CELL DELAY VARIATION PERFORMANCE OF CBR AND VBR MPEG-2 SOURCES IN AN ATM MULTIPLEXER

Javier Zamora, Dimitris Anastassiou and Kand Ly
Department of Electrical Engineering
and Image Technology for New Media Center
Columbia University, New York, NY 10027, USA
e-mail: javier@ee.columbia.edu

ABSTRACT

Video services require specific constraints regarding the delay variation or jitter experienced when they are transmitted in packet networks such as ATM. This delay component is mainly generated in multiplexing processes and it has a direct impact on the final QoS. In this paper the jitter issue is addressed in the environment of a video server connected to an ATM Network. Both CBR and VBR MPEG-2 streams are considered as traffic sources. For each video source its delay variation is studied using first order and second order statistics such as jitter variance and GCRA, respectively. We study several traffic scenarios, where correlation between video sources is considered . Finally the obtained results are compared with the M+D/D/1 model.

1 INTRODUCTION

One of the most important issues in the integration of video services in an ATM network is the delay such services experience across a connection. In this paper the problem of delay is addressed in the environment of MPEG-2 Transport Streams (TS) over ATM networks. Insuring that the delay variation experienced by the TS, remains within certain bounds with a very high probability is critical for the design (i.e. memory constraints) and operation (i.e. perceptual Quality of Service) of MPEG-2 decoders. The Cell Delay Variation (CDV), commonly named jitter, is a complex function of the number and type of ATM switches (multiplexers), scheduling algorithms and amount and type of traffic between the two ends of the connection [1]. The jitter component, CDV in the ATM layer, is mainly generated in buffering and cell scheduling processes.

In this paper we consider the case of a video server connected to an ATM network, this is the case of a Video-on-Demand (VoD) service [2]. The video server can be modeled as a generic ATM multiplexer with a specific scheduling algorithm that will depend on the architecture of the system. We study the delay introduced in each individual video source multiplexed in the video server under different scenarios. In this way, we can observe the Quality of Service (QoS) per video source type instead of the QoS associated to the aggregated traffic at the output of the multiplexer. The traffic scenarios are defined both by the traffic characteristics of the target video source and the cross-traffic generated by the rest of the video sources. In Section 2, the ATM multiplexer model, the delay measurements, the video sources used and the traffic scenarios are presented. Section 3 details the performance results for the different scenarios considered as well a comparison with an analytical model. Finally in Section 4 some concluding remarks are given.

2 CDV SCENARIOS

2.1 ATM Multiplexer

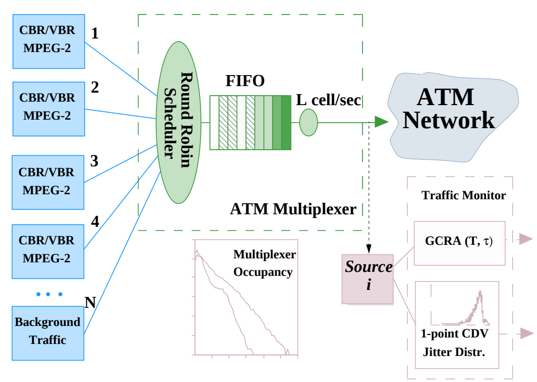

Figure 1: ATM Multiplexer Model

Fig. 1 shows the simulation scenario used in this work. This scenario consists on one ATM multiplexer with N input ports, and one output port. As mentioned in Section 1, this multiplexer can model one port of an ATM switch or the network interface of a video server. The input and output link rates of the system are identical and equal to 149.76 Mbps (353,207.57 cells/sec). The multiplexer buffer uses a FIFO policy and is assumed to be sufficiently large to prevent cell loss due to buffer overflow. A hierarchical round-robin scheduling algorithm is used to resolve contention between two or more sources in the access to buffer, i.e. in the case of cell contention, sources with higher bit rate have higher priority.

The output of the multiplexer is directly connected to an ATM network.

2.2 Video Sources and Scenarios

We use both Constant Bit Rate (CBR) and Variable Bit Rate (VBR) video sources. The video streams are coded using MPEG-2 standard and multiplexed in TSs with fixed 188-byte packets. We adopt a 376-byte Protocol Data Unit (PDUs) containing 2 TS packets, following the recommendation from The ATM Forum. Such PDUs are mapped into 8 ATM cells when the AAL5 is used. Although the rate between frames in the VBR sources varies, the rate within the rate does not because we assume a constant frame rate, rather than a constant slice rate or constant block rate.

