MODELING THE SELF-SIMILAR BEHAVIOR OF PACKETIZED MPEG-4 VIDEO USING WAVELET-BASED METHODS

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ABSTRACT

Video streaming has already been very popular on the Internet through services such as news bulletins from different parts of the world and on-demand music-video clips. With rapidly developing wireless technologies, video streaming to mobile devices will be very common. In this paper, we investigate the self-similar scaling behavior that is present in variable bit rate (VBR) MPEG-4 video. As the usage of video services over packet-based wireless networks increases, new workload models will be necessary to study the quality of service aspects of video traffic. A key finding of our study is that MPEG-4 video encoder output traffic has fractal behavior and this behavior exists regardless of the compression ratio.

1. INTRODUCTION

A significant amount of research has been carried out on the performance implications of the self-similar nature of network traffic on network performance since the groundbreaking study of Leland, Taqqu, Willinger, and Wilson on the self-similarity of Ethernet traffic [1] in 1993. Since then, it has been shown that certain kinds of network traffic exhibit self-similarity over many time scales.

Variable bit rate (VBR) video has been shown to exhibit long-range dependence [2, 3]. This is mainly due to the fact that the adjacent pictures in a video cannot be too different from each other and this generates substantial autocorrelation in the frame sizes that are next to each other. Although long-range dependence does not necessarily imply self-similarity, it is a characteristic of self-similar processes. Therefore, VBR video may exhibit interesting scaling behavior.

Traditionally, video sources have been modeled by short-range dependent models such as Markov chains. A number of studies have shown the suitability of these models when evaluating the performance of video traffic in the network. The irrelevance of long-range dependence for the video traffic when designing buffers is discussed in [4, Chapter 12].

However, the video community is increasingly using the Moving Pictures Expert Group (MPEG) standards. MPEG coding involves transmitting an I-frame periodically to protect against transmission errors. The resulting periodic time series may not be directly modeled by stationary, short-range dependent models.

Web and video traffic have started to constitute a significant portion of Internet traffic and will also be the dominant sources of wireless traffic in the near future. MPEG-4 standard is particularly designed for video streaming over wireless networks. In this paper, we look at very recent MPEG-4 traces generated by an MPEG-4 coder. We draw conclusions about the scaling behavior of the MPEG-4 video at the source using wavelet-based methods to identify uniform or non-uniform scaling behavior over fine time scales. A simple model that uses only a few parameters, such as wavelet coefficients, yet characterizes the bursty behavior of the video source can be very useful for assessing the quality of service that will be experienced by the receiver. Model parameters can be used to make admission control decisions when responding to video requests from clients.

In Section 2, we give an overview of the mathematical concepts used throughout the paper. In Section 3, we describe the video traces and the tools we used in analysis. In Section 4, we present the results of the analysis. Finally, in Section 5, we close with discussion and conclusions.

2. BACKGROUND

In this section, we briefly introduce the mathematical concepts used throughout the paper. Most of the material is summarized from [4-7]. Please refer to these references for details.

A process $\{X(t) \mid t \in \mathbb{R}\}$ is self-similar with Hurst parameter $0<H<1$ if $X(0)=0$ and $\{X(at) \mid t \in \mathbb{R}\}$ and $\{a^H X(t) \mid t \in \mathbb{R}\}$ have the same finite-dimensional distribution [4]. H measures how the entire process scales from one time scale to another.

Let us define the wavelet and scaling functions that form an orthonormal basis in L^2 as:

$$\psi_{j,k}(t) = 2^{j/2}\psi(2^j t - k) \quad (1)$$

$$\phi_{j,k}(t) = 2^{j/2}\phi(2^j t - k) \quad (2)$$

for $j, k \in \mathbb{Z}$.

