On the Combined Adoption of QoS Schemes to Improve the Delivery Quality of MPEG Video Streams

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Abstract

The quality perceived by a user of an MPEG video transmission may be strongly degraded by indiscriminated discards of packets under the best-effort model. This paper analyzes different Quality of Service (QoS) strategies and how to best combine such strategies to enhance the delivery quality of MPEG streams. Results cover issues such as how to: (i) apply redundancy (either by tolerating a certain level of losses or by changing the compression factor in MPEG encoding); (ii) adequately protect the different types of MPEG frames in a Differentiated Services environment; and (iii) analytically do the mapping of network losses onto application quality. Moreover, we investigate the mutual influence exerted by the analyzed QoS schemes when simultaneously adopted to improve the delivery quality of MPEG video streams.

INTRODUCTION

The hierarchical structure of MPEG encoding with a possible error propagation through its frames imposes a great difficulty on sending MPEG video streams over lossy networks. Small packet loss rates may translate into much higher frame error rates. For example, a 3% packet loss percentage could translate into a 30% frame error probability [1]. This situation may seriously degrade the perceived quality by a user at the video reproduction. Moreover, network resources may be wasted with the transmission of information that becomes useless to the receiver. Some portion of the received data may become useless to the decoder as insufficient frame data are available for decoding the frame because of losses in the network or because a frame, in which the current frame depends on, is undecodable.

This paper evaluates different possibilities to improve the delivery quality of an MPEG video stream crossing a lossy network like the Internet or an intranet. We investigate how to: (i) apply redundancy, either by using Forward Error Correction (FEC) to tolerate some losses or by using a different compression factor in the MPEG encoding; (ii) adequately protect the different types of MPEG frames adopting a Differentiated Services (DiffServ) architecture [2]; and (iii) analytically do the mapping of network QoS (in terms of packet loss probabilities) onto application QoS (in terms of decodable MPEG frames). Furthermore, we evaluate how to best combine the studied techniques to improve the delivery quality of the MPEG stream.

The remaining of the paper is organized as follows. First, we present an overview of related work. We then briefly review the MPEG structure and define our evaluation metrics. The Model Section introduces our analytical model to measure the impact of losses in the video stream considering the defined evaluation metrics. We discuss afterward the obtained results for different QoS schemes. Finally, we present our concluding remarks.

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RELATED WORK

In the MPEG video literature, common strategies for QoS provisioning include the adoption of different GOP structures, different frame dropping priority mechanisms, or FEC schemes. Changing the GOP pattern is a strategy to better adapt the MPEG stream to the available transmission conditions. Turaga *et al.* [3] propose models for variable bit rate (VBR) video traffic that allow for different frame types and variable GOP patterns.

Indiscriminated packet discards may seriously degrade an MPEG video stream because of its hierarchical structure. Due to this feature of MPEG systems, different frame dropping priority schemes are proposed to protect different types of frames against such indiscriminated discards. Hemy *et al.* [4] propose the use of filters in some nodes within the network to selectively drop frames of an MPEG stream.

Progressive protection of different types of frames using mechanisms based on the DiffServ architecture [2] are also analyzed [5, 6]. Shin *et al.* [7] propose a framework to map categorized video packets (in terms of loss and delay) onto relative DiffServ levels, while taking into account a given pricing model.

Video delivery can significantly be improved by the adoption of FEC mechanisms. A media-independent FEC scheme is the focus of recent efforts [8]. Another alternative is the development of FEC mechanisms that take into account the characteristics of the data being protected. The PET scheme [9] has been developed based on the particular features of MPEG video streams and allows for FEC including the support of priorities.

Although QoS schemes for MPEG video streams have been widely investigated, commonly such QoS strategies are only studied individually. This paper analyzes the combined adoption of different QoS approaches to enhance the quality of MPEG streams. We investigate the mutual influence that such approaches exert on each other when adopted simultaneously. Moreover, we evaluate how to best combine the analyzed techniques to improve the delivery quality of an MPEG video stream.

