

# Robust Video Coding Based on Tree Structure Motion Compensation

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## ABSTRACT

One inherent problem of network video is the sensitivity of the compressed bit-stream to data loss. Error propagation is one of the most important factors that affect the quality of network video. This paper discusses a new scheme for robust video coding to cope with this problem. First, error propagation in Block Motion Compensation (BMC) in H.263 is analyzed using a Markov chain model. Several observations are made from a numerical evaluation of the Macro-Block (MB) error probability. Since a high degree of correlation exists across multiple frames in typical videoconferencing sequences, a tree-structure motion estimation and compensation (TMEC) scheme is proposed based on the above observations. This structure reduces the length of error propagation and implicitly increases the MB intra-refresh rate. Simulations show that the new scheme has better performance than that of traditional H.263 encoder in dealing with error propagation.

## 1. Introduction

The most commonly used video compression techniques today are based on MPEG and H.26x standards, where block motion compensation is employed. While this technique is very efficient in exploiting inter-frame redundancies, it is very sensitive to channel errors. Often a single error in one frame propagates to tens and even hundreds of the following frames, because of the recursive structure of the motion prediction and compensation.

Schemes preventing or alleviating error propagation can be roughly sorted to three categories: Forced Intra Update (FIU), Prediction Confinement (PC), and Selective Recovery (SR). FIU tries to stop error propagation by forcing macro-blocks to be intra-coded based on some strategy [2,4,5,6]. PC restricts the scope of motion estimation either spatially or temporally [2,8], thus restricts the scope of error propagation. SR deals with this problem with feedback information about the corrupted MB from decoder [1,3]. The FIU and PC based techniques are simple, but it is hard to control the trade-off of coding gain and error resilience in such techniques. SR based techniques are very efficient, but require a feedback which is impossible in many applications, e.g. video broadcasting.

In this paper, we propose a new scheme to deal with the error propagation. It makes use of the correlation existing across multiple frames in videoconference sequences. The motion estimation and compensation structure of the H.263 is rearranged to a tree structure. With such a scheme, errors occurring in most of the frames terminate after a few frames. While errors occurring in other frames propagate as in H.263, the propagation

length is shortened and the MB intra-refresh rate is implicitly increased in the proposed scheme. Based on the analysis of the error propagation with a Markov chain model, the proposed scheme is expected to provide better error performance. Simulation results confirm this expectation.

## 2. Error Propagation in H.263

In H.263, three types of frames, intra-coded (I), predicted (P) and bi-directionally-predicted frames (PB) are defined to exploit spatial and temporal redundancies. While I frames are totally intra-frame coded, P and PB frame are coded using BMC. In BMC, a macro-block (MB) in the current frame is compared with MB-size blocks in the reference frame within a specified search region. The minimum value of an appropriate cost function is compared with a threshold to determine the coding mode of the MB. If it is less than the threshold, the macro-block is inter-coded. The difference between the macro-block and its best matching block is computed pair-wise for further intra-frame coding. Otherwise, the macro-block is intra-coded, in which the original data is coded without motion compensation.

Given the above difference in encoding of inter and intra coded macro-blocks, the probability of error recovery of the MB is different for the two types. In inter-coded macro-blocks, this probability is:

$$P_{error} = P_{RE} + P_{NE} \quad (1)$$

In intra-coded macro-blocks, this probability is:

$$P_{error} = P_{NE} \quad (2)$$

where  $P_{RE}$  is the probability that the reference block is incorrectly recovered and  $P_{NE}$  is the probability that the macro-block is corrupted in transmission.

This probability characterizes the error propagation and can be analyzed using the Markov chain model introduced in [7]. To make the analysis tractable, it is assumed that:

- 1) Only I and P frames are used in H.263 encoder.
- 2) The error in a macro-block (MB) affects only those MBs in the future that are at the same spatial location as the original erroneous MB.

With the above assumptions, we have the two-state Markov chain model as shown in Figure 1. Here,  $q_0$  is the probability

with which a MB is intra-coded,  $p_e$  is the probability that a MB is corrupted in transmission. State  $S_t = 0$  denotes error-free reconstruction of MB; state  $S_t = 1$  denotes reconstruction with error.

