On the Use and Calculation of the Hurst Parameter with MPEG Videos Data Traffic

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Abstract

Multimedia data traffic on the Internet has an highly self-similar structure. Self-similarity can be expressed by using the “Hurst parameter”. In the literature there are three basic methods proposed to evaluate the Hurst parameter, respectively: R/S analysis; variance time analysis, and periodogram analysis. This paper analyses and compares these techniques by using a set of MPEG videos. We propose the best method for two different tasks: traffic admission control and traffic shaping. We also present a detailed description of the algorithm for various situations. Finally, we analyse the behaviour of the \( H \) parameter when various flows of self-similar traffic are multiplexed together. We also present a possible scheme for MPEG-video servers to maintain bounded the aggregated value of \( H \).

Keywords: traffic management and control; multimedia traffic control, congestion, admission and flow control.

1. Introduction

Internet and network traffic generally presents a structure that is far from being represented by Poisson based models. A number of studies have shown that the distribution of packet interarrivals differs from exponential [1][13] for both local-area and wide-area network traffic. These studies have also demonstrated that actual network traffic is self similar or long range dependent (this effect is also called the Joseph effect). Intuitively, traffic presents the self-similar property if it looks similar across different time-scales. This means that it shows a bursty behavior independently of the time scales at which it is displayed. Processes with this property have an auto-correlation function that decays slowly, and can be characterised by the Hurst parameter (indicated by \( H \)) [8]. Auto-correlation functions that decay hyperbolically are studied in [2] for several videos. They show that a long-range dependence exists and that it can be modelled using self-similar processes. Moreover, the Hurst parameter is suggested as a measure of the degree of self-similarity of a data stream because it allows the evaluation of the bursty nature of a data flow.

This parameter can be used as a data stream control and description parameter. It could be used in intermediate nodes and in end-nodes to evaluate the characteristics of the current flow of data and to make decisions about, for example, admission or congestion control. In this paper, we have studied the mathematical tools which are available for the computation of \( H \), and defined some usage rules for the protocol designer. The Hurst parameter and the following usage rules could be introduced in such protocols as RSVP or IPv6.

In the literature there are three basic methods proposed to evaluate the Hurst parameter, respectively: R/S analysis [9]; variance time analysis [6], and periodogram analysis [1]. They are all based on some form of statistical observation of a flow of data cells or packets. In this paper, we apply these three techniques to real traffic generated using 19 different MPEG-1 videos [11]. Nowadays, ATM networks provide the ideal transport mean for many new video/multimedia services – thanks to the speed, reliability and large bandwidth. However, services such as real time video can quickly saturate ATM links. By statistically comparing the results obtained by using the three methods, we evaluated which is the best for two basic tasks: admission control decision-making in intermediate nodes; and data traffic correction in traffic shaping devices.

We show that the R/S technique is more stable and richer in information than the other techniques, and therefore the best for admission control protocols. The periodogram method is the simplest to implement while preserving stability and correct behaviour. This method is
suggested for use by network traffic shaping devices where it can be used to regenerate traffic with lower demands on the routers. We apply the results of our study by presenting a set of rules that could be used in video servers to empirically estimate the $H$ parameters when several sources of self-similar traffic are multiplexed.

The paper is organised as follows. Section 2 presents a resume about the theory of self-similarity. Section 3 describes the MPEG workload used and presents the statistical analysis results. Section 4 presents the simulation experiments regarding the behaviour of self-similar data traffic when multiplexed by an ATM switch. Finally, section 5 presents the main conclusions.

2. Mathematical Basis of Self-Similar Stochastic Processes

In this section we give a short description of the mathematical basis for self-similar stochastic processes (long-range dependence). We also present the three basic methods to calculate the $H$ parameter: R/S analysis, variance-time analysis and periodogram analysis. For detailed reviews of these concepts see [6] and [1]. A Matlab [12] implementation code is linked with the three methods.

