A Cooperative QoS Control Framework For Streaming Video Applications

Ahmed Mehaoua[1] and Raouf Boutaba[2]
[1] University of Versailles, CNRS-PR*i*SM Lab.
45 av. des Etats-Unis, 78000, Versailles, France
[2] University of Waterloo, Dept. of Computer Science
200 University Avenue West, Waterloo,
Ont. N2L 3G1, Canada

***Abstract*-This article describes a cooperative framework for the transport and the QoS control of delay-tolerant video streaming applications using MPEG-2 encoding and broadband ATM networks. The proposed framework integrates three components: 1) a dynamic video frame-level priority assignment mechanism based on MPEG data structure and feedback from the network (DexPAS), 2) an audio-visual AAL-5 SSCS with Forward Error Correction capabilities (AV-SSCS), and 3) an intelligent packet video discard mechanism called FEC-PSD, that adaptively and selectively adjusts cell drop levels to switch buffer occupancy, video cell payload type and forward error correction capability of the destination. The proposed QoS control and video delivery framework is evaluated using simulation.**

I. INTRODUCTION

Asynchronous transfer of video requires careful integration between the network and the video end systems. A number of issues must be addressed in order to tackle the problem on an end-to-end basis. Among these issues are the selection of: the ATM bearer capacity, the ATM adaptation layer, the mechanism of encapsulation of MPEG-2 packets into AAL, the scheduling algorithms in the ATM network for control of delay and jitter, and the error control and correction schemes.

Unspecified Bit Rate (UBR) best effort service is widely available in today ATM backbone networks. This service is based on the excess bandwidth in the network with lower usage cost. It is suitable that this service could efficiently support delay tolerant video applications such as streaming video and interactive VOD. Unfortunately, UBR as initially defined in [1], is not appropriate for carrying such demanding traffic. This paper particularly focuses on unidirectional delay tolerant streaming video applications and attempts to enhance the UBR transport service to efficiently support them.

In order to ensure optimal end-to-end quality, each component along the transmission path must be designed to provide the desired level of QoS. Therefore, optimizing only specific components in the path may not be sufficient for ensuring the QoS desired by the application. The QoS control framework proposed in this paper integrates the three following mechanisms and protocols: A new AAL5 Service Specific Sub-layer with FEC control capability, an intelligent video data encapsulation and priority marking mechanism located at the source, and an efficient cell scheduling policy with adaptive video slice drop at the switch.

The paper is organised as follows. In the next section, we present a brief summary of the state of the art in video transport over ATM broadband networks. We describe in Section 3 the different components of the QoS control framework for streaming video delivery. In section 4, we evaluate and discuss the performance of the cooperative framework using simulation. Finally, we conclude in section 5.

II. RELATED WORK

Various data protection and recovery techniques have been proposed to cope with the problem of transmitting compressed video streams over lossy networks. These schemes attempt to minimise picture quality degradation induced by data loss during network congestion.

Data protection and recovery techniques are usually implemented at the adaptation layer or above such as layered video encoding with data prioritization, which is one of the most popular approaches [2][3]. Forward Error detection and Correction (FEC) techniques associated with byte interleaving and error concealment mechanisms at the destination have also been proposed to address this issue [4], [5] and [6].

At the network level, smoothing algorithms attempt to reduce the burstiness and the peak bandwidth of video streams prior to transmission by applying complex shaping and buffering techniques at the source [7][8]. This should minimise switch buffer oscillation, ease cell scheduling and thereby reduce cell loss probability.

To provide differentiated classes of service to the connections and ease the cell scheduling within the network, data priority assignment at the link or ATM layer is a powerful and cost-effective strategy. In the context of MPEG video communication, several implementations have been proposed.

Human perception is less sensitive to low frequency components of a video signal. Therefore in [2], the 8x8

0-7803-7206-9/01/$17.00 © 2001 IEEE

DCT transformed video blocks are partitioned into an essential or base layer (comprising the lowest frequency DC coefficients), and an enhancement layer (consisting of the set of high frequency AC coefficients). The information contained in the base layer is then packetized and transmitted at high priority (HP), while information in the enhancement layer is transmitted at a low priority (LP) with a best effort delivery service. The cell loss priority (CLP) bit in the ATM header is used to provide a two-level block-based cell priority mechanism within a single channel.

