Measurement Analysis of Cell Stream in ATM Network Integrating CATV and Internet

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Abstract

The project of interconnecting CATV in Hyogo Prefecture, Japan has started since March, 1998. In this project, there are three CATV companies in Hanshin area; Kobe, Nishinomiya and Amagasaki. An ATM switch is equipped in each company and these CATVs are connected serially in the above order. Each company provides the video service to the rest of companies using the MPEG2 over ATM. In the service area of each CATV, subscribers are able to access the Internet using cable modem. In our testbed network, cells with two types of requirement for QoS are multiplexed; cells for MPEG2 which require the real-time transmission and those for Internet packets which are much more sensitive for the cell loss ratio. Recently, it has been shown that the traffic such as Ethernet LAN, WAN, and ATM network has the statistical characteristics of self-similarity and long-range dependency (LRD). In general, the traffic with LRD degrades the network performance and hence it is important to capture the traffic characteristics in terms of LRD for investigating the performance measures such as cell loss probability, transmission delay, and jitter process. In this paper, we investigate the characteristics of cell stream from the point of view of self-similarity and estimate the Hurst parameters under the various situations on our experimental network. Our results show that if there exists self-similarity in the ATM network integrating CATV and Internet, cells for Internet play a crucial role for the self-similar nature of the network.

1 Introduction

The experimental network for the project of interconnecting CATV in Hyogo prefecture, Japan, has started since March 1998. The research has been performed by Kobe Multi-node Integrated Connection Research Center (KOMIC), which has been established by Telecommunications Advancement Organization of Japan (TAO).

In this project, three CATV companies in Hanshin area, Kobe, Nishinomiya and Amagasaki are connected serially through optical fiber trunk lines, and all kinds of data are transmitted via ATM network. The data

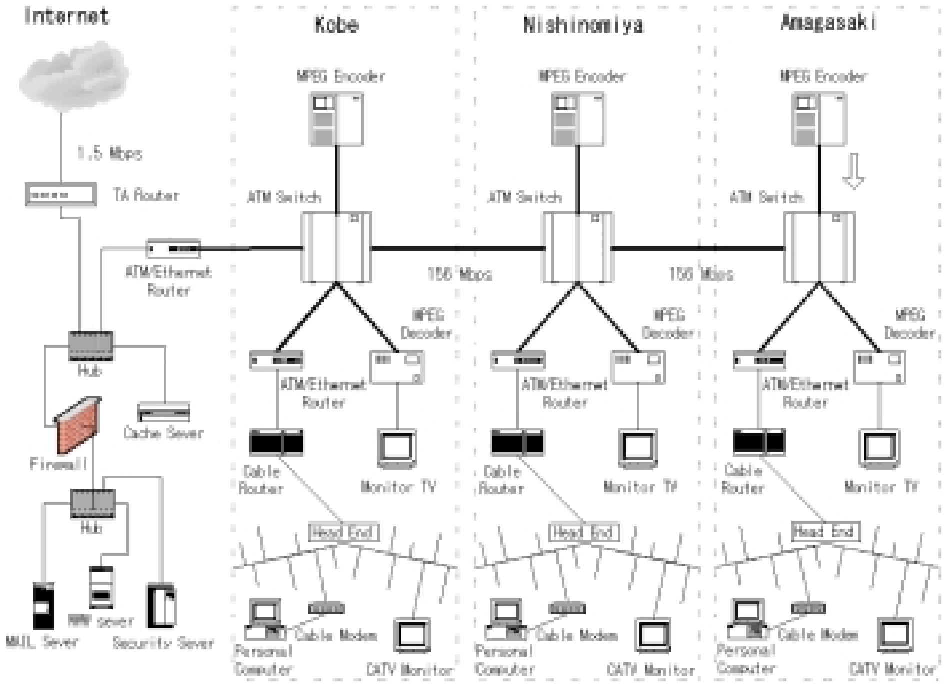


Figure 1: Facilities.

stream consists of two types of cells. One is for compressed CATV programs by MPEG2, and the other is for the information created by Internet services such as WWW, E-mail, FTP and so on. We call the former MPEG cells and the latter Internet cells.

Each CATV company provides the video service to the rest of companies using the MPEG2 over ATM. Each MPEG2 stream is sent to the other two CATV companies according to the function of multicast implemented in ATM switches. On the other hand, the CATV subscribers are able to access the Internet using the cable modem.