EVALUATION METRICS FOR MPEG

MPEG encodes video as a sequence of three types of compressed frames (I, P, or B). The whole video sequence is decomposed into smaller units which are coded together and called GOPs (Group of Pictures). The GOP pattern specifies the number and temporal order of P and B frames between two successive I frames. Such a GOP pattern is characterized by two parameters: the I-to-I frame distance (N), and the I-to-P frame distance (M). This hierarchical structure with dependencies for the decoding of some frames in each GOP is illustrated in Figure 1. For a given pattern (N,M), the number of frames from each type ($N_{\{I,P,B\}}$) in a single GOP are $N_I = 1$, $N_P = \frac{N}{M} - 1$, and $N_B = \frac{N}{M}(M - 1)$.

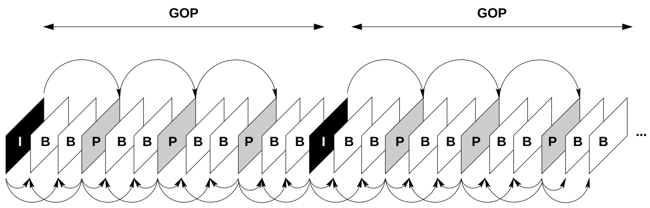


Figure 1. GOP structure ($N = 12$ and $M = 3$)

In order for a P or B frame to be considered decodable, all the frames they depend on must also be considered decodable. Thus, an incorrect I or P frame propagates problems to all dependent frames and corrupts these as well. In the worst case, a whole GOP may be considered undecodable due to an incorrect I frame, as all other frames in the GOP depend directly or indirectly on the I frame. For example, the effects of an undecodable I frame of a GOP with $N = 12$ will persist for 12 frames, or almost 500 ms at a typical frame rate of 25 frames per second, which is quite noticeable to a user.

To evaluate the transmission of an MPEG video stream, we consider the following metrics: *Fraction of decodable frames* and *fraction of useless data received*. The former reports the number of decodable frames over the total number of frames sent by a video source. The latter reports the fraction of the data received that is useless to the decoder. The decoder may have useless data from partially received frames or from frames that can not be decoded because they depend on other undecodable frames.

The adopted criterion to consider a frame decodable defines that at least a fixed fraction dt (decodable threshold) of the data in each frame must be received to consider the frame decodable. Further, a frame is considered decodable if and only if all the frames it depends on are also considered decodable. Therefore, when $dt = 1.0$, the decoder is completely intolerant to losses, that is, one lost packet is enough to render a frame undecodable. Similarly, with $dt = 0.75$, 25% of the data from a frame may be absent due to losses in the network and the frame is still considered decodable. If the decoder

Table 1. Adopted Notation

Variable	Definition
ξ_I, ξ_P, ξ_B	probability for a frame to be directly lost, but not indirectly lost
$\alpha_I, \alpha_P, \alpha_B$	packet loss probability of packets containing data from each type of frame
C_I, C_P, C_B	mean number of packets to transport the data of each type of frame

can tolerate a certain level of losses ($dt < 1.0$), then we assume the use of a Forward Error Correction (FEC) scheme in the video transmission. The tolerance to losses is obtained at the expense of additional data introduced into the video stream (FEC redundancy).

MODEL

We adopt the notation described in Table 1 to model the impact on quality considering the defined evaluation metrics. From the hierarchical structure of MPEG encoding, a frame may be lost (considered undecodable) directly or indirectly. Direct loss of a frame indicates that there are not enough frame data to decode it. We assume direct frame losses to be mutually independent. Indirect loss of a frame happens when a frame is considered undecodable because some frame it depends on is directly undecodable. We observe also that consecutive B frames have the same dependency throughout the hierarchical structure and may be considered as a B group. Each GOP pattern has $(M-1)$ B frames in each B group. Thus, using similar argumentation as in [10], the expected number of correctly decodable frames in a GOP is

$$\begin{aligned} N_{\text{dec}} &= (1-\xi_I) + (1-\xi_I)\sum_{j=1}^{N_P}(1-\xi_P)^j \\ &\quad + (M-1)(1-\xi_I)(1-\xi_B) \\ &\quad \times \left((1-\xi_I)(1-\xi_P)^{N_P} + \sum_{j=1}^{N_P}(1-\xi_P)^j\right). \end{aligned} \tag{1}$$