In [9], the authors proposed to adapt the previous approach to the macroblock layer. The DC value is still assigned to the HP stream, and the macroblock header, and the motion vectors for the predictive frames (i.e. P- and B-) are also included. The remaining 63 DCT coefficients are splitted into two sub-streams according to a predefined parameter β. β specifies the number of AC coefficients that are to be placed in the HP stream. The remaining (63-β) coefficients are transmitted in the LP stream. To allow the regeneration of the original bit stream by the destination, the macroblock address is joined to the LP information.

These two techniques send the HP and LP video data onto the same virtual channel using the same ATM service class. In [10], a novel approach is evaluated performing a connection-level prioritisation. The base layer and the enhancement layer of a hierarchically encoded MPEG-2 video are transmitted over distinct channels, i.e; a VBR-rt guaranteed VC and an ABR best effort VC respectively.

The drawbacks of these priority techniques are the high complexity (i.e. bit stream parsing) and the special devices required at the destination to synchronise and recover the original video stream.

Thus, simpler approaches have been proposed in [11] and [12], where video data partition and priority assignment are implemented at the video frame layer. The cells belonging to MPEG frames are set to different priority level according to the current frame coding mode. I-frame cells are assigned high priority over P- and B-frame cells. In [11], a static priority partition is proposed, while in [12] a dynamic and adaptive priority assignment is preferred with reference to the network congestion level.

Additionally, in order to cope with the problem of packet fragmentation and poor transmission performance of traditional packet services (IP, Frame-relay, …) over ATM, some mechanisms have been designed to preserve packet integrity and achieve higher good throughputs. *Packet Tail Discard* or *Partial Packet discard* (PPD) has been proposed first to address this problem [13]. If a switch drops a cell, the subsequent cells of the packet are also dropped. Romanov et al. have shown that PPD improves network performance to a certain degree, but it is still not optimal. Consequently, they proposed a new mechanism called *Early Packet Discard* (EPD) that achieves better throughput performance but does not guarantee fairness among the connections [5]. When the switch buffer queue reaches a threshold, entire newly arriving packets (i.e. AAL5 PDU) are preventively discarded. To improve its fairness, Heinanen and Kilkki have introduced selective packet drop based on per-Virtual Circuit accounting and the scheme is referred to as *Fair Buffer Allocation* (FBA).

Since video slice is the main coding processing unit in MPEG, coding and decoding of blocks and macroblocks are feasible only when all the pixels of a slice are available, adaptation of PPD and EPD to the slice layer are proposed in [14]. The enhanced schemes, referred to as Adaptive Partial video Slice Discard (A-PSD) and Adaptive Early Video Slice Discard (A-ESD), are evaluated in their ability to gracefully degrade picture quality during network congestion and optimise network resource utilisation without introducing noticeable visual artefacts.

Nevertheless, none of the previously mentioned smart data packet discard schemes are considering Forward Error Correction and Error Concealment capabilities of the end terminals. Therefore, we are proposing in the following section an enhancement to PPD in order to intelligently stop video cell discard as early as congestion stops and the forward error correction mechanism can effectively recover the missing data.

III. A Cooperative QoS Control Framework

A.. A Dynamic Priority Cell Marking Mechanism

Since the ATM cell header only includes one Cell Loss Priority (CLP) bit to discriminate between video data, it cannot capture the full range of MPEG video data structures. Thus, we propose a video data formatting and prioritization mechanism based on the Extended CLP (ExCLP) field and the Dynamic-Priority Assignment Scheme introduced in [3] and [12] respectively. The new mechanism is referred to as "*Dynamic and Extended Priority Assignment Scheme*" or "DexPAS" in short.

In this paper, the emphasis is on the video slice and video frame layers. The data encapsulation is made at the video slice layer and the priority assignment is performed at the video frame level.

DexPAS uses ExCLP field to dynamically assign cell priorities according to the current MPEG frame type, e.g., (I)ntra (P)redictive or (B)i-directional predictive, and the reception of backward congestion signals from the network.

