Enhanced H.264/AVC Video Streaming using Network-adaptive Multiple Description Coding

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***Abstract*—This paper presents a network-adaptive multiple description coding (MDC) method for enhanced video streaming over multipath channels. The novel feature of the proposed MDC network adaptation scheme is the generation of a controlled amount of side information to compensate for drift distortion due to packet loss. This yields higher robustness of multiple description (MD) H.264/AVC streams than single description (SD) ones. Multiple Description Scalar Quantisation (MDSQ) is used to split an SD video stream in two complementary streams (two descriptions) for transmission over a multipath channel. The simulation results show that significantly better quality is achieved by using the proposed scheme instead of either SDC streams or classic SDC-MDSQ network adaptation without side information.**

***Index Terms*—Network-adaptive Multiple Description Video Coding, Multiple Description Scalar Quantisation, video streaming.**

I. Introduction

It is known that current data networks cannot assure a predefined level of quality of service (QoS). For example, wireless networks always suffer from different kinds of fading and multipath interference, thus packet loss an variable delay are inevitable. In order to improve the video quality in lossy channels, particularly those that can provide multiple paths between the sender and the receiver, Multiple Description Coding (MDC) is seen as a promising approach. In MDC, several streams are produced by the encoder and each one (description) is an independent coded representation of the same source signal. The interesting features in MDC are the possibility of any single description to be independently decoded and the fact that joint decoding of all descriptions yields higher signal quality than individual decoding of only one description [1].

Network adaptation is used in video streaming whenever a compressed stream must be matched to a new set of constraints or networks different from those assumed when the original signals were encoded, imposing modification of bit rate, spatial and temporal resolutions or different coding standards. Multiple description (MD) network adaptation finds application in edge internetworking nodes to match single description coded (SDC) streams to multipath networks. In MD network-adaptive video, an SDC stream is split into multiple descriptions to be transmitted over the multiple paths that can reach the target receiver. The benefits of using path diversity in video communications were recently discussed in [2]. In the absence of errors or data loss over the communication channels, all descriptions reach the decoder and high quality frames are reconstructed. Since video coding algorithms are strongly based on temporal predictions, many of these high quality frames are then used as reference for others in order to provide the necessary predictions. Therefore, when a description does not reach the decoder, the predictions reconstructed by that decoder do not match those originally used in the SDC stream. This mismatch generates distortion which is accumulated in the decoder reconstruction loop and propagated throughout all subsequent predicted blocks, i.e., drift.

Previous work in this field address different aspects of MDC video over channels with path diversity. In [3] a MD adaptation method is proposed using Multiple Description Scalar Quantisation (MDSQ) in order to deal with handoff in wireless LAN applications. In [4] a combination of both MDC and scalable coding is proposed and the authors show that a reasonable performance can be obtained under some limited packet loss conditions. However, these MD schemes do not compensate for drift which make them unsuitable in case of long loss bursts. In [5] a MD adaptation scheme is proposed where some DCT coefficients are duplicated into all descriptions and others are alternated between the two descriptions according to channel conditions. In [6] a method based on forward error correction (FEC) codes is devised to obtain two descriptions. Again, none of these works take into account the mismatch problem which gives rise to drift when only one description reaches the decoder.

The MDC network adaptation scheme presented in this paper makes use of an MDC architecture recently proposed by the authors in [7]. While the effectiveness of such MDC architecture in drift control was already demonstrated, neither its networking performance nor that of a classic MDC scheme have been evaluated before under comparable packet loss conditions. In this paper, extensive simulations were carried out under different packet loss conditions to evaluate the performance of MDC network adaptation schemes in video streaming over multipath packet networks. An interesting result that was found in this work is that a small controlled amount of extra MDC redundancy leads to a significant quality

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increase of received video in comparison with both SDC and the classic MDC scheme.

II. Classic Network-adaptive MDC

The MDC network adaptation schemes used in this work are tailored to H.264/AVC coded video which is structured according to the network abstraction layer concept combined with RTP encapsulation. H.264/AVC distinguishes between two different conceptual layers: the video coding layer (VCL) and the network abstraction layer (NAL). Both the VCL and NAL definitions are part of the H.264/AVC standard. The MDSQ module used to generate two descriptions is non-normative. The VCL specifies an efficient representation for the coded video signal, while the NAL defines the interface between the video codec itself and the outside world. NAL units provide the appropriate support for packet-based transport such as current IP networks. In this work, the RTP packetization mode implemented on the reference software JM 11.0 is used. Each slice encoded on VLC layer corresponds to one NAL unit, and consequently, one transmitted RTP packet.

