Unequal Error Protection for H.263+ bitstreams over a wireless IP network

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ABSTRACT

This paper presents an original solution to efficiently transmit video bitstreams over an IP networked wireless channel via an unequal rate allocation protection scheme. The originality of this scheme is that it proposes a sensitivity estimation not only for the video stream itself as classically done, but also for the network headers used over the IP wireless network, here considered in their compressed version. Based on this sensitivity measure, the protection allocation algorithm is able to propose an efficient unequal rate allocation scheme using rate compatible punctured codes.

Numerical results obtained in the case of H.263+ bitstreams transmitted over an error prone wireless compressed RTP/UDP/IP network show that taking into account both video and headers sensitivity allows this Unequal Error Protection (UEP) scheme to provide PSNR improvements of about 5 dB when compared to Equal Error Protection (EEP) scheme with a low additional complexity.

1. INTRODUCTION

Among the efficient Forward Error Correction (FEC) solutions proposed in the literature for protecting multimedia transmissions, Unequal Error Protection is one of the most widely recognized as efficient to deal with image [1][2] and video [3][4][5], where the different levels of sensitivity in the stream make it worth to provide different protection levels.

Naturally, such an unequal error protection approach can be extended to a more general context, typically by considering the protection of other layers in the transmission chain, with for instance the integration of both application and IP network layers, up to eventually the overall optimization of the end-to-end transmission chain. Yet, when considering emerging applications and services such as video streaming over wireless IP networks, it appears that this general approach is not considered and that most of the papers investigating schemes to improve the robustness of video coding through FEC either deal with UEP video data solutions with no network consideration, or study only network packet loss impact on the video stream. Papers considering the two aspects at the same time are rare, based on the consideration that efficient frame-level video UEP schemes are hardly adaptable to intra-frame approach (dealing with differentiation inside a frame) or in an IP packetization context [3], or that packet loss protection schemes should be limited to a packet loss only context [4].

This paper proposes to consider the application of an UEP scheme not only to video data but also on IP network headers, taking consequently into account the impact of both network losses (packet losses) and of channel effects (bit errors). The proposed system is able to deal with both levels and, for this reason, can take advantage of any error sensitivity variations in the networked video stream, providing consequently a clear improvement in an IP wireless erroneous context. In practice, to avoid excessive bit rate consumption over the wireless channel, compressed network headers instead of full ones will be considered, following the path proposed in [6].

The paper is organized as follows. Section 2 introduces the considered system model, together with the three different types of sensitivity classes that can be discriminated in a networked video context. Section 3 presents the new measure introduced to estimate the sensitivity of each different class. Section 4 then presents the original adaptive UEP scheme, including a description of potential candidate FEC codes and practical considerations on network headers impact. Numerical results are then presented in Section 5 and conclusions are drawn in Section 6.

2. SYSTEM MODEL

The considered system model is presented in Figure 1. Based on the sensitivity estimation of the transmitted stream different classes, and depending on the channel impact and overall target bit rate, the rate allocation algorithm determines the optimal protection rates to be applied by means of FEC. The fact that the different layers sensitivities can be estimated independently permits the allocation not to suffer from the FEC different localization in the transmission chain.

Three different levels appear consequently in the data transmitted over the IP wireless channel:

1. the *inter-frame* level, corresponding to frame type distinction (*e.g.* I, P or B) common in predictive video standards, to take into account the impact on the overall quality [3] for different frames type;
2. the *intra-frame* level, corresponding to distinctions made inside a given frame, based on its subdivision into different syntax elements such as headers, motion vectors, texture…;

3. the integration of network layer leads to the introduction of a *supra-frame* level, which corresponds to the effect introduced by the network, that is to say to the loss of packets when headers are not correctly decoded.

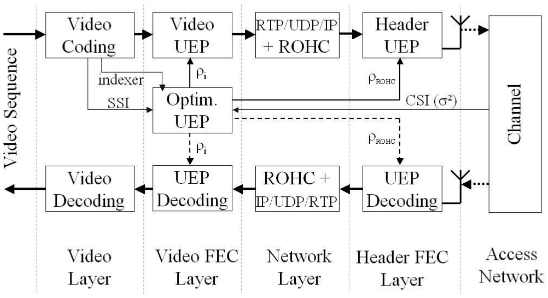

Figure 1 – System model for Unequal error protection of video bitstreams over IP wireless networks.