Table 1 presents the mapping of MPEG data frames into the ExCLP field. Cells belonging to Intra-coded frames (I-cells) are assigned a high priority while B-frame cells (B-cells) have the lowest priority. P-cells are alternatively assigned a high or a low priority depending on the network load.

Cell Type	*CLP*	*PTI-AUU*	*Priority*
I-/P- frame	0	0	High
P-/B- frame	0	1	Low
End of CB	1	0	Very High
End Of Slice	1	1	Very High

Table 1: New ExCLP Field Mapping for DexPAS

We propose to define a flag to distinguish between successive video slices. The cell having its ExCLP flag set to '11' is referred to as the End of video Slice (EOS) cell. Both EOB and EOS cells will be treated as *"very high"* priority cells in our implementation, that is, they are preserved with the most effort. As a result, DexPAS takes advantage of both static I/PB and static IP/B priority partitioning techniques [11].

B. An Enhanced Audiovisual AAL5 Protocol

Classical AAL5 only provides error detection by means of CPCS packet length integrity and CRC-32 checks. It is not possible to locate which cell was dropped or which cell includes bit errors. Therefore, the task of the proposed Video Service Specific Convergence Sublayer (SSCS) is to implement a robust Forward Error Correction (FEC) mechanism targeted to MPEG video transmission.

The proposed FEC-SSCS protocol is based on both Reed-Solomon and Parity Codes.

The proposed audiovisual SSCS protocol has a two-byte header and a two-byte trailer information (see Figure 1). The header is composed of a 4-bit Sequence Number (SN), a 4-bit Sequence Number Protection (SNP), a 4-bit Payload Type (PT), and a 4-bit Control Block Length (CBL).

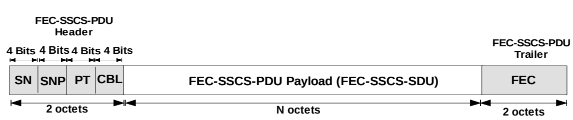

Fig. 1. The AAL-5 AV-SSCS Protocol

The trailer is composed of a 2-byte Forward Error Correction field (FEC) applied only to the payload. The FEC scheme uses a Reed-Solomon (RS) code, which enables the correction of up to 2 erroneous bytes in each block of 564 bytes (i.e. 3 x 188). So, it is only used for recovering of cell errors due to electrical or physical problems along the communication path. The sequence number (SN) of 4 bits enables the receiver entity to detect and locate up to 15 consecutive SSCS PDU losses. The SNP contains a 3-bit CRC, and an even parity check bit protects the result. The PT field specifies the type of embedded information for discrimination purpose (I-frame, P-frame, B-frame, Audio, Data, Headers, FEC information, etc..).

At destination and using Both AAL-5 SSCS and CPCS protocols the detection of erroneous or lost SSCS PDUs are assured. CPCS layer is able to identify received corrupted AAL PDUs by CRC-32 and missing cells by length mismatch. In the extreme situation of missing entire PDUs, the sequence number will permit the detection to up to 15 consecutive packet losses.

C. An Intelligent Video Slice Discard Mechanism.

In [15], a scheme called Adaptive Partial Slice Discard (A-PSD) has been proposed to cope with the problem of random video packet elimination during network congestion. The proposed approach consists to select the packet (i.e. the video slice) to be dropped with respect to MPEG data type and network congestion level.

In [16], we have proposed enhancement to the Adaptive Partial Slice Discard (A-PSD) to support Forward Error Correction feature. The new scheme, named FEC Adaptive Partial Slice Discard (FEC-PSD), is performed at both control block (CB) and video slice levels. Our approach is to reduce the number of corrupted video slices received at destination. Knowing that a number 'T' of cells per control block can be recovered by the destination using FEC codes based on both Reed-Solomon and Parity codes. Let us define the parameter 'T' as the Drop Tolerance (DT) that corresponds to the maximum number of cells per CB that may be discarded by A-PSD before considering the CB as definitely lost.

