PROPAGATION MODEL FOR UNCERTAINTY OF REFERENCE PIXELS AND MODEL-BASED INTRA REFRESHMENT FOR H.264 BITSTREAMS

Dong Wook Kang, Ki-Doo Kim* and Seung Jun Lee***

*Kookmin University, **McubeWorks Inc.

ABSTRACT

We propose a novel propagation model for uncertainty of reference pixels and the model-based improved intra refreshment method for the H.264 which can incorporate with both RD-optimized mode decision and SAD-based fast mode decision. Simulations on RTP/IP transmission over WCDMA channels in the constant quality test conditions show that the BDPSNR of the proposed intra refreshment algorithm is 1.89 dB which is greater by 1.36 dB and 1.08 dB than the periodic GOB intra refreshment and the multiple-decoder emulation algorithm, respectively. Other simulations in case of constant bit rate (64 kbps) encoding show that the quality of decoded pictures is improved by 2.48 dB with the proposed model-based intra refreshment, which corresponds to an improvement of 0.91 dB compared with the periodic GOB refreshment.

1. INTRODUCTION

As it is impossible or impractical to correct all the transmission errors in mobile channels, a video codec should contain some tools to reduce or overcome the effect of the errors. Forced intra refreshment is one of those tools. Forced intra refreshment increases the error resiliency of the bitstream but decreases the coding efficiency [1].

Periodic intra refreshment is the simplest method to increase the error resiliency of the bitstream. There are two types of periodic intra refreshment; periodic I-picture insertion and periodic GOB intra refreshment. Because periodic I-picture insertion is used for other purposes such as random access and fast search, its period is not guaranteed to be always optimized to the best error resiliency. In order for a periodic GOB intra refreshment algorithm to yield a satisfactory performance, its period is chosen properly considering the probability of the transmission errors as well as the activity of the picture and the period of the inserted I-pictures.

Mode decision-incorporated intra refreshment is another approach. This method decides the encoding mode of a macroblock based on the rate and the expected distortion of the decoded pictures considering both the quantization noise and transmission errors. High complexity mode decision algorithm for the H.263 was the first algorithm in this category [2]. For the H.264 JM, the multiple-decoder emulation method has been adopted, where the encoder emulates multiple decoders which reconstruct pictures assuming random channel errors and use the reconstructed pictures as the reference frames for consequent inter-mode encoding [3]. This algorithm has the capability of self-adjustment of the rate of intra-refreshment according to the activity of the picture. However, since the performance of this algorithm is affected by the number of decoders very seriously, this linear growth of the required memory size becomes a critical factor for practical implementation. Recently the drift model-based mode decision methods [4],[5] have been introduced for the H.264, where the encoder replaces emulation of multiple decoders with the drift-nose propagation model.

Though mode decision-incorporated intra refreshment methods yield better performance compared with the periodic intra refreshment algorithms, they should be incorporated with time-consuming RD-optimization procedure.

In this paper, we propose a new uncertainty model for the encoder's reference pixels and a model for its frame-by-frame propagation. Based on this model, we also propose a new intra refreshment algorithm. The proposed algorithm can be incorporated with both RD-optimized mode decision and SAD-based fast mode decision.

2. PROPSED MODEL FOR UNCERTAINTY OF ENCODER'S REFERENCE PIXELS AND THE MODEL-BASED IMPROVED INTRA REFRESHMENT METHOD

2.1. A New Model for the Uncertainty of Encoder's Reference Pixels

When a bitstream is corrupted, the decoded pixels may be different from the reference pixels constructed by the encoder for motion compensated prediction, which results in more seriously distortion from the original pixels. We define the expected difference as the uncertainty contained in the encoder's reference pixel. If we minimize the uncertainty at the encoder side, we may expect that the decoder may decode the pixels which are the most close to the reference pixels and at the same time the most faithful to the original pixels.

Based on the stochastic theory, we propose a new propagation model for the uncertainty of reference pixel: for inter mode,

$$H_n = (1-p)H_{n-1}(mv)\exp(pn_r) + p\left(H_{n-1} + \log_2\left(\frac{(\tilde{x}_n - \tilde{x}_{n-1})^2}{Q}\right)\right)\exp(pn_r) \tag{1}$$

for intra mode, on the other hand,

$$H_n = p\left(H_{n-1} + \log_2\left(\frac{(\tilde{x}_n - \tilde{x}_{n-1})^2}{Q}\right)\right) \tag{2}$$

where H_n and H_{n-1} : the uncertainty of a reference pixel in the current and the previous frames, $\tilde{x}_n$ and $\tilde{x}_{n-1}$: the corresponding reference pixels, p : the probability of transmission error, Q : the quantization step size, $H_{n-1}(mv)$: the uncertainty of the motion-compensated pixel of the previous frame, and n_r : the number of frames having been encoded consecutively as inter-mode.

