

# RTP/AVPF Compliant Feedback for Error Resilient Video Coding in Conversational Applications

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**Abstract**— Feedback-based error-resilient video coding relies on efficient transmission of feedback messages. The Audio-Visual Profile with Feedback (AVPF) for Real-time Transport Control Protocol (RTCP), i.e. RTP/AVPF, supports low-latency feedbacks. In this paper, a reference picture selection (RPS) method using RTP/AVPF-compliant feedback is proposed. A restriction period is first derived in the codec layer based on the previously transmitted back-channel message, the RTCP reporting interval, the round-trip time, and the processing delay of the encoder. Then, a feedback message is transmitted when the restriction period is passed and an incorrectly reconstructed picture is detected. At the encoder, the decoded picture buffer (DPB) is adaptively controlled to combat feedback delay fluctuation in RTP/AVPF. Simulation results show that the proposed entire solution outperforms traditional RPS, wherein a back-channel message is transmitted for every lost picture and the DPB is managed by sliding window.

## I. INTRODUCTION

Compressed video data is vulnerable to packet losses, mainly because of the use of inter prediction to achieve high compression ratio, as in most of today's video codecs, e.g., the Advanced Video Coding (H.264/AVC) standard [1]. Therefore, error control methods play a key role in low-latency video applications over error-prone networks. Error control techniques can roughly be classified into three categories: interactive error control, forward error correction and concealment, and error concealment by post-processing. Feedback-based error-resilient video coding falls into the category of interactive error control methods. In feedback-based error-resilient video coding, the decoder sends feedback messages, also known as back-channel messages, to the encoder, indicating which pictures or parts of them are correctly or incorrectly reconstructed. The encoder can adapt the error-robustness of the compressed video data selectively based on the received messages.

A variety of feedback-based error-resilient video coding techniques have been proposed and comprehensive reviews of these techniques have been presented in [2] and [3]. Feedback-based intra refresh [3] and Reference Picture Selection (RPS) [4] are two typical feedback-based error-

resilient video coding methods. The feedback-based intra refresh method stops error propagation by switching to intra coding mode for some macroblocks (MBs) based on the received back-channel messages.

Feedback based error resilient video coding methods, such as RPS, operate more efficiently when the feedback delay is as short as possible. When RTP/AVPF [5] compliant RTCP packets are utilized to carry the feedback messages, the excessive transmission of back-channel messages should be avoided for two reasons. First, as the allowed transmission times and the RTCP bandwidth are limited, unnecessary back-channel messages may delay the transmission of more important messages at RTCP agent. Second, generating unnecessary feedback messages at the decoder within a certain period of time (called restriction period in this paper) decreases the efficiency of the feedback channel.

In RPS, efficient management of the decoded picture buffer (DPB) is another important issue. To perform RPS, both the encoder and the decoder should typically store multiple reference frames into the decoded picture buffer (DPB) to cover the maximum feedback delay [3]. If DPB size can cover the maximum feedback delay, the DPB can be managed with a first-in-first-out (FIFO, also known as sliding window) manner. Otherwise, an adaptive method should be used to manage the DPB for guaranteeing the existence of the correctly decoded reference picture in the DPB. To apply RPS on a very limited memory, Wang et al. [6] proposed a method to decrease the number of stored reference frames to two frames at the decoder side, to store the latest reference picture and a reference picture that is known to be correct. The decoder decides which picture to be stored in the decoder according the correctness of the decoded picture. Mulroy et al. [7] recently presented a method in which the encoder creates decoded reference picture marking commands (called marking commands or memory management control operation, MMCO, commands in this paper) for each picture to maintain pictures from three different time instants in the DPB. This method does not guarantee to store the latest correct reference picture in the DPB when the DPB size can cover the feedback delay and also requires a large amount of

MMCO commands, which increase the complexity as well as consume bandwidth.

In contrast to earlier works, the constraints of the RTCP packet scheduling governed by RTP/AVPF are considered when transmitting feedback messages in the presented method. The proposed feedback transmitting method restrains to transmit feedback message in the restriction period to avoid excessive transmission of feedback messages. In addition, a standard-compliant DPB management method using long-term reference pictures is proposed to guarantee that the latest correct reference picture is stored in the DPB if the DPB size covers the feedback delay as well as to guarantee that an earlier correct long-term reference picture is stored in the DPB if the DPB size can not cover the feedback delay. The management of long-term reference pictures does not follow the FIFO rule. The proposed DPB management method creates marking commands to mark a short-term reference picture as a long-term reference picture only after receiving a feedback message indicating correct short-term reference picture therefore the excessive creation of MMCO commands is avoided.

