ITU - Telecommunications Standardization Sector
STUDY GROUP 16
Video Coding Experts Group (Question 15)
Seventh Meeting: Monterey, 16-19 February, 1999
Document Q15-G-43
Filename: q15g43.ps

Error Propagation in Motion Compensated Video over Wireless Channels

Madhukar Budagavi
Department of Electrical Engineering
Texas A&M Univsersity
College Station, TX 77840

Jerry D. Gibson
Department of Electrical Engineering
Southern Methodist University
Dallas, TX 75275-0338

Abstract

The use of multiple frames in block motion compensation (BMC) provides us with a new framework for increasing the robustness of video coders. In this paper, we study the error robustness properties of multiframe BMC (MF-BMC) coders by modeling the error propagation process in the MF-BMC approach as a multiple Markov chain. Using Markov chain analysis we find that the probability of error propagation can decrease (i.e. robustness can increase) by (i) The use of additional frames in BMC, and by (ii) Decreasing the probability with which blocks in the immediate previous frame are chosen for motion compensation. We outline a simple scheme that modifies the probabilities of macroblock prediction to achieve additional robustness.

The MF-BMC coders proposed in this paper are a multiframe extension of the base level H.263 coder and are found to be more robust than the base level H.263 coder when subjected to simulated errors commonly encountered on wireless channels.

1 Introduction

The increasing popularity of mobile personal communication systems (PCS) has generated interest in the development of robust and efficient video coders for use on wireless channels. The video coding approaches for wireless channels are closely linked to the type of error control used on the channel. They can be broadly categorized into closed-loop [1, 2] and open-loop approaches [3, 4] based on whether receiver feedback is present or not. We presented a multiframe block motion compensated (MF-BMC) video coder in [5] and found it, through simulations in an open-loop configuration, to be more bit efficient and more robust to transmission errors commonly encountered on wireless channels, when compared to the single frame BMC (SF-BMC) approach such as in the base level H.263 codec. The multiframe BMC approach matches blocks in the current frame with those in multiple previous frames to find a best match [6] [5]. In this paper, we model the error propagation process in the MF-BMC approach as a multiple Markov chain [7] and specifically show for the two frame BMC (2F-BMC) approach that (i) Use of the additional frame in BMC decreases the probability of error propagation thereby increasing robustness, and (ii) The probability of error propagation increases monotonically with the probability with which blocks in the immediate previous frames are chosen for motion compensation. Also, based on Markov chain simulations, we generalize the above two conclusions to multiple (≥ 2) frames and find them to be true for the general MF-BMC approach. Based on the insight we gain into the error propagation process by the use of the Markov chain model, we outline a simple scheme which modifies the probabilities of macroblock prediction to achieve additional robustness. We present simulation results using commonly used test video data to demonstrate the improved robustness of our MF-BMC schemes.

2 Multiframe Block Motion Compensation

The overall structure and syntax of the MF-BMC coder implemented is similar to that of the base level H.263 coder [8]. The essential difference is that the MF-BMC approach is used for motion compensation. The parameter vector used to characterize the MF-BMC consists of a single motion vector signifying the relative displacement of the matching block, and a lag value which indicates the frame number of the frame which contains the matching block. Only the MF-BMC procedure is elaborated further: A macroblock X in the current frame k is matched with displaced blocks of the same size in the search region, B, in each of the previous decoded frames : $(k-1),(k-2),\ldots,(k-K)$. Matching is done using the sum absolute difference (SAD) criterion. The set of K minimum SADs for the current macroblock is calculated using the following motion estimation procedure:

$$\begin{aligned} min\_sad(i) \quad = \quad & \min_{(dx,dy)\in B} \sum_{(nx,ny)\in X} |s(nx,ny,k) \\ & -\hat{s}(nx+dx,ny+dy,k-i)|, \\ & i=1,\ldots,K \end{aligned} \qquad (1)$$

where (dx, dy) is the displacement vector, i is the index of the previous frame relative to the current frame k, and $s(\cdot)$ and $\hat{s}(\cdot)$ are the input and the reconstructed video respectively. The motion estimation procedure yields K motion vectors, with one motion vector for each frame. The optimum lag value can be obtained by selecting the frame number which gives the minimum SAD

$$lag = \arg \min_{i\in[1,K]} min\_sad(i). \qquad (2)$$

The motion vector that is transmitted is the one corresponding to the optimum value of lag obtained. Note that the above procedure does not involve motion interpolation and the motion compensation that is done is performed using information from exactly one frame.