In our testbed network, there are two types of cells with requirement for different QoS and these cells are synthesized and multiplexed through optical fiber trunk lines. In general, it is difficult to efficiently integrate these two kinds of traffic stream with entirely different characteristics.

The effectiveness of traffic management and control mechanisms in the integrated circumstance of broadcasting and communication data traffic through ATM networks is the crucial matter to be studied. For details of our research subjects, readers are referred to [1], [7], [11].

Recently, the statistical characteristics of self-similarity and long-range dependency have been shown to apply to all sorts of networks such as Ethernet LAN, WAN, and ATM network [3], [5], [6].

Network arrivals are often modeled as Poisson process for analytic simplification, even though a number of traffic studies have shown that packet intervals can not been modeled with exponential distribution. Markovian arrival processes, e.g., Poisson processes, would have a characteristic burst length which would tend to be smoothed by averaging over a long enough time scale. However, the importance of long-range dependence in network traffic has been beginning to be observed in studies such as [3], [5], [6], which show aggregating streams of network traffic typically intensifies the self-similarity instead of smoothing. Afterwards, many studies have showed that significant traffic variance is present over the wide range of time scales. Markovian arrival processes can not afford to describe the phenomenon sufficiently, yet the notion of self-similar processes can describe the these burst and correlation on time series.

The statistical characteristics of self-similarity have been shown to apply to ATM network, differing from usual telephone network and packet exchange network [5]. In [5], the authors investigate the characteristics of ATM cell level aggregated traffic from the point of self-similarity. They also analyzed the separated data in the aggregated traffic. Hence our testbed network is also expected to have self-similarity on its traffic. In

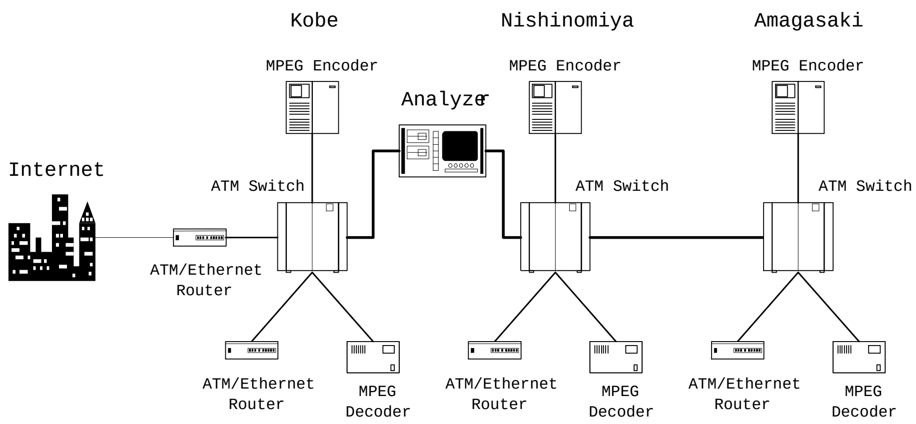


Figure 2: Measuring environment.

general, the traffic with LRD degrades the network performance and hence it is important to capture the traffic characteristics in terms of LRD for investigating the performance measures such as cell loss probability, transmission delay, and jitter process. So, in this paper, in order to construct the simulation model of this network for investigating the correlation between Internet and MPEG cells for the future, we investigate the characteristics of cell stream transmitted on the backbone network and estimate its Hurst parameter.

This paper is organized as follows. In Section 2, we outline the measuring environment of our testbed network. In Section 3, we summarize our methods of data analysis for self-similarity. In Section 4, we estimate the Hurst parameter from the data collected by KOMIC. Finally, we conclude our work in Section 5.

2 Measuring Environment of Testbed Network

We illustrate our testbed network in Fig.1. For details, the readers are referred to [1], [7]. Note that in this network, MPEG2 connections are established with PVC CBR, while Internet connections are established with SVC.

2.1 Traffic Measurements

In this paper, we analyze several kinds of data set collected by KOMIC on January 8, 1999 and February 3, 1999. These collected data sets are the multiplexed traffic on the fiber trunk lines of the ATM backbone (see Fig.2).

In the measuring environment, we have two directions. We call cell stream from Kobe to Nishinomiya "Right" and that from Nishinomiya to Kobe "Left". We have the data of particular case in which Nishinomiya's Encoder didn't work. We call the data one MPEG source data in contrast with the other data under which two MPEG sources (Nishinomiya and Amagasaki) work. These data sets include the time-stamps accurate to within 10 μs.

