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A Concealment Aware UEP Scheme for H.264 using RS Codes

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Abstract

H.264/AVCis currently the most widely adopted video coding standard due to its high compression capability and flexibility. However, compressed videos are highly vulnerable to channel errors which may result in severe quality degradation of a video. This paper presentsa concealment aware Unequal Error Protection (UEP) scheme for H.264 video compression using Reed Solomon (RS) codes. The proposed UEP technique assigns a code rate to each Macroblock (MB) based on the type of concealment and a Concealment Dependent Index (CDI). Two interleaving techniques, namely Frame Level Interleaving (FLI) and Group Level Interleaving (GLI) have also been employed. Finally, prioritised concealment is applied in cases where error correction is beyond the capability of the RS decoder. Simulation results have demonstrated that the proposed framework provides an average gain of 2.96 dB over a scheme that used Equal Error Protection (EEP).

***Keywords**: H.264 video compression, RS codes, UEP, interleaving; prioritised concealment*

1. Introduction

With the emergence of highly sophisticated mobiles devices, there has been an explosive growth in video traffic. Video compression standards have constantly received high attention due to their ability to reduce the size of a video in order to meet the increasing bandwidth requirements of video traffic over the internet [1-3]. H.264 is today one of the most popular and most commonly adopted video compression standard among users. In 2013, H.265, which is the successor of H.264 was developed and has shown to provide up to 50% compression ratio as compared to H.264 [2]. However, H.264 is still the most widely utilised video compression standard due to its lower complexity and capability of providing excellent video quality. Several recent works on H.264 have been proposed in [4, 5, 6]. However, compressed videos are highly vulnerable to errors during transmission over communication channels. Therefore, there is a need to find solutions to cater for the problem of channel errors in order to ensure efficient transmission of compressed video over unreliable channels. Anerror correcting technique which has received consistently high attention during the last few decades is Reed Solomon codes introduced by I. S. Reed and G. Solomon in 1960 [7]. The basic idea behind the use of RS codes with H.264 video coding standard is to add redundant information to the original compressed video data with the aim to allow error detection and correction by the receiver in case errors might have occurred during transmission [8].Moreover, interleaving can be applied to the RS coded video data to improve the error correction capability of the RS decoder. An interesting approach is to apply UEP to the RS coded video packets based on the type of concealment which will be used for error correction. An outline of forward error correction codes and UEP techniques developed for H.264 video transmission is given next.

Over the past decade, many error correcting codes have been studied with the H.264 video coding standard in order to ensure better Quality of Service. An interesting concept using UEP Luby transform codes at the application layer and rate-compatible punctured convolutional codes at the physical layer was proposed in [9] for robust H.264 video transmission. Simulation results have shown that the proposed cross-layer forward error correction scheme surpassed other forward error correction schemes that used either UEP coding at the physical layer alone or equal error protection schemes at the application layer and the physical layer. For instance in [10], an effective error correction algorithm was proposed which used the H.264 codec in conjunction with turbo coding and experimental results have shown that the proposed technique

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produced higher Quality of Experience. In addition in [11], the authors proposed a novel point-to-point H.264 Video Streaming over IEEE 802.15.4 together with RS Error Correction. The results have demonstrated that real-time video streaming is achieved with more reliability [11].

The application of UEP with error correcting codes has proved to be a very powerful method of combatting the problem of packet losses over erroneous communication channels. For example in [12], a new trapezoidal UEP scheme was proposed which has shown to achieve higher robustness while reducing the coding redundancy as compared to a traditional UEP scheme. Moreover, the authors in [13], used the H.264 error resilient tool of data partitioning to apply UEP to different data partitions. Thesimulation results have shown that the proposed scheme in [13] demonstrated efficient adaptation to the network conditions and graceful reconstruction quality degradation against a large range of packet loss rate and available bandwidth. Along the same line, in [14], Expanding Window Random Linear Codes which are an UEP fountain coding scheme was proposed for H.264 slice-partitioned data and results have shown the effectiveness of using the proposed scheme for multimedia broadcast applications.

In this paper a novel concealment aware UEP scheme for H.264 using RS Codes is proposed. The proposed UEP technique assigns a code rate to each Macroblock (MB) based on two factors. The first factoris the type of concealment, spatial or temporal, which will be used in case of loss during transmission. The second factor is the Concealment Dependent Index (CDI) which determines the effectiveness of the concealment algorithm based on the location of the MB in a frame. In addition, two types of interleaving techniques referred as Frame Level Interleaving (FLI) and Group Level Interleaving (GLI) are also used with UEP to further improve the error correction capability of the RS decoder. Another concept referred as, prioritised concealment [15] is also applied in cases where error correction is beyond the capability of the RS decoder. Simulation results have demonstrated that the proposed framework provides an average gain of 2.96 dB over EEP. Moreover, with the use of prioritised concealment an additional gain of 0.96 dB is achieved. Results have also shown that FLI outperforms GLI by 4.17 dB at a packet loss rate of 0.2. However, at a packet loss rate of 0.4, GLI has shown to outperform FLI by 5dB.

The remainder of this paper is organized as follows. Section 2 presents the research method of the proposed framework. Section 3 demonstrates the experimental results and finally Section 4 draws some conclusions and scope for future works.

2. Research Method

In Figure 1 the encoder of the proposed framework is shown. The input to the encoder consists of the video sequence containing N frames. Each frame, which is made up of 99 MBs, is processed by the H.264 encoder to create 99 arrays of bits each representing a MB. Each sequence of bits of length, L_s is then converted into k symbols by the RS encoder using a bit rate, R_b, such that:

$$L_s = k \times R_b \tag{1}$$

Where:

L_s represents the length of a bitstream.krepresents the total number of symbols obtained.$R_b$is thenumber of bits per symbol.

After the transformation from bits to symbols, each symbol array is converted into a Galois field array before the code rate allocation is performed. In this work, a UEP scheme is proposed with RS codes such that the most important MBs are given higher protection. The importance of each MB is determined based on the type of concealment, spatial or temporal, used during H.264 encoding and the CDI which checks the location of each MB in a frame.

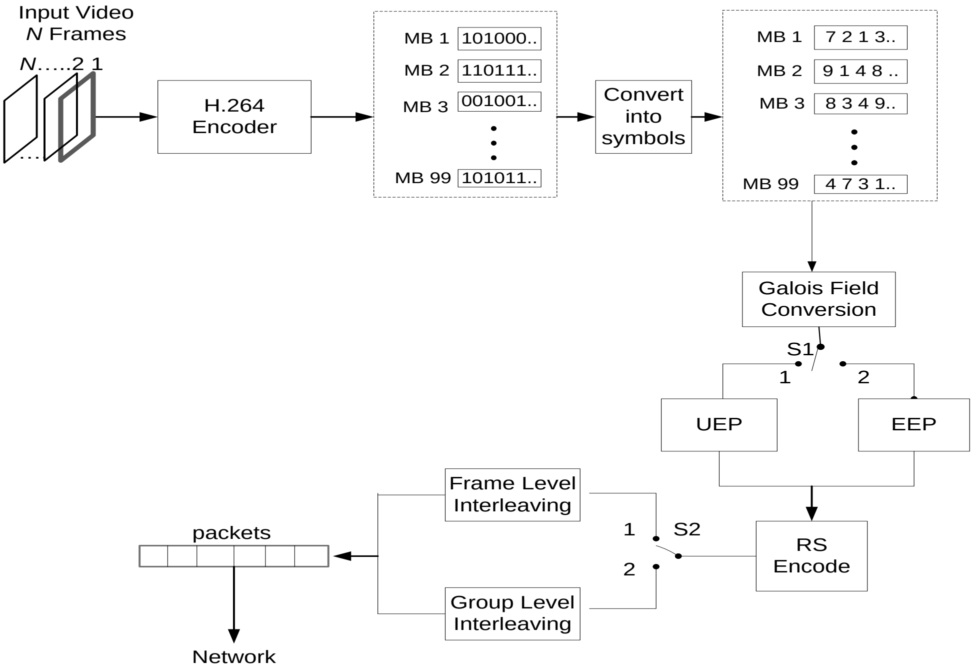


Figure 1. Proposed Encoder

To select the UEP scheme switch S1 is placed in position 1. For the EEP scheme, switch S1 is placed in position 2. The UEP scheme is further explained in section 2.1. During RS encoding, each symbol array of length k is converted into an array of length n, consisting of, n-k, parity symbols [7, 8]. In addition, two types of interleaving referred as Frame level Interleaving (FLI) and Group Level Interleaving (GLI) are performed. When using FLI, switch S2 is placed into position 1. To select FLI, packets are formed such that each one of them contains symbols from all the 99 MBs in a frame. With GLI, a frame is first divided into nine groups of 11 MBs and interleaving is performed across each group. For instance, a packet will contain symbols from a group of 11 MBs. This whole process is repeated for each frame after which the packets are transmitted over a communication channel. Further details on the interleaving schemes are given in section 2.2. Figure 2 illustrates the decoder of the proposed system.

