EVALUATION OF JOINT SOURCE AND CHANNEL CODING OVER WIRELESS NETWORKS

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ABSTRACT

Transmission of digital video signals over wireless networks demands efficient compression algorithms as well as reliable coding strategies. In this project, we provide a thorough evaluation of the joint source-channel video coding methodology from two points of view: source coding design for error resilience and channel coding for error detection and recovery. We investigate the current ITU video compression standard, H.263+, for 3G wireless transmission. In particular, we concentrate on error resilient features provided within the standard and forward error correction (FEC) to find the optimal combination of various system parameters under different lossy channel conditions.

1. INTRODUCTION

We examine the tradeoffs in source and channel coding for video transmission over a wireless channel. In particular, we explore the error resilient features as recommended by the ITU for the H.263+ coder and forward error correction (FEC) using Reed Solomon codes [1]. The advantages of using error resilience include standards compliance and no additional delay. The disadvantages include slight reduction in compression efficiency and by definition, error resilience is designed to reduce error propagation, not detect and correct errors. Channel coding using FEC has the advantage of the ability to detect and correct for errors. Channel coding can be used to design an unequal error protection scheme for high and low priority data and FEC can be added at the application layer for current networks where the physical and link layers cannot be altered and may provide channel conditions which are not acceptable for video applications. The disadvantage of FEC includes additional overhead (bandwidth), additional delay and additional software at the client in order to be able to decode and play the video. Other work which examined the tradeoffs between source-channel coding for video over wireless includes [2], [3], and [4].

We examine the H.263+ coder for video transmission over a wireless network. The particular annexes that we explore within the standard are annexes related to coding efficiency such as Annex D – unrestricted motion vector mode, Annex F - advanced prediction mode, and Annex I - advanced INTRA coding mode. We also examine annexes related to error resilience (the ability to recover or mitigate error propagation) such as Annex K - slice structured mode, Annex N - reference picture selection mode, and Annex V - data partitioning.

The experiments use the H.263+ standard and software which emulates the UMTS (Universal Mobile Telecommunication System), 3G network provided by [5]. The overall system consists of one computer which acts as the server, both encoding and packetizing the bitstream. The bitstream is sent to the UMTS proxy machine and corrupted according to the traditional Gilbert 2-state model with parameters for the bit error rate (BER) and error burst length. The third machine acts as the client, decoding and playing the video and a fourth computer is used to initiate and monitor the proxy.

2. EXPERIMENTS

All our experiments are based on QCIF resolution (176x144 pixels) video and rates less than or equal to 64 kbps.

2.1 Evaluation of annexes of H.263+ for source coding

Our first set of experiments examined annexes D, F, I, K, and N. Annex D, F, and I are three optional mechanisms regarding the coding efficiency improvement. The Unrestricted Motion Vector mode, known as Annex D in the standard recommendation, allows motion vectors to point outside the pictures, and extends the range of motion vectors from the default value $[-16, 15.5]$ to $[-31.5, 31.5]$. The Advanced Prediction mode, known as Annex F, provides the one/four motion vectors selection for each macroblock, and implements motion compensation by a weighted sum of three prediction values for the 8×8 luminance block. The Advanced INTRA coding mode, referred to as Annex I, provides schemes to improve the coding efficiency of INTRA macroblocks, including encoding INTRA blocks based on the prediction from neighboring INTRA blocks.

The annexes regarding coding efficiency in H.263+ are trying to get rid of further redundancy in the bitstream, resulting in more dependency within the bitstream. Therefore, it is more likely to cause error propagation through motion compensation and differential coding.

Annexes K and N are two optional modes to introduce error resilience to the H.263+ bitstream. In Annex K, Slice Structured mode is designed to substitute the GOB structure, where the slice boundary is treated in the same way as is the picture boundary, i.e., any dependency across slices is avoided, therefore, slice headers can serve as resynchronization points. Annex N, the Reference Picture Selection mode allows the encoder to choose the reference picture for prediction of the INTER pictures. It breaks a given source video sequence into more than one thread, and all the threads are encoded independently within a period and then a Sync Frame is inserted regularly to merge the threads. Therefore, the decoder can depend on the successfully received threads to suppress the temporal error propagation.

Obviously, the adoption of annexes such as Annex K and I will inevitably result in a substantial penalty with respect to coding efficiency. Therefore, it is worth examining how the combination of the annexes affects the overall performance of H.263+ coders with respect to the coding efficiency as well as the error resilience of the bitstream.