To evaluate the quality of a video stream, we adopt as a criterion the fraction of decodable frames per GOP. Therefore, we define the picture quality (Q) of an MPEG video stream as

$$Q = \frac{N_{\text{dec}}}{N}, \quad 0 \le Q \le 1. \tag{2}$$

The measure Q is an objective metric to assess video quality. Evidently, in video communications (such as in communications in general) we would rather be interested in evaluating QoS as observed by (human) end users, taking into account measures such as MOS (mean opinion scores) [11]. As our study is based on a modeling approach, contents of video streams (i.e. the semantics of video communications) are not taken into account. In earlier studies [10, 11], we observed that a quality measure such as Q is slightly pessimistic as compared to the quality observed by humans, because MPEG streams tend to recover from partial losses of frames thanks to their temporal and spacial redundancy. Nevertheless, measure Q tends to be a sufficiently good approximation to subjective video quality assessments, more so, as in network optimizations there is some inherent approximation in boundary conditions (such as overall system load) anyway.

At the receiver of a video transmission, the mean number β of correctly received packets for each frame type are $\beta_I = (1-\alpha_I)C_I$, $\beta_P = (1-\alpha_P)C_P$, and $\beta_B = (1-\alpha_B)C_B$. Thus, for an entire GOP the expected number of correctly transmitted packets is

$$P_{\text{corr}} = \beta_I N_I + \beta_P N_P + \beta_B N_B. \tag{3}$$

From the total number of correctly received packets, not all of them are useful to decode a frame. Useful packets are those which belong to a decodable frame. Using Equation 1 and the mean number β of correctly received packets for each frame type, the expected number of useful packets in a GOP is

$$\begin{aligned} P_{\text{useful}} &= (1-\xi_I)\beta_I + (1-\xi_I)\beta_P\sum_{j=1}^{N_P}(1-\xi_P)^j \\ &\quad + (M-1)(1-\xi_I)(1-\xi_B)\beta_B \\ &\quad \times \left((1-\xi_I)(1-\xi_P)^{N_P} + \sum_{j=1}^{N_P}(1-\xi_P)^j\right). \end{aligned} \tag{4}$$

A fraction of the correctly received packets is not useful to the decoder. This fraction (U) of useless data received is defined as

$$U = \frac{P_{\text{corr}} - P_{\text{useful}}}{P_{\text{corr}}}, \quad 0 \le U \le 1. \tag{5}$$

From Q and U we can evaluate the delivery quality of an MPEG video stream and the waste of resources due to some amount of useless data received.

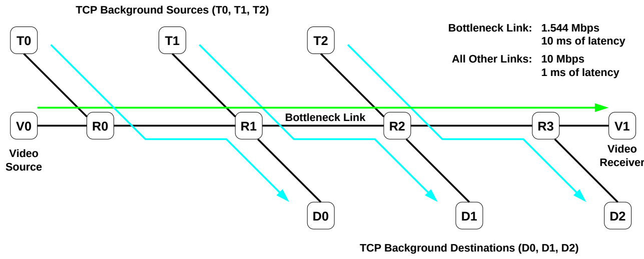


Figure 2. Network scenario

To validate the described analytical model, we carried out simulations in the ns-2 simulator [12] using the network scenario depicted in Figure 2. A video source generates packets based on a public available MPEG frame trace file (see [13] and references therein for details of the generation of the frame trace file). We used the Starwars-IV movie sequence, encoded with high quality, which has a mean bit rate of 0.28 Mbps and peak rate of 1.9 Mbps. Each frame is fragmented into packets of 200 octets. The video stream is transmitted from node V0 to node V1 over UDP. The TCP background sources use the TCP-Reno implementation. The TCP cross traffic is generated by FTP applications, which are active during the whole simulation, with packets of 1500 octets. A number of TCP sources are uniformly distributed among the nodes T0, T1, and T2, and send packets to nodes D0, D1, and D2, respectively. Doing so, independent TCP background traffic interferes with the video stream at each hop. The TCP sources start transmitting before the video sources. Thereby, video streams find intermediate routers already loaded with background traffic, avoiding thus initial transient periods. Such actions provide a conservative and pessimistic scenario that reflects realistic traffic conditions.