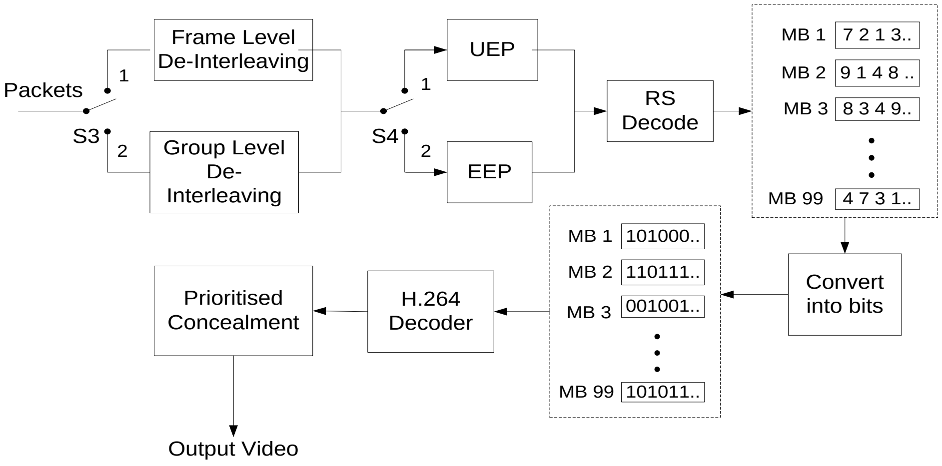


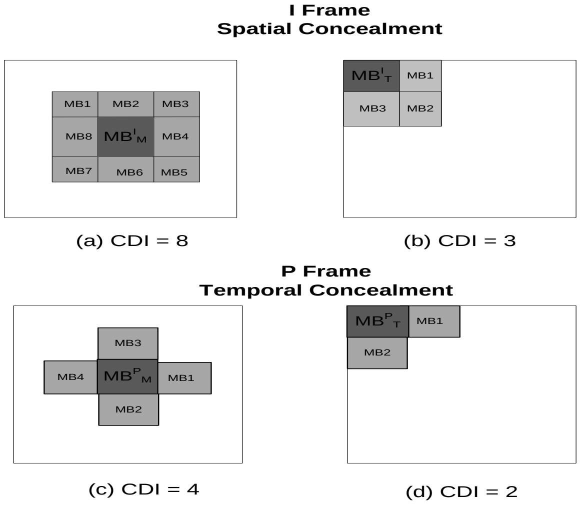
Figure 2. Proposed Decoder

De-Interleaving is first performed at the decoder so that the symbols are restored into their original positions. Either FLI or GLI de-interleaving is performed depending on the type of interleaving used at the encoder. If FLI de-interleaving is used switch S3 is placed at position 1. Otherwise, if GLI de-interleaving is used S3 is placed at position 2. RS decoding is then performed using either UEP or EEP. If the UEP scheme is used, S4 is placed in position 1 and for the EEP scheme, S4 is placed in position 2. RS decoding is then performed on each packet where error correction is performed. The RS decoder outputs arrays of symbols which are then converted into bits before sending them to the H.264 decoder. The H.264 decoder converts the bits into frames. Finally, prioritised concealment as proposed in [16] is performed.Concealment of MBs is required because at high packet loss rates, error correction might be beyond the capability of the RS decoder.

2.1. Unequal Error Protection (UEP)

In this work, UEP has been used with RS codes to offer higher protection to the most important MBs from packet loss. The importance of a MB is determined by two factors which is the type of concealment, either spatial or temporal, and the CDI value. In video compression, an I-frame represents a frame which is intra coded and is least compressed as compared to a P frame which is inter coded and more compressed. Therefore, an I frame needs to be given more protection as compared to a P frame which, in fact, uses the I frame as a reference frame for decoding. The CDI metric calculates the total number of MBs available to allow concealment of a lost MB. In this work, FSE [16] which is spatial concealment method is used for I frames and LI [17] which is a temporal concealment technique is used for P-Frames. For spatial concealment, a total of 8 neighbouring MBs are required for an effective concealment of a lost MB. On the other hand, for temporal concealment, 4 MBs located on the top, bottom, left and right of the lost MB is needed for concealment.

Figure 3 illustrates four MBs: MB^{I}_{M}, MB^{I}_{T}, MB^{P}_{M} and $MB^{P}_{T.}$ Figure 3(a) shows MB^{I}_{M} which is located in the middle of an I frame. Since MB^{I}_{M} is surrounded by 8 MBs, MB1, MB2, MB3, MB4, MB5, MB6, MB7 and MB8, in case MB^{I}_{M} is lost, all the surrounding MBs can be used for spatial concealment. Therefore CDI is 8 in this case. Figure 3(b) shows MB^{I}_{T} which is located in the topmost border of an I frame. MB^{I}_{T} is surrounded by only 3 MBs, MB1, MB2 and MB3. In case MB^{I}_{T} is lost only 3 MBs will be available to be used for concealment, therefore CDI is 3 in this case. Figure 3(c) shows MB^{P}_{M} which is located in the middle of a P frame. In case MB^{P}_{M} is lost during transmission, it requires four MBs located in the top, bottom, right and left for temporal concealment. Since MB^{P}_{M} islocated in the center, the neighbouring MBs: MB1, MB2, MB3 and MB4 can be used for concealment, therefore CDI is 4 in this case. Figure 3(d) shows MB^{P}_{T} which is located at the topmost border of a P frame. In case MB^{P}_{M} is lost during transmission, only two MBs, MB1 and MB2 are available to be used for temporal concealment. Therefore CDI is 2 in this case.



(a) CDI = 8 (b) CDI = 3

(c) CDI = 4 (d) CDI = 2

Figure 3. CDI for spatial and temporal concealment

Hence, to ensure an effective spatial concealment, the CDI of a lost MB must be 8. Furthermore, to achieve an efficient temporal concealment, the CDI of a lost MB must be 4. Hence, higher protection needs to be given to MBs with lower CDI to ensure that they are correctly received and can further be used for concealment of other MBs.

The rate assigned to each MB is given by Equation 2 [7, 8]:

$$Rate=\frac{k}{n} \tag{2}$$

Where:

k represents the length of the symbol array of a MB.n represents the length of the codeword after RS encoding.

Therefore, n consists of k data symbols and n-k parity symbols. The error correcting capability, t is given by Equation (3) [7, 8]:

$$t=\frac{(n-k)}{2} \tag{3}$$

From equation 2 and 3 it can be concluded that a high number of parity symbols leads to a greater error correcting capability of the RS decoder. Consequently, the lower the rate, the higher the number of parity symbols which can be used for error correction which therefore results in greater protection.

Figure 4 illustrates a flowchart which describes the UEP rate allocation process.

First, the algorithm checks whether the MB belongs to an I frame or a P frame. If it belongs to an I frame, higher protection is given to the MB. I-frame also implies that spatial concealment must be used. Next, the algorithm checks whether, the CDI of the MB is less than eight. If it is less than eight, this implies that in case of loss, the concealment of the MB will not be effective. Higher protection is therefore given to a MB with CDI less than 8. A lower rate is assigned to a P –frame as compared to an I frame. For a P frame if the CDI is less than 4, higher protection is given to the MB.

Rate 1 is assigned to the MB belonging to an I frame and having a CDI less than eight. Rate 2 is assigned to the MB belonging to an I frame and having a CDI of eight. Rate 3 is assigned to the MB belonging to a P frame and having a CDI less than four. Rate 4 is assigned to the MB belonging to a P frame and having a CDI of four.

In general, Rate 1 < Rate 2 < Rate 3 < Rate 4.

