Scientific Journals
of the Maritime University of Szczecin

Zeszyty Naukowe
Politechniki Morskiej w Szczecinie

2024, 77 (149), 38–46
ISSN 2392-0378 (Online)
DOI: 10.17402/595

Received: *22.01.2024*
Accepted: *29.02.2024*
Published: *31.03.2024*

User experience evaluation study on the quality of 1K, 2K, and 4K H.265/HEVC video content

Przemyslaw Falkowski-Gilski[1]✉, Tadeus Uhl[2], Christian Hoppe[3]

[1] https://orcid.org/0000-0001-8920-6969
[2] https://orcid.org/0000-0001-6849-9168

[1] Gdansk University of Technology, Faculty of Electronics, Telecommunications and Informatics Poland
[2] Flensburg University of Applied Sciences, Germany
[3] Viakom GmbH, Germany
e-mail: [1]przemyslaw.falkowski@eti.pg.edu.pl, [2]tadeus.uhl@hs-flensburg.de, [3]christian.hoppe@viakom.de
✉ corresponding author

Keywords: H.265/HEVC (High-Efficiency Video Coding), QoS (Quality of Service), QoE (Quality of Experience), UX (User Experience), ITU-T Rec. BT.500-14, Video Content

JEL Classification: C63, C83, C88, C93

Abstract
Nowadays, most content creators focus on distributing rich media at the highest possible resolution. Currently, the majority of sold consoles, media players, computer hardware, as well as displays and TVs are advertised as 4K-compatible. The same trend is observed in the case of popular online streaming services and terrestrial TV broadcasts. Generally speaking, it is assumed that higher bitrates provide higher subjective judgements. In this paper, we present the results of a user experience (UX) evaluation study on the quality of video content coded and transmitted in different resolutions in the internet protocol (IP) environment. The image resolutions include 1K (1920×1080 pixels; full-HD), 2K (2560×1440 pixels; wide-QHD), and 4K (3840×2160 pixels; ultra-HD) content that are processed in the H.265/HEVC (high-efficiency video coding) format. A subjective evaluation is carried out in a laboratory consisting of 20 iMacs with a 21.5-inch 4K Retina (4096×2304 pixels) display. The group of viewers included 28 individuals aged between 21–35 years old, comprising people with and without visual impairments. The obtained UX results are compared with previous experiments, including both objective quality of service (QoS) and subjective quality of experience (QoE), as well as the impact of downscaling to 1K from 2K and 4K. The outcomes of this study may be of particular interest to any party interested in video content processing and distribution, as well as consumption and storage.

Introduction

Today, video streaming services play one of the most important roles in IP networks. According to Cisco studies (Cisco, 2019), the transmission of motion pictures already generates around 70 % of traffic over the Internet. A similar tendency can be seen in mobile wireless and cellular terrestrial networks. Therefore, it is important to investigate the matter of delivered video content at varying quality, which is the main aim of this paper.

The methods of encoding video content are constantly evolving over the last years and are continuously updated:
- MPEG-1: 1993 defined as ISO/IEC 11172,
- MPEG-2: 1994 defined as ISO/IEC 13818,
- MPEG-4 (AVC): 1999 defined as ISO/IEC 14496,
- MPEG-5 (HEVC): 2013 defined as ISO/IEC 23008-2,
- MPEG-6 (VVC): 2022 defined as ISO/IEC 23090-3.

Furthermore, the quality of the image is also persistently being refined. When it comes to image resolution of today's TVs, the 1K (1920×1080 pixels; full HD) standard is being replaced more and more often by the improved format of 2K (2560×1440 pixels; wide QHD) or even 4K (3840×2160 pixels; ultra HD). This fact certainly has a major impact on the bitrate and congestion of the transmitted content. It motivates researchers to examine and evaluate the new possibilities in video coding and distribution.

In practice, video quality can be assessed in different ways, which include technical quality of service (QoS), subjective quality of experience (QoE), and user experience (UX). There are currently many measurement methods available for QoS and QoE evaluation, namely ITU-T Rec. J.144 (ITU-T, 2004), ITU-T J.147 (ITU-T, 2002), ITU-T J.247 (ITU-T, 2008), ITU-T J.341 (ITU-T, 2016), ITU-P.1204.4 (ITU-T, 2020), mean squared error (MSE) (Wang & Bovik, 2009), new quality index (NQI) (Wang & Bovik, 2002), peak signal-to-noise ratio (PSNR), and structural similarity index (SSIM) (Wang at al., 2004). UX-related studies are usually performed in purpose-built studios using human test groups. A similar approach is utilized in this paper.

In the field of QoS, QoE, and video content, a large number of published papers can be found (Uhl et al., 2018; Klink et al., 2019; Hoppe & Uhl, 2020; Klink & Uhl, 2020; Uhl & Hoppe, 2020; Uhl, Hoppe & Klink, 2020; Uhl, Klink & Hoppe, 2020). Other works related to UX can also be seen (Law et al., 2009; Song, Tjondronegoro & Docherty, 2012; Staelens et al., 2015; Hammer, Egger-Lampl & Möller, 2018; Uhl, Hoppe & Klink, 2021). This paper will contribute to all of them.