MDSQ is a method for designing multiple descriptions of quantised coefficients to generate several coded representations of the same video stream. The main principle is to find two quantisers which result in coarse reconstructed transform coefficients if inverse quantisation is done separately for each one, whereas finer reconstructed values are obtained if joint inverse quantisation is performed. The MDSQ method is based on an index assignment operation which consists in mapping the original residue transform coefficients i_0 into a two dimensional coding space (i_1, i_2).

The index assignment function used in this paper follows the same approach as proposed in [8]. It is defined by an index assignment matrix as shown in Table I, whose elements are the SDC quantiser indices, i.e., central indices, each one corresponding to a pair of side indices defined by the respective column and row. The amount of redundancy is controlled by an index spread parameter k where $2k+1$ is the number of diagonals of the index matrix. In Table I $k=2$ which means that 5 diagonals are used. In general, MDC algorithms use balanced descriptions where the respective rates and distortions are approximately the same in all descriptions. In this paper, a similar approach is used for network-adaptive MDC by generating two balanced descriptions where the coding efficiency is improved by mapping small values onto zeros, as shown in Table I, e.g., $i_1 = 0$ for central indices $i_0 = -3, -2, 0, 1, 4$ and $i_2 = 0$ for $i_0 = -4, -1, 0, 2, 3$.

TABLE I
Index assignment with k=2

i1 (Description 1) \ i2 (Description 2)	-4	-3	-2	-1	0	1	2	3	4	5
-4	-20	-16	-14							
-3	-17	-15	-12	-8						
-2	-13	-11	-10	-6	-4					
-1		-9	-7	-5	-1					
0			-3	-2	0	1	4			
1					2	5	6	8		
2					3	7	10	12	14	
3						9	11	15	16	18
4							13	17	20	...
5								19	...	...

Fig. 1 shows a classic network adaptation MDC scheme used in video streaming where one SDC stream is split into two descriptions. Each NAL unit of the SDC bitstream corresponds to one RTP packet that is received at the network adaptation node. The common coding information embedded in original stream, such as slice maps, prediction modes and motion vectors are duplicated in each description. An index assignment function is applied to the transform residues followed by CAVLC encoding [3].

At the decoder, if corresponding packets are received from both descriptions, then an inverse index assignment process restores the SDC index to be inverse quantised and inverse transformed. However, if any packet is not available for decoding, then a decoding mismatch occurs in predicted blocks because the original predictions generated in the SDC encoder loop can no longer be replicated in the decoder reconstruction loop. This will generate different prediction blocks and consequently drift accumulation which propagates throughout all predicted slices.

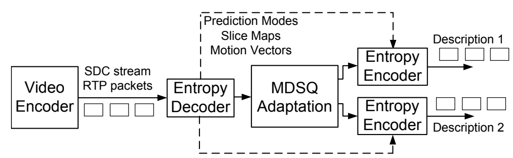

Fig. 1. MDC network adaptation scheme.

III. MD adaptation with mismatch control

Fig. 2 shows a functional diagram of a network adaptation MDC scheme capable to overcome the decoder mismatch. This scheme also operates on SDC packetised streams and use MDSQ to make two distinct descriptions. Single description VCL information is maintained in both descriptions, such as, slice mapping, motion information and prediction modes. The incoming encoded SDC residues are decoded and used in order to generate a controlled amount of side information for the specific purpose of compensating the decoding mismatch referred to above. The side information is generated from the incoming stream, for each description, by encoding the difference between the original SDC signal and the signal decoded from the description itself. This side information is encoded using the same encoding parameters as the incoming stream, such as motion information and prediction modes. The amount of extra redundancy introduced in this process is controlled by a quantisation parameter used to encode the side information of each description. The side information is then multiplexed and packetized along with the corresponding description in the same packet. A detailed description of this MDC scheme and its performance can be found in [7].

After reordering the received packets, the decoder knows which packets are lost in any description and then decides how to decode the received stream. If both corresponding packets

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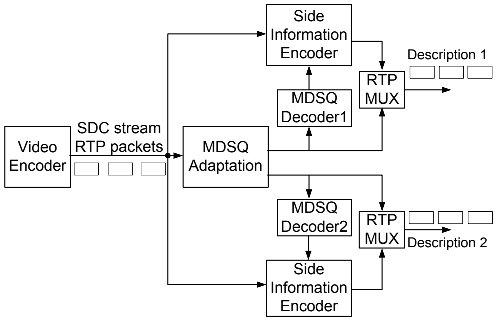

Fig. 2. Proposed MDC network adaptation scheme.

are received, then the MDSQ decoder merges the respective decoded indices in order to obtain the original transform coefficients. In this case, the side information is not used. If only the packet of one description is received, then the decoder uses the side information in order to decode the corresponding slice with controlled mismatch. In the case where both packets are lost, then some error concealment strategy must be used. In this work the frame copy method is used.