2.1. Self-similar Stochastic Processes

Intuitively, a stochastic process presents the self-similar property if it looks similar across all time-scales, and exhibits a bursty behaviour that is independent of the time scale at which it is displayed. Processes with this property are characterised by an autocorrelation function that decays slowly.

Let us consider $X = (X_t; t \geq 0)$, a covariance stationary stochastic process with mean $\mu$, variance $\sigma^2$, and autocorrelation function $r(k)$, $k \geq 0$. This stochastic process has the following auto-correlation form:

$$r(k) \sim k^H \sigma(L(k) as k \rightarrow \infty,$$

where $L$ is a slowly varying function (i.e.: $\lim_{t \to \infty} L(tx)/L(t) = 1 \forall x > 0$) and $0 < H < 1$. We define $X^{(m)} = (X_k^{(m)}; k \geq 0)$ as a new covariance stationary time series, obtained by averaging the original series $X$ over non-overlapping blocks of size $m$ for each $m=1, 2, 3, \ldots$, that is $X^{(m)}$ is given by:

$$X_k^{(m)} = \frac{1}{m} \sum_{i=k}^{k+m-1} X_i.$$

Process $X$ is called self-similar with Hurst parameter $H = 1 - \beta/2$ if the aggregated process $X^{(m)}$ has the same correlation structure as $X$, that is if $r^{(m)}(k) = r(k)$, for all $m > 0$ ($k > 0$). In [2] the Hurst parameter is suggested as a measure of the degree of self-similarity in a data stream. Evaluating this parameter is important because it could be used to give a metrics of the importance of self-similarity characteristics in a given stream of data. Basically, as $H$ grows and nears 1, the self-similar behaviour of a traffic stream becomes more evident and relevant to the network node performance.

2.2. R/S Analysis

Given $n$ observations $(X_i; k = 1, 2, \ldots, n)$ with sample mean $\bar{X}$ and sample variance $S^2$, the re-scaled adjusted range $(R/S)$ is given by:

$$R(n) = \left( \frac{1}{n(S(n))} \right) \max(0, W_1, W_2, \ldots, W_n) - \min(0, W_2, \ldots, W_n).$$

Where $W_k = (X_{i1} + X_{i2} + \ldots + X_{ik}) - k^* \bar{X}$, $k > 0$. As defined in [9] self-similar processes are well represented by the equation $E\left(\frac{R(n)}{S(n)}\right) \sim \alpha n^{\alpha}$, as $n \to \infty$, where $0.5 < \alpha < 1$.

We can therefore estimate $H$ by plotting $\log(E[R(n)/S(n)])$ versus $\log(n)$ and using a least-square linear approximation technique. For practical robustness purposes, given an observation of length $N$, one must subdivide the series into $K$ non-overlapping blocks, each of size $N/K$ and compute the re-scaled adjusted range $R(k,n)/S(k,n)$ for each of the new “starting points” $k_0 = n/K + 1, i = 1, 2, \ldots$, which satisfy $(k_0 + n) \leq N$. Figure 1 shows a Matlab implementation of the code for the R/S method.

```matlab
function rs_analysis(A)
long_wavelength(A);
n_grups=5;
t_grups=floor(long_w/5); 
lag=round(logspace(start,stop,number_of_point));
index=1; N=1;
result=[];
for i=1:length(lag)
t_subgr=lag(i);
for n=1:n_grups
    start_g=(n-1)*t_subgr;
    first_g=1+start_g;
    mean=mean(A(first:1+start_g-1));
    for q=1:t_subgr
        x=A(first:1+start_g-1);
        x=mean(abs(x) - mean(x));
    end;
    S=std(A(first:1+start_g-1));
    max=max(0,max(W)) , min=min(0,min(W));
    if (S=0) & (max-min)=0
        result(index)=(1/8) * (max-min); %size(index)=n
        index=index+1;
    end;
end;

[a, b]=min_square (log10(size),log10(result));
N=a;
```

Figure 1. Matlab implementation of the code for the R/S method
2.3. Variance-Time Analysis

