H.264 VIDEO STREAMING WITH DATA-PARTITIONING AND GROWTH CODES

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ABSTRACT

This paper demonstrates that Growth codes, based on Raptor channel coding, allow incremental protection of H.264 video codec data-partitioned Network Adaption Layer units. When combined with increased protection of video reference frames, in an ADSL erasure channel up to 10 dB in video quality (PSNR) can be gained through this scheme compared to equal error protection with rateless codes. Equivalent gains occur in a wireless channel from combining data-partitioning with error protection. The bitrate overhead from data-partitioning is also shown to be less than from other H.264 error resilient tools.

Index Terms— video streaming, UEP channel coding, H.264, data partitioning

1. INTRODUCTION

The H.264/Advanced Video Codec (AVC), as part of its network-friendly approach, introduces Network Adaptation Layer units (NALUs) as a per-slice container for transmission. While research has investigated NALUs packetization issues [1], data partitioning (DP) of NAL units into A, B, and C types [2] of decreasing priority for error resilience purposes deserves attention. In this paper, we additionally apply application-layer Forward Error Correction (AL-FEC) to Unequal Error Protection (UEP) of data-partitioned NALUs by means of rateless channel codes for multicast delivery. In particular, Raptor codes [3], which are a systematic variety of rateless code, are Maximum Separable Distance codes (as are Reed-Solomon (RS) codes) but unlike RS-codes also have linear decode complexity.

While the Third Generation Partnership Project (3GPP) (for cellular wireless networks) in release 6 standardized protection of the Multimedia Broadcast Multicast System (MBMS) with Raptor Codes [4], it did *not* include UEP. The scalable nature of Growth codes [5] or equivalently Expanding Window codes [6] lends itself to UEP while in MBMS, the form of rateless coding applied provides all-or-nothing protection in an Equal Error Protection (EEP) manner. AL-FEC is certainly necessary for video streaming in wireless environments despite the concatenated codes that exist at the physical layer. For example, AL-FEC also is specified in ETSI's DVB IPTV service, as an acknowledgment of the fragile nature of compressed video streams, both due to the predictive nature of motion compensation and due to the sequential nature of variable length coding.

In this paper, we demonstrate that applying Growth codes across an erasure channel significantly improves video quality by a combination of *both* error resilience and error control. Moreover, of the error resilience tools available in H.264, DP has the least overhead, balancing the increased overhead arising from AL-FEC. As our findings are general, a combination of data-partitioned NALUs with Growth codes can be applied both to broadband wireless multicast (typically IEEE 802.16d,e or 3GPP's Long Term Evolution) and. Asymmetric Digital Subscriber Line (ADSL). Because error bursts are prevalent in ADSL, in [7] EEP rateless codes were proposed for this prevalent access network. Compared to EEP rateless coding, we have found that through a combination of data-partitioning and Growth codes, over an ADSL channel gains of up to 10 dB in PSNR are possible, depending on video encoding complexity and noise level.

The work in [8] introduced UEP to rateless codes but only mentioned in passing applications to video streaming. Prior work [6] applied Expanding Window codes to layered video coding without additional error resilience. In perhaps, the nearest research to that reported in this paper Growth codes [5] selectively protected I-frames over P-frames in single layer streaming. In our paper, the idea newly incorporates DP, as by protecting motion vectors in the A partition it is possible to aid error concealment upon loss of the C partition, which contains disposable macroblock transform coefficients. Therefore, by means of DP a more fine-grained form of UEP is achieved than in the earlier schemes with scalable rateless coding. Work on combining FEC with DP [9] prior to rateless coding also aimed to deal with [10] the greater risk if priority data *were* to occur later in the compressed bitstream.

2. BACKGROUND

Rateless coding is ideally suited [11] to a binary erasure channel in which either the error-correcting code works or the decoder fails and reports that it has failed. In erasure coding all is not lost as flawed data may be reconstructed from a set of successfully received data (if sufficient of the data are received). An (*n, k*) RS erasure code over an alphabet $q=2^L$ (where L is the number of source symbols) has the property that if *any* k out of n symbols transmitted are received successfully then the original k symbols can be decoded.

