# Improved 3D Multi-View Stereoscopic Video Decoding through Dispersed Flexible Macro-block Ordering and Multi-Dimensional Error Concealment

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***Abstract***

*Video communications over wireless channels is still a major problem due to limited bandwidth and the presence of channel errors. Low transmission rate in mobile networks requires a reduction of used video resolution as well as the use of highly efficient video compression technique. This gives rise to data loss and visual artifacts, and hence a marked decrease in video quality. Since the transmission of video content is over real time channel, it is not possible to re-send any erroneous or lost information. It is therefore necessary to conceal these errors at the decoder side using appropriate methods, such as Error Concealment (EC) methods. In this paper, we propose using of Dispersed Flexible Macro-block Ordering (DFMO) error resilience method in the encoder to aid the proposed Multi-Dimensional EC (MDEC) algorithms in the decoder to conceal the erroneous Macro-Blocks (MBs) of intra and inter coded frames of 3D stereoscopic video. Our extensive simulation results obtained demonstrate that the proposed combination algorithms can significantly improve the objective and subjective 3D video quality.*

***Keywords:*** *3D Stereoscopic Video, Error Resilience, Error Concealment, Intra and Inter Frames, Spatio-Temporal and Inter-view Correlations*

## 1. Introduction

The importance of 3D Multi-View Video (3D MVV) has been significantly increased recently. With the fast progress of 3D display technologies, 3D MVV is expected to replace traditional video in the near future in many applications. Stereoscopic video related strategies are becoming popular at present; it is a simple format of 3D MVV coding. 3D stereoscopic video consists of images of the same scene captured from different perspectives. It can provide different views of the same scene, offering interactivity as well as 3D perception [1].

3D stereoscopic video transmitted over wireless networks is always subject to packet losses including both random and burst errors. Packet loss rates and its impact on the decoded video can be limited in several ways. There are several tools to secure video content prior to transmission. One of those tools is called Forward Error Correction (FEC) methods [2], which add redundant information to enable recovery of corrupted data. Another possibility could be the application of Automatic Repeated Request (ARQ) methods [3], which provide the re-transmission of lost information. However, these methods increase the amount of information that must be transmitted over the network and implement latency. The solution could be provided by using post-processing Error Concealment (EC) methods, which aim to restoration the lost information in decoder from information that is available at the encoder [4].

While the FEC and ARQ methods provide lossless recovery [2, 3], the EC methods deployed in decoder try to realize the closest approximation of the original image. Also, we can use Error Resilience (ER) methods [5] in the encoder to help the EC algorithms in the decoder to reconstruct the lost Macro-Blocks (MBs) and frames. ER methods refer to mechanisms used in the encoder that enhance the ability of the compressed bit-stream to resist channel errors. ER functionality in the encoder produces a bit-stream that supports error recovery at the decoder.

Flexible Macro-block Ordering (FMO) is one of the new error resilience tools that can be used to mitigate the effects of error in error prone environments. Using FMO, each MB can be assigned independently to a certain slice group by using a Macro-Block Allocation map (MBAmap) [6]. FMO method depends on how the MBs are ordered. FMO also provides a way to spread the erroneous MBs within the frame and take advantage of the spatial locations of the successfully decoded MBs for improving EC mechanism. So, a suitable MBAmap disperses the error MBs in a frame and thus EC algorithms at the decoder can recover lost MBs from neighbouring MBs that are correctly received [7]. Therefore, FMO is a powerful when conjunction with EC algorithms in the decoder.

In this paper, our goal is to reconstruct the 3D stereoscopic video sequences transmitted over noisy channel with high objective and subjective quality. We focus on concealing the pre-compressed 3D stereoscopic video sequences generated by Multiview Codec (MMRG) reference software [8], based on H.264/AVC codec [9]. We propose different hybrid EC algorithms, which exploit the intra-view and inter-view correlations between frames and views to conceal lost MBs of intra and inter-frames. The rest of this paper is organized as follows: Section 2 presents Flexible Macro-block Ordering (FMO). In Section 3, we introduce Error-Concealment (EC). In Section 4, we present the proposed conjunction of Dispersed FMO (DFMO) error resilience and Multi-Dimensional EC (MDEC) algorithms. Section 5 presents our experimental simulation results and finally section 6 concludes the paper.

