Recent Advances in Transport Level Error Control Techniques for Wireless Video Transmission

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***Abstract* — Transmission of compressed video over wireless channels remains a challenging task due to the noisy nature of the wireless channels and a single bit error in the compressed video bit-stream might cause the reconstructed video to be severely distorted. Numerous error control techniques have been proposed in the literature in order to minimize the video quality degradation caused by transmission errors in wireless channels. This paper provides a brief review of the recent advances in transport level error control techniques for wireless video transmission. In addition, the transport level error control techniques implemented in the latest mobile TV and digital TV standards will also be briefly discussed.**

I.INTRODUCTION

With the increasing popularity of wireless broadband networks, such as Worldwide Interoperability for Microwave Access (WiMAX), Wi-Fi, High-Speed Downlink Packet Access (HSDPA), etc, transmission of compressed video over wireless broadband networks is gaining popularity. Although wireless broadband networks are able to transmit compressed video data at high bit-rate of more than 1Mbps, robust transmission of compressed video over wireless networks remains a challenging task due to the inherent high bit-error-rate (BER) and channel quality fluctuations of the wireless networks [1]-[2].

As a result of the extensive use of variable length coding in video coding standards, the compressed video bit-stream is very vulnerable to transmission errors and a single transmission error in the coded video bit-stream may cause the video decoder at the receiving end to skip to the next slice or frame and this may result in significant visual quality degradation. In addition, due to the use of motion-compensated based video coding technique, a single bit error in the compressed video bit-stream may cause the error to propagate spatially to neighboring macroblocks and also temporally to adjacent frames [3]. In view of this, successful video communications in the presence of errors requires careful design of the video encoder and decoder, and other system at transport level.

In order to mitigate the effect of transmission errors on the reconstructed video quality at the receiver, numerous error-resilient video coding techniques have been proposed in the literatures. Several excellent review papers on error control techniques for robust video transmission over networks are given in [1], [4]-[5]. It is the objective of this paper to provide an up-to-date review on the recent advances in transport level error control techniques for wireless video transmission, since the previous major surveys on this topic were published in 1998 and 2000 in [1] and [4] respectively. In addition, unlike the previous surveys in [1], [4], which cover all the aspects of wireless video transmission error control techniques, this paper focuses on transport level error control techniques.

This paper is organized as follows. In Section II, a brief general review of the error control techniques for robust video transmission is given. The in-depth review of the latest transport level error control techniques is given in Section III, followed by discussion and conclusion in Section IV.

II. TRANSPORT LEVEL ERROR CONTROL TECHNIQUES

In this section, the recent advances in transport level error control techniques for robust video transmission over wireless channels is presented.

A. FEC Code Allocation

One of the methods to increase the robustness of wireless video transmission is by adding FEC codes to the compressed video bit-stream. However, adding FEC codes to the compressed video bit-stream comes at a price of adding redundancy back to the bit-stream, which is a conflict of reducing the redundancy in the video during the compression process. In order to transmit the compressed video over the normally bandwidth limited wireless channels, the video source has to be further compressed in order to reduce its output bit-rate further to accommodate the extra bit-rate needed to add FEC codes to the compressed video bit-stream [6]. In the event that the FEC code protected compressed video is transmitted over error prone wireless channels, the adding of FEC codes will improve the overall reconstructed video quality at the receiving end [7]. On the other hand, in the event that the FEC code protected compressed video is transmitted over low error rate wireless channels, the adding of FEC code may reduce the overall received video quality. Thus, FEC codes have to be carefully allocated to the compressed video bit-stream to make sure that the compressed video bit-stream is not over protected in low error rate wireless channels and also at the same time not under protected in high error rate wireless channels. This very often leads to unequal error protection of compressed video bit-stream [8], in which the more important compressed video bit-

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stream is protected with a high protection order FEC code while the less important compressed video bit-streams are protected with a low protection order FEC code.

Due to the complexity associated with implementing unequal error protection in practical environments, equal error protection of compressed video bit-stream is normally implemented in practical wireless video transmission. In equal error protection, the same protection order is equally allocated to the whole video bit-stream, without considering the different importance or sensitivity of different bits in a video bit-stream. In this case, the most important header part and the less important AC coefficients are equally protected using the same protection order FEC code, which makes the equal error protection less efficient, compared to unequal error protection [9]. In the recent digital video broadcasting-handhelds (DVB-H) [10] standard, due to the computational complexity of unequal error protection, equal error protection is used to protect the transmitted audio-video against transmission errors by using a link-layer FEC scheme known as multiprotocol encapsulation (MPE) FEC.