3 Error Propagation Characteristics

To analyze the error robustness properties of the MF-BMC coder, we model the error propagation process in MF-BMC coding as a multiple Markov chain [7]. We compare the error propagation performances of the SF-BMC and the MF-BMC approaches by calculating the probability of error propagation due to a transmission error. A simplified model of motion compensation is assumed to make the analysis more tractable. Assumptions made are that an error in a macroblock affects only those macroblocks in the future which are at the same spatial location as the original erroneous macroblock and that the probability of resynchronization due to the occurrence of an INTRA coded macroblock in INTER pictures is low. The probabilities of error propagation are calculated at a macroblock level, and calculations assume that the error corrupts the whole macroblock. Hence, the performance improvement is measured in terms of the probability that a macroblock is not in error.

The calculation of the probability of error propagation and the Markov chain formulation are illustrated with the SF-BMC and the two frame BMC (2F-BMC) approaches as examples. Consider Fig. 1. Let X_t denote a macroblock at time t. The macroblocks shown in the figure are the macroblocks which occur at the same spatial location in the picture but at different time instants. In the SF-BMC approach, since X_t is predicted from X_{t-1} with probability 1, the error propagates with probability 1 and all subsequent macroblocks will be in error. Now consider the sequence of macroblocks coded using the 2F-BMC approach as shown in Fig. 1(b). The corresponding four-state Markov chain is shown in Fig. 1(c). Each state is defined by (S_t, S_{t-1}), with $S_t = 0$ denoting X_t is error free and $S_t = 1$ denoting X_t is erroneous. Probability of error propagation p_e, which is equal to the probability of entering the recurrent state $(1,1)$ from the transient state $(1,0)$, is $\frac{1}{2-p}$. Thus (i) when $0 \le p < 1$, $p_e < 1$ (i.e. p_e is better than that for SF-BMC), and (ii) p_e is monotonically increasing in p (i.e. it is better to predict less from the immediate previous frame). Markov chain simulations for the K-frame MF-BMC approach were done by modeling the error propagation process as a K-multiple Markov chain, which in turn can be modeled as a 2^K-state Markov chain [7].

4 Improving Error Robustness

Note that if the optimal motion estimation procedure of (2) is used, the various probabilities with which the current macroblock is predicted from the previous ones depend on the particular video sequence being coded and are not under user control. Thus the error performance improvement that can be achieved depends on the particular video sequence that is being coded. Equation (2) can be modified to include a sub-optimal lag estimation procedure so as to control the probabilities of macroblock prediction as desired. This leads to a trade-off between coding gain and error robustness. Many of the $min\_sad(i)$'s for a macroblock tend to cluster around their global minimum. Thus

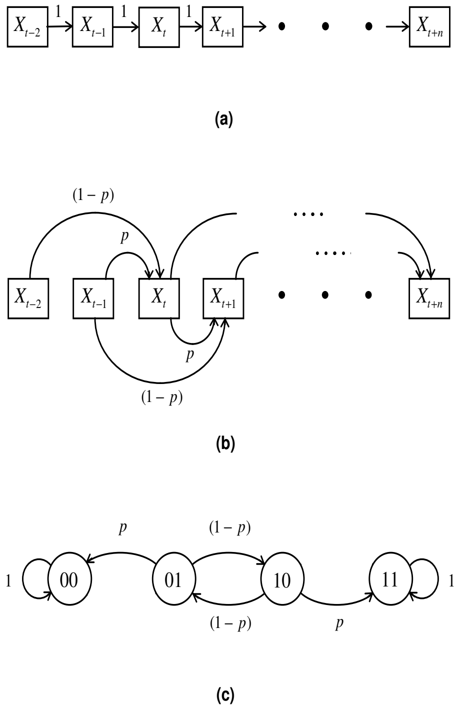

Figure 1: Prediction of a sequence of macroblocks: (a) SF-BMC approach (b) 2F-BMC approach (c) Markov chain for the 2F-BMC approach.