An ATM analyzer (HP E4210B) used for measuring the cell stream and it's equipped in Kobe CATV office. The analyzer records the time-stamps of cells coming in and going out. The analyzer's capacity being able to measure continuously is 7.34MB. Hence, a measurement span of ATM traffic is restricted within a few seconds. The total number of cells are 131,072 cells and total number of bytes are 6,946,816 bytes for each data series.

In Table 1 to 4, we summarize the qualitative feature of measured data. Table 1 shows the description of data collected on January 8, 1999. We present the feature of the Internet cells contained in the measured traffic in Table 2. We also show the corresponding descriptions on February 3, 1999 in Table 3 and 4. It

Table 1: Qualitative feature of traffic measurements for high bitrate data.

Measurement Period: January 8, 1999				
Data Set	Measurement Span (s)	Direction	# of MPEG Sources	Bit Rate (Mbps)
R-1_1	6.0910829	Right	1	9.124
R-1_2	5.5301356	Right	1	10.049
R-1_3	6.3653521	Right	1	8.731
L-1_1	6.3312494	Left	1	8.778
L-1_2	6.4701180	Left	1	8.589
L-1_3	6.7403174	Left	1	8.245
L-2_1	3.6361174	Left	2	15.284
L-2_2	3.5231654	Left	2	15.774
L-2_3	3.4062480	Left	2	16.315

Table 2: Detail description of Internet cells for high bitrate data.

Data Set	Total of Internet Cells	Rate of Internet Cells (%)	Mean Bit Rate of Internet Cells (Mbps)
R-1_1	33804	25.8	2.353
R-1_2	42785	32.6	3.280
R-1_3	29455	22.5	1.962
L-1_1	16312	12.4	1.092
L-1_2	13562	10.3	0.888
L-1_3	8856	6.7	0.557
L-2_1	9770	7.5	1.139
L-2_2	9318	7.1	1.121
L-2_1	13716	10.5	1.707

is observed that we have two types of data in terms of Internet cells. We call data of Table 1 “high bitrate data” and that of Table 3 “low bitrate data”.

The naming rule of measured data set is as follows. The name of measured data set consists of the three characters: one capital letter and two decimals (e.g. L-1_1). Alphabet means the direction of MPEG stream, first decimal presents the number of active MPEG source in the measured data, and second decimals is the data set number.

3 Estimating Methods for Self-Similarity

In this section, we summarize our estimating methods. For details, readers are referred to [2], [6], [9], [10].

3.1 Aggregated Variance Method

Given a stationary time series $X = \{X_t : t = 1, 2, \cdots, N\}$, we define the aggregated series $\{X_k^{(m)} : k \geq 1, m = 1, 2, \ldots\}$ by summing the original series X over non-overlapping blocks of size m. That is,

Table 3: Qualitative feature of traffic measurements for low bitrate data.

Measurement Period: February 3, 1999				
Data Set	Measurement Span(s)	Direction	# of MPEG Sources	Bit Rate (Mbps)
R-1_4	8.18963990	Right	1	0.848
R-1_5	8.15607610	Right	1	0.852
R-1_6	8.19518260	Right	1	0.847
R-1_7	8.12046040	Right	1	0.855
R-1_8	8.09941050	Right	1	0.858
L-1_4	8.20971400	Left	1	0.846
L-1_5	8.20520660	Left	1	0.847
L-1_6	8.20720900	Left	1	0.846
L-1_7	8.20116780	Left	1	0.847
L-1_8	8.20920610	Left	1	0.846
L-2_4	4.10383060	Left	2	1.693
L-2_5	4.10585300	Left	2	1.691
L-2_6	4.10424500	Left	2	1.692
L-2_7	4.10437570	Left	2	1.692
L-2_8	4.10236470	Left	2	1.693

$$X_k^{(m)} = \frac{1}{m}\sum_{i=1}^{m} X_{m(k-1)+i}, \; k \geq 1. \tag{1}$$

for successive values of m. The index k, is a label of kth block. If the time series has the self-similarity, $\mathrm{Var}X^{(m)} \sim \sigma^2 m^\beta$ as $m \to \infty$ where $\beta = 2H - 2 < 0$.