However, in practice not only must n, k and q be small but crucially the computational complexity of the RS decoder is of order $n(n-k)\log_2 n$. The family of Digital Fountain (DF) codes does allow a continual stream of additional symbols to be generated in the event that the original data could not be decoded. It is the ability to easily generate additional redundant data that makes DF codes rateless. Decoding will succeed with small probability of failure if any of $k(1+\varepsilon)$ symbols are received, where ε is a small fractional overhead, typically 5-10% [12], to ensure with high probability that all k symbols are decodable if received without error (rateless codes are constructed in probabilistic fashion). The probability of decoder failure is $\partial = 2^{-k\varepsilon}$, which implies: that the risk of failure is reduced for larger k and that the smaller the data symbol the more efficient the error coding.

Paradoxically, it is not the ability to continually generate redundant data that is the current attraction of rateless codes but the extraordinary performance of one of the DF codes. Raptor codes [3] have constant time encode and linear in k decode computational complexity, though additional pre-coding is necessary for formation of a systematic code. In fact, data can be recovered without feedback [13] and in the presence of long runs of errors, which is convenient as feedback is not applicable to broadcast media or when the latency introduced by feedback is detrimental to a real-time service such as video. Despite this, Raptor code protection can still fail to protect if the extent of error exceeds a threshold. In Growth codes [5], this problem is overcome by protecting the most important symbols by an inner window. All other windows in an expanding sequence protect the inner window and in general there is a nested sequence of protection.

Combining, error resilience with error control involves additional data overhead. However, Fig. 1 shows that of four common error resilience tools in H.264 data-partitioning has the least overhead. In Fig. 1, the horizontal axis represents the mean bitstream rate arrived at by setting the quantization parameter (QP) to the given value, while the vertical axis represents the mean overhead rate with that QP. As the quality decreases (higher QP) the advantage of data-partitioning increases as the relative overhead of all schemes increases. Tests of the Akiyo, Coastguard, and Mobile sequences, showed that the overhead is not strongly dependent on coding complexity, with the size of overhead ordering between the schemes preserved.

3. METHODOLOGY

3.1 Data partitioning

H.264 DP is defined in the standard as:

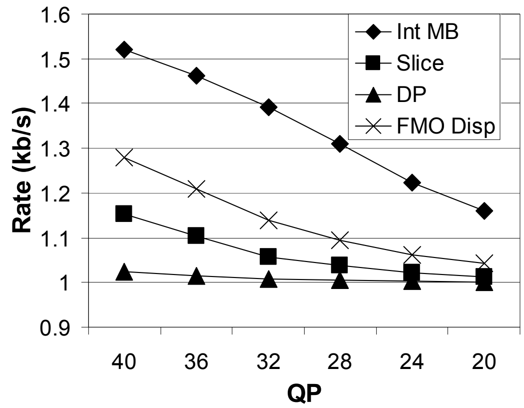

Fig. 1. QCIF 'Foreman' rates according to QP (horizontal axis) plotted against overhead rate (vertical axis) arising from H.264 error resilience tool: Int MB = Intra-coded macroblock refresh, FMO Disp = Flexible Macroblock Ordering with checkerboard (two slices), DP, Slice = slice structuring with 3 slices per frame.

Partition A contains the slice header, macroblock types, quantization parameters, prediction modes, and motion vectors in a type-2 NALU.

Partition B contains residual information of intra-coded macroblocks in a type-3 NALU.

Partition C contains residual information of inter-coded macroblocks in a type-4 NALU.

Each NALU has a 1-byte NAL header and is preceded in the bit-stream by a 4-byte start-code, which implies that splitting into three NALUs, each with a 1-byte slice identity incurs a minimal overhead of 12 bytes. In fact, because for most predictively-encoded frames, the encoder outputs few intra-coded macroblocks, the size of NALU B is small, which is why NALUs for A and B were given common protection for predictive frames, as the risk of error reduces as the data size, k in Section 2, is increased. For intra-coded reference frames a single type-5 NALU was created for the tests rather than have separate A and B partitions each with their own redundant data.

Fig. 2 is the simple way we applied Growth codes. To inter-coded frames. Priority data in partitions A and B are protected by two sets of overlapping redundant data (which can be of varying extent), while the less important C partition is protected less. An advantage of rateless codes is that the extent of protection can easily be made a design parameter, rather than the quantized levels resulting from RS codes. To avoid the need for NAL fragmentation (as is proposed for MBMS to ensure constant length-symbols (NAL blocks)), byte-level protection is proposed, i.e. a byte is the coding symbol. This has the added advantage that the smaller the data symbol the more effective the rateless error coding.