Three different scenarios are studied: only CBR MPEG-2 TSs, only VBR MPEG-2 TSs and a mixture of CBR and VBR MPEG-2 TSs. Table 1 describes these three traffic scenarios. Each of them tries to reflect a typical case in a video server with $N = 35$ heterogeneous video sources: a few video streams of high quality (10 Mbps), streams with quality between TV and VCR quality (2.5-5 Mbps), streams for software decoders (0.8 Mbps) and aggregate traffic modeled as Poisson Traffic. All scenarios have an utilization $\rho \simeq 0.9$ of the multiplexer. The VBR streams are independent from each other with burstiness, $B = peak\ rate/avg.\ rate$, ranging from 2.58 to 9.89.

Rate (Mbps)	CBR No. Src.	VBR No. Src.	CBR+VBR No. Src.
10	3	3	2+1
5	7	7	4+3
2.5	10	10	5+5
0.8	15	15	8+7

Table 1: Traffic Scenarios. $\rho \simeq 0.9$, $N = 35$ + 20 Mbps Poisson Background Traffic.

2.3 Delay Measurements

The traffic pattern of each video source is monitored at the output of the multiplexer (Fig. 1) where its cell interarrival times are compared with the original video traffic pattern. The jitter for cell k from video source n, $j_{k,n}$ is defined as $t_{k,n} - r_{k,n}$, where $t_{k,n}$ is the theoretical departure time for cell k from video source n, in other words, the departure time in absence of cross-traffic. And $r_{k,n}$ is the actual departure time for the same cell and video source. In the absence of cross-traffic, $j_{k,n}$ has a probability mass function equivalent to a Kronecker delta function $\delta_{m,0}$, where m is expressed in cell units. For this reason, the variance ${\sigma_n}^2$ of the random variable jitter J_n is an indicator of the jitter introduced in the video source n. We consider also the skewness, ν, which is a measure of symmetry of the probability mass function and is defined as $\nu_n = E[(J_n - \mu_n)^3]/{\sigma_n}^3$, with $\mu_n = E[J_n]$. This third moment measure indicates how uniform the delay variation is generated (i.e. a cell clump is compensated by a cell gap of the same magnitude).

Other more complicated and insightful statistics are the 1-Point Cell Delay Variation (CDV) and the Generic Cell Rate Algorithm (GCRA) which is equivalent to the continuous state leaky bucket algorithm [3]. The CDV for cell k and source n, $y_{k,n}$ is defined as $c_{k,n} - r_{k,n}$, where $c_{k,n}$ is the cell's reference arrival time for that cell and video source. Such reference arrival time is defined as follows

$$c_{k+1,n} = \begin{cases} c_{k,n} + T_n & \text{if } c_{k,n} \geq r_{k,n} \\ r_{k,n} + T_n & \text{otherwise} \end{cases} \quad (1)$$

where T_n is the period which corresponds to CBR TS n. The reference arrival time eliminates the effects of cell gaps and provides a measurement of cell clumping.

The GCRA(T_n,τ_n) defines a leaky bucket running at a rate of $1/T_n$ with a tolerance of $100\tau_n/T_n$ and is a second-order statistic that measures the burst tolerance. If the tolerance is 0%, we only admit the cells that are not violating the traffic contract, i.e. cells whose interarrival time is greater than or equal to the nominal period T_n. By increasing the value of τ_n the number of admitted cells will increase. A less bursty source will have more cells admitted. For this reason, the GCRA measures the deviation of a multiplexed video source from a nominal network traffic contract. In order to have all cells admitted for a non-ideal source, it is necessary to increase the tolerance beyond 0%. For the VBR streams, the concept of GCRA is virtually extended using a different $T_{k,n}$ and $\tau_{k,n}$ for each cell k from video source n [4].

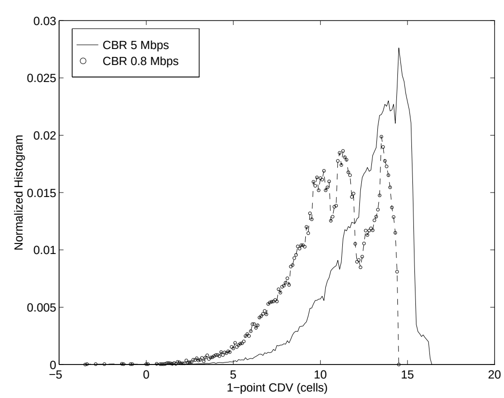

Figure 2: 1-point CDV Normalized Histogram for Scenario CBR.