From the propagation model (1) and (2), we see first that the uncertainty increases in proportion to the activity of the corresponding pixel. The uncertainty of the stationary pixels would not increase even if the corresponding bitstream were lost because the error concealment algorithm would reconstruct the same pixels as the normal decoders. Therefore, increase in the uncertainty of a pixel results solely from the activity of the pixel. The term $\log_2\left((\tilde{x}_n - \tilde{x}_{n-1})^2 / Q\right)$ denotes the incremental uncertainty and represents the entropy due to the pixel activity or a transformation from the expected incremental drift noise.

We also see that the uncertainty increases in proportion to the probability of transmission error. If an error occurs during the transmission of any pixel information, some decoders will reconstruct the corresponding pixel by an error concealment algorithm, that may be different from the encoder's reference pixel. The percentage of the error concealing decoders is the same as the transmission error probability. So the uncertainty of the encoder's reference pixel will increase as much as the difference multiplied by the error probability.

We also find that pixels encoded in the inter mode will inherit the uncertainty of the motion-compensated pixels of the previous frame. Because the inheritance results from the motion compensation, the probability of the inheritance is the same as the probability of correctly transmitted corresponding bitstream and the term $(1-p)H_{n-1}(mv)$ represents the corresponding uncertainty component.

If a moving pixel is encoded consecutively in the inter mode, the number of surrounding pixels affected by the uncertainty of the pixel increases exponentially. Therefore, a spatial propagation model is required to describe this phenomenon accurately. However, because the uncertainty is just used to compute incremental cost of a macroblock unit in the long run, we can expect the same effect by weighting the uncertainty of the originated pixel exponentially. The term $\exp(pn_r)$ represents the observation.

2.2 Improved Intra Refreshment Method Based on the Proposed Uncertainty Model

Suppression of the uncertainty of encoder's reference pixels will reduce the quality fluctuation of the decoded pictures and improve the minimum as well as the consequent average quality of the decoded pictures. Therefore, elimination of the uncertainty in encoder's reference pixels results in improved error resiliency of the corresponding bitstream.

We propose two types of intra refreshment methods based on the above-mentioned uncertainty model for reference pixels; one for RD-optimized mode decision scheme and the other for SAD-based fast mode decision scheme.

For an RD-optimized mode decision scheme, mode is selected in view of minimization of the cost defined as

$$J_{RD-Opt} = Q_n^2 + \lambda_{RD-Opt} \cdot (R_n + H_n) \tag{3}$$

where Q_n^2 denotes the quantization noise power of a macroblock n, R_n represents the number of bits used to encode the corresponding macroblock, H_n is sum of the uncertainty of reference pixels in the corresponding macroblock, and λ_{RD-Opt} is the Lagrangian coefficient.

For an SAD-based fast mode decision scheme, mode is selected in view of minimization of the cost defined as

$$J_{Fast} = SAD_n + \lambda_{Fast} \cdot \left(\tilde{R}(mv) + H_n\right) \tag{4}$$

where SAD_n denotes sum of the motion compensated absolute residual signals (inter mode) or sum of intra-predicted absolute residual signals (intra mode), $\tilde{R}(mv)$ represents the number of bits expected to be used to encode the corresponding macroblock estimated by the motion vector, H_n is the uncertainty of reference pixels in the corresponding macroblock, and λ_{Fast} is the Lagrangian coefficient. $\lambda_{Fast} = \sqrt{\lambda_{RD-Opt}}$.

3. SIMULATION RESULTS

Simulation has been performed with the proposed models using test periods of the periodic I-picture insertion 1,2,4,8, and infinity seconds. The performance of the proposed intra refreshment algorithm was compared with that of the forced intra refreshment of 1, 1/2, and 1/4 GOB per frame. In case of RD-optimized mode decision scheme, the performance of the multiple decoder emulation method was also compared. For each intra refreshment algorithm, an RD-curve is composed of the rate of bitstream and the average quality of the decoded pictures obtained from twenty channel simulations per each bitstream following the common test conditions for RTP/IP over 3GPP/3GPP2 [6]. The quality of the decoded pictures was evaluated by the PSNR defined as

$$PSNR = 10 \cdot \log_{10}\left(\frac{\left(255^2\right)\left(20\right)NM}{\sum_{k=1}^{20}\sum_{n=1}^{N}\sum_{i=1}^{M}\left(\tilde{y}_{k,n,i} - x_{n,i}\right)^2} \right) \tag{5}$$

where x and $\tilde{y}$ mean the original and the decoded pictures, k, n, and i are the indices representing simulated channel, the decoded frame, and the pixel position.