Figure 3 shows the fraction of decodable frames (Q) and fraction of useless data received (U) in face of an increasing load in the network. In the simulation results, the error bars show the 99% confidence interval. We compare simulation results to the results obtained from our analytical model that has been fed with the parameters ξ and α extracted from the simulations. Besides validating the model, the results make evident how strongly an MPEG stream may be degraded in a best-effort network. Although Figure 3 indicates that a certain level of loss tolerance ($dt < 1.0$) may significantly improve the quality of the video transmission, we investigate hereafter the effects of the compression factor, the tolerance to losses, and the introduction of drop precedence levels.

QoS AND VIDEO STREAMS

Our objective is to evaluate the video transmission of an MPEG stream considering the compression factor of different GOP patterns, the level of tolerance to losses, and the mapping of different types of frames onto different drop precedence levels. Furthermore, our investigation covers the effects of simultaneously adopting such QoS strategies. To perform the evaluation, we consider two classes of GOP patterns:

Class 1: $I(BP)^k B \quad ; k \in \{1, 2, \ldots, 7\}$
Class 2: $I(BBP)^k BB \quad ; k \in \{1, 2, 3\}$

GOPs from Class 1 have less B frames than GOPs from Class 2 for the same GOP size (N). Therefore, GOPs from Class 2 are expected to have on average a higher compression rate than comparable GOPs from Class 1.

The mapping of frames onto network priorities P_h (high priority) and P_l (low priority) covers three possibilities as shown in Table 2. Background traffic is always mapped onto P_l. P_h and P_l are implemented as different virtual queues managed in a RIO (RED with IN and OUT) scheme [14], reflecting different levels of drop precedence.

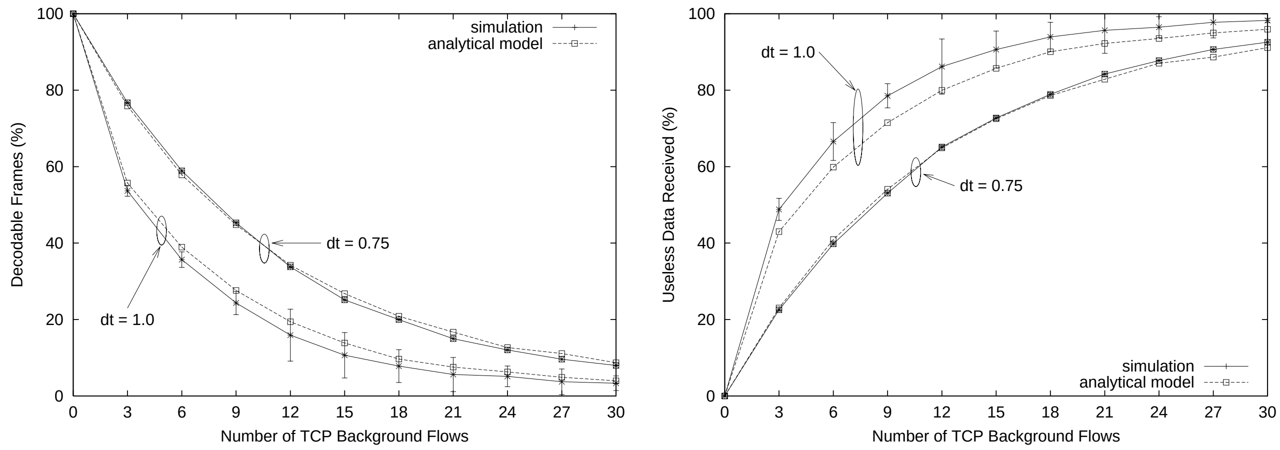
Table 2. Mapping of frames onto network priorities

Mapping	I	P	B
M1	P_h	P_h	P_h
M2	P_h	P_h	P_l
M3	P_h	P_l	P_l

For the experiments, we first take two GOP patterns, named GOP1 and GOP2:

