive integrated moving average) (Beran et al., 1995), FBM (fractional brownian motion) (Taqqu and Levy, 1986; Norros, 1995), FGN (fractional Gaussian noise), highly variable ON-OFF sources (Likhanov et al., 1995; Willinger et al., 1997), and $M/G/\infty$ model (Krunz and Makowski, 1998).

As the major new character in the current video traffic may be related to its long-range dependence, some models based on *self-similarity* have been proposed lately. The notion of *self-similarity* is based on fractals, where zooming in or out keeps the general object shape the same. In the case of network traffic, this notion is known in the stochastic sense not the topological sense. In the stochastic sense, *self-similarity* is applied to the statistical aspects as the time scale is varied. The self-similarity property has been identified, although with various degrees of conclusiveness, in Ethernet-LAN traffic (Willinger et al., 1997), in the World Wide Web traffic (Crovella and Bestavros, 1997), in ATM queues (Tsybakov and Georganas, 1997), and recently in multimedia networks (Sahinoglu and Tekinay, 1999).

Table 1 Basic statistics of the traces.

Trace name	GOP frames			I-frames		
	Mean	Covar	Peak/mean	Mean	Covar	Peak/mean
Terminator	10,905	1.03	7.30	37,388	0.22	2.13
Soccer	27,129	0.96	6.90	79,143	0.32	2.37
Starwars	9313	1.39	13.40	44,012	0.32	2.84
Talk	14,537	1.14	7.35	64,734	0.16	1.65
News	20,664	1.26	9.41	85,420	0.30	2.28
Race	30,749	0.69	6.58	79,241	0.26	2.35
Lambs	7311	1.53	18.36	38,024	0.34	3.53
Dino	13,078	1.13	9.15	55,076	0.21	2.17

2.3. Traces

The work to be undertaken will be based on video traces used in Rose (1999). The traces were extracted from MPEG-1 sequences which have been encoded with the Berkeley MPEG-encoder. The frame sizes are in bits, and were generated with a capture rate of 25 frames per second (for more information consult Rose (1995)). The basic statistics of the traces (variations of these were reported in Rose (1997)) are shown in Table 1.

3. Self-similarity trail

3.1. Conventional tests

Before applying the considered tool, some well established test will be first applied to the considered video traces. We will start with a graphical test to have an a priori sense of the existence of self-similarity in these traces. From the essence of self-similarity, we present two such methods: