Protection Modes for Segmented Video Streaming over Broadband Wireless

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Abstract—**Segmented or data-partitioned H.264/AVC codec video streaming separates-out important information from the compressed bitstream and places it into separate packets. Because of the damaging impact of error bursts on real-time video streams, it has become common to apply application-layer forward error correction (FEC) for transport over broadband wireless access networks, herein IEEE 802.16e. In this paper an adaptive FEC scheme using Raptor coding is applied to segmented video. The paper sets out to answer the question whether equal or unequal error protection is preferable in that situation. Though UEP offers a reduction in bitrate there are multiple dB gains in video quality, which will prove attractive to end-users, if equal error protection is provided. Overhead from using EEP rather than UEP was found to be about 1% of the overall bitrate.**

Keywords-data-partitioning; equal error protection; IEEE 802.16e; unequal error protection; video streaming; WiMAX

I. INTRODUCTION

In previous research by the authors [1], segmented or data-partitioned video streaming [2] was protected with equal error protection (EEP) across all segments. In data-partitioned video, the compressed video bitstream is segmented into up to three partitions according to the importance of the content type to the decoding of the video. Consequently, it is also possible [3] to apply unequal error protection (UEP) by duplicating one or more of the higher-priority segments. (Though notice carefully that this paper is *not* another contribution to UEP as it advocates EEP). Additionally, it is also feasible [4] to directly protect higher-priority segments through the differential use of scalable channel coding, namely by means of Raptor rateless coding [5]. However, it is not clear to what extent lower-priority segments can be left unprotected without adverse effect on video quality or indeed whether lower complexity EEP is preferable at a small increase in bitrate. This paper directly compares EEP with UEP by carefully selecting appropriate configurations for segmented video streaming.

In an H.264/AVC (Advanced Video Coding) codec, when data-partitioning is enabled, every slice is divided [6] into three separate partitions and each partition is located in either of type 2 to type-4 Network Abstraction Layer units (NALUs). A slice is a sub-division of a picture or video frame. For simplicity of interpretation just one slice per frame was employed in this paper. It is then optionally possible to divide each slice into up to three data partitions. Two basic forms of source coding occur: 1) intra-coding in which predictive reference is made to spatially adjacent macroblocks (MBs), as present in periodic I-frames; and 2) inter-coded in which temporal reference is made other video frames, P-frames using prior P-frames or I-frames. An MB is the coding unit for predictive coding. P-frames usually have a majority of their MBs coded in inter-mode. For purely intra-coded frames, I or I-frames, just two data partitions are possible but as an IPPPP… coding structure (that is one I frame followed by all P-frames) is used with distributed intra-refresh, apart from the first frame all slices are divided into three. (Intra-refresh refers to the practice of embedding intra-coded MBs in a P-frame in order to arrest temporal error propagation.) A NALU of type 2, also known as partition A, comprises the most important information of the compressed video bit-stream of P-frames, including the MB addresses, motion vectors and essential headers. If any MBs in these frames are intra-coded, their frequency transform coefficients are packed into a type-3 NALU, also known as partition B. Type 4 NAL, also known as partition C, carries the transform coefficients of the motion-compensated inter-picture coded MBs. These three partitions, types A, B, and C, form segments of the video bitstream. They are subsequently formed into Real-time Transport Protocol (RTP) packets by the codec prior to dispatch as IP/UDP packets. It is assumed that header compression over a broadband wireless link will greatly reduce the header overhead [7] from 40 B to one or two B on average.

This paper examines a channel adaptive variety of protection with hybrid automatic repeat request (ARQ), which is suited to unicast video-on-demand (VoD). However, another attraction of data-partitioning is that for multicast video it might provide a form of graceful degradation in which the lower priority partition-C packets can be dispensed with, if transmission conditions do not permit them. Compared to the Scalable Video Coding (SVC) extension to H.264, there are less data dependencies between layers, which arise in H.264/SVC in order to reduce the overhead of fine-grained scalability. However, this does *not* imply SVC is not suited to mobile applications but simply that in some circumstances a less complex form of layering may be appropriate. Whereas, data-partitioning only allows basic quality scalability, SVC also brings resolution and temporal scalability, which is suited to the variety of mobile device types. To continue, examining whether EEP is necessary or UEP is a feasible protection mode has a bearing on multicast schemes for video distribution, including Internet Protocol TV (IPTV). In fact, VoD is often provided as a value-added service beyond a basic IPTV multicast service.

Because the evaluation uses distributed intra-refresh rather than periodic intra-coded frames, delay arising from multiple packets forming I-frames is avoided. As no B-frames are used the schemes are suitable for the low-complexity processors on mobile devices, which can take advantage of H.264/AVC's Baseline profile. And by adopting Constant Bit-Rate (CBR) streaming not only is comparison between different schemes fairer but a form of streaming is utilized that allows commercial providers to plan storage capacity and bandwidth utilization, at a cost in some video quality fluctuations. From [8] it is important to set constrained inter-prediction (CIP), as otherwise partition-B cannot be made completely independent of partition-C. On the other hand, it's not possible to make partition-C independent of partition-B without breaking the codec standard. Reconstruction of all partitions is dependent on the survival of partition-A, though that partition remains independent of the other partitions.

The remainder of this paper is organized as follows. Section II relates physical and software approaches to UEP. Physical layer UEP avoids bitrate overhead but is inflexible compared to software UEP. Section II also reviews application layer EEP in wireless video streaming. Section III sets the context of the broadband wireless case study in this paper, while Section IV describes the simulation model and its validity. Section V is our evaluation of UEP compared to EEP for segmented video. Concluding remarks are made in Section VI.

II. RELATED WORK

The idea of UEP for segmented video bitstreams has taken various forms prior to the H.264/AVC codec standard. In an MPEG-4 codec, partitioning was internal to a packet with just two partitions: the first, header, motion and other shape information; and the second, the texture (transform coefficients), with decoder resynchronization headers placed internally at the start of each partition. In [9], physical-layer forward error correction (FEC) channel coding is enhanced for a fixed-sized part of the start of each video. Unfortunately, as the size of the first MPEG4 partition may vary in size, some motion vectors could receive less protection. Besides, each network traversed by the video stream would need to have special arrangements for this type of traffic. Finally, by placing both partitions in one packet, no account is taken of the risk of decoder de-synchronization from packet loss.

To avoid these problems, [10] proposed that MPEG-4 internal partitions should be split between packets from two different streams, with headers to allow partitions from the same video frame to be identified. This is what now occurs within an H.264/AVC codec, except three rather than two streams are formed. In [10], UEP was implemented by placing each of the MPEG-4 streams in different General Packet-Radio Service (GPRS) channels, with different channel coding rates. However, the scheme in this paper employs application-layer protection, in addition to any physical-layer protection that may be present. This makes the solution more amenable to end-to-end control.

In [11] another approach was taken for broadcast video in which hierarchical modulation favored those H.264/AVC partitions with more important data for the reconstruction of the video frame. One reason H.264/AVC data-partitioning was chosen rather than other forms of layering was that it does not significantly increase the bitrate of the composite stream. In fact, this is the same reason that Hierarchical Quadrature Amplitude Modulation (HQAM) was chosen rather than channel coding, that it does not increase the bitrate. However, in extensions to the scheme, Turbo channel coding was additionally required for poor wireless channel conditions. The proposed scheme was intended to be flexible, altering the QAM symbol constellation according to the desired bitrates. HQAM is not the only form of physical layer prioritization and in [12] data partitions were mapped onto different antennas in a space-time block coding.

Two segments were employed with high-priority bits (those separated more) for partition-A and low-priority bits for the partitions-B and –C. The prioritization is different to the arrangement in this paper, because herein partition-A and –B are grouped as a high-priority segment. However, this is explained by the different picture coding structures in each paper. In this paper, the use of distributed intra-refresh macroblocks rather than periodic intra-coded pictures (I-pictures) means that it is important to protect partition-B packets that contain intra-coded transform coefficients.

