The Effect of MMT AL-FEC on QoE of Error-Concealed Video Streaming

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Abstract

In this paper, we assess subjective QoE (Quality of Experience) and objective application-level QoS (Quality of Service) of video IP transmission with error concealment mechanisms of H.264/AVC and AL-FEC (Application-Level Forward Error Correction) of MMT (MPEG Media Transport), which is an application-level protocol for video transmission. The mutual effect is expected to realize more efficient video streaming from a QoE point of view. The experiment treats two contents, two types of the number of slices per picture frame, and two types of the total bitrate of video and its FEC code. We experiment with several load conditions. We then compare FEC schemes with three code rate values and no FEC scheme. We show from the assessment results that the appropriate code rate for QoE enhancement depends on not only network conditions but also contents.

Key words: audio and video IP transmission, MMT, AL-FEC, error concealment, subjective assessment

1. Introduction

For any Internet users, video streaming services are widely used applications. As the consumers, the essential quality criterion is QoE (Quality of Experience)\(^1\). MMT (MPEG Media Transport)\(^2\) has been gaining much expectation as an application-level communication protocol for video transmission. The protocol mainly considers H.265/HEVC transmission. It also has the role of replacement of MPEG2-TS, which has been widely used in broadcasting. It is employed for next-generation high-definition television broadcasting in the U.S.\(^3\) and Japan\(^4\).

MMT can provide the synchronized output of multiple media from various transmission channels, e.g., broadcasting, wired and wireless IP communications. The adaptation of IP transmission is one of the major characteristics. MMT opens up next-generation television services by means of integration of broadcasting and communications.

This paper focuses on IP-based transmission. Quality degradation of transmitted streams can occur owing to the best-effort nature of IP. Wireless access is also indispensable in current IP networking scenarios. It evolves to achieve larger bandwidth and higher functionality such as 5G cellular networks. A major characteristic of 5G is ultra-low latency. The future network applications are expected to make use of low latency.

To satisfy the requirement of low latency communications, we need to utilize quality enhancement mechanisms without retransmission. For recovering from errors and packet losses over the networks, in MMT, we can employ AL-FEC (Application-Level Forward Error Correction).

There are many papers discussing video streaming QoE with AL-FEC. Reference 5) evaluates QoE of IPTV with AL-FEC through RTP/UDP/IP. It assesses three objective measures: NTIA-VQM, PSNR (Peak Signal-to-Noise Ratio), and DMOS-KPN. In 7), Kumar and Oyman deal with QoE of eMBMS live video streaming with AL-FEC. They employ PSNR and the occurring ratio of re-buffering as the performance measures. However, both studies do not perform a subjective assessment and do not treat MMT.

Besides, at the application-level, video error concealment can be used for mitigating the deterioration by the errors and packet losses\(^6\). It is a method to interpolate lost video slices due to packet drop with other information of the video stream. The spatial quality of the error-concealed video degrades compared to the original one since the method cannot perfectly recover the information.

It has not been clarified the effect of the combination of AL-FEC and error concealment on QoE of audiovisual IP transmission over MMT. The mutual effect of AL-FEC and error concealment can realize more effi-
cient video streaming from a QoE point of view. Both AL-FEC and error concealment mitigate the negative effect of packet loss. However, the strategies to manage the loss are different. To show the feasibility of QoE enhancement, we need to appreciate the relationships among the various factors affecting QoE, which include not only AL-FEC and error concealment but also various parameters such as network conditions and contents.

This paper is aimed at QoE enhancement by means of an appropriate combination of error concealment and AL-FEC on MMT. As the first step, we assess the joint effect of AL-FEC and the error concealment mechanism in H.264/AVC on subjective QoE and objective application-level QoS, which is closely related to QoE. The reason we employ H.264/AVC is its support for various error concealment techniques. H.265/HEVC omits error concealment mechanisms for encoding high definition video, although the primary target of MMT is H.265/HEVC transmission. FFmpeg, which is a decoder employed in this paper, also cuts the concealment mechanisms for H.265/HEVC.

The performance of AL-FEC is affected by the application-level PDU (protocol data unit) generation process. Thus, we need to consider the effect of AL-FEC in MMT.

We organize the remainder of this paper as follows. Section 2 discusses the related work. Section 3 introduces the AL-FEC mechanism in MMT. Sections 4 and 5 describe the experimental method and the QoE assessment method, respectively. Section 6 presents the experimental results. Section 7 concludes this paper.

