Robust H.264/AVC Video Transmission using Data Partitioning and Unequal Loss Protection

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Abstract-In this work, we present an adaptive unequal loss protection (ULP) scheme for H264/AVC video transmission over lossy networks. This scheme combines erasure coding, H.264/AVC error resilience techniques and importance measures in video coding. The unequal importance of the video packets is identified in the group of pictures (GOP) and the H.264/AVC data partitioning levels. The presented method can adaptively assign unequal amount of forward error correction (FEC) parity across the video packets according to the network conditions, such as the available network bandwidth, packet loss rate and average packet burst loss length. A near optimal algorithm is developed to deal with the FEC assignment for optimization. The simulation results show that our scheme can effectively utilize network resources such as bandwidth, while improving the quality of the video transmission. In addition, the proposed ULP strategy ensures graceful degradation of the received video quality as the packet loss rate increases.

Index Terms—H.264/AVC, Adaptive Unequal Loss Protection, FEC Assignment Optimization.

I. INTRODUCTION

Multimedia applications has become common traffic in most networks. The majority of networks such as IP (Internet protocol) networks operate in a lossy environment without quality-of-service (QoS) guarantees. Thus, how to ensure robust transmission of compressed video has been a big technical challenge. When data is transmitted over lossy networks, packets may be lost due to errors as well as congestion. This problem is very serious and even catastrophic in the transmission of compressed bitstreams with strong spatio-temporal dependency, where errors will propagate and substantially deteriorate the received video quality [1].

Error control techniques, such as FEC, retransmission, error resilience, and error concealment, can be used to enhance video performances in error prone environments. Conventional retransmission based schemes such as automatic repeat request (ARQ) are not viable options for conversational and streaming services due to constraints on real-time delay and jitter [2]. Error resilience and error concealment is used from the video compression coding perspective. Error resilient schemes limit

the scope of damages caused by transmission error by encoding each frame based on the semantic of the compression layer elaborately. Error concealment is a post-processing technique used by the decoder.

In this paper, we focus on the ULP scheme for robust H.264/AVC video transmission over lossy networks. By analyzing the existing unequal importance settings in H.264/AVC coding schemes, and exploiting the H.264/AVC data partition resilience tool, we present an unequal loss protection (ULP) scheme that can differentiate the importance of the stream packets according to the derivations of the packets. Firstly, the stream packets are classified by the GOP sequence number of the frames, which indicates the picture group the packets come from. The packets to be transmitted earlier in the sequence are more important. The packets are then classified again by the H.264/AVC data partition type, which standardly gives each type partition different importance. Reed-Solomon (RS) codes with different recoverability are used in our erasure coding approach. As a dropped packet can be regarded as an erasure, we call the FEC code or FEC coding used in the video transmission system the erasure code or erasure coding.

Subject to the constraints of available network bandwidth and packet loss condition, how to assign FEC parity data to different FEC encoding blocks in the ULP scheme in order to get the best video quality is an optimization problem for FEC assignments. The paper uses a distortion estimation model to asses the video quality and models the network packet loss based on the two-state Markov model. The paper proposed an approximately assignment algorithm to resolve this optimization problem.

The paper is organized as follows. We start with the overviews of the related work in Section 2. Section 3 identifies the unequal importance in the different levels of H.264/AVC video encoding schemes and describes the proposed adaptive ULP scheme in detail. In Section 4, the simulation results are given. Section 5 concludes the paper.

II. RELATED WORKS

In recent years, many authors make an effort to use FEC approach to protect video transmission over wireless and wired networks. Boyce proposed a high priority partitioning (HiPP) method [3]. In this method, a data splitting function similar to MPEG2 data partitioning is performed on an MPEG video stream, and RS coding is performed only on the high priority partitions. However, this ULP method used a nonstandard data partitioning protocol. The PET implementation for MPEG-1 [4] allows users to set different levels of protection for different frames in a GOP. Like PET, the schemes in [5], [6] only focus on unequal protection for a particular single level - either GOP level or resynchronization packet level. In [1], an unequal packet loss resilience scheme for MPEG4 is presented by jointly exploiting the unequal importance existing in two levels, which are GOP level and resynchronization packet level, however this data partitioning method is not the MPEG4 standard.