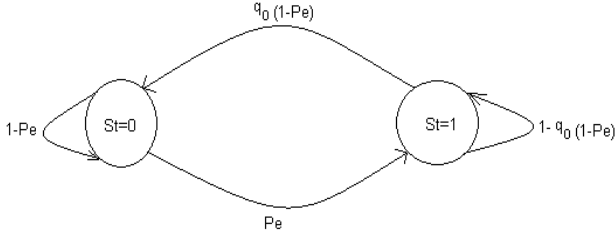


Figure1: Markov model for error propagation

The K-step transition matrix with the above probabilities is then given by:

$$T_K = \begin{pmatrix} 1-p_e & p_e \\ q_0 * (1-p_e) & 1-q_0 * (1-p_e) \end{pmatrix}^K \quad (3)$$

Thus, the MB error probability in frame K+1 is:

$$P_r \{S_{t=K+1} = 1\} = p_e * T_K(1,1) + (1-p_e) * T_K(0,1) \quad (4)$$

Figure 2 shows the numerically evaluated macro-block error probabilities calculated using (4) as a function of frame number. It is obvious from the figure that the effect of error propagation on video quality can be alleviated by increasing intra-coding frequency and/or decreasing the channel error rate. Alternately, for a given channel error rate and intra-coding frequency, the video quality can be improved by shortening the error propagation length. This is because the MB error probability is always an increasing function of time (frame number) due to error propagation and accumulation.

### 3. The Tree Structure Motion Compensation

One observation about videoconference sequences is that strong correlation exists between frames which are even tens of frames apart. Motivated by these observations, we propose the following tree-structure motion estimation and compensation (TMEC) scheme, as shown in Figure 3.

- 1) Three types of frames are defined in this structure: root frame, stem frame and branch frame. Stem frames are frames whose frame numbers are multiples (except 0) of K, which is defined as the length of branches (number of frames in a branch). Root frame is defined as the first frame of the tree. Branch frames are those frames whose frame numbers are not multiple of K.

- 2) As in traditional H.263 standard, the first frame is an I frame. So, the root frame is always intra-coded, while other frames are inter-coded.
- 3) The frames after the root frame are P frames. If its frame number is not a multiple of K, it is predicted with reference to the previous frame as in traditional H.263. Otherwise (that is, if it is a stem frame), it is predicted with reference to its previous stem frame or the root frame. This frame itself becomes a stem frame. The following observations are made about this structure.

Firstly, it is obvious in such a structure that the total length between the last frame and the first frame is roughly 1/K of that in traditional H.263 structure. Thus, the maximum error propagation length is reduced to approximately 1/K of that of H.263. Secondly, since correlation between frames decreases with the distance between them, compared with the traditional structure, an implicit increased intra-coding frequency is expected with the new structure. Finally, an error occurring in a branch frame will terminate after at most K frames, which means that errors in (K-1)/K of the frames will terminate within K frames.

### 4. Simulation and Results

A tree structure motion compensation codec (branch length=10) has been implemented to test its error resilient performance. Two cases are studied.

- 1) *Error occurs in a branch frame.* In this case, the same frame is identically corrupted in a H.263 encoded sequence and a TMEC encoded sequence, in which the corrupted frame is a branch frame. Figure 4 and figure 5 show the visual and quantitative results of error propagation in this case, in which frame #2 is identically corrupted in both sequences. It is obvious that only several frames are affected by error propagation in TMEC coded sequence, while most of the frames are corrupted by error propagation in H.263 coded sequence. This is because no error in a branch frame propagates beyond the range of that branch in the TMEC, while errors propagate without such restriction in the traditional H.263 encoder.
- 2) *Error occurs in a stem frame/root frame.* In this case, the same frame is identically corrupted in a H.263 encoded sequence and a TMEC encoded sequence, in which the corrupted frame is a stem/root frame. Figures 6 and 7 show the visual and quantitative results of error propagation of such case, in which frame # 10 is identically corrupted in both sequences. Unlike the previous case, errors are obvious in both sequences because of error propagation. However, it is also noticed that we get better reconstruction in TMEC encoded sequence, as shown in Figure 7 (c) and Figure 6, because of the increased intra refresh rate.

### 5. Conclusions

In this paper, we use a two state Markov chain model to analyze error propagation in H.263. A tree structure motion compensation scheme is proposed based on this analysis to combat error propagation in network video. On commonly used test sequences, the proposed scheme is found to provide

improved error propagation property compare with the traditional H.263 structure.

As other error resilient video-coding schemes, the new scheme gains error robustness at the cost of coding gain. In this scheme, this trade-off is controlled by the branch length (K) and the loss of coding gain is within acceptable limits in all cases as shown in Table 1.

