Enhanced H.264 Transmission with Multiple Description Coding, Prioritised Concealment and FMO

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***Abstract*—H.264 is presently one of the most frequently adopted video coding standards capable of achieving good video quality. Due to its enhanced compression capability, H.264 is extensively used in a wide range of applications such as Mobile TV broadcasting, video conferencing and High Definition TV. Nonetheless, compressed videos are highly sensitive to channel errors which may result in severe visual quality degradation. Therefore, transmission of compressed video over communication channels is a very challenging task. In this work, a recently developed prioritized concealment and Flexible Macroblock Ordering (FMO) scheme were combined with Multiple Description Coding (MDC) for video transmission. The prioritised concealment algorithm used auto-correlation and the FMO scheme used Space and Time (ST) Interpolation. The FMO scheme was applied to MDC whereby ST interpolation was performed over different descriptions to enhance its performance. Moreover, a channel model that specifically considers losses on multiple channels was used to assess the performance. Simulations results show that the proposed scheme achieved a gain of 3.38 dB in Y-PSNR over a conventional scheme as compared to a gain of 1.94 dB in Y-PSNR, when using an existing FMO and prioritisation scheme.**

***Index Terms*—H.264 Video Compression; MDC; Prioritised Concealment; ST-FMO.**

I. Introduction

H.264/AVC is one of the most widely adopted video compression format developed by Joint Video Team (JVT) which is a joint collaboration of ITU-T Video Coding Experts Group and the ISO/IEC JTC1 Moving Picture Experts Group[1-5]. H.264 is extensively used in a wide range of applications, such as Mobile TV broadcasting, videoconferencing and High Definition TV [3]. Recently, H.265 which is in fact the successor of H.264 has been developed by JVT with the aim of providing higher compression as compared to H.264 [2]. According to a report published in early 2016 by Encoding.com [6], which is one of the most well-reputed cloud media processing services, H.264 is still the most commonly adopted video coding format for the web as well as mobile video with a significant 72% usage [6]. H.265, for instance, demonstrated a constant growth since its release with 6% usage [6]. Furthermore in [7], the authors compared the performance of H.264 and H.265 and the simulation results demonstrated that H.265 achieved two times better compression as compared to H.264, but H.265 performed two times slower than H.264 [7]. In addition, recently the author in [8] proposed an optimal complexity H.264 encoding for video streaming over next generation of wireless multimedia sensor networks by developing a mathematical model and using the most efficient H.264 encoder configuration setting on H.264 coding. However, compressed video is highly sensitive to channel errors. Therefore, it is crucial for a video compression standard to address the issue of packet loss during video transmission over communication channels. One efficient error resilient method for combating the effect of burst errors in H.264 encoded video is to use Flexible Macroblock Ordering (FMO). FMO orders the Macroblocks (MBs) within a frame so that the neighbouring MBs are not transmitted consecutively, thus ensuring an effective concealment of lost MBs [9]. Moreover, prioritisation of concealment order which has been extensively studied over the years has shown to lead to more efficient concealment of lost MBs [5]. An alternative approach is to combine FMO with Multiple Description Coding in order to deal with packet losses over congested networks without the need for retransmission of lost MBs. An outline of FMO, prioritisation techniques and MDC strategies developed for H.264 video transmission is given next.

Over the past ten years, many FMO techniques have been studied in order to improve video transmission over communication channels. For example, in [10] the authors proposed a novel technique where FMO was used in conjunction with locality-awareness in order to improve video streaming over P2P networks. In [9], an Explicit Chessboard-Wipe (ECW) FMO scheme which described a new ordering mechanism of the MBs was proposed which outperformed the existing Chessboard FMO type by an average gain of 1.52 dB [9].

The prioritisation of concealment order is a powerful method for improving error concealment of corrupted MBs. For instance, in [11], an effective boundary match algorithm for the estimation of damaged motion vectors was studied where error concealment for each MB was performed depending on the priority of its frame. In addition, the authors in [12] presented a temporal error concealment technique along with Adaptive Error Concealment Orders Determination (AECOD), which provided an enhanced recovery performance as compared to other error concealment techniques [12]. In [13], the authors presented a novel prioritisation technique referred as the impact factor algorithm, which calculated the influence each corrupted MB has on the subsequent frames.

Multiple Description Coding techniques have also proved to be very effective in preventing packet losses. For instance, in [14], a new MDC scheme was proposed which was based on spatial subsampling. In addition, an adaptive concealment method was used to further enhance the video quality. The authors in [15] proposed MDC along with time division of a video stream and its application in multipoint videoconferencing. Results showed that the proposed technique provided acceptable video quality even if one of the two descriptions was lost during transmission. In [16], the authors presented a model which enabled comparison of the distortion of MDC video coding as well as path diversity with single description coding.

In this paper, a recently developed prioritised concealment and FMO scheme [5] was combined with MDC for video transmission. The prioritised concealment algorithm used auto-correlation and the FMO scheme used Space and Time Interpolation. The FMO scheme was applied to MDC whereby ST interpolation was performed over different descriptions to enhance its performance. Moreover, to the best of our knowledge, the existing MDC techniques have never been studied in conjunction with FMO. With MDC, two different loss models have been used. The first model used the Gilbert Eliot channel model and the second model used a composite channel model, which models the path behaviour for MDC more efficiently. Moreover, a channel model that specifically considers losses on multiple channels was used to assess the performance. Simulations results showed that the proposed scheme achieved a gain of 3.38 dB over a conventional scheme as compared to a gain of 1.94 dB, when using an existing FMO and prioritisation scheme.

The remainder of this paper is organized as follows. Section II provides background information on existing MDC, Gilbert Elliot channel models and a recently developed ST-FMO and prioritisation scheme based on autocorrelation. Section III presents the proposed framework. Section IV demonstrates the experimental results, and finally Section V draws some conclusions and scope for future works.

II. Literature Review

A. *Multiple Description Coding (MDC)*

One of the best-known techniques for combating packet loss is MDC. The basic principle of the MDC technique is the generation of at least two descriptions of the same data and the transmission of each description through separate channels. In case one description is corrupted, the second description can be used for the reconstruction of the data. The main aim of MDC is to reduce distortion of data without the need for retransmission, thus reducing the effect of noise and delay over unreliable communication channels. Many MDC schemes have been experimented over the past decades. Originally in [17], Apostolopoulos proposed to divide the input into odd and even frames where Description 1 contained odd frames whereas and the remaining even frames were found in Description 2. Each encoder processes the descriptions separately before transmission over distinct channels. An alternative MDC approach is to send the motion vectors between frames in the descriptions in order to enhance the concealment of lost MB [18]. For instance, even motion vectors are inserted into a description containing odd frames. Therefore, motion vectors are available which leads to better concealment of lost MBs. MDC has proved to be very efficient due to its ability to combat packet loss as compared to Single Description Coding (SDC), where all the frames are transmitted through a single channel [19,20].

B. *Gilbert Elliot Channel Model*

Gilbert-Elliot model is a popular channel model which has been widely used for representing the loss process in H.264 video transmission over a single channel [21]-[23]. The Gilbert Elliot channel model is represented by a two-state Markov chain, as shown in Figure 1 [21]-[23]. In this model, there are two states referred as "good" and "bad" state [23]. A good state indicates that data has been correctly transmitted and a bad state represents loss of data. In Figure 1, P_G represents the packet loss probability for a Good state, P_B represents the packet loss probability for a Bad state, y represents the probability of transiting from good state P_G to bad state P_B and z represents the probability of transiting from bad state P_B to good state P_G.

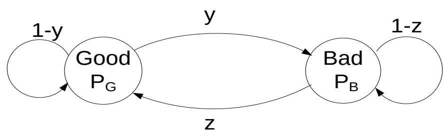

Figure 1: Gilbert-Elliot Channel Model [21]-[23].

The steady state probabilities S_{p1} and S_{p2} for being in states P_G and P_B respectively are given by Equation (1) and (2) [21]- [23]:

$$S_{p1} = \frac{z}{y+z} \quad (1)$$

$$S_{p2} = \frac{y}{y+z} \quad (2)$$

The average Packet loss rate, P_{loss} is given by the Equation [21]-[23]:

$$P_{loss} = P_G.S_{p1} + P_B.S_{p2} \quad (3)$$

In this paper, the following assumptions have been made:

- Packet loss rate at Good state, $P_G = 0$;
- Packet loss rate at Bad state, $P_B = 1$;

Therefore,

$$P_{loss} = P_B.S_{p2} \quad (4)$$

$$P_{loss} = \frac{y}{y+z} \quad (5)$$

Using Equation (5), z can be derived as shown:

$$(y+z).P_{loss} = y \quad (6)$$

$$z = \frac{y}{P_{loss}} - y \quad (7)$$

Using Equation (5), y can be derived as shown:

$$(y+z).P_{loss} = y \quad (8)$$

$$y = \frac{z.\ P_{loss}}{1-P_{loss}} \quad (9)$$

In this paper, y is set to the Packet Loss Rate, *PLR*, of the channel. Therefore, z is calculated using the Equation 7 as shown:

$$z = \frac{y}{PLR} - y \tag{10}$$

C. Channel Model for MDC

In [16], the authors proposed a novel channel model for MDC video communication, which precisely predicts distortions during MDC video transmission. This approach considers that the probability of all the descriptions is corrupted at the same time is lower than the probability that a single path is corrupted [16]. Therefore, this model provides an effective path behaviour for MDC. The channel model developed for describing path diversity system for MDC with two descriptions is shown in Figure 2. Each state 00, 01, 10 or 11 represents the current condition of each channel: channel 1 and channel 2.

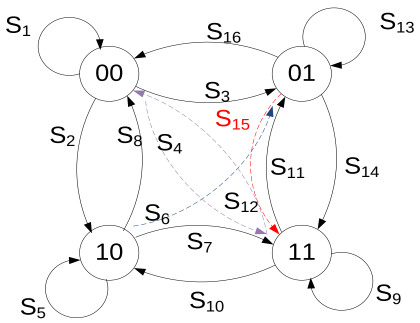

Figure 2: State Diagram of Channel Model [16]

Table 1
Channel States Description

State Transition	Current State	Next State	Next state of Channel 1	Next State of Channel 2
S_1	00	00	No Loss	No Loss
S_2	00	10	Drop	No Loss
S_3	00	01	No Loss	Drop
S_4	00	11	Drop	Drop
S_5	10	10	Loss	No Loss
S_6	10	01	Recovered	Drop
S_7	10	11	Loss	Drop
S_8	10	00	Recovered	No Loss
S_9	11	11	Loss	Loss
S_{10}	11	10	Loss	Recovered
S_{11}	11	01	Recovered	Loss
S_{12}	11	00	Recovered	Recovered
S_{13}	01	01	No Loss	Loss
S_{14}	01	11	Drop	Loss
S_{15}	01	11	Drop	Loss
S_{16}	01	00	No Loss	Recovered

Table 1 describes the 16 state transitions S_1 to S_{16} as shown in Figure 2 [16]. For example, consider state transition S_2 which represents a transition from state 00 to 10. At state 00, both channels 1 and 2 are in the "Good" state, while at state 10, channel 1 is in the "Bad" state and channel 2 in the "Good" state.

D. Composite Channel Model for MDC

This paper proposes a new channel model referred as composite channel which uses a combination of the modified version of the existing channel model as described in [16] and Equation (7) and (9) derived previously in section B. With the composite channel model state transition, S_{15} represents a transition from state 01 to 10 as compared to the channel model in [16], where S_{15} represents a transition from state 01 to 11. In addition, the "Good" and "Bad" states in this paper have been derived using the assumptions described in section B. The flowchart illustrating the new composite channel algorithm used for generating the good and bad state for MDC is given in Figure 3.

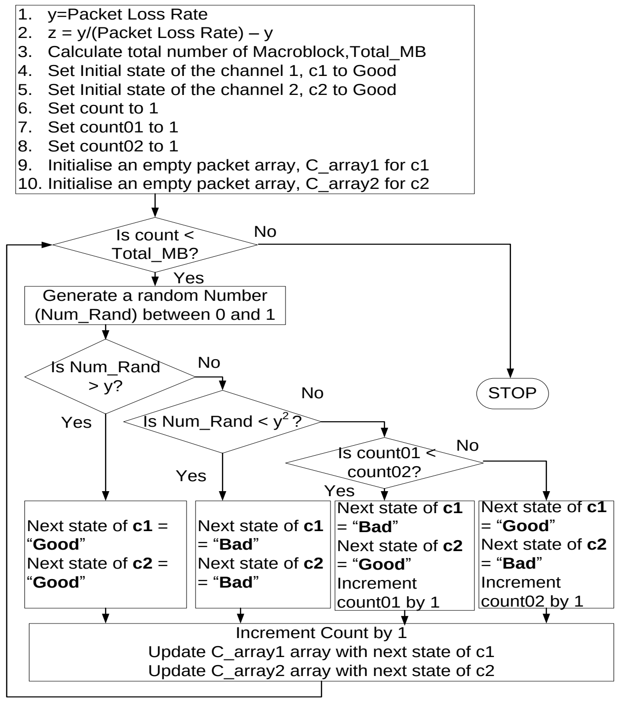

Figure 3: Flowchart illustrating the composite channel algorithm

For each MB, which is transmitted over the channel, a channel state array is generated which determines whether the MB is lost or correctly received and count is incremented by 1. count01 and count02 are used to determine whether a transition will occur to either "01" or "10". Total_MB represents the total number of MBs, which are transmitted over the channel. The initial status of the channels c1 and c2 is set to 1 which represents a "Good" state. Two empty channel state arrays, C_array1 and C_array2 are initialised. y is set to the packet loss rate of the channel and z is calculated using Equation (10).

