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Estimation of ATM Traffic Descriptors for the Transport of MPEG-4 over ATM Using the Virtual Buffer Measurement Technique

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Abstract – **In this paper, we applied the virtual buffer measurement technique to estimate near-minimal sets of ATM traffic descriptors for transport of stored MPEG coded video over ATM networks. To evaluate estimated traffic descriptors (TDs) accuracy, we simulate the transport of the MPEG-4 SPTSs over an ATM network with a traffic policing function in the access point. The results had shown that for a great majority of the MPEG-4 traces, the VB technique is capable to estimate a near-minimal set of ATM TDs. However, an improvement must be done so that it can be used to estimate near-minimal TDs for any MPEG-4 sequence.**

I. INTRODUCTION

It is expected that MPEG-4 [1] coded video will take a significant portion of the traffic in future broadband networks [2]. MPEG-4 provides very efficient video coding, covering the range from the very low bit rates of wireless communication to the bit rates of high definition television (HDTV). Also, because MPEG-4 is object based. It allows the transmission of different types of multimedia on the same traffic stream. On the other hand, ATM (Asynchronous Transfer Mode) [2] is being considered the most promising transport technology to offer end-to-end QoS guaranties. In this scenario, precise MPEG traffic descriptors estimation for transport over ATM networks is fundamental, because:

- Connection admission control algorithms [2] use these traffic descriptors to allocate and maintain quality of service in active connections.
- Each connection is policed with relation to its traffic descriptors with the objective to verify if allocated QoS has not been overlapped. If this occurs, ATM cells will be discarded, causing the loss of MPEG transport packets.

However, there are many factors that difficult these traffic descriptors estimation. The mainly are:

- The uncertainty related with sources behavior.
- The construction of mathematical models that capture sources behavior.
- The existence of an infinite number of traffic descriptors that can be used to describe a certain MPEG traffic stream.
- The real time nature of MPEG coded video.

To simplify the problem, in this work we assume that a statistically representative sample of the MPEG streams is available, so eliminating the real time nature of the coded video and the necessity for mathematical models. Therefore, in this work we consider just the transportation of stored MPEG coded video over ATM, like in a near video on demand system [3] over ATM.

To estimate the ATM traffic descriptors in this case, three approaches are being used:

- Effective bandwidth techniques [4].
- Direct traffic stream estimation using GCRA (Generic Cell Rate Algorithm).
- Virtual buffer measurement estimation technique [5].

Thus, in this paper we use virtual buffer (VB) measurement technique to estimate near-minimal sets of ATM traffic descriptors (TDs) for stored MPEG transport over ATM networks. The remaining of this paper is divided as follows: section II presents the VB technique; section III presents our technique implementation; section IV presents the application of the VB technique on the estimation of ATM TDs for 10 MPEG-4 traces; section V shows an accuracy evaluation of the estimated TDs; section VI describes a convergence problem found when using the VB technique to estimate ATM TDs for MPEG-4 traces; finally, in section VII we draw some conclusions about the results.

II. VIRTUAL BUFFER MEASUREMENT TECHNIQUE

The virtual buffer measurement technique [5][6] is an efficient ATM traffic descriptors estimation technique, which can be used to estimate all near-minimal sets of TDs PCR (Peak Cell Rate), CDVT (Cell Delay Variation Tolerance), SCR (Sustainable Cell Rate) and MBS (Maximum Buffer Size) for a desired ATM VBR traffic stream. According to [5], the VB technique is more

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efficient than direct estimation using GCRA, and is able to be used not only in computational simulations, but also in real world networks. The VB technique allows substituting the direct GCRA simulation of a traffic applied to a dual GCRA by the equivalent simulation of this traffic applied to a VB.

