UNEQUALLY ERROR PROTECTED DATA PARTITIONED VIDEO WITH COMBINED HIERARCHICAL MODULATION AND CHANNEL CODING

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ABSTRACT

This paper presents an efficient unequal error protection (UEP) approach for data partitioned video over wireless channels. We consider two methods: 1) forward error correction (FEC) with variable code-rates, and 2) hierarchical quadrature amplitude modulation (HQAM) combined with FEC with a fixed code-rate. In a low-delay application, the variable bit rate ratio between the high-priority and low-priority layers imposes certain constraints on these two methods. These constraints are discussed and solutions are proposed. Simulation results with an H.264 video codec show that combined HQAM and FEC outperforms FEC alone in both Gaussian and fading channels while having advantage over the nonlayered transmission.

1. INTRODUCTION

For video transmission over wireless channels, reliable transmission is not guaranteed and the channel quality can be highly variable. Therefore, in applications such as video over mobile networks where the coded source data is highly sensitive to errors, strong forward error correcting codes (FEC) with a low code-rate R (high overhead) should be applied. This will limit the available source rate and impair the quality of the delivered video. To tackle this problem, if an estimate of the channel condition is available at the transmitter, the code-rate can be adaptively tuned. However, in the absence of feedback as assumed in this paper, prioritised layered transmission can be used where the coded data is divided into layers with different importance. High priority (HP) layers are well protected and low priority (LP) layers have less protection, this is called unequal error protection (UEP) and has been widely studied in the literature e.g. [1, 2, 3].

There are a variety of methods of dividing a bitstream into layers. Among them, data partitioning (DP) is considered in this paper since it has two advantages. First, it has been included in the current specification of the H.264 standard which is considerably more compression efficient than its predecessors. Second, it imposes no significant overhead on the coded video as opposed to many other layering techniques [3]. In H.264 DP, the headers and motion information are placed in the HP layer and the residual data are associated to two other separate units; which in this paper we group as one LP layer. Let us call the HP and LP source rates s_{HP} and s_{LP} respectively. If FEC is desired for UEP, the code-rate of HP layer R_{HP} should be smaller than that of LP layer R_{LP}, and the total channel rate for transmission will become:

$$ch_{total} = ch_{HP} + ch_{LP} = \frac{s_{HP}}{R_{HP}} + \frac{s_{LP}}{R_{LP}}. \qquad (1)$$

In [1] the application of the above UEP method with MPEG-4 DP has been analysed, and its superiority over nonlayered transmission has been confirmed. The experiments in [2, 3] confirm that UEP with H.264 DP (we abbreviate it to UEP-DP) is also superior to nonlayered transmission. However, none of the mentioned articles thoroughly consider the delay limitations of a wireless system. As listed in [4], there are applications such as live streaming or video telephony that have strict delay constraints. A constant bit rate (CBR) stream may be used in such applications to avoid any delay. However, even in a CBR video, the individual layers of DP will have variable rates under the influence of picture contents and the motion of objects. Therefore, adding prioritised FEC will cause the required channel rate (ch_{total} in equation 1) to be variable. This can be seen from Fig. 1 for an example of a CBR video.

This paper proposes solutions to maintain a constant ch_{total} for UEP-DP. In case of prioritised FEC, we frequently switch the code-rates as explained in Section 2. Disadvantages of this method are discussed and a more efficient solution by combining hierarchical modulation and FEC is introduced in Section 3. Section 4 gives the simulation results, followed by a conclusion in Section 5.

2. UEP-DP WITH SWITCHED, PRIORITISED FEC

To maintain a constant channel rate for UEP-DP, the channel code-rates (R_{HP} and R_{LP}) can be frequently adjusted with respect to the size of the HP and LP layers. We note that the protection of the main priority HP layer should not be compromised; hence, we fix R_{HP} whatever the size of

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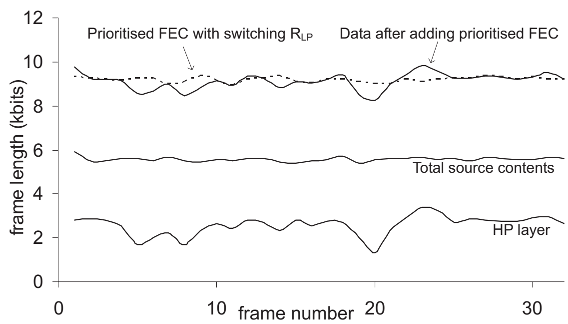


Fig. 1. A data-partitioned video after adding UEP, Foreman QCIF at 10 Hz, CBR 60kbps, $R_{HP} = 1/2, R_{LP} = 3/4$.

the HP layer and only vary R_{LP}. For example, we can select $R_{HP} = 1/2$, and switch R_{LP} between $3/5, 2/3, 3/4 \, and \, 1/1$ to maintain a fixed ch_{total}. Fig. 2 lists different switching modes in our FEC UEP-DP with their corresponding capacities for the HP and LP source data. Note that in this work, we allocate 60 per cent of each transmitted packet to the source data and 40 per cent to the control parity. When loading packets of each frame, the actual percentage between the HP and LP source units (after adding to a smoothing buffer) is calculated and the appropriate mode from Fig. 2 that offers the nearest HP and LP ratio is selected. It should be mentioned that the selected mode should be reported to the receiver in order to perform the corresponding channel decoding procedure. This very low rate control data can be transmitted reliably, and in this work it is assumed to be error free. Fig. 1 shows how this switching method provides a smooth ch_{total} for a low-delay transmission.

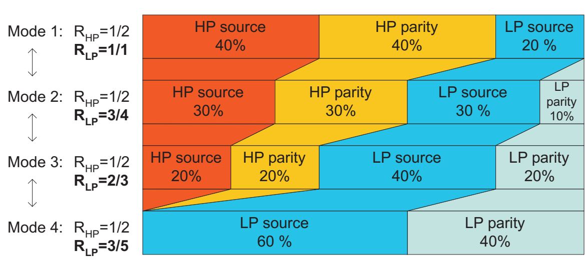
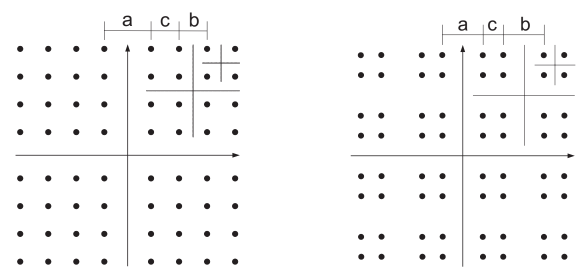


Fig. 2. Capacity of a transmitted packet in switched FEC.

The above UEP-DP approach has certain limitations. Generally, its parity bit overhead is high such that with a limited channel rate, in order to provide good protection the source rate must be restricted to very low values. However, reducing the source rate in data-partitioned video will increase the proportion of the HP layer, as the motion information becomes the dominant part of the data. This further limits the system performance because the LP layer will have less opportunity for protection, i.e. R_{LP} will be more often switched to 1/1 (Mode-1 of Fig. 2). Even in the example of Fig. 1 where a moderate source rate of 60 kbps is used, our experiments show that more than 20 per cent of the LP units are sent in Mode-1. To overcome this problem, we employ HQAM to offer UEP as discussed below.

3. UEP-DP WITH SWITCHED HIERARCHICAL QAM COMBINED WITH FEC

A conventional square M-HQAM constellation [5] offers two levels of priority, where M (≥ 16) denotes the number of signal points in the constellation. HP data bits occupy the two most significant bits (MSBs) of each point label while LP data occupy the remaining bits (i.e. 2 bits for 16- and 4 bits for 64-HQAM). Fig. 3(a) shows such a constellation diagram for 2-level 64-HQAM, where the distances between quadrants (a in Fig. 2(a)) and between points inside each quadrant b are adjusted such that $a > b$, giving a distance factor $\alpha = a/b$. For a given average signal power, increasing the value of α increases the HP protection, but decreases the LP protection, thus providing a simple UEP. However, the fixed number of MSBs and LSBs requires the channel rates ch_{HP} and ch_{LP} to be constant and as noted earlier, for data partitioning there is no such constant relationship. We therefore, resort to a multilevel HQAM to switch the HP and LP bit lengths as explained below.