3 CDV PERFORMANCE

3.1 CBR Scenario

For this traffic scenario since all sources (except the background traffic) are CBR sources, no statistical multiplexing is built up and the maximum delay is basically bounded by the number of sources accessing the multiplexer. In our case, the average occupancy has the value of 3.18 cells. The cell delay variation in each video source is caused by the ratio between the different rates, the phase of these sources from other sources and the potential cell collision with the Poisson background traffic. There is also a periodic jitter caused for using a slotted system, this component is bounded to ± 1 cell. In Fig. 2 the CDV normalized histogram for CBR Scenario is shown. We observe that the higher the rate is the higher the CDV value is. However these values are on the same order of magnitude, ranging from an average CDV value of 10.66 cells for CBR 0.8 Mbps TSs to 13.17 cells for CBR 10 Mbps TSs. With regard to the jitter, ${\sigma_n}^2 \approx 5.5$ cells^2 and $|\nu_n| < 0.06$ for all the video sources, which indicates that the jitter is bounded to a few cells and is basically periodic (symmetry of the histogram around the origin).

All the previous values are first-order statistics of delay. One important question is how compliant with the network traffic contract is a video stream at the output of the multiplexer. To answer this question we use the GCRA that provides a second-order statistic measure of the traffic pattern. Fig. 3 shows the performance of GCRA for this scenario. We clearly appreciate that higher bit rates sources suffer more the effect of the delay variation. For instance we need a tolerance of 10% to admit all the cells from a CBR 0.8 Mbps TS, but we need a tolerance of 70% to have all the cells compliant in the case of a CBR 10 Mbps TS. The higher the rate is, the shorter the period T_n, expressed in cells, is. Therefore the probability of contention with the rest of sources is also higher. Moreover, a CDV value maps to higher tolerance values for higher bit rate TSs.

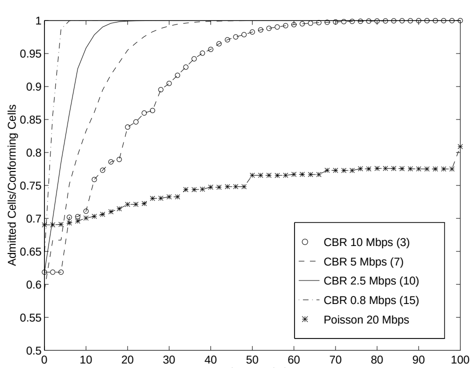

Figure 3: GCRA(T_n, τ_n) performance for Scenario CBR.

3.2 VBR Scenario

3.2.1 Independent Video Sources

In this scenario we use 35 VBR MPEG-2 TSs from different video sequences with an average burstiness of 5. In this case a statistical multiplexing is built up. However, the nature of MPEG-2 streams, which have the periodic structure of the Group of Pictures (GoP), provokes a higher multiplexer occupancy values than desired, because of the periodic pattern. For the VBR Scenario the average occupancy is 508.4 cells, sensibly higher to the value in Scenario CBR. In this kind of scenario the causes of cell delay variation are more complex than in the CBR Scenario. We observe that the jitter variance, ${\sigma_n}^2$ increases for the lower bit rates (Table 2), where the aggregate cross-traffic from the rest of the sources is higher. At the same time the skewness, ν_n is negative and an order of magnitude larger than in the CBR Scenario. This indicates that the jitter is not periodic creating more bursty patterns, since the variance in the negative side of the histogram, which corresponds to the cell clumping, is higher.

A GCRA run at the peak rate T_{peak_n} will certainly admit all its cells, while a GCRA run at average rate T_{avg_n} will have very poor performance without allocating a very high tolerance. For this reason, we extend the GCRA concept to the VBR case by using a different period $T_{k,n}$ for each cell k of video source n. Fig. 4 shows the GCRA performance for the VBR Scenario. We observe the same tendency as in the CBR Scenario. However if we compare both scenarios, the performance is worse for the VBR case, since the cell contention is more stochastic for the nature of the VBR video streams.

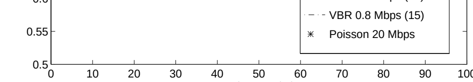

Figure 4: GCRA$(T_{k,n}, \tau_{k,n})$ for Scenario VBR.