Software approaches to UEP may combine prioritized channel encoding of video segments with interleaving across packets. In Priority Encoding Transmission (PET) [13], parity symbols of a systematic code are included in successive packets such that high-priority segments can be recovered even if a large number of packets are erased, while lower priority segments will be lost if a few packets amongst the interleaved group are erased. PET is capable of refinement in a rate-distortion manner [14] but with just three partitions the relevance of such refinements appears restricted. Besides a problem with all packet-interleaving methods is the risk of increased latency if the decoder may have to wait for all the packets in an interleaved group to arrive before reconstruction can take place.

Application-layer EEP leads to an increase in bitrate but in return gains in flexibility and the ability to address the special needs of compressed video arising from the risk of temporal error propagation. Application-layer Raptor code has been found necessary [15] for a number of error-prone network environments, because of the stringent anticipated requirements for IPTV [16]. The Digital Video Broadcast (DVB) project has specified [17] optional application-layer rateless coding, as has 3GPP [18].

In [2], UEP for data-partitioned video was compared with EEP for non-data-partitioned video. Though it was found that non-scalable video with EEP resulted in on average better quality video, the probability of lost frames or poor video reconstruction was reduced in the UEP alternative.

Unfortunately, [2] did not also investigate a combination of EEP with data-partitioning, as occurs in this paper.

III. CONTEXT

The paper compares UEP and EEP in the context of broadband wireless video streaming. IPTV is anticipated to be a key application of broadband wireless access networks such as IEEE 802.16e (mobile WiMAX) [19]. IPTV services include: live TV programs with or without interactivity; video-on-demand unrelated to the streaming of TV programs; as well as streaming of time-shifted TV programs [20]; the latter two of which certainly require unicast streaming.

Capacity studies for WiMAX [21] suggest up to 16 mobile TV users per cell in a 'lossy' channel depending on factors such as the form of scheduling and whether multiple Input Multiple Output (MIMO) is activated. The emerging IEEE 802.16m variant is likely to further increase the capacity available for IPTV services, along with a corresponding improvement in device sophistication.

However, error bursts can still disrupt a fragile compressed bitstream, because of the source-coding data dependencies, which arise both from motion-compensated prediction and entropy coding within the codec. Consequently, sports scenes with high temporal complexity or those news scenes in which there is a high-spatial coding complexity are at risk, because of larger packet sizes and because of the difficulty of reconstructing pictures when prior or neighboring data are missing.

The basis of the protection of data-partitioned video scheme [3] is rateless coding, which is employed in an adaptive manner by retransmission of additional redundant data as and when it is required. Rateless codes are a probabilistic channel code in the sense that reconstruction is not guaranteed. Raptor coding [5], as used herein, is a systematic variety of rateless code that does not share the high error floors of prior rateless codes. It also has O(n) decode computational complexity.

Details of the adaptive channel coding scheme are already given in [1] [3] and, consequently, are not reproduced herein. As the same scheme is applied to UEP and EEP transmission, the results in Section V are relative to each other but are not indicative of the overall performance that is achievable. As mentioned in Section I, hybrid ARQ is employed to ensure extra redundant data is available in the next WiMAX frame, the consequences of which are further discussed in Section V.

IV. SIMULATION MODEL

To establish the behavior of rateless coding under WiMAX the ns-2 simulator was augmented with a module from the Chang Gung University, Taiwan [20] that has proved an effective way of modeling IEEE 802.16e's behavior. Ten runs per data point were averaged (arithmetic mean) and the simulator was first allowed to reach steady state before commencing testing.

In the evaluation, transmission over WiMAX was carefully modeled. The PHYsical layer settings selected for WiMAX simulation are given in Table I. The antenna heights are typical ones taken from the standard [19]. The antenna is modeled for comparison purposes as a half-wavelength dipole, whereas a sectored set of antenna on a mast might be used in practice to achieve directivity and, hence, better performance. The IEEE 802.16 Time Division Duplex (TDD) frame length was set to 5 ms, as only this value is supported in the WiMAX forum simplification of the standard [19]. The data rate results from the use of one of the mandatory coding modes [17] for a TDD downlink/uplink sub-frame ratio of 3:1. The WiMAX base station (BS) was assigned more bandwidth capacity than the uplink to allow the BS to respond to multiple mobile subscriber stations (MSs). Thus, the parameter settings in Table I such as the modulation type and physical-layer coding rate are required to achieve a datarate of 10.67 Mbps over the downlink. Notice that there is 1/2 channel coding rate at the PHY-layer of IEEE 802.16e, in addition to the application layer channel coding that we add. However, as discussed in Section II, application layer coding is frequently used in wireless systems because of the high error rates that can occur.

