Enhanced Temporal Error Concealment for 1Seg Video Broadcasting

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Abstract. Transmission of compressed video over error prone channels may result in packet losses or errors, which can significantly degrade the image quality. Such degradation even becomes worse in 1Seg video broadcasting, which is widely used in Japan and Brazil for mobile phone TV service recently, where errors are drastically increased and lost areas are contiguous. Therefore the errors in earlier concealed MBs (macro blocks) may propagate to the MBs later to be concealed inside the same frame (spatial domain). The error concealment (EC) is used to recover the lost data by the redundancy in videos. Aiming at spatial error propagation (SEP) reduction, this paper proposes a SEP reduction based EC (SEP-EC). In SEP-EC, besides the mismatch distortion in current MB, the potential propagated mismatch distortion in the following to be concealed MBs is also minimized. Compared with previous work, the experiments show SEP-EC achieves much better performance of video recovery in 1Seg broadcasting.

Keywords: Error Concealment, Spatial Error Propagation, 1Seg.

1 Introduction

Transmission of compressed video over error prone channels such as wireless network may result in packet losses or errors in a received video stream. Such errors or losses do not only corrupt the current frame, but also propagate to the subsequent frames [1]. Several error control technologies, such as forward error correction (FEC), automatic retransmission request (ARQ) and error concealment (EC), have been proposed to solve this problem. Compared with FEC and ARQ, EC wins the favor since it doesn't need extra bandwidth and can avoid transmission delays [2].

The EC scheme attempts to recover the lost MBs by utilizing correlation from spatially or temporally adjacent macro blocks (MBs), i.e., spatial error concealment (SEC) or temporal error concealment (TEC) [2]. For TEC, which is focused on by this paper, several related works have been published to estimate the missing motion vector (MV) by using the correctly received MVs around the corrupted MB. In [3], the well-known boundary matching algorithm (BMA) is proposed to recover the MV from the candidate MVs by minimizing a match criterion, the side match distortion (D_{sm}), between the internal and external boundary of the reconstructed MB (see detail in section 3). This algorithm is adopted in H.264 reference software JM [4] and described in detail in [5, 6]. The main improvement of BMA is OBMA (Outer BMA)

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[7] also known as decoder motion vector estimation (DMVE) in [8], where the D_{sm} is calculated by the difference of 2 outer boundaries of reconstructed MB instead of internal and external boundary in BMA. Although BMA and OBMA have similar design principle that to minimize mismatch distortion, it is empirically observed that OBMA has better performance in video recovery [7, 8]. 2 variations of OBMA can be found in [7], that multiple boundary layers match, and more candidate MVs search (called refined search). According to evaluations of [7], 1 layer match gives better performance than multiple layers, while refined search gives better performance than original OBMA.

To our knowledge, most of the published works are based on minimization of mismatch for the current lost MB. However, there is no published work considering such observation, that the mismatch error in current lost MB could also propagate to the succeeding MBs in the succeeding EC process. Therefore such kind of propagated mismatch error should also be included in D_{sm} formulation. On the other hand, the lost MBs in 1Seg video broadcasting (see detail in section 2), which is the latest mobile phone TV service widely used in Japan and Brazil, are usually contiguous inside the corrupted frame (spatial domain), therefore in such case the spatial error propagation (SEP) is becoming critical.

Aiming at SEP reduction, this paper proposes a SEP reduction based EC (SEP-EC), where the mismatch not only in current concealed MB but also in the following to be concealed MBs are both minimized.

The rest of this paper is organized as follows. Section 2 presents our work's motivation, which is for 1Seg application. Section 3 gives an overview of well-known BMA and OBMA. Based on OBMA, we present proposed SEP-EC in section 4. Finally section 5 and 6 show our experiments and conclusion.

2 1Seg Application Based Motivation

Our work is targeted to 1seg application [9]. 1Seg is a recently widely used mobile TV service, which is one of services of ISDB-T (Integrated Services of Digital Broadcasting- terrestrial) in Japan and Brazil. Due to errors drastically increased in wireless mobile terminal, EC is critical for 1Seg.