3.2 Video stream organization

The standard 'Foreman', and 'Mobile' video sequences, with medium to high motion, at Common Intermediate

Format (CIF)-30Hz @ 1 Mbps were decoded in Extended Profile with H.264 JM14.1 decoder software. The Group of Picture (GOP) size was the normal 15 with IPP… format. With 9 slices per-frame, each P-frame generated 27 NALU-bearing packets, and each reference IDR-frame resulted in 9 packets.

IDR-frame NALUs were accorded one and a half as much protection (in terms of redundant rateless bytes) as the total allowance for P-frames, which was 10% (as in MBMS). Empirical investigations caused us to split equally the total P-frame allowance between a protection group formed by A, B, and C NALUs (redundant symbols marked E in Fig. 2) and a protection group formed by A and B (redundant symbols marked D in Fig. 2).

Symbol (byte) erasures are detected by the radio receiver. After decoding, it is assumed that a Cyclic Redundancy Check (CRC) included in each packet determines the success of reconstructing a NAL with redundant symbols. The A and B protection group, with redundant data split between its two packets, is first decoded. If this decode is successful then partition C is decoded with the aid of redundant symbols E included in its packet. If decode of A and B NALs is not successful using D (as judged by their CRCs) then E is applied to the decoding of protection group A and B. Lastly, decode of partition C is attempted with redundant symbols from E.

For error concealment within an H.264/AVC slice the motion vectors from partition A were averaged to obtain an estimate of a replacement macroblock. This takes place if the average motion activity is sufficient (more than a quarter pixel).

3.3 Channel models

In wireless broadband simulations, the well-known Gilbert-Elliott (G.-E.) discrete time, two-state ergodic Markov chain channel model was applied to create error bursts, similar to the bursts resulting from fading on a wireless channel. If the burst length L is fixed and equal to the average time in a bad state T_B, then the average error rate, R, is found as

$$R = \frac{L}{T_G + L} \qquad (1)$$

where the average time in the good state with no errors, T_G, is varied according to a desired average error rate. The transition probabilities are found from (2).

$$T_G = \frac{1}{1 - P_{GG}}, T_B = \frac{1}{1 - P_{BB}} \qquad (2)$$

where P_{GG} is the probability that given the current state is good (G), the probability that the next state is also G (and similarly for P_{BB} with the other probabilities following from these).

For an ADSL link, repetitive electrical impulse noise (REIN) was modelled with fixed length (8 ms) bursts. The bursts are randomly placed to achieve bit error rates

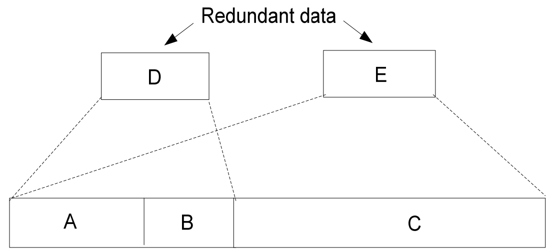

Fig. 2. Growth code UEP of A and B NALUs over C NALUs.

between 10^{-7} and 5.10^{-2}. This is the same channel model as used in [7] for ADSL.

4. RESULTS

In simulations, by way of comparison, UEP with Growth codes was compared to an equivalent level of uniform protection (EEP) by rateless codes. Though for ease of interpretation average symbol (byte) erasure code rate is reported, to obtain PSNR figures packet (NALU) loss rates after error correction were employed. In Fig. 3, the average symbol erasure rate is varied, with an average burst size of ten symbols. It is apparent, that the EEP scheme results in greater symbol loss, which is reflected in the video quality (PSNR). This is a relative result (as PSNR is a relative measure) which depends on coding complexity, as Mobile has greater spatial complexity than Foreman.

Fig. 4 is similar to Fig. 3 except that increasing the average burst size to twenty symbols slightly reduces the video quality. In Fig. 5, the UEP scheme results in a greater percentage loss of C partition packets (NALUs) with consequently relatively more protection afforded A and B partition packets. In the UEP scheme, because relative to IDR-frame packets less protection is given to A and B partition packets, less IDR-frame packets are lost. From Fig. 5, it should be noted that in the UEP scheme, greater loss of C packets does *not* result in more A and B packets, a gain from employing the UEP scheme.

The UEP scheme was also applied to a REIN model channel. Within the range of symbol erasure rates similar to those modeled for a broadband wireless channel, the gain over EEP, Figure 6, was around 10 dB rather than 5 dB, a considerable advantage from applying our scheme on an ADSL channel.