The rest of the paper is organized as follows. Section 2 gives an overview of a video transmission system allowing feedback. The feedback message generation algorithm is presented in Section 3. Reference picture selection and decoded reference pictures management are described in Section 4. Simulation results and conclusions are presented in Sections 5 and 6, respectively.

## II. OVERVIEW OF FEEDBACK-BASED SYSTEM

The Real-time Transport Protocol (RTP) and its companion protocol, the Real-time Transport Control Protocol (RTCP), are widely used in video communications over the Internet Protocol (IP). An RTP profile known as the audio-visual profile with feedback (RTP/AVPF) [5] is often used in low-latency conversational video applications, such as video telephony. RTP/AVPF enables the transmitting of feedback messages encapsulated into RTCP packets. When limited bandwidth is allocated to the RTCP stream, which is usually the case, the RTCP reporting interval is limited. To achieve timely feedback, the concept of Early RTCP packet as well as the algorithm of Early RTCP transmission was introduced in RTP/AVPF.

### A. Definitions and Terminology

In RFC 3550 [8], known as RTP, the RTCP transmission is controlled by defining RTCP transmission interval between two consecutive RTCP packets. RFC 3550 calculates the RTCP transmission interval based on sharable RTCP bandwidth and average size of RTCP packets. In RFC 4585, known as RTP/AVPF, the RTCP transmission interval of RFC 3550 is noted as Regular RTCP interval. In addition, the RTP/AVPF defines that RTCP packets can be reported earlier than the next Regular RTCP transmission time. Such an earlier transmission is defined as Early RTCP transmission. A Regular RTCP packet is transmitted at the time slot which is scheduled according to the Regular RTCP interval. An Early

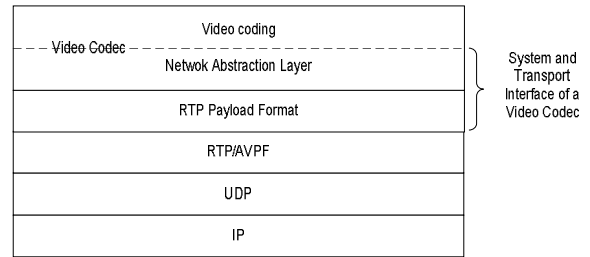


Fig. 1. Protocol stack for feedback-based video communication systems.

RTCP packet is transmitted at the time slot which is earlier than the next scheduled time slot to transmit a Regular RTCP packet.

### B. Protocol Stack for Feedback-based Video Communication Systems

In both video data and back-channel message transmission, our system makes use of an RTP/UDP/IP [5][8]-[13] protocol stack as shown in Fig 1. In the application layer, typical RTP and AVPF enabled RTCP are utilized to transport video data and feedback messages. AVPF not only reports sender report (SR) and receiver report (RR), but also reports the feedback messages by utilizing RTCP scheduling algorithm defined in RTP/AVPF. A feedback message containing correct reference picture identification is encapsulated into an RTCP packet as Reference Picture Selection Indication (RPSI) which is one of the application layer feedback messages defined in RTP/AVPF. The RTP and RTCP packets generated in the application layer are encapsulated as UPD and IP packets consecutively at transport layer and Internet layer.

The modified RTCP transmission algorithm in RTP/AVPF [5] is outlined as follows. If no feedback message has to be reported to the video sender, the Regular RTCP packet is transmitted. Otherwise, if a receiver detects the need to send a feedback message, it may send the message earlier than the next regular RTCP packet. Before sending an Early RTCP packet, the RTCP agent has to check whether an Early RTCP packet has been transmitted after transmitting the previous Regular RTCP packet. If no Early RTCP packet has been reported since last Regular RTCP packet, an Early RTCP packet containing a feedback message can be sent. Otherwise, the feedback message should be encapsulated into the next Regular RTCP packet. This means only one Early RTCP packet can be transmitted between two consecutive Regular RTCP packets. After sending an Early RTCP packet, the RTCP reporting engine must update the time to send the next Regular RTCP packet by delaying one more Regular RTCP interval.