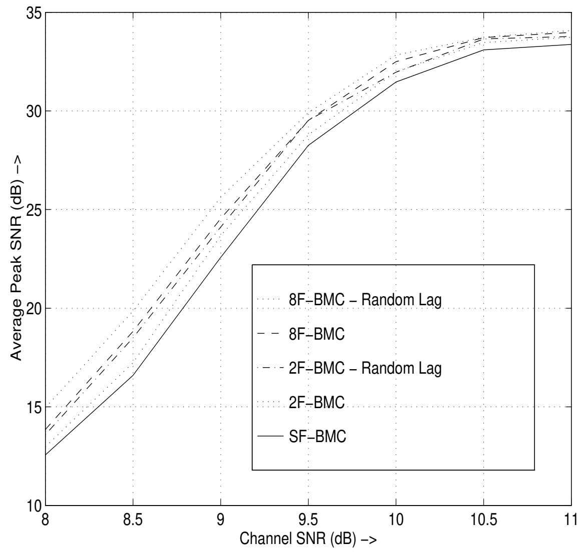

Figure 2: PSNR versus channel SNR performance of MF-BMC approaches over AWGN channel.

by employing a strategy which randomly selects the lag parameter from the set corresponding to the cluster of $min\_sad(i)$'s and which reduces the probability of selection of $lag = 1$, we increase the robustness of the MF-BMC approach without drastically increasing the bit-rate. More details of the Random Lag (RL) selection based coder are given in [9].

5 Simulation Results

The average performance of the MF-BMC approach to transmission errors was studied by transmitting the encoded bitstreams through simulated AWGN and wireless channels. The experiment consisted of transmitting the encoded bitstream of the *Carphone* and *Foreman* video sequences. For simplicity, BPSK modulation was used. As the main purpose of the experiment was to compare the performance of SF-BMC and MF-BMC approaches, no channel coding was done. Figure 2 shows the average peak signal-to-noise ratio (PSNR) [10] values (averaged over 200 runs of the experiment with different initial seeds for the random number generator) obtained under different AWGN channel SNRs for the MF-BMC approach. The encoded bitstreams for $K = 1$ (SF-BMC), $K = 2$ (2F-BMC), and $K = 8$ (8F-BMC) were obtained using the optimum lag selection process of (2), whereas the bitstreams for 2F-BMC–RL and 8F-BMC–RL were obtained using a random lag selection process. Bitrates for the MF-BMC–RL case are approximately the same as that for the SF-BMC

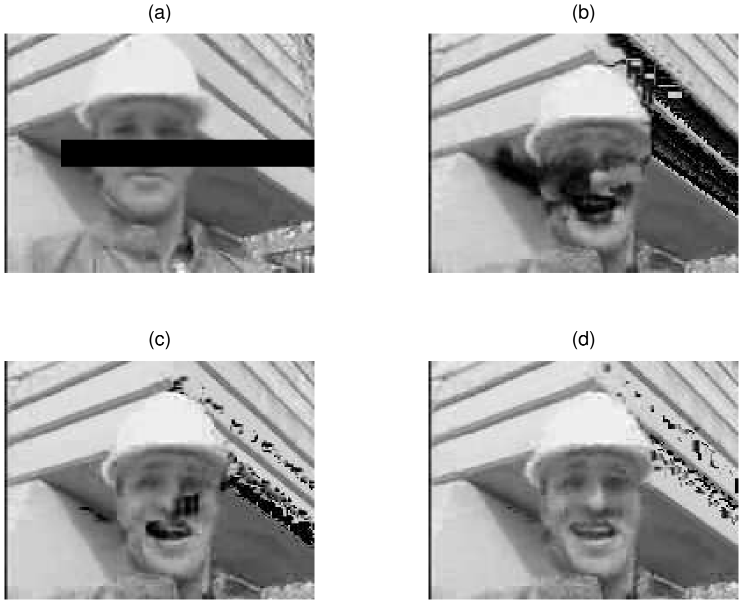

Figure 4: Error propagation due to an error in the 12th frame: (a) Frame 12 - Identically corrupted in all sequences (b) Frame 62 of SF-BMC decoded sequence (c) Frame 62 of 8F-BMC decoded sequence (d) Frame 62 of 8F-BMC–RL decoded sequence.