In 1Seg, H.264 format is specified for video compression. Table I shows the specification [9] for video compression and transmission in 1Seg related to this work.

According to Table I, even 1 broken TS packet may cause huge connected area loss (from the start of broken packet to the end of the frame) inside a frame. This is because 1) slice mode and FMO mode [10] are prohibited; 2) for QVGA sized video, each picture/slice usually consists of at least more than 1 TS packet (normally more than 3); and 3) variable length coding (VLC) based entropy coding is included in H.264. Fig. 1 shows a comparison of a typical loss picture (Stefan sequence) in FMO enabled scenario and 1Seg scenario, where green parts are the destroyed area.

Traditional JM [4] can only handle the slice (equivalent to picture in 1Seg) loss problem, whereas can not handle TS packet loss, whose size is much less than slice. In our experiments in section 5, we modified JM to support 1Seg.

Table 1. Specification for Video Part in 1Seg Related to EC

Picture size	320x240(QVGA)
Compression method	H.264, baseline profile, level 1.2
Error resilient tools restriction	No slice mode No FMO (flexible MB ordering) mode
Transmission unit	TS (Transmission Stream) packet (188 Byte)

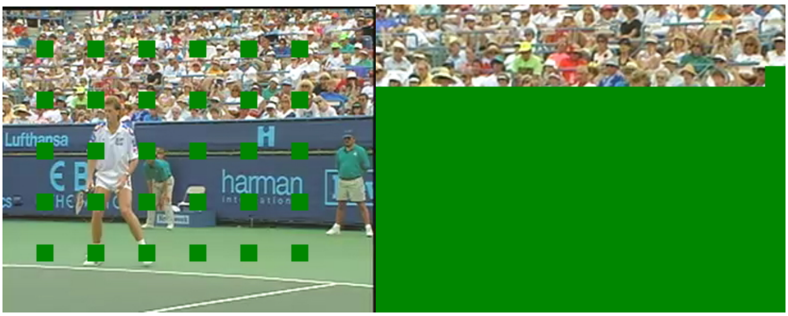

Fig. 1. A typical broken frame in FMO enable case (left) and 1Seg case (right)

As shown in Fig. 1, the lost MBs are independent in left picture, which means the errors in current concealed MB could not propagate to other corrupted MBs. However, 1Seg case should suffer such situation that the errors in current concealed MB may propagate to other corrupted MBs inside the same picture, this is so called spatial error propagation (SEP). In section 4, we will propose our solution toward this problem.

3 Boundary Matching Algorithm (BMA) and Outer BMA (OBMA) for TEC

For each lost MB, BMA [4, 5, 6] is utilized to recover the lost mv (motion vector) from candidate mvs (mv^{can}s) by the criterion of minimizing the side match distortion (D_{sm}) between the IN-MB and OUT-MB, see Fig. 2. The IN-MB is projected by mv^{can}, which is the candidate mv belongs to one of 4 available neighbors[1] in current frame, either correctly received (OK MB) or concealed MB. To save the space, Fig. 2 only shows left (concealed MB) and top (OK MB) neighbors.

The D_{sm} is determined by the sum of absolute differences between the predicted MB and the neighboring MBs at the boundary, shown in Eq. (1)[2].

[1] For simplification, all 4 neighbors are not divided into sub-blocks, meaning each neighbor only has 1 mv.