For a given m, dividing the data, $\{X_t : t = 1, 2, \cdots, N\}$, into N/m blocks of size m, we compute its sample variance,

$$\begin{aligned}\widehat{\mathrm{Var}}X^{(m)} &= \frac{1}{N/m}\sum_{k=1}^{N/m}(X_k^{(m)})^2 \\ &\quad -(\frac{1}{N/m}\sum_{k=1}^{N/m}(X_k^{(m)}))^2. \end{aligned}\tag{2}$$

We compute this method for different values of m repeatedly and plot the the sample variance versus m on a log-log plot. Since $\widehat{\mathrm{Var}}X^{(m)}$ is an estimate of $\mathrm{Var}X^{(m)}$, the resulting points will form a straight line with slope $\beta = 2H - 2$. If X has no long-range dependence, the slope should equal -1.

3.2 Absolute Value Method

We consider the aggregated series (1). We take the first absolute moment of this series,

$$AM^{(m)} = \frac{1}{N/m}\sum_{k=1}^{N/m}|X_k^{(m)} - EX^{(m)}|, \tag{3}$$

where $X_k^{(m)}$ is define in (1) and $EX^{(m)}$ is the overall series mean. $AM^{(m)}$ behaves like m^{H-1} for large m. For successive values of m, the sample absolute first moment of the aggregated series is plotted versus m on a log-log plot. The result should be a straight line with a slope of $H - 1$. If the series has no long-range dependence and finite variance, then $H = 0.5$ and the slope of the fitted line should be $-1/2$.

Table 4: Detail description of Internet cells for low bitrate data.

Data Set	Total of Internet Cells	Rate of Internet Cells (10^{-1}%)	Mean Bit Rate of Internet Cells (kbps)
R-1_4	65	0.496	0.421
R-1_5	109	0.832	0.708
R-1_6	53	0.404	0.342
R-1_7	363	2.769	2.368
R-1_8	902	6.882	5.902
L-1_4	219	1.670	1.413
L-1_5	56	0.427	0.361
L-1_6	115	0.877	0.742
L-1_7	48	0.366	0.310
L-1_8	110	0.839	0.709
L-2_4	95	0.725	1.227
L-2_5	42	0.320	0.541
L-2_6	29	0.221	0.374
L-2_7	86	0.656	1.110
L-2_8	68	0.519	0.878

3.3 R/S Method

For a time series $X = \{X_i : i \geq 1\}$, $Y_j = \sum_{i=1}^{j} X_i$ is a partial sum. We define $R(k,m)$ as follows.

$$\begin{aligned} R(k,m) &= \max_{0<i<m} [Y_{k+i} - Y_k - \frac{i}{m}(Y_{k+m} - Y_k)] \\ &- \min_{0<i<m} [Y_{k+i} - Y_k - \frac{i}{m}(Y_{k+m} - Y_k)]. \end{aligned} \tag{4}$$

$R(k,m)$ is called the adjusted range. In order to study the properties that are independent of the scale, $R(k,m)$ is standardized by

$$S(k,m) = \sqrt{\frac{1}{m} \sum_{i=k+1}^{k+m} (X_i - \bar{X}_{k,m})^2}\ , \tag{5}$$

where $\bar{X}_{k,m} = m^{-1} \sum_{i=k+1}^{k+m} X_i$. The ratio is called the rescaled adjusted range or R/S-statistic.

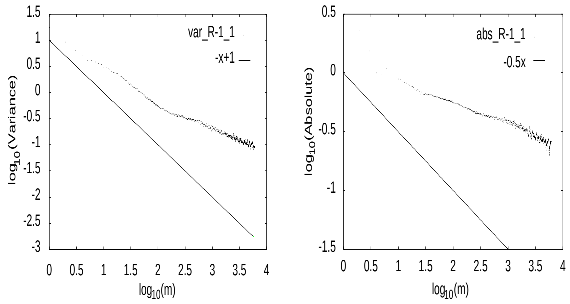
$$\begin{aligned} \frac{R(k,m)}{S(k,m)} &= \frac{1}{S(k,m)} (\max_{0<i<m} [Y_{k+i} - Y_k \\ &\quad - \frac{i}{m}(Y_{k+m} - Y_k)] \\ &\quad - \min_{0<i<m} [Y_{k+i} - Y_k \\ &\quad - \frac{i}{m}(Y_{k+m} - Y_k)]) \end{aligned} \tag{6}$$

For a large values of m, we have the properties as follows from empirical finding

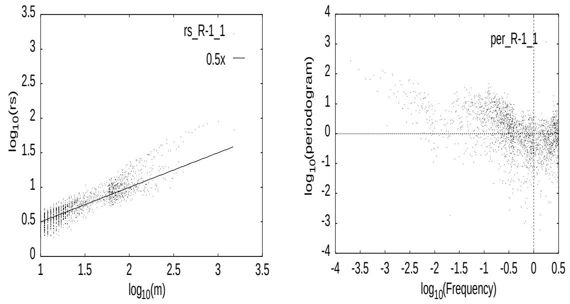
$$\log E[R/S] \approx a + \log m^H, \tag{7}$$

where a is constant. R/S-statistic is plotted versus m on a log-log plot. The result will be a straight line with a slope of H.