The relation between the variance of an aggregated process \( X^{(m)} \) and the block size \( m \) is given by:

\[
\text{Var}(X^{(m)}) = \alpha m^\beta, \quad 0 < \beta < 1 \quad \text{as} \quad m \to \infty.
\]

or equivalently \( X^{(m)}(k) \to 0, \) as \( m \to \infty \) \((k=1,2,...)\). This relation indicates that aggregated processes with long range dependence have a non-degenerate correlation structure and that variance decreases linearly (for large \( m \)). This analysis consists in plotting \( \log(\text{Var}(X^{(m)})) \) against \( \log(m) \), and dividing the original series into non-overlapping blocks of size \( m \) for various values of \( m \). To obtain an estimate of \( \beta \), we use the slope of a simple least squares line for the obtained points. Again, using the well-known relation \( H = 1 – \beta / 2 \), we can estimates \( H \). To obtain a representative estimate, the initial block size \( m \) (transient period), and the number of groups \((N/m)\) must be large enough. Figure 2 shows a Matlab implementation for the method.

```
function vari_analysis(X)

long_v=length(X);
lag=floor(logspace(start,stop,number_of_point));
for i=1:length(lag);
    t_subgrp=floor(lag(i));%Number of blocks N/m
    result[i]=[]; resultl[i]=[]; size[i]=[];
    for j=1:k;
        first=(i-1)*(t_subgrp)+1;
        xl=mean(X(first:first+t_subgrp-1));
        resultl[i]=resultl[i] xl;
    end
    result[i]=result [resulti];
    size[i]=size t_subgrp;
end;
[a, b]=in_square (log10(size), log10(result));
H=1-a/2;
```

Figure 2. Matlab implementation of the code for the variance method

2.4. Periodogram Analysis

The periodogram of a time series \( X = (X_1, X_2, ..., X_N) \) is defined as:

\[
I(v) = \frac{1}{2\pi N} \sum_{j=1}^{N} X(j) e^{i2\pi v j}, \quad i=1,2,..., q; \quad q = \frac{(N-1)}{2}
\]

Where \( v \) is the frequency and \( N \) is the length of the series. In the finite variance case \( I(v) \) is an estimate of the series spectral density. Series with long-range dependence will have a spectral density proportional to \( |v|^{-\beta} \) for frequencies close to the origin, and so a log-log plot of the periodogram versus the frequency, can be approximated by a straight line with a slope of \( 1-2H \). In practice, we use only the lowest 10% of the frequencies for the calculation.

Figure 3 shows a Matlab implementation for the periodogram method.

```
function periodogram_analysis(X)

long_v=length(X);
[p, p1, e] = psd(X, [long_v/10], 0.95);
[a, b] = least_square (log10 (e), log10 (p));
H=(1-a)/2;
```

Figure 3. Matlab implementation of the code for the periodogram method

3. Self-Similarity Analysis Applied To Real Data Traffic

In this section we present the results of applying the statistical methods described in section 0 to several MPEG-1 encoded video sequences\(^2\). Each video consists of 40,000 frames –equivalent to approximately half an hour. The frame size traces were extracted from MPEG-1 sequences, after being encoded with an adapted version of the Berkeley MPEG-encoder (version 1.3). The videos were captured in motion-JPEG format from a VCR (VHS) with a SUN SPARCstation 20 and SunVideo. The capture rate of the SunVideo video system was 25 fps. More details can be found in [3].

A standard MPEG encoder tries to reduce the spatial and temporal redundancy using several modes of compression resulting in the generation of three different types of compressed frames: I-frames (I), P-frames (P), and B-frames (B). Typically I-frames are larger than P-frames, while B-frames have the lowest size. The MPEG coding technique, arrange the compressed frames using a deterministic periodic sequence called Group of Pictures (GOP). The pattern used to encode the MPEG sequences used in this work follows an “BBPPBBPBBPBB” GOP pattern [3].

