PAPER

Efficient Flexible Macroblock Ordering Technique

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SUMMARY The H.264/AVC standard provides several new error-resilient features to enable the reliable transmission of compressed video signals over lossy packet networks. Flexible Macroblock Ordering (FMO) is one of the most interesting resilient features within the H.264/AVC standard. Unlike former standards, in which slices were constructed out of consecutive raster scan macroblocks, FMO suggests new slices composed of spatially distributed Macroblocks (MBs), and organized in a mixed-up fashion. H.264/AVC specifies seven types of FMO. The standard defines also an explicit FMO type (Type 6), which allows explicitly assignment of each MB within the frame to any available slice groups. Therefore new FMO types can be used and integrated into H264/AVC without violating the standard. In this paper we propose a new Explicit Chessboard-Wipe (ECW) Flexible Macroblocks Ordering (FMO) technique, which outperforms all other FMO types. The new ECW ordering results in effective error scattering which maximizes the number of correctly received macroblocks located around corrupted macroblocks, leading to better error concealment. Performance evaluations demonstrate that the proposed Explicit FMO approach outperforms all the FMO types. Both subjective and objective visual quality comparative study has been also carried out in order to validate the proposed approach.

key words: wireless video, H.264/AVC, flexible macroblock ordering, error resilient algorithm

1. Introduction

The recent growth of video services and wireless networks has generated a great interest in transmitting digital video over an error-prone communications channel. Video quality suffers significant degradation when transmitted over error-prone wireless channels, due to transmission packet loss, errors caused by fading in wireless channel, and codec prediction mechanisms used by current video compression standards for compression purposes. The transmission of compressed video streams over error-prone networks requires an encoder equipped with error resilient tools [1]–[3]. The H.264/AVC standard introduces enhanced error robustness capabilities enabling resilient and reliable transmission of compressed video signals over wireless lossy packet networks. Those robustness capabilities are achieved by integrating some new error resilience tools that are essential for a proper delivery of real-time video services. Those tools

include the Intra Refreshing, Arbitrary Slice Ordering, Sequence Picture Parameter Sets, Redundant Slices tools and Flexible Macroblock Ordering (FMO) [4], [5].

FMO is a very powerful tool for error resilience. For instance, slice groups can be constructed in such a way that, if one slice group is not available at the decoder, each lost macroblock may be surrounded by macroblocks of other slice groups (above, below, right, and left). In that case, the missing macroblock can be reconstructed in a very effective way using interpolation based on surrounding (available) sample values. Using FMO, macroblocks are no longer assigned to slices in raster scan order. Instead, each macroblock can be assigned freely to a specific slice group (i.e., a set of slices) using a Macroblock Allocation map (MBAmap). There can be up to eight slice groups in one picture and within a slice group; macroblocks are coded in default scan order. The macroblocks within a certain slice group can, furthermore, be grouped into several slices. The case where there is only one slice group within a frame is identical to the case that no FMO is used at all. H.264/AVC specifies seven types of FMO. FMO type 6 is the most general type where the entire MBAmap is actually coded into a Picture Parameter Set (PPS) [6], [7].

In the case of FMO type 0, each slice group has a maximum number of macroblocks that it can contain in raster scan order before another slice group is started (Chessboard like pattern). FMO type 1 is also known as scattered slices or dispersed slices. Macroblocks are assigned to a slice group based on the total number of slice groups. The MBAmap does not have to be coded because this formula is known to both the encoder and decoder. FMO type 2 uses one or more rectangular slice groups and a background. The rectangular slice groups are allowed to overlap each other but macroblocks in overlapping areas can be part of only one slice group. The order in which the slice groups are declared in a PPS determines which slice group a macroblock resides in. The macroblock number of the top left macroblock and the bottom right macroblock of each slice group is coded into a PPS by means of the syntax elements. FMO types 3, 4, and 5 are commonly known as evolving slice groups. In these situations, the configuration of slice groups can change every picture by making use of certain periodic patterns. The latter three types of FMO only have two slice groups of which one enlarges with a number of macroblocks as opposed to the other. In the case of FMO Spiral type 3, one slice group starts at the center macroblock and it will grow by a number of macroblocks in a

rotational manner. The direction can be clockwise or counterclockwise depending on the value of the syntax element slice_group_change_direction _flag (coded in a PPS). FMO type 4 indicates that one slice group evolves in a raster scan manner. In other words, a certain amount of macroblocks will be added to this slice group in raster scan order or in reverse raster scan order (again depending on the syntax element slice_group_change_direction_flag). This means that one slice group will evolve from top to bottom or vice versa. FMO type 5 is the horizontal counterpart of FMO type 4. One slice group will evolve from left to right or vice versa. The same syntax elements are used as in type 4 to code the direction and the size of the successive enlargements [7]–[9].