The VB technique is based on the existent equivalence between the VB and a GCRA (I, L), where L and I are, respectively, the limit and the increment of the GCRA. This equivalence is illustrated in the Figure 1, and the following aspects support it:

- The overflow of a certain occupation threshold in the VB is equivalent to the overflow of a certain conformance threshold in the traffic policer.
- Other equivalence between the two systems is the equivalence between the VB service rate (SR) and the inverse of the increment I used in the GCRA traffic policer. Or:

$$SR = \frac{1}{I} \quad (1)$$

- Finally, there is an equivalence between the maximum virtual buffer fill (MBF) and the GCRA (I, L) limit L. Or:

$$MBF = L \quad (2)$$

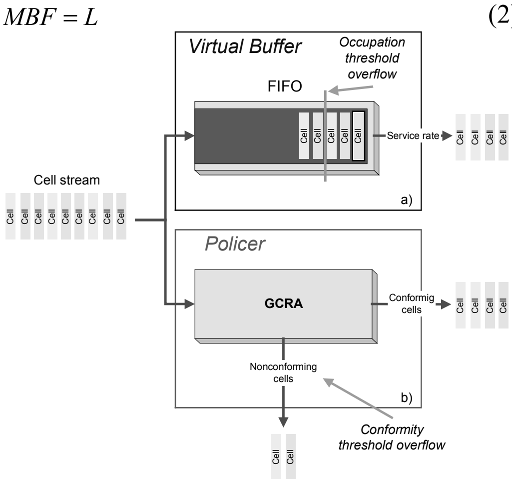

Figure 1. Equivalence between VB and traffic policer.

The equivalence between the VB and the GCRA traffic policer is demonstrated in [5], and is based on the following proposition:

<u>Proposition 1</u>: A traffic stream that results in a maximum VB occupation (MBF) of m ATM cells when processed by a VB served at a rate of $1/I$ cells/sec will be GCRA (I, L) conforming if $L = m.I$ and will be nonconforming if $L < (m-1).I$.

In [5] this proposition is used to determine all the near-minimal possible ATM TDs of a certain VBR stream. This is done applying the proposition 1 to a dual traffic policer composed by a GCRA (T_0, T_0), followed by a GCRA ($T_S, BT + T_0$), where:

$$T_0 = \frac{1}{PCR} = CDVT \quad (3)$$

$$T_S = \frac{1}{SCR} \quad (4)$$

It is important to observe that with the restriction $T_0 = CDVT = 1/PCR$, there exists just one minimal value for the PCR of a certain VBR traffic stream. Therefore, applying proposition 1 to each of the GCRA traffic policers we have:

- GCRA (T_0, T_0) – In this case I=L=T_0. So the only possible solutions for the equation $L = m.I$ will be m = 0 and m = 1. Because we are looking for the minimal VB service rate, whose value is equivalent to the traffic stream PCR, the m value that requires the lower VB service rate will be m = 1. Therefore, the traffic stream PCR's will be equal to the minimal VB service rate that produces an MBF of one cell.
- GCRA ($T_S, BT + T_0$) – In this case, $I = T_S$ and $L = BT + T_0$, with $T_S = 1/SCR$. Substituting I and L in the equation $L = m.I$, we have:

$$BT = \frac{MBF}{SCR} - T_0 \quad (5)$$

This expression offers a burst tolerance (BT) value that results in VBR traffic conformance when submitted to a GCRA ($T_S, BT + T_0$). Since each VB service rate is equivalent to a valid SCR (smaller than the traffic stream PCR and larger than the mean traffic stream rate), the expression (5) offers a minimal BT for each SCR. T_0 can be determined from a previous application of proposition 1 in a GCRA (T_0, T_0). The correspondent maximum burst size (MBS) can be obtained from equation:

$$MBS = \left\lfloor \frac{BT}{T_S - T_0} \right\rfloor + 1 \quad (6)$$

Therefore, from the equivalence of VB with GCRA (T_0, T_0) and GCRA ($T_S, BT + T_0$), it is possible to estimate the ATM TDs of a VBR traffic stream. This is done simulating the VBR traffic applied to a FIFO queue that is served at a constant service rate. Therefore, the VB technique consists of varying this service rate, measuring the maximum FIFO occupation (MBF) and estimating the TDs.