For a time series of length N, subdivide the series into K, each size of N/K. Then, for each lag m, compute $R(k_i, m)/S(k_i, m)$, starting at points $k_i = iN/K + 1, i = 1, 2, \cdots$, such that $k_i + m \leq N$.

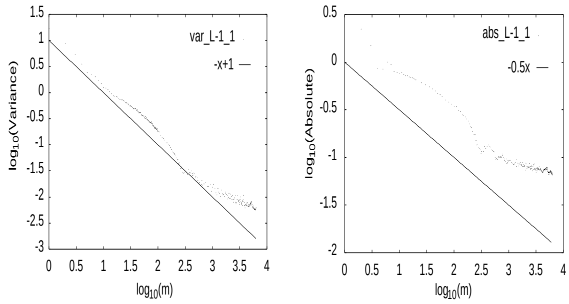


(a) Aggregated variance (b) Absolute value

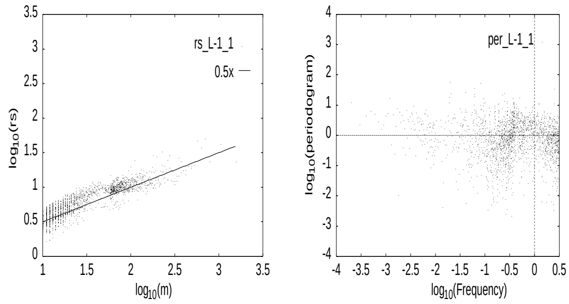


(c) R/S (d) Periodogram

Figure 3: Graphical results for R-1_1.



(a) Aggregated variance (b) Absolute value



(c) R/S (d) Periodogram

Figure 4: Graphical results for L-1_1.

3.4 Periodogram Method

The periodogram is defined as follows

$$I(\lambda) = \frac{1}{2\pi N} |\sum_{j=1}^{N} X_j e^{ij\lambda}|^2, \tag{8}$$

where λ, $\{\lambda : 0 \leq \lambda \leq \pi\}$, is the frequency and N is the length of the series. $I(\lambda)$ is an estimator of the spectral density of X_t, $\{X_t : t = 1, \ldots, N\}$, and a series with long-range dependence will have a spectral density proportional to $|\lambda|^{1-2H}$ close to the origin. That is

$$I(\lambda) \quad \approx \quad c_f |\lambda|^{1-2H}, \tag{9}$$

where c_f is constant. A log-log plot of periodogram versus the frequency have a straight line with a slope of $1-2H$ as $\lambda \to 0$. In practice, only the lowest 10% of the frequencies is usually used for the calculation.

4 Inference for Self-Similarity on Testbed Network

In this section, we show the results of the analysis for the traffic of the testbed network and estimate the Hurst parameter.

4.1 Results of Data Analysis

First, we apply four graphical methods described in the previous section to the high bitrate data (Table 1). In order to evaluate the self-similarity of ATM cell stream, we estimate the Hurst parameter of the measured data. We need to decide the cut-off points for each method. For decision of cut-off points, we assume that

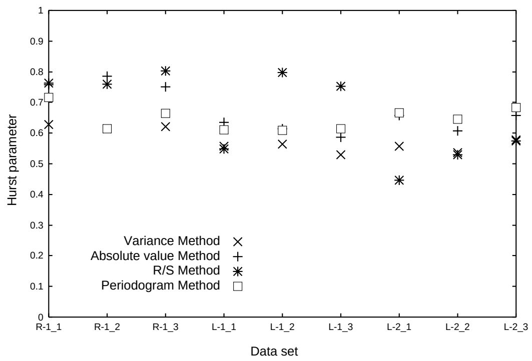


Figure 5: The result of estimating Hurst parameter

measured series X_t is distributed according to Fractional Gaussian Noise (FGN). We generated samples of FGN by Fast Fourier Transform (FFT) with several Hurst parameters (see [8] for details). The maximum time scale of FGN data is equal to measured data. We applied four graphical methods to these data sets, and chose the cut-off points in which slope of the least square line indicates the given Hurst parameter. Readers are referred to [13] for details.