First, the algorithm checks whether count is less than Total_MB. If so, a random number, Num_rand, between 0 and 1 is generated. If Num_rand is greater than y, the next state of both the channels c1 and c2 is set to "Good". Otherwise, if Num_rand is less than y^2 next state of both the channels c1 and c2 is "Bad". Or else, if Num_Rand is more than y^2 and less than y, transition will occur to either 01 or 10 which is determined by values of count01 or count02. In that case, if count01 is less than count02, the next state of channel 1, c1 is set to "Bad" and channel 2, c2 is set to "Good". In addition, count01 is incremented by 1. Otherwise if count01 is greater than count02, the next state of channel 1, c1 is set to "Good" and channel2, c2 is set to "Bad". Then, count02 is incremented by 1. After each iteration, count is then incremented by 1. Furthermore, C_array1 and C_array2 are updated with the new state of the channel. Lastly, if count is greater than Total_MB, the algorithm stops. The output of this algorithm is two channel state arrays, C_array1 and C_array2 of size Total_MB with values 0 or 1. “0” indicates that the packet is lost and “1” represents that the packet received correctly.

E. ST-FMO

ST-FMO is a recently proposed FMO technique in [5] which greatly increases the number of spatial and temporal neighbouring MBs to ensure a more effective error concealment of lost MB. This new ST-FMO method functions in two stages. In the first stage, ECW-FMO [9] is applied to each frame in order to achieve spatial FMO [5]. In the second stage, the frames are shuffled within a GOP in such a way that no successive frames are transmitted together [5].

F. Prioritised Concealment using auto-correlation

Over the years, prioritizing error concealment of lost MBs has proved to be a viable solution to reduce the effect of channel errors. In [5], a novel prioritized concealment technique was proposed which used the auto-correlation function to determine the order of concealment. This technique calculates the extent of similarity between spatial or temporal MBs [5].

For I-Frames, the similarity between two MBs was determined using the Intraframe Autocorrelation algorithm, A_I, and is calculated using Equation (11) [5, 24]:

$$A_I = \frac{\sum_m \sum_n \left(Y_p(s,t) - \mu_Y\right)\left(Z_p(s,t) - \mu_Z\right)}{\sqrt{\sum_m \sum_n \left(Y_p(s,t) - \mu_Y\right)^2 \sum_m \sum_n \left(Z_p(s,t) - \mu_Z\right)^2}} \tag{11}$$

where, A_I = correlation coefficient.
$Y_p(s,t)$ = First block of pixels.
$Z_p(s,t)$ = Second block of pixels.
s and t = Pixel positions.
μ_Y and μ_Z = The mean values of $Y_p(s,t)$ and $Z_p(s,t)$

Using Equation (11), the correlation between the surrounding MBs of the lost MB is computed. Therefore, the higher the correlation value between the two MBs, the higher the similarity between them. The average Intraframe autocorrelation, AV_C of all the Wt MBs around the lost MB was calculated as follows [5, 24]:

$$AV_C = \frac{1}{W_t} \sum_{i=1}^{W_t} A_I^{\,i} \tag{12}$$

where: Wt = total number of MBs surrounding the lost MBs.

AV_c is then calculated for all the lost MBs. The order of concealment of the MBs in an I-Frame will depend on its AV_c value where the MB having the highest AV_c value will be concealed first [5, 24].

For P-Frames, temporal correlation is used whereby interframe correlation, A_{It} is calculated using the Equation (13) and (14) [5, 24].

$$A_{It} = \frac{\sum_m \sum_n \left(U_p(s,t) - \mu_{U_p}\right)\left(U_{p-1}(s,t) - \mu_{U_{p-1}}\right)}{\sqrt{\sum_m \sum_n \left(U_p(s,t) - \mu_{U_p}\right)^2 \sum_m \sum_n \left(U_{p-1}(s,t) - \mu_{U_{p-1}}\right)^2}} \tag{13}$$

where : A_{It} = correlation coefficient between adjacent MBs represented by U_p and U_{p-1} [24].
U_p = current frame.
U_{p-1} = previous frame
μ_{U_P} and $\mu_{U_{p-1}}$ = The mean values of $U_p(s,t)$ and $U_{p-1}(s,t)$.

Therefore, the average Interframe autocorrelation, AV_{CP} is calculated as follows:

$$AV_{CP} = \frac{A_{It}^{\,1} + A_{It}^{\,2} + A_{It}^{\,3} + A_{It}^{\,4}}{4} \tag{14}$$

where: $A_{It}^{\,1}$ = correlation between two adjacent MBs, MB_1 and MB_2.
MB_1 = MB located on top of the lost MB from the current frame.
MB_2 = MB located adjacent of MB_1 from the previous frame.

Similarly, $A_{It}^{\,2}$, $A_{It}^{\,3}$ and $A_{It}^{\,4}$ represent the correlation between MBs found on the right, left and bottom of the lost MB respectively and their corresponding adjacent MBs from the previous frame. Further details about the autocorrelation algorithm are given in [5].

III. PROPOSED SYSTEM

A. Proposed Encoder

This paper proposes a novel combination of an existing MDC scheme as described in [18] with ST-FMO [5] which enhances the performance of error concealment of corrupted MBs. Moreover, this paper also uses a prioritisation scheme using auto-correlation of neighbouring pixels as proposed in [5]. In this work, the same concealment selection algorithm was used as explained in [5] where Frequency Selective Extrapolation (FSE) [25] was used for spatial concealment whereas Lagrange Interpolation (LI) [26] has been used for temporal concealment.

In Figure 4, the encoder of the proposed system is shown. The first step consists of the conversion of the video sequence containing X frames into Y GOPs each having length L_G using the Equation (15) as shown [5, 27].

$$X = Y \times L_G \tag{15}$$

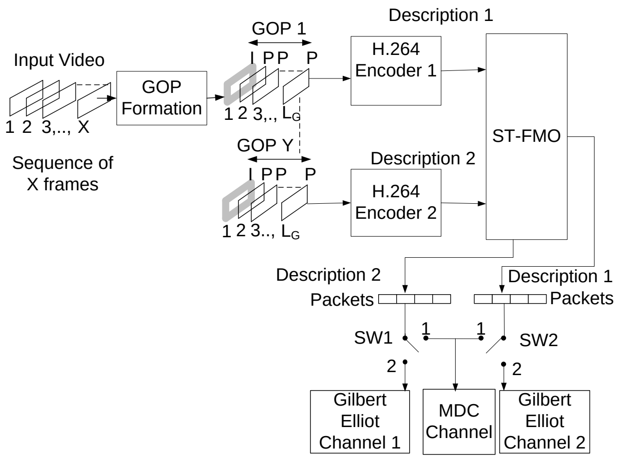

Figure 4: Proposed Encoder with MDC

Each GOP is processed separately by two separate encoders, Encoder 1 and Encoder 2. Encoder 1 processes odd numbered frames and even numbered Motion Vectors whereas Encoder 2 processes even numbered frames and odd numbered Motion Vectors to create two descriptions. ST-FMO is applied to each description before transmission over either a Gilbert Elliot Channel by placing switches SW1 or SW2 in position 2 or the composite channel model where both switches SW1 and SW2 will be in position 1. This technique is proposed to further enhance the transmission of the H.264 encoded bitstream over erroneous channels. When ST-FMO is used in conjunction with MDC, the MBs are propagated across a GOP which avoids transmission of consecutive MBs. Consequently, this technique prevents neighbouring MBs to get corrupted which allows efficient concealment of a lost MB using its correctly received neighbours.

B. Proposed Decoder

Figure 5 represents the decoder for the proposed scheme. After transmission over either a Gilbert Elliot channel or the composite channel model, the system uses inverse ST-FMO to re-organize the packets in such a way that restores the initial positions of the packets. Then, each description is processed by the decoders, Decoder 1 and Decoder 2 to produce two outputs, Output 1 and Output 2 respectively. Output 1 contains odd numbered Frames and even numbered Motion Vectors and Output 2 consists of even numbered Frames and odd numbered Motion Vectors. The two outputs are then interleaved in order to obtain a video sequence of continuous frames as well as an array of Motion Vectors. Prior to concealment, prioritization of concealment using auto-correlation [5] is then used to determine the order of concealment of the MBs based on their autocorrelation value. This process ensures a more efficient concealment of the MBs. Finally, each MB is concealed using a concealment algorithm, where either FSE [25] or LI [26] concealment method is selected adaptively using a concealment selection algorithm [5]. For I frames, spatial concealment is used whereas for P frames temporal concealment is used.

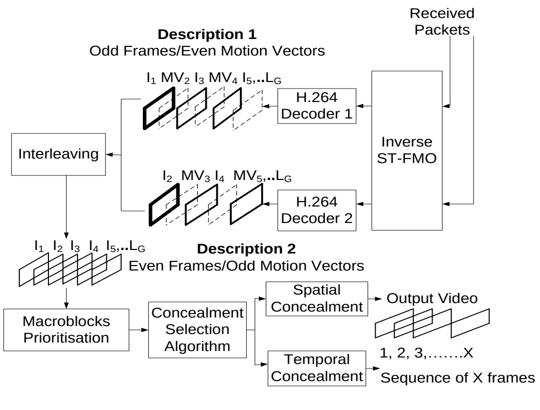

Figure 5: Proposed Decoder with MDC

C. ST- FMO scheme with MDC

Figure 6 describes the ST-FMO scheme [5] with MDC. Essentially, it is the temporal shuffling of the frames which is changed by taking into consideration transmission over two channels, Gilbert Elliot channel model and composite channel model. Each GOP is passed through separate encoders, encoder 1 and encoder 2 to produce two descriptions, description 1 and description 2 respectively. Description 1 contains odd numbered frames and even numbered motion vectors. Description 2 contains even numbered frames and odd numbered motion vectors. Each description is transmitted through either a Gilbert Elliot path or composite channel. Using ST-FMO, the order of transmission of the frames within each GOP is changed as per the below algorithm:

i. Receive Original_GOP
   % Original_GOP represents a GOP containing a sequence of Frames
ii. Calculate GOP_length
   % The length of the GOP, Original_GOP is calculated
iii. Set Index = 2
   % Initial Index is set to 2 so that the second frame within the GOP, Original_GOP is transmitted first.
iv. for i= 1:GOP_length
   % Each Frame within Original_GOP is reordered.
v. Reorder_GOP(1,Index) = Original_GOP(1,Index)
   % The order of the Frame is changed to form a new GOP, Reorder_GOP.
vi. Index = Index + 2;
   % Increment Index by 2 so that the fourth frame is sent next followed by the sixth frame and so on.
vii. if (Index > GOP_length)
   % Checks whether the GOP_len is exceeded.
viii. Set Index = 1;
   % If GOP_len is exceeded, continue transmission now starting from the first frame followed by the third frame and so on.
ix. end
x. end

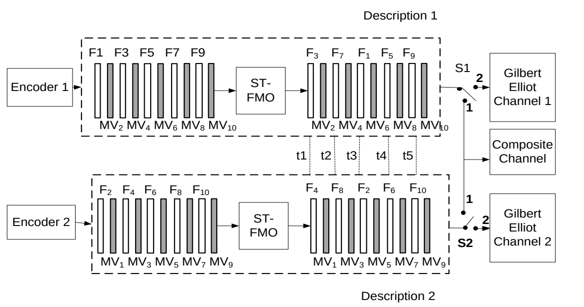

Figure 6: Proposed ST- FMO with MDC

The main objective of this algorithm is to ensure that no two consecutive frames within a GOP are transmitted together. This is because at high packet loss rates, the burst errors are longer and occur more frequently which may cause errors to propagate across two consecutive frames.

Consider a loss scenario as shown in Figure 7, where burst errors occur at time instant t2 and t3 during transmission of Description 1 and time instant t1 and t2 during transmission of Description 2.

Using the conventional scheme (no ST-FMO) from Figure 7, it can be observed that Frame 2, 3, 4 and 5 from both descriptions are lost. Frame 2 can be concealed using spatial concealment as it is encoded as an I-Frame in the second description. In addition, Frame 5 can be concealed using Frame 6 (next frame) as reference frame. Frame 3 can be concealed using either Frame 2 or Frame 4, and Frame 4 can be concealed using either Frame 3 or Frame 5. Therefore, it is quite a challenging task to conceal Frame 3 and Frame 4, since their reference frames are affected by burst errors.

Using the ST-FMO scheme as shown in Figure 8, where the frames are not transmitted consecutively, it can be observed that at the same time instants from Figure 8, Frames 7, 1, 4 and 8 are affected by burst errors. Frame 1 is concealed using spatial concealment. With this method, all the remaining frames can be concealed using either the previous or next frames for temporal concealment. For example, Frame 8 can be concealed using frame 9 (next frame) as reference frame as Frame 7 is also corrupted.

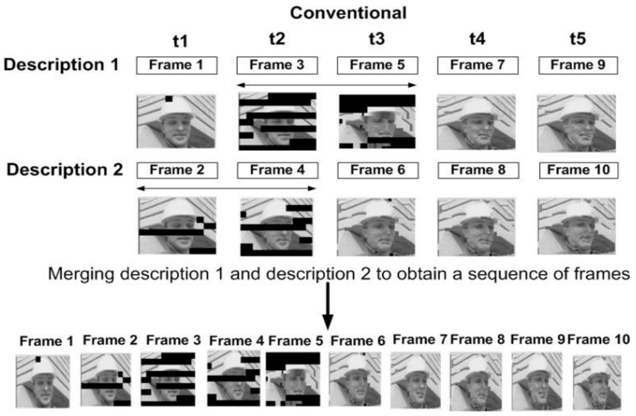

Figure 7: Illustration of a typical loss scenario of a GOP using a conventional scheme with Packet Loss Rate of 0.2.

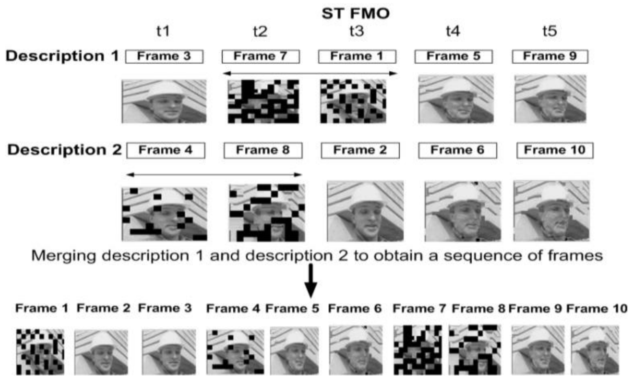

Figure 8: Illustration of a typical loss scenario of a GOP using ST-FMO with MDC with Packet Loss Rate of 0.2.

IV. Simulations and Results

In order to evaluate the performance of the proposed technique, nine different schemes as described in [5] have been compared. In [5], all the nine schemes were simulated with Single Description Coding. For instance, in this paper the performance of the nine schemes outlined in Table 2 has been analyzed by using MDC. The schemes have been simulated using Matlab with the Foreman and Akiyo video sequences each consisting of 300 frames with GOP length of 15. Each frame is of size 144x176 pixels and a rate of 25 frames per second has been used. In Table 2, a brief description of each of the nine schemes is given [5].

For example, with Scheme 1, ST-FMO [5] has been used with autocorrelation as prioritization [5] whereas Scheme 5 uses ECW-FMO of [9] along with Impact Factor [13] as prioritization technique. Scheme 9 represents a conventional scheme where neither FMO nor prioritization technique is used. In all the simulations, FSE [30] and LI [31] concealment techniques were used. For spatial concealment FSE [30] was used whereas for temporal concealment LI [31] was used [5].

Table 2
Schemes Tested [5]

Scheme	Type of FMO	Type of Prioritization
1	ST-FMO[5]	Autocorrelation[5]
2	ECW-FMO[9]	Autocorrelation[5]
3	No FMO	Autocorrelation[5]
4	ST-FMO[5]	Impact Factor[13]
5	ECW-FMO[9]	Impact Factor[13]
6	No FMO	Impact Factor[13]
7	ST-FMO[5]	No Prioritisation
8	ECW-FMO[9]	No Prioritisation
9	No FMO	No Prioritisation

Table 3
Conditions for the schemes tested.

Condition	Video Sequence	Channel Type
1	Foreman	Gilbert Elliot
2	Akiyo	Gilbert Elliot
3	Foreman	Composite
4	Akiyo	Composite

All the schemes have been tested using the four conditions as shown in Table 3. For example, with Condition 1, Foreman video sequence was used with MDC. Each description was transmitted over a Gilbert Elliot Channel model. While with Condition 4, Akiyo video sequence was transmitted over the composite channel model. The performance of the nine different schemes for each of the above four conditions has been given in Table 4, 5, 6 and 7 for packet loss rates of 0.2 and 0.4 and the graphs of Y-PSNR (dB) against Packet loss Rate have been plotted for only three main schemes: Scheme 1, Scheme 5 and Scheme 9 to ensure better visual clarity.

A. Simulation Results using Condition 1: MDC with Gilbert Elliot Channel using Foreman Sequence.

Table 4 shows the results with MDC using two Gilbert Elliot Channel models obtained for the nine schemes. All nine schemes were tested with a Foreman video sequence. The results obtained at two Packet Loss Rates of 0.2 and 0.4 are shown in Table 4.

Table 4
Results using Gilbert Elliot Channel Model with Foreman Sequence

Scheme	GOP 15	
	Packet Loss Rate = 0.2	Packet Loss Rate = 0.4
Scheme 1	17.7850	14.7310
Scheme 2	17.7266	14.6331
Scheme 3	17.7223	14.6195
Scheme 4	17.4491	14.2927
Scheme 5	17.4013	14.2332
Scheme 6	17.3970	14.2063
Scheme 7	17.4243	14.2142
Scheme 8	17.2885	14.1106
Scheme 9	17.1382	14.1093

Figure 9 represents a graph of Y-PSNR against Packet Loss Rate during MDC transmission using two Gilbert Elliot channels with a GOP length of 15. It is observed that Scheme 1 provides an average gain of **0.44** dB over Scheme 5 in the range of $0.1 \leq$ Packet Loss Rate ≤ 0.4. Over the same range, Scheme 1 also outperforms Scheme 9 by **0.63** dB. It is also observed that at a packet loss rate of 0.2, Scheme 1 outperforms Scheme 5 and Scheme 9 by 0.38 dB and 0.65 dB respectively.

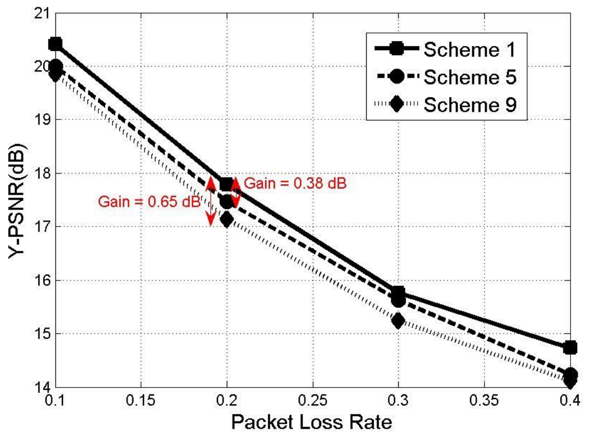

Figure 9: Graph of Y-PSNR against Packet Loss Rate with GOP length = 15 using MDC and Gilbert Elliot channel model for the Foreman sequence

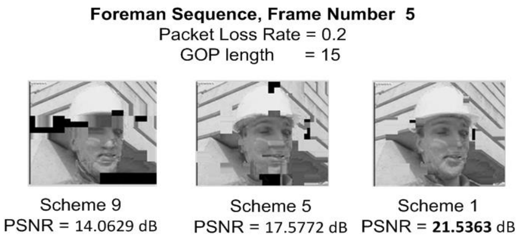

Figure 10: Comparison in Video frame quality of Foreman sequence using Scheme 1, Scheme 5 and Scheme 9

Figure 10 shows the comparison in visual quality using Scheme 1, Scheme 5 and Scheme 9. It can be seen that Scheme 1 provides better visual quality of the frame and highest PSNR value 21.5363 dB.

B. Simulation Results using Condition 2: MDC with Gilbert Elliot Channel using Akiyo Sequence.

Table 5 shows the results with MDC using two Gilbert Elliot Channel models obtained for the nine schemes. All nine schemes were tested with the Akiyo video sequence. The results obtained at two Packet Loss Rates of 0.2 and 0.4 are shown in Table 5.