Because every given VB service rate is a valid SCR, in [5] it is presented two methods that can be used to choose just one (SCR, MBS) pair for a certain VBR traffic stream. The first one is briefly discussed in this paper and is based on the effective bandwidth criteria. The second is based on limiting the MBS to a reasonable value and then selecting the corresponding SCR value.

III. VB IMPLEMENTATION

This section describes the software, Virtual Buffer VBR Traffic Descriptors Estimator (available for download in [11]), which was developed to estimate VBR TDs using the VB technique. The developed software reads from an external file a VBR traffic stream whose TDs will be estimated. Such traffic stream must be in a 40 bytes AAL-SDU (ATM Adaptation Layer – Service Data Units) format. The reasons for that will be discussed in section IV. To simulate the system in Figure 1a the software uses an event-driven simulation technique [7]. The software posses a priority queue in each which system event is ordered according to a predetermined execution time. Therefore, simulation dynamics is obtained executing the highest priority event and adjusting simulation time according to this event.

The software executes two algorithms in sequence. The first one estimates just one (PCR, CDVT) pair, while the second estimates a set of (SCR, MBS) pairs. Following we present these algorithms.

A. Estimation of a (PCR, CDVT) Pair

This estimation algorithm realizes an interactive simulation of the Figure 1a system to obtain a better possible estimation of a (PCR, CDVT) pair. At each interaction, VB is submitted to service rate of SR cells/second and its maximum occupation is monitored. Convergence is obtained when it is found a service rate that produces a MBF of one cell. This situation occurs in the threshold between a SR that produces a MBF of one cell and a SR that produces a MBF of two cells.

First, it is done an initial configuration of the variables:

- SR – VB service rate. It is initiated with a value equal to the input VBR traffic stream. The program users must supply this value.
- $SR_{MBF=1}$ – Service rate that produces a MBF = 1.
- $SR_{MBF=2}$ – Service rate that produces a MBF = 2.
- Δ_{SR} – Module of difference between $SR_{MBF=1}$ and $SR_{MBF=2}$.

After the configuration of the initial variables, the program begins a loop that continues until MBF converges to one. Then a FLAG is changed and the estimation process finishes. Inside this loop, at each interaction, an event-driven simulation is executed. This simulation proceeds until there are no more events to be processed or the maximum simulation time is reached ($t_{\max}$). The executed events are:

(1) <u>READ_TRAFFIC</u> – This event reads from an external file the 40 bytes AAL-SDUs. For each AAL-SDU, a cell packetization delay is added and an event SCHEDULE_CELL is scheduled in the priority event queue.

(2) <u>SCHEDULE_CELL</u> – This event stores a cell in the FIFO queue, increases a stored cells counter and verifies if a new maximum occupation occurred. If the VB server is OFF, this event schedules a REMOVE_CELL event to begin to serve cells.

(3) <u>REMOVE_CELL</u> – This event removes a cell from the FIFO queue and decreases stored cells counter. If the queue isn't empty, a new event REMOVE_CELL is scheduled to serve cells at the beginning of the next service time.

When events execution finishes, an adjust in VB service rate is done depending on the obtained MBF:

- <u>MBF ≥ 3</u> – In this case, SR isn't sufficient to serve VBR traffic stream with MBF = 1. If a previous SR has already produced a MBF equal to 1 and a MBF equal to 2 has not been produced yet, we adjust SR decreasing it by half of the difference between $SR_{MBF=1}$ and the current SR. However, if a previous SR has already produced a MBF equal to 2 and a MBF equal to 1 has not been produced yet, we adjust SR increasing it by half of the difference between $SR_{MBF=2}$ and the current SR. Finally, if none of the situations have occurred previously, an empirical adjust is done using:
$$SR = SR + \frac{SR}{10}.\log(MBF) \quad (7)$$
- <u>MBF = 2</u> – In this case, SR isn't still sufficient to serve VBR traffic stream with just one cell in VB. If a previous SR has already produced a MBF equal to 1, we adjust SR increasing it by half of the difference between $SR_{MBF=1}$ and $SR_{MBF=2}$. Otherwise, we increase SR by an empirical value of 200 cells/sec.
- <u>MBF = 1</u> – In this case, the VB service rate is sufficient to serve VBR traffic stream with MBF = 1. However, we are searching for a minimal $SR_{MBF=1}$. Thus, we need to adjust SR decreasing it by half of the difference between $SR_{MBF=1}$ and $SR_{MBF=2}$. Otherwise, we decrease SR in 200 cells/sec.