Therefore, unlike the simple A-PSD, FEC-PSD stops discarding cells when the congestion decreases and the number of previously dropped cells in every CB is below DT. Using this approach, the proposed scheme acts at a finer data granularity, i.e Control Block, and better preserves entire slices from elimination. The flexibility proposed by this mechanism cannot be achieved without the use of DexPAS, which allows the detection of both slice, and control block boundaries at the cell level. Additional information on the operation modes of the proposed mechanism is available in [16]

The integration of the three mechanisms (i.e. DexPAS, FEC-PSD and the enhanced AAL-5 AV-SSCS) provides us an efficient and cooperative video delivery service with quality of picture (QoP) control. The aim of this framework is to ensure graceful picture degradation during network overload periods as well as increase of network performance, e.g., effective throughput. It allows accurate video cell discrimination, progressive drop and intelligent data recovery by dynamically adjusting the FEC-PSD mode in respect to cell payload types, switch buffer occupancy, and Drop Tolerance.

IV. Performance Evaluation and Analysis

A. Network Simulation Model

The simulation network topology consists of two ATM switches and ten MPEG2 video connections crossing the backbone (bottleneck) link with a capacity of 155 Mbps (OC-3). We evaluate the video delivery and control framework in a LAN configuration by setting the physical backbone link distance to 1 km. Link distances between the source/destination and the access switch nodes are constant and set to 0.2km. The ATM switches are simulated as non-blocking, shared finite output-buffered switches. Switch buffer size varies from 80,000 to 220,000 cells for both SWITCH-1 and SWITCH-2 in the simulation configuration. The video sources generate MPEG2 data at a rate specified in a trace file available at [17]. The video sequences uses SIF format and were encoded at a resolution of 352x240 pixels per frame, a frame rate of 30 frames/sec, and 15 slices/frame. The Peak and Mean Cell Rate are 20 and 5 Mbps respectively.

The level of network congestion is monitored through the occupancy of the switch buffers and three congestion thresholds (LT, MT and HT). We carried out our simulation with seven switch buffer configurations. For each of them, the same method is applied to determine the values of the three thresholds. HT, MT and LT are respectively set to 0.9, 0.8 and 0.7 of the maximum queue size (Qmax), where Qmax is set to one of the following values: 80,000, 100,000, 120,000, 140,000, 160,000, 180,000, 200,000 and 220,000 cells.

The transmitted AV-SSCS-PDUs contain 3 MPEG2 Transport Stream (12 cells) and a Control Block is built with 15 AV-SSCS-PDUs (except for the last CB).

We compare the performance of the proposed framework at the video slice level (i.e. application layer) with the three following schemes associated with the classical AAL-5 protocol:

- Random Discarding with no Priority Assignment (No_RD)
- Selective Cell Discarding with Extend Priority Assignment (Ex_SCD [3]).
- Partial Slice Discarding with Extend Priority Assignment (Ex_PSD [14]).

B. Performance Analysis

From Figure 2, we observe that the mean cell transfer delay (CTD) increases proportional to the buffer size. As expected, No-RD has the largest mean CTD, since the No_RD scheme attempts accommodate every cell in its switch buffer until it overflows, meanwhile increasing the queue delay. We also notice that Dex_PAS + FEC-PSD (i.e. Dex_PSD) has a longer mean-CTD than the other two schemes even though it tries to drop low priority cells at the light congestion stage in order to leave space for the high priority ones. This is mainly due to its overhead, which results to larger switch buffer occupancy. On one hand, it preventively discards low priority cells at light congestion and switches to slice level to discard the whole slice as in Ex-PSD, which reduces the average queue length. On the other hand, it introduces 15% percent overhead due to stuffing bits and FEC redundancy codes that in turn increases the average queue length.