2. Related work

There are many studies on MMT. Most of the studies exploit the inherent hybrid media delivery and synchronization mechanisms.

In 8), Park et al. present an empirical analysis of the channel-zapping time regarding the MMT and MPEG-DASH technologies. They clarify the important factors and propose a simple method for fast channel zapping. The paper only focuses on the channel zapping time; the authors omit other factors affecting QoE.

Afzal et al. adapt the MMT protocol to mobile multipath video streaming solutions in 9). They propose a scheduling strategy that considers both path characteristics (path-aware) and video features (content-aware) to improve QoE. The paper does not employ FEC and does not evaluate subjective QoE.

Reference 10) develops an MMT receiver and experiments with hybrid content delivery. It enables synchronized media presentation and seamless switching of multiple video streams. However, the paper does not have a quantitative evaluation.

In 11), Ma et al. design a VR video streaming system using MMT to support FoV (Field of View)-based streaming strategy, in which each full immersive video is partitioned into several spatial tiles. The tiles are coded at different quality levels. They propose a dynamic buffer size management according to FoV prediction. In their design, playback continuity has a higher priority than improving video quality. They evaluate the proposed method with a QoE model from start-up delay and re-buffering time.

Lee et al. also consider VR video streaming by means of MMT. They aim at reducing view adaptation delay by selective delivery of an I-frame during viewpoint updates. They also focus on delay performance.

As for AL-FEC in MMT, Nakachi et al. employ LDGM (Low-Density Generator Matrix) codes for a networked distributed storage system based on MMT. The codes are suitable for the transmission of massive data sets such as 8K/4K video. The system consists of three parts: a cache server, networked distributed storage, and user terminals. It is to recover the data lost under network congestion, disconnection, and storage failures. They evaluate the error recovery performance by means of packet error rate and PSNR. However, they employ JPEG2000 and not consider error concealment.

Reference 14) proposes a method of FEC code rate adaptation according to network conditions and video frame patterns. However, it only shows the redundancy and the output frame rate for a given packet loss ratio.

Most of the studies on error concealment such as 6) focus on concealment algorithms. To the best of the author’s knowledge, there is no study exploiting the joint effect of AL-FEC and video error concealment for QoE enhancement of audiovisual transmission with MMT as we summarize in Table 1.

3. MMT AL-FEC

MMT supports six AL-FEC schemes: Reed-Solomon, Structured LDPC, RaptorQ, RaptorQ LA, FireFort-LDGM, and Pro-MPEG. They have advantages and disadvantages in complexity, efficiency, ability, and so on. Among them, we employ Reed-Solomon in this pa-
per. It is a block code and widely used in various applications. Figure 1 shows the packet structure of MMTP (MMT Protocol) in this paper.

ISO/IEC23008-1 Annex C specifies three SSBG (Source Symbol Block Generation) modes to deal with AL-FEC in MMT. We choose ssbg_mode1 from the three modes. The mode divides each source packet into fixed-length blocks and then generates FEC codes. If a divided piece is shorter than the fixed length, a block is composed of the piece and padding bits.

In order to transmit H.264/AVC video with MMT, we consider a NAL (Network Abstraction Layer) unit, which has a slice, as a source packet for AL-FEC. That is, we regard the NAL unit as an MPU (Media Processing Unit); it is a generic container for independently decodable data. This is because we attempt to evaluate the effect of error concealment in this paper, although it is not strictly aligned the standard; the standard generally considers a GOP (Group of Pictures) as an MPU. The divided blocks from the NAL unit are called as source code blocks. If the final piece of a divided NAL unit is shorter than the fixed length, padding is performed; it causes overhead.

We employ the one-stage FEC coding structure, in which FEC code is generated just one time for each source packet. From the source code blocks, the mechanism creates repair blocks. To compose an MMTP packet, we attach an MMTP packet header and an MMTP payload header before the source code block and a source FEC payload ID after the source code block. For each repair block, we compose an MMTP packet with an MMTP packet header, a repair FEC payload ID, and the repair block.

This study sets the total bitrate of the video encoding bitrate and the FEC bitrate to a constant value for all the code rate values. Hence, there is a tradeoff between error resilience and video quality.