Convergence is achieved when the difference between $SR_{MBF=1}$ and $SR_{MBF=2}$ is smaller than 10^{-6} and MBF = 1. The (PCR, CDTV) pair is obtained using the expressions:

$$PCR = SR \quad (8)$$

$$CDVT = 1/PCR \quad (9)$$

B. Estimation of a Set of (SCR, MBS) Pairs

As we have seen, the equivalence between the VB and the GCRA (T_S, $BT - T_0$) policer results in an infinite set of (SCR, MBS) pairs conforming to this policer. To obtain only one (SCR, MBS) pair it is necessary to fix one of these descriptors according to a specific method. Instead of implementing some methods to fix one of these TDs, we opted in this first software version to estimate a set of

(SCR, MBS) pairs, in such way that a choice external to the program could be done. Therefore, users must inform the desired number of (SCR, MBS) pairs (N_E) to be estimated. The program then varies the SR value from $SR = 1/N_E .PCR$ to $SR = PCR$, simulating again the VB system for each of these service rates. For each SR value a new Figure 1a system simulation is executed and the (SCR, MBS) pairs and the burst tolerance (BT) are obtained from expressions:

$$SCR[k] = \left(\frac{k+1}{N_E}\right).PCR \quad (k = 0 \text{ up to } k < N_E) \qquad (10)$$

$$BT[k] = \frac{MBF}{SCR[k]} - CDVT \qquad (11)$$

$$MBS[k] = \left\lfloor \frac{BT[k]}{\frac{1}{SCR[k]} - CDVT} \right\rfloor + 1 \qquad (12)$$

IV. ATM TRAFFIC DESCRIPTORS ESTIMATION

In this section we apply the VB technique to estimate nrt-VBR traffic descriptors for 10 MPEG-4 frame size sequences that are publicly available on the Technical University Berlin [9][10]: Jurassic Park I Movie, Silence of the Lambs Movie, Boulevard Bio Talk Show, Formula I, Futurama Cartoon, Simpson's Cartoon, South Park Cartoon, Die Firma Movie, Die Hard III Movie and Mr. Bean Movie. However, before we can apply these sequences in the VB program (publicly available in [11]), we need to generate a MPEG Simple Program Transport Stream (SPTS) for each frame size sequence. The procedure used to transform these sequences (see [12]) is based on the ATM Forum Video on Demand (VoD) Specification 1.1[13]. Although this specification was designed for CBR MPEG-2 streams, it has been used in several studies of VBR MPEG-2 transport over ATM networks [14][15]. Our adaptation approach also adopted the frame-based PES encapsulation presented in [8].

A. Results

Table 1 summarizes the estimated (PCR, CDVT) pairs for each MPEG-4 SPTS, while Figure 2, Figure 3 and Figure 4 show a set with 30 estimated (SCR, MBS) pairs for each of these streams.

TABLE 1. ESTIMATED (PCR, CDVT) PAIRS.