An excellent review of the FEC code allocation for coded video transmission over wireless channels is given in [11]. In order to efficiently allocate FEC codes to the compressed video bit-stream, a simple control mechanism that dynamically adjusts the amount of protection based on the packet-loss information fed back to the transmitter was proposed in [12]. It is found in [12] that such adaptive control allows the application layer to maintain optimal video quality regardless of the variation in packet loss rates. In [13], the influence of FEC coding block size, coding rate and compressed video's intra-updating rate on the end-to-end video performance is investigated. Furthermore, method of optimally selecting the few parameters in order to minimize the end-to-end distortion is also shown in the paper.

B. Hierarchical Modulation

Another transport-level error resilient method that has received considerable attention in recent years is the hierarchical modulation [14] approach. Hierarchical modulation, as illustrated in Fig. 1, is a simple and efficient approach to provide different levels of protection to different parts of a bit-stream according to its importance and very often it is associated with UEP. This is achieved by using the non-uniform signal-space constellation of hierarchical modulation. The advantage of this approach is that the different parts of a compressed video bit-stream can be protected with different levels of protection according to its importance without an increase in transmission bandwidth, power, etc. However, hierarchical modulation approach comes with one drawback, in which the number of protection levels provided by hierarchical modulation is limited by the modulation order used. For example, the number of protection levels that can be offered by hierarchical 16-QAM is only limited to 2, in which the two MSBs with lower error rate are classified as high priority bits while the two LSBs with higher error rate are classified as low priority bits.

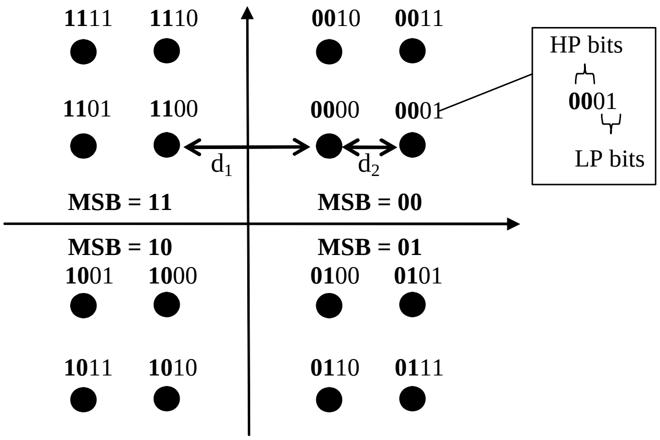

Fig. 1. Illustration of hierarchical 16-QAM constellation diagram (adapted from [19]).

One of the applications of hierarchical modulation is to use it to upgrade the existing satellite TV systems. For the existing digital broadcast networks, such as the digital satellite TV using QPSK modulation, hierarchical 16-QAM can be used to upgrade the existing systems by adding additional data transmission capacity [15]. By upgrading the modulation scheme of the existing digital broadcast networks from QPSK to hierarchical 16-QAM, the existing users will still receive the same TV channels without changing the decoders while the new subscribers using new decoders will receive additional TV channels through the additional capacity added by the hierarchical 16-QAM. This can be achieved because the upgraded system using hierarchical 16-QAM consists of a basic constellation using the two MSBs, which is the same as the original system using QPSK modulation, and a secondary constellation using the two LSBs which carries the additional data needed for the new TV channels.

C. Unequal Error Protection

It is a well known fact that the binary bits in a compressed video bit-stream are not equally important, with some of the binary bits having higher importance compared to other binary bits. For example, the video bit-stream's header is much more important than the AC coefficients data and thus it should be better protected against transmission errors. Unequal error protection (UEP), which is based on the priority encoding transmission in [16], is a transport level error control technique in which the more important bits in the compressed video bit-stream are better protected against transmission errors compared to the less important bits.

There are many approaches in which the more important video bit-stream can be better protected against transmission errors compared to the other less important video bit-stream. The two commonly used approaches are by using FEC codes and hierarchical modulation in order to have different protection orders to the compressed binary bit-stream. For UEP using FEC code, a stronger FEC code is allocated to the more important compressed video bit-stream, compared to the less important bit-stream, as shown in Fig. 2. On the other hand, for UEP using hierarchical modulation, the more important compressed video binary bits are mapped to the MSBs of the symbol bits with a lower error rate while the least important compressed video binary bits are mapped to the LSBs of the symbol bits with a higher error rate.

UEP can be mainly classified into three categories according to the consideration of different aspects of the compressed video bit-stream's sensitivity to transmission errors. The three UEP categories are:

i. UEP using different importance of binary bits in a video bit-stream.
ii. UEP using different importance of frames in a GOP.
iii. UEP using different importance of layers in scalable video coding.

1) UEP using Different Importance of Binary Bits in a Video Bit-stream.

