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Real-Time Frame-Layer Rate Control for Low Bit Rate Video over WLAN

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Abstract—**This paper presents a new real-time frame-layer rate control for low bit rate video over WLAN. Compared with the conventional TMN8, the proposed algorithm improves the quality of the compressed video significantly in both objective and subjective tests.**

I. Introduction

In block-based video coders such as MPEG and H.263, the number of bits and distortion for each image block encoding are controlled by the quantization parameter of the block. The objective of the rate control is to select the quantization parameters so that the encoder produces bits at transmission bandwidth and the overall distortion is minimized. Therefore, the rate control not only regulates the output bit-stream to meet certain given conditions, but also enhances the quality of coded video. However, the rate control algorithms are not standardized since they are independent of the decoder structure. Most existing H.263+ rate control algorithms including TMN8 [1] focus on macroblock-layer rate control for the predictive frames.

In this paper, we present a real-time frame-layer rate control algorithm that performs better than TMN8 for H.263+ over IEEE 802.11b wireless LAN (WLAN).

II. Proposed frame-layer rate control method

First we estimate the target bandwidth for video transmission over WLAN. The WLAN card of the video server for our experiments can periodically measure the link status of the WLAN channel that is the received signal strength indication (RSSI) value. We estimate the target bandwidth for the period that is the time interval between two successive measurements of the RSSI. Then the target bit budget is optimally allocated to each frame using the frame-layer rate control method. Fig. 1 shows the basic concept, where the bundle of frames during the time interval is referred to as the temporal frame segment.

For the frame-layer rate control, we employ an empirical data-based frame-layer rate-distortion (R-D) model using the quadratic rate model and the affine distortion model [2] with respect to the average quantization parameter (QP) in a frame, which is given by

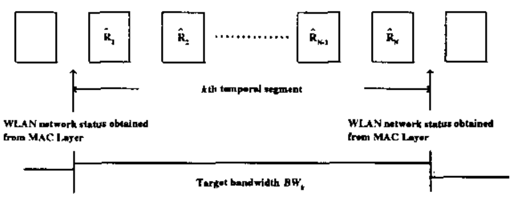

Fig. 1. The basic concept of the proposed algorithm.

$$\hat{R}(\bar{q}_i) = (a\bar{q}_i^{-1} + b\bar{q}_i^{-2}) \cdot MAD(\hat{f}_{ref}, f_{cur}), \quad (1)$$
$$\hat{D}(\bar{q}_i) = a'\bar{q}_i + b', \quad (2)$$

where a, b, a', and b' are the model coefficients, $\hat{f}_{ref}$ is the reconstructed reference frame at the previous time instant, f_{cur} is the uncompressed image at the current time instant, MAD$(\cdot,\cdot)$ is the mean of absolute difference between two frames, and q_i is the average QP of all macroblocks in the ith frame, respectively.

Consider a new formulation of frame-layer rate control based on the R-D model as follows: Determine $\bar{q}_i,\ i = 1, 2, ..., N_k^{SEG}$ to minimize

$$\sum_{i=1}^{N_k^{SEG}} \hat{D}_i(\bar{q}_i) \cdot (\hat{D}_i(\bar{q}_i) - D_{i-1}), \quad (3)$$

subject to

$$\sum_{i=1}^{N_k^{SEG}} R_i \leq BW_k^{SEG} \cdot T_k^{SEG}, \quad (4)$$

where $\hat{D}_i$ is the estimated distortion of the current frame, D_{i-1} is the actual distortion of the previous frame, N_k^{SEG} is the number of encoding frames in

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the kth temporal segment, BW_k^{SEG} and T_k^{SEG} are the bandwidth and the time interval of kth temporal segment, respectively. In (3), we introduce a formulation minimizing the average distortion over an entire segment as well as variations in distortion between frames, which can avoid "flicker problems" caused by abrupt changes in video quality.