Remark: Most of previous researches have not indicate the criteria for decision of cut-off points. This is still an open problem and hence we make the FGN assumption. The further research is needed for the validity of this assumption. However, this is beyond the scope of our study.

We chose $10^{0.3}$ and $10^{2.0}$ as the cut-off points for Aggregated Variance and Absolute Value methods. For the R/S methods, we chose that the cut-offs are $10^{2.5}$ and $10^{3.5}$. Note that the R/S method is very sensitive for deciding the cut-off points in case of the data having the weak long-range dependency [13]. For periodogram method, according to [6], [9], the only lowest 10% of the frequencies are used for calculation of estimating the Hurst parameter. However, our results for periodogram showed that 10% of the frequencies are not always sufficient for estimating H, so we estimate Hurst parameter using all plots [13].

We show examples of the results of Aggregated Variance, Absolute Value, R/S and Periodogram Methods in Fig.3 for Right traffic (R-1_1), and in Fig.4 for Left traffic (L-1_1). For the results of other data sets, readers are referred to [13]. In Figs. 3 and 4, the solid lines present $H = 0.5$.

Fig.5 is the result of estimating Hurst parameters applying four methods. From this figure, we can see that each Right data has larger value than each Left data except R/S method. Seeing the Table 2, the mean

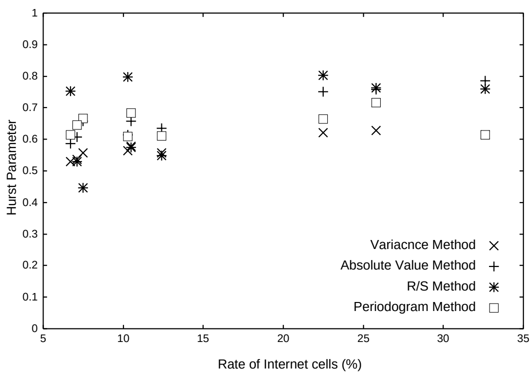


Figure 6: Estimation results for high bit rate

Table 5: Estimating results of separated data.

	Aggregated Variance	Absolute Value	R/S	Periodogram Method
MPEG	0.458529	0.753994	0.351121	0.803301
Internet	0.761861	0.841106	0.749321	0.682505
mixture	0.632345	0.766817	0.762778	0.716207

bit rate of Internet cell of each Right data is larger than that of Left data. This implies that when the Internet traffic on the ATM network increases, the long-range dependency on the ATM cell streams become strong.

As for R/S method we can't observe the tendency that the Internet traffic increase the long-range dependency of whole stream. One of the reasons is that R/S Method is very sensitive to the presence of short range dependency[12] in the whole stream. As a result, it is difficult to decide the cut-off points in case of the data contained weak long-range dependent traffic.

It is difficult to determine the value of Hurst parameter of this ATM cell streams because the time scale of measuring is not long enough. However, estimated Hurst parameters in Fig.5 are indicating that the ATM cell streams in this project exhibits self-similar nature in a certain level. If we assume that our testbed network has self-similarity, then its Hurst parameter would be around 0.6.

Fig.6 depicts the relation of the rate of Internet cell and Hurst parameter without taking the direction into account . From Fig.6, it is observed that as the rate of Internet cell becomes large, the Hurst parameter tend to increase except R/S method. From these results, we conclude that the Hurst parameter is about 0.6 when Internet cells account for nearly 10% of all cells transmitted on the backbone line, and that the Hurst parameter becomes larger than 0.6 as the Internet cells increase. Therefore we can assume that when the rate of Internet cell is $20 \sim 30\%$, from Fig.6, the Hurst parameter is more than 0.6, on the other hand, when the rate of Internet cell is nearly 10%, the Hurst parameter is about 0.6.

Next, we analyze the low bitrate data using four graphical methods, and illustrate the results in Fig.8. In Fig.7, we show the relation of average bit rate of Internet cell and Hurst parameter without taking the direction into account. In [5], it was reported that the Hurst parameter of CBR stream is quite large. From Fig.7, we observe this tendency of the estimated results of Absolute value and Periodogram methods, while not for Variance and R/S methods. The reason is discussed in the following subsection.