A two-state Gilbert-Elliott channel model [23] simulated the channel model for WiMAX. Though this model does not reproduce the physical characteristics that give rise to noise and interference, it does model the error bursts [24] commonly experienced by an application. It is such bursts that are particularly harmful [25] to compressed video data. In the Gilbert-Elliott model PGG is the probability of remaining in the god state, while PG is the probability of byte error in the good state, which was modelled internally by a Uniform distribution. PBB and PB are the corresponding parameters for the bad state.

Two video clips with different source coding characteristics were employed in the tests to judge content dependency. The first test sequence was *Paris*, which is a studio scene with two upper body images of presenters and moderate motion. The background is of moderate to high spatial complexity leading to larger slices. The other test sequence was *Football*, which has rapid movements and consequently has high temporal coding complexity. Both sequences were CBR encoded at Common Intermediate Format (CIF) (352 × 288 pixel/picture), with a Group of Pictures (GOP) structure of IPPP….. at 30 Hz, i.e. one initial I-picture followed by all predictive P-pictures. It was, therefore, necessary to protect against error propagation in the event of inter-coded P-picture slices being lost. To ensure higher quality video, 2% intra-coded MBs (randomly placed) were included in each frame (apart for the first I-picture) to act as anchor points in the event of slice loss. The JM 14.2 version of the H.264/AVC codec software was utilized to assess the objective video quality (PSNR) after packet loss, relative to the input YUV raw video. Lost partition-C slice packets were compensated for by error concealment using the motion vectors in partition-A at the decoder.

TABLE I. IEEE 802.16E PARAMETER SETTINGS

Parameter	*Value*
PHY	OFDMA
Frequency band	5 GHz
Bandwidth capacity	10 MHz
Duplexing mode	TDD
Frame length	5 ms
Max. packet length	1024 B
Raw data rate (downlink)	10.67 Mbps
IFFT size	1024
Modulation	16-QAM 1/2
Guard band ratio	1/16
MS transmit power	245 mW
BS transmit power	20 W
Approx. range to SS	1 km
Antenna type	Omni-directional
Antenna gains	0 dBD
MS antenna height	1.2 m
BS antenna height	30 m

OFDMA = Orthogonal Frequency Division Multiple Access,
QAM = Quadrature Amplitude Modulation, TDD = Time Division Duplex

V. EVALUATION

Tests evaluated various metrics, especially video quality for EEP and UEP alternatives. As mentioned in Section III, in the UEP alternative partitions-A and –B form one segment with rateless coding applied, while partition-C was unprotected. The size of per-packet redundant data [3] was adaptively found from:

$$R = L/(1-BL) - L, \qquad (1)$$

where L is the payload length and BL is the instantaneous probability of byte loss (a byte within a packet is the rateless code symbol). Up to 5% zero-mean Gaussian noise was additively allowed to distort the channel estimate to account for estimation inaccuracy. The rateless code belief propagation algorithm [25] has a small probability (analyzed in [3]) of failure and in which case extra redundant data were sent in the next packet. Only one retransmission over the WiMAX link is allowed to avoid increasing latency. However, as a retransmission request can be sent in the return TDD sub-frame, the additional delay is restricted to one WiMAX frame transmission time, i.e. a minimum of 5 ms.

To see the effect of channel conditions, the Gilbert-Elliott parameters were varied to produce a poor Channel 1 and a somewhat better Channel 2. The settings were CH1 = (PGG =0.95, PBB = 0.96, PB=0.02, PB=0.165) and CH2 = (PGG= 0.97, PBB=0.94, PB = 0.01, PB = 0.05). Similarly, the CBR data rate was tested both at 1 kbps and 1 Mbps for the two video clips of Section IV, *Football* and *Paris*. To ensure independence between partitions B and C, CIP was turned on and 2% intra-refresh macroblocks were randomly added to the P-picture slices (refer to Section IV). Though a visual representation might pick out more clearly some results, for reasons of compactness and because some data representations are not helped by using charts, the presentation in this paper is through a set of Tables.