## 2. Flexible Macro-Block Ordering (FMO)

The H.264/AVC video codec standard [9], enables the division of an image in regions called slice groups. Each slice group can be divided in several slices and a slice can also be decoded independently. Error resilient mechanisms are introduced at the encoder of H.264/AVC codec to make the transmitted video bit-streams more robust to potential errors and to facilitate error concealment process at the decoder. The error resilient schemes adopted by H.264/AVC codec to mitigate the effect of packet loss are: (a) slice coding that limits the spatial error propagation, (b) insertion of regular intra coded frames that limits the temporal error propagation, and (c) Flexible Macro-block Ordering (FMO) that limits both spatial and temporal error propagation and allows more flexibly deciding what slice MBs belong to, in order to spread out errors and keep errors in one part of the frame from compromising another part of the frame [10].

FMO allows flexibility in changing the encoding and transmission order of MBs on top of the normal raster scan order. This is accomplished by dividing the picture into slice groups, and each slice group can contain several slices. The MBs can be assigned freely on any slice group with the use of an FMO tool [6]. An identification number for each MB is given by the MBAmap to specify which slice group that MB belongs to. Therefore the main advantage of using FMO is the ability to contain the spatial and temporal propagation of error within the slice boundary. Since each slice is designed to be decodable independently of other slices. So FMO allows the encoder and decoder to resynchronize their states at the slice boundary in the event that there is an error in the bit-streams.

The H.264/AVC standard supports six common different FMO map types as shown in Figure 1. FMO type 0 uses run lengths which are repeated to fill the frame. Therefore only those run lengths have to be known to rebuild the MBAmap on the decoder side. FMO type 1 (DFMO), also known as scattered slices, uses a function, which is known to both the encoder and decoder, to spread the MBs. FMO type 2 is used to mark rectangular areas around regions of interest inside a frame. MBAmaps can be stored using the top left and bottom right coordinates of those rectangles. FMO types 3 to 5 are dynamic ones and they let the slice groups grow and shrink over the different pictures in a cyclic way [7].

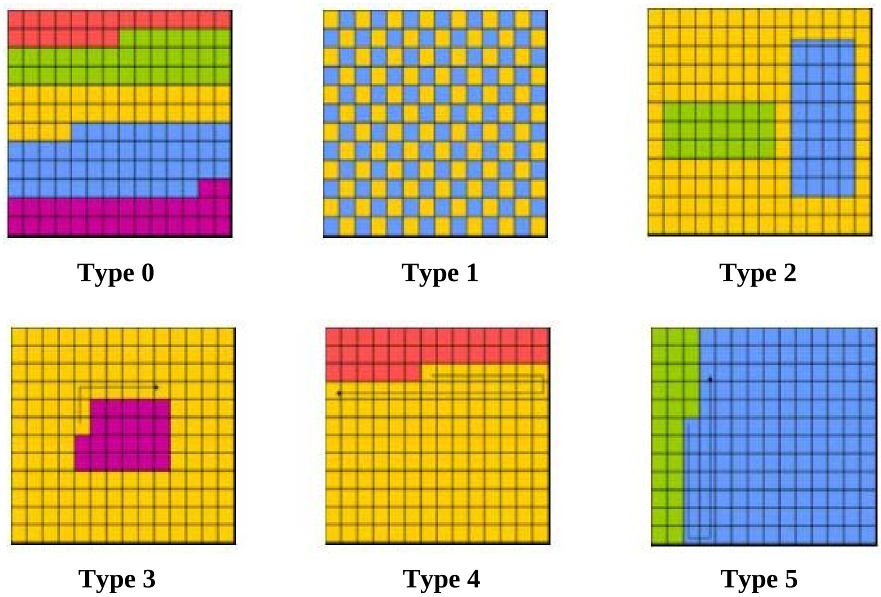



**Figure 1. Different Types of Flexible Macro-Block Ordering (FMO)**

As we shown above that various FMO types are available [6, 7], but the most efficient one is the Dispersed FMO (DFMO) type 1, where consecutive MBs are transmitted in different slice-groups to protect the neighborhood MBs. DFMO uniformly scatters possible errors to the whole frame to avoid error accumulation in a limited region [5]. DFMO increases the probability that a corrupted MB has distortion-free neighbors which can be used to aid EC at decoder. Therefore we propose to use DFMO at the encoder to enhance the performance of the proposed MDEC algorithms at the decoder.