Combining FEC algorithms with appropriate error resilient tools are often shown to be advantageous for transmission of H.264/AVC coded streams, while maintaining the computational cost at reasonable levels [7], [8], [9]. Several protection schemes for H.264/AVC video transmission [9], [10], [11] were proposed based on Flexible Macroblock Ordering (FMO), one of the error-resilient features of the H.264/AVC codec. The data partitioning of H.264/AVC and rate compatible punctured convolutional codes (RCPC) were proposed for video transmission over wireless channels in [12]. The RCPC codes were applied at the network adaptation layer (NAL) and data partitions were unequally protected according to their importance.

III. PROPOSED UNEQUAL LOSS PROTECTION SCHEME AND PROBLEM FORMULATION

A. Unequal Loss Protection Scheme

We use the erasure capability of RS codes across video packets for FEC protection. When decoding the received data, the receiver is assumed to know the exact location of the lost packets. This information is not needed in a general FEC scheme. Erasure codes are typically used for sending packets through the Internet since the receiver can detect the location of the lost packets by notifying the sequence number of the missed packet. In a typical erasure code, the sender encodes parity packets before sending both the original and parity packets to the receiver. The receiver can reconstruct the original packets upon receiving a fraction of the total packets. For example, RS(N, K) code takes K original packets and produces (N - K) parity packets, resulting in a total of N packets form a block of packets (BOPs). If K or more packets are received, then all the original packets can be completely reconstructed. Hence, a larger N/K ratio leads to a higher level of protection for data [13].

The proposed ULP scheme is based on distinguishing the different importance of the video packets. Firstly, different importance of video frames exists in the GOP level. In compressed video, different frame types (I, P and B) are assigned different levels of importance. The I-frame is most important, and the P-frame is more important than the Bframe. In addition, the frames in a GOP have a descending order of importance from the beginning frames to the ending frames. A GOP sequence starts with an I-frame, and all the other frames depend on it. The first P-frame is predicted using the I-frame. Subsequent P-frames use the previous Pframe as their reference until the next GOP starts. B-frames are predicted from the preceding and following I-frame or Pframe. Due to this temporal dependency, the decoding of the current frame strongly depends on its preceding frames in a GOP. The earlier a frame is lost in a GOP, the more frames that will be corrupted afterwards [2].

Secondly, the unequal importance of video packets can be found by using H.264 data partitioning error resilience. H.264/AVC makes a distinction between a Video Coding Layer (VCL) and a Network Abstraction Layer (NAL). The output of the encoding process is VCL data which is a sequence of bits representing the coded video data. Then those data are mapped to NAL units (NALU) prior to transmission or storage. A coded video sequence is represented by a sequence of NAL units that can be transmitted over a packet-based network or a bitstream transmission link or stored in a file. The purpose of separately specifying the VCL and NAL is to distinguish between coding-specific features (at the VCL) and transport-specific features (at the NAL) [14], [15]. Normally, each coded slice is encapsulated into one NALU. In the case of data partitioning, each coded slice is split into three partitions, which are each encapsulated in a NALU of their own. The H.264/AVC specification defines three data partitions (A, B & C): partition A (PA) contains the slice header, macroblock types, quantization parameters, prediction modes, and motion vectors; partition B (PB) contains residual information of intracoded macroblocks; and partition C (PC) contains residual information of inter-coded macroblocks. In decoding, PA is independent of PB and PC, but not vice versa. Data partitioning with constrained intra prediction option makes decoding PB independent of the corresponding PC. However, no option exists to make the decoding of PC also independent of PB [16]. The purpose of data partitioning is to divide the coded data into several data streams with different importance. A network that can provide different transmission or protection priorities to the packets with corresponding importance is able to protect the important data in a more efficient way.