Table 5
Results using Gilbert Elliot Channel Model with Akiyo Sequence

Scheme	GOP 15	
	Packet Loss Rate = 0.2	Packet Loss Rate = 0.4
Scheme 1	24.3882	14.3430
Scheme 2	24.3648	14.2359
Scheme 3	24.3573	14.1680
Scheme 4	22.1568	13.2727
Scheme 5	22.0509	13.2170
Scheme 6	22.0451	13.1916
Scheme 7	20..7558	10.6552
Scheme 8	20.7523	10.6414
Scheme 9	20.2690	10.6184

Figure 11 is the graph of Y-PSNR against Packet Loss Rate with MDC transmission over the Gilbert Elliot channel a GOP length of 15. It is observed that Scheme 1 provides an average gain of **1.94** dB over Scheme 5 in the range of $0.1 \leq$ Packet Loss Rate ≤ 0.4. Over the same range, Scheme 1 also outperforms Scheme 9 by **3.38** dB. It is also observed that at a packet loss rate of 0.2, Scheme 1 outperforms Scheme 5 and Scheme 9 by 2.34 dB and 4.12 dB respectively.

Figure 12 shows the comparison in visual quality using Scheme 1, Scheme 5 and Scheme 9. It can be seen that Scheme 1 provides better visual quality of the frame and highest PSNR value of 28.2509 dB.

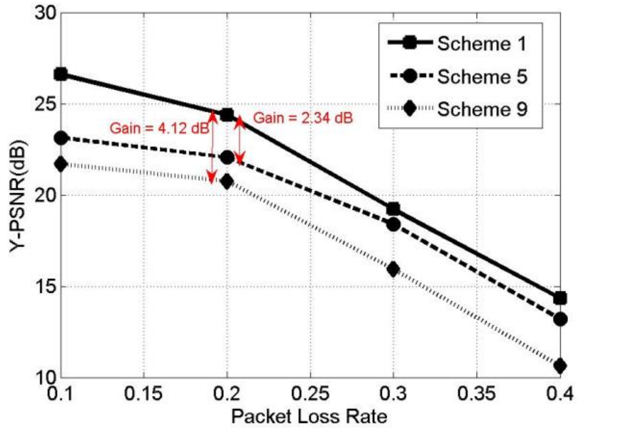

Figure 11: Graph of Y-PSNR against Packet Loss Rate with GOP length = 15 using MDC and Gilbert Elliot channel model for the Akiyo sequence

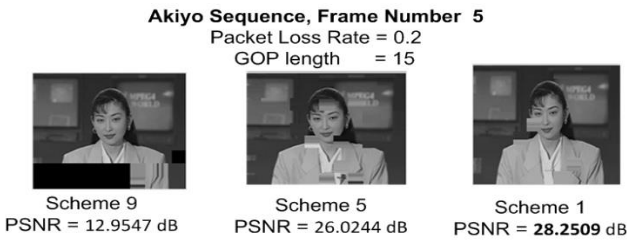

Figure 12: Comparison in Video frame quality of Foreman sequence using Scheme 1, Scheme 5 and Scheme 9

C. Simulation Results using Condition 3: MDC with Composite Channel using Foreman Sequence.

Table 6 shows the results with MDC using the composite Channel model obtained for the nine schemes. All nine schemes were tested with a Foreman video sequence. The results obtained at two Packet Loss Rates of 0.2 and 0.4 are shown in Table 6.

Table 6
Results using the Composite Channel Model with Foreman Sequence

Scheme	GOP 15	
	Packet Loss Rate = 0.2	Packet Loss Rate = 0.4
Scheme 1	20.9513	18.0633
Scheme 2	20.9014	18.0330
Scheme 3	20.8670	18.0116
Scheme 4	20.5656	17.5076
Scheme 5	20.4614	17.4511
Scheme 6	20.3775	17.4322
Scheme 7	19.7613	16.8920
Scheme 8	19.5944	16.8879
Scheme 9	19.5305	16.8460

Figure 13 shows Graph of Y-PSNR against Packet Loss Rate with a GOP length of 15 using MDC and the composite channel model for the Foreman sequence. It is observed that Scheme 1 provides an average gain of **0.75** dB over Scheme 5 in the range of $0.1 \leq$ Packet Loss Rate ≤ 0.4. Over the same range, Scheme 1 also outperforms Scheme 9 by **1.24** dB. It is also observed that at a Packet Loss Rate of 0.2, Scheme 1 outperforms Scheme 5 and Scheme 9 by 0.49 dB and 1.42 dB respectively.

Figure 14 shows the comparison in visual quality using Scheme 1, Scheme 5 and Scheme 9. It can be seen that Scheme 1 provides better visual quality of the frame and highest PSNR value of 24.8622 dB.

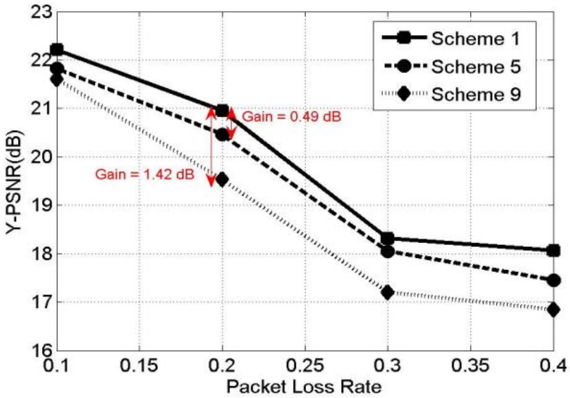

Figure 13: Graph of Y-PSNR against Packet Loss Rate with GOP length = 15 using MDC and the Composite channel model for the Foreman sequence

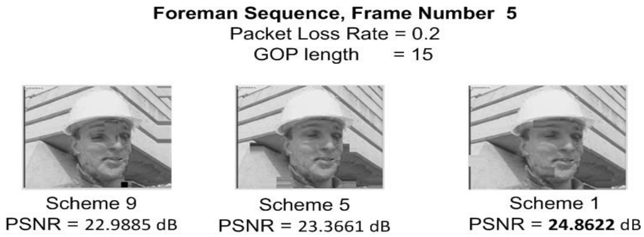

Figure 14: Comparison in Video frame quality of Foreman sequence using Scheme 1, Scheme 5 and Scheme 9

D. Simulation Results using Condition 4: MDC with Composite Channel using Akiyo Sequence.

Table 7 shows the results with MDC using the composite Channel model obtained for the nine schemes. All nine schemes were tested with the Akiyo video sequence. The results obtained at two Packet Loss Rates of 0.2 and 0.4 are shown in Table 7.