This paper is organized as follows: first, we relate to the field of video quality in general terms. Then, we introduce and describe the test environment in detail. Next, we present and discuss measurement results, followed by several graphical representations. At the end, the paper concludes with a summary and an outlook on future work.

Evaluation of video service quality in ITU-T regulations

The term QoE, defined in ITU-T Rec. P.10 (ITU-T, 2017), is the overall acceptability of an application or service, as perceived subjectively by the end-user. It embraces the complete end-to-end system link, including effects and segments of the transmission link such as client, terminal, network, infrastructure, etc., and may be influenced by user expectations, background of an individual, and context. Hence, in principle, QoE is measured subjectively by the end-user and may differ from one to another. However, it is often estimated using objective QoS measurements.

QoE is strongly related but different from the field of UX, which also focuses on users' experiences with various systems or services. Historically, QoE has emerged from telecommunication research, while UX has its roots in human-computer interaction (HCI) (Wechsung & De Moor, 2014). Therefore, both fields may be considered as multi-disciplinary. In contrast to UX, the goal of improving QoE for end-users is more strongly motivated by pure economic needs (Reichl, Tuffin & Maillé, 2012).

QoE aims to consider each and every factor that contributes to the user's perceived quality of a system or service. This includes the network and telecom infrastructure, as well as human and contextual factors (Reiter et al., 2014), namely:

- Human influence factors:
  - Low-level processing (visual and auditory acuity, gender, age, mood, etc.);
  - Higher-level processing (cognitive processes, socio-cultural and economic background, expectations, needs and goals, other personality traits, etc.);
- System influence factors:
  - Content-related (upscaling, downscaling, etc.);
  - Media-related (encoding, resolution, sample rate, etc.);
  - Network-related (bandwidth, delay, jitter, etc.);
  - Device-related (screen resolution, display size, etc.);
- Context influence factors:
  - Physical context (location, space, etc.);
  - Temporal context (time of the day, frequency of use, etc.);
  - Social context (interpersonal relations during the experience, etc.);
  - Economic context (household income, etc.);
  - Task context (multitasking, interruptions, task type, etc.);
  - Technical and information context (relationship between systems, services, etc.).

Studies in the field of QoE have typically focused on system factors, primarily due to their origin in the QoS and network engineering domains. Through the use of dedicated test laboratories, the context is often sought to be kept constant. This is also how it is perceived and handled in this experiment.

Evaluation of video service quality using human individuals

Used video sequences

Appropriate reference video sequences had to be found to assess video quality in a UX study. After extensive research, we chose the content sourced from previous work (Mercat, Viitanen & Vanne, 2020). Figure 1 shows the selected video sequence called "Runner".

Figure 1. Selected video sequences – "Runner" (Mercat, Viitanen & Vanne, 2020)

The modified numerical tool from previous research (Uhl & Jürgensen, 2014), shown in Figure 2, is used to obtain the video sequences required for this UX study.

At first, and performed by the tool, a reference raw video file was loaded. Then, the video was encoded using FFmpeg (FFmpeg, 2024) in accordance with the selected codec. Next, the encoded data was encapsulated according to the selected transport protocol (here, native RTP) using FFmpeg. The "Errors" block represents the generation of a selected level of network (Channel) impairments.

Then, the packed video was decoded to the same format as the reference video (raw video, same resolution, and encoding rate) using FFmpeg. During decoding, the error correction mechanisms were deliberately switched off so that the effects of network impairments were not eliminated. The decoded video sequences were then saved and made available for the UX study. The "Errors" block was designed for a non-deterministically distributed packet loss (a binominal distribution with probability P) and a non-deterministically distributed burst size (exponential distribution) with a selectable mean value. The effects of jitter and out-of-order packet delivery were converted into losses.

The following parameters were assumed for the numerical tool in order to carry out the UX study later:

- Encoding: H.265/HEVC with default medium profile (for details, see a prior document (X265 preset options, 2024))
- Packaging: native RTP with a NAL size of 1468 bytes and UDP header = 1500 bytes
- 1K, 2K, and 4K video sequences with an image refresh rate of 30 FPS
- Encoding rates: 6750 (1K), 10500 (2K), and 15000 (4K) kbps. These coding rates were deliberately chosen to cover the entire range of coding rates for this codec. The following principle was established: the higher the image resolution, the higher the coding rate. In other words, the more image information to encode, the higher the coding rate.
- Video sequence length: 10 s
- Packet loss (binominal distribution): 0–3 %
- Burst size: 1

Since FFmpeg does not currently support the encoder for MPEG-6 (VVC), this encoder was not considered in our study. Due to time constraints for conducting the UX study, only one representative video sequence, i.e., "Runner", was chosen. It is characterized by flowing movement, good changes in the image background due to zooming, as well as relatively good colour intensity.