Then, a signal $X(t)$ can be represented as the expansion, for $j, k \in \mathbb{Z}$:

$$X(t) = \sum_k c_{J_0,k}\phi_{J_0,k}(t) + \sum_{j=J_0}^{\infty}\sum_k d_{j,k}\psi_{j,k}(t) \quad (3)$$

$$c_{j,k} = \left\langle X(t), \phi_{j,k}(t) \right\rangle \quad (4)$$

$$d_{j,k} = \left\langle X(t), \psi_{j,k}(t) \right\rangle \quad (5)$$

where J_0 corresponds to the coarsest scale used by the expansion. The coefficients $c_{j,k}$ and $d_{j,k}$ correspond to the Discrete Wavelet Transform (DWT) of the signal.

When J_0 approaches $-\infty$, we have:

$$X(t) = \sum_{j,k} d_{j,k}\psi_{j,k}(t) \quad (6)$$

where $d_{j,k}$ are the wavelet coefficients.

A function is pointwise Lipschitz $\alpha>0$ at ν, if there exists $K>0$, and polynomial p of degree $m=\lfloor\alpha\rfloor$ such that $\forall t \in \mathbb{R}$:

$$\left| f(t) - p(t) \right| \le K \left| t - \nu \right|^{\alpha} \quad (7)$$

Lipschitz regularity of a function at ν is the sup of α such that the function is Lipschitz α. Lipschitz regularity is used to characterize singular structures.

Fractals are signals that are singular at almost every point. Most fractals are self-similar. Multifractals are signals whose singularities vary from point to point. In general, one cannot compute the pointwise Lipschitz regularity of a multifractal since its singularities are not isolated. Therefore, a wavelet-based partition function is defined as

$$Z(q, j) = \sum_k \left| C_j d_{j,k} \right|^q \quad (8)$$

where C_j is a normalizing constant and $d_{j,k}$ are the wavelet coefficients. Note that an abrupt burst in the signal generates a large wavelet coefficient, which in turn gets magnified by taking the q^{th} power across scales, which enables us to characterize the bursty behavior of the signal.

The scaling exponent represents the asymptotic decay of the partition function:

$$\tau(q) = \liminf_{j\to\infty} \frac{\log Z(q, j)}{\log j} \quad (9)$$

Table 1. Statistics of the MPEG-4 traces studied.

	SW HI	SW ME	SW LO	SL HI	SL ME	SL LO
Comp. ratio	27.62	97.83	142.52	13.22	43.43	72.01
Mean Mbps	0.28	0.08	0.053	0.58	0.18	0.11
Std Mbps	0.18	0.091	0.091	0.464	0.213	0.176
Peak Mbps	1.9	0.94	0.94	4.4	2.4	2.3
Hurst Param	0.903	0.847	0.770	1.000	0.997	0.935

3. TRACES AND TOOLS

We use MPEG-4 traces that are available from the Telecommunication Networks Group, Technical University of Berlin [8]. The video resolution for each movie is 176x144 pixels (corresponding to QCIF) with 8 bits/pixel, which is suitable for transmission over wireless networks to mobile devices. The two traces we have studied are Star Wars IV (SW) and Silence of the Lambs (SL). The traces consist of the number of bytes that arrives in 40 ms (corresponding to 25 frames per second). For each movie, the high quality (HI), medium quality (ME), and the low quality (LO) outputs are studied. The Hurst parameters for the traces are computed using R/S statistics. For further information on computations, refer to [8]. Table 1 shows the frame statistics of the two movies studied.

To study the traces we use MATLAB© Wavelet Toolbox 2.1 available from the MathWorks Inc. and WaveLab802, another MATLAB© toolbox for wavelet analysis, available from Stanford University [9].

4. RESULTS

For each movie and for each quality level, Figures 1-6 plot the following:

1. The number of bytes per frame: The plots show the bursty nature of the video traffic generated by the encoder. The non-stationarity is apparent from the trace plots.

2. The Continuous Wavelet Transform (CWT): CWT plots show the repetitive (or periodic) pattern of the traffic over many scales (i.e. self-similarity). The intensity of the gray levels corresponds to the magnitude of signal at a given scale and time. The CWT is computed using the Gaussian Wavelet.

3. Partition Function: We look at the fine scales. We see the slope of curves increasing with increasing q (nonlinearly). Dips in the curve imply "interesting" fractal behavior. For details on this interpretation, refer to [5, 6].