GOP1: $IBPB$
GOP2: $IBBPBBPBBPBB$

GOP1 and GOP2 correspond respectively to the lowest and highest compression for GOP patterns belonging to Class 1 and to Class 2. We extract through simulation over the scenario of Figure 2 the parameters ξ and α for GOP1 and GOP2 when facing 30 TCP background flows, the case where quality is already heavily degraded in Figure 3. Then, these parameters are used to feed our analytical model and obtain the results for the large variety of remaining patterns. It should be noted that these analytical QoS predictions are done without any support by additional simulation experiments. Results



(a) Decodable Frames

(b) Useless Data Received

Figure 3. MPEG Video Stream through a Best-Effort Network

are shown as a range between the highest and lowest expected picture quality Q (as defined in Equation 2) for the MPEG video stream under the given conditions, i.e. the analytical model provides an upper and a lower bound for the video quality to be expected by the receiving end user. The level of quality predicted analytically in this way is valid (i.e. very close to actual system behavior) indeed as we could successfully verify thanks to additional simulation experiments.

Effects of Compression

Experiment I compares the performance achieved by GOP patterns that have different compression factors. We consider all the GOP patterns that belong to either Class 1 or Class 2, as shown in Table 3. There are $k+1$ and $2(k+1)$ B frames at each GOP in Class 1 or Class 2, respectively. Figure 4 presents the fraction of decodable frames of patterns from each class handled by different mappings onto network drop precedences. The results presented here consider no loss tolerance ($dt = 1.0$).

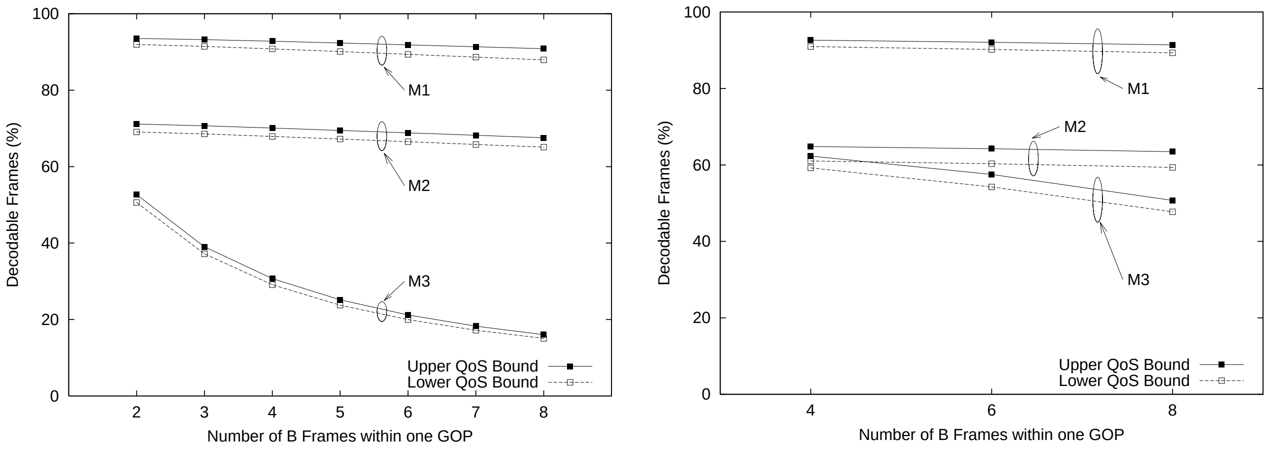
The higher the compression is within each class (more B frames), the lower is the expected quality. For both GOP classes the decrease in quality due to an increasing compression is relatively small on either M1 or M2. However, a more significant degradation in quality is observed for M3. This degradation in quality because of an increasing compression is stronger in GOPs from Class 1 than in GOPs from Class 2. This points out the importance of the P frames. In Class 1, for the same number of B frames we have more P frames. Moreover, we observe how schemes that protect the data from P frames can significantly improve the expected quality of a video stream.