[2] There is a notation rule needs explanation. In Fig. 2, $Y_i^{IN}(mv^{can})$ is the i-th pixel in the IN-MB, which is projected by mv^{can} in the reference frame. Such rule can be similarly applied in Eq.(3), and (6) in the rest parts.

$$D_{sm} = \frac{1}{B}\left\langle \sum_{i=1}^{N} \left| Y_i^{IN}(mv^{can}) - Y_i^{OUT} \right| \right\rangle \qquad (1)$$
$$where, mv^{can} \in \{mv^{top}, mv^{bot}, mv^{lft}, mv^{rt}\}$$

N is the total number of the available boundary pixels, B is the number of available boundaries. In Fig. 2, N=32, B=2. The winning prediction mv mv^{win} is the one which minimizes the side match distortion D_{sm}:

$$mv^{win} = \underset{mv^{can} \in \{mv^{top}, mv^{bot}, mv^{lft}, mv^{rt}\}}{\text{Arg Min}} D_{sm} \qquad (2)$$

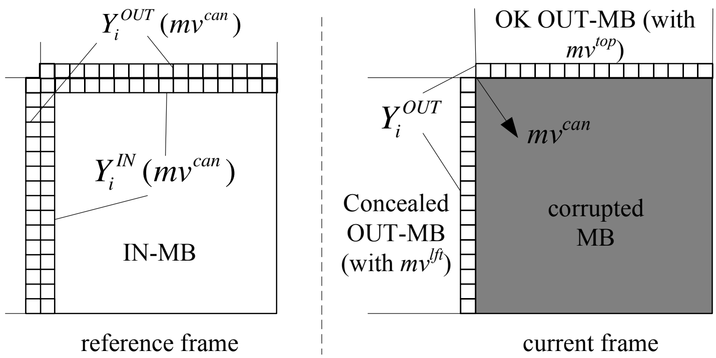

Fig. 2. BMA and OBMA based TEC in H.264

The main improvement of BMA is OBMA, where the main difference is the D_{sm} calculation. The D_{sm} calculation is shown in Eq. (3):

$$D_{sm} = \frac{1}{B}\left\langle \sum_{i=1}^{N} \left| Y_i^{OUT}(mv^{can}) - Y_i^{OUT} \right| \right\rangle \qquad (3)$$
$$where, mv^{can} \in \{mv^{top}, mv^{bot}, mv^{lft}, mv^{rt}\}$$

where the D_{sm} is calculated by the difference of 2 outer boundaries ($Y_i^{OUT}(mv^{can})$ and Y_i^{OUT}) of reconstructed MB (see Fig. 2), instead of internal and external boundary in BMA.

According to the evaluation of [7], OBMA provides better image recovery compared with BMA. Also, the reason of it is explained in [7]. Since OBMA has better performance, in this paper, we implement the proposed algorithm with OBMA.

4 Proposed SEP-EC

4.1 Spatial Error Propagation (SEP) Reduction Based Dsm Calculation

It is inevitable that the current concealed MB may cause mismatch distortion compared with the original current MB. As discussed in section 2, in 1Seg, this kind of distortion may propagate to spatial domain, ie., the succeeding MBs inside the corrupted picture, since the current concealed MB might be used to conceal the neighboring corrupted MBs. Therefore, considering the potential propagated distortion, the total side match distortion can be expressed as follows:

$$D_{sm\_total} = (D_{sm\_cur} + D_{sm\_pgt}) / 2 \tag{4}$$

where, D_{sm_cur} and D_{sm_pgt} are side match distortion for current MB itself, and the potential propagated side match distortion for neighboring corrupted MBs, respectively. Division by 2 is because the distortion should be normalized by boundary.

As for current side match distortion D_{sm_cur} calculation, traditional OBMA can be used without any change. D_{sm_cur} is the minimal D_{sm} for current MB which calculated by mv^{win} . Similar to Eq. (2) and (3), D_{sm_cur} can be easily formulated as follows:

$$D_{sm\_cur} = \underset{mv^{can} \in \{mv^{top}, mv^{bot}, mv^{lft}, mv^{rt}\}}{\text{Min}} D_{sm} \tag{5}$$

where, D_{sm} is calculated with OBMA, see Eq. (3).