## III. PROPOSED FEEDBACK TRANSMISSION METHOD

We propose a feedback transmission method at codec layer. Upon knowing a picture is incorrectly decoded, the decoder transmits a feedback message only when the picture is not within a so-called restriction period. The definition and calculation of the restriction period is presented in Section 3.A.

### A. Restriction Period

A restriction period is a period when a back-channel message is not transmitted. It is expected that the error propagated in restriction period will be stopped by the next incoming refresh picture for which the encoder has reacted to the said feedback message by encoding the picture using an earlier correctly decoded picture for inter prediction or as in intra coded picture. Therefore, transmitting feedback messages within the restriction period is redundant. The restriction period is calculated as follows:

$$RP_i = AgentD_i + RTT + ED_i \quad (1)$$

where  $RP_i$  denotes the restriction period after transmitting the  $i^{th}$  feedback message,  $AgentD_i$  denotes the delay to report the  $i^{th}$  feedback message at the RTCP agent,  $RTT$  denotes round-trip time (RTT), and  $ED_i$  denotes the processing delay to encode a refresh picture which performs the RPS after receiving the  $i^{th}$  feedback message.

In RTP/AVPF, the delay to report feedback message at the RTCP agent, i.e.,  $AgentD_i$ , fluctuates between 0 to  $2 \times T_{rr}$ , which results in a large fluctuation of restriction period value. However, as can be seen from (1), the restriction period is equal to a period of time from generating a feedback message to receiving the corresponding refresh picture.

An example of the restriction period is shown in Fig. 2. We assume that picture 22 and picture 25 are partially lost. When the decoder detects the partial loss of picture 22 and deduces that picture 22 was not in the restriction period, a feedback message is generated and sent to RTCP agent for transporting to the encoder. In this example, the restriction period starts when the feedback message is generated and ends when the corresponding refresh picture, i.e., picture 28, is received. During this restriction period no feedback should be generated.

### B. Feedback Transmission Algorithm

We define a correct or incorrect picture via (2), in a way similar as in [6],

$$C(i) = \begin{cases} C_p(i) & \text{picture } i \text{ is coded only using spatial prediction} \\ C_p(i) \& C_r(i) & \text{picture } i \text{ is coded using temporal prediction} \end{cases} \quad (2)$$

where  $C(i)$  equal to 1 indicates that picture  $i$  is correct and 0 indicates that picture  $i$  is incorrect,  $C_p(i)$  equal to 1 indicates that all slices of picture  $i$  are correctly received by the decoder, and 0 indicates that at least one slice of picture  $i$  is lost.  $C_r(i)$  equal to 1 indicates that all reference pictures of picture  $i$  are correct, and 0 indicates that at least one reference picture of picture  $i$  is incorrect. When a picture is only spatially predicted (Intra coded), its correctness is dependent only on  $C_p(i)$ : whether all of its slices are correctly received. When inter prediction is used, a picture is correct only when all its slices are correctly received and all its reference pictures are correct.

A back-channel message is generated when a picture is not

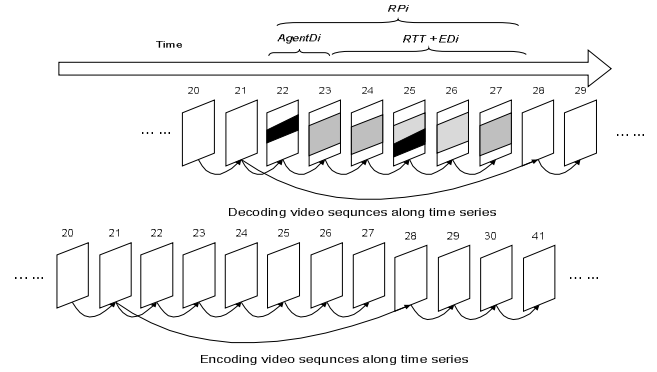


Fig. 2. Restriction period to generate feedback message.

correct and the following time restriction condition is satisfied:

$$Tg(c(i)) - Tp > RP \quad (3)$$

where  $Tg(c(i))$  denotes the time of detecting an incorrectly reconstructed picture  $i$ ,  $Tp$  denotes the time when the previous feedback message was generated, and  $RP$  denotes the restriction period.

After a back-channel message is sent, if the back-channel message is lost or the refresh picture is entirely lost, then no refresh picture will appear within the restriction period. In this case, the time restriction condition is satisfied for a picture that is incorrect, when the restriction period has elapsed and a new back-channel message is then generated and transmitted.