## 3. Error Concealment (EC)

In wireless networks, 3D stereoscopic video transmission may suffer from random and burst packet losses due to channel errors, node failures, route changes, interference and fading in the wireless channel, *etc*. The packet losses can seriously degrade the received 3D video quality. Since the stereoscopic video has two views [11], as shown in Figure 2, the key objective is how to effectively exploit the relationship between two adjacent fames within the same view which is the intra-view correlation or inter-frame correlation as well as the relationship between these two views which is the inter-view correlation to recover the missing frame due to frame loss. Therefore, it is challenging to provide error resilient and concealment for reliable video communications over such wireless lossy networks. Thus the effective way to fix the errors produced by packet losses is using Error Concealment (EC) methods at the decoder [12]. The main task of EC is to replace missing parts of video content by previously corrected decoded parts of the video sequence in order to eliminate or reduce the visual effects of bit stream error.

Due to the predictive coding structure of 3D stereoscopic video codec which is shown in Figure 2 [13], that is used to compress the transmitted stereoscopic video, which utilizes intra and inter coded frames, therefore errors could propagate to the subsequent frames and to the adjacent views and result in poor video quality [14]. As discussed before, it is not possible to retransmit all erroneous or lost packets due to delay constraints on real-time video transmission. Thus there is a need for post-processing EC methods at decoder. EC algorithms are attractive since they have the advantage of reducing the visual artifacts caused by channel errors or erasures without increasing the bit rate or transmission delay. Therefore, we propose using of EC algorithms to enhance the video quality at the decoder through exploiting the spatial and temporal correlations between the neighboring image parts (MBs) within the same frame or the past and future frames, and also by exploiting the inter-view correlations between the left and right views of 3D stereoscopic video.

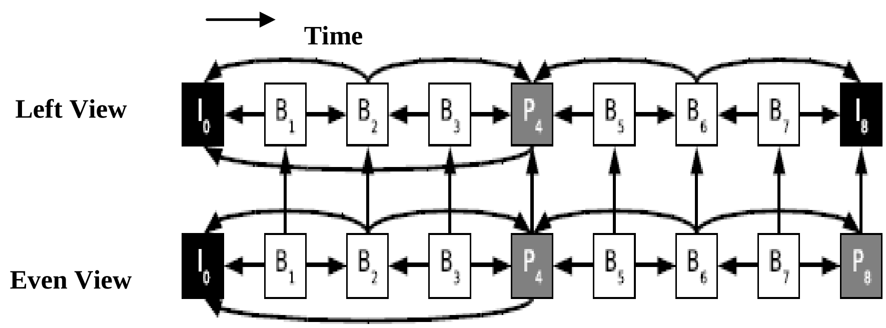



**Figure 2. The Proposed Encoding Scheme for 3D Stereoscopic Video Coding [13]**

## 4. Proposed Joint DFMO-MDEC Algorithms

In 3D stereoscopic video, the temporal, spatial and inter-view correlations between the left view and its corresponding right view are very rich. Both the left and the right view frames of a stereoscopic video might be erroneously received over error-prone networks. Therefore, the intra and inter correlations inside the stereo image pair can be used for error concealment. In this section, we present our joint proposed error resilience (ER) and error concealment (EC) algorithms for intra-frames (**I** frames) and inter-frames (**P** and **B** frames) of stereoscopic video. Intra-frames EC are not only essential for improving the video quality of reconstructed intra-frames but also for improving the video quality of reconstructed inter-frames in the subsequent frames and views.

We propose to use Dispersed Flexible Macro-block Ordering (DFMO) type 1 ER method with the proposed Multi-Dimensional EC (MDEC) algorithms. In the following we detail our proposed MDEC algorithms for intra-frames and inter-frames to improve the subjective and objective quality of reconstructed 3D stereoscopic video: the joint Space and Time Domain EC (STDEC), Inter-View Domain EC (IVDEC), and the hybrid Time and Inter-View Domain EC (TIVDEC) algorithms.