According to the unequal importance identification, the video packets will be assembled into several BOPs. We obtain the importance weights D_a , D_b and D_c for PA, PB and PC partitions by experimental method. When the N/K ratio is fixed, the FEC parity are chopped into three parts according to the importance of weights. Then, we get three sub FEC assignment problems that assign different amount FEC parity to different partitions. For each of them, when K_{p_i} is given, the total number of BOPs is calculated using $J = round(\sum_{t=1}^{T} Z_{p_i,t}/K_{p_i})$, where i = 1, 2 or 3 and then p_i stands for PA, PB or PC respectively; $Z_{p_i,t}$ is the number of



Fig. 1. BOP structure

 p_i packets in the *t*-th frame and *T* is the total number of frames in a GOP. Fig. 1. shows the video packets are assembled into BOPs, where K_j denotes the number of video packets in BOP *j* and F_j is the number of FEC parity packets in the same BOP *j*. Then, the target is to find the number of FEC packets for each assembled BOP using assignment algorithm based on unequal importance of the video packet and network constrain conditions.



Fig. 2. System Framework

B. Problem Formulation and FEC Assignment

There are two main steps in the system. The first is to distinguish the importance of the video packets to different levels according some classification criteria. The second step is to find the optimal FEC assignment subjected to the constraints of the network status such as available bandwidth and the packet loss rate, etc. We have talked about the first step in the Section Unequal Loss Protection Scheme. Now we concentrate on the second step. Under particular packet loss rate and average burst loss length, when the FEC redundancy is fixed, the system target is to find an optimal FEC assignment \vec{F} by minimizing an performance metric $D(\vec{F})$. Fig. 2. presents the process that the theoretical model how to find the optimal assignment by iterative running the FEC assignment algorithm based on the feedback information from the distortion model. Firstly, the classified video packets are assembled into several BOPs and an initial assignment is given by the algorithm. Then, the distortion model calculates the performance metric based on the network model and change the assignment method until find the assignment that gets the minimal distortion.



Fig. 3. Two-state Markov model

The two-state Markov model [17] is widely used to model the packet loss behavior of the Internet for its simplicity and mathematical tractability [1][18][19]. The two states of the model are denoted G (good) and B (bad). In state Gpackets are received correctly and timely whereas in state B packets are lost. The model is fully described by the transition probabilities p_{GB} between states G and B and p_{BG} between states B and G (Fig. 3). These parameters are not very intuitionistic, normally, the average loss probability P_B and the average burst loss length L_B , which is the average number of consecutively lost packets, are used to describe the an Internet connection features.

$$P_B = \frac{p_{GB}}{p_{GB} + p_{BG}} \tag{1}$$

$$L_B = \frac{1}{p_{BG}} \tag{2}$$

The Markov model is determined by the distribution of error-free intervals (gaps). Let gap of length v be the event that after a lost packet v - 1 packets are received and then again a packet is lost. The gap density function g(v) gives the probability of a gap length v, i.e. $g(v) = P_r(0^{v-1}|1)$, where "1" denotes a lost packet, and " 0^{v-1} " denotes v - 1 consecutively received packets. The gap distribution function G(v) gives the probability of a gap length than v - 1, i.e.