## IV. REFERENCE PICTURE SELECTION AND DECODED PICTURE BUFFER MANAGEMENT

In this section, firstly, we describe the method for selection of reference pictures based on feedback messages by the encoder. Secondly, we propose a method to manage multiple decoded reference pictures for RPS. In our method, the latest correct reference picture present at both the encoder and the decoder is preserved and the latest correct reference picture is updated along with the incoming new feedback message. The encoder decides which reference pictures are stored in the decoder and generates the corresponding marking commands, if necessary, to direct the decoder to store appropriate reference pictures. Our method makes uses of long-term reference pictures defined in H.264/AVC.

### A. Reference Picture Selection

After receiving a back-channel message, which contains the indication of a correct reference picture, the encoder codes the next picture as follows. If the correct reference picture indicated in the feedback message is not stored in the encoder but the encoder stores a long-term reference picture indicated as correct in a previous back-channel message, then the encoder encodes the next picture as inter picture using the long-term reference picture as a reference. Otherwise, if the correct reference picture indicated in the feedback message is

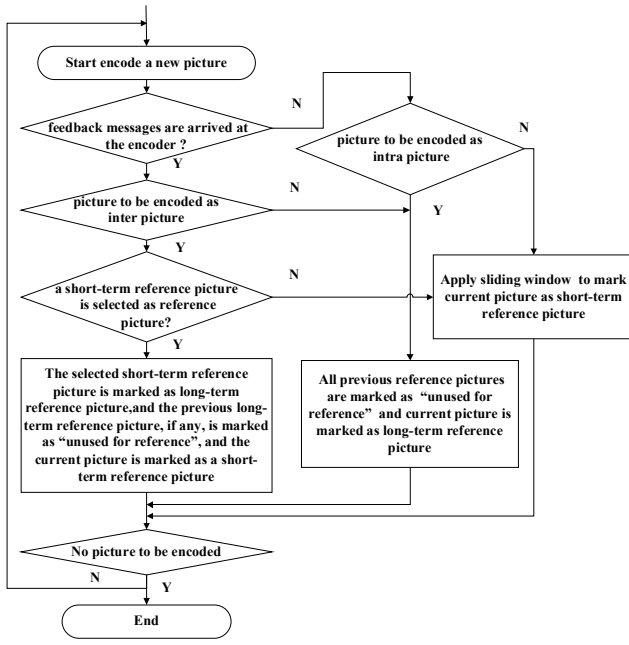


Fig. 3. Feedback based adaptive DPB memory control.

not stored in the encoder and the encoder does not store a long-term reference picture indicated as correct in a previous back-channel message, the next picture is coded as an intra picture. Otherwise (the correct reference picture indicated in the back-channel message is stored in the encoder), the next picture is coded as an inter picture using the indicated reference picture for inter prediction.

### B. Decoded Picture Buffer Management

If no feedback message arrives at the encoder before encoding a picture, the picture is marked as short-term reference picture except the first intra picture which is marked as long-term reference picture, and sliding window is applied to manage the short-term reference pictures as defined in H.264/AVC. Otherwise, a feedback message has arrived at the encoder before encoding the current picture, the adaptive memory control is applied to manage the multiple decoded reference pictures as depicted in Fig. 3. When adaptive memory control is applied, the encoder generates and includes corresponding memory management control operation commands to the current coded picture. The decoder manages its DPB according to the instructions contained in the bitstream as specified in H.264/AVC.

## V. SIMULATION RESULTS

The simulations were performed according to the common conditions for Scalable Video Coding (SVC) error resilience testing specified in JVT-P206 [14], which is also applicable for H.264/AVC error resilience tests. The considered application environment was 3G wireless conversational video communication using RTP/UDP/IP for transporting.