TABLE II. PERFORMANCE METRICS FOR CHANNEL 1'S CONDITIONS WITH EEP

With EEP	***Football*** **2% Intra-Refresh CIP** **500 kbps IPPP…**	***Football*** **2% Intra-Refresh CIP** **1 Mbps IPPP…**	***Paris*** **2% Intra-Refresh CIP** **500 kbps IPPP…**	***Paris*** **2% Intra-Refresh CIP** **1 MBR IPPP…**
Dropped packets %	*0*	*0*	*0*	*0*
Packet end-to-end mean delay(s)	*0.0068*	*0.0084*	*0.0068*	*0.0087*
Mean PSNR (dB)	*33.54*	*39.00*	*35.88*	*40.58*
Corrupted packets %	*24.61*	*30.64*	*21.77*	*30.55*
Corrupted packet mean delay (s)	*0.0170*	*0.0183*	*0.0166*	*0.0171*

TABLE III. PERFORMANCE METRICS FOR CHANNEL 1'S CONDITIONS WITH UEP

With UEP	***Football*** **2% Intra-refresh CIP** **500 kbps IPPP…**	***Football*** **2 Intra CIP** **1 Mbps IPPP…**	***Paris*** **2 Intra CIP** **500 kbps IPPP…**	***Paris*** **2 Intra CIP** **1 Mbps IPPP…**
Dropped packets %	*11.02*	*10.38*	*12.77*	*15.11*
Packet end-to-end mean delay(s)	*0.0068*	*0.0083*	*0.0066*	*0.008*
Mean PSNR (dB)	*30.56*	*30.5*	*28.3*	*28.02*
Corrupted packets %	*13.58*	*20.25*	*9.00*	*15.44*
Corrupted packet mean delay (s)	*0.0164*	*0.0183*	*0.0161*	*0.017*

Tables II and III show EEP and UEP protection modes respectively. No outright packet loss in these or subsequent Tables, except due to internal packet corruption. Though the percentage of corrupted packets is high under EEP, because all extra redundant data for all partitions can be requested, it was possible to reconstruct all packets after one retransmission. However, under UEP, reconstruction of the longer partition-C

TABLE IV. MEAN PER-FRAME OVERHEAD IN BYTES FROM RATELESS CODING

	Football **2% Intra -refresh CIP** **500 kbps** **IPPP…**	***Football*** **2% Intra -refresh CIP** **1 Mbps** **IPPP…**
EEP/CH1	41	84
UEP/CH1	28	51
EEP/CH2	10	20
UEP/CH2	7	12
	Paris **2% Intra -refresh CIP** **500 kbps** **IPPP…**	***Paris*** **2% Intra -refresh CIP** **1 Mbps** **IPPP…**
EEP/CH1	42	82
UEP/CH1	19	25
EEP/CH2	10	19
UEP/CH2	5	6

TABLE V. PERFORMANCE METRICS FOR CHANNEL 2'S CONDITIONS WITH EEP

With EEP	***Football*** **2% Intra-refresh CIP** **500 kbps IPPP…**	***Football*** **2% Intra-refresh CIP** **1 Mbps IPPP…**	***Paris*** **2% Intra-refresh CIP** **500 kbps IPPP…**	***Paris*** **2% Intra-refresh CIP** **1 Mbps IPPP…**
Dropped Packets %	*0*	*0*	*0*	*0*
Packet end-to-end mean delay(s)	*0.0067*	*0.0084*	*0.0068*	*0.0082*
Mean PSNR (dB)	*33.54*	*39.00*	*35.88*	*40.58*
Corrupted packets %	*11.41*	*20.51*	*12.33*	*18.00*
Corrupted packet mean delay (s)	*0.0172*	*0.0180*	*0.0163*	*0.0169*