MPEG-4 SPTS	PCR	CDVT
Jurassic Park I Movie	1198.3762	0.000834462437
Silence of the Lambs Movie	1600.0000	0.000625000000
Boulevard Bio Talk Show	925.0000	0.001081081080
Formula 1	1000.0000	0.001000000000
Futurama Cartoon	3259.5052	0.000306795030
Simpson's Cartoon	3259.5052	0.000306795030
South Park Cartoon	3597.8094	0.000277946905
Die Firma Movie	725.0000	0.001379310350
Die Hard III Movie	1200.0000	0.000833333334
Mr. Bean Movie	1103.1250	0.000906515581

As we have seen, any of these (SCR, MBS) pairs will be conforming to the policer GCRA (T_S, $BT + T_0$). To obtain only one (SCR, MBS) pair for each MPEG-4 SPTS, we choose arbitrarily the pair whose SCR corresponds to 80 % of the PCR presented in Table 1. Table 2 summarizes the selected (SCR, MBS) pairs. The figures also show a SCR versus BT curve for each MPEG-4 SPTS.

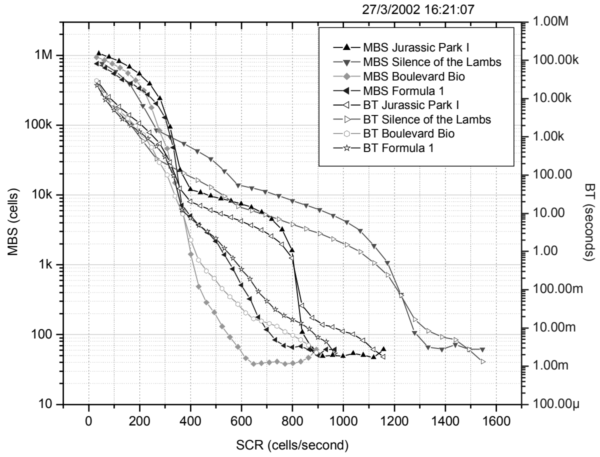

Figure 2. Set of estimated (SCR, MBS) pairs: traces 1 up to 4.

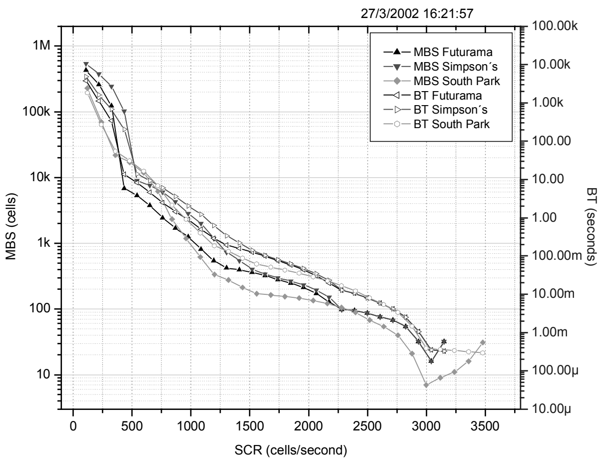

Figure 3. Set of estimated (SCR, MBS) pairs: traces 5 up to 7.

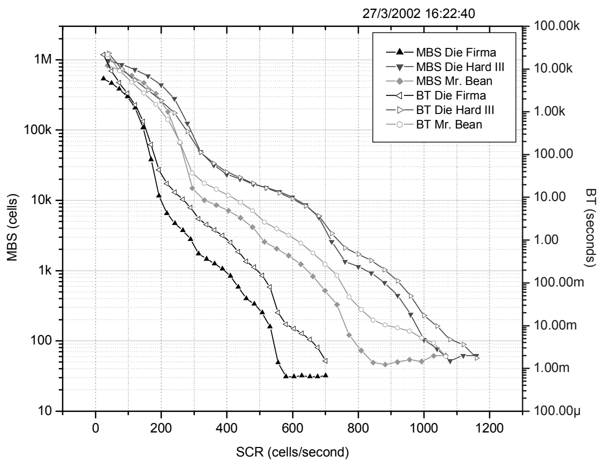

Figure 4. Set of estimated (SCR, MBS) pairs: traces 8 up to 10.

TABLE 2. SELECTED (SCR, MBS) PAIRS.