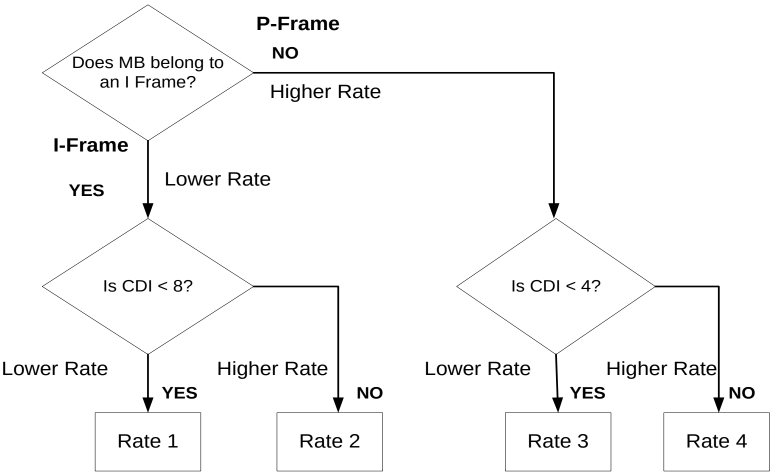


Figure 4. Flowchart Illustrating the Rate Allocation process

2.2. Interleaving

Consider for example a frame with 99 MBs as shown in Figure 5. In the interleaving block, packets are formed in such a way that each of them consists of symbols from either a group of 11 MBs referred as GLI or a whole frame consisting of 99 MBs namely FLI interleaving. This allows information pertaining to a specific MB to be propagated across several packets. In case of packet loss, the MB can be recovered with the information contained in the remaining correctly received packets. Therefore, with the use of the parity symbols, the RS decoder can perform error correction. A description of each interleaving scheme is given next.

2.2.1. FLI

Figure 5 illustrates the FLI interleaving process. Figure 5(a) shows a typical Foreman video frame of size 144x176 which is made up of 99 MBs each of size 16x16. In addition, each MB after RS encoding is represented by an array of length, n, which comprises of both data and parity symbols.

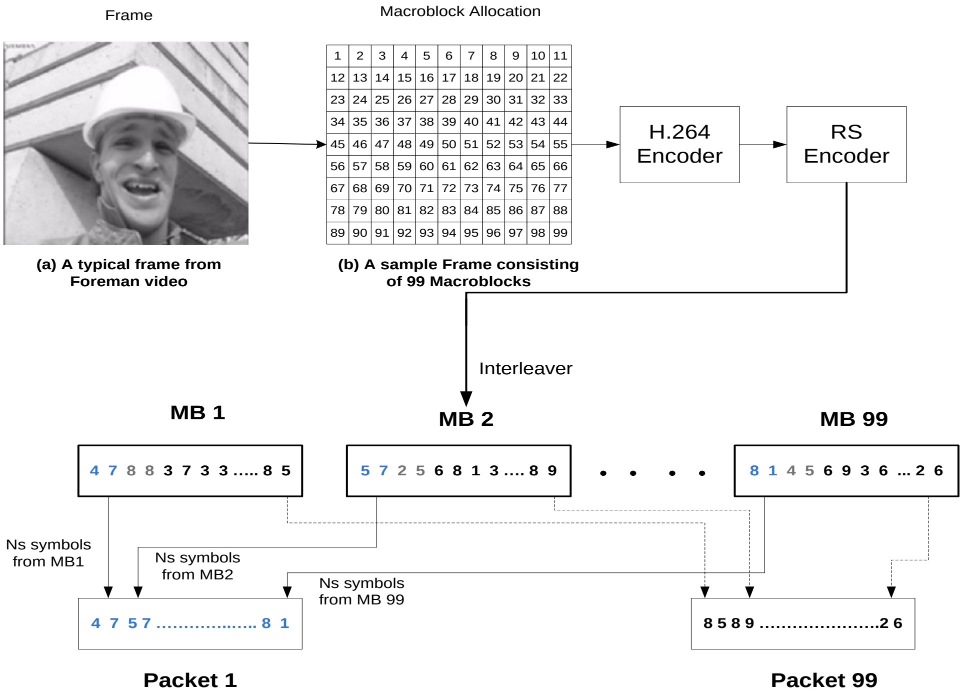
The idea behind FLI interleaving is to form packets made up of symbols from each of the 99 MBs. N_s which represents the number of symbols required from each MB to creates packet is obtained using equation (4) below:

$$N_s = \frac{n}{99} \qquad (4)$$

Where,

nrepresents the length of a symbol array representing a MB.

For example, in Figure 5, packet 1 is created by taking the first N_s symbols from each of the 99 MBs. This process continues until the last packet (packet 99) is created using the last symbols of length, N_s from each MB. After this process, all the symbols have been re-arranged to form 99 packets each of length n.



