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Joint FMO and Adaptive Intra Refresh for Error Resilience in H.264 Video Coding

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Abstract — **In this paper, we propose an explicit Flexible Macroblock Ordering (FMO) map using distortion from error propagation. The effects caused by the damaged MBs of the current frame to the next frame and the other MBs in the same slice group are estimated. These effects can be used in the evaluation of the MBs' importance in the current frame, and a suitable map with a reduced effect of error propagation can be generated. In addition, to counteract with error propagation, intra refresh is a known method used to reduce the dependency between frames therefore could stop error propagation. Taking into account the channel state information, this paper also proposes an intra refresh algorithm that chooses the number of intra MBs for each frame. MBs having much effectiveness to the current frame and the next frame will be chosen for intra coding mode. By coupling this method with proposed FMO, it would help reduce the loss of important and intra coded MB. Results show that the proposed method has some improvements in terms of PSNR and the number of undecodable macroblocks as compared to some other methods.**

I. INTRODUCTION

One of the new characteristics of the H.264/AVC standard [1] is the possibility of dividing an image in regions called slice groups. Each slice group can be divided in several slices and a slice can also be decoded independently. FMO [2] consists of deciding on which slice each macroblock of the image belongs. Each macroblock can be assigned freely to a slice group using an MBAmap (MacroBlock Allocation map). The MBAmap consists of an identification number for each macroblock of the image that specifies on which slice group that macroblock belongs. The number of slice groups is limited to 8 for each picture to prevent complex allocation schemes. By generating a suitable MBAmap, the errors MBs in a frame are dispersed. Consequently, the error concealment algorithm in decoder can recover the lost information from neighboring MB that is correctly received.

However, when the number of loss important MBs is reduced by using FMO, error propagation remains an impediment when transmitting video signal over error-prone channel. Although intra MBs can effectively stop error propagation, the number of intra MBs in a frame is limited by compression efficiency. Coding efficiency will be reduced if the intra refresh rate is high because of rate-distortion optimization. Moreover, a limited target bit rate is allocated for each frame because of limitations in bandwidth and frame rate. A frame with high number of intra MBs will consume high target bit rate affecting the target bit rate of next frames. Thus, it is imperative to choose a suitable intra-refresh rate to balance the benefit of reducing error propagation effect and the drawback of using a high number of intra coded MBs.

In recent times, there are some researches works focusing on resolving intra refresh. In [1], a fix number of MBs with the highest distortion in the current frame will be coded in Intra mode. However, due to the difference in number of coding bits or bitcount in frames, a fix number intra coded MBs is not always the best solution for frames with higher bitcount. With these frames, if we use a high number of intra MBs, the bit count will be higher and it may result in increase of buffer delay, which is not desired in real-time video transmission. Another studies by [4], [5] choose the suitable MB for intra coding, cost for each type mode is computed. However, the algorithm has to try all possible intra and inter modes because rate distortion optimization (RDO) is used. This is relatively time-consuming and may cause delay in real-time applications.

In this work, a new method for explicit FMO map is proposed by using *impact factor* of MBs which is computed by taking into account both distortion-from-error concealment and distortion-from-error propagation instead of using single indicator such as bitcount [6] or distortion from error concealment [7]. After estimating *impact factor*, MBs are sorted in descending order of distortion and are consequently arranged to 8 slice groups. Also, based on the estimated *impact factor*, some MBs are coded as intra MBs. The number of intra coded MB depends on the estimated channel state for transmitting previous frame because quality of current frame depends heavily on that of previous frame. If the packet error rate of the previous frame is high, the distortion in the current frame caused by error propagation is high and vice-versa. Therefore, if the channel state is bad, to stop error propagation from the previous frame, the number of intra coded MBs in the current frame are increased. Otherwise, the number of intra coded MBs is reduced.

The succeeding parts of this paper are organized as follows. Section II gives the detailed description of our proposed method. Simulation results and discussions are presented in Section III. Lastly, Conclusion is given in Section IV.

II. PROPOSED METHOD

In this work, two-pass architecture is used for encoding. In the first pass, all MBs in P frame are encoded in inter mode. After that, *impact factor* estimation of each MB in a frame is computed. Based on *impact factor*, slice group map is created. In the second pass, based on feedback information from decoded frames, channel state for transmitting the previous frame is predicted.