(a) Mode-2: $\alpha = 1.5, \beta = 1$ (b) Mode-3: $\alpha = 1, \beta = 2$

Fig. 3. Modes 2 and 3 of switched 64-HQAM.

In a multilevel HQAM [6, 7] the constellation points are placed in such a way that groups of bits within the point label have similar degrees of protection as illustrated in the constellation diagram of Fig. 3(b) for 3-level 64-HQAM. Two distance factors are now introduced $\alpha = a/b$ and $\beta = b/c$. (This constellation could support three priorities with 2 bits each, but this work focuses only on 2-priority cases.) The values of α and β will determine the system "mode". Mode-1 with $\alpha = \beta = 1$, is nonhierarchical QAM where all bits have the same immunity to noise and could be assigned to LP data. In Mode-2, by setting $\alpha > 1$ (and $\beta = 1$) the conventional HQAM is achieved, i.e. there are 2 HP bits and 4 LP bits. Finally, mode-3 with $\alpha = 1$ and $\beta > 1$, gives the first 4 bits a higher immunity than the last 2 bits. By switching between these three modes the percentage of HP bits can be changed between 0, 33, and 66 per cent but its protection remains unchanged as shown in Fig. 4 with α and β values as listed on the figure. What actually changes with this switching arrangement is the protection of the LP bits, similar to the switching of Section 2. Here the default option uses Mode-2 with $\alpha = 1.5, \beta = 1$. When HP data occupy more than 33 per cent of the transmission buffer, the system switches to (Mode 3 with $\alpha = 1, \beta = 2$) which permits the transmission of 4 bits for HP and 2 bits for LP without losing HP protection; the loss is principally only in LP performance (as seen in Fig. 4). If HP percentage becomes less than 25 per cent, the adaptive system switches to Mode-1 ($\alpha = 1, \beta = 1$) and uses all the capacity to send LP data. This provides better protection for LP than the default situation.

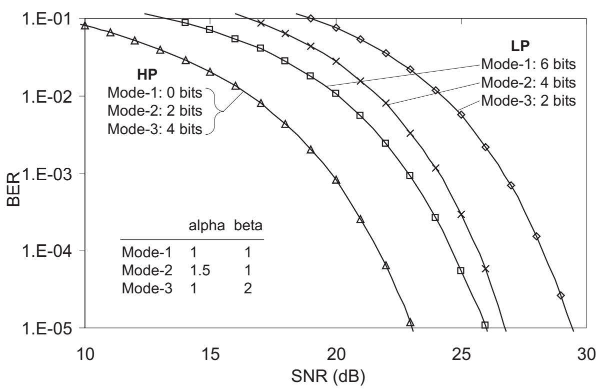


Fig. 4. BER vs. SNR for LP and HP bits for three HQAM modes, in a Gaussian channel.

The improved HP protection offered by HQAM is at the price of lower noise immunity for the LP layer. In order to improve the protection of the layers we can incorporate channel coding before modulation to shift the BER curves of Fig. 4 towards the desired SNR region. This combination of switched HQAM and fixed FEC offers a number of advantages. Firstly, we can add protection with a constant channel code-rate for both HP and LP layers. Therefore, the LP data will never be transmitted unprotected, as opposed to the switched FEC where we often need to switch R_{LP} to 1/1. Secondly, the protection of the HP layer becomes better than expected, as the high reliability of the HP bits' soft information will improve the effectiveness of the FEC employed in this work. Finally, similar to switched FEC, for a CBR video ($s_{total} = s_{HP} + s_{LP}$ is constant), this incorporation of FEC will not require a variable channel rate because $R_{HP} = R_{LP} = R$ and from equation 1: $ch_{total} = s_{total}/R$. The following simulation results confirm that this combination outperforms the switched FEC.

4. SIMULATION RESULTS

The unequal-error-protected transmission of data-partitioned coded video has been simulated in Gaussian and fading (COST 207 channel model [8]) environments with a constant total channel rate, ch_{total} = 100 kbps. For FEC we employed turbo codes with generators G1=5 and G2=7 and a Log-MAP algorithm with three iterations in the decoder. Other turbo coding (TC) parameters are the same as detailed in [9]. The received bits passed to the decoder include their reliabilities extracted from the soft demapping process for HQAM as in [10].