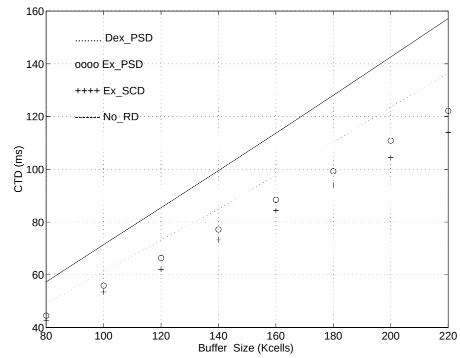

Fig. 2. Mean Cell Transfer Delay

Intuitively it is expected that Dex_PAS + FEC_PSD (Dex_FEC_PSD in the figure) has better performance at slice level. This is exhibited by figures 3, 4, 5, and 6. The proposed framework significantly improves the percentage of non-corrupted video slices arrivals at the destination. Indeed, the aggregated Slice Loss Ratio (SLR) is reduced to achieve an upper bound of 6.8% of the total number of transmitted video slice. In comparison, No_RD, Ex-SCD and Ex_PSD reach 16.6%, 12.2% and 8.9% respectively.

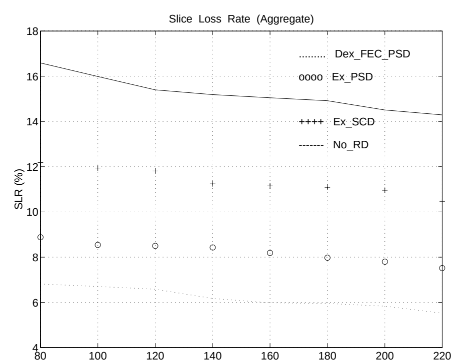

Fig. 3. Slice Loss Ratio (Aggregate Stream)

Finally, the SLR per sub-flow is analysed for the four approaches as follows. We observe that, Ex_PSD and Dex_FEC_PSD outperform the other approaches by better protecting I-frames, though for aggregate SLR, our new scheme has the best performance. This is consistent with the results obtained at cell level. There is a trade-off between fair distribution of cell discarding among the connections (i.e. VCs) and the speed of reactions to congestion. With B-frame, Dex_PAS and FEC_PSD (Dex_FEC_PSD) demonstrate the best SLR value, and performs correctly with P-frames. This further indicates the capability provided to protect data at the slice level by the FEC mechanism based on Parity and Reed-Solomon correction codes.

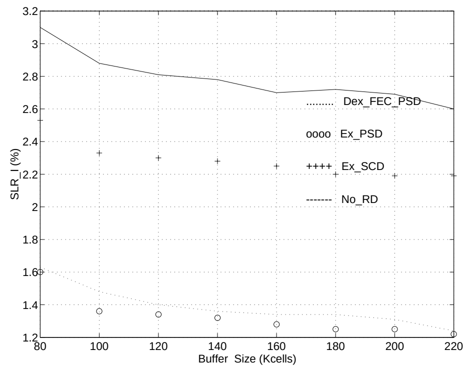

Fig. 4. Slice Loss Ratio (I Frame)

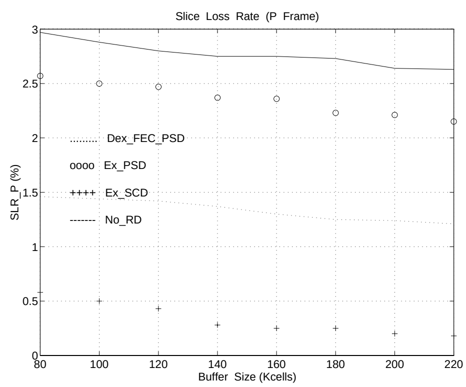

Fig. 5. Slice Loss Ratio (P Frame)

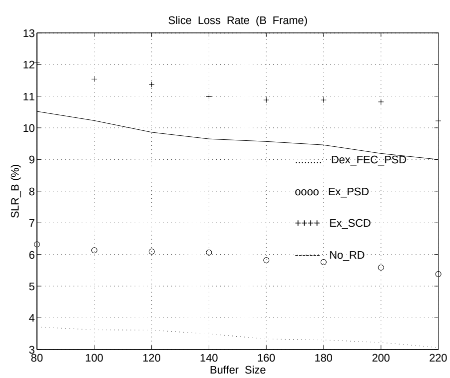

Fig. 6. Slice Loss Ratio (B Frame)

V. CONCLUSION

A cooperative video QoS control framework is proposed and evaluated using simulation. Two congestion control mechanisms and a new transport protocol have been designed and integrated within this framework that better take into account MPEG-2 video streams properties and requirements.