A key finding is that the compression ratio does not affect the fractal behavior of video (as demonstrated by the figures).

4. Scaling Exponent: Non-linearity of the curve implies that the time-series is multifractal. Straight line would have implied exact self-similarity (monofractal process).

5. CONCLUSION

Understanding the self-similar behavior of video traffic and building models for workload for video servers will undoubtedly help network engineers design better networks and software for video services over the wireless Internet. Models can be used in a variety of admission control algorithms to prevent congestion in wireless networks. A recent study that uses Multifractal Wavelet Model to model and infer network traffic may also be applied to generate synthetic MPEG-4 traffic for performance evaluation [10]. The models also provide compact descriptions of the traffic. These descriptions can be used for resource allocation algorithms, traffic shapers, and pricing and policy controllers to improve the quality of the network services for mobile users.

This study shows that self-similar scaling is present in video traffic and compression ratio does not change this behavior.

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6. REFERENCES

[1] W. E. Leland, M. S. Taqqu, W. Willinger, and D. V. Wilson, "On the Self-Similar Nature of Ethernet Traffic," *ACM SIGCOMM Proceedings on communications architectures, protocols and applications*, vol. 23, issue 4, October 1993.

[2] M. W. Garrett and W. Willinger, "Analysis, Modeling and Generation of Self-Similar VBR Video Traffic," *ACM SIGCOMM Proceedings on communications architectures, protocols and applications*, vol. 24, issue 4, October 1994.

[3] J. Beran, R. Sherman, M. S. Taqqu, and W. Willinger, "Long-Range Dependence in Variable-Bit-Rate Video Traffic," *IEEE Transactions on Communications*, vol. 43, no. 2/3/4, Feb./March/Apr., 1995.

[4] K. Park and W. Willinger, editors, *Self-Similar Network Traffic and Performance Evaluation*, John Wiley & Sons, Inc., 2000.

[5] A. C. Gilbert, "Multiscale Analysis and Data Networks," *Applied and Computational Harmonic Analysis,* 10, 185-202, 2001.

[6] A. Feldmann, A. C. Gilbert, P. Huang, and W. Willinger, "Dynamics of IP traffic: A study of the role of variability and the impact of control," *ACM SIGCOMM Proceedings on applications, technologies, architectures, and protocols for computer communication*, vol. 29, issue 4, August 1999.

[7] S. Mallat, *A Wavelet Tour of Signal Processing*, 2nd ed., Academic Press, 1999.

[8] F. H. P. Fitzek and M. Reisslein, "MPEG-4 and H.263 Video Traces for Network Performance Evaluation (extended version)," *Technical Report: TKN-00-06*, TU Berlin Department of Electrical Engineering, Telecommunication Networks Group, October 2000.
http://www-tkn.ee.tu-berlin.de/research/trace/trace.html.

[9] *WaveLab802*, http://www-stat.stanford.edu/~wavelab.

[10] V. J. Riberio, R. H. Riedi, and R. G. Baraniuk, "Wavelets and Multifractals for Network Traffic Modeling and Inference," *Proc. IEEE International Conference on Acoustics, Speech, and Signal Processing,* vol. 6, pp. 3429-3432, 2001.

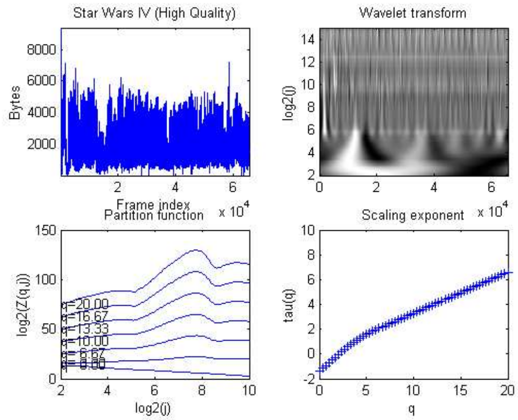

Figure 1. Star Wars IV (High Quality)