The simulation conditions are summarized in Table 1 for constant quality encoding which extends the common test simulation conditions recommended by JVT [7]. For performance comparison, the BDPSNR (Bjonteggard Delta PSNR), which computes the average PSNR differences between two RD-curves [8], is used.

Figure 1 shows the BDPSNR of the intra refreshment algorithms with SAD-based fast mode decision scheme with periodic I-picture insertion as a reference. The proposed uncertainty model-based intra refreshment method incorporating the SAD-based fast mode decision yields the BDPSNR of 0.13 dB to 1.70 dB according to the period of I-picture insertion and, when it cooperates with RD-optimized mode decision it yields the BDPSNR of 0.48 dB to 1.89 dB. When it is compared with the periodic GOB intra refreshment algorithm, the proposed method gives improved performance by 0.68 dB to 1.40 dB. Compared with the multiple decoder emulation method, the proposed method gives improved performance by 1.04 dB to 1.38 dB according to the period of I-picture insertion.

The performances of intra refreshment algorithms are also compared for a constant bit rate (64 kbps) encoding. The simulation conditions for this case are the same as Table 1 except that the Qp is adjusted frame-by-frame to make the rate of the output bitstream to be 64 kbps.

Figure 2 shows the simulation results. The performance has been investigated by the amount of improvement in the PSNR of decoded pictures compared with that of none-GOB intra refreshment incorporated with SAD-based fast mode decision scheme. Figure 2(a) shows that the proposed model-based fast mode decision algorithm gives the PSNR improvement of 0.22 dB to 3.01 dB according to the period of I-picture insertion. It also shows that the best period of GOB intra refreshment depends strongly on the period of I-pictures inserted. As shorter the period of inserted I-pictures, the best period of GOB intra refreshment gets longer. We note that, however, the performance of the proposed algorithm is always superior to that of the periodic GOB refreshment in all cases. This is because the proposed uncertainty propagation model controls the rate of intra refreshment by adapting to the period of inserted I-pictures. Figure 2(b) shows the performance of intra refreshment algorithms incorporated with RD-optimized mode decision scheme. In case of IPPP type encoding (period of inserted I-pictures is infinity), the PSNR improvement by the proposed model-based intra refreshment algorithm is from 0.15 dB to 2.35 dB according to the period of I-picture insertion. The multiple decoder emulation algorithm yields comparable performance to the proposed method in case of long and infinity period of inserted I-pictures. It shows much worse performance with a short period of inserted I-pictures. For example, when every 6 frame is encoded as I-picture, the performance of the proposed algorithm is improved by 1.95 dB from that of the multiple-decoder emulation scheme.

Table 1 Simulation conditions for the constant quality encoding.

Sequence	Silent Hall monitor Akiyo	Container Foreman News	Car phone Weather Students
Frame rate	15	10	7.5
Total frames	150	100	75
Qp	28, 32, 36, 40		
Coding options used	Hardmard transform, no B-slice, no FMO, CAVLC, RTP format, no partition, MV search range of 16, no redundant slice, 1 slice/frame, the number of reference frame =1		
Codec	JM6.1e		

4. CONCLUSION

A new propagation model for the uncertainty in the reference pixels is proposed and implemented for improved intra-refreshment to generate error-resilient H.264 bitstreams. The proposed algorithm could operate with and without RD optimization procedure. The quality of decoded pictures of the proposed intra-refreshment method turned out to be superior to the conventional schemes. The BDPSNR test has shown that the performance of the proposed algorithm is improved by 1.40 dB and 1.38 dB from the GOB refreshment algorithm and the multiple-decoder emulation scheme, respectively. At 64 kbps encoding without interim I-pictures, the average PSNR of the decoded pictures of the proposed method was observed to be improved by 0.91 dB from that of the conventional GOB refreshment. Hence, the proposed algorithm is expected to be applicable for the error-prone mobile video services.