MPEG-4 SPTS	SCR	MBS
Jurassic Park I Movie	958.701033	51
Silence of the Lambs Movie	1280	107
Boulevard Bio Talk Show	740	41
Formula 1	800	66
Futurama Cartoon	2607.60417	76
Simpson's Cartoon	2607.60417	76
South Park Cartoon	2878.24755	21
Die Firma Movie	580	31
Die Hard III Movie	960	237
Mr. Bean Movie	882.5	46

V. ATM TRAFFIC DESCRIPTORS VERIFICATION

To verify the accuracy of the estimated traffic descriptors, we simulated the transport of the MPEG-4 SPTSs over an ATM network with a dual traffic policing function (GCRA (T_0, T_0) + GCRA $(T_S, BT+T_0)$) in the access point. We call the GCRA (T_0, T_0) as policer A and the GCRA $(T_S, BT+T_0)$ as policer B.

A. Traffic Descriptors Configuration

Following the procedure presented in [5], for each MPEG-4 SPTS we realized a conformance test based in 3 stages:

1. Conformance test with variation in PCR and CDVT – The values of SCR and MBS are kept constant and the values of PCR (used in policer A) are decreased from 100% to 84% of the estimated PCR for this trace in steps of 4%. According with equation (3), the values of CDVT are increased from 100% to 116% of the estimated CDVT also in steps of 4%.
2. Conformance test with variation in SCR – The values of PCR, CDVT and MBS are kept constant and the values of SCR (used in policer B) are decreased from 100% to 68.75% of the estimated SCR for this trace, in steps of 6.25%.
3. Conformance test with variation in MBS – The values of PCR, CDVT and SCR are kept constant and the values of MBS (used in policer B) are decreased from 100% to 68.75% of the estimated MBS for this trace, in steps of 6.25%.

B. Results and Discussions

B.1 Conformance Test with Variation in PCR and CDVT

Table 3 shows that, when applying policer A with a slight reduction in the PCR (4% with relation to the estimated PCR) violations are caused in 70% of the MPEG-4 sequences. Therefore, for these MPEG-4 sequences we can say that the estimated PCR is near to the minimal PCR value. However, for 30% of the MPEG-4 sequences a large reduction in the PCR (8% up to 16%) must be done to cause violations in policer A. For these sequences, the VB technique isn't capable to estimate a near-minimal PCR. The cause of this problem will be discussed in the next section.

TABLE 3. VIOLATIONS CAUSED BY PCR REDUCTION IN POLICER A.

Trace	Number of Violating Cells									
	100%		96%		92%		88%		84%	
	A	B	A	B	A	B	A	B	A	B
Jurassic	0	0	2	2	6	6	15	14	23	23
Silence	0	0	2	4	9	8	15	20	84	45
Boulevard	0	0	16	0	32	32	64	48	80	80
Formula 1	0	0	4	2	10	5	65	11	175	74
Futurama	0	0	0	3	0	9	7	13	19	26
Simpson's	0	0	0	3	0	9	7	13	21	30
South Park	0	1	0	1	0	2	0	3	0	3
Die Firma	0	0	22	3	44	44	66	66	88	88
Die Hard	0	0	3	7	9	15	45	28	75	50
Mr. Bean	0	0	2	2	4	3	26	6	47	53

B.2 Conformance Test with Variation in SCR

Table 4 shows that violations are caused in 80% of the MPEG-4 sequences when applying policer B with a slight reduction in the SCR (6.25% with relation to the estimated SCR). For these MPEG-4 sequences we can say that the estimated SCR (arbitrarily selected from a set of valid (SCR, MBS) pairs) is near to the minimal SCR value. However, for 20% of the MPEG-4 sequences the VB technique isn't capable to estimate a near-minimal SCR.

TABLE 4. VIOLATIONS CAUSED BY SCR REDUCTION IN POLICER B.