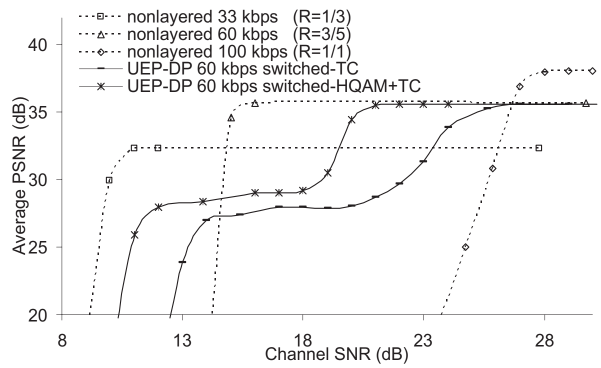
For the following tests, the Foreman QCIF sequence at 10 Hz is used with a total length of 33 frames comprising NAL-units of no more than 150 bytes. The first frame is an (assumed) error-free intraframe and the rest are P-frames. The reason we did not consider more frames is that for data-partitioning the picture drift and so the average quality is directly related to the number of P-frames. We assumed that after 33 frames an intraframe would stop the propagation of errors. For CBR video we employed the rate controller of [11] with a rate accuracy of 3 per cent. For confidence, we ran each experiment 100 times and recorded the average PSNR results after an error concealment similar to [4].

The average PSNR of pictures versus channel symbol SNR is depicted in Fig. 5(a) for a Gaussian channel for two UEP-DP scenarios: first, FEC with $R_{HP} = 1/2$ and RLP switching between $3/5, 2/3, 3/4$, and $1/1$, and second, switched HQAM combined with turbo-coding with $R_{HP} = R_{LP} = 3/5$. The source rate of the data-partitioned video for both cases is 60 kbps while the remaining 40 kbps of the channel rate is dedicated to the FEC codes. For reference, three non-layered cases are also included in the figure (shown dotted) with different source rates and code-rates as listed on the figure. It can be seen that our switched HQAM combined with TC has outperformed the switched TC alone. For the HP part (low SNRs), it has provided a better protection even with a higher R_{HP}, and for the LP part the advantage of the combined method is evident.

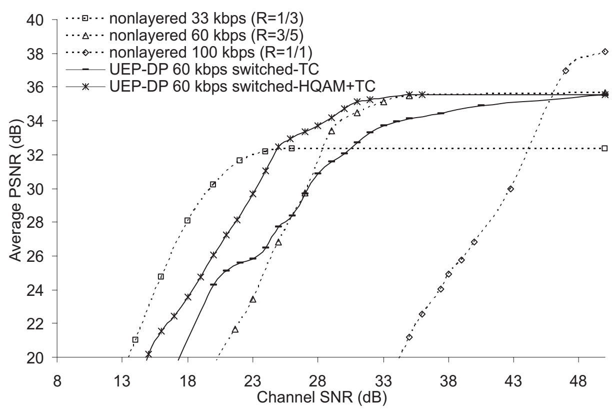
Comparing the UEP-DP curves with the nonlayered curves is also interesting. When the entire channel rate is dedicated to the source, i.e. $s_{total} = 100$ kbps and $R = 1/1$, the nonlayered service will be available only at high SNRs and UEP-DP is clearly a more attractive choice. However, in a conservative design, by dedicating 66 kbps of the channel rate to the FEC ($s_{total} = 33$ kbps, $R = 1/3$) the nonlayered video service is available over a wide SNR range with an even better quality than UEP-DP at the lower SNRs. However at higher SNRs, UEP-DP has outperformed the conservative nonlayered curve by about 3 dB. Finally, if we compare the UEP-DP curve with the middle nonlayered one ($s_{total} = 60$ kbps, $R = 3/5$), there is a significant gain at low SNRs with a penalty at middle SNRs (as a result of picture drift in DP), and almost the same PSNR at high SNRs.