The key point is how to formulate $D_{sm\_\_pgt}$. An accurate expression of potential propagated distortion is hard to figure out, yet it has some way to estimate by looking at how current errors propagate to its neighbors. Fig. 3 shows the scenario that the mismatch distortion in current MB propagates to its corrupted neighborhoods.

Let's think about concealment of MB_j which is the j-th corrupted MB next to current concealed MB. Like the EC process of current MB, EC of MB_j should also select a wining mv ($mv_j^{win\_nbr}$) from candidate mv set (mv^{lft} and mv^{top}, in Fig. 3) by the minimal D_{sm}. Note that, mv^{lft} is actually mv^{win_cur}, which is the wining mv of current concealed MB.

Suppose mv^{win_cur} is chosen as winning mv ($mv_j^{win\_nbr}$) for the neighbor MB_j, then the distortion of current MB should propagate to MB_j. Therefore the propagated distortion can be formulated by calculating D_{sm} in MB_j, shown as Eq. (6):

$$D_{sm\_pgt} = \begin{cases} \text{if } mv_j^{win\_nbr} == mv^{win\_cur}, \\ \qquad \dfrac{1}{M}\sum_{j=1}^{M}\left(\dfrac{1}{B}\sum_{i=1}^{N}\left|Y_{i,j}^{OUT\_nbr}(mv_j^{win\_nbr}) - Y_{i,j}^{OUT\_nbr}\right|\right); \\ else, \\ \qquad 0 \end{cases}$$

$$\text{where, } mv_j^{win\_nbr} = \underset{mv^{can\_nbr} \in \{mv^{top}, mv^{bot}, mv^{lft}, mv^{rt}\}}{\text{Arg Min}} D_{sm\_nbr}^{j} \tag{6}$$

$Y_{i,j}^{OUT\_nbr}(mv_j^{win\_nbr})$ and $Y_{i,j}^{OUT\_nbr}$ are shown in Fig. 3. i is the index of pixel in outer boundary of MB_j, j is the index of neighboring corrupted MB. N is the number of calculated pixels in outer boundary of MB_j, *B* is the number of available boundaries. For MB_j in Fig. 3, *N*=32, *B*=2. *M* is the number of all neighboring MBs which are not concealed yet. Taking Fig. 3 as an example, *M* is 2, the number of blue MBs.

Given Eq. (5) and (6), the D_{sm_total} in Eq. (4) can be finally calculated.