$$R(m,n) = \begin{cases} G(n) & \text{for } m = 1\\ \sum_{v=1}^{n-m+1} g(v)R(m-1,n-v) & \text{for } 2 \le m \le n \end{cases}$$
(3)

$$P(m,n) = \begin{cases} \sum_{v=1}^{n-m+1} P_B G(v) R(m,n-v+1) & \text{for } 1 \le m \le n \\ 1 - \sum_{m=1}^{n} P(m,n) & \text{for } m = 0 \end{cases}$$
(4)

$$P_{p_{i},j}(\overrightarrow{F_{p_{i}}}) = \begin{cases} RPLP(N_{p_{i},j}, K_{j}) & j = 1\\ RPLP(N_{p_{i},j}, K_{j}) . \prod_{n=1}^{j-1} (1 - RPLP(N_{p_{i},n}, K_{n})) & j \neq 1 \end{cases}$$
(5)

$$G(v) = P_r(0^{v-1}|1).$$

$$g(v) = \begin{cases} 1 - p_{BG} & \text{for } v = 1\\ p_{BG}(1 - p_{GB})^{v-2}p_{GB} & \text{for } v > 1 \end{cases}$$
(6)

$$G(v) = \begin{cases} 1 & \text{for } v = 1\\ p_{BG}(1 - p_{GB})^{v-2} & \text{for } v > 1 \end{cases}$$
(7)

Let R(m, n) be the probability of m-1 packet losses within the next n-1 packets following a lost packet. It can be calculated using the recurrence with the equation (3).

Then the probability of m lost packets within a block of n packets is calculated using the equation (4).

Using P(m, n), we can analytically calculate the residual packet loss probabilities (RPLP) after RS code protection, for example, if RS(N, K) is used, then:

$$RPLP(N,K) = \sum_{m=N-K+1}^{N} \frac{m}{N} P(m,N).$$
 (8)

If it is known how many losses are acceptable for the video decoder, RPLP can be used to design the overall system. However, in our ULP scheme the video packets are a progressive data that the impact of the residual loss probabilities for those data on the video quality is not obvious since it also depends on their different importance. Therefore, we need to go one step further to combine RPLP with a packet loss distortion model to evaluate the FEC assignment performance for the optimizing process.

In [5][20], a packet distortion model called the expected length of error propagation (ELEP), which can qualify the temporal propagation effect of packet loss on video quality degradation, is proposed. The ELEP is simple but efficient model and also is adopted by [21]. The ELEP model is motivated by the fact that the fewer frames are corrupted, the better quality of reconstructed video would be achieved. The any lost packet of the t^{th} frame in the GOP will result in a length of error propagation T+1-t of frames (inclusive of the t^{th} frame). If such length of error propagation is averaged over BOP j, we can obtain the average length of error propagation for BOP j, denoted as LEP_j :

$$LEP_{j} = \frac{1}{K_{j}} \sum_{k=1}^{K_{j}} (T + 1 - f_{k,j})$$
(9)

where $f_{k,j}$ is the frame index of the *k*th video packet in BOP *j*. For example, $f_{k,j} = t$ means the *k*th video packet comes from the *t*th frame in the GOP.

Let $F_{p_i,j}$ denotes the number of FEC parity packets assigned to partition p_i in BOP j, then the FEC assignment vector for the partition p_i in the current GOP is $F_{p_i} = [F_{p_i,1}, F_{p_i,2}, ..., F_{p_i,j}, ... F_{p_i,J}]$. Given a FEC assignment vector F_{p_i} , we can compute the probability of error propagation starting from BOP j without no packet loss occurring in the preceding BOPs using the following equation (5).

The overall temporal propagation due to losses in partition p_i can be formulated as following:

$$T_L(\overrightarrow{F_{p_i}}) = \sum_{j=1}^J LEP_j \cdot P_{p_i,j}(\overrightarrow{F_{p_i}})$$
(10)

Therefore, the system performance metric $D(\vec{F})$ can be compute as ELEP:

$$D(\vec{F}) = D_a \cdot T_L(\vec{F_{p_1}}) + D_b \cdot T_L(\vec{F_{p_2}}) + D_c \cdot T_L(\vec{F_{p_3}})$$
(11)