Test procedure and equipment

The subjective UX part of this study was performed according to ITU-T Rec. BT.500-14 (ITU-T, 2019) on an Intel Core i7 iMac with a 21.5-inch 4K Retina (4096×2304 pixels) display. The group of viewers consisted of 28 individuals aged between 21–35 years old, including those with correction glasses or contact lenses (due to visual impairments) and those without them (normal eyesight). Each person undertook a training phase before starting the essential study, during which they could adjust the stand and viewing angle, as well as screen

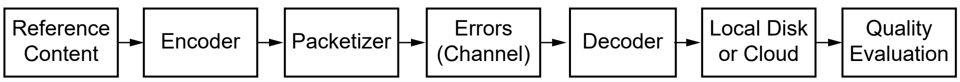

Figure 2. Block diagram of the used numerical tool

Figure 3. Laboratory class with the 4K Retina iMacs used in the visual content quality evaluation

brightness level, of the display according to their own preferences. This was performed in order to best meet their everyday settings based on each individual's background and previous experience.

The laboratory class included 20 iMac stands, as shown in Figure 3, enabling evaluations to be carried out simultaneously on a wider group of individuals. The whole campaign was performed during a single week. A single session took about 20 minutes. Users were asked to provide a score in a standard 5-step mean opinion score (MOS) scale, from 1 (bad quality) to 5 (excellent quality), as well as feedback and comments with respect to consumed content.

The processed video content, including 5 files for each resolution, is described in Table 1. Namely, 1K-, 2K-, and 4K-processed files (15 files in total) were presented in a randomized way in full-screen mode. There was a short break between switching from one resolution to another so that users could write down their comments. Of course, no one was informed about the resolution, bitrate, or other parameters of the currently evaluated video content. For the purpose of this study, the presented files were anonymized and only labeled as Video 1–5.

In order to test the impact of upscaling and downscaling, the set of 2K and 4K files were presented to the end users by two different means:

1) Cloud-based streaming via OneDrive – content transmitted on-demand and downscaled from 2K/4K to 1K with negligible delays, no buffering was observable;
2) Video player via VLC – content downloaded in 2K/4K in advance and played from the local drive.

In the case of the 1K set of video files, the quality evaluation was performed only using OneDrive, as this was the highest resolution supported by the Internet media player.

Results

The measurement results gathered as part of the conducted UX tests are presented in Figures 4–8 in a 5-step MOS scale. All obtained data is processed using the analysis of variance (ANOVA) statistical method, with the confidence level set at 0.95. It is noteworthy that the obtained confidence intervals for measured parameters are always less than 10 % of their average values. This proves that a sufficiently large number of measurements have been made in order to treat obtained results as reliable (see Figures 4–12). In the case of all the figures, when it comes to respective samples, the word "burst" refers to the size of the group of lost packets,

Table 1. Types of processed video content

	Content and bitrate		
Media player	1K (1920×1080 pixels; full-HD); 6750 [kbps]	2K (2560×1440 pixels; wide-QHD); 10500 [kbps]	4K (3840×2160 pixels; ultra-HD); 1500 [kbps]
One Drive (cloud environment with downscaling)	+	+	+
VLC (local disk without downscaling)	–	+	+

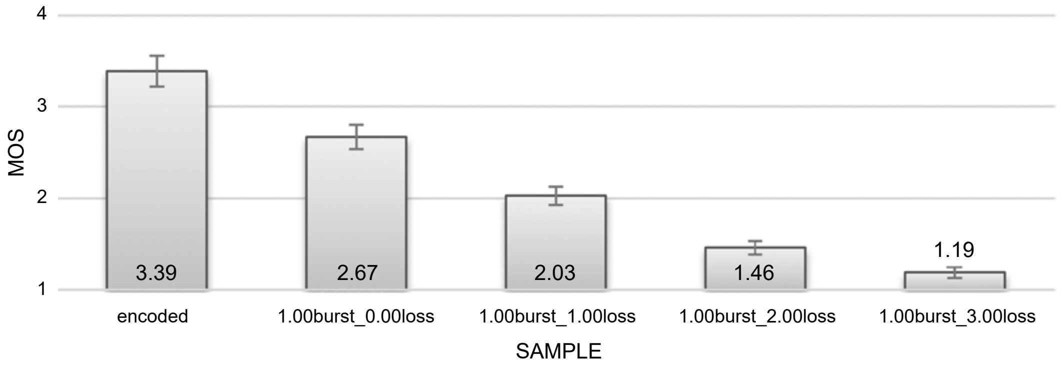

Figure 4. UX values for H.265/HEVC codec with 1K (1080p) and encoding rate 6750 kbps as a function of packet loss (for age group 21–35 years old) – content from OneDrive