A. FMO Explicit Map Generation

1. Loss Probability of a Macroblock

Assuming single bit error occurs independently in the bit stream and error probability of single bit is *p*, we will estimate the probability that l^{th} MB in slice group is error. The probability the l^{th} MB will be error in the event that at least a single bit error occurred in first *l* MBs of slice group. Assume that the first *l* MBs in slice groups have *n* bits shown in Fig. 1.

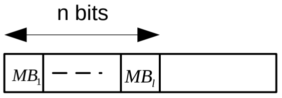

Fig. 1. Bit number of the first *l* MBs in a slice

The error probability of l^{th} MB is computed as in eq. (1),

$$P(MB_l)=\sum_{i=1}^{n}\binom{n}{i}p^i q^{(n-i)}=1-q^n \qquad (1)$$

, where p is error probability of single bit, $q=1-p$ is no error probability of single bit. *i* is the number of bits error. In Rayleigh fading wireless channel simulator [9], the error probability of a single bit is approximated 0.06.

2. Distortion and Error Propagation Analysis

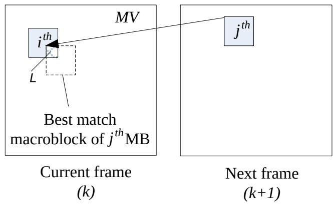

Fig. 2. Effect of a loss MB to a MB in the next frame

In the current frame, it is assumed that i^{th} MB has error. To stop this error that may be propagated to the next frame, non motion-compensated error concealment is used by replacing the i^{th} MB with the co-located MB in the previous frame. The *distortion-from-error-concealment* is computed as shown in eq. (2),

$$D_{EC_i}=\sum_{(x,y\in M)}\left|f_k(x,y)-f_{k-1}(x,y)\right| \qquad (2)$$

, where frame k^{th} and $(k-1)^{th}$ are the current frame and previous frame, respectively, $f(x,y)$ is the reconstructed pixel value at the coordinate (x,y) and M is the damaged i^{th} MB.

To estimate the effect of error propagation, the *distortion-from-error-propagation*, D_{EP_i} , is defined. D_{EP_i} is the distortion caused by i^{th} MB in the current frame to j^{th} MB in the next frame through motion compensation. Assuming that the best match macroblock of j^{th} MB in the next frame covers a part of i^{th} MB in the current frame and this reference area is denoted by *L* as shown in Fig.2.

Let $R_k(i,j)$ denotes the distortion of j^{th} MB caused by *L* in case i^{th} MB has no error. $R_k(i,j)$ is computed as shown in eq.(3),

$$R_k(i,j)=\sum_{(x,y)\in L}\left|f_k(x,y)-f_{k+1}(x-MV_x,y-MV_y)\right| \qquad (3)$$

, where (x,y) is the pixel coordinate in the current frame and (MV_x,MV_y) is the motion vector of j^{th} MB.

Let $R'_k(i,j)$ denotes the distortion of j^{th} MB caused by *L* in case i^{th} MB has error. $R'_k(i,j)$ is computed in eq. (4).

$$R'_k(i,j)=\sum_{(x,y)\in L}\left|f_{k-1}(x,y)-f_{k+1}(x-MV_x,y-MV_y)\right| \qquad (4)$$

The *distortion-from-error-propagation* caused by i^{th} MB in k^{th} frame to $(k+1)^{th}$ frame is computed as shown in eq. (5),

$$D_{EP_i}=\sum_{j\in\{S\}}\left|R_k(i,j)-R'_k(i,j)\right| \qquad (5)$$

, where *S* is a set of MBs in the next frame which reference i^{th} MB in the current frame.

Finally, to estimate the importance of an MB in the current frame, we have to consider the *total distortion* caused by this MB in case of error. The *total distortion* of i^{th} MB is computed as shown in eq. (6).

$$D_{Total_i}=D_{EC_i}+D_{EP_i} \qquad (6)$$

Based on the *total distortion*, MBs are sorted in descending order and mapped to 8 slices consecutively to have an *initial slice group map*.

Seeing that losing i^{th} MB will affect the rest of MBs in the slice group, we now compute the *impact factor (IF)* of i^{th} MB, D_{IF_i} , from the *initial slice group map*:

$$D_{IF_i}=\left(\sum_{\tau=m}^{N}D_{Total_\tau}\right).P\left(MB_m\right) \qquad (7)$$

Where τ denotes the index of MBs in slice group from i^{th} MB to the last MB in the slice group. m is position of i^{th} MB in slice group. D_{Total_τ} is the *total distortion* of MB computed from eq. (6) and $P(MB_m)$ is error probability of i^{th} MB in the slice group computed in eq. (1). Based on eq. (7), the *IF* of each MB is computed and MBs are then sorted in descending order and a *new slice group map* is generated.