The problem of finding the optimal FEC assignment vector $\overrightarrow{F_{p_i}}$ is formulated as minimize $D(\overrightarrow{F})$ subject to:

$$F_{p_i,j} \ge F_{p_i,j+1}, \quad i = 1, 2, 3, \quad 1 \le j \le J$$
 (12)

$$\sum_{i=1}^{3} \sum_{j=1}^{J} L_{p_i,j} F_{p_i,j} \le B_{FEC}$$
(13)

where $L_{p_i,j}$ is the length of partition p_i of BOP j, the computing method is same as [1], B_{FEC} is the FEC parity bit budget. The equation (12) means that the ULP scheme gives more strong protection to the earlier packets of the progressive video data by adding more FEC parity packets. The equation (13) is selected according to the network bandwidth.

The residual packet loss rate is used in the distortion model and the constraints in [1], but the computing method is not correct. Actually, the author used the probabilities of more than N - K packets lost within N packets as the residual packet loss rate after RS(N, K) code protection. There are three different probabilities in the system, table I shows their differences: (1) the probability of m lost packets within n

TABLE I THREE DIFFERENT PROBABILITIES: P(m, n), $P_{l>m}$, RPLP(N, K) $(P_B = 0.1 \& L_B = 2)$

(m,n)	P(m,n)	$P_{l>m}$	$\begin{aligned} RPLP(N,K)\\ (N=n,K=m) \end{aligned}$
(0,15)	0.404308	0.595692	
(1,15)	0.211247	0.384445	0.000006
(2,15)	0.150224	0.234220	0.000026
(3,15)	0.098749	0.135471	0.000083
(4,15)	0.060838	0.074633	0.000228
(5,15)	0.035407	0.039226	0.000568
(6,15)	0.019555	0.019671	0.001298
(7,15)	0.010271	0.009401	0.002759
(8,15)	0.005132	0.004269	0.005496
(9,15)	0.002436	0.001833	0.010289
(10,15)	0.001095	0.000738	0.018111
(11,15)	0.000463	0.000275	0.029914
(12,15)	0.000182	0.000093	0.046137
(13,15)	0.000066	0.000027	0.065887
(14,15)	0.000021	0.000006	0.085918
(15,15)	0.000006		0.1

packets (denoted by P(m, n) in table I); (2) the probability of more than m lost packets within n packets (denoted by $P_{l>m}$ in table I); and (3) the residual packet loss rate of after RS(N,K) protection (denoted by RPLP(N,K) in table I). Those three probabilities are computed under the packet loss rate $P_B = 10\%$ and the average burst loss length $L_B = 2$ using the 2-state Markov model in table I. (2) is treated as (3) in [1]. We can see, if using the [1] method to compute the residual packet loss rate, some residual packet loss rates (38.4445\%, 23.422\% and 13.5471\%) are bigger than the original packet loss rate (10%) when using RS(15, 1)RS(15, 2) RS(15, 3) codes to protect the transmission.

There are two methods can be used to obtain the D_a , D_b and D_c values. The first method (M1): the H.264/AVC standard has clearly defined that PA is the most important partition and PB is more important than PC. We can assign the D_a , D_b and D_c values according to some source coding parameters, which can influence the dependencies of the partitions, such as intra coding mode, the number of reference frames, constrained intra prediction option and so on. The second method (M2): for one particular type of video, when the encoding parameters are fixed, we can get the D_a , D_b and D_c values by the partition loss sensitivity tests before the video transmission. For example, we use JM12.4 [22] to encode the first 100 frames of the standard video test sequence Paris.cif. Next we measure the PSNR values over three groups of packets loss experiments. In the first group experiment, we only randomly loss 1%, 2%,....20% PA packets and calculate the average *PSNR* values respectively. The second and third group tests are over the PB and PC packets losses. Therefore, we are able to get the importance percentage for the each type partition, which are exactly the values of D_a , D_b and D_c , according to the PSNR values. The results are 55.47%, 18.67% and 25.86% for the PA, PB and PC partitions respectively. The M1 method is simple and time saving but the M2 method is more precise. For example, if according to the M1 method, the D_b value should be bigger than the D_c value. But we can see from the M2 method results, the practical measurement is

TABLE II Average PSNR Comparison, L_B =5

PLR	ULP	ELP
0	36.076351	36.076351
5	31.664282	25.562605
10	25.030335	23.390512
15	23.69039	21.099506
20	22.486677	20.751098

that D_c is bigger than D_b . That's because there are only 246 PB NALU packets, but got 1582 PC NALU packets in this scenario video data.