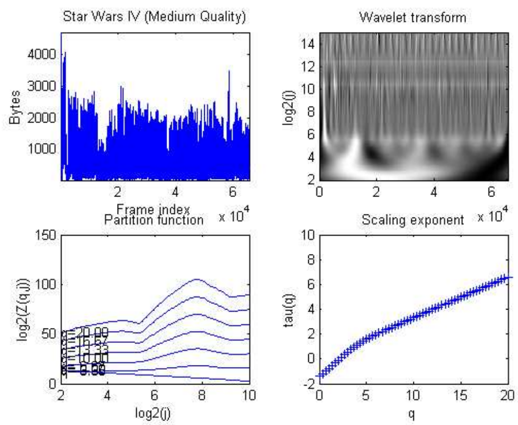

Figure 2. Star Wars IV (Medium Quality)

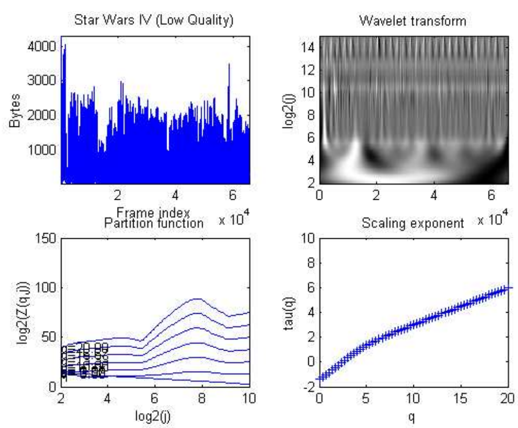

Figure 3. Star Wars IV (Low Quality)

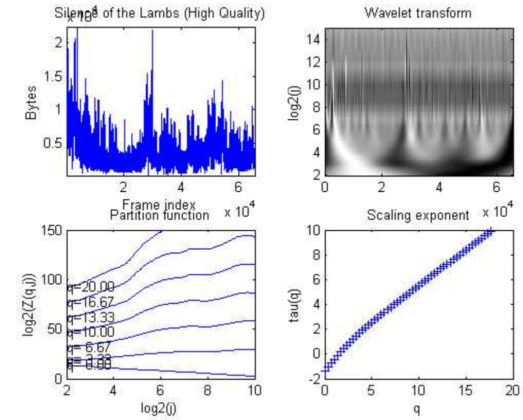

Figure 4. Silence of the Lambs (High Quality)

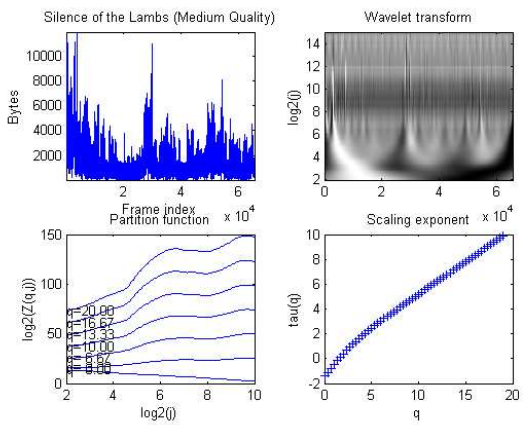

Figure 5. Silence of the Lambs (Medium Quality)

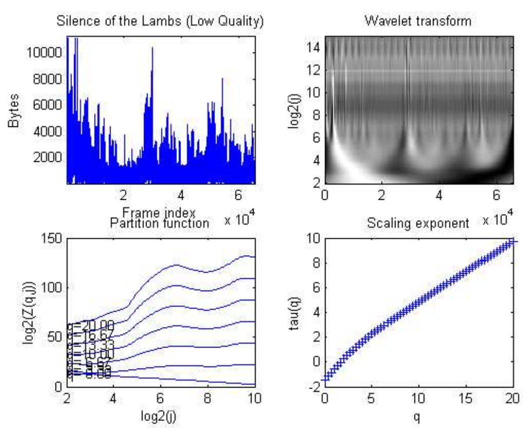

Figure 6. Silence of the Lambs (Low Quality)