**Algorithm 1: Space-Time Domain Error Concealment (STDEC)**

1. Find the locations of the lost MBs.
2. Find the 8x8 adjacent sub-blocks to the lost MB and their matching blocks in the reference frame.
3. Find the most correlated Motion Vectors (MVs) between the adjacent sub-blocks and their matching references blocks.
4. Select the MVs of the MBs that give the smallest Sum of Absolute Differences (SAD) [15].
5. Apply the Weight Pixel Averaging Algorithm (WPAA) [16], to find the matching pixels surrounding the lost MB's pixels.
6. Find the highest matching Disparity Vectors (DVs) between pixels inside the lost MB and pixels surrounding the lost MB.
7. Calculate the average value of the selected MVs and DVs found in the previous steps.
8. Replace the lost MBs with the averaged calculated value in step 7.

**Algorithm 2: Inter-View Domain Error Concealment (IVDEC)**

1. Find the locations of the lost MBs.
2. Apply WPAA algorithm [16], to find the matching pixels to the lost MB's pixels inside the other view.
3. Find the most correlated candidate DVs to lost MB inside the reference frame in the other view.
4. Average DVs values of the most correlated candidate MBs.
5. Replace the lost MB with the candidate MBs by using the averaged calculated value.

**Algorithm 3: Time and Inter-View Domain Error Concealment (TIVDEC)**

1. Find the locations of the lost MBs.
2. Apply the WPAA algorithm [16], to find the matching pixels and to calculate the candidates DVs to the lost MB within the references frames in the other view.
3. Apply the Outer Block Boundary Matching Algorithm (OBBMA) [17] algorithm, to find the most matched candidates MVs to the lost MB within the reference frames inside the same view.
4. Average DVs and MVs values of the candidate MBs.
5. Set appropriate coefficient values to the averaged values of MVs and DVs (avg (MVs) and avg (DVs), respectively) depending on Scene Change Detection Algorithm [16] by selecting between the following two cases:
    - Candidate MB = 1/3 avg (MVs) + 2/3 avg (DVs).
    - Candidate MB = 2/3 avg (MVs) + 1/3 avg (DVs).

   This depending on "Is the Temporal information > Spatial information or vice versa?".
6. Replace the lost MBs with the candidates MBs by using the weighted average calculated value of MVs and DVs in the previous step.

We proposed different EC algorithms for intra and inter coded frames due to their different coding and decoding dependent references frames in the prediction structure of stereoscopic video as shown in Figure 2. So, for example, if an error occurs in $\mathbf{I_0}$ intra-frame in the left view that is shown in Figure 2, it can be concealed by using STDEC algorithm. Also, for instance if an error occur in $\mathbf{I_8}$ intra-frame, it can be reconstructed by exploiting STDEC and IVDEC algorithms. But if an error occurs in $\mathbf{P_4}$ or $\mathbf{B_2}$ or $\mathbf{B_6}$ inter-frames in the left view, it can be concealed by using TIVDEC algorithm. Also, if an error occurs in $\mathbf{B_1}$ or $\mathbf{B_3}$ or $\mathbf{B_5}$ or $\mathbf{B_7}$ inter-frames in the left view, it can be recovered by applying IVDEC algorithm. The same idea of concealment can be applied to the intra and inter coded frames of the right view of 3D stereoscopic video as shown in prediction structure of Figure 2. So, we can employ the appropriate EC algorithm depending on the erroneous frame type and its location within the certain view.

## 5. Simulation Results

In order to evaluate the performance of the proposed joint DFMO-MDEC algorithms, we run some experiments on three well-known test 3D video sequences: "EXIT" [18], "IU", "VK" [19]. The moving objects in the EXIT sequence are in simple slow motion, while the ones in the "IU" and "VK" sequences involve fast and complex motion. Multiview MMRG video [8] reference software is employed as a platform for our proposed simulation work, based on H.264/AVC codec [9]. For each sequence, the encoded bit-streams are produced with applying DFMO algorithm using Multiview MMRG video [8], and then transmitted over a communication noisy channel with various random Packet Loss Rates (PLRs) (3%, 5%, 10% and 20%) and then concealed at the decoder by the proposed MDEC algorithms. We used the Peak Signal to Noise Ratio (PSNR) value as the objective measure of the recovered and concealed frame to evaluate the performance of the proposed DFMO-MDEC algorithms.