Five QCIF-resolution (176x144 luma samples) test sequences at 15 frames/s with varying bit rates were encoded:

Mother-daughter (48 kbps), Salesman (64 kbps), News (64 kbps), Foreman (96 kbps) and Carphone (96 kbps). For each sequence, 4000 frames were encoded using sequence repetition as defined in JVT-P206. The target slice size was 200 octets, and one slice was encapsulated into one RTP packet. The observed RTP layer packets loss rates were about 4%. In forward video transmission, the 40-octet RTP/UDP/IP header per packet was considered in the bitrate calculations. To evaluate the performance of the proposed feedback transmission method in RTP/AVPF compliant RTCP transmission, especially with Early RTCP transmission, the RTCP bandwidth was set to 72 octets per second for the Mother-daughter and Salesman, 96 octets per second for News, and 160 octets per second for Foreman and Carphone. With such a simulation condition, each feedback message can not be transmitted immediately to the encoder. But the feedback messages can still be transmitted with acceptable feedback delay so that the encoder can perform error resilient video coding such as using RPS. The 40-octet RTCP/UDP/IP header per packet was also considered in the Regular RTCP interval calculation of RTP/AVPF as described in section 2.2. Early RTCP packets defined in RTP/AVPF were used to report feedback messages to the encoder as described in section 2.2.

We implemented the proposed feedback transmission method (PFTM) combined with the proposed feedback based adaptive memory control (PFAMC), denoted as PFTM+PFAMC, in an H.264/AVC codec implementation. To evaluate the effectiveness of the proposed methods, we also implemented a traditional feedback transmission method (TFTM) combined with the proposed feedback based adaptive memory control (PFAMC), denoted as TFTM+PFAMC, as well as TFTM combined with a sliding window memory control (SWMC), denoted as TFTM+SWMC, wherein TFTM generates a back-channel message whenever a partial or an entire picture loss is detected by the H.264/AVC decoder. To analyze the effectiveness of feedback-based error-resilient video coding compared to macroblock-based Intra Refresh, we also present the simulation results of Adaptive Intra Refresh (AIR), which is close to the method presented in [15]. AIR stops error propagation by coding MBs as intra mode without relying on feedbacks. All of the error resilient video coding methods use the same error concealment technique, which is similar to the one presented in [16], wherein the motion vectors of neighbor macroblocks are used to conceal the lost macroblocks. When a non-refresh picture is entirely lost and a refresh picture is partially or entirely lost, a simple previous picture copying method is applied to conceal the lost picture.

Two sets of simulation were performed. The first set was configured to have different link delays but the same DPB size, while the second set was configured to have different DPB sizes but the same link delay. In all the simulations, though multiple reference pictures were stored in both the encoder and the decoder for those cases using RPS, only one reference picture was used in motion compensation, including AIR.

Table I Average PSNR of link delay 100 and DPB size 8

Sequence	Bit Rates (Kbps)	Error Free PSNR (dB)	PSNR of PFTM +PFAMC (dB)	PSNR of TFTM +PFAMC (dB)	PSNR of AIR (dB)
Mother-daughter	47	37.86	34.60	33.47	34.27
Salesman	47	35.67	32.73	32.01	32.48
News	63	35.15	31.35	29.52	30.89
Foreman	94	33.59	30.03	29.26	29.71
Carphone	94	34.36	30.58	30.14	31.18

Table II Average PSNR of link delay 150 and DPB size 8

Sequence	Bit Rates (Kbps)	Error Free PSNR (dB)	PSNR of PFTM +PFAMC (dB)	PSNR of TFTM +PFAMC (dB)	PSNR of AIR (dB)
Mother-daughter	47	37.86	33.96	32.79	34.27
Salesman	47	35.67	30.83	30.47	32.48
News	63	35.15	30.48	29.31	30.89
Foreman	94	33.59	29.53	29.33	29.71
Carphone	94	34.36	30.60	30.01	31.18

Table III Average PSNR of link delay 200 and DPB size 8

Sequence	Bit Rates (Kbps)	Error Free PSNR (dB)	PSNR of PFTM +PFAMC (dB)	PSNR of TFTM +PFAMC (dB)	PSNR of AIR (dB)
Mother-daughter	47	37.86	33.82	32.66	34.27
Salesman	47	35.67	30.99	30.81	32.48
News	63	35.15	30.40	29.24	30.89
Foreman	94	33.59	29.53	29.22	29.71
Carphone	94	34.36	30.40	30.04	31.18

Tables I, II and III present the average luma PSNR values of two different combinations including PFTM+PFAMC and TFTM+PFAMC, wherein link delays were set to 100 ms, 150 ms and 200 ms, respectively, and the DPB size was set to 8.