Four categories of videos constitute this sample, respectively: movies (labelled as bond, dino, lambs, starwars, terminator and movie); sport (race, soccer1, soccer2, atp and showl); news/talk shows (news2, talk1 and talk2); and various (mv1, mv2, mrbean, simpkins and asterix).

We have generated the ATM cell stream (each 48 bytes of video correspond to a cell) for each video, and we have applied the previous analysis to evaluate the Hurst parameter. Figure 4 shows the behaviour of the \( H \) parameter for the three methods and the 19 videos. It can be seen that the R/S and the periodogram methods present a trend that is quite similar, while the variance method has a higher variability.

\(^2\) Thanks to Oliver Rose of the University of Würzburg who made these traces available: ftp://ftp-info3.informatik.uni-wuerzburg.de/pub/MPEG/
The first result of this analysis was the detection of the presence of self-similarity (long range dependence) in all MPEG generated traffic, since all video presented a value of $H$ greater than 0.5 in all the methods. The obtained results obtained also suggested a simplistic and rough classification of the videos into three categories. Low activity sequences that include videos with a Hurst parameter close to 1; medium activity sequences for the remaining videos.

Further analysis is required to assess whether the results obtained are due to the long-range dependence of the data traffic. We know that a Hurst value between 0.5 and 1 is a strong indication of long range dependence in data series, however the Hurst value can also rise for short-range dependence in such temporal series with trends going to 0 slowly [2]. For sufficiently large time series, it is possible to distinguish between short and long range dependence by deploying the aggregated R/S statistical method.

This method consists of aggregating the original series over non-overlapping blocks of size $t$, to obtain different time series $X^t$. Two different situations can arise by plotting the R/S method for these series. First, if the calculated sequence of values of $H$ remains close to the original value, then no short-range dependency exists, and a “true” long dependence exists in the data series. On the other hand, if the original series presents short-range dependencies, the slope of the R/S plot comes closer to 0.5 as the aggregation size increases.

Figure 5 shows the Hurst parameter estimate for four of the videos, as a function of different aggregation levels $t$. It can be seen that movie and simpsons show stable behaviour for $H$: the average values are respectively: 0.865 (standard deviation 0.01) and 0.82 (standard deviation 0.03). On the contrary, videos like asterix and race present a decreasing trend, revealing the presence of short-range dependence (average values are respectively: 0.797 (standard deviation 0.09) and 0.765 (standard deviation 0.11).

![Figure 5. Hurst exponent estimates of the plot diagram of R/S, as a function of the aggregation level $t=1$ (original series), $t=10$, $t=50$ and $t=100$](image)

Only four of the 19 videos (respectively – asterix, movie, race, soccer1 and soccer2) showed short-range dependence. In the other cases, the slopes of the min-square approximation were uninfluenced by this aggregation method, giving values closer to the Hurst parameter obtained for the original series. Note that although this method could be inadequate for a small data set, the method can be used to acquire an initial idea about the short and long-range dependence for a medium sized data set. As shown before, the R/S and the periodogram methods give the best results when evaluating $H$.

<table>
<thead>
<tr>
<th></th>
<th>R/S Analysis</th>
<th>Variance</th>
<th>Periodogram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movie</td>
<td>-</td>
<td>-0.0506</td>
<td>0.6211 (0.0045)</td>
</tr>
<tr>
<td>Simpsoes</td>
<td>-</td>
<td>-</td>
<td>-0.1833 (0.4526)</td>
</tr>
<tr>
<td>Asterix</td>
<td>-0.0506 (0.0369)</td>
<td>-</td>
<td>-0.1833 (0.4526)</td>
</tr>
<tr>
<td>Race</td>
<td>0.0621 (0.0045)</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 1. Correlation among the values generated using the three different methods
Despite this, it is quite stable and does not over-estimate the value of $H$. The R/S method is more difficult to implement, but it has the advantage of allowing us to determine whether a traffic flow is long range auto similar, or not.