As an error in a network packet header leads to the loss of payload video data it transmits, and ultimately to a lower reconstructed video quality contribution, it appears that the network headers can be viewed as another sensitivity class.

3. SENSITIVITY DISCRIMINATION

While it is generally admitted that elements of a compressed video bitstream present different sensitivity to bit errors [1][4][5], precise quantification of these sensitivities are not well agreed upon in the state-of-the-art. Based on this remark, and on the fact many solutions rely on a contextual dependence of the classes which cannot be applied when considering heterogeneous classes, we propose to establish a model for sensitivity estimation valid for different inter, intra and supra level classes.

Considering a class C_j, its sensitivity, or influence ξ_{Cj}, will be estimated by measuring the impact of errors introduced with a Bit Error Rate (BER) generator in said class when the others classes are left error free. The distortion value relative to the class $\widehat{E[MSE_Y]}_{C_j}$ can then be obtained using the Mean Square Error (MSE) criterion for N_I tests on a given video sequence of N_F frames:

$$\widehat{E[MSE]} = \frac{\sum_I^{N_I} \sum_F^{N_F} \sum_x^{N_L} \sum_y^{N_C} [X_{I,F(x,y)} - X'_{I,F(x,y)}]^2}{N_I\ N_F\ N_L\ N_C\ 256^2}.$$

Making the hypothesis that the classes are independent, one can link the observed distortion and the class influence. Taking the different class sizes into account when deriving the overall distortion (unlike the solution proposed in [5]), to ensure that our model reflects reality, we find that the total distortion is obtained as the sum of all marginal distortion contributions ξ_{C_j} due to a specific class of partial size $\mu_{Cj} = size(C_j) / \sum_{C_i} size(C_i)$ in the bitstream:

$$E[MSE](BER) = \sum_{Cj} \mu_{Cj}\, \xi_{Cj}(BER) \quad (1).$$

Moreover, as error free classes contributions are only due to the source coding operation influence ξ_s, measured with the error free sequence MSE distortion, one finds:

$$\widehat{E[MSE_{C_j}]}(BER) = \sum_{C_i} \mu_{C_i}\, \widehat{\xi_{C_i}}(BER(C_i))$$

$$\widehat{E[MSE_{C_j}]}(BER) = \xi_S(1-\mu_{C_j}) + \widehat{\xi_{C_j}}(BER)\mu_{C_j}$$

which leads to :

$$\widehat{\xi_{\mathbf{C_j}}}(\mathbf{BER}) = \xi_{\mathbf{S}} + \frac{\widehat{\mathbf{E[MSE_{C_j}]}}(\mathbf{BER}) - \xi_{\mathbf{S}}}{\mu_{\mathbf{C_j}}} \quad \forall j\ \forall BER \quad (2)$$

The class sensitivity numerical values are obtained by performing a double estimation of the MSE for the sequence without errors and the sequence with selected errors, placed in one class C_j only in each case.

4. ADAPTIVE ALLOCATION OF PROTECTION

4.1. Forward Error Correction tools: RCPC

Introduced by Hagenauer in [7], rate-compatible punctured convolutional (RCPC) codes allow to use variable rate coding using a static low rate code (mother code R=1/N). Almost as efficient as the best known convolutional codes of same rates while offering a low complexity, these RCPC codes permit to reach different coding rates thanks to puncturing tables, which allow not to transmit all the redundancy introduced by the mother coder. Such codes allow to easily adapt the channel coding protection to the source sensitivity, with assigning more protection (lower coding rate) to more sensitive data. Figure 2 shows that we can establish for every possible coding rate and every channel condition a quality of service (*e.g.* BER over an Additive White Gaussian Noise (AWGN) channel), modeling this way the effect of a given rate code.

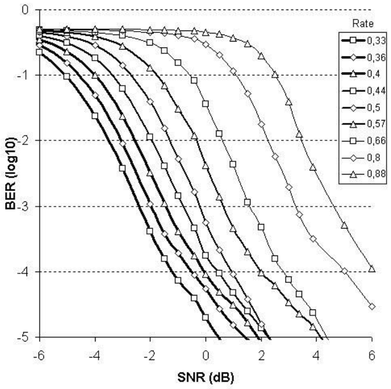

Figure 2 – Performance of different puncturing patterns for a unique mother code (R=1/3, M=6, taken from [7]) over an AWGN channel.