Table 7
Results using the Composite Channel Model with Akiyo Sequence

Scheme	GOP 15	
	Packet Loss Rate = 0.2	Packet Loss Rate = 0.4
Scheme 1	25.3683	19.7256
Scheme 2	25.1289	19.6546
Scheme 3	24.9945	19.6078
Scheme 4	24.1191	18.7985
Scheme 5	23.7990	18.7145
Scheme 6	23.7981	18.7040
Scheme 7	23.9319	18.3820
Scheme 8	23.6056	18.3618
Scheme 9	23.5309	18.1991

Figure 15 represents a graph of Y-PSNR against Packet Loss Rate with MDC transmission using the composite channel model. It is observed that Scheme 1 provides an average gain of **1.29** dB over Scheme 5 in the range of 0.1 ≤ Packet Loss Rate ≤ 0.4. Over the same range, Scheme 1 also outperforms Scheme 9 by **2.03** dB. It is also observed that at a Packet Loss Rate of 0.2, Scheme 1 outperforms Scheme 5 and Scheme 9 by 1.57 dB and 1.84 dB respectively. In Figure 15, the straight line drawn at a Y-PSNR of 25.5 dB represents the target Y-PSNR which will be used for determination of the expected throughput in section E.

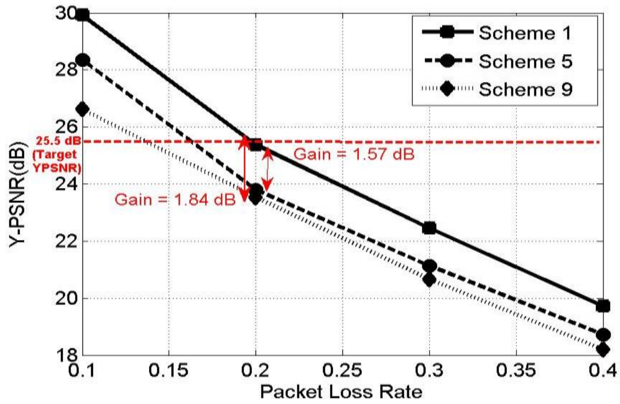

Figure 15: Graph of Y-PSNR against Packet Loss Rate with GOP length = 15 using MDC and the Composite channel model for the Akiyo sequence

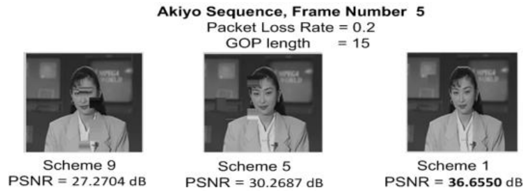

Figure 16: Comparison in Video frame quality of Foreman sequence using Scheme 1, Scheme 5 and Scheme 9

Figure 16 shows the comparison in visual quality using Scheme 1, Scheme 5 and Scheme 9. It can be seen that Scheme 1 provides better visual quality of the frame and highest PSNR value of 36.6550 dB.

E. Throughput and Complexity analysis

Figure 17 represents the graph of expected throughput against Packet Loss Rate for the results obtained using Condition 4. The target Y-PSNR is set to 25.5 dB as shown in Figure 15. The expected throughput is calculated as follows:

$$\textit{Expected Throughput} = 100\ [1 - (A_{loss} - T_{loss})] \quad (16)$$

where: A_{loss} represents the actual loss.
T_{loss} represents the tolerable loss.

The difference between the actual and the tolerable loss represent the percentage of the packets that needs to be retransmitted to achieve the target Y-PSNR of 25.5 dB.. Hence, this leads to a loss in throughput. For example, in Figure 15 at a Packet Loss Rate (Actual loss) of 0.2, Scheme 1 has a Y-PSNR value of 25.3683. This implies that it has achieved the target Y-PSNR of 25.5 dB. Scheme 5 and scheme 9 have Y-PSNR values of 23.7990 dB and 23.5309 dB respectively. Therefore, both Scheme 5 and 9 have not achieved the target Y-PSNR of 25.5 dB. In addition, it can also be observed that at a packet loss rate of 0.15, Scheme 5 surpassed the target Y-PSNR. Therefore, 5 % of the MBs needs to be retransmitted to reduce the loss to 0.15.In this case, T_{loss} is 0.15. On the other hand, scheme 9 was able to achieve the target Y-PSNR of 25.5 dB at a packet loss rate of 0.1 dB which implies that T_{loss} is 0.1 for Scheme 5 and 10 % of the MBs needs to be retransmitted to reduce the loss to 0.1. Therefore, at a packet loss rate of 0.2, the expected throughput for each scheme can be calculated using equation 16.

Expected throughput for Scheme 1 = 100-(0.2-0.2) = 100%. Expected throughput for Scheme 5 = 100-(0.2-0.15) = 95%. Expected throughput for Scheme 9 = 100-(0.2-0.1) = 90%.

Similarly, the expected throughput was calculated for the range of $0.1 \leq$ Packet Loss Rate ≤ 0.4 for Schemes 1, 5 and 9 as shown in Figure 17. From Figure 17, it can be observed that Scheme 9 experiences a constant loss in throughput to achieve the target Y-PSNR. Hence, it can be seen from Figure 17 that the proposed scheme (Scheme 1) provides better throughput as compared to Scheme 5 and Scheme 9.

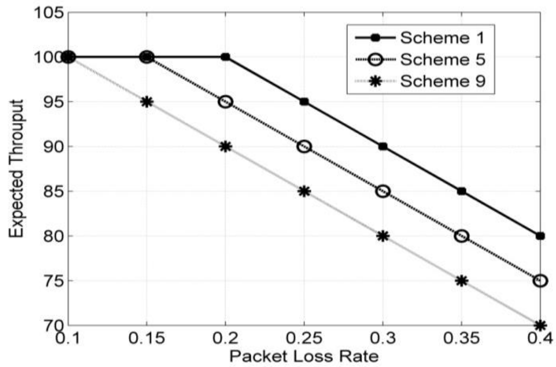

Figure 17: Throughput Analysis

There is a minor increase in complexity in both the encoder and decoder of the proposed system since it involves the creation of two descriptions and the reordering of MBs. Nonetheless, the results have also shown that significant gains have been obtained using the proposed scheme as compared to a conventional scheme. However, the compression is not impacted since both MDC and ST-FMO have been performed after the H.264 encoding when all the frames have been converted into bits. In other words, MDC and ST-FMO is applied after all the coefficients have been converted into bits.

V. Conclusion

This paper presents a novel framework for H.264 video transmission where MDC is used in conjunction with a newly developed prioritised concealment and ST-FMO. This new combination of MDC with ST-FMO and prioritised concealment has proved to be a very efficient method to address the issue of burst errors on H.264 compressed video transmission over unreliable communication channels. On the other hand, prioritised concealment uses the autocorrelation algorithm to calculate the order of concealment of the lost MBs. A comparative analysis of the proposed scheme was performed against eight schemes with a GOP length of fifteen using the Foreman and Akiyo sequences. The simulations results when using the Akiyo sequence over the Gilbert Elliot channel model have shown that the proposed scheme achieved a gain of 3.38 dB over a conventional scheme as compared to a gain of 1.94 dB when using an existing FMO and prioritization scheme. Therefore, it can be concluded that the combination of MDC with ST-FMO and prioritised concealment have proven to be a powerful technique in reducing the effect of burst errors. Video applications such as mobile TV, broadcasting, video conferencing and High Definition TV are highly prone to burst errors, which lead to poor Quality of Service. The proposed technique arranges the MBs in a GOP in such a way to avoid transmission of consecutive MBs. Therefore, in case of burst errors, no two consecutive MBs gets corrupted which allows concealment of the lost MB using the correctly received neighbouring MBs. Therefore, video applications could significantly benefit from the proposed scheme. Several interesting future works can be envisaged from this proposed technique. A straightforward future work would be to analyze the performance of the proposed scheme with H.265. Finally, a new concealment algorithm could be implemented for both spatial and temporal concealment, which could be tested with the proposed scheme.