For each sequence, we assumed that the left view is delivered erroneously and the right view is delivered correctly. So, if the left view frame is transmitted erroneously, we can conceal each erroneous frame by employing the appropriate proposed MDEC algorithm depending on its reference frames as shown in Figure 2. In our simulation results, we assume that the erroneous frames are $\mathbf{I_{33}}$, $\mathbf{B_{34}}$, and $\mathbf{P_{37}}$ of the left view. Thus we will select the appropriate MDEC algorithm to conceal each erroneous frame. As shown in Figure 2, the erroneous $\mathbf{I_{33}}$ intra-frame can be concealed using the STDEC and IVDEC algorithms. Also, the corrupted $\mathbf{B_{34}}$ inter-frame can be reconstructed by applying IVDEC algorithm. But, the lost MBs within the $\mathbf{P_{37}}$ inter-frame can be recovered by exploiting TIVDEC algorithm. For simulation, we will compare the performance of the proposed MDEC algorithms with and without using DFMO type 1 ER method in the encoder.

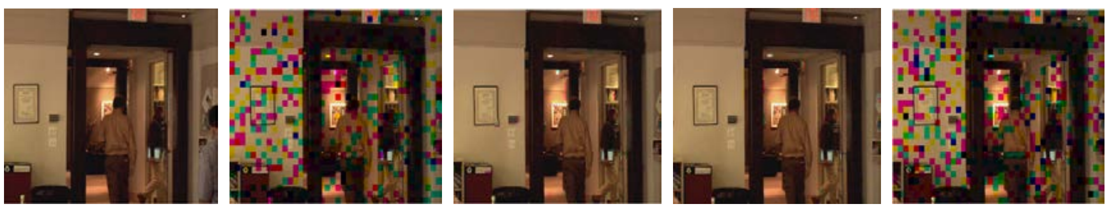
Figure 3, Figure 4, and Figure 5, show the subjective experimental results for the "Exit", "IU", and "VK" test video sequences, respectively, which are different in motion characteristics. For each sequence, we select the $\mathbf{I_{33}}$ intra-coded frame and $\mathbf{B_{34}}$ and $\mathbf{P_{37}}$ inter-coded frames at channel PLR=20%. We recovered the selected erroneous MBs inside the frames with the appropriate proposed EC algorithms with and without using DFMO in the encoder. The corresponding objective Peak Signal to Noise Ratio (PSNR) results for the same selected frames of the same video sequences are shown in Figure 6, Table 1, and Figure 7 at different channel PLRs. From all the results, we observe that using of joint DFMO-MDEC algorithms (EC - FMO) has the best subjective and objective results compared to using of MDEC only (EC - No FMO) or DFMO ER only (No EC - FMO). So, DFMO ER method can be used in the encoder to aid the proposed MDEC algorithms in the decoder to mitigate the channel errors efficiently. Also, we detect that our proposed DFMO-MDEC algorithms give sufficient results for different characteristics 3D videos sequences.

(a) (b) (c) (d) (e)

**[3.1] $I_{33}$ Intra-Frame.**

(a) (b) (c) (d) (e)

**[3.2] $B_{34}$ Inter-Frame.**



(a) (b) (c) (d) (e)

**[3.3] $P_{37}$ Inter-Frame.**

**Figure 3. Subjective Simulation Results for the Selected $I_{33}$, $B_{33}$, and $P_{37}$ Intra and Inter Frames within the Left View of the "Exit" Sequence at Channel PLR 20%: (a) Original Right Frame; (b) Corrupted Left Frame; (c) EC - No FMO; (d) EC - FMO; (e) No EC - FMO**

(a) (b) (c) (d) (e)

**[4.1] $I_{33}$ Intra-Frame.**

(a) (b) (c) (d) (e)