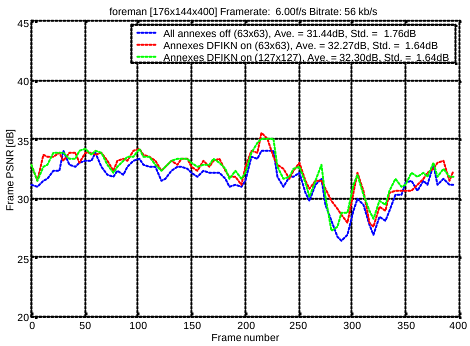


Figure 1 Evaluation of annexes of H.263+ over “Forman”

Figure 1 illustrates the PSNR results for the video sequence "Foreman" with and without the above annexes at a rate of 56 kbps and 6 fps. The results with the annexes turned on include a range of motion vectors of 63×63 as well as 127×127. The annexes result in an average improvement in PSNR of 0.8 dB. Similar experiments were done for six other video sequences and the results are summarized in Table 1.

Table 1 Evaluation of annexes of H.263+ over different videos

Video	Annexes off (63×63)		Annexes on (63×63)		Annexes on (127×127)	
	Avg. PSNR (dB)	Std. (dB)	Avg. PSNR (dB)	Std. (dB)	Avg. PSNR (dB)	Std. (dB)
Claire	42.94	1.20	42.64	1.25	42.63	1.25
Mother	39.47	1.51	39.64	1.37	39.68	1.34
Salesman	37.74	2.51	38.05	2.31	38.41	2.52
Wireless	33.79	2.82	34.10	2.79	34.12	2.84
Vfa	32.50	3.79	32.79	3.19	32.80	3.18
Foreman	31.44	1.76	32.27	1.64	32.30	1.64
Laura	27.68	2.30	27.63	2.35	27.62	2.34

In summary, the combination of the efficient coding annexes with the error resilient annexes results in overall compression performance similar or slightly better than turning off the annexes.

Furthermore, we evaluate the performance of the H.263+ coder and its annexes at various bitrates by examining its rate-distortion behavior. In terms of the annexes, we observe similar results that the encoder with all five annexes turned on provides limited improvement. Since with the annexes in use, the H.263+ coder can achieve a much higher degree of error resilience while maintaining the same level of coding efficiency, we will turn on all the annexes in the following experiments.

2.2 Evaluation of INTRA refresh period

In H.263+, INTRA/INTER decision is made on a macroblock-by-macroblock basis. The source coder usually decides INTRA/INTER modes in a rate-distortion sense, and hence the INTER mode is much more likely to be chosen so that the video data can be efficiently represented. For the sake of reliability of the bitstream, however, it is beneficial to choose INTRA more often since INTRA macroblocks can serve as a resynchronization point and completely stop temporal error propagation. Therefore, the encoder may intentionally force a macroblock to be coded as INTRA as a scheme of error resilience. Forced INTRA mode can be set in an adaptive way based on the video content or the channel condition, or just set regularly determined by the INTRA refresh period in units of time. Nevertheless, coding efficiency will inevitably suffer due to shorter INTRA refresh periods.

We evaluate extensive experiments of encoding different video sequences at different INTRA refresh periods at a fixed bitrate. With the increment of INTRA refresh, less INTRA modes are selected, and thus higher average PSNRs of the decoded pictures are achieved. Moreover, we would like to know how much we need to pay for the introduction of forced INTRA modes in terms of the coding bitrates. We have examined the rate-distortion behavior of the H.263+ coder by coding at different bitrates but with a fixed INTRA refresh period. Also, we have investigated source coding with different INTRA refresh periods but at a fixed bitrate. We notice that with the decrement of the INTRA refresh period, the average PSNR value decreases accordingly, which is equivalent to source coding at a lower bitrate while keeping the INTRA refresh period constant. In other words, we introduce more error resilience to the bitstream by choosing INTRA modes more frequently at a price of sacrificing bitrate for pure source coding efficiency without error resilience consideration. Alternatively, we can choose a larger INTRA refresh period, achieving better compression performance so that the same distortion can be achieved at a lower bitrate and the remaining bits can be used for error protection using FEC. The goal here is to match the PSNR of the source coder with error resilience to a (lower bandwidth) version of the source coder without error resilience and additional FEC to match the final bitrates.