FMO techniques are based on data interleaving to decrease the influence of consecutive packet loss caused by burst errors. Using FMO, each MB in the frame can be assigned to a certain slice group in a smart ordering way, which enables easier reconstruction of missing blocks in the decoder side. This mechanism does macroblock rearrangement so that burst errors are distributed throughout the frame. Unique rearrangement of MBs which distributes the error throughout the frame, improves error resilience in the coded video. Therefore, in contrast to grouping MBs into slices in a raster scan order, by using FMO the MBs are grouped into slices derived from spatially different locations within the frame. Scattering the error spatially within the video frame increases the probability that the neighborhood of a corrupted MB is properly received, and therefore allows more effective error concealment by the decoder [10], [11].

In recent years several techniques for streaming H.264/AVC video with new error resilience tools that are essential for a proper delivery of real-time video services over wireless lossy packet networks have been devised [12]–[17]. In [12] the authors evaluated the H.264 codec specifically concerning the error resilience features available. Their analysis was centered on the types of error in wireless ad-hoc networks, which were modeled as random and burst packet losses. They suggest tuning the encoder according to the expected packet loss rates inside the network to increase the overall PSNR of the sequence. The authors also demonstrate that the chessboard like pattern FMO type achieves good PSNR recovery for different error bursts sizes. Another approach [13] tackles the problem of burst error in wireless video transmission using FMO. They propose an interleaving method where texture coefficients are sampled and grouped into several interleaved groups so that burst error cannot damage all groups from one block. In [14] the authors present a three dimensional (3D) flexible macroblock ordering FMO technique. The proposed 3D macroblocks allocation method results with PSNR gain of about 1–2 dB for broadcast video application for 10% packet loss. Other method proposed an Explicit Spiral-Interleaved Flexible Macroblocks Ordering (FMO) technique, which improves video transmission qualities, under lossy transmission channels [15]. Alternatively another scheme proposes the use of isolated regions coding for unequal error protec-

tion [16]. The isolated regions technique allows partitioning pictures spatially and temporally to regions of interest. The quality of an isolated region can be improved in an enhancement layer, whereas the layer may not provide any quality improvement to the leftover region. The method presents error isolation capabilities achieved by FMO, preventing error from spreading from less important areas, such as background, to more important areas such as region of interest within the frame, or areas that are more difficult for concealment by the decoder.

In this paper, we propose a new Explicit Chessboard-Wipe (ECW) Flexible Macroblocks Ordering (FMO) technique, which outperforms all other FMO types. The new ECW ordering results in effective error scattering which maximize the number of correctly received macroblocks located around corrupted macroblocks, leading to better error concealment. The proposed scheme greatly improves video transmission quality over lossy wireless transmission channels. The remainder of this paper is organized as follows. In Sect. 2 we analyze H.264/AVC Flexible Macroblocks Ordering (FMO) techniques regarding the ability for error concealment. Section 3 presents the proposed error-resilience techniques, including the new Chessboard-Wipe FMO type. Section 4 describes the experimental results and the simulation framework. Specifically analyses the subjective and objective visual quality of the proposed ECW FMO technique. Finally conclusions are discussed in Sect. 5.

2. Problem Description

Flexible Macroblock Ordering (FMO), available in the Baseline and Extended, but not in the Main profile, allows to assign Macroblocks (MBs) to slices in an order other than the scan order. To do so, each MB is statically assigned to a slice group using a macroblock allocation map (MBAmap). Within a slice group, MBs are coded using the normal scan order. In frame prediction mechanisms, such as Intra prediction or motion vector prediction, however, are only allowed if the spatially neighboring MBs belong to the same slice group. To illustrate this relationship, please consider Fig. 1. All MBs of the picture are allocated either slice group 0 or slice group 1, depicted in grey and white, respectively, in a checkerboard-like pattern. Assume that the picture is small enough to fit into two slices, one encompassing all macroblocks of slice group 0 and the other encompassing all

Fig. 1   A picture with a size of 24 MBs and two slice groups.

1	2	3	4	5	6	7	8	9	10	11
12	13	14	15	16	17	18	19	20	21	22
23	24	25	26	27	28	29	30	31	32	33
34	35	36	37	38	39	40	41	42	43	44
45	46	47	48	49	50	51	52	53	54	55
56	57	58	59	60	61	62	63	64	65	66
67	68	69	70	71	72	73	74	75	76	77
78	79	80	81	82	83	84	85	86	87	88
89	90	91	92	93	94	95	96	97	98	99

1(a)

1	2	3	4	5	6	7	8	9	10	11
12	13	14	15	16	17	18	19	20	21	22
23	24	25	26	27	28	29	30	31	32	33
34	35	36	37	38	39	40	41	42	43	44
45	46	47	48	49	50	51	52	53	54	55
56	57	58	59	60	61	62	63	64	65	66
67	68	69	70	71	72	73	74	75	76	77
78	**79**	**80**	**81**	**82**	**83**	**84**	**85**	**86**	**87**	**88**
89	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**

1(b)