### Acknowledgment

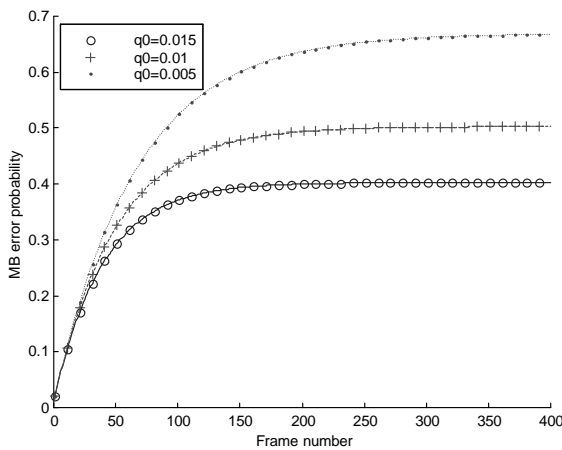
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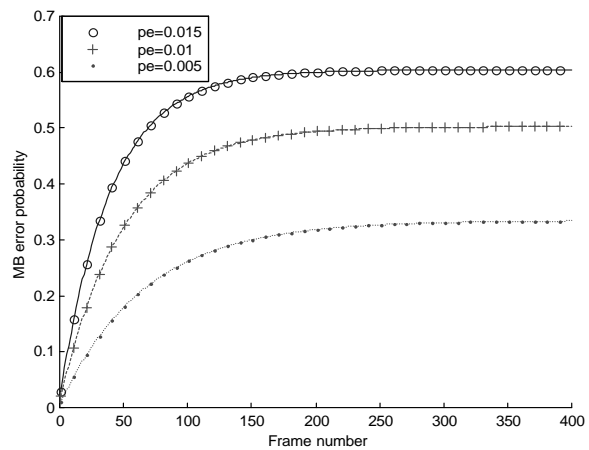
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(a):  $pe=0.01$



(b):  $q0=0.01$

Figure 2: Macro-block error probability

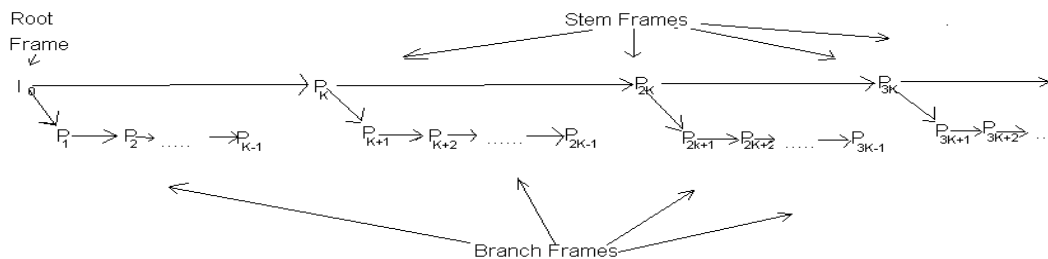


Figure 3: The tree structure motion estimation and compensation scheme



Figure 4: Comparison of error propagation due to error in Frame #2

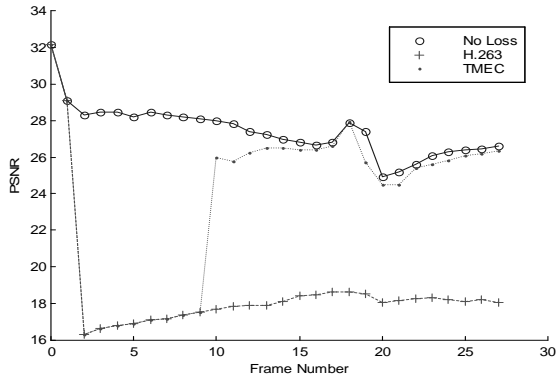


Figure 5: PSNR transition of case 1)

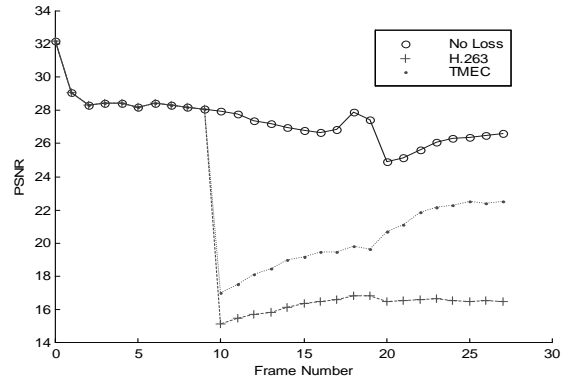


Figure 6: PSNR transition of case 2)



Figure 7: Comparison of error propagation due to error in frame #10

Sequence	Rate	Branch Length (K)							Largest PSNR Difference
		1 (H.263)	2	4	6	8	10	12	
Carphone	30KBPS	30.65	30.12	29.95	29.99	30.00	30.13	30.19	0.70
	50KBPS	32.77	32.30	32.09	32.13	32.15	32.19	32.22	0.68
Foreman	30KBPS	28.97	28.26	28.28	28.43	28.53	28.69	28.53	0.71
	50KBPS	30.97	30.34	30.32	30.42	30.43	30.51	30.65	0.65

Table 1: Comparison of compression performance of TEMC with H.263