**[4.2] $B_{34}$ Inter-Frame.**

**(a) (b) (c) (d) (e)**

**[4.3] $P_{37}$ Inter-Frame.**

**Figure 4. Subjective Simulation Results for the Selected $I_{33}$, $B_{33}$, and $P_{37}$ Intra and Inter Frames within the Left View of the "IU" Sequence at Channel PLR 20%: (a) Original Right Frame; (b) Corrupted Left Frame; (c) EC - No FMO; (d) EC - FMO; (e) No EC - FMO**

**(a) (b) (c) (d) (e)**

**[5.1] $I_{33}$ Intra-Frame.**

**(a) (b) (c) (d) (e)**

**[5.2] $B_{34}$ Inter-Frame.**

**(a) (b) (c) (d) (e)**

**[5.3] $P_{37}$ Inter-Frame.**

**Figure 5. Subjective Simulation Results for the Selected $I_{33}$, $B_{33}$, and $P_{37}$ Intra and Inter Frames within the Left View of the "VK" Sequence at Channel PLR 20%: (a) Original Right Frame; (b) Corrupted Left Frame; (c) EC - No FMO; (d) EC - FMO; (e) No EC - FMO**

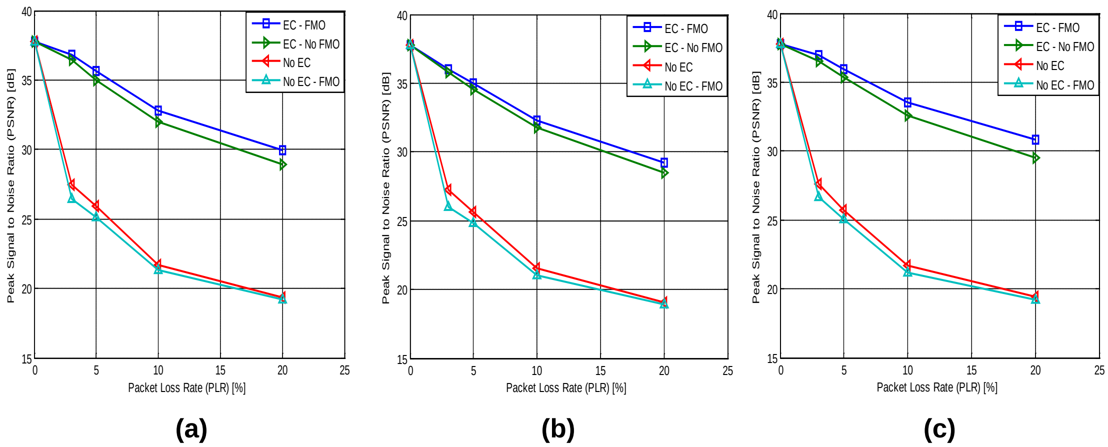


**Figure 6. PSNR Performance for the Selected Intra and Inter Frames within the Left View of the "Exit" Test Sequence with Different PLRs for the proposed ER and EC Modes:**
**(a) $I_{33}$ Intra-Frame; (b) $B_{34}$ Inter-Frame; (c) $P_{37}$ Inter-Frame**

**Table 1. PSNR Performance for the Selected $I_{33}$ and $B_{34}$ and $P_{37}$ Intra and Inter Frames within the Left View of the "IU" Test Sequence with Different PLRs for the proposed ER and EC Modes**

| Sequence | | Frame Type | Applied Method | Packet Loss Rate (PLR) % 0% | 3% | 5% | 10% | 20% |
|---|---|---|---|---|---|---|---|---|
| IU | PSNR (dB) | $I_{33}$ (Intra-Frame) | EC-FMO | 37.52 | 35.968 | 33.103 | 29.526 | 26.237 |
| | | | EC-No FMO | 37.52 | 35.827 | 32.649 | 28.938 | 25.379 |
| | | | No EC | 37.52 | 26.549 | 24.989 | 20.829 | 18.972 |
| | | | No EC-FMO | 37.52 | 25.401 | 24.211 | 20.363 | 18.624 |
| | | $B_{34}$ (Inter-Frame) | EC-FMO | 37.52 | 34.997 | 32.867 | 28.769 | 25.904 |
| | | | EC-No FMO | 37.52 | 34.827 | 32.529 | 28.124 | 25.228 |
| | | | No EC | 37.52 | 26.421 | 24.635 | 20.619 | 18.739 |
| | | | No EC-FMO | 37.52 | 25.367 | 23.802 | 20.210 | 18.492 |
| | | $P_{37}$ (Inter-Frame) | EC-FMO | 37.52 | 36.621 | 33.731 | 30.461 | 27.375 |
| | | | EC-No FMO | 37.52 | 36.312 | 33.401 | 29.939 | 26.352 |
| | | | No EC | 37.52 | 26.772 | 25.230 | 21.326 | 19.302 |
| | | | No EC-FMO | 37.52 | 25.532 | 24.492 | 20.827 | 19.116 |