1	45	3	46	5	47	7	48	9	49	11
56	2	58	4	60	6	62	8	64	10	66
12	57	14	59	16	61	18	63	20	65	22
67	13	69	15	71	17	73	19	75	21	77
23	68	25	70	27	72	29	74	31	76	33
78	24	80	26	82	28	84	30	86	32	88
34	79	36	81	38	83	40	85	42	87	44
89	35	91	37	93	39	95	41	97	43	99
50	90	51	92	52	94	53	96	54	98	55

2(a)

1	45	3	46	5	47	7	48	9	49	11
56	2	58	4	60	6	62	8	64	10	66
12	57	14	59	16	61	18	63	20	65	22
67	13	69	15	71	17	73	19	75	21	77
23	68	25	70	27	72	29	74	31	76	33
78	24	**80**	26	**82**	28	**84**	30	**86**	32	**88**
34	79	36	**81**	38	**83**	40	**85**	42	**87**	44
89	35	**91**	37	**93**	39	**95**	41	**97**	43	**99**
50	90	51	**92**	52	**94**	53	**96**	54	**98**	55

2(b)

1	2	3	4	5	6	7	8	9	10	11
36	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	45	12
35	64	65	66	67	68	69	70	71	46	13
34	63	84	85	86	87	88	89	72	47	14
33	62	83	96	97	98	99	90	73	48	15
32	61	82	95	94	93	92	91	74	49	16
31	60	81	80	79	78	77	76	75	50	17
30	59	58	57	56	55	54	53	52	51	18
29	**28**	**27**	**26**	**25**	**24**	**23**	22	21	20	19

3(a)

1	2	3	4	5	6	7	8	9	10	11
36	37	38	39	40	41	42	43	44	45	12
35	64	65	66	67	68	69	70	71	46	13
34	63	**84**	**85**	**86**	**87**	**88**	**89**	72	47	14
33	62	**83**	**96**	**97**	**98**	**99**	**90**	73	48	15
32	61	**82**	**95**	**94**	**93**	**92**	**91**	74	49	16
31	60	**81**	**80**	79	78	77	76	75	50	17
30	59	58	57	56	55	54	53	52	51	18
29	28	27	26	25	24	23	22	21	20	19

3(b)

Fig. 2 Loss of slices C and D (1,2,3)a and slices H and I (1,2,3)b, without FMO 1(a,b), while using FMO for Type 0: Chessboard like pattern 2(a,b) and Type 3: Spiral 3(a,b).

MBs of slice group 1. From Fig. 1 the shaded MBs belong to slice group 0 and the white MBs to slice group 1. Clearly, when losing one of the two slices (slice group 0: 0, 2, 4, 7, 9, 11, 12, 14, 16, 19, 21, 23 and spice group 1: 1, 3, 5, 6, 8, 10, 13, 15, 17, 18, 20, 22), each lost (inner) MB has four neighboring MBs which can be used to conceal the lost information.

Assume that different nine slice groups of a QCIF frame are constructed for raster scan ordering (without FMO), and for two FMO types, type 0: chessboard like pattern and type 3: spiral. Each of the nine slice groups consist of eleven MBs as follows

Slice Group A: Macroblocks (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11),
Slice Group B: Macroblocks (12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22),
Slice Group C: Macroblocks (23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33),
Slice Group D: Macroblocks (34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44),
Slice Group E: Macroblocks (45, 46, 47, 48, 49, 50, 52, 53, 53, 54, 55),
Slice Group F: Macroblocks (56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66),
Slice Group G: Macroblocks (67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77),
Slice Group H: Macroblocks (78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88),
Slice Group I: Macroblocks (89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99).

The number within each MB indicates the slice number, to which it belongs. We consider, for the example, two scenarios, in which for each one a burst of two slices gets lost during transmission: in the first case slices C and D are lost, while in the second case slices H and I are lost.

Figure 2 depicts how the different nine slice groups of a QCIF frame are constructed for raster scan ordering (without FMO), and for two FMO types: chessboard like pattern and spiral. The number within each MB indicates the slice to which it belongs where macroblocks marked in black color indicates loss macroblock. We consider 3×3 spatial neighborhood around lost MB. Assume that loss MBs that are surrounding by five and more correctly adjacent received MBs have very good potential to be reconstructed using their adjacent neighbors. Figure 3 depicts the total number of correctly adjacent received MBs surrounding the lost MBs for loss slices C-D and slices H-I respectively. No FMO ordering has the worst performance both in term of scattering and in the ability to reconstruct lost MBs using adjacent cor-

rectly received MBs. For the first case (slices C and D are lost), Chessboard-like pattern shows 9 loss MBs which are surrounded with 6 adjacent received good MBs while 7 MBs are found for the spiral FMO. In the second case (slices H and I are lost) for the Chessboard-like pattern 4 of the 22 lost MBs have 6 adjacent good MBs, while for the spiral ordering there are 4 loss MBs of the 22 lost MBs with 5 adjacent correctly received MBs. This study is supported by experimental results described in Sect. 4.