Figure 2 demonstrates how many bits have to be dropped if we choose more INTRA modes. The data in the figure are obtained by locating the "matching points" between the operational rate-distortion curves and the distortion-INTRA refresh period curves. For "Wireless", for example, at 56 kbps and INTRA refresh period of 0.5 secs, the average PSNR value of the decoded pictures are approximately 33dB, whereas it only requires 43 kbps to achieve the same performance with INTRA refresh of 1 sec. Hence if error resilience is realized by INTRA refresh, 13 kbps has to be sacrificed.

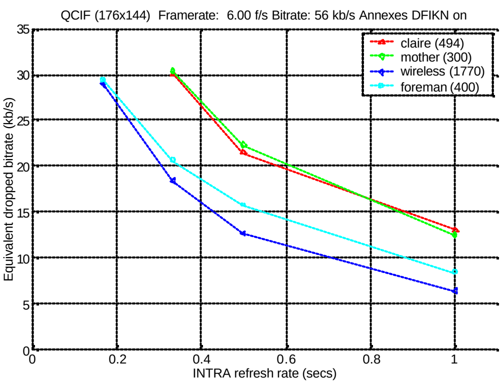


Figure 2 Matching points between rate-distortion curves and distortion-INTRA refresh curves

2.3 Joint source-channel coding over lossy channels

The next set of experiments evaluate different parameter settings for error resilient features within the source coding stage and FEC for channel coding.

Error resilience is introduced into the bitstream in the source coding stage, especially by exploiting INTRA refresh, slice structure (Annex K), and reference picture selection mode (Annex N). In particular, we are interested in adjusting the INTRA refresh period and the size of slice in order to achieve an optimal tradeoff between source coding efficiency and error resilience capabilities. On the other hand, FEC with Reed Solomon coding is added in the application layer for error protection. Basically, there are three modes for error protection: No Error Protection, NEP, where FEC is not used; Equal Error Protection, EEP, where the entire bitstream is equally protected by FEC; Unequal Error Protection, UEP, where error protection is only applied to the higher priority portion of the bitstream. Moreover, we design two sub-modes for UEP: UEP-1 includes header information together with motion vectors in the higher priority flow, while UEP-2 includes header information, motion vectors, as well as slice-wise INTRA data in the higher priority flow. We consider three channel conditions: good channel condition with BER at level of 10^{-5}, average channel condition with BER at 10^{-4}, and poor channel condition with BER at 10^{-3}.

First, we exploit the matching points to compare the performance of error resilience realized by INTRA refresh with that of FEC realized by Reed-Solomon coding under the first two channel conditions. We choose two matching points for "Wireless" and three for "Mother" to implement both NEP and EEP modes under good and average channel conditions. The coding parameters for "Wireless" at the matching point of INTRA refresh 0.5 secs under good channel condition are set as in Table 2, and it is observed that there are some small errors with NEP mode at this point. The parameters at the matching point of 1/3 secs under average channel condition are given in Table 3, and even though half of the macroblocks are forced to be INTRA, errors are much more frequent with NEP mode. However, there is no error when the EEP mode is adopted at both of the two matching points. Similar results were achieved with "Mother".

At the matching point set in Table 2, the number of errors are small and the propagation time of each error occurrence is very short, so that the resulting errors with NEP can be ignored. Moreover, considering the advantages of NEP mode where no additional delays, bandwidth and software are needed and remains completely compliant with the standard, we conclude that if the channel condition is good enough, error protection can be achieved purely by adopting error resilience schemes. Nevertheless, since error resilience has no capability to correct errors, when the lossy channel conditions get worse, we need to employ error control coding to improve the reliability of the bitstream. We also notice that if the channel is not poor, we can achieve very good error protection performance by using low rate Reed Solomon codes for protection.