Table 3. GOP Patterns for Experiments I and II

GOP Pattern	B Frames
$IBPB$	$2 \times B$
$IBPBPB$	$3 \times B$
$\vdots$	
$IBPBPBPBPBPBPBPB$	$8 \times B$
$IBBPBB$	$4 \times B$
$IBBPBBPBB$	$6 \times B$
$IBBPBBPBBPBB$	$8 \times B$

Effects of Tolerance to Losses

In experiment II, we evaluate the QoS improvement if the decoder can tolerate a number of losses in a frame and thus allows to still consider such frames as being decodable ($dt < 1.0$). The adoption of a FEC scheme provides this feature at the expense of data redundancy. The intended FEC scheme [8] adds redundant information in a fashion that k video packets are protected by FEC in such a way that n packets ($n > k$) are transmitted, which are all of the same importance to the receiver.



(a) Class 1

(b) Class 2

Figure 4. Effects of Compression with $dt = 1.0$

If at least k packets out of the n packets composing a frame are correctly received, the video information can be correctly decoded and the frame is considered decodable. Such result is independent of which packets are lost within the frame.

We denote by c_0 the needed data rate to send the video stream when $dt = 1.0$. When $dt = 1.0$, the system is completely intolerant to losses and there is no redundant data in the video stream as no FEC scheme is in use. Given a certain decodable threshold (dt) value q ($0 \leq q \leq 1$), the needed capacity to send the redundant video stream is $c(q) = \frac{c_0}{q}$. Thus, considering $c(q) = c_0(1 + v(q))$, the overhead $v(q)$ imposed by the adoption of a certain level of tolerance to losses is given by

$$v(q) = \frac{c(q) - c_0}{c_0} = \frac{1-q}{q}. \quad (6)$$

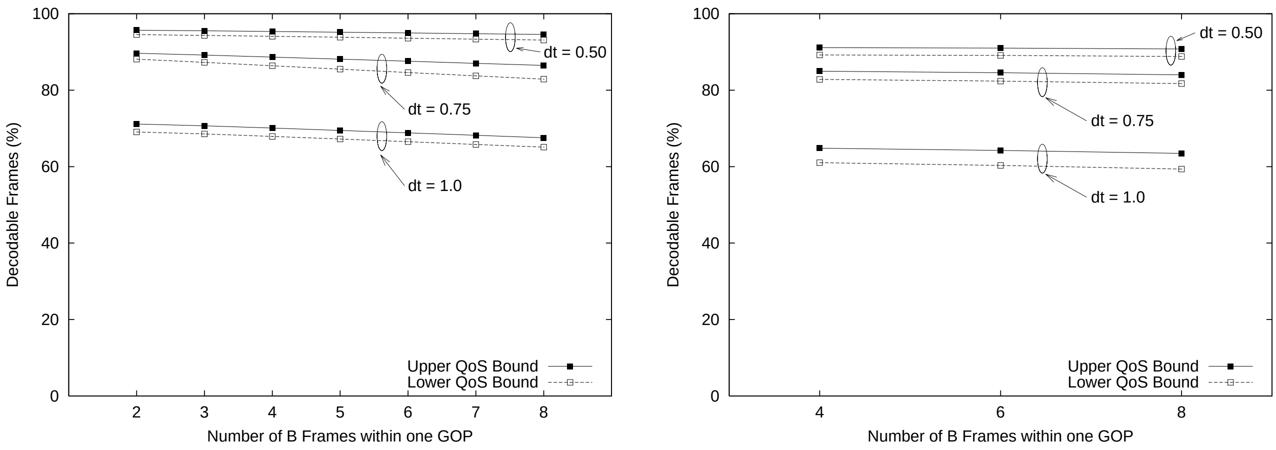
Therefore, to take into account the data redundancy due to the adoption of a FEC scheme, we use Equation 6 to consider an overhead of 33% for $dt = 0.75$ and of 100% for $dt = 0.50$ in the size of each frame. The GOP patterns are the same as for experiment I (Table 3). Under the M1 mapping variant, all packets from video frames are mapped onto P_h and thus the background traffic has a higher drop precedence when compared with video packets from any frame. As a consequence of not having many discards of video packets, the results for different values of dt almost overlap, diminishing the effects of some tolerance to losses. Under mapping variants where certain video packets and the background traffic are mapped onto the same drop precedence, the benefits of some tolerance to losses become clear as in Figure 5, which presents different values of dt handled by the M2 mapping variant.