Since every lost MB has several spatial neighbors that belong to the other slice, an error-concealment mechanism has a lot of information it can employ for efficient concealment. Experiments have shown that, in video conferencing applications with CIF-sized pictures, and at loss rates up to 10%, the visual impact of the losses can be kept so low that it takes a trained eye to identify the lossy environment — an efficiency level that was not achievable before with source-coding based tools. The price of the use of FMO is a somewhat lower coding efficiency (because of the broken in-picture prediction mechanisms between no neighboring MBs) and, in highly optimized environments, a somewhat higher delay [5]–[7]. It should be emphasized that the most important property when concealing a Macroblock (MB) is how many correctly received adjacent Macroblocks (MBs) there are and not the distance between them.
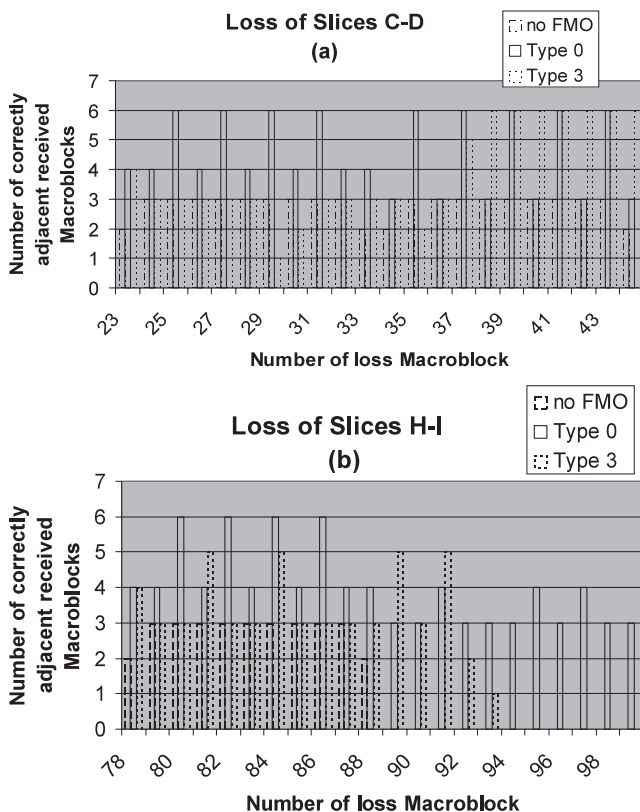
3. Proposed FMO Technique

H264/AVC Flexible Macroblock Ordering is one of the most interesting resilient features within the H.264/AVC standard. The standard defines also an explicit FMO type (Type 6), which allows explicitly assignment of each MB within the frame to any available slice groups. Therefore new FMO types can be used and integrated into H264/AVC without violating the standard. We propose a new FMO type basically combined from the two standard FMO types: Type 0 and Type 5. FMO Type 0, the chessboard-like pattern is defined by mapping each frame into two slice groups, allocating all the even MBs to the first group, and all odd MBs to the second slice-group. FMO Type 5, wipe is defined by mapping each frame into two slice groups. The first group contains MBs in vertical scan order from the top-left and all other MBs are in the second slice group. Figure 4 demonstrates the proposed Explicit ChessboardWipe (ECW) FMO as a combination of the above two standards types. The proposed ECW technique exploits the FMO Type 0 and defines a unique Chessboard-Wipe MB ordering type adapting Type 5 wipe pattern. The proposed ECW method is fully compatible with the H.264/AVC codec utilizing the Explicit FMO Type 6, which permits any efficient way of allocating MBs into slice groups. Unlike former standards, in which slices were constructed out of consecutive raster scan macroblocks, FMO suggests new slices composed of spatially
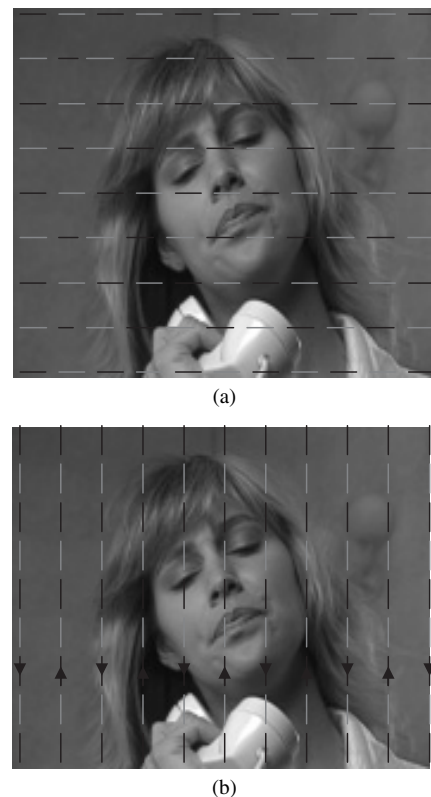

Fig. 3 Total number of correctly adjacent received MBs surrounding the lost MBs for loss slices C-D (a) and slices H-I (b) respectively.