Fig. 5(b) shows the same experiments as Fig. 5(a) but in a fading environment. As expected, higher channel SNRs are required for reliable transmission in all experiments. However, the combined switched HQAM+TC is still superior to the others. By comparing the combined HQAM+TC with the nonlayered graph at 60 kbps (the same source rate), where in a

Gaussian channel the UEP-DP had a lower performance than the nonlayered curve in the middle SNR regions, surprisingly in a fading channel it has outperformed the nonlayered curve at all SNR regions (except its negligible overhead at very high SNR). This is because in a fading environment where errors occur in long bursts, turbo coding will not perform as well as in Gaussian channel, and hence even the nonlayered curves suffer from temporal error propagation in a certain SNR region.



(a) In a Gaussian channel,



(b) In a fading channel.

Fig. 5. Foreman QCIF@10 Hz, s_{total}=$60kbps$, UEP-DP with 1) switched TC, R_{HP}=$1/2$, R_{LP}=$3/5, 2/3, 3/4, 1/1$, and 2) switched HQAM + fixed TC, R_{HP}=R_{LP}=$3/5$.

5. CONCLUSION

For a low-delay and reliable video service, we have shown that unequal error protection can be used for data-partitioned video (UEP-DP). It was shown that for a constant channel rate, not only the total source rate should be controlled, but also the forward error correction (FEC) code-rates must be frequently adjusted. We argued that this may not be a good solution and a better approach would be the combination of hierarchical modulation and a fixed FEC. In our experiments for video over wireless channels, we observed that UEP-DP has a penalty in a Gaussian channel over certain SNR regions compared to nonlayered transmission. In a fading environment, however, UEP-DP is advantageous over a wider SNR region.

6. REFERENCES

[1] M. Budagavi, W.R. Heinzelman, J. Webb, and R. Talluri, "Wireless MPEG-4 video communication on DSP chips," *IEEE Signal Processing Mag.*, vol. 17, no. 1, pp. 36.53, Jan. 2000.

[2] O. Harmanci and A.M. Tekalp, "Optimization of H264 for low delay video communications over lossy channels," *Proc. IEEE Int. Conf. Image Processing, ICIP*, vol. 5, pp. 24–27, Oct. 2004.

[3] M.M. Ghandi and M. Ghanbari, "Layered H.264 video transmission with hierarchical QAM," *Elsevier J. Visual Commun. Image Representation, Especial issue on H.264/AVC*, 2005.

[4] T. Stockhammer and M.M. Hannuksela, "H.264/AVC video for wireless transmission," *IEEE Wireless Commun.*, vol. 12, no. 4, pp. 6–13, Aug. 2005.

[5] ETSI, "Digital video broadcasting (DVB); framing structure, channel coding and modulation for digital terrestrial television," *EN 300 744*, vol. 1.4.1, 2001.

[6] B. Barmada, M.M. Ghandi, E.V. Jones, and M. Ghanbari, "Prioritized transmission of data partitioned H.264 video with hierarchical QAM," *IEEE Signal Processing Lett.*, vol. 12, no. 8, pp. 577–580, August 2005.

[7] P.K. Vitthaladevuni and M.S. Alouini, "A recursive algorithm for the exact BER computation of generalized hierarchical QAM constellations," *IEEE Trans. Inform. Theory*, vol. 49, no. 1, pp. 297–307, Jan. 2003.

[8] T. Keller, M. Munster, and L. Hanzo, "A turbo-coded burst-by-burst adaptive wide-band speech transceiver," *IEEE J. on Selected Areas in Commun.*, vol. 18, no. 11, pp. 2363–2372, Nov. 2000.

[9] C. Berrou and A. Glavieux, "Near optimum error correcting coding and decoding: Turbo codes," *IEEE Trans. Commun.*, vol. 44, no. 10, pp. 1261–1271, Oct. 1996.

[10] B. Barmada and E. V. Jones, "Adaptive modulation and coding for multimedia services," *Proc. IEE 3G 2004 Mobile Commun. Technols.*, pp. 321–325, Oct. 2004.

[11] M.M. Ghandi and M. Ghanbari, "A lagrangian optimized rate control algorithm for the H.264/AVC encoder," *Proc. Int. Conf. Image Processing, ICIP*, vol. 1, pp. 123–126, Oct. 2004.