For different link delays, PFTM+PFAMC always outperform TFTM+PFAMC for the test sequences. The average improvements of different link delays for Mother-daughter, Salesman, News, Foreman and Carphone were 1.15 dB, 0.42 dB, 1.39 dB, 0.43 dB and 0.46 dB, respectively. This clearly shows the effectiveness of the proposed feedback transmission method. Moreover, PFTM+PFAMC with link delay 100 ms outperforms AIR for all test sequences except Carphone. The average improvements were 0.33 dB, 0.25 dB, 0.46 dB and 0.32 dB for Mother-daughter, Salesman, News and Foreman, respectively. However, TFTM+PFAMC with link delay 150 ms and 200 ms does not outperform AIR for all test sequences under the limited RTCP bandwidth to carry the feedback messages.

Tables IV, V and VI present the average luma PSNR values of two different combinations including PFTM+PFAMC and

Table IV Average PSNR of link delay 100 and DPB size 16

Sequence	Bit Rates (Kbps)	Error Free PSNR (dB)	PSNR of PFTM +PFAMC (dB)	PSNR of TFTM +SWMC (dB)	PSNR of AIR (dB)
Mother-daughter	47	37.86	34.74	34.72	34.27
Salesman	47	35.67	33.23	31.28	32.48
News	63	35.15	31.53	30.50	30.89
Foreman	94	33.59	29.79	30.37	29.71
Carphone	94	34.36	31.15	31.19	31.18

Table V Average PSNR of link delay 100 and DPB size 8

Sequence	Bit Rates (Kbps)	Error Free PSNR (dB)	PSNR of PFTM +PFAMC (dB)	PSNR of TFTM +SWMC (dB)	PSNR of AIR (dB)
Mother-daughter	47	37.86	34.60	33.97	34.27
Salesman	47	35.67	32.73	29.84	32.48
News	63	35.15	31.35	29.86	30.89
Foreman	94	33.59	30.03	29.62	29.71
Carphone	94	34.36	30.58	30.92	31.18

Table VI Average PSNR of link delay 100 and DPB size 4

Sequence	Bit Rates (Kbps)	Error Free PSNR (dB)	PSNR of PFTM +PFAMC (dB)	PSNR of TFTM +SWMC (dB)	PSNR of AIR (dB)
Mother-daughter	47	37.86	34.19	33.87	34.27
Salesman	47	35.67	31.50	29.94	32.48
News	63	35.15	30.28	29.58	30.89
Foreman	94	33.59	29.66	29.48	29.71
Carphone	94	34.36	30.22	30.54	31.18

TFTM+SWMC, wherein the DPB sizes were set to 16, 8, and 4, respectively, and link delay was set to 100 ms. On average, PFTM+PFAMC outperforms TFTM+SWMC by 0.32 dB, 2.13 dB and 1.07 dB for Mother-daughter, Salesman and News, respectively. The combination with PFAMC yields significant improvement compared to the combination involving SWMC for Salesman.

The performance of PFAMC depends on the content of the test sequences as well as the interval between the long-term reference picture and the picture using the long-term reference picture as a reference for inter prediction. In general, PFAMC performs well for sequences with small motion and complex textures. This is the reason why a significant improvement was achieved with the Salesman sequence when the PFTM+PFAMC combination was used compared with the TFTM+SWMC combination. An important advantage of the proposed PFAMC compared to SWMC can be observed from Tables IV, V and VI. PFAMC performed quite well with a DPB size of 8 because PFAMC requires a DPB size covering a medium feedback delay instead of the maximum feedback

delay. However, the performance of SWMC was acceptable when DPB size was set to the maximum 16 since SWMC requires DPB size to covering the maximum feedback delay. Comparing PFTM+PFAMC with AIR, the proposed combinations outperform AIR as long as the DPB size covers the medium feedback delays such as for DPB size 8 and 16 for most of the test sequences. However, as can be expected, for most of the DPB sizes, particularly 4 and 8, AIR remained superior to the RPS using SWMC.

## VI. CONCLUSIONS

An RTP/AVPF-compliant feedback transmission method for error-resilient video coding was proposed in this paper. By restraining from transmitting unnecessary back-channel messages within the so-called restriction period, efficient transmission of back-channel messages was realized under the RTCP bandwidth constraint. In addition, the proposed feedback based decoded picture buffer management guarantees that a correctly decoded reference picture is available in the decoded picture buffer for scenarios where feedback delays fluctuate dramatically, which is typical in RTP/AVPF. Simulation results showed the efficiency of proposed feedback transmission method as well as proposed decoded picture buffer management method.

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