### Table 1: Overview of the related work

| Reference | MMT | AL-FEC | Error concealment |
|-----------|-----|--------|-------------------|
| 8)        | *   | *      | *                 |
| 9)        | *   |        |                   |
| 10)       | *   |        |                   |
| 11)       | *   |        |                   |
| 12)       | *   |        |                   |
| 13)       | *   | *      |                   |
| 14)       | *   | *      |                   |
| 6)        | *   | *      | *                 |

*: Reference deals with the topic

4. **Experimental method**

In order to evaluate the joint effect of AL-FEC and error concealment on QoE, we experiment with two contents, two types of the number of slices per picture frame, and two types of the total bitrate of video and its FEC code. The conditions are selected heuristically for confirming the basic characteristics of the joint method. We then need to evaluate other conditions as future work.

Figure 2 shows the experimental system. All the links in the network are 100 Mbps full-duplex Ethernet. Media Server transmits video and audio streams to Media Client through MMTP/UDP. For audio, each MMTP/UDP packet includes an MU (Media Unit),
which is an information unit for media synchronization control. Table 2 shows the specifications of video and audio. The video image size is 1920 × 1080 pixels, and the video frame rate is 29.97 frame/second (MU/s). We employ two contents: drama (a scene of historical drama) and sport (a scene of figure skating). Both contents have BGM and scene change, and sport has a larger movement than drama. The duration is 20 seconds.

![Fig. 2 Experimental network](image)

As the interference traffic against video and audio, Web Server transmits Web traffic to Web Client according to requests generated by WebStone 2.5, which is a Web server benchmark tool. For the number of client processes, we employ 10, 15, and 20. As the number increases, the interference traffic becomes heavier.

To implement AL-FEC, we employ OpenFEC, which is an open-source library of FEC. x264 and FFmpeg are used as an encoder and a decoder, respectively. A video frame is divided into several slices, and a NAL unit is composed of a slice. In this paper, we split a video frame into 4 or 17 slices. The size of a slice affects the efficiency of codec and the ability of the error concealment.

As the values of the code rate of FEC, we use 1/2, 2/3, and 5/6. We compare them with a method that does not perform FEC code generation (i.e., the code rate is 1). In the method without FEC, we divide a slice into fixed-length source code blocks with padding if needed. Besides, in any code rate except for 1, we generate at least a repair block for a NAL unit. Thus, note that the actual code rate can have a difference from the setting code rate. In this paper, we set the block size is 512 bytes. The assessment with various block lengths is a future study.

Also, we do not employ FEC for audio transmission owing to the simplicity of implementation. This is because we focus on the effect of FEC on video quality. We consider only the media transfer phase. We have not implemented signaling mechanisms before/after the media transfer phase.

As the total video bitrate of the source video stream and FEC blocks, we consider two values: 3 Mbps and 6 Mbps. When we do not employ FEC, we use 3 Mbps or 6 Mbps as the video encoding bitrate. For employing FEC, we set the video encoding bitrate with consideration of the code rate: 1.5 Mbps and 3 Mbps for the code rate 1/2, 2 Mbps and 4 Mbps for the code rate 2/3, and 2.5 Mbps and 5 Mbps for the code rate 5/6. Note that the network-level transmission rate increases as the code rate decreases because of overheads.

We employ the error concealment scheme as the video output. We utilize Frame Copy and the interpolation from neighboring macroblocks for video error concealment. FFmpeg is equipped with the methods. Besides, other error concealment methods can affect the performance; the assessment is future study. We use the simple playout buffering control with the playout buffering time 500 ms.

5. QoE assessment method

In the experiment, we ask the assessors to evaluate video and audio output at Media Client. To reproduce the experimental conditions easily, we employ trace files which record the receive timing of video slices and audio MUs. The assessors evaluate the first 10 seconds of the video and audio transmission in the experiment.

For the sake of mitigating the assessors’ burden, we exclude 15 Web clients from the experimental patterns. Thus, the number of stimuli is 32 for each content, i.e., the combination of the three FEC code rates and without FEC, two types of the video transmission bitrate, two types of the number of slices per video frame, and two values of the number of Web clients. Furthermore, we add five dummy stimuli.