3.2.2 Correlated Video Sources

In this scenario, we replace the 10 uncorrelated VBR 2.5 Mbps streams by 10 correlated VBR 2.5 Mbps streams. This experiment tries to reflect a video server where several users are accessing the same video stream in a short period of time. Each one of these VBR video streams differs 1 second (30 frames) from the previous one. Table 2 compares the values of ${\sigma_n}^2$ and ν_n for the uncorrelated and correlated case. We observe that the jitter variance of the correlated VBR 2.5 Mbps is two times the jitter variance of the uncorrelated streams. The rest of the video streams do not have a sensitive change in the value of the jitter variance. However the skewness for the VBR 2.5 Mbps TS is now positive, this indicates that these sources suffer the delay from that correlation in large gaps in their cell streams.

Rate (Mbps)	${\sigma_n}^2$ Uncorr.	ν_n Uncorr.	${\sigma_n}^2$ Corr.	ν_n Corr.
10	23.77	-1.55	25.98	-1.45
5	20.01	-0.82	20.34	-0.43
2.5*	46.60	-0.82	95.86	1.06
0.8	402.34	-1.13	428.20	-0.70

Table 2: Impact of correlated 2.5 Mbps VBR sources.

3.3 CBR+VBR Scenario

Table 3 shows the jitter variance and skewness for the CBR+VBR. In this case the presence of deterministic traffic (CBR video streams) reduces the values of ${\sigma_n}^2$ and $|\nu_n|$ for the VBR video streams in relation to the VBR Scenario. By contrast the ${\sigma_n}^2$ and $|\nu_n|$ for the CBR video streams increase in relation to the CBR Scenario, due to the presence of the non deterministic cross-traffic (VBR video streams).

Rate (Mbps)	${\sigma_n}^2$ CBR	ν_n CBR	${\sigma_n}^2$ VBR	ν_n VBR
10	5.89	-0.16	7.34	0.09
5	8.07	-0.11	7.52	0.35
2.5	20.17	0.05	15.77	0.30
0.8	123.20	0.19	132.88	0.27

Table 3: Jitter Parameters for Scenario CBR+VBR.

3.4 M+D/D/1 Model

Fig. 5 shows the jitter normalized histogram for a 2.5 Mbps video source from the CBR Scenario and the VBR Scenario when it is compared to the inter-exit time distribution $f_1(k)$ and the limit inter-exit time distribution $f_\infty(k)$ from the M+D/D/1 model [5] with equivalent conditions ($d = T_{2.5\ Mbps}$, $\rho = 0.9$). $f_1(k)$ is a conservative bound for the Scenario CBR because it considers a Poisson cross-traffic. This assumption is not valid when the number of sources is not high enough, as it is the case in a video server. $f_\infty(k)$ provides a very conservative bound for both scenarios.

4 CONCLUSIONS

We have studied the cell delay variation incurred in an ATM video server when CBR and VBR MPEG-2 TSs are multiplexed. From the results of the analyzed scenarios, we observe that the higher the statistical multiplexing is, the higher cell delay variation is. For this reason, VBR streams experience more jitter when they are multiplexed along other VBR sources. This jitter is dependent on the correlation with the other VBR sources. For all the scenarios the high bit rate sources are more sensitive to the GCRA rather than low bit rate sources. Both first and second order statistic measures are necessary to have a good understanding of the jitter impact on the QoS. Finally, classical Markovian models do not accurately describe the jitter process. This difficulty is increased with non stationary conditions derived from the fact that the observed cross-traffic by a particular source is changing along its connection time.

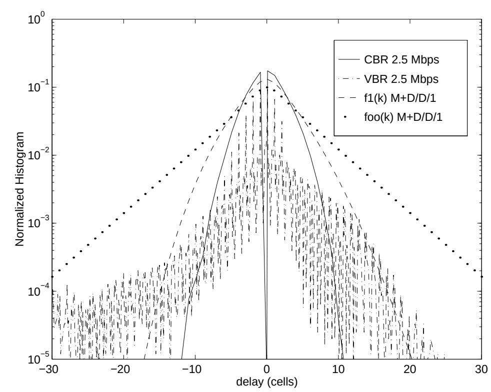

Figure 5: Jitter Comparison of CBR and VBR 2.5 Mbps sources with equivalent M+D/D/1 Model.

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