The ultimate goal of this framework is twofold: First, minimising loss of critical video data with bounded end-to-end delay for arriving cells and second, reducing the bad throughput crossing the network during congestion. Compared to previous approaches, performance evaluation shows a good protection of Predictive coded (P-) and Bi-directional Predictive coded (B-) frames at the MPEG video slice layer.

REFERENCES

[1] ATM Forum TM-SWG, "Traffic Management Specification 4.0", at-tm-0056.000, April 1996.

[2] B. DeCleen, P. Pancha, M. El Zarki, 'Comparison of priority partition methods for VBR MPEG', IEEE INFOCOM'94, Toronto, Canada, June 1994, pp.689-96.

[3] A. Mehaoua, R. Boutaba and G. Pujolle, ' An Extended Priority Data Partition Scheme for MPEG Video Connections over ATM', IEEE Symposium on Computers and Communications 97, Alexandria, Egypt, July 1997, pp. 62-67.

[4] Y. Rasheed and A. Leon-Garcia, "AAL1 with FEC for the Transport of CBR MPEG2 Video over ATM networks," IEEE INFOCOM 96, San Francisco CA, March 1996.

[5] Y. Wang and Q-F. Zhu, 'Error Control and Concealment for Video Communication: A review', Proceedings of the IEEE, Vol. 86, N.5, May 1998, pp. 974-997.

[6] G. Ramamurthy and D. Raychaudhuri, 'Performance of packet video with combined error recovery and concealment', IEEE INFOCOM'95, Boston, April 1995, pp. 753-61.

[7] W. Feng and S. Sechrest, 'Smoothing and buffering for delivery of prerecorded compressed video', ACM Computer Communications Review, October 1995, pp. 709-717.

[8] J.D Salehi, Z.-L Zhang, J.F Kurose, and D. Towsley, 'Supporting stored video : Reducing rate variability and end-to-end resource requirements through optimal smoothing', ACM SIGMETRICS '96, May 1996, pp. 222-231.

[9] P. Pancha and M. El Zarki, 'MPEG coding for variable bit rate video transmission', IEEE Communication magazine, pp.54-66, May 1994.

[10] A. Mehaoua and R. Boutaba, 'A hybrid VBR/ABR Service for Layered Video Communications: A Simulation-based Analysis', IEEE Workshop on Broadband Switching System '97 (BSS'97), Taipei, Taiwan, December 1997, pp. 88-96.

[11] T. Han and L. Orozco-Barbosa, "Performance requirements for the transport of MPEG video streams over ATM networks", in ICC'95, Washington, pp. 221--225, June 1995.

[12] A. Mehaoua, R. Boutaba and G. Pujolle, 'An Adaptive and Selective Cell Drop Policy with Dynamic Data Partitioning for Best Effort Video over ATM', in 22nd IEEE International Conference on Computer Networks (LCN'97), Minneapolis, E-U, 2-5 November 1997, pp. 519-28.

[13] G. Armitage and K. Adams, 'Packet Reassembly during Cell Loss', IEEE Network Magazine, Vol.7, No.5, September 1993, pp. 26-34.

[14] A. Mehaoua, R. Boutaba and Y. Iraqi, 'Partial versus Early Packet Video Discard', in IEEE GLOBECOM 98, Sydney, Australia, November 1998.

[15] A. Mehaoua and R. Boutaba, "Performance Analysis of Cell Discarding Techniques for Best Effort Video Communications over ATM Networks", in Journal of Computer Networks and ISDN Systems, Vol.29, issue 17-18, Elsevier Science, North Holland, pp. 2021-2037, February 1998.

[16] A. Mehaoua, R. Boutaba, S. Pu, Y. Rasheed, A. Leon-Garcia, 'Towards An Efficient ATM Best Effort Video Delivery Service', in IEEE ICC 99, Vancouver, Canada, June 1999.

[17] M.R. Izquierdo and D.S. Reeves, "MPEG VBR slice layer model using linear predictive coding and generalized periodic markov chains", in International Performance, Computing and Communications Conference, Scottsdale, Arizona, February 1997.