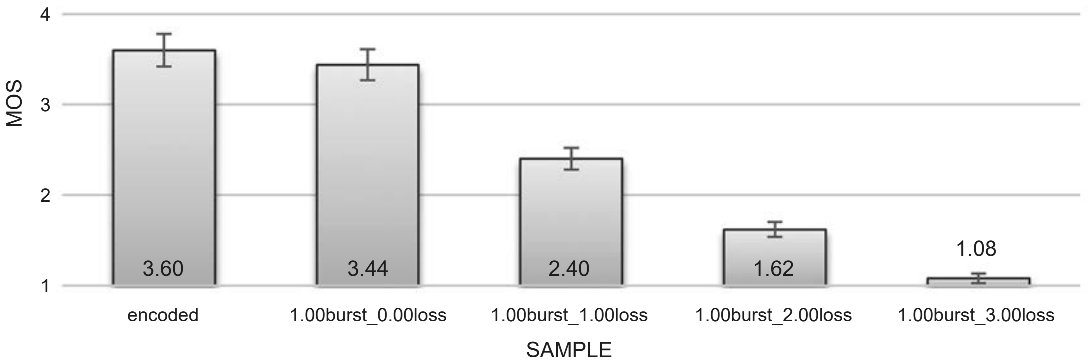

Figure 5. UX values for H.265/HEVC codec with 2K (2560p) and encoding rate 10500 kbps as a function of packet loss (for age group 21–35 years old) – content from OneDrive

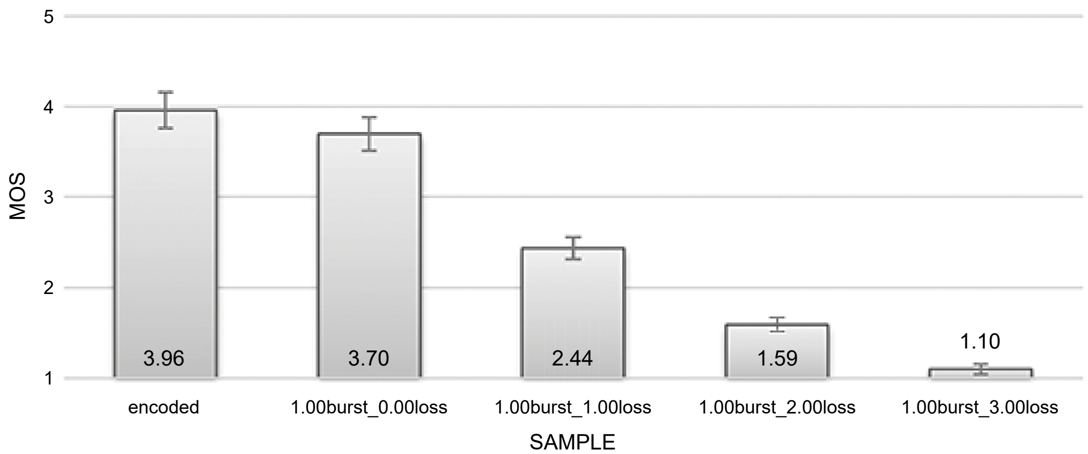

Figure 6. UX values for H.265/HEVC codec with 2K (2560p) and encoding rate 10500 kbps as a function of packet loss (for age group 21–35 years old) – content from VLC

whereas "loss" means the probability of packet loss expressed as a percentage.

Scores from Figures 4–8 show a rapid decline in video quality rating as packet loss increases. A "good" rating (i.e., an MOS score equaling about 4) is only noticeable in a lossless environment. With a packet loss of 1 %, the video quality is still acceptable to the viewers. As packet loss continues to increase, the video quality becomes rated as insufficient or even unacceptable (the MOS score equaling about 1). This is a very critical assessment, significantly different from the quality evaluations in QoE (see, for example, previous works (Uhl et al., 2018; Uhl, Hoppe & Klink, 2020) and QoS (see, for example, earlier research (Uhl & Hoppe, 2020; Uhl, Hoppe & Klink, 2021)). In these papers, the video

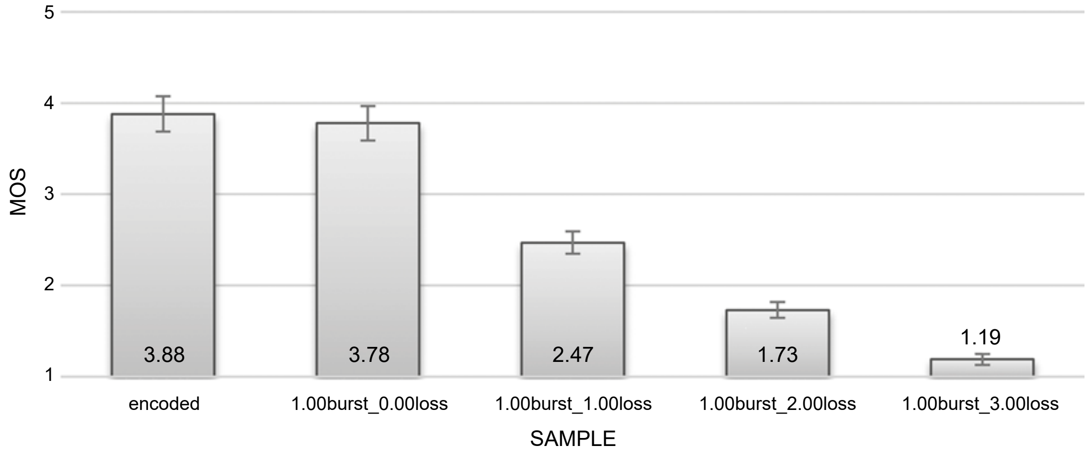

Figure 7. UX values for H.265/HEVC codec with 4K (3840p) and encoding rate 15000 kbps as a function of packet loss (for age group 21–35 years old) – content from OneDrive