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References

[1] T. Wiegand,, Draft ITU-T Recommendation and Final Draft International Standard of Joint Video Specification (ITU-T Rec. H.264 |ISO/IEC 14496-10AVC, ITU-T Rec.H.264 | ISO/IEC 14496-10AVC, 2003.

[2] B. Bross, W.-J. Han, J.-R. Ohm, G. J. Sullivan, and T. Wiegand, High Efficiency Video Coding (HEVC) Text Specification Draft 9, Joint Collaborative Team on Video Coding (JCT-VC) of ITU-T SG 16 WP 3 and ISO/IEC JTC 1/SC 29/WG 11, document JCTVC-K1003, Shanghai, China, Oct. 2012.

[3] Vcodex. (2016). An Overview of H.264 Advanced Video Coding. [online] Available at: https://www.vcodex.com/an-overview-of-h264-advanced-video-coding/ [Accessed 11 Sep. 2016].

[4] E. Richardson, *The H.264 Advanced Video Compression Standard.* Chichester: John Wiley & Sons, 2010.

[5] T P Fowdur, D Indoonundon and K M S Soyjaudah. "A Novel Prioritised Concealment and Flexible Macroblock Ordering Scheme for Video Transmission". *International Journal of Computer Applications* 150(6):35-42, September 2016.

[6] Prnewswire.com. (2016). Encoding.com Publishes its 2016 Global Media Format Report. [online] Available at: http://www.prnewswire.com/news-releases/encodingcom-publishes-its-2016-global-media-format-report-300208716.html [Accessed 11 Sep. 2016].

[7] M.B. Dissanayake and D. L. B. Abeyrathna "Performance Comparison of HEVC and H.264/AVC Standards in Broadcasting Environments". *Journal of Information Processing Systems*. vol.11, No.3, pp.483-494, September 2015

[8] Ahmed, A. "An optimal complexity H.264/AVC encoding for video streaming over next generation of wireless multimedia sensor network". *Signal, Image and Video Processing,* 10(6), pp.1143-1150,2016

[9] K. Psannis, Y. Ishibashi, "Efficient Flexible Macroblock Ordering Technique," *IEICE Transactions On Communications*. E91-B (2008) 2692-2701. doi:10.1093/ietcom/e91-b.8.2692.

[10] Majed M. Alhaisoni "An Enhanced Approach to Adaptive Video Streaming over P2P Networks", IJCSI International Journal of Computer Science Issues, Vo. 12, pp. 267- 274, 2015.

[11] S. M. Marvasti-Zadeh, H. Ghanei-Yakhdan and S. Kasaei, "A novel boundary matching algorithm for video temporal error concealment", International Journal of Image, Graphics, and Signal Processing, vol. 6, No. 6, pp. 1-10, 2014.

[12] X. Qian, G. Liu, and H. Wang, "Recovering Connected Error Region Based on Adaptive Error Concealment Order Determination", *IEEE Trans. Multimedia,* 11(4), pp.683-695,2009.

[13] Y. Dhondt, P. Lambert, R. Van de Wall, "A flexible macroblock scheme for unequal error protection," *Proceedings of the IEEE International Conference on Image Processing (ICIP '06*), pp. 829–832, 2006.

[14] N. Gadgil, H. Li , E. Delp, "Spatial subsampling-based multiple description video coding with adaptive temporal-spatial error concealment," *Picture Coding Symposium (PCS)*, pp. 90-94,2015.
[15] Tarakanov, O. Gushchina, "Analysis of multiple description coding algorithm with time division of video stream in task of multipoint videoconferencing," *Proc. of First Int. Scientific-Practical Conf. Problems of Infocommunications Science and Technology*, pp.85 -87, 2014.
[16] J. Apostolopoulos, W. Tan, S. Wee, G. Wornell., "Modeling Path Diversity for Multiple Description Video Communication," *IEEE International Conference on Acoustics, Speech, and Signal Processing*, pp. 2161-2164, 2002.
[17] J. Apostolopoulos, "Error-resilient video compression through the use of multiple states," *International Conference on Image Processing,* pp 352-355, 2000.
[18] G. Zhang and R. Stevenson, "Efficient error recovery for Multiple Description video coding," *ICIP 04: International conference on Image processing IEEE*, 2004.
[19] M. Kazemi, K. Sadeghi, S. Shirmohammadi, "A Mixed Layer Multiple Description Video Coding Scheme," *IEEE trans. Circuits and Systems for Video Technology,* 2012 : pp.202-215.
[20] N. Kamnoonwatana, D. Agrafiotis, C.N. Canagarajah, "Flexible adaptive multiple description coding for video transmission," *IEEE Trans. Circ. Syst. Video Technol.* 22 (1) (2012) 1-11.
[21] E. Gilbert, "Capacity of a Burst-Noise Channel," *Bell System Technical Journal*. 39 (1960) 1253-1265. doi:10.1002/j.1538-7305.1960.tb03959.x.
[22] E. Elliott, "Estimates of Error Rates for Codes on Burst-Noise Channels," *Bell System Technical Journal*. 42 (1963) 1977-1997. doi:10.1002/j.1538-7305.1963.tb00955.x.
[23] G. A. AL-Suhail, S.A. Subber, "Estimating MPEG-4 Video Transmission over Gilbert Wireless Channels," *Basrah Journal of Science,* pp. 6-19, 2013.
[24] K. Thyagarajan, *Image and Video Compresion with Matlab*, John Wiley & Sons,INC ., Publication, 2010.
[25] A. Kaup, K. Meisinger, T. Aach, Frequency selective signal extrapolation with applications to error concealment in image communication, AEU - International Journal Of Electronics And Communications. 59 (2005) 147-156. doi:10.1016/j.aeue.2005.03.015.
[26] J. Zheng and L. P. Chau, "A temporal error concealment algorithm for (H.264) using Lagrange interpolation," *Proceedings of the 2004 International Symposium on Circuits and Systems,* ISCAS 04, 2004 : pp. 133–136.
[27] T.P Fowdur, D. Indoonundon, S. Soyjaudah, "An enhanced framework for H.264 video transmission with joint prioritisation of retransmission and concealment order," *9th International Symposium on Communication Systems, Networks & Digital Signal Processing (CSNDSP)*, pp. 634-639,2014.