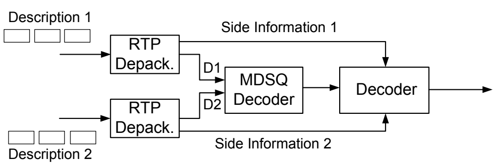

Fig. 3. MDSQ Decoder

IV. Simulation Results

Excluding temporary outage where communication is lost for several seconds, there are two types of packet loss that can be considered: i) random packet loss and ii) burst packet loss. The received quality and the overall effect of packet loss are greatly dependent of the loss pattern occurring along transmission networks. Nevertheless, in both types of packet loss, error propagation along various frames in the decoded video sequence is inevitable.

Also, using MDC in video streaming over multipath channels, the effect of packet loss in each channel has distinct consequences in error propagation of decoded sequences in comparison with SD streaming. For instance, burst packet losses in SDC streaming may be equivalent to isolated packet losses in multipath channels. Since the error concealment performance is expected to be better in the case of isolated packet losses, then MDC network adaptation is also expected to enhance the video quality delivered to users in comparison with SDC.

The MDC network adaptation schemes described in the previous sections, were evaluated assuming multipath communication channels with several packet loss rates (PLR) for isolated and burst packet loss error patterns. SDC streaming in the same channel conditions is also evaluated for comparison. In the case of MDC, each description is streamed over two independent paths with the same PLR.

Random packet loss was simulated using uniformly distributed packet drop. Burst packet loss was simulated using a 2-state Markov model in order to generate a mean burst duration of 100 ms that corresponds to a consecutive fail of 3 frames of the decoded sequence for the same average packet loss rates. In order to obtain valid results, the transmission of each sequence (*bus* and *coastguard*) was simulated 400 times under the same network conditions, i.e., average packet loss rates of 3%,5%,10% and 20%.

The simulation results compare the PSNR of received video when using the proposed MDC network adaptation scheme compared with that obtained classic MDC adaptation scheme and also SDC. In order to assure a fair comparison, the transmitted bit rates are the same in all cases. The GOP structure is IBBPBBP..., GOP size of 21 frames, 4 slices/frames, CIF@30Hz, using *bus* and *coastguard* sequences. The original SDC stream was encoded using QP0=14 for both the initial I frame and subsequent frames. QP0=17 was used in the classic network-adaptive MDC scheme while the proposed one used QP0=18 and $QP1 = QP2 = 28$. In the proposed scheme the side information is only used in I and P frames, contributing with 16% to the total MDC redundancy of 51%, comparing with SDC at QP0=18. Both MDC network adaptation schemes use an index assignment matrix of 3 diagonals ($k = 1$) for generating the two descriptions over the whole GOP, i.e., two descriptions are generated for all frames. In this case a single index encoded in a description represents 3 coefficients in the original SDC stream. For all schemes frame copy error concealment was used whenever one packet is lost. This applies to the case of SDC and also to MDC when both descriptions are simultaneously lost.

Figures 4 and 5 show the PSNR obtained after transmission of *bus* and *coastguard* sequences under isolated packet loss. These PSNR results are the average values of the overall 400 runs for distinct PLR channel conditions. It is clear that for the lossless case (i.e., PLR=0%) both the SDC and classic MDC network adaptation scheme achieve better PSNR in comparison with the proposed scheme because of the redundancy introduced by side information. In the case of lossy transmission, the simulation results show that the proposed MDC network adaptation scheme improves the average PSNR for all PLR. Comparing with SDC transmission the quality gains are 3.85dB for PLR=3%, 6dB for PLR=5%, 8.5dB PLR=10% and 9dB for PLR=20%. Comparing with classic MDC, the PSNR gains are 1.15dB for PLR=3%, 1.43dB for PLR=5%, 2.53dB for PLR=10% and 3.92dB for PLR=20% for *bus* sequence. Identical results are obtained for *coastguard* sequence.