Considering the same level of tolerance to losses, an increasing compression within each class of GOPs does not significantly influence the perceived quality of the delivered stream. Nevertheless, the application of a FEC scheme can strongly improve the delivery quality of the MPEG video stream (similar observation as in [10]). GOPs from Class 1 take a better advantage of a certain level of loss tolerance. This can be seen when comparing GOP patterns from the two classes with the same number of frames, for example, comparing $N_B = 6$ in Figure 5(a) and $N_B = 8$ in Figure 5(b).

Effects of Drop Precedence Levels

Experiment III compares the appliance of different drop precedence levels or priority mappings (Table 2) to five representative GOP patterns presented in Table 4. Some of these GOP patterns present the same number of B frames, although distributed in a different manner depending on which class they belong to. Figure 6 shows the fraction of decodable frames for each pattern handled by a different drop precedence mapping and for different levels of loss tolerance.

For the same number of B frames, quality degrades



(a) Class 1

(b) Class 2

Figure 5. Effects of Tolerance to Losses for the M2 Mapping Variant

Table 4. GOP Patterns for Experiment III

	GOP Pattern	B Frames
1	$IBPB$	$2 \times B$
2	$IBPBPBPB$	$4 \times B$
3	$IBBPBB$	$4 \times B$
4	$IBPBPBPBPBPBPBPB$	$8 \times B$
5	$IBBPBBPBBPBB$	$8 \times B$

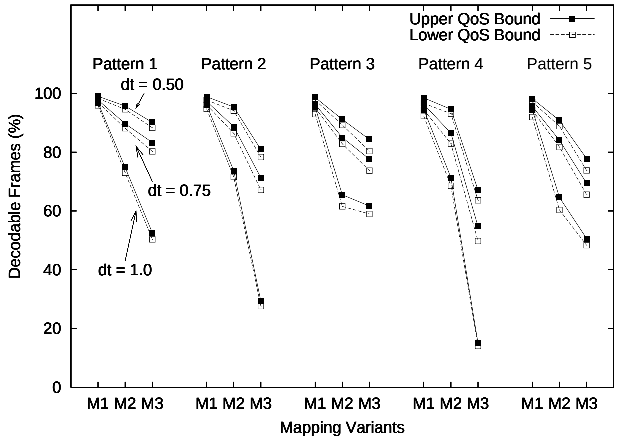


Figure 6. Drop Precedence Mappings for Different GOP Patterns

more on GOPs from Class 1 than on GOPs from Class 2 as frames get a lower priority mapping. Note that for the same number of B frames, GOPs from Class 1 have more P frames. Again, this shows the importance of P frames in the hierarchical structure of MPEG. GOPs from Class 2 take a better advantage of a certain tolerance to losses provided by a FEC scheme as frames get a lower priority mapping. As opposed to intuition, more compressed GOP patterns may have better quality than less compressed ones under specific circumstances (as an example, cf. Pattern 1 versus Pattern 3, for dt=1.0 and M3 mapping in Figure 6). This quite astonishing result may become more evident to the reader by considering that under a mapping as M3, a pattern like $IBBB$ is expected to get on average a better quality than a less compressed pattern like $IBPB$.

CONCLUSION

In this paper, we have identified a variety of techniques that allow the improvement of the delivery quality of MPEG streams to end users. From an analytical model, we have evaluated the impact of frame losses in the quality of MPEG streams and in the waste of network resources. Our assessment has considered issues such as the use of redundancy either by applying a FEC scheme to tolerate losses or by changing the compression factor in a GOP pattern generation. We have also covered how to best use a differentiation scheme among different types of MPEG frames and how to adequately protect them from losses. Furthermore, we have evaluated the effects of simultaneously adopting different QoS strategies to improve the delivery quality of MPEG streams.