The proposed frame-layer rate control algorithm consists of two steps. The first step is to find the optimal bit-rates with the current Lagrange multiplier, and the second step is to adjust the Lagrange multiplier based on residual bit-rates. These two steps are iterated with low complexity through fast convergence method. Therefore, the proposed rate control algorithm does not produce time delay from encoding. However, a negligible performance loss due to its intrinsic sub-optimality is inevitable in our design.

For the Lagrangian method, we can define a penalty function for the ith frame by combining

$$P_i(\bar{q}_i) = \hat{D}_i(\bar{q}_i) \cdot (\hat{D}_i(\bar{q}_i) - D_{i-1}) + \lambda_i \cdot max(\hat{B}_i^{res}, 0), \quad (5)$$

$$\hat{B}_i^{res} = \sum_{j=1}^{i-1} R_j + \hat{R}_i(\bar{q}_i) - \sum_{j=1}^{i} \frac{MAD_k^j}{Ave\_MAD_{k-1}} \frac{BW_k^{SEG} \cdot T_k^{SEG}}{N_k^{SEG}}, \quad (6)$$

where $P_i(\bar{q}_i)$ and λ_i is the cost function and the Lagrange multiplier for the ith frame, R_j is the used bitrate for the jth frame, MAD_k^j is the MAD between (j-1)th and jth frames of the kth temporal frame segment, Ave_MAD_{k-1} is the average of MADs of the $(k-1)$th temporal frame segment. Note that $\hat{B}_i^{res}$ denotes the estimated bit based on the R-D model.

Based on the rate and distortion models, we can determine the optimal QP to minimize the above penalty function. It was shown in [3] that $P_i(\bar{q}_i)$ is a convex function generally. Thus, we can get its optimal solution by using the gradient method as described in (7). However, note that what we finally need is not $\bar{q}_i^*$, but $\hat{R}_i(\bar{q}_i^*)$ which is the target bit budget for the ith frame.

$$\bar{q}_i^* = arg \min_{\bar{q}_i} P_i(\bar{q}_i). \quad (7)$$

After frame-layer rate control, we use the existing macroblock layer rate control algorithm of TMN8 to allocate effectively the bit budget to each macroblock with the solution $\hat{R}_i(\bar{q}_i^*)$.

III. Experimental Results and Conclusions

The performance of the proposed frame-layer rate control scheme is compared with that of TMN8. For the performance comparison for four test sequences, we show the average PSNR value and the standard deviation (σ) of PSNR in Table I. It is clearly seen that the proposed frame rate control algorithm can improve both the average PSNR value and the standard deviation when compared with TMN8. The PSNR plots associated with the "CARPHONE" sequence as a function of the frame number are shown in Fig. 2. It is seen that the proposed frame rate control can reduce the quality degradation better than TMN8. Experimental results are provided to demonstrate the superior performance of the proposed scheme.

TABLE I

PERFORMANCE COMPARISON OF THE PROPOSED ALGORITHM WITH TMN8.

Sequence	Method	Ave. PSNR	σ of PSNR
FOREMAN	TMN 8	29.728	1.125
	Proposed	30.161	0.935
CARPHONE	TMN 8	31.404	2.387
	Proposed	32.047	2.066
NEWS	TMN 8	33.168	0.841
	Proposed	33.363	0.619
SALESMAN	TMN 8	34.501	1.256
	Proposed	34.552	1.125

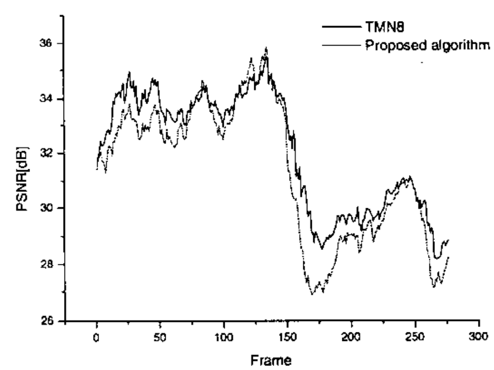

Fig. 2. PSNR comparison for "CARPHONE" sequence.

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