TABLE VI. PERFORMANCE METRICS FOR CHANNEL 2'S CONDITIONS WITH UEP

With UEP	***Football*** **2% Intra-refresh CIP** **500 kbps IPPP…**	**Football** **2% Intra-refresh CIP** **1 Mbps IPPP…**	***Paris*** **2% Intra-refresh CIP** **500 kbps IPPP…**	***Paris*** **2% Intra-refresh CIP** **1 Mbps IPPP…**
Dropped packets %	*3.71*	*6.79*	*7.55*	*11.11*
Packet end-to-end delay(s)	*0.0067*	*0.0081*	*0.0065*	*0.0079*
Mean PSNR (dB)	*32.22*	*34.9*	*30.76*	*30.16*
Corrupted packets (%)	*7.69*	*13.71*	*4.77*	*6.88*
Corrupted packet mean delay (s)	*0.0159*	*0.0179*	*0.0156*	*0.0164*

packets is no longer possible, leading to an increase in the percentage of dropped packets to over 10% and a decrease in the percentage of corrupted packets. The main impact in terms of objective video quality (PSNR) is a drop in quality when UEP is employed. Clearly, Table III shows the maximum drop in quality, as it would be possible to protect partition-C with a reduced percentage of rateless redundant data compared to partition-A and –B packets. In contrast, gains from UEP are twofold. Firstly, because the percentage of corrupted packets is significantly reduced, the overall delay arising from the need to retransmit extra redundant data for these packets is reduced. Mean corrupted packet delay is greater for the longer-sized 1 Mbps as packets are longer. Secondly, there is an increase in the bitrate arising from the reduction in rateless code overhead. The mean per-frame overhead is given in Table IV. The overhead from using UEP, in that respect, is about half of that of EEP. However, the maximum overhead for EEP at 500 kbps (42 B at 30 Hz) is a rate of 42 × 8 × 30 = 10 kbps or 2% of the CBR rate. For EEP at 1 Mbps the maximum overhead is 84 × 8 × 30 = 20 kbps or again 2% of the CBR rate. Therefore, the relative bitrate saving from using UEP rather than EEP is about 1% of the overall bitrate, which obviously is a small percentage. For this small gain in bitrate the drop in video quality is severe.

From Table V, with EEP the performance metrics essentially remain the same except for a reduction in the number of corrupted packets arising from the improved channel conditions. This will cause overall delay to be reduced but, as no packets are lost outright, there is no loss in video quality. When UEP is employed in Table VI, there is also a reduction in the percentage of dropped packets, in most cases below 10%. This has the effect of improving the objective video quality by several dB but the quality is still well below the level of the EEP streams.

These results imply that in both types of channel condition tested there is a significant impact on video quality from reducing protection of partition-C. The gains from using Performance metrics for channel 2's conditions with EEP motion-copy error concealment to compensate the quality for the loss of partition-C are not strongly apparent. The observation can be applied to both types of video content tested.

This does not mean that there is no gain from data partitioning, as it has been long known that motion-copy error concealment can significantly improve video quality. For example, in [10] there was a 5 dB improvement in quality for MPEG-4 data-partitioning. In [26], the gain after whole frame loss from refining motion-copy (RMC) error concealment (through recursive estimation of motion vectors over multiple frames) was compared to previous frame replacement (PFR) and motion-copy (MC) error concealment. Motion-copy concealment takes the motion-vectors of the previous correctly-received frame to replace lost macroblocks. In [26], for a 5% packet loss rate, MC gained by at least 2 dB in PSNR over PFR, and a further at least 2 dB if RMC was used. Thus, the availability of exact motion vectors from protected partition-A will significantly benefit video quality. It should also be added that the smaller packet sizes of partition-A [11] protect those packets more than partition-C packets, even when EEP is applied.

VI. CONCLUSION

As user expectations of mobile video streaming rise, then video quality becomes an important determinant of the take-up of a service. In this paper, it was shown that equal error protection can result in at least several dBs gain over unequal error protection of data-partitioned video. The overhead from using EEP rather than UEP was about 1% of the overall constant bit rate. As there will always be some redundant data overhead in application-layer error FEC, even with the adaptive scheme in this paper, the advantages in reduction of the bitrate of unequal protection will be reduced in comparison to hardware unequal protection. As data-partitioning already brings advantages in terms of smaller packet sizes for more important data and the ability to compensate if texture data is lost, equal error protection is preferable except when there is a severe shortage of available bandwidth.

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