The local hill-climbing algorithm [23][5][1][21][24] is used to search the optimal FEC assignment based on the distortion $D(\vec{F})$ computing.

IV. SIMULATION RESULTS

In this section we present simulation results obtained with the proposed ULP scheme under the two-state Markov transmission model and the ELEP packet distortion model. The input sequence for the experiments is the CIF test sequence *Paris* encoded using JM12.4 at 30 fps, frames pattern *IPBPBPB...*, GOP length 100 frames. The JM12.4 source coding software, which is provided by the Joint Video Team (JVT), is chosen because it supports H.264/AVC data partitioning for the purpose of error resilience. For simplicity and clearness, we just do the tests over the first GOP. Each frame is divided into 11 slices and each slice is divided into different partitions.

In the two-state Markov model, we configure $L_B = 5$ and the packet loss rate P_B varied with 5% ,10% ,15% and 20%. For the network bandwidth constraint parameter, we control the FEC rate equals 20%. In the distortion model, the D_a , D_b and D_c parameters use the values that presented in the last section.

For system validation, an equal loss protection (ELP) scheme is also implemented by equally protecting each type of partition under the same total FEC parity data with the proposed ULP scheme.

The measured average PSNR values are plotted in table II, which clearly shows the presented scheme has much better PSNR values as the packet loss rate increases. We can see that the proposed ULP scheme which combines FEC assignment optimization with unequal loss protection achieves the graceful PSNR value degradation. The PSNR values of the ELP scheme drops very quickly with the packet loss rate increasing. With the same constraints, the PSNR values of the proposed scheme are always bigger than that of the ELP protection.

In the system, we used the *motion vector copy* concealment algorithm to deal with the losses that ULP and ELP fail to recover. This algorithm belongs to frame level concealment and is not an elaborate concealment algorithm. Therefore, the accuracy of the comparisons in PSNR may be affected slightly due to this reason. Therefore, the user perceived quality is also investigated. Fig. 4 shows the snapshots of the 100th frame



Fig. 4. Frame 100 at $P_B = 5\%$ with: (a) Proposed ULP; (b) ELP

for the proposed ULP and ELP at the 5% packet loss rate, respectively. We can see that the frame quality for ULP (Fig. 4 (a)) is much better than that of ELP (Fig. 4 (b)), which implies that user perceived quality is significantly improved when using the proposed ULP scheme.

V. CONCLUSION

An adaptive unequal packet loss protection scheme for robust H.264/AVC video transmission over lossy networks is presented. This novel approach efficiently integrates erasure coding, H.264/AVC data partitioning and unequal protection techniques for video transmission in a lossy environment. We derived a theoretical framework by which the whole ULP system is formulated to deal with a constrained optimization problem. The typical network packet loss behavior is simulated using an analytically tractable two-state Markov model. A packet loss distortion model is used to evaluate the FEC assignment performance for the optimization process.

It has been shown that the proposed method is able to adaptively assign unequal amounts of FEC parity checks across video packets according to the network conditions, such as the available network bandwidth, packet loss rate and average packet burst loss length. Furthermore, with the near optimal algorithm developed the video transmission quality is significantly enhanced at the reduce cost of network resources. From the simulations results, we also see that when the number of packet losses increases the proposed ULP scheme will ensure a smooth degradation of the received video quality.

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