5. REFERENCES

[1] Y. Wang, S. Wenger, W. Jiantao, and A. K. Katsaggelos, "Error resilient video coding techniques," IEEE Signal Processing Magazine, pp.61-82, July 2000.

[2] Stephan Wenger, Guy Côté, Michael Gallant, and Faouzi Kossentini, “H.263 Test Model Number 11 (TMN-11) rev 3,” Oct., 1999.

[3] Gisle Bjontegaard, “H.26L Test Model Long Term Number 8 (TML-8) draft 0,” June. 2001.

[4] Chul-Woo Kim, Dong-Wook Kang, and In Seong Hwang, “High complexity mode decision for error prone channel,” ITU-T SG16/Q6 Contribution: JVT-C101, May 2002.

[5] M. Zhonguha, Y. Songyu, and Z. Zhaoping, “Error resilient intra refresh scheme H.26L stream,” Electronics Letters, vol. 38, no.19, pp. 1153-1154, Sep. 2002.

[6] Viktor Varsa, Marta Karczewicz, Göran Roth, Rickard Sjöberg, Thomas Stockhammer, and Günther Liebl, "Common Test Conditions for RTP/IP over 3GPP/3GPP2," ITU-T SG16/Q6 Contribution: VCEG-M77, April, 2001.

[7] G. Sullivan and G. Bjonteggard, “Recommended simulation common conditions for H.26L coding efficiency experiments on low-resolution progressive-scan source material,” ITU-T SG16/Q6 Contribution: VCEG-N81, Sept. 2001.

[8] G. Bjonteggard, “Calculation of average PSNR differences between RD-curves,” ITU-T SG16/Q6 Contribution: VCEG-M33, Mar. 2001.

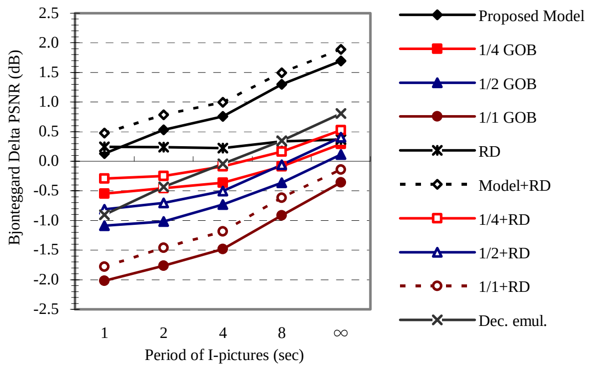
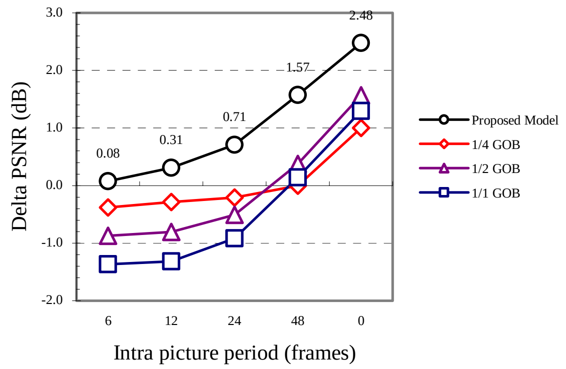
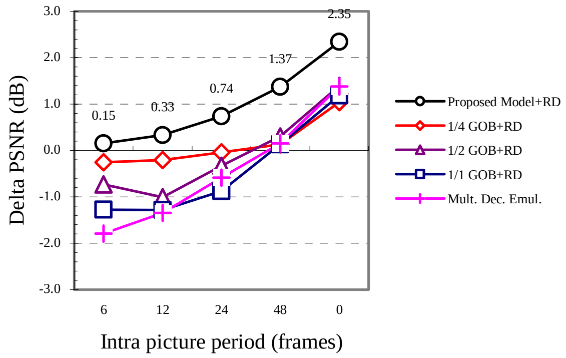


Figure 1 The BDPSNR of intra refreshment algorithms in case of constant quality (Qp=28, 32, 36, and 40) encoding. The reference algorithm is none-GOB/frame intra refreshment incorporated with SAD-based fast mode decision scheme.



(a)



(b)

Figure 2 The PSNR improvement of decoded pictures according to the intra refreshment algorithms in case of constant bit rate (64kbps) encoding. The reference algorithm is none-GOB/frame intra refreshment incorporated with SAD-based fast mode decision scheme: (a) Intra refreshment algorithms incorporated with SAD-based fast mode decision scheme, (b) intra refreshment algorithms incorporated with RD-optimized mode decision scheme.