Fig. 4 Proposed Explicit Type 6 FMO as a combination of Chessboard like pattern Type 0(a) and the Wipe Type 5 (b).

1	56	12	67	**23**	78	**34**	89	50	90	**35**
79	**24**	68	13	57	2	45	3	58	14	69
25	80	**36**	91	51	92	**37**	81	**26**	70	15
59	4	46	5	60	16	71	**27**	82	**38**	93
52	94	**39**	83	**28**	72	17	61	6	47	7
62	18	73	**29**	84	**40**	95	53	96	**41**	85
30	74	19	63	8	48	9	64	20	75	**31**
86	**42**	97	54	98	**43**	87	**32**	76	21	65
10	49	11	66	22	77	**33**	88	**44**	99	55

(a)

1	56	12	67	23	78	34	**89**	50	**90**	35
79	24	68	13	57	2	45	3	58	14	69
25	**80**	36	**91**	51	**92**	37	**81**	26	70	15
59	4	46	5	60	16	71	27	**82**	38	**93**
52	**94**	39	**83**	28	72	17	61	6	47	7
62	18	73	29	**84**	40	**95**	53	**96**	41	**85**
30	74	19	63	8	48	9	64	20	75	31
86	42	**97**	54	**98**	43	**87**	32	76	21	65
10	49	11	66	22	77	33	**88**	44	**99**	55

(b)

Fig. 5 Loss of slices C and D (a) and slices H and I (b) for the proposed ECW FMO technique.

Fig. 6 Total number of correctly adjacent received MBs surrounding the lost MBs for loss slices C-D (a) and slices H-I (b) for the proposed ECW FMO technique.

distributed MBs, and organized in a mixed-up fashion. The encoder may divide every coded frame into different macroblocks partitions by mapping of MBs into slice groups using specific allocation map which is named MBAmap.

Assume that different nine slice groups of a QCIF frame are constructed. Each of the nine slice groups consist of eleven MBs. Figure 5 demonstrates the potential benefit of using FMO technique. The figure depicts how the different nine slice groups of a QCIF frame are constructed. The number within each MB indicates the slice number, to which it belongs. We consider 3×3 spatial neighborhood around lost MB. We consider, for the example, two scenarios, in which for each one a burst of two slices gets lost during transmission: in the first case slices C and D are lost, while in the second case slices H and I are lost. Assume that lost MBs that are surrounding by five and more correctly adjacent received MBs have very good potential to be reconstructed using their adjacent neighbors. Figure 6 depicts the total number of correctly adjacent received MBs surrounding the lost MBs for loss slices C-D and slices H-I respectively.

The benefit of the non scan ordering is unmistakable, especially for the proposed ECW FMO method. One can notice the significant scattering of the lost MBs within the frame, which increase the number of correctly received adjacent MBs around a missing MB. For the first case (loss of slices C and D), ECW method shows 16 lost MBs which are surrounded with 5 (and more than 5) adjacent good MBs, while only 9 such MBs are found for the chessboard ordering. We obtain even better results for the second case (slices 8 and 9 are lost), where for the ECW most (20) of the 22 lost MBs have 5 (and more than 5) adjacent good MBs, while for the chessboard ordering there are only 4 MBs with 6 adja-
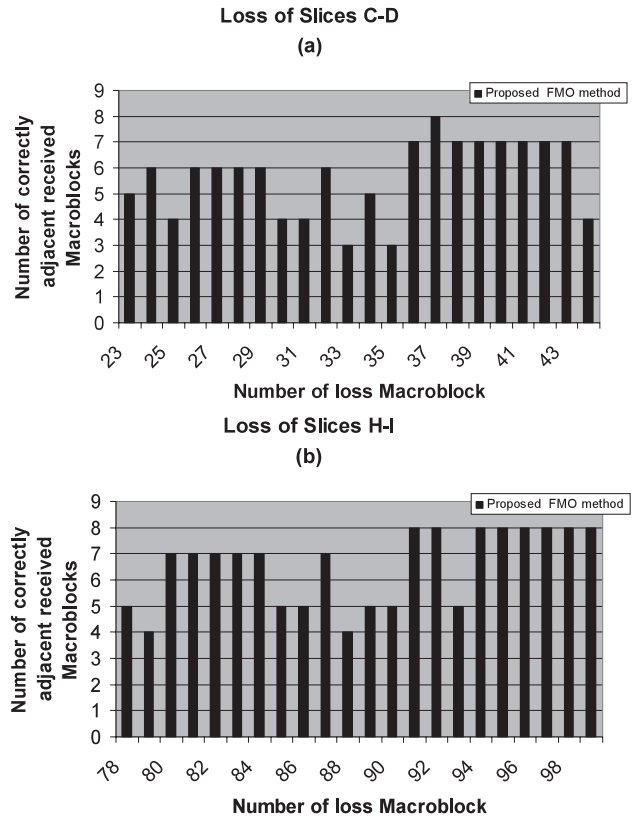
cent correctly received MBs. This observation is supported by experimental results described in Sect. 4.