4.2. Allocation algorithm

In an optimal approach, the level of protection for each class must be precisely established based on the criterion of optimal user reconstructed video quality. Considering sensitivity values derived in Section 3 and channel coding means such as RCPCs, their common dependence to a quality of service criterion such as BER allows to numerically associate a sensitivity value to each class protected by a given FEC level for a given channel condition. The characterization (sensitivity, coding rate, channel state) leads to the identification of a states space that for a given channel condition associates any class for all channel coding rates with a sensitivity value (noted ξ_{C_i,R_j}). Then, considering the fact that the proportional loss of quality is primarily due to the temporary most sensitive class, a water-filling algorithm schematized on the flow chart on Figure 3 is used in order to determine the FEC rates to be applied for a given allowed global user bit rate and estimated channel conditions. Beginning with the minimal protection rate for each class, the algorithm successively determines the target class C_T, in practice the most sensitive class with current protection rates, and adds FEC (in a rate-compatible manner, that is by reducing R(C_T)) to it, provided the authorized global bit rate is not exceeded. The procedure is iterated up until the authorized global bit rate is allocated or maximal rate is attained for all classes, and then rates to be applied to each class are known (R^*).

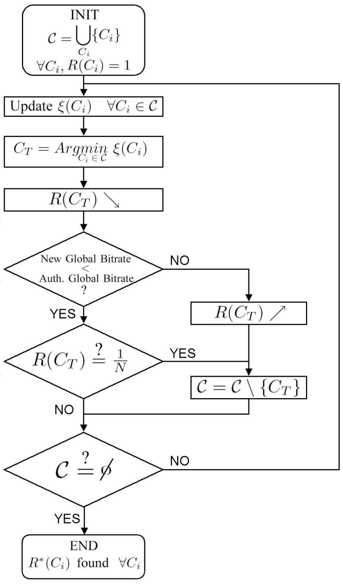

Figure 3 – Flow Chart of Water-Filling Rate Allocation Algorithm.

4.3. System processing

While we established before that network headers could be seen as just another class for the UEP allocation algorithm, practical considerations make us propose to treat them in practice slightly differently from the other classes. To ensure that the system can transmit in a synchronized manner the rate variations between the transmitter and receiver side, we suggest to consider that the header rate is constant for every sent packet. The receiver can then easily decode the protected and compressed packet header (PCH), as it knows the coding rate that was applied to it. Remains the protected video data (Pr. Data), for which the receiver must have information on which and when puncturing tables must be used. For this purpose, we propose to use the eXtension field of the RTP header (or any similar field in other network headers configuration), enabling to add data in the header. With a partitioning likely not to be more precise than payload segmentation (a few kbits before FEC), then only one transition at the most is planned to happen in a given packet, that is to say that information on two rates and one stream position shall be transmitted in each packet.

In other words, 16 bits should be sufficient to transmit this information to the receiver, allowing us to claim that the proposed UEP system does not increase significantly the complexity or the bitrate. In practice, considering that in established mode ROHC header compression generally results in a three bytes header [6], we can assume that due to the eXtension fields a five bytes header is used in our system. Any error in the compressed header will then cause the loss of all the data carried in the payload. Once the network header is decoded, the UEP decoding module is able to decode the video data. The concatenation of the data in the packets is processed thanks to the “sequence number” field in the RTP header that enables to know the sequence order of these packets to reconstruct the video stream accordingly. Decoding steps at the receiver are illustrated in Figure 4, corresponding to first FEC decoding of the compressed header (CH), and its decompression into header (H), followed by data decoding and re-concatenation of the payload.

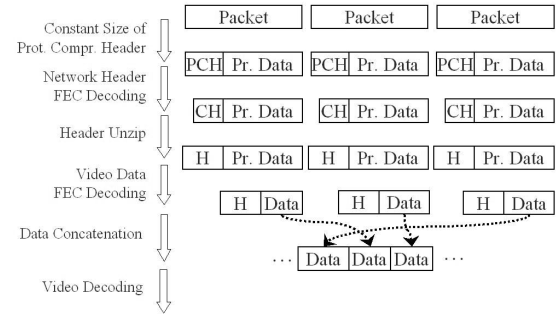

Figure 4 – Reception scheme at network level.