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

(a) A typical frame from Foreman video

(b) A sample Frame consisting of 99 Macroblocks

Figure 5. Illustration of Frame Level Interleaving process

2.2.2. GLI

Figure 6 illustrates the GLI process where a typical Foreman video frame of size 144x176 is made up of 9 rows (slices) each containing 11 MBs. With GLI, the MBs are first grouped to form 9 slices following which interleaving is performed across each slice. Therefore, in this case each packet is made up of $N_s$symbols belonging to 11 MBs. With GLI, N_s, is calculated as follows:

$$N_s = \frac{n}{11} \qquad (5)$$

For example in Figure 6, it can be observed that packet 1 is formed from the first symbols of length $N_s$obtained from each of the 11 MBs belonging to slice 1. Packet 11 is created by using the last symbols of length,N_s, from each of the 11 MBs. This process is repeated until all the 9 slices are interleaved to form 99 packets.

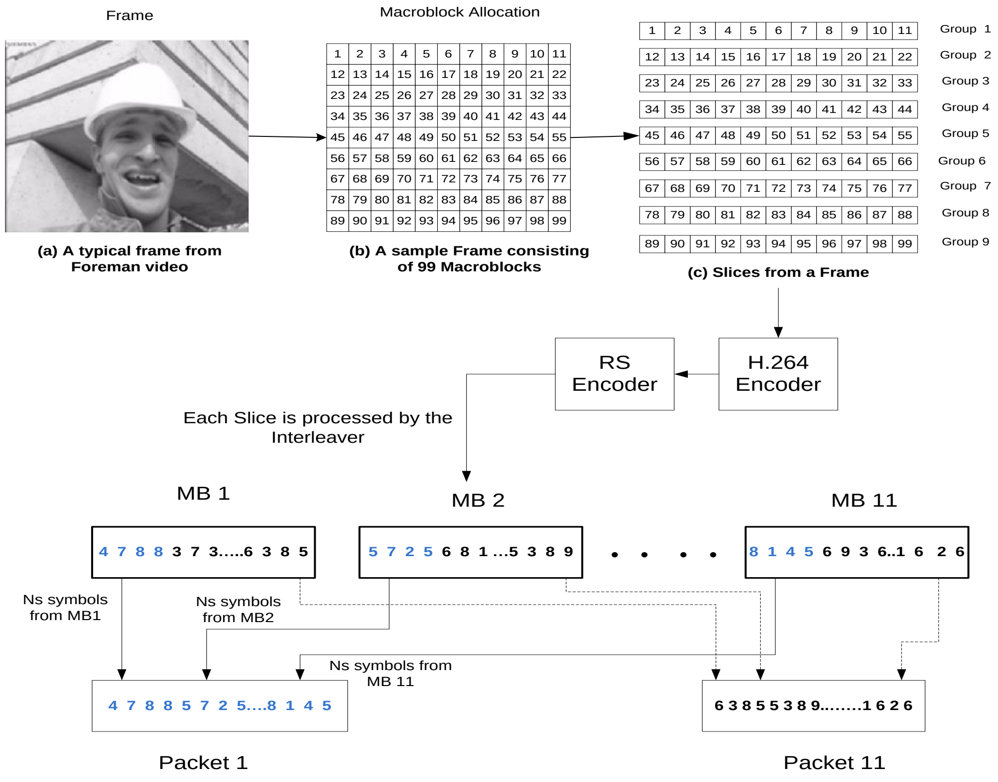


Figure 6. Illustration of Group Level Interleaving process

3. Results and Analysis

In line with the goals of this work, four different schemes have been compared. The list of parameters used for the simulations is given below:

Video Sequences : Foreman, News
Framerate : 25 frames per second
Number of Frames : 300
Frame size : 144x176
Channel Model : Gilbert Elliot Channel.

The schemes have been simulated using Matlab. The UEP and EEP rate allocation schemes for each video sequence are given in Table 1.

Table 1. Rate Allocation for UEP and EEP schemes

		Foreman Sequence		News Sequence	
		UEP Rate Allocation	EEP Rate Allocation	UEP Rate Allocation	EEP Rate Allocation
I Frame	CDI < 8	1/4	7/20	1/3	1/2
	CDI = 8	1/3	7/20	2/5	1/2
P Frame	CDI < 4	4/11	7/20	5/8	1/2
	CDI = 4	1/2	7/20	2/3	1/2

A brief description of each scheme is given in Table 2 where scheme 1 represents the proposed framework which uses UEP and prioritisation based on autocorrelation for concealment [15]. Scheme 2 uses UEP but does not employ prioritised concealment. Scheme 3 uses EEP and prioritised concealment whereas Scheme 4 utilises EEP but does not make use of prioritised concealment. In all the simulations, FSE [16] is used as spatial concealment and LI [17] is used as temporal concealment. The simulation is carried out with both FLI and GLI and the results are analysed.