Lastly, the sum of D_{IF} of all MBs in the current frame using the *initial slice group map* and *new slice group map* is computed. The slice map that will yield a lower sum of *IF* will be used for that particular frame.

Also based on *IF*, some highest MBs of frame are selected for intra coding. With the above arrangement, intra MBs are not concentrated in a slice group. Thus, the number of error intra MBs is reduced if a slice group is error.

B. Intra Refreshment with Considering Channel State

In this paper we use a two-state Markov model that is a simplified Gilbert-Elliot channel model at the packet level. This model has been shown to be sufficient in modeling the burst nature of packet errors. The model has two states, a good state (G) and a bad state (B). Based on feedback information, probability of each frame in good state $P_g(m)$ is predicted. Channel state is estimated by comparing $P_g(m)$ of m^{th} frame to mean of three previous frames.

```
If ( $P_g(m) < mean(P_g(m-1), P_g(m-2), P_g(m-3))$
        Channel state is bad;
        Number of intra coded MB = $\alpha$ ;
Else
        Channel state is good;
        Number of intra coded MB = 0;
```

Slice group	*Impact Factor* Values of MBs
0	2830 **695** 397 235 5 0 0 0 0 0 0 0 0
1	2334 582 332 193 5 0 0 0 0 0 0 0 0
2	2064 575 332 173 5 0 0 0 0 0 0 0 0
3	**1512** 522 318 138 4 0 0 0 0 0 0 0 0
4	**1470** 504 318 125 0 0 0 0 0 0 0 0 0
5	**1274** 485 294 108 0 0 0 0 0 0 0 0 0
6	888 432 290 80 0 0 0 0 0 0 0 0 0
7	**770** 414 240 69 0 0 0 0 0 0 0 0 0

Fig. 3. MB-to-Slice group assignment of 6th Akiyo

Empirically, α is selected as five and these MBs satisfied two conditions: having high D_{IF} and not intra coded in the previous frame. As shown in Fig.3, MBs with highest *IF* is selected. However, some MBs with high value of D_{IF} are coded in intra mode in 5th frame, thus 6th frame chooses next MBs.

III. SIMULATION RESULTS AND DISCUSSION

A. Experimental Setup

To analyze the effectiveness of using the proposed explicit FMO map for video transmission compared to previous works, the reference software JM 9.2 was used. For practical considerations, baseline profile and only macroblock coding mode 16x16 are used at the encoder. At the decoder, the non-motion compensated error concealment is used. The decoder simulates the effect of error propagation due to variable length coding in a slice by considering MBs from the error MB to the last MB in slice as undecodable MBs. The following video sequences are used in the experiment: Akiyo, Foreman, Carphone and Claire. Each sequence was encoded for a total of 100 frames at a frame rate of 10 frames per second. Rate control was enabled and bit rate was set at 32kbps. The default encoder parameters were used with the exception FMO related parameters (see [9] for detailed information about the H.264 JM encoder parameters). To investigate the benefits of using FMO on wireless channel, the Rayleigh fading wireless channel simulator was used in this simulation. The details of the simulator can be found in [10]. To simulate the effects of slow and fast fading channels, the maximum Doppler frequency parameter was set to 1Hz for slow-fading and 40Hz for fast-fading. The average bit error rate (BER) and average packet error rate (PER), for 80-bit packet [6], are 0.06 and 0.09, respectively both for fast and slow fading channel conditions.

B. Results and Analysis

Table 1. Comparison of Number of Undecodable MB

Undecodable MB	Akiyo		Foreman		Claire		Carphone	
	Slow	Fast	Slow	Fast	Slow	Fast	Slow	Fast
NoFMO+NoIntra	1599	5714	1411	5913	1430	5261	1558	5270
FMO+NoIntra	434	1314	**504**	1228	513	**1131**	545	1155
FMO + RIR	486	1158	556	1208	**440**	1163	550	**1108**
Proposal method	**388**	**1167**	565	**1189**	479	1173	**542**	1118

Table 2. Comparison of Average PSNR (dB)