The variance method is the most unstable. A variation of this method, called the aggregated variance method, allows us to estimate the self-similar parameter $H$ by a simple least square fit. However, this estimation of the $Hurst$ parameter is highly depend on the number of points used to calculate the slope of the line. A more robust estimation of $H$ can be obtained by ensuring: (i), the length of each block is sufficiently large; and (ii), there are enough blocks.

Table 2 shows the $H$ parameter as a function of the length of the block used in the figure 2 algorithm. Typically, the slope varies for small values of $d$ and begins to stabilise as the length of the initial segment increases. However, there are several cases in which the $Hurst$ parameter varies significantly for all ranges of $m$ ($10 \ldots 500$), and it does not seem to be asymptotically stable. We think this is because in the above estimation we only consider condition (i), and so the results can be misleading. The right-hand column of Table 2 shows the $Hurst$ parameter obtained with the aggregated variance method, taking into account conditions (i) and (ii), explained in the previous paragraph, equals to 25.

Finally, we can say that the periodogram method is a good method to be inserted in intermediate network nodes, like routers, to evaluate the $H$ parameter on-line. We propose this method for taking decisions from dedicated protocols. The R/S method is better for deeper mathematical analysis of traffic flow, typically on end-nodes, which can regulate traffic by sending backward control information to the sending end node. The periodogram method is probably the best method for special devices, like traffic shapers [14]. This is because they can evaluate the behaviour of the traffic flow being handled and eventually take action to modify the value of $H$ by, for example, varying the inter-cells delays.

### 4. Multiplexing Auto-Similar Data Traffic

This last section presents the application of the results of the previous sections to a video-server. We show some empirical rules that can be used to evaluate the effects of serving various videos (i.e. multiplexing self-similar traffic). We also describe how video synchronisation can control the resulting value of $H$.

The results of this section could be extended to evaluate the aggregated value of $H$ when various streams of self-similar traffic are merged (multiplexed) by a router, or an ATM switch. This information would be required by shaping devices and protocols to define possible rules for admission control – and knowing in advance what would