4. Experiments

The proposed ECW Flexible Macroblock Ordering (FMO) is evaluated and compared to all other FMO types in term of video quality and the ability to improve error concealment. We simulate the scenario of the H.264-based video transmission for different erroneous environments. Simulations were done using the H.264 Test Model (http://iphome.hhi.de/suehring/tml/) [17]. We have used error concealment methods adopted by the H.264 standard, i.e., weighted averaging for Intra frames, and boundary-matching-based motion vector recovery for Inter frames. All test sequences are in QCIF format (176×144 pixels/frame) and encoded at target frame rate 15 frames/s, the number of frames to be encoded/decoded is 150 frames. The first frame in a GOP (Group of Pictures) is intra frame and the remaining consecutive frames are Inter encoded. Frames were partitioned into slices and the slices are organized in packets for transmission where each slice is packed in one packet. The simulations were carried out on the following QCIF video traces: Suzie, News, Mother-daughter and Coastguard.

In order to evaluate the proposed ECW FMO scattering and error concealment abilities extensive simulations were
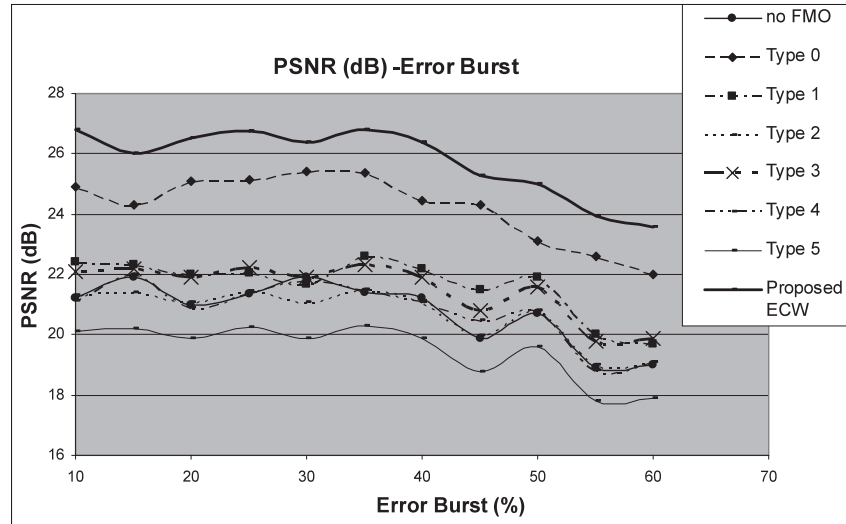
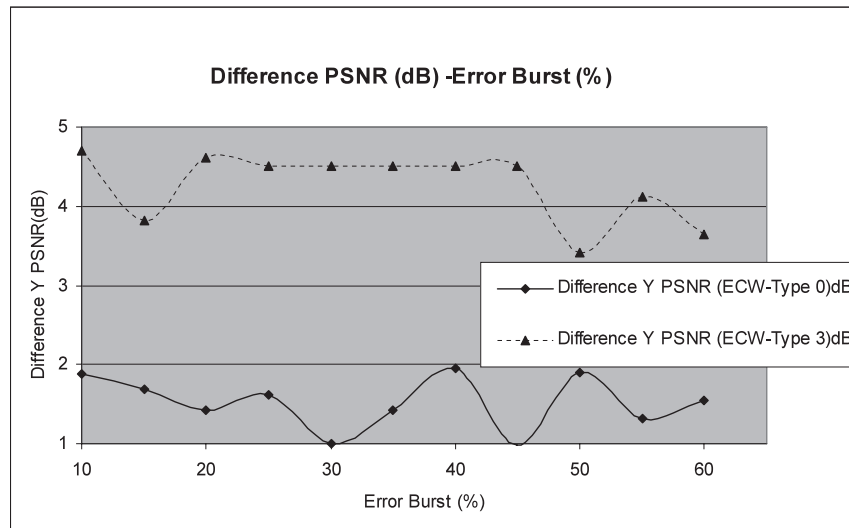**Fig. 7** Average PSNR as a function of burst packet loss for different FMO types.

Fig. 8 PSNR difference for the proposed ECW FMO method the Chessboard like pattern (Type 0) and the Spiral (Type 3) as a function of burst packet loss.

carried out with geometric analysis. Moreover to simulate the effect of the error burst on arbitrary blank frame we conduct several experiments with different burst size. For each burst size, we examine the effect of the error location by moving the starting point of the error by one MB at a time. This way we cover all missing slices possibilities due to an error burst with given length. The results shown are the average of all those experiments. For instance 90 simulations were derived for 10% error burst differ by the location of the error start point, 80 simulations were derived for 20% error burst differ by the location of the error start point. Hence for error burst ranging from 10% to 60% frame loss approximately 390 experiments were derived.