In the assessment, we evaluate QoE multidimensionally. The way of the assessment is based on the Semantic Differential (SD) method. Because it becomes a large burden for the assessors, we employ a simple way with three pairs of polar terms shown in Table 3. Note that the experiment was performed in Japanese. This paper has translated the used Japanese terms into En-
Each criterion is evaluated to be one of five grades. The best grade (score 5) represents the positive adjective (the right-hand side one in each pair in Table 3), while the worst grade (score 1) means the negative adjective (the left-hand side one). The middle grade (score 3) is neutral. We then calculate the MOS (Mean Opinion Score), which is an average of the rating scale scores for all the users. The assessors are 17 male students of our university who major in computer science. ITU-T Rec. P.911 describes that at least 15 subjects should participate in the experiment. Thus, we employed 17 assessors. On the other hand, we need to evaluate with more assessors; it is a future study issue.

6. Experimental results

This section shows the assessment results of application-level QoS and QoE. In this study, we deal with PSNR as an application-level QoS parameter, although some papers such as References 5) and 7) utilize it as a QoE metric.

6.1 Application-level QoS

In this paper, we treat the audio MU loss ratio, the video MU loss ratio, the slice loss ratio for video, and PSNR as the application-level QoS parameters. The slice loss ratio represents the percentage of lost slices in an output frame; it shows the image quality of the video stream. When we employ error concealment, the slice loss ratio is the same as the error concealment ratio in Reference 18). The MU loss ratio is the ratio of the number of MUs not output at the recipient to the number of MUs transmitted by the sender. PSNR is widely used as a measure of image quality.

Figure 3 shows the video MU loss ratio. The video slice loss ratio is depicted in Fig. 4. Figure 5 represents the audio MU loss ratio. Figures 3 through 5 are the results for the video bitrate 6 Mbps. Figures 6 and 7 present the PSNR of video luminance for the video bitrate 3 Mbps and that for the video bitrate 6 Mbps, respectively.

We find in Fig. 3 that the video MU loss occurs for the number of slices 4 without FEC. The loss ratio increases as the interference traffic (i.e., the number of Web clients) increases. When the number of slices is 4, the size of a slice is larger than that for the number of slices 17. Thus, the effect of a lost MMTP packet becomes large in the 4 slices. On the other hand, when we employ FEC, it can recover lost MMTP packets. Thus, the MU loss ratio can be reduced.

We also see in Fig. 4 that the slice loss ratio increases as the number of slices per frame decreases, and FEC can reduce the slice loss ratio. Besides, the small code...
rate is more efficient for decreasing the slice loss ratio. This is because not only the enhancement of error correction performance by the high redundancy but also the decrement of video source encoding bitrate affect the loss ratio.

Figure 5 shows that the audio MU loss ratio is smaller than about 1%; there is no substantial degradation of audio quality. The audio MU loss ratio does not have a definite tendency against the number of slices, the contents, and the code rate of FEC.

We notice in Figs. 6 and 7 that the scheme without FEC has the larger PSNR than the schemes with FEC when the number of Web clients is 10. This is because the high source encoding bitrate can provide excellent image quality under the lightly loaded condition. Besides, as the interference traffic increases, the schemes with FEC have a larger PSNR than the scheme without FEC. When the video bitrate is 3 Mbps with sport under the 20 Web clients condition, the moderate code rate obtains the best PSNR. Thus, the appropriate code rate is vital to enhance QoS.

6.2 QoE

We show the QoE assessment results in Figs. 8 through 13. Figures 8 and 9 display the assessment results of “video is jaggy – clear”. We depict the assessment results of “video is corrupt – neat” in Figs. 10 and 11. In addition, Fig. 12 is the result of “overall quality of video and audio is bad – excellent” with the video transmission rate 3 Mbps, while Fig. 13 is for the video transmission rate 6 Mbps.

We notice in Fig. 8 that the MOS value of “video is jaggy – clear” relies on the original video encoding bitrate; the MOS value without FEC is higher than those with the three FEC code rates. This is because the higher video encoding bitrate can provide higher
image quality. On the other hand, in sport under the heavily loaded condition, the MOS value with the FEC code rate 5/6 is higher than that without FEC. This is because the image collapse due to slice loss masks the difference of the image quality.

In Fig. 9, we see that the FEC code rate 5/6 is effective in sport with 10 Web clients. Besides, when the load traffic becomes heavy, the FEC code rates with high redundancy can achieve high MOS values.

We find in Figs. 10 and 11 that the MOS value of “video is corrupt – neat” highly correlates with the redundancy; the small code rates enhance the MOS values.