Trace	Number of Violating Cells											
	100%		93.8%		87.5%		81.3%		75%		68.8%	
	A	B	A	B	A	B	A	B	A	B	A	B
Jurassic	0	0	0	0	0	64	0	1068	0	2743	0	5074
Silence	0	0	0	254	0	799	0	1765	0	3064	0	4784
Boulevard	0	0	0	0	0	0	0	8	0	30	0	116
Formula 1	0	0	0	2	0	16	0	130	0	634	0	2210
Futurama	0	0	0	3	0	9	0	41	0	78	0	139
Simpson's	0	0	0	3	0	14	0	50	0	109	0	169
South Park	0	0	0	15	0	33	0	59	0	112	0	176
Die Firma	0	0	0	18	0	66	0	125	0	245	0	649
Die Hard	0	0	0	73	0	207	0	542	0	2095	0	5477
Mr. Bean	0	0	0	3	0	66	0	269	0	602	0	1187

B.3 Conformance Test with Variation in MBS

TABLE 5. VIOLATIONS CAUSED BY MBS REDUCTION IN POLICER B.

Trace	Number of Violating Cells											
	100%		93.8%		87.5%		81.3%		75%		68.8%	
	A	B	A	B	A	B	A	B	A	B	A	B
Jurassic	0	0	0	0	0	2	0	2	0	4	0	6
Silence	0	0	0	1	0	3	0	4	0	5	0	8
Boulevard	0	0	0	0	0	0	0	16	0	16	0	32
Formula 1	0	0	0	1	0	2	0	3	0	4	0	4
Futurama	0	0	0	1	0	2	0	3	0	5	0	7
Simpson's	0	0	0	1	0	2	0	3	0	5	0	7
South Park	0	0	0	1	0	1	0	1	0	2	0	2
Die Firma	0	0	0	0	0	3	0	22	0	22	0	38
Die Hard	0	0	0	2	0	5	0	8	0	11	0	14
Mr. Bean	0	0	0	1	0	2	0	2	0	3	0	3

Table 5 shows that when applying policer B with a slight reduction in the MBS (6.25% with relation to the estimated MBS) violations are caused in 70% of the MPEG-4 sequences. Therefore, for these MPEG-4 sequences we can say that the estimated MBS (arbitrarily selected from a set of valid (SCR, MBS) pairs) is near to the minimal MBS value. However, for 30% of the MPEG-4 sequences the VB technique isn't capable to estimate a near-minimal MBS.

VI. The Problem With the VB Technique

For certain MPEG-4 traces the VB technique isn't capable to estimate a near-minimal set of ATM TDs. The problem can be better understood by looking at Figure 5. It shows the VB convergence point and the conformance test for the Simpson's stream at policer A (leaky bucket).

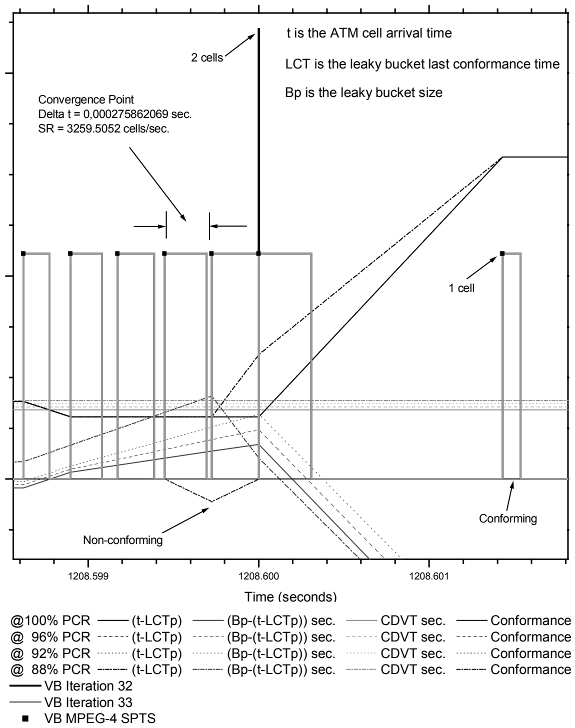

Figure 5. Simpson's convergence point and conformance test.