4.2 Characteristics of Analytical Methods for MPEG Stream

We separate the MPEG and Internet cells from high bit rate data (R-1_1), and analyze these individually. Fig.9 illustrates the graphical results with Aggregated Variance and Absolute Value Methods. Fig.10 presents

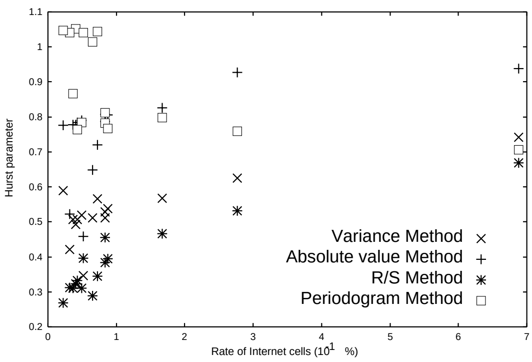
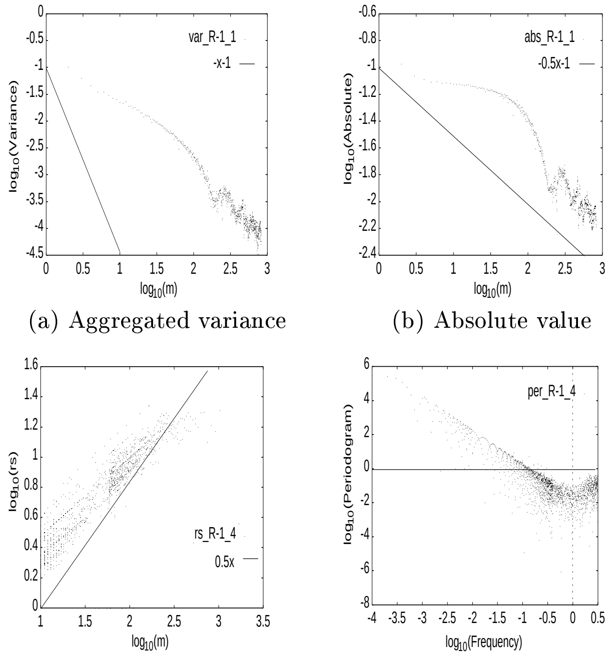


Figure 7: Estimation results for low bit rate



(a) Aggregated variance (b) Absolute value

(c) R/S (d) Periodogram

Figure 8: Graphical results for low bitrate.

the results with R/S and Periodogram Methods. In both figures, (a) and (b) are the results for MPEG data, (c) and (d) for Internet and (e) and (f) for data of whole stream. From these figures, we observe that the estimated value for MPEG stream is very small as for the Variance and R/S method. On the other hand, we find that the self-similarity with $H > 0.5$ appear in MPEG stream using Absolute Value and Periodogram methods. As for the Internet stream, it exhibits the self-similar nature with long-range dependency with all methods. Table 5 shows the estimation results of original and separated data.

These and previous results show the weak point of Variance and R/S methods to estimate the Hurst parameter for regular time series. MPEG cells are transmitted with PVC-CBR. This means that MPEG stream is a highly correlated time series. Thus the Hurst parameter must be close to 1 [5]. However the estimating values for MPEG cells with Variance and R/S methods are very small in Table 5. The extremely small variance of CBR data might cause the inaccurate estimation.

Though two methods used here do not capture the high correlation of MPEG stream, those seem to work well for Internet and aggregated traffic, since the dominant factor of statistical behavior of measured data is Internet stream.

5 Conclusion

In this paper, we investigated the characteristics of cell streams in the ATM network integrating CATV and Internet. Using the four graphical methods, we estimated the Hurst parameter of our testbed network. We observed that the Hurst parameter is around 0.6 provided that the traffic has self-similarity.

We also investigated the effect of the amount of the Internet cells on the Hurst parameter of whole stream. We conclude that the Hurst parameter is about 0.6 when Internet cells account for nearly 10% of all cells transmitted on the backbone line, and that the Hurst parameter becomes larger than 0.6 as the Internet cells increase.

Finally we investigated the Hurst parameter of MPEG and Internet streams contained in the whole stream separately. By estimating the Hurst parameters of MPEG and Internet streams, we observed the characteristics of Variance and R/S methods which can not capture the long-range dependency of MPEG cells. Though MPEG stream is highly correlated, the periodicity of MPEG stream does not matter in its QoS control. However Internet stream will cause the degradation of QoS for MPEG2 since Internet stream exhibits LRD when Internet cells increase.

For the future work, we will construct the simulation model of the Internet cell generator and investigate the jitter behavior of MPEG2 at the decoding points of the testbed network. This is a crucial matter for keeping the QoS of MPEG2 at the required level. By the simulation we will investigate the effects of the number of ATM switches and the cell streams of MPEG2 and Internet.