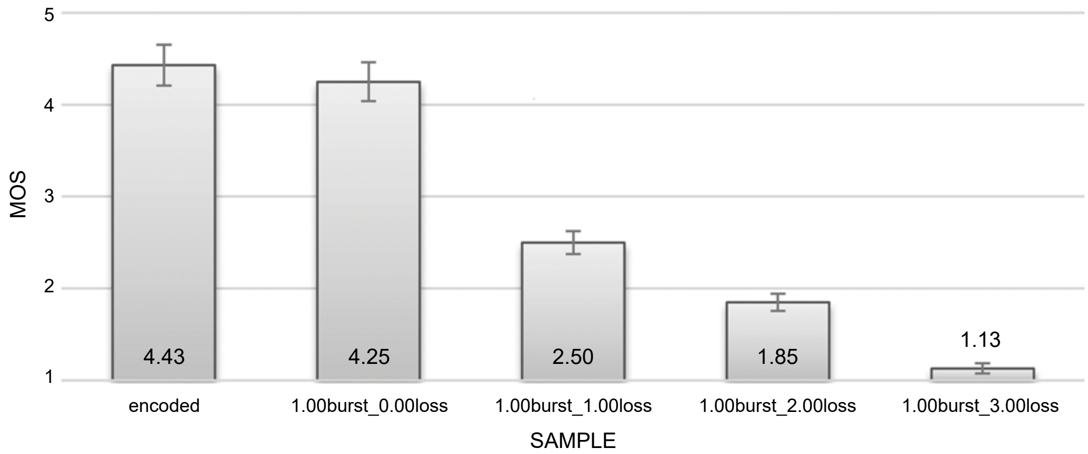

Figure 8. UX values for H.265/HEVC codec with 4K (3840p) and encoding rate 15000 kbps as a function of packet loss (for age group 21–35 years old) – content from VLC

quality was sufficient, up to a 2 % packet loss. One of the key aspects could relate to the high-class technical specs of the iMac display.

Further comparison of the results from the UX, QoE, and QoS studies shows that the nature of changes in the curve describing the evaluation of video quality (i.e., the negative exponential function) as a function of packet loss coincides in all the papers cited here. Only the steepness of the negative exponential function differs significantly depending on the type of research. Thus, it can be seen that the UX studies are very critical and significantly differ from the results of QoS and QoE evaluations.

It should also be added that, in the case of UX research, the native resolution of the material for evaluation had a large impact on the research results. In addition, the content streamed from the browser (OneDrive cloud) was rated worse by some people participating in the UX studies than from the local disk (VLC player). It should be pointed out that 2K and 4K resolution is supported by VLC (no downscaling necessary – native support for 1K, 2K, and 4K content) but not by OneDrive (downscaling to 1K necessary – native support only for 1080p content). Additionally, based on the obtained results, it can be said that 4K resolution is not always necessary to obtain a very good video quality rating, even on a display with 4K native resolution support.

Discussion

Further analysis of the UX research results confirmed that mature (older) people are more demanding users. As experienced individuals with a wider background in multimedia content consumption, they can notice more distortions, which is reflected in the results of the assessments (as shown in Figures 9–11).

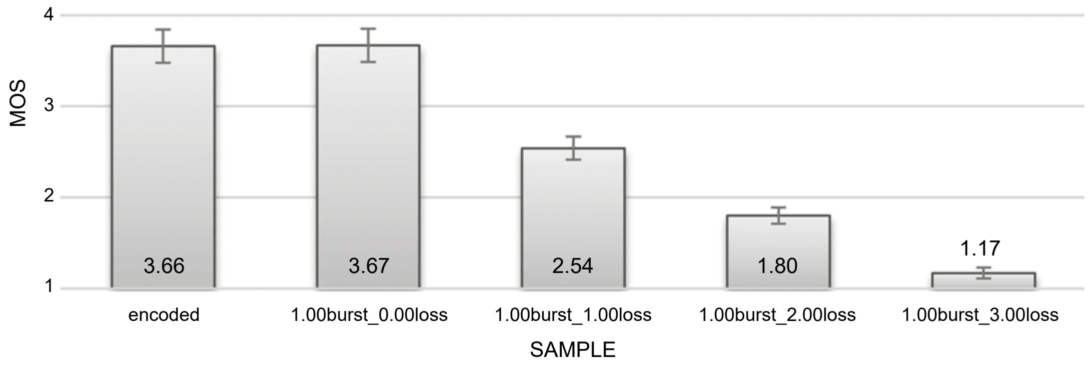

Figure 9. UX values for H.265/HEVC codec with 2K (2560p) and encoding rate 10500 kbps as a function of packet loss (for age group 21–22 years old) – content from OneDrive