The average PSNR values for the different FMO types obtained for error burst ranging from 10% to 60% frame loss (i.e., loss of 10 MBs to 60 MBs for a QCIF frame) are presented in Fig. 7. It can be seen that the proposed ECW achieves better results than all other FMO types. Specifically, the proposed ECW type and the chessboard-like pattern achieve good results compared with all other FMO types. The absolute values of PSNR do not convey the advantage of the proposed ECW FMO technique. For this purpose, we compute the Y PSNR values for the Chessboard like pattern (Type 0) and the Spiral (Type 3) and uses these values as references. We computed the difference between the reference PSNR values and the PSNR value resulting using the proposed ECW FMO method.

These differences are plotted in Fig. 8. An improvement of an average 1.52 dB is achieved over the Chessboard-like pattern (Type 0) and an average 4.25 dB over the Spiral FMO (Type 3). Although a less improvement is achieved over the chessboard- like type, we should remember that the
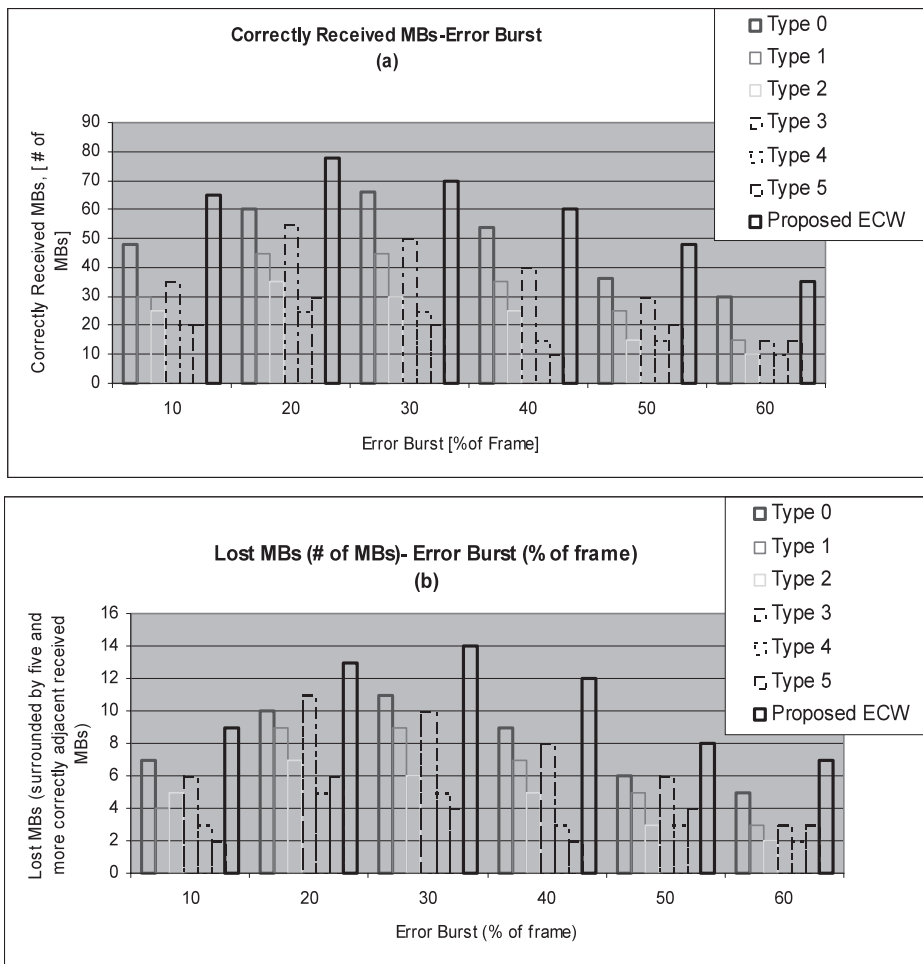
Fig. 9 Correctly adjacent received MBs (a) and the number of lost MBs with good potential to be reconstructed (b) as a function of different error bursts for all the FMO types.

PSNR criterion doesn't always tend to reflect the real improvement achieved.

Another measurement is also used in order to evaluate the potential for good concealment. This measurement reflecting the correctly adjacent received MBs surrounding the loss MB. Figure 9 presents the total number of correctly adjacent received MBs surrounding the lost MBs per frame, as well as the number of lost MBs that are surrounding by five and more correctly adjacent received MBs per frame. Those MBs have very good potential to be reconstructed using their adjacent neighbors. For error burst of 10% frame loss (loss of 10 MBs for a QCIF frame), ECW results with 65 correctly received adjacent MBs (out of 89) comparing to 48 by Chessboard like pattern (Type 0) and only 35 by Spiral (Type 3). ECW depicts that 9 MBs (out of 10) are surrounded by more than 5 good MBs, comparing to 7 MBs by Chessboard like pattern (Type 0) and 6 MBs by Spiral (Type 3). For error burst of 60% frame loss, ECW depicts 35 correctly adjacent received MBs, while Chessboard-like pattern (Type 0) shows 30 MBs and Spiral (Type 3) only 15 MBs. Furthermore ECW shows 7 MBs surrounded by 5 good MBs, while Chessboard like pattern (Type 0) shows