Figures 6 and 7 show the average PSNR obtained after transmission of the *bus* and *coastguard* sequences under burst packet loss. The experimental results also show that proposed MDC network adaptation scheme improves the decoded video quality in the case of burst packet losses. In comparison with SDC transmission the quality gains are 0.6dB for PLR=3%, 3dB for PLR=5%, 6dB PLR=10% and 7.8dB for PLR=20%. Comparing with classic network-adaptive MDC, the gains

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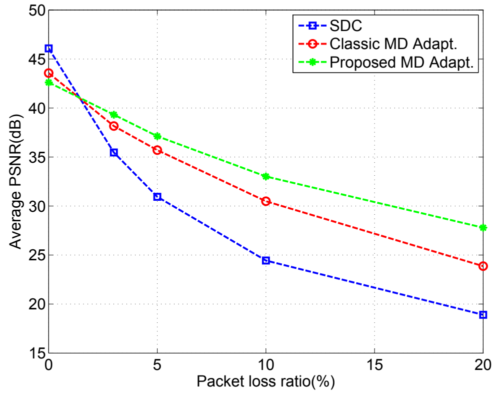

Fig. 4. Average PSNR for *bus* (random packet loss).

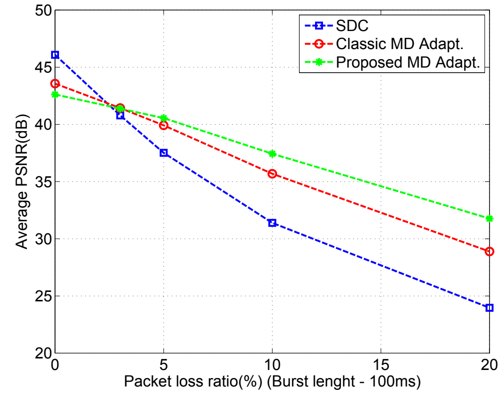

Fig. 6. Average PSNR for *bus* (burst packet loss).

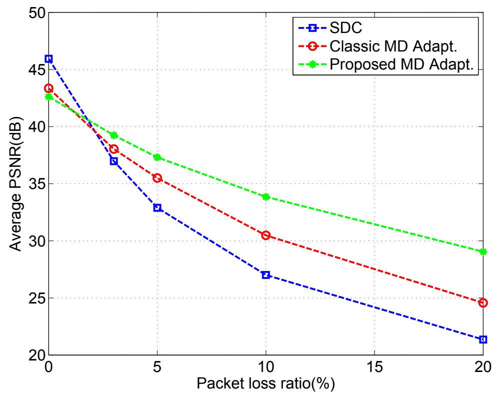

Fig. 5. Average PSNR for *coastguard* (random packet loss).

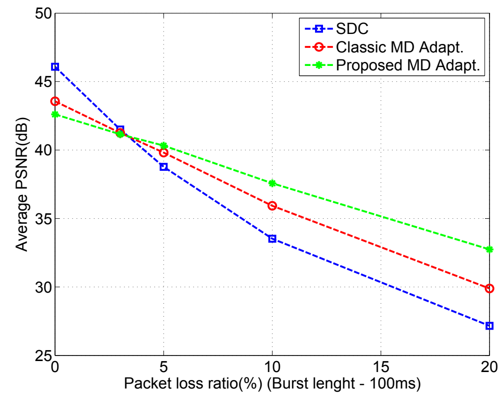

Fig. 7. Average PSNR for *coastguard* (burst packet loss).

are 0.6dB for PLR=5%, 1.8dB for PLR=10% and 2.9dB for PLR=20% for *bus* sequence. In this case for lower PLR the PSNR gains are lower than in the case of isolated losses because the burst errors are very localized and mitigated by the GOP structure of the sequence. For higher PLR, the PSNR gains are significantly improved. For *coastguard* sequence the results are inline with these ones.

Overall, these results show that network-adaptive MDC can be used to improved the robustness of video streaming over multipath channels. In particular, the proposed scheme exhibits consistently better performance over existing classic schemes because of its improved drift characteristics. Significantly higher average PSNR is obtained when compared with both the classic MDC adaptation scheme and SDC.

V. Conclusions

In this paper the performance of a network-adaptive MDC scheme was evaluated under different packet loss conditions. Better efficiency than SDC and classic MDC over multipath networks was achieved. While drift degradation severely compromises the efficiency of SDC and classic network-adaptive MDC, the proposed scheme proves to be effective in preventing drift distortion and improving error robustness by using a controlled amount of side information. The experimental results show that the quality of video streaming can be significantly improved in multipath delivery channels.

Acknowledgment

This work was partially supported by Fundacao Para a Ciencia e Tecnologia (FCT), under grant SFRH/BD/50035/2009.

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