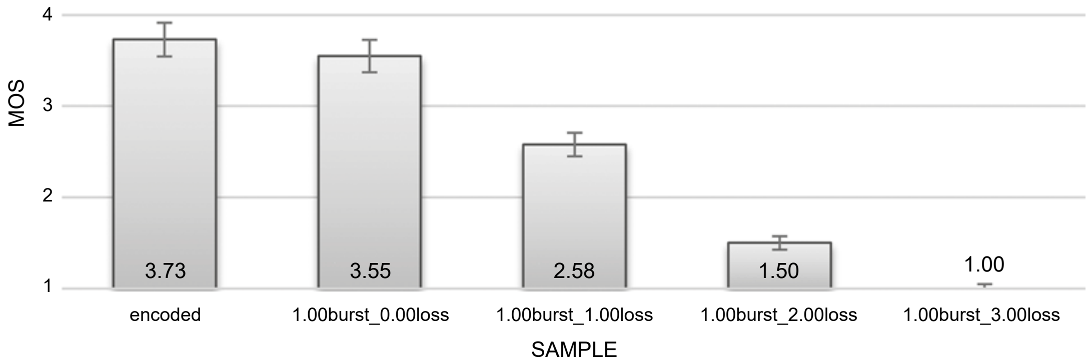

Figure 10. UX values for H.265/HEVC codec with 2K (2560p) and encoding rate 10500 kbps as a function of packet loss (for age group 23–24 years old) – content from OneDrive

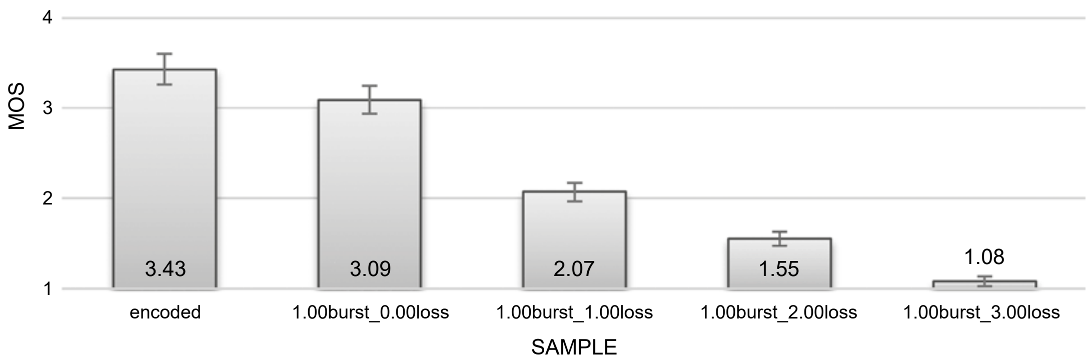

Figure 11. UX values for H.265/HEVC codec with 2K (2560p) and encoding rate 10500 kbps as a function of packet loss (for age group 25–35 years old) – content from OneDrive

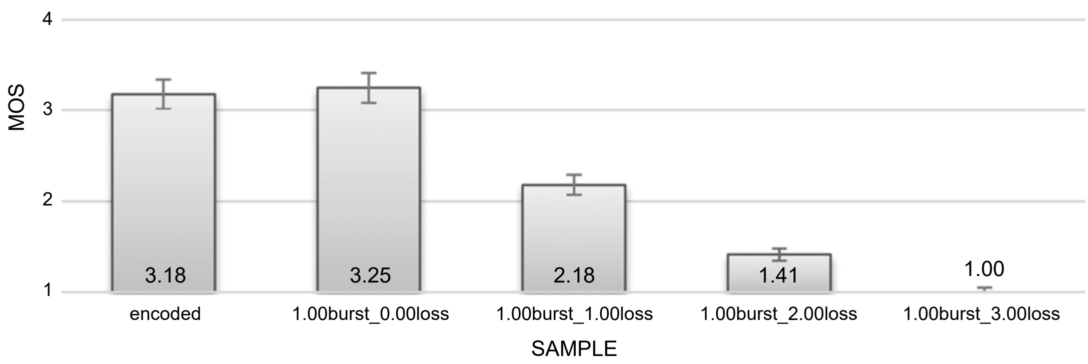

Figure 12. UX values for H.265/HEVC codec with 2K (2560p) and encoding rate 10500 kbps as a function of packet loss (age group 21–35 years old with visual impairments) – content from OneDrive

In this research, there is also a possibility of testing a group of people with serious visual impairments in the UX-related aspect. As might be expected, the evaluation of video quality in this group provided even worse results than in the groups without correction glasses or contact lenses. This is illustrated in the selected example of Figure 12, which should be compared with the scores in Figure 5.

In conclusion, it should be emphasized that the expenditure of time and resources in UX research is very large, which is different from QoE and significantly dissimilar from automated QoS research. This implies that UX studies are rarely carried out and, due to the time involved, are not widely used. Most often, ready-made available tools are used to measure the level of quality, yet the majority are licensed.

Conclusions

As part of this paper, UX-type research on the evaluation of video quality in the IP environment has been presented. It was very important to prepare appropriate video sequences for this research, which was completed on the basis of a selected numerical tool. Different image resolutions, i.e., 1K (1920×1080 pixels; full-HD), 2K (2560×1440 pixels; wide-QHD), and 4K (3840×2160 pixels; ultra-HD), were considered in our study involving the most popular video codec at present, that is, H.265/HEVC.