5 MBs and Spiral (Type 3) only 3 MBs.

Evaluation of the video quality is an important task in the area of video processing. Often quality is required to be measured automatically (without human's interference), and this goal is achieved with objective metrics. However, objective metrics can only serve as an estimation of the real quality of video, which is the subjective opinion of actual viewers. Consequently several subjective visual tests demonstrate the superior of the proposed approach. We conducted subjective visual tests with three different FMO types: the proposed FMO method, Type-0 chessboard like pattern and the Type 3: Spiral. The four QCIF video traces: Suzie, News, Mother-daughter and Coastguard affected by burst error with 20% and 40% frame loss. Several representation results are depicted in Fig. 10, Fig. 11 and Fig. 12. Figure 10 shows the 45′th frame after concealment for the four QCIF video traces affected by burst error with 20% frame loss. Figure 11 depicts the 135′th frame after concealment for the four QCIF video traces affected by burst error with 40% frame loss. The quality achieved with the proposed ECW FMO technique is superior for all the cases. Figure 12 demonstrates the visual effect of the error burst

Fig. 10 Visual effect for burst error 20% frame loss for different video traces. The 45th reconstructed frame using Type 3: Spiral (1,2,3,4)a, Type 0:chessboard like pattern (1,2,3,4)b, and the proposed ECW FMO technique (1,2,3,4)c.

location for the Coastguard video sequence. In this case two scenarios were examined. In the first scenario error occurs at the beginning of the frame transmission. In the second scenario error occurs at the middle of the frame transmission. Both scenarios have error burst with 30% frame loss. It can be seen that for both scenarios the proposed ECW FMO technique outperforms the other FMO types (Type 0 and Type 3) since it achieves better visual quality.

5. Conclusions

Error resilient is a key technique that enables robust streaming of stored video content over noisy channels. It is particularly useful when content has been produced independent of the transmission network conditions. In this paper, we investigated H.264/AVC Flexible Macroblocks Ordering (FMO) techniques regarding the ability for error concealment. We propose a new Explicit Chessboard-Wipe (ECW) Flexible Macroblocks Ordering (FMO) technique which outperforms all other FMO types. The proposed ECW method is fully

compatible with the H.264/AVC codec utilizing the Explicit FMO Type 6, which permits any efficient way of allocating MBs into slice groups. The encoder may divide every coded frame into different macroblocks partitions by mapping of MBs into slice groups using specific allocation map which is named MBAmap. Simulation results indicate that ECW FMO technique enhances the ability for error concealment, and therefore the video quality. Moreover ECW FMO technique achieves better results compared to all other FMO types introduced by the standard, in term of subjective and objective video quality, especially when compressed video signal is transmitted over burst packet loss networks. Future work will include the impact of the proposed ECW FMO technique in the coding efficiency compared to all other FMO techniques.

Fig. 11 Visual effect for burst error 40% frame loss for different video traces. The 135th reconstructed frame using Type 3: Spiral (1,2,3,4)a, Type 0:chessboard like pattern (1,2,3,4)b, and the proposed ECW FMO technique (1,2,3,4)c.
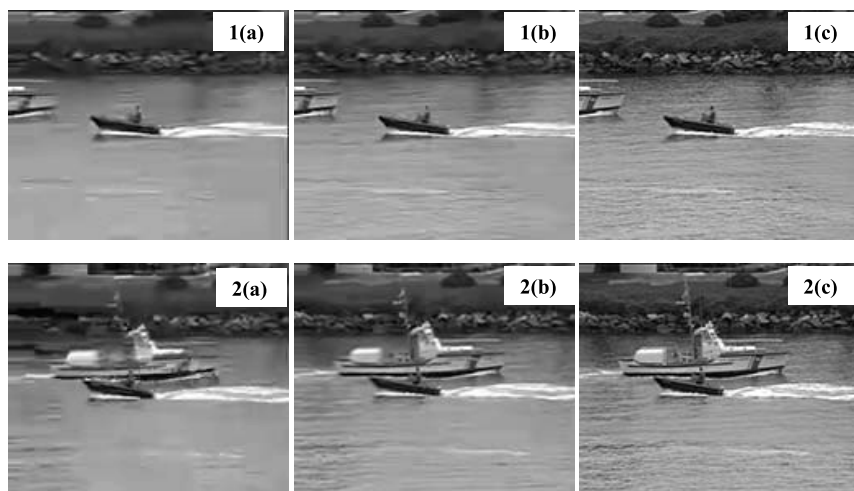

Fig. 12 Error burst with 30% frame loss at the begging of the frame transmissionphase (1). Error burst with 30% frame loss at the middle of the frame transmission phase (2). Error burst effect for Tpye 3: Spiral (1,2)a, Type 0: chessboard like pattern (1,2)b, and the proposed ECW FMO technique (1,2)c.

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