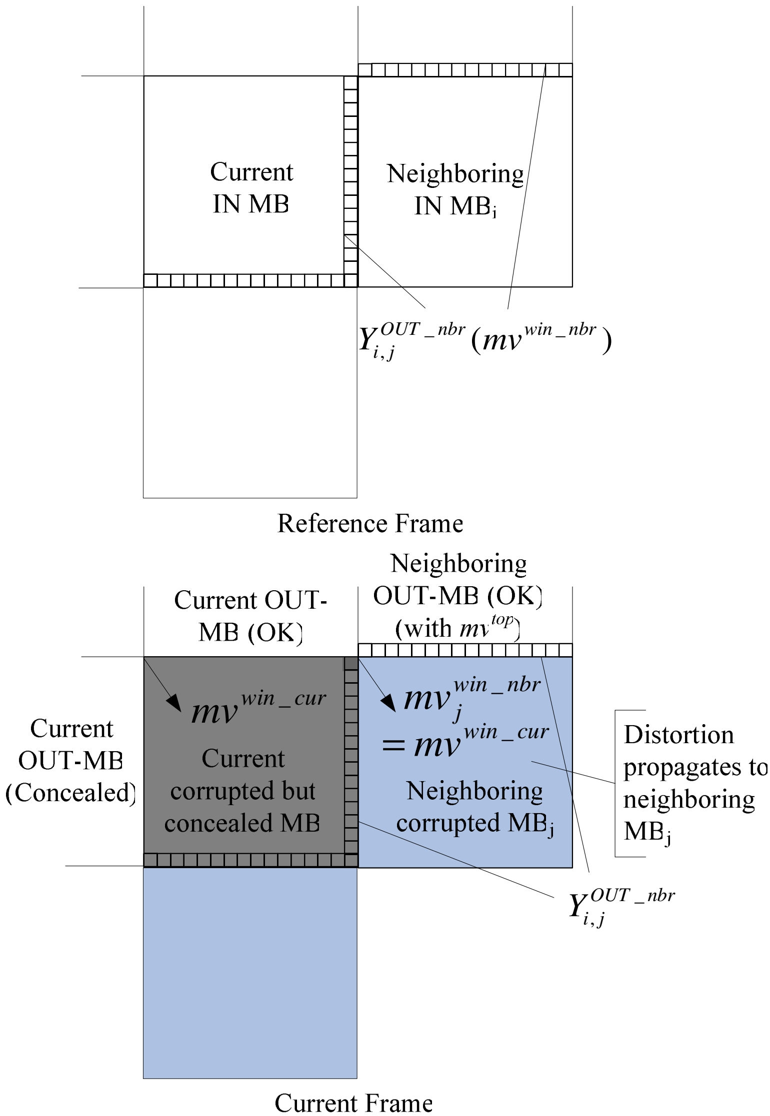

Fig. 3. Illustration of D_{sm_pgt} calculation

As mentioned in section 1, [7] reported that there are 2 variations of OBMA, that multiple boundary layers match, and more candidate MVs search (called selective search (SS)). According to evaluations of [7], 1 layer match gives better performance than multiple layers, while selective search gives better performance than original OBMA. Therefore in this paper, we combined SS with our proposal. In this combination, the mv candidate set is enlarged by SS, while the criterion is our proposed D_{sm_total} in Eq. (4). For more details of SS, please refer to [7].

4.2 Discussion of How Far the Errors May Potentially Propagate

As discussed before, it is difficult to give an accurate expression of potential propagated distortion. Actually the D_{sm_pgt} in Eq. (6) is not an accurate one, since the error may also propagate to a little farer neighbors which are not adjacent to current MB as well as the adjacent neighbors. Fig. 4 shows a scenario that the mismatch distortion propagates to $\mathrm{MB}_j^{'}$, which is next to neighboring MB_j. It is easy to find much more such kind of farer neighbors. Therefore, how far the errors in current corrupted MB may potentially propagate deserves discussion. Let L be an integer to show the distance of it. L=1 means errors propagate to the adjacent neighbors, L=2 means errors propagate to the second closest neighbors, etc..

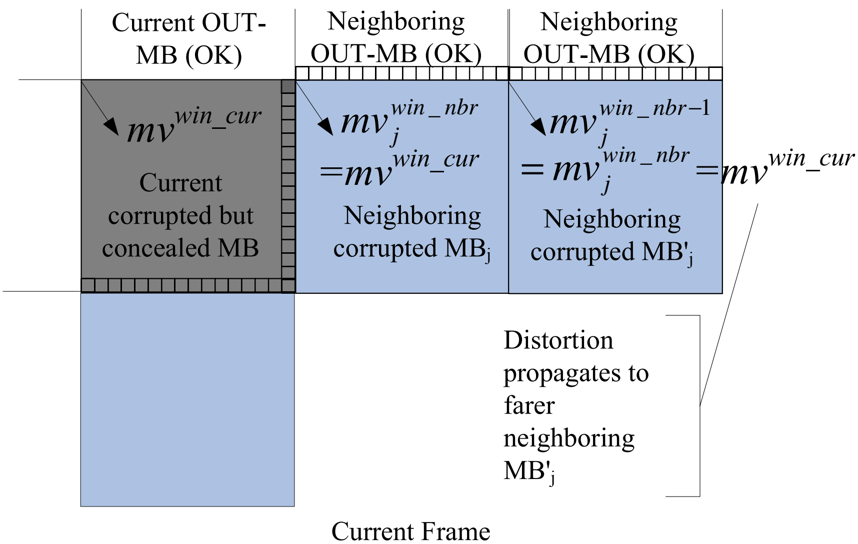

Fig. 4. Illustration of error propagates farer when L=2

We did experiments of SEP-EC to show how L will affect the recovered image quality. In these experiments, we set different Ls in advance, to observe the recovered image quality with PSNR. Fig. 5 shows the result of it. It can be seen L=1 is enough for D_{sm_pgt} formulation, since large L may bring huge computation cost, while almost could not improve image quality any more. Not that all sequences are tested by SEP-EC, without SS.