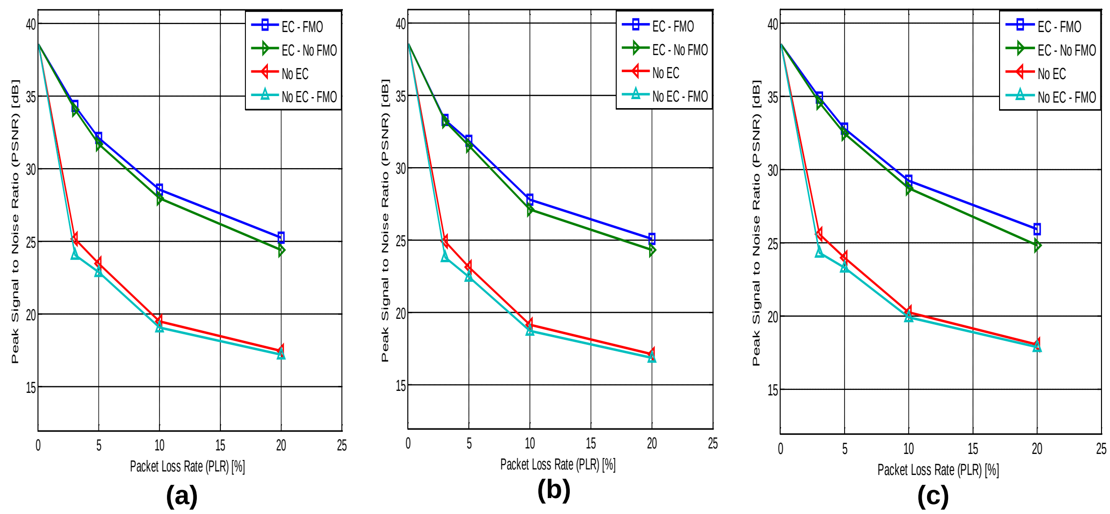



**Figure 7. PSNR Performance for the Selected Intra and Inter Frames within the Left View of the "VK" Test Sequence with Different PLRs for the proposed ER and EC Modes:**
**(a) $I_{33}$ Intra-Frame; (b) $B_{34}$ Inter-Frame; (c) $P_{37}$ Inter-Frame**

## 6. Conclusion

In this paper, we have proposed different Multi-Dimensional Error Concealment (MDEC) algorithms for intra-frames and inter-frames of 3D Multi-View stereoscopic video coded sequences corrupted by random channel errors. We proposed using of Dispersed Flexible Macro-block Ordering (DFMO) Error Resilience (ER) method in the encoder to aid the proposed MDEC algorithms in the decoder to conceal the erroneous Macro-Blocks (MBs) of intra and inter coded frames of 3D stereoscopic video. The main crux of our proposed algorithms is to jointly utilize the spatial, temporal and inter-view correlations in stereoscopic sequences for EC of both intra-frames and inter-frames. Our experimental results show that our proposed joint time domain, space domain and inter-view domain EC algorithms are significantly superior to conventional EC algorithms that exploit correlation in only the space domain or only the time domain, *e.g.*, [5, 6, 7, 11]. Our results demonstrate the importance of using DFMO ER in the encoder in addition to MDEC in the decoder to enhance the subjective video quality, as well significant gain in objective PSNR. We conclude that the using of DFMO ER method jointly with the proposed joint space-time-view EC algorithms can conceal errors and lost MBs of intra-frames and inter-frames of different characteristics 3D stereo video efficiently, and delivering high quality.

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