The first category is by considering that the binary bits in the compressed video bit-stream are not equally important. In a typical video packet, the headers of the bit-stream and video frame are the most important parts as a corrupted video packet header may cause the whole packet to be undecodable. The second most important part of a typical video packet are the motion vectors in P-frames and DC data in I-frames while the AC coefficients data is normally classified as the least important part of a video bit-stream. The data partitioning function in the H.264 video coding standard is one example of error resilient video encoding method that makes use of the fact that the binary bits in a compressed video bit-stream are not equally important. In [17] the header part is protected by a high protection order FEC code while the motion data and DC data, which are the second most important data after the header part, are protected by a medium protection order FEC code while the least important AC data are protected by a low protection order FEC code.

Instead of using different FEC codes to provide the different protection orders required for UEP, UEP can also be achieved by using hierarchical modulation [18]. In [18], the binary bits of the most important network abstract layer (NAL), namely NAL-A are mapped to the two MSBs of the hierarchical 16-QAM with lower error rate while the less important NAL-B and NAL-C are mapped to the two LSBs of the hierarchical 16-QAM with higher error rate.

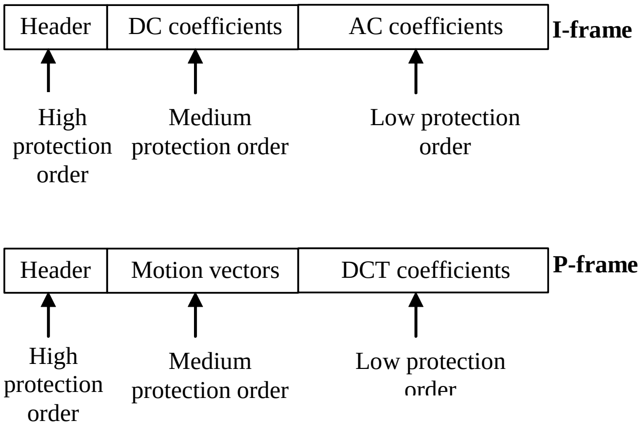

Fig. 2. Illustration of UEP using different importance of binary bits in a video bit-stream (adapted from [17]).

2) UEP using Different Importance of Frames in a GOP

The second category of UEP is by considering the different importance of frames in a GOP. By making use of the fact that the I-frame and the earlier P-frames in a GOP are more important than the rest of the frames, they should then be allocated a higher protection order [19]-[20], as illustrated in Fig. 3. In [20], the frames in a GOP are classified into three priorities, namely high, medium and low priorities which are protected by high, medium and low protection order FEC codes respectively. The I-frame and the early P-frames in a GOP constitute the high priority data while the P-frames in the middle of a GOP constitute the medium priority data. The rest of the P-frames constitute the low priority data.

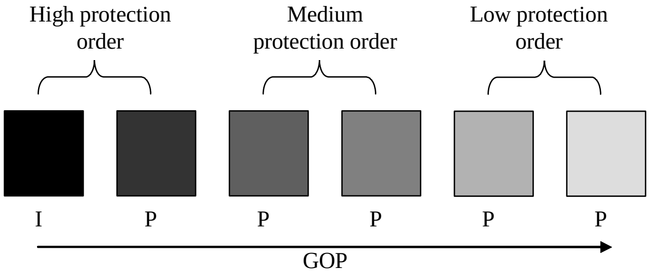

Fig. 3. Illustration of UEP using different importance of frames in a GOP (adapted from [20]). The darker the gray colour, the more important.

3) UEP using Different Importance of Layers in Scalable Video Coding

The third category of UEP is by considering the different importance of different layers in scalable video coding [2], [21], as illustrated in Fig. 4. By making use of the fact that different layers of scalable video coding are not equally important, more protection should be allocated to the more important base layer, compared to the enhancement layers. In [21], the enhancement-layer bit-stream is first packetized into a group of independent and scalable data packets. Parity packets, which are also scalable, are then generated. Unequal protection is finally achieved by properly shaping the data packets and the parity packets. In [22], the more important base layer video bit-stream is mapped to the hierarchical QAM's higher priority symbol bits with lower error rate while the less important enhancement layer video bit-stream is mapped to the lower priority symbol bits with higher error rate.

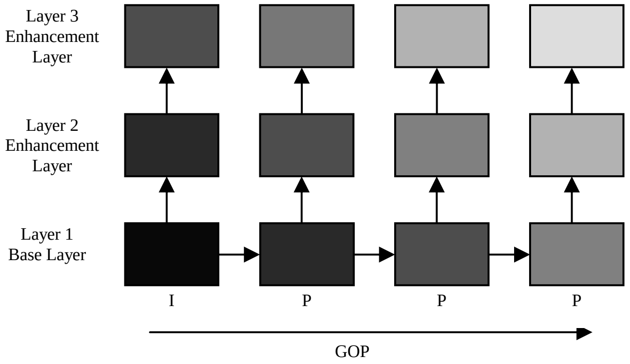

Fig. 4. Illustration of UEP using different importance of layers in scalable video coding (adapted from [2]). The darker the gray colour, the more important.