Table 2. Schemes tested

Schemes	Rate Allocation		Prioritised Concealment
	UEP	EEP	
1	Yes	No	Yes
2	Yes	No	No
3	No	Yes	Yes
4	No	Yes	No

3.1. Results using FLI using Foreman and News Sequences

Figure 7 shows a graph of Y-PSNR against Packet Loss Rate for the Foreman sequence with GOP length = 3 using FLI. It is observed that scheme 1 which uses UEP and prioritised concealment provides an average gain of 2.98 dB over scheme 3 which uses EEP and prioritised concealment. This is because with UEP, higher protection is given to the most important MBs, hence the MBs are recovered correctly. In addition, scheme 1 provides an average gain of 0.96 dB in the range of 0.1 ≤ Packet Loss Rate ≤ 0.4 over scheme 2 which does not use prioritised concealment.

Figure 8 shows a Graph of Y-PSNR against Packet Loss Rate for the News sequence with GOP length = 3 using FLI. It is observed that scheme 1 which uses UEP and prioritised concealment provides an average gain of 1.07 dB over scheme 3 which uses EEP and prioritised concealment. In addition, scheme 1 provides an average gain of 0.214 dB in the range of 0.1 ≤ Packet Loss Rate ≤ 0.4 over scheme 2 which does not use prioritised concealment.

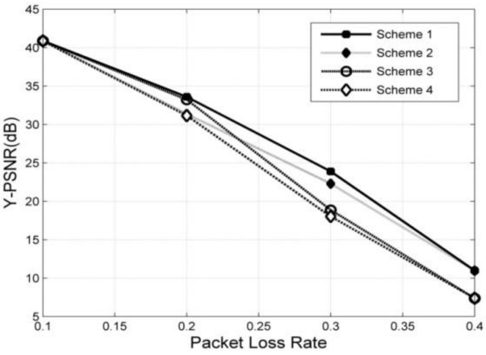


Figure 7. Graph of Y-PSNR(dB) against Packet loss Rate for the Foreman sequence using FLI

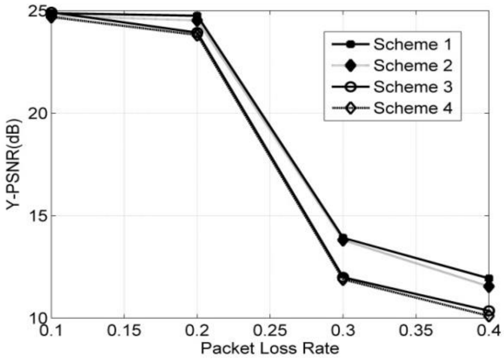


Figure 8. Graph of Y-PSNR(dB) against packet loss rate for the News sequence using FLI

3.2. Results with GLI using Foreman and News Sequences

Figure 9 shows a Graph of Y-PSNR against Packet Loss Rate for the Foreman sequence with GOP length = 3 using GLI. It is observed that scheme 1 which uses UEP and prioritised concealment provides an average gain of 1.26 dB over scheme 3 which uses EEP and prioritised concealment. In addition, scheme 1 provides an average gain of 1.06 dB in the range of 0.1 ≤ Packet Loss Rate ≤ 0.4 over scheme 2 which does not use prioritised concealment.

Figure 10 shows a Graph of Y-PSNR against Packet Loss Rate for the News sequence with GOP length = 3 using GLI. It is observed that scheme 1 which uses UEP and prioritised concealment provides an average gain of 1.31 dB over scheme 3 which uses EEP and prioritised concealment. In addition, scheme 1 provides an average gain of 0.215 dB in the range of 0.1 ≤ Packet Loss Rate ≤ 0.4 over scheme 2 which does not use prioritised concealment.