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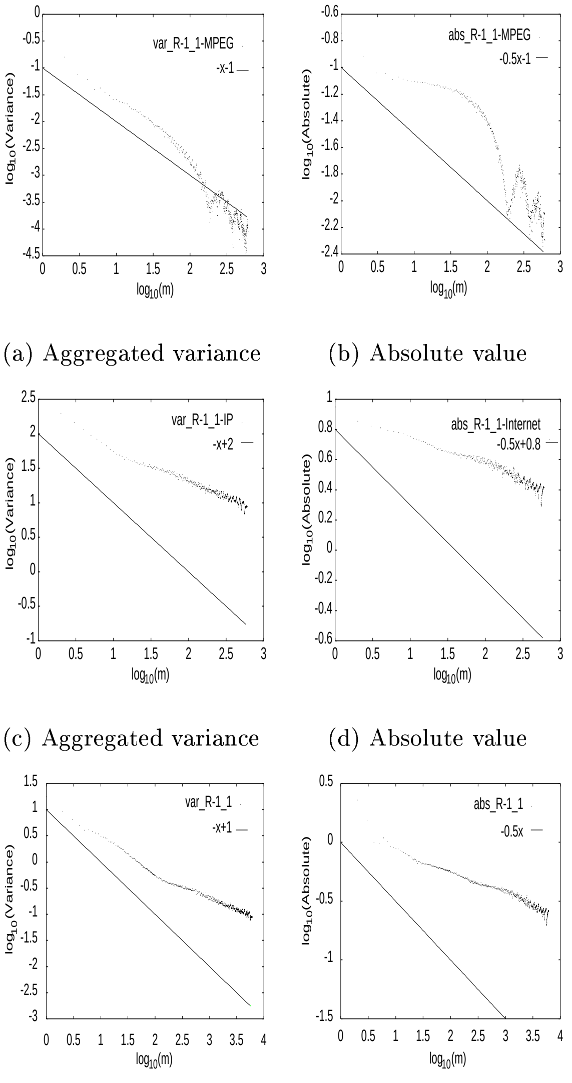
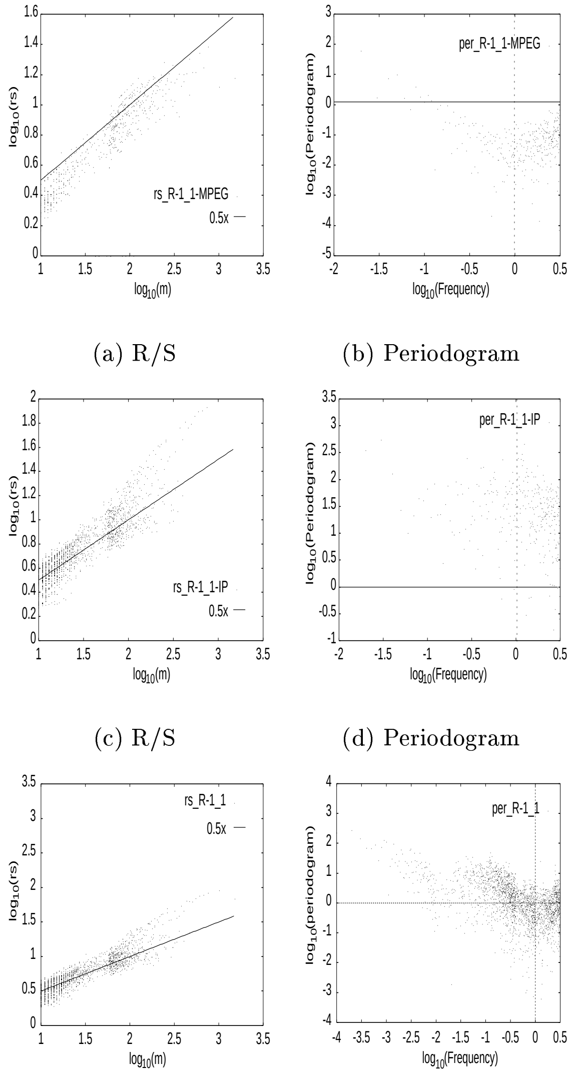


(a) Aggregated variance (b) Absolute value

(c) Aggregated variance (d) Absolute value

(e) Aggregated variance (f) Absolute value

Figure 9: Results under aggregated variance and absolute value methods.



(a) R/S (b) Periodogram

(c) R/S (d) Periodogram

(e) R/S (f) Periodogram

Figure 10: Results under R/S and periodogram methods.