<table>
<thead>
<tr>
<th>MPEG Sequence</th>
<th>$d=10$</th>
<th>$d=100$</th>
<th>$d=200$</th>
<th>$d=300$</th>
<th>$d=400$</th>
<th>$d=500$</th>
<th>$d=25, b=25$</th>
</tr>
</thead>
<tbody>
<tr>
<td>dino</td>
<td>0.84</td>
<td>0.81</td>
<td>0.80</td>
<td>0.80</td>
<td>0.80</td>
<td>0.80</td>
<td>0.86</td>
</tr>
<tr>
<td>lambs</td>
<td>0.90</td>
<td>0.86</td>
<td>0.84</td>
<td>0.82</td>
<td>0.81</td>
<td>0.79</td>
<td>0.91</td>
</tr>
<tr>
<td>bond</td>
<td>0.89</td>
<td>0.88</td>
<td>0.88</td>
<td>0.88</td>
<td>0.87</td>
<td>0.88</td>
<td>0.90</td>
</tr>
<tr>
<td>starwars</td>
<td>0.88</td>
<td>0.86</td>
<td>0.86</td>
<td>0.86</td>
<td>0.87</td>
<td>0.88</td>
<td>0.88</td>
</tr>
<tr>
<td>terminator</td>
<td>0.76</td>
<td>0.74</td>
<td>0.73</td>
<td>0.73</td>
<td>0.73</td>
<td>0.73</td>
<td>0.77</td>
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<tr>
<td>movie</td>
<td>0.78</td>
<td>0.73</td>
<td>0.7</td>
<td>0.67</td>
<td>0.65</td>
<td>0.64</td>
<td>0.81</td>
</tr>
<tr>
<td>race</td>
<td>0.70</td>
<td>0.6</td>
<td>0.55</td>
<td>0.53</td>
<td>0.52</td>
<td>0.53</td>
<td>0.84</td>
</tr>
<tr>
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<td>0.7</td>
<td>0.62</td>
<td>0.6</td>
<td>0.59</td>
<td>0.57</td>
<td>0.56</td>
<td>0.81</td>
</tr>
<tr>
<td>soccer2</td>
<td>0.71</td>
<td>0.64</td>
<td>0.63</td>
<td>0.63</td>
<td>0.64</td>
<td>0.66</td>
<td>0.84</td>
</tr>
<tr>
<td>apt</td>
<td>0.72</td>
<td>0.66</td>
<td>0.65</td>
<td>0.65</td>
<td>0.66</td>
<td>0.66</td>
<td>0.82</td>
</tr>
<tr>
<td>sbowl</td>
<td>0.78</td>
<td>0.73</td>
<td>0.71</td>
<td>0.71</td>
<td>0.71</td>
<td>0.71</td>
<td>0.79</td>
</tr>
<tr>
<td>news2</td>
<td>0.75</td>
<td>0.65</td>
<td>0.6</td>
<td>0.57</td>
<td>0.55</td>
<td>0.54</td>
<td>0.81</td>
</tr>
<tr>
<td>talk1</td>
<td>0.8</td>
<td>0.72</td>
<td>0.68</td>
<td>0.66</td>
<td>0.64</td>
<td>0.63</td>
<td>0.84</td>
</tr>
<tr>
<td>talk2</td>
<td>0.78</td>
<td>0.71</td>
<td>0.68</td>
<td>0.67</td>
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<td>0.67</td>
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<tr>
<td>mtv1</td>
<td>0.84</td>
<td>0.8</td>
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<td>0.77</td>
<td>0.77</td>
<td>0.76</td>
<td>0.86</td>
</tr>
<tr>
<td>mtv2</td>
<td>0.86</td>
<td>0.81</td>
<td>0.77</td>
<td>0.73</td>
<td>0.7</td>
<td>0.7</td>
<td>0.91</td>
</tr>
<tr>
<td>mrbean</td>
<td>0.87</td>
<td>0.84</td>
<td>0.83</td>
<td>0.82</td>
<td>0.82</td>
<td>0.81</td>
<td>0.88</td>
</tr>
<tr>
<td>simpsons</td>
<td>0.81</td>
<td>0.77</td>
<td>0.75</td>
<td>0.73</td>
<td>0.71</td>
<td>0.7</td>
<td>0.84</td>
</tr>
<tr>
<td>asterix</td>
<td>0.83</td>
<td>0.8</td>
<td>0.78</td>
<td>0.78</td>
<td>0.77</td>
<td>0.78</td>
<td>0.84</td>
</tr>
</tbody>
</table>

Table 2. Hurst exponents obtained with the aggregated variance method, as a function of the lag d (first 6 columns), and the estimates with minimum numbers of group=25 and minimum length of every group=25, (last column)
be the output characteristic of the data stream. The main result of this work is the evidence of the benefits of synchronising the transmission of MPEG video streams to control the resulting $H$.

Taken into account the deterministic structure (periodic GOP) of the MPEG video compression pattern, in this section we consider the degree of synchronisation among several multiplexed MPEG sequences to measure the differences starting time of the multiplexed streams.

We said that two MPEG streams are synchronised if they are multiplexed following the same frame pattern sequence. On the other hand, if one of the streams starts several frame period after the start of the first stream, we will consider as unsynchronised streams.

![Figure 6. The ATM switch model](image)

For this study we have used a simplified model of the multiplexing device, an ATM switch, based on a single central queue with size $B$ and with a constant service time of $S$ Mb/s. The queue service policy was first come-first serve (FCFS) [15].

Each MPEG video sequence was modelled as a sequence of cell-trains. Each cell train starts every 33 msec. in order to maintain a constant quality-motion picture of 30 frames/sec. Figure 6 shows the model used for simulations. The multiplexer processes the aggregated traffic, and sends the generated traffic to the unique output line.