The obtained results pointed out the importance of P frames in the GOP structure. Any scheme that intends to differentially handle data from different types of frames must strongly consider the protection of P frames to achieve a significant quality improvement. This is true, specially if the adopted GOP pattern belongs to Class 1. The difference between the highest and the lowest quality as predicted by means of our analytical model (in order to get bounds for performance as observed on Application Layer) is always small and therefore negligible, which suggests the good predictability quality that may be achieved by the adopted model. Another key point is the need of adopting FEC mechanisms, as they can strongly improve the delivery quality over lossy networks. The combination of protecting more important frames (from the point of view of the hierarchical structure of MPEG encoding) with an additional tolerance to losses for the frames that are more susceptible to losses has been shown as an efficient strategy to improve the delivery quality of a video transmission. From our findings, GOP patterns belonging to Class 2 can typically achieve a stronger quality improvement by the different analyzed techniques. Hence, for most boundary conditions, we recommend the adoption of GOP patterns from Class 2 to take a better advantage of the analyzed QoS schemes.

REFERENCES

[1] Boyce, J. M., and R. D. Gaglianello. 1998. "Packet Loss Effects on MPEG Video Sent over the Public Internet." In Proc. of the ACM Multimedia 98, Sept.

[2] Blake, S., D. L. Black, M. Carlson, E. Davies, Z. Wang, and W. Weiss. 1998. *An Architecture for Differentiated Services.* Internet RFC 2475, Dec.

[3] Turaga, D. S., and T. Chen. 2001. "Hierarchical Modeling of Variable Bit Rate Video Sources." In Proc. of the 11th Packet Video Workshop, PV'2001, Apr.

[4] Hemy, M., U. Hengartner, P. Steenkiste, and T. Gross. 1999. "MPEG Systems Streams in Best-Effort Networks." In Proc. of the 9th Packet Video Workshop, PV'1999, Apr.

[5] Ashmawi, W., R. Guérin, S. Wolf, and M. Pinson. 2001. "On the Impact of Policing and Rate Guarantees in Diff-Serv Networks: A Video Streaming Application Perspective." In Proc. of ACM SIGCOMM'2001, Aug.

[6] Ziviani, A., J. F. de Rezende, O. C. M. B. Duarte, and S. Fdida. 2002. "Improving the Delivery Quality of MPEG Video Streams by Using Differentiated Services." In Proc. of the 2nd European Conference on Multiservice Networks, ECUMN'2002, Apr.

[7] Shin, J., J. Kim, and C.-C. J.Kuo, 2001, "Quality of Service Mapping Mechanism for Packet Video in Differentiated Services Network," IEEE Transactions on Multimedia, 3, no. 2, (June): 219–231.

[8] Frossard, P., and O. Verscheure, 2001, "Joint Source/FEC Rate Selection for Quality-Optimal MPEG-2 Video Delivery," IEEE Transactions on Image Processing, 10, no. 12, (December): 1815–1825.

[9] Albanese, A., J. Blömer, J. Edmonds, M. Luby, and M. Sudan, 1996, "Priority Encoding Transmission," IEEE Transactions on Information Theory, 42, no. 6, (November): 1737–1744.

[10] Wolfinger, B. E. 1997. "On the Potential of FEC Algorithms in Building Fault-Tolerant Distributed Applications to Support High QoS Video Communications." In Proc. of the ACM Symp. on Principles of Distributed Computing, PODC'97, Aug.

[11] Heidtmann, K., J. Kerse, T. Suchanek, B. E. Wolfinger, and M. Zaddach. 2001. "Fehlertolerante Videokommunikation über verlustbehaftete Paketvermittlungsnetze." In Proc. of KiVS'2001, Springer-Verlag, Feb.

[12] Fall, K., and K. Varadhan. 2002. *The NS Manual.* UC Berkeley, LBL, USC/ISI, and Xerox PARC, Jan.

[13] Fitzek, F. H. P., and M. Reisslein, 2001, "MPEG-4 and H.263 Video Traces for Network Performance Evaluation," IEEE Network, 15, no. 6, (November): 40–54.

[14] Clark, D. D., and W. Fang, 1998, "Explicit Allocation of Best Effort Packet Delivery Service," IEEE/ACM Transactions on Networking, 6, no. 4, (August): 362–373.