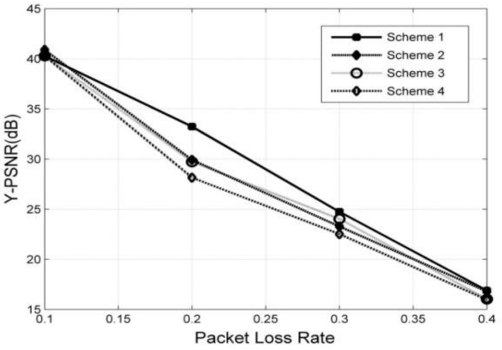


Figure 9. Graph of Y-PSNR(dB) against Packet loss Rate for the Foreman sequence using GLI

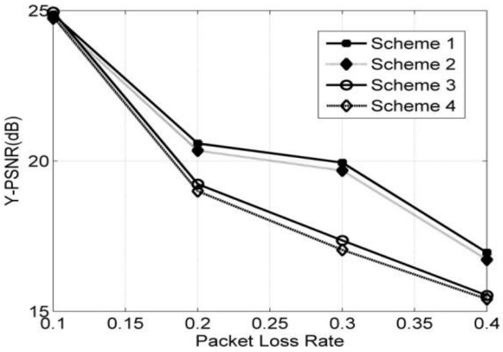


Figure 10. Graph of Y-PSNR(dB) against Packet loss Rate for the News sequence using GLI

3.3. Comparison between FLI and GLI

Figure 11 represents the results obtained by comparing the two types of interleaving, FLI and GLI. It can be observed at low Packet Loss Rates (PLR <0.24), FLI is seen to outperform GLI whereas at high Packet Loss Rates (PLR > 0.24) GLI surpasses FLI. For example, at a Packet Loss Rate of 0.2 with the News sequence, FLI achieves a gain of 4.17 dB over GLI. When using FLI, the burst errors are propagated across 99 packets as compared to GLI where the errors are propagated across 11 packets of one group. Hence, the number of errors contained in a packet created using FLI is less than that which uses GLI which allows the RS decoder to correct all the errors when using FLI. While, when using GLI, the errors contained in one packet are beyond the error correcting capability of the RS decoder.

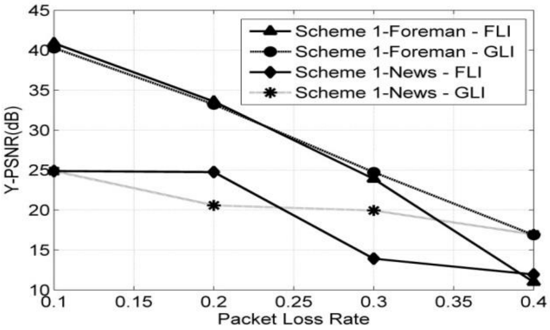


Figure 11. Graph of Y-PSNR (dB) against Packet loss Rate comparing the performance of FLI and GLI for both the Forman and news sequence

On the other hand at a Packet Loss Rate of 0.4 with the News sequence, GLI outperforms FLI by 5 dB.At high Packet Loss Rate, the number of errors is beyond the error correcting capability of the RS decoder when using both FLI and GLI. With the use FLI at high Packet Loss Rates, a large amount of errors are distributed across 99 packets which causes severe degradation of the whole frame. However, when using GLI at high Packet Loss Rates the burst errors may affect only part of the 9 groups causing some of the groups to be correctly decoded. This allows better performance of GLI as compared to FLI at high Packet Loss Rates.

4. Conclusion

The aim of this paper is to enhance the performance of H.264 video transmission with the use of UEP with RS codes and two interleaving methods. The objective of using UEP with RS codes is to protect the most important MBs from packet loss. The importance of a MB is determined by two factors which are the type of concealment, spatial and temporal, and the CDI value. Since an I-frame contains more significant information as compared to a P frame, higher protection is given to an I frame. The CDI measures the effectiveness of the concealment algorithm in case of packet loss. A low CDI will lead to an ineffective concealment. Therefore, higher protection is given to MBs having lower CDI to ensure that they are corrected by the RS decoder in case they have been subject to packet loss without the need for concealment. In addition, two types of interleaving referred as FLI and GLI are proposed. The FLI technique creates packets which consist of symbols from all the 99 MBs in a frame. With GLI, the MBs are grouped into slices and interleaving is performed within each group. FLI has shown to perform better than GLI at low packet loss rates whereas GLI proved to be more efficient at high packet loss rates. Simulation results have demonstrated that the proposed framework outperformed an EEP scheme by an average gain of2.96 dB when using the Foreman sequence with FLI. Moreover, the use of prioritised concealment has shown to further improve the results by an average gain of 0.96 dB.Numerous future works can be considered from this proposed technique.An interesting future work would be to explore the way in which an existing FMO and MDC scheme can be integrated with the proposed scheme. Finally the proposed scheme can be analysed with H.265 and the results compared with H.264.

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