We see in Fig. 12 that the MOS value without FEC is larger than that with FEC when the number of Web clients is 10. Besides, the appropriate code rate differs as the number of slices per frame and contents for the number of Web clients 20. For both contents, as the number of slices per frame increases, the MOS values tend to increase. This is because the error concealment works effectively as the number of slices increases.

In Fig. 13, we notice that the code rate with high redundancy can enhance the MOS values when the video bitrate is 6 Mbps. However, the moderate code rate 5/6 can maximize the MOS value in drama with the number of slices 17 under the lightly loaded condition. This is because the error concealment works well in drama.

Table 4 shows the correlation coefficient of video QoE and QoS parameters with the overall quality. We notice in the table that the overall quality is strongly affected by the video collapse. Thus, we can confirm that the error concealment plays an important role. In addition, the video MU loss ratio has approximately equivalent absolute coefficient value to the video resolution. Hence, the PSNR, which represents the spatial quality and cannot include the temporal quality, is insufficient for streaming quality assessment.

### 6.3 Effect of error concealment

To evaluate the effect of the error concealment quantitatively, we compare PSNR with the error concealment and that without the error concealment in this section. Note that the error concealment does not affect the results of the MU loss ratio and the slice loss ratio. Figures 14 and 15 depict the PSNR of video luminance without error concealment.

We find in Figs. 6 through 15 that the error concealment can change the relationship between FEC code rate and PSNR especially in drama. With error concealment, the larger code rate (i.e., lower redundancy) has higher PSNR. The smaller code rate (i.e., higher redundancy) is better without error concealment. Thus, we can confirm that the application-level error concealment can affect the appropriate AL-FEC code rate for the network-level error recovery.
In addition, we perform a linear regression analysis for each content. We employ the PSNR value ($PSNR$) as the dependent variable and the video slice loss ratio ($SL$), the video bitrate ($BR$), and the code rate ($CR$) as the independent variable. We also define a dummy variable representing with ($EC = 1$) or without ($EC = 0$) the error concealment. We then achieve the following equations. Here, let $R^2$ denote the contribution rate adjusted for degrees of freedom.

$$\begin{align*}
PSNR_{\text{drama}} &= 39.912 + 0.416 \times BR \\
&\quad + 2.532 \times CR - 1.096 \times SL \\
&\quad + 1.298 \times EC \quad (R^2 = 0.758) \\
PSNR_{\text{sport}} &= 28.028 + 1.018 \times BR \\
&\quad + 6.618 \times CR - 1.826 \times SL \\
&\quad + 0.669 \times EC \quad (R^2 = 0.908)
\end{align*}$$

We notice in the equation that the coefficient for $EC$ in sport is smaller than that in drama. Thus, the effect of error concealment in sport is smaller than that in drama. Besides, the coefficient for $CR$ in sport is larger than that in drama. They imply that the joint effect of error concealment and AL-FEC depends on contents.

7. Conclusions

In this study, we assessed the QoE of video IP transmission with error concealment mechanisms of H.264/AVC and AL-FEC of MMT. We then found that the appropriate code rate can enhance QoE according to not only network conditions but also contents. The effect of error concealment can differentiate by contents. The application-level error concealment can affect the appropriate AL-FEC code rate for the network-level error recovery. The above observations show the feasibility of QoE enhancement by means of the joint mechanism.

In the future study, the assessment under various conditions, including wireless networks, is needed. We have to evaluate with an FEC mechanism for audio. Employment of another FEC scheme is also a future study issue. The assessment with other error concealment techniques is also needed.

This paper is an extended version of work presented as a short paper at IEEE CloudNet 2018\textsuperscript{[21]}. This paper deals with multidimensional QoE assessment results (Section 6.2) and comparison between with and without error concealment (Section 6.3); they are not included in the previous paper.

Appendix

In app.Table 1, we describe abbreviations in this paper.

| Abbreviation | Full description |
|--------------|-----------------|
| QoE          | Quality of Experience |
| MMT          | MPEG Media Transport |
| AL-FEC       | Application-Level Forward Error Correction |
| PSNR         | Peak Signal-to-Noise Ratio |
| PDU          | Protocol Data Unit |
| MMTP         | MPEG Protocol |
| SSBG         | Source Symbol Block Generation |
| NAL          | Network Abstraction Layer |
| MPU          | Media Processing Unit |
| GOP          | Group of Pictures |
| MU           | Media Unit |
| SD           | Semantic Differential |
| MOS          | Mean Opinion Score |

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