Obtained results have shown that in the group of participating individuals, especially considering their background, skills, and health condition, all of these factors play an important role in video content evaluation. Older, more experienced people are more critical since they can notice more distortions in the assessed video sequences. People with visual impairments evaluate more critically than people without these defects. This probably relates to the anatomy of the human eye.

Our research has also shown that the UX assessments are more critical than QoS or QoE evaluations, which may be performed using automated tools. When building such technical measurement tools, it is necessary to carry out UX research at the outset because they provide the data necessary to create models of the human sense of sight in order to implement them in these tools and related algorithms.

In the near future, it would be interesting to continue the UX research presented in this paper using other reference video sequences, such as the one chosen here (i.e., Runner). Other video codecs, such as H.266 and VP9, could additionally be investigated as well. Further research is planned in this direction. Supplementary sources of inspiration may be found in earlier work (Biernacki, 2018; Biernacki, 2019; Falkowski-Gilski & Uhl, 2020; Jacob et al., 2021), including the recent surveys on telemeetings, videoconferencing, and unified communications, as well as video streaming and buffering (Wiśniewski et al., 2017; Baraković Husić et al., 2020; Mongay Batalla, 2020; Skowronek et al., 2022).

References

1. Baraković Husić, J., Baraković, S., Cero, E., Slamnik, N., Oćuz, M., Dedović, A. & Zupčić, O. (2020) Quality of experience for unified communications: A survey. *International Journal of Network Management* 30 (3), e2083, doi: 10.1002/nem.2083.
2. Biernacki, A. (2018) Traffic prediction methods for quality improvement of adaptive video. *Multimedia Systems* 24, pp. 531–547, doi: 10.1007/s00530-017-0574-5.
3. Biernacki, A. (2019) Identification of adaptive video streams based on traffic correlation. *Multimedia Tools and Applications* 78, pp. 18271–18291, doi: 10.1007/s11042-019-7183-6.
4. Cisco (2019) *Cisco visual networking index: Forecast and trends, 2017–2022*. White paper.
5. Falkowski-Gilski, P. & Uhl, T. (2020) Current trends in consumption of multimedia content using online streaming platforms: a user-centric survey. *Computer Science Review* 37, 100268, doi: 10.1016/j.cosrev.2020.100268.
6. FFmpeg (2024) https://ffmpeg.org. [Accessed: January 20, 2024].
7. Hammer, F., Egger-Lampl, S. & Möller, S. (2018) Quality-of-user-experience: A position paper. *Quality and User Experience* 3, 9, doi: 10.1007/s41233-018-0022-0.
8. Hoppe, C. & Uhl, T. (2020) A comparison study of DASH technique by video streaming over IP under use the RTP and HTTP protocols. *Journal of Telecommunications and Information Technology* 67 (1), pp. 70–75, doi: 10.26636/jtit.2020.137819.
9. ITU-T (2002) *Rec. J.147: Objective picture quality measurement method by use of in-service test signals*.
10. ITU-T (2004) *Rec. J.144: Objective perceptual video quality measurement techniques for digital cable television in the presence of a full reference*.
11. ITU-T (2008) *Rec. J.247: Objective perceptual multimedia video quality measurement in the presence of a full reference*.
12. ITU-T (2016) *Rec. J.341: Objective perceptual multimedia video quality measurement of HDTV for digital cable television in the presence of a full reference*.
13. ITU-T (2017) *Rec. P.10: Vocabulary for performance, quality of service and quality of experience*.
14. ITU-T (2019) *Rec. BT.500-14: Methodologies for the subjective assessment of the quality of television images*.
15. ITU-T (2020) *Rec. P.1204.4: Video quality assessment of streaming services over reliable transport for resolutions up to 4K with access to full and reduced reference pixel in-formation*.
16. Jacob, I.J., Shanmugam, S.K., Piramuthu, S. & Falkowski-Gilski, P. (2021) *Data intelligence and cognitive informatics*. In Proceedings of ICDICI 2020, Springer, Cham.