PSNR (dB)	Akiyo		Foreman		Claire		Carphone	
	Slow	Fast	Slow	Fast	Slow	Fast	Slow	Fast
NoFMO+NoIntra	30.22	26.59	17.67	15.54	28.37	24.65	22.41	19.75
FMO+NoIntra	**34.93**	31.28	19.98	17.95	32.18	29.63	24.64	23.07
FMO + RIR	31,26	30.60	20.56	**18.93**	29.28	27.72	23.83	22.34
Proposal method	34.58	**31.57**	**20.74**	18.49	**33.43**	**30.8**	**26.32**	**23.15**

A number of experiments have been carried out to verify the performance of the proposed algorithm. The results are compared to method using FMO without intra refreshment and method using both FMO and intra refreshment but the number of intra coded MB in each frame is fixed and MBs are chosen randomly for intra refresh (RIR) [8]. In comparison, PSNR and the total number of undecodable MBs are used as the performance metrics in quantifying the effectiveness of methods.

Table 1 shows the number of undecodable macroblocks for slow and fast fading channels. The results show that the new method is more effective than the previous method almost all kinds of test video sequences as well as in both fading environments. The proposed method could reduce the number of undecodable macroblock up to 78%.

Table 2 shows the average PSNR of video in the scenario of slow and fast fading channels. The simulation results show that for both cases of fading, PSNR is increased in the following order: NoFMO+NoIntra, FMO + RIR, FMO+NoIntra, and Proposed method. Although the same slice group map is used, the proposed method has selected suitable MBs for intra coding mode. In additional, the proposed method can adjust the number of intra coded MB by monitoring the channel state. Therefore, the compression effective is guaranteed. On the other hand, FMO+RIR method uses five intra coded MBs randomly in every frame. As a result, the compression effect in some frames is reduced and the average PSNR is lower than the method using FMO only. However, in some cases, the average PSNR of proposed method is low because the quality of video measurements in terms of PSNR depends solely on the location of bit errors and the error concealment method applied. In this study, simple non-motion compensated error concealment is used, hence we expected that the higher PSNR improvement could be achieved if more sophisticated methods of error concealment technique is applied in further studies. Nevertheless, there is no direct relation between the number of undecodable macroblock and PSNR as several other factors have to be taken into account.

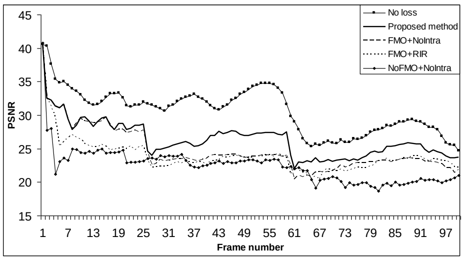

Fig. 4. PSNR comparison of Carphone in Slow fading

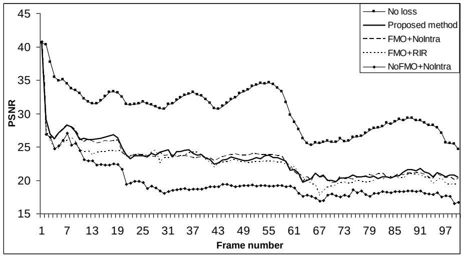

Fig. 5. PSNR comparison of Carphone in Fast fading

Fig. 4 and 5 show the average PSNR curve of Carphone test sequence in the slow and fast fading case, respectively. From the figures, the PSNR improvement of the proposed method can be clearly observed. This improvement is achieved by using an accurate method in estimating the importance of MB to generate slice group map and in adjusting the number of intra coded MB for each frame. Additionally, by using FMO, the important MBs are dispersed in the whole frame, thus reducing the loss of important MBs. Consequently, the PSNR of proposed method is increased. However, in fast fading case, the proposed method is not much effective. The reason is the imprecise in channel state prediction when using two-state Markov model for fast fading case. This causes the number of intra coded MBs in some frames are not correct and thus compression efficiency is reduced.

IV. CONCLUSIONS

The proposed method considering the inter-frame error propagation to quantify the importance of a MB for generating slide group map has been effective in mitigating errors in wireless transmission of H.264 video streams. In additionally, to stop error propagation between frames, intra refresh is used. By using two-state Markov model, channel state is predicted to adjust the number of intra coded MBs for each frame. The results are shown better in terms of average PSNR and number of undecodable MBs compared to some previous methods not using intra refresh and using intra refresh but MBs is selected randomly.

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