The first result of this study is shown in Figure 7. This figure shows the behaviour of the $H$ parameter of the output data traffic when an equally distributed set of sources is applied to the multiplexer. Each MPEG video sequence was modelled as a sequence of cell-trains. Each cell train starts every 33 msec. in order to maintain a constant quality-motion picture of 30 frames/sec. Figure 6 shows the model used for simulations. The multiplexer processes the aggregated traffic, and sends the generated traffic to the unique output line.

![Figure 7. Behaviour of the $H$ parameter of the output data traffic when an equally distributed and totally unsynchronised set of sources is applied to the multiplexer](image)

We have repeated the experiment by completely synchronising the input streams. Complete synchronisation means that the $n$ streams were received at the input lines of the multiplexer at the same instant of time $t_0$.

The left part of Figure 8 shows the result of synchronising $n$ sources with $H=73$ (line with diamonds), $H=0.83$ (line with squares) and $H=0.90$ (line with triangles). The result is an output stream with the same $H$ parameter as the input stream. The right part of Figure 8 shows the same experiment but with the $n$ sources unsynchronised by just one frame. As figure 8 shows, the output ATM cells present a $Hurst$ parameter that tend to 0.90 as the number of source increase. It seems that when similar MPEG sequences are multiplexed, if we want to maintain the $Hurst$ parameter of the initial streams we need to maintain the synchronisation among the sources.

Finally, the experiment was rerun with the $n$ sources completely synchronised and with $n/2$ of the source with $H=0.90$ and the remaining $n/2$ with $H=0.73$. The result was that for $2<n<20$, the value of $H$ for the output stream remained constant at $H=0.82$. This last result convinced us of the importance of synchronising the input streams for a multiplexing device, such as a video-on-demand server. These results shows that when a video server has to distribute various videos with the same $H$ – or combinations of $H$ – to generate a lower $H$ – it would be best to send it with a lower $H$ value video and completely synchronised.
5. Conclusions

In this paper we have studied the mathematical tools available for the computation of $H$ and defined some usage rules for the protocol designer. The statistical behaviour has been analysed using the three basic statistical methods: the R/S method, variance method, and periodogram method. We have also used the aggregate of the R/S for a more complete analysis.

The MPEG sequences show higher levels of complexity than conventional traffic models and this gives researchers new performance problems in high-speed network traffic. To see the behaviour of the self-similar parameter in high-speed networks, we have simulated an initial ATM multiplexer model and the effect of multiplexing several representative MPEG sequences in the Hurst parameter were studied.

The periodogram method resulted to be the simplest of the methods to implement. In fact, it can be implemented by a sequence of eight vectorial products and an FFT operator. Despite this it is quite stable and does not overestimate the value of $H$. The R/S method is more difficult to implement but it has the added advantage of allowing us to determine whether a traffic flow is long range auto similar, or not. We have presented a method for quickly evaluating this characteristic. The variance method is the most unstable of all the methods.

The periodogram method is a good method for inserting in intermediate network nodes, such as routers, in order to evaluate on-line the $H$ parameter and so allow dedicated protocols to take decisions based on the value of this parameter.

The R/S method is better for deeper mathematical analysis of traffic flow, typically on end-nodes, which can regulate traffic by sending backward control information to the sending end node. The periodogram method is probably the best method for special devices – such as traffic shapers – that can evaluate the behaviour of the traffic flow they are handling, and eventually take action to modify the value of $H$ by, for example, varying the inter-cell delays.

The final section devised some empirical rules to evaluate the aggregated value of $H$ when various streams of self-similar traffic are merged (multiplexed). This information would be required by shaping devices and protocols to define possible rules for admission control – and so knowing in advance what would be the output characteristic of the data stream. This last section showed the importance of synchronising the input streams of a multiplexing device.

As an example, a video-on-demand server was proposed that shows that when a video server has to distribute various videos with the same $H$ – or combinations of $H$ to generate a lower $H$ – it would be best to send it with a lower $H$ value video and completely synchronised.

References