17. Klink, J. & Uhl, T. (2020) *Video quality assessment: some remarks on the selected objective metrics*. In Proceedings of the 28th International Conference on Software, Telecommunications and Computer Networks (SoftCOM'20), Split, Croatia, pp. 1–5.
18. Klink, J., Pasławski, M., Pawłowski, P. & Uhl, T. (2019) *Video quality assessment in the DASH Technique*. In Proceedings of the 27th International Conference on Software, Telecommunications and Computer Networks (SoftCOM'19), Split, Croatia, pp. 1–5.
19. Law, E.L.C., Roto, V., Hassenzahl, M., Vermeeren, A.P.O.S. & Kort, J. (2009) *Understanding, scoping and defining user experience: A survey approach*. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Boston, USA, pp. 719–728.
20. Mercat, A., Viitanen, M. & Vanne, J. (2020) *UVG dataset: 50/120fps 4K sequences for video codec analysis and development*. In Proceedings of the 2020 Multimedia Systems Conference (MMSys'2020), ACM, Istanbul, Turkey, pp. 297–302.
21. Mongay Batalla, J. (2020) On analyzing video transmission over wireless WiFi and 5G C-band in harsh IIoT environments. *IEEE Access* 8, 118534–118541, doi: 10.1109/ACCESS.2020.3005641.
22. Reichl, P., Tuffin, B. & Maillé, P. (2012) Economics of quality of experience. In: Hadjiantonis, A. M., Stiller, B. (eds) *Telecommunication Economics*. LNCS, Springer, Berlin-Heidelberg, vol. 7216, pp. 158–166.
23. Reiter, U., Brunnström, K., De Moor, K., Larabi, M. C., Pereira, M., Pinheiro, A., You, J. & Zgank, A. (2014) Factors influencing quality of experience. In: Möller, S., Raake, A. (eds) *Quality of Experience*. TLABS, Springer, Cham, pp. 55–72.
24. Skowronek, J., Raake, A., Berndtsson G.H., Rummukainen, O.S., Usai, P., Gunkel, S.N.B., Johanson, M. Habets, E.A.P., Malfait, L., Lindero, D. & Toet, A. (2022) Quality of experience in telemeetings and videoconferencing: A comprehensive survey. *IEEE Access* 10, pp. 63885–63931, doi: 10.1109/ACCESS.2022.3176369.
25. Song, W., Tjondronegoro, D. & Docherty, M. (2012) Understanding user experience of mobile video: Framework, measurement, and optimization. In: Tjondronegoro, D. (ed.) *Mobile Multimedia – User and Technology Perspectives*. InTech, Rijeka, pp. 3–30, doi: 10.5772/1366.
26. Staelens, N., Pinson, M.H., Corriveau, P., De Turck, F. & Demeester, P. (2015) *Measuring video quality in the network: From quality of service to user experience*. In Proceedings of the International Workshop Video Process. Consumer Electron (VPQM), pp. 1–6.
27. Uhl, T. & Hoppe, C. (2020) A new parameterized model for determining quality of online video service using the modern H.265/HEVC and VP9 codecs. *Journal of Telecommunications and Information Technology* 4, pp. 72–78, doi: 10.26636/jtit.2020.146220.
28. Uhl, T., Hoppe, C. & Klink, J. (2020) *Modern codecs by video streaming under use DASH technique: A objective comparison study*. In Proceedings of the 28th International Conference on Software, Telecommunications and Computer Networks (SoftCOM'20), Split, Croatia, pp. 1–5.
29. Uhl, T., Hoppe, C. & Klink, J. (2021) *H.264/AVC and H.265/HEVC codecs in the IP environment: A comparison study of QoE, QoS and UX*. In Proceedings of the 29th International Conference on Software, Telecommunications and Computer Networks (Soft-COM'21), Hvar, Croatia, pp. 1–6.
30. Uhl, T. & Jürgensen, H.S. (2014) *New tool for examining QoS in the IPTV service*. In Proceedings of the World Telecommunication Congress (WTC'14), Berlin, Germany pp. 1–3.
31. Uhl, T, Klink, J. & Hoppe, C. (2020) Suitability of transport techniques for video transmission in IP networks. *International Journal of Electronics and Telecommunications* 66 (1), pp. 133–138, doi: 10.24425/ijet.2020.131854.
32. Uhl, T., Nowicki, K., Klink, J. & Hoppe, C. (2018) *Comparison study of H.264/AVC, H.265/HEVC and VP9-coded video streams for the service IPTV*. In Proceedings of the 26th International Conference on Software, Telecommunications and Computer Networks (SoftCOM'18), Split, Croatia, pp. 1–6.
33. Wang, Z. & Bovik, A.C. (2002) A universal image quality index. *IEEE Signal Processing Letters* 9 (3), pp. 81–84, doi: 10.1109/97.995823.
34. Wang, Z. & Bovik, A.C. (2009) Mean squared error: Love it or leave it? A new look at signal fidelity measures. *IEEE Signal Processing Magazine* 26 (1), pp. 98–117, doi: 10.1109/MSP.2008.930649.
35. Wang, Z., Bovik, A.C., Sheikh, H.R. & Simoncelli, E.P. (2004) Image quality assessment: From error visibility to structural similarity. *IEEE Transactions on Image Processing* 13 (4), pp. 600–612, doi: 10.1109/TIP.2003.819861.
36. Wechsung, I. & De Moor, K. (2014) Quality of experience versus user experience. In: Möller, S., Raake, A. (eds) *Quality of Experience*. TLABS. Springer, Cham, pp. 35–54.
37. Wiśniewski, P., Mongay Batalla, J., Bęben, A., Krawiec, P. & Chydziński, A. (2017) On optimizing adaptive algorithms based on rebuffering probability. *ACM Transactions on Multimedia Computing, Communications, and Applications* 13 (3s), pp. 1–20, doi: 10.1145/3092837.
38. X265 preset options (2024) https://x265.readthedocs.io/en/master/presets.html [Accessed: January 20, 2024].

Cite as: Falkowski-Gilski, P., Uhl, T., Hoppe, C. (2024) User experience evaluation study on the quality of 1K, 2K, and 4K H.265/HEVC video content. S*cientific Journals of the Maritime University of Szczecin, Zeszyty Naukowe Politechniki Morskiej w Szczecinie* 77 (149), 38–46.