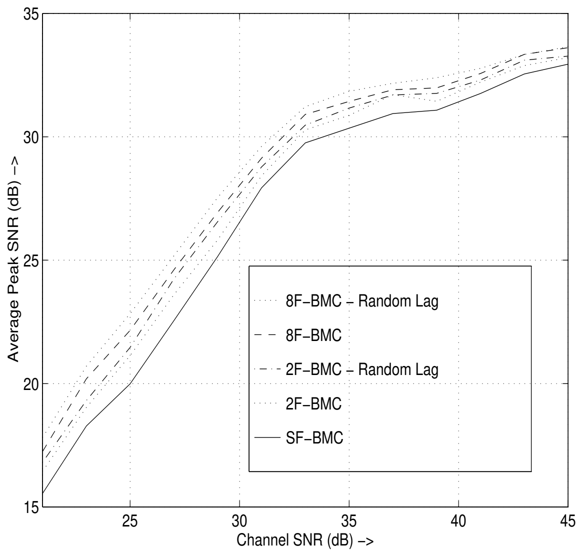

Figure 3: PSNR versus channel SNR performance of MF-BMC approaches over Rayleigh fading channel with $f_m = 2$.

case (around 29–33 kbps), where as that of the MF-BMC are lower than that of the SF-BMC case. Significant PSNR improvements in the range of 0.65–3.25 dB are achieved in the 8F-BMC–RL case. Similar results are obtained over a simulated Rayleigh flat fading (slow fading) [11] channel with the PSNR improvement for the 8F-BMC–RL case being about 0.7–2.85 dB (See Fig. 3). Figure 4 shows an example reconstruction of the luminance component of *Foreman* video sequence decoded from identically corrupted SF-BMC, 8F-BMC, 8F-BMC–RL bitstreams. The 8F-BMC–RL approach has been able to overcome most of the transmission errors in this case. Some artifacts, however, do remain. The reader is encouraged to try out our prototype decoder, a copy of which along with some sample bitstreams can be downloaded from *http://ee.tamu.edu/~madhukar/icip97.html* . The prototype decoder demonstrates the entire sequence which generated the pictures shown in Fig. 4.

It should be noted that the improvements in performance have come at the cost of increased motion estimation complexity at the encoder and increased memory requirements at both the encoder and the decoder.

References

[1] M. Khansari, A. Jalali, E. Dubois, and P. Mermelstein, "Low bit-rate video transmission over

fading channels for wireless microcellular systems", *IEEE Trans. Circuits Syst. Video Technol.*, vol. 6, no. 1, pp. 1–11, Feb. 1996.

[2] L. Hanzo and J. Streit, "Adaptive low-rate wireless videophone schemes", *IEEE Trans. Circuits Syst. Video Technol.*, vol. 5, no. 4, pp. 305–318, Aug. 1995.

[3] R. Stedman, H. Gharavi, L. Hanzo, and R. Steele, "Transmission of subband-coded images via mobile channels", *IEEE Trans. Circuits Syst. Video Technol.*, vol. 3, no. 1, pp. 15–27, Feb. 1993.

[4] R. Mann Pelz, "An unequal error protected $p \times 8$ kb/s video transmission for DECT", in *Proc. VTC*, 1994, pp. 1020–1024.

[5] Madhukar Budagavi and J. D. Gibson, "Multiframe block motion compensated video coding for wireless channels", in *Proc. Asilomar Conference on Signals, Systems, and Computers*, 1996.

[6] M. Gothe and J. Vaisey, "Improved motion compensation using multiple temporal frame", in *IEEE Pacific Rim*, 1993, pp. 157–160.

[7] J. L. Doob, *Stochastic Processes*, John Wiley & Sons, Inc., New York, 1953.

[8] International Telecommunications Union, Telecommunications Standardization Sector, "Draft Recommendation H.263 - Video coding for low bitrate communications", 1995.

[9] Madhukar Budagavi and J. D. Gibson, "Multiframe block motion compensated video coding for wireless channels", submitted to *IEEE Trans. Circuits Syst. Video Technol.*, 1997.

[10] A. N. Netravali and B. G. Haskell, *Digital Pictures : Representation and Compression*, Plenum, New York, 1988.

[11] W. E. Jakes, Jr., Ed., *Microwave Mobile Communication*, Wiley, New York, 1974.