The terrestrial digital video broadcasting (DVB-T) standard [23] and QUALCOMM's MediaFLO standard [24] supports the use of hierarchical modulation. By utilizing the hierarchical modulation feature together with the scalable video coding, digital video broadcasting operators using DVB-T or MediaFLO can then make use of UEP technique in their video broadcasting. With this a coarse resolution of the video can be transmitted using the high priority bits of the hierarchical modulation with low error rate while the fine resolution of the video can then be transmitted using the low priority bits with higher error rate. The use of this UEP technique in digital video broadcasting will prevent the case of sudden disruption of reception as the subscribers will still receive a coarse resolution video in the case of poor reception situation. In addition, it will also increase the operator's coverage as those receivers which are far from the transmitter will still receive a low quality base layer video, which will not be possible using traditional equal error protection.

D. Adaptive Modulation

Wireless video transmission using adaptive modulation has gained attention in the recent years, thanks to the advancements in adaptive modulation and channel estimation techniques [25]. In wireless video transmission using adaptive modulation, the modulation order and constellation size are changed according to the instantaneously or near-instantaneously estimated channel condition. In [26], the transceivers will switch to a higher modulation order (for example, from 8-QAM to 16-QAM) if the estimated channel condition is good in order to accommodate a higher video data bit rate, which will result in a higher received video quality. On the other hand, if the estimated channel condition is poor, a lower modulation order, which is able to reduce the data's BER by reducing the data throughput, will be used in order to maintain the reconstructed video quality at the receiver.

In addition to changing the modulation order according to the estimated channel condition, the constellation size or offset angle of the 8-PSK can also be changed according to the estimated channel conditions [19].

E.Cross Layer Optimization

Majority of the error resilient video coding techniques in the literatures work independently at different layers of the OSI layer model, without taking into consideration the characteristics of other layers. For example, the modulation scheme at the physical layer is optimized in order to get the highest throughput, without explicitly considering the specific characteristics of the video data at the application layer. Conversely, the compression algorithms at the application layer do not consider the mechanisms provided by the lower layers for error protection, resource allocation, etc. These single layer optimization approaches are simple to implement in practical environments but may result in sub-optimal performance which may not result in the highest reconstructed received video quality at the receiver [27].

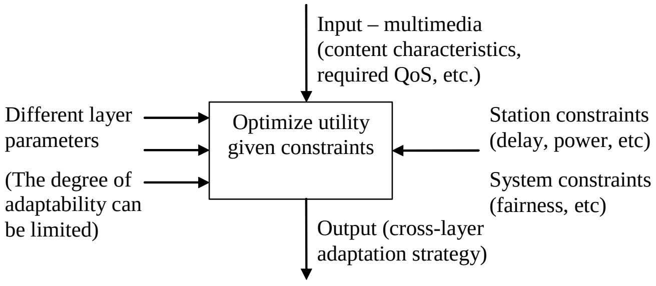

Fig. 5. Illustration of the cross-layer optimization scheme in [27] (adapted from [27]).

As a result of this drawback of the single layer optimization approach, cross-layer optimization techniques for robust video transmission over wireless channels have gained attention in recent years. Compared to single layer optimization approach, cross-layer optimization approach optimizes various parameters at various layers of the OSI model and this will result in improved video quality at the receiver. In [27], the cross layer optimization problem is to find a global optimal strategy that will result in the best reconstructed video quality at the receiver, given the different resource management, adaptation and protection strategies available in the physical, medium access control and application layers, as illustrated in Fig. 5.

In [28], an adaptive cross-layer protection strategy for robust streaming of video over IEEE 802.11 WLAN was proposed. The proposed cross-layer technique enhances the robustness and efficiency of video transmission over WLAN by performing tradeoffs between throughput, reliability, and delay depending on the channel conditions and application requirements. This cross-layer technique optimizes the application and MAC layers by using the H.264 data partitioning feature at the application layer and an appropriate

QoS mapping at the IEEE 802.11e's MAC layer.

With the increasing popularity of the IEEE 802.16e, namely Mobile WiMAX standard, a cross-layer optimization of video broadcast over WiMAX was proposed in [29]. The proposed cross-layer optimization technique optimizes the coverage, spectrum efficiency and the video quality.

III. CONCLUSION

A review of the recent advances in transport level error control techniques in wireless video compression is presented in this paper. The advantages and disadvantages associated with each of the transport level error control techniques are also presented.

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