5. CONCLUSIONS

Growth codes in conjunction with H.264/AVC DP can allow a hierarchy of protection, both within P-frames and between P- and IDR-frames. There is minimal overhead as CRCs are already part of the existing NAL scheme [1] and uniform Rateless coding (though not Growth codes) has already been applied to multimedia over wireless. For video streaming over an ADSL channel, the advantages of this variation upon AL-FEC may well be considerable owing to the longer error bursts.

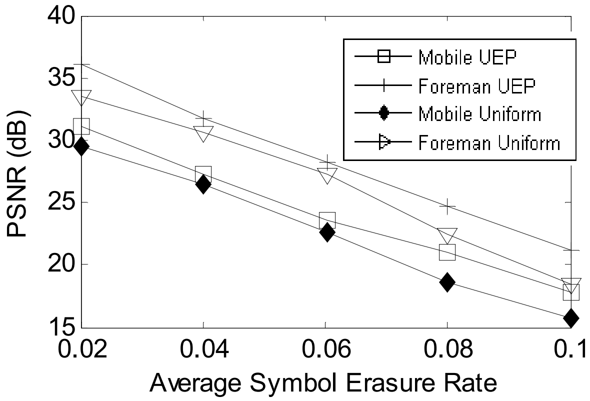

Fig. 3. Effect of UEP compared to uniform protection (EEP) for increasing symbol erasure lengths with an average error burst size of ten symbols for a G-E. channel.

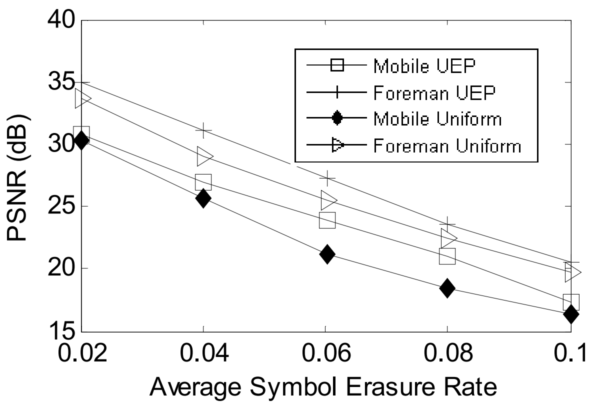

Fig. 4. Effect of UEP compared to uniform protection (EEP) for increasing symbol erasure rates with an average error burst size of twenty symbols in a G-E channel.

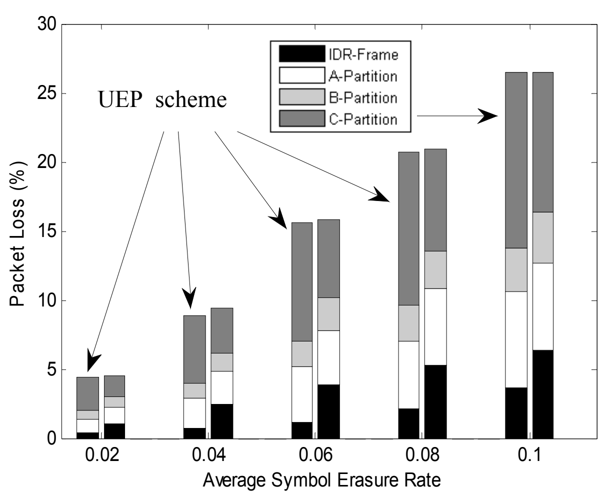

Fig. 5. Packet (NALU) loss distribution for the Mobile clip with average burst length of twenty symbols with UEP to the left and EEP to the right for a G-E channel.

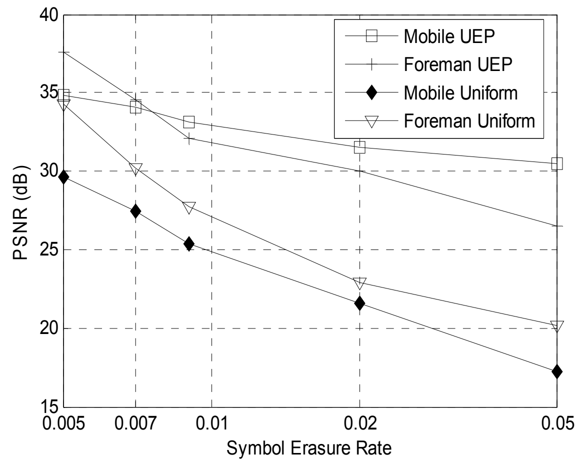

Fig. 6. Effect of UEP compared to uniform protection (EEP) for increasing symbol erasure rates with an average error burst size of twenty symbols in a REIN model channel.

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