Observe that for Simpson's trace the VB convergence occurred at iteration 33. At iteration 32 the VB still have a MBF = 2. When policing this trace in the ATM network (each SPTS packet is adapted in exactly one ATM cell) a violation occurs just if $Bp - \left(t - LCT_p\right) > CDVT$ (see Figure 5) and if a certain number of small spaced ATM cells are received (because of leaky bucket's inertia). Therefore, the problem arises because at the convergence point the adapted SPTS doesn't have an enough number of cells to produce a violation when policed with a PCR inferior to the estimated PCR. For the Simpson's sequence, just 6 cells are transmitted at the convergence point. This number of cells isn't sufficient to cause a violation just with a slight decrease in the PCR.

At this time, we are working in a solution to this problem. It is based on determining a convergence point with a minimal number of ATM cells.

VII. Conclusions

In this paper we implemented a virtual buffer measurement technique for finding the near-minimal sets of ATM traffic descriptors of a given MPEG-4 SPTS. To verify the accuracy of the estimated traffic descriptors, we simulated the transport of the MPEG-4 SPTSs over an ATM network with a dual traffic policing function in the access point. The results had shown that for a great majority of the MPEG-4 traces, the VB technique is capable to estimate a near-minimal set of ATM TDs. However, for certain MPEG-4 traces the VB technique fails. The problem behind this fail was presented in Section 0, and an improvement in the VB technique must be made so that it can be used to estimate near-minimal ATM TDs for any MPEG-4 sequence.

Acknowledgments

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References

[1] Rob Koenen, "MPEG-4: Multimedia for Our Time", IEEE Spectrum, Vol. 36, Number 2, February 1999.

[2] G. Sackett and C. Metz, "ATM and Multiprotocol Networking", McGraw Hill, 1997.

[3] Bing Zheng and Mohammed Atiquzzaman, "Multimedia over ATM: Progress, Status and Future", 7° IEEE IC3N, October 1998.

[4] B. L. Mark and G. Ramamurthy, "Real-time Estimation of UPC parameters for Arbitrary Traffic Sources in ATM Networks," Proceedings of IEEE Infocom'96, 1996, pp. 384-392.

[5] David W. Petr, Gopi K. Vaddi e Yong-Qing Lu, "UPC Parameter Estimation Using Virtual Buffer Measurement with Application to AAL *2* Traffic", IEEE Globecom´99, 1999.

[6] H. Zhu e V. S. Frost, "In-Service Monitoring and Estimation of Cell Loss Ratio QoS in ATM Networks", IEEE/ACM Transactions on Networking, Vol. 4, No. 2, pp. 240-248, April 1996.

[7] San K. Shanmugan, "Simulation and Implementation Tools for Signal Processing and Communication Systems", IEEE Communications Magazine, July 1994.

[8] Christos Tryfonas, "MPEG-2 Transport over ATM Networks", MSc Thesis, University of California at Santa Cruz, 1996.

[9] Frank H. Fitzek and Martin Reisslein, "MPEG-4 and H.263 Video Traces for Network Performance Evaluation", IEEE Network Magazine, November 2001.

[10] http://www-tkn.ee.tu-berlin.de/research/trace/trace.html

[11] http://www.mc21.fee.unicamp.br/alberti/programs.htm

[12] A. M. Alberti, E. Andrade and L. Mendes, "Estimativa de Descritores de Tráfego MPEG-4 para o Transporte em Redes ATM Utilizando a Técnica do Buffer Virtual", XIX Simpósio Brasileiro de Telecomunicações, September 2001.

[13] ATM Forum, "Audiovisual Multimedia Services: Video on Demand Specification 1.1", March 1997.

[14] Ahmed Mehaoua, Raouf Boutaba and Guy Pujolle, "An Adaptative and Selective Cell Drop Policy with Dynamic Data Partitioning for Best Effort Video over ATM".

[15] Hassan Naser and Alberto Leon-Garcia, "Performance Evaluation of MPEG-2 Video Using Guaranteed Service over IP-ATM Networks", International Conference on Multimedia Computing and Systems, 1998.