5. NUMERICAL RESULTS

Simulations have been done in the case of an H.263+ bitstream transmitted over a simulated error prone wireless IP network with header compression. In that case (which our algorithm is not limited to), we considered 13 different classes, namely one supra-frame class (corresponding to the network RTP/UDP/IP compressed header of five bytes, as explained in Section 4.3), two inter-frame classes (corresponding to Intra (I) and Inter (P) frames) and for each inter-frame class, at most six intra-frame classes (Header, MCBPC, CBPY, DC, VLC and Vector, as given by the H.263+ standard). The numerical experiments were done with the H.263 TMN 3.2 video codec [8] in QCIF format with GOB synchronization option with for each plot 1000 'Trevor' video sequence with format I_1P_{14} (30Hz). Figure 5 presents illustrates estimated sensitivity for both video data and compressed network headers.

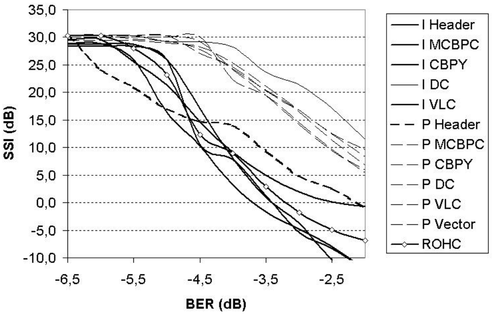

Figure 5 – Error sensitivity results for a networked H.263+ bitstream.

The PSNR results obtained by applying the water-filling algorithm described in Section 4 to determine the optimal UEP coding rates are presented in Figure 6, together with the results obtained for an EEP scheme with same overall coding rate R=1/2. In both cases a BCJR decoding algorithm [9] was applied to the RCPC code of [7], whose quality of service was presented in Figure 2. A gain of about 5 dB in terms of PSNR (or equivalently about 1 dB in terms of SNR) can be observed.

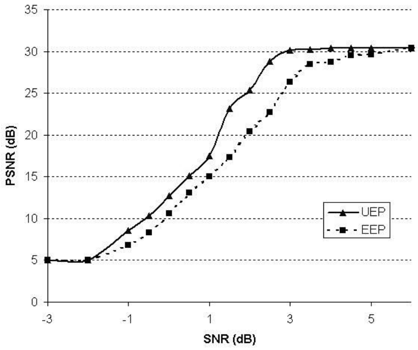

Figure 6 – Performance comparison between Unequal and Equal error protection for H.263+ 'Trevor' sequence over an AWGN channel.

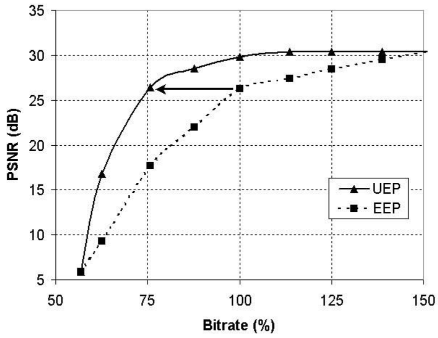

Figure 7 – Bandwidth gain for UEP vs. EEP for H.263+ 'Trevor' sequence over an AWGN channel at SNR=3 dB.

This gain can also be expressed in terms of bit rate gain for the same perceived quality, as illustrated by Figure 7 where the PSNR values obtained for various FEC global rates are given for both UEP and EEP schemes. It can be seen that the UEP scheme achieves the same performance with up to about 25% less bit rate, *i.e.* for half as much redundancy.

6. CONCLUSIONS

The application of Unequal Error Protection to networked video data is presented in this paper, where an original rate protection allocation method is proposed, together with a new measure for class sensitivity estimation, valid both for video data and network headers. This method can be applied to any channel coding scheme, provided if offers different protection levels like rate compatible punctured codes do, any transmission channel, any type of network headers and any source coding scheme. Numerical results have shown that in the context of a H.263+ codec transmission over RTP/UDP/IP protocol stack with header compression, followed by an AWGN channel, gains of about 5 dB in terms of PSNR could be obtained. Naturally, in practice, the algorithm should be applied to data-partitioned coders, to ensure that the classes' separation does not cost too much in terms of side information to be transmitted.

7. ACKNOWLEDGMENT

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7. REFERENCES

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