Table 2 Coding parameters for "Wireless" under good channel

	Payload bitrate (b/s)	Video bitrate (b/s)	INTRA refresh (secs)	Slice size (mbs)	Latency (secs)	Packet size (bytes)	Slot length (bytes)
NEP	56,000	55520	0.5	33	1	1,452	1,452
EEP	56,000	43350	3.0	33	1	1,452	320

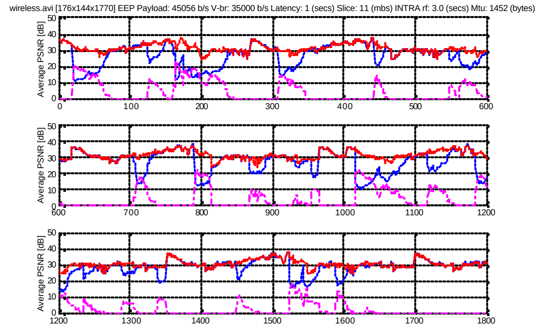
Table 3 Coding parameters for "Wireless" under average channel

	Payload bitrate (b/s)	Video bitrate (b/s)	INTRA refresh (secs)	Slice size (mbs)	Latency (secs)	Packet size (bytes)	Slot length (bytes)
NEP	56,000	52800	1/3	33	1	1,452	320
EEP	56,000	37546	3.0	33	1	1,452	320

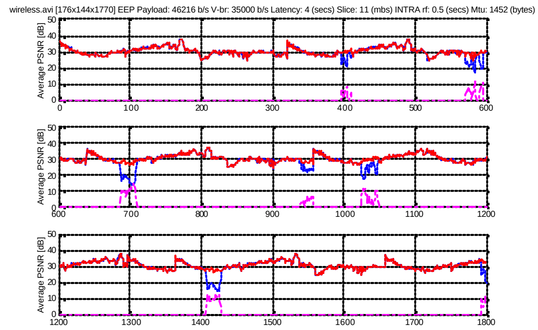
Under poor channel conditions when the BER is high, error resilience does not provide enough protection resulting in unacceptable decoded video quality. For the poor channel condition, we have to adopt channel coding for detection and correction of errors. Moreover, we know that an (N,k) Reed Solomon code can correct up to $\lfloor (N-k)/2 \rfloor$ symbol errors. If the BER of the lossy channel gets larger than the error correction capability of the Reed Solomon codes, error control coding becomes ineffective and the decoded video quality will seriously degrade.

Under the poor channel condition, we first set the coding parameters as given in the first row of Table 4, which are almost the same as the EEP mode in Table 3 except that we allocate 2k more bitrate for the error control codes. Simulation results are shown in Figure 3 (a). The red curves denote the PSNR values obtained with error-free transmission, and the blue ones are obtained when errors are present. We observe that even though we cast more error protection for the bitstream, the decoded video quality is terribly corrupted by the 10^{-3} level burst errors. We adjust the coding and packetization parameters to be as the second row of Table 4, which results in much better coding performance even though the BER of the channel is as high as 10^{-3}, as shown in Figure 4 (b). Specifically, we decrease the INTRA refresh period from 3 secs to 0.5 secs, and increase the latency from 1 sec to 4 secs, with the other parameters remaining the same as in the worse case.

From the experimental results, we find that by combining error resilience realized by INTRA refresh with error control coding schemes, we can exploit INTRA refresh updates to prevent error propagation and gain resynchronization in case error control coding becomes ineffective. Interleaving across slots can decentralize error effects and is very suitable to deal with burst errors. The higher the latency is, the larger the window we can use to implement the interleaving. However, interleaving has two negative effects – large latency requires large memory at both encoder and decoder sides as well as large time delay for the coding process.



(a) Worse results



(b) Better results

Figure 3 EEP for "Wireless" under poor channel condition

Table 4 Coding parameters for "Wireless" under poor channel

	Payload bitrate (b/s)	Video bitrate (b/s)	INTRA refresh (secs)	Slice size (mbs)	Latency (secs)	Packet size (bytes)	Slot length (bytes)
Worse	56,000	35000	3.0	11	1	1,452	320
Better	56,000	35000	0.5	11	4	1,452	320

[1] ITU-T Recommendation H.263, "Video Coding for Low Bit Rate Communication," Feb. 1998.

[2] Klaus Stuhlmüller, Niko Färber, Michael Link, and Bernd Girod, "Analysis of Video Transmission over Lossy Channels," *IEEE J. Select. Areas Commun.*, vol. 18, pp. 1012-1032, June 2000.

[3] Stephan Wenger, Gerd Knorr, Jörg Ott, and Faouzi Kossentini, "Error Resilience Support in H.263+," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 8, pp. 867-877, Nov. 1998.

[4] Robert E. van Dyck, and David J. Miller, "Transport of Wireless Video Using Separate, Concatenated, and Joint Source-Channel Coding," *Proceedings of the IEEE*, vol. 87, pp 1734-1750, Oct. 1999.

[5] Software provided by Michael Link, Lucent Technologies.