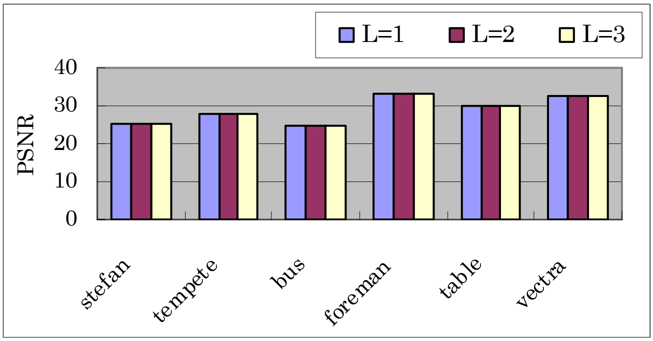

Fig. 5. Discussion of *L* by SEP-EC

5 Experiments

The proposed algorithm is evaluated based on the H.264 codec under the specification of 1Seg application. The JM9.1 reference software is used in the experiment, which is modified to support the packet loss in 1Seg application, while traditional JM can only support slice loss. Note that here a frame normally is divided into several TS packets. 50 frames for stefan, tempete, bus, foreman, table, and vectra sequences in QVGA format are encoded. Slice mode and FMO mode are disabled. "IPP…" GOP pattern is used, and frame rate is set on 30fps. No transmission errors occur in I frames. For each P frame, a number of packets are randomly destroyed to simulate the transmission under the bit error rate of 2%.

As for the objective comparison , the average PSNR of all decoded frames using 5 different methods are presented in Table 2, ie., BMA, OBMA, OBMA with SS (OBMA-SS), proposed SEP-EC, and proposed SEP-EC with SS (SEP-EC-SS). Experiments show our algorithm can provide higher PSNR performance compared with BMA and OBMA.

Table 2. Average PSNR Comparison

	stefan	tempete	bus	foreman	table	vectra
BMA	24.56	27.16	24.22	32.74	29.58	31.51
OBMA	25.15	27.65	24.63	32.95	29.88	32.02
OBMA-SS	25.46	27.78	24.88	33.21	30.16	32.4
SEP-EC	25.61	27.86	24.75	33.13	30.21	32.53
SEP-EC-SS	25.79	28.23	25.15	33.32	30.36	32.8

An example of vision comparison is shown in Fig. 6. Sequence for Stefan is presented. There are some noticeable mismatches in the areas of player, and the advertisement panel, denoted with red circle. However, proposed SEP-EC and SEP-EC-SS can avoid this mismatch efficiently.

(a) damaged frame (b) recovered by BMA

(c) recovered by OBMA (d) recovered by OBMA-SS

(e) recovered by SEP-EC (f) recovered by SEP-EC-SS

Fig. 6. Vision comprarison

6 Conclusion and Discussion

This paper proposed an enhanced EC, where an spatial error propagation reduction is taken as consideration of temporal error concealment in 1Seg broadcasting. In this method, besides the mismatched distortion in current MB, the mismatched distortion in the following MBs, which will be concealed in the succeeding process is also minimized. Compared with BMA and OBMA, the experiments under 1Seg application show our proposal achieves much better performance of video recovery.

It is easy to know that the mismatch errors may not only propagate to following MBs inside the current lost frame, but also to the succeeding frames, this is so called temporal error propagation (TEP). In the future, the D_{sm} calculation should also involve such TEP reduction consideration.

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