INTL JOURNAL OF ELECTRONICS AND TELECOMMUNICATIONS, 2020, VOL. 66, NO. 1, PP. 133-138
Manuscript received November 18, 2019; revised January, 2020. DOI: 10.24425/ijet.2020.131854

Suitability of Transport Techniques for Video Transmission in IP Networks

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***Abstract*—The paper discusses the problem of video transmission in an IP network. The authors consider the ability of using the most popular video codecs that use both the MPEG2 Transport Stream and Dynamic Adaptive Streaming over Hypertext Transfer Protocol (DASH). The main emphasis was given to ensuring the quality of service and quality assessment methods, taking into account not only the service- or network provider's point of view but also the end user's perspective. Two quality assessment approaches were presented, i.e. objective and subjective methods. The authors presented the results of the quality evaluation for H.264/MPEG-4, H.265/HEVC and VP9 codecs. The objective measurements, proved by statistical analysis of user opinion scores, confirmed the ability of using H.265 and VP9 codecs in both real time and streaming transmissions, while the quality of video streaming over HTTP with the H.264 codec proved inadequate. The authors also presented a connection between the dynamics of network bandwidth changing and MPEG-DASH mechanism operation and their influence on the quality experienced by users.**

***Keywords*—service quality, MPEG2-TS, MPEG-DASH, H.264, H.265, VP9, PEVQ, VQuad-HD**

I. Introduction

In current IP networks new types of services continue to appear. Many of them are connected with the transport of video content, which constitutes a major fraction of today's Internet traffic. According to CISCO reports [1], [2], in 2016 video constituted 67% of the global Internet traffic and nearly 60% of mobile traffic. The volume of video traffic is growing very fast, especially in mobile communications, and is estimated to reach nearly 80% of the world's mobile traffic by 2022. It is estimated that mobile video will increase ninefold between 2017 and 2022, while smartphones will be the main piece of equipment used [2]. The vast majority of new multimedia services have become possible thanks to advances in the fields of network technology and audio and video compression. This trend poses new challenges in providing the best-quality video. In order to guarantee a proper level of the quality of multimedia transmission on an unreliable transport platform, which the Internet is, appropriate transport techniques are needed. Video service is currently implemented in two forms. The first one contains real-time services, e.g. IPTV (Television over IP), VToIP (Video Telephony over IP). The second form encompasses services in which time does not play a principal role. These are streaming services, e.g. VoD (Video on Demand). In order to guarantee a good-quality video service, effective transport techniques are needed. In real-time services, MPEG2-TS [3] is currently the most commonly used technique. In the transport layer, it is based on the UDP protocol. In order to support this service in the network, the RTP protocol is additionally applied at the application layer. Video streaming (non-real time service) is most often implemented using the Transmission Control Protocol (TCP) in the transport layer and the HTTP on the application layer. In order to deliver the best quality video to the user in the real network environment, the data stream has to be dynamically adapted to the varying network circumstances.

The MPEG-DASH method is currently the most commonly used transport technique for videostreaming services [4]–[6]. This technique combines two important aspects: the resolution and the coding rate of the image, which both have an impact on the bandwidth required in the network [7]. If the bandwidth is severely limited, video sequence encoding is used with a lower resolution and a lower coding rate [8]. When the network situation improves, it reverts to higher resolutions and coding rates. Currently, the most commonly used video codecs are: H.264, H.265 and VP9. All the mentioned codecs can be used in conjunction with both transport techniques for a video stream. At this point, the question arises: how effective are the new codecs in conjunction with the various transport techniques for a video stream? Finding the answer to this question is the motivation and content of this work. To assess the quality of services on the network, well chosen methods are required. As a part of this paper, a comparative study of video stream transport methods in an IP environment will be presented in conjunction with the latest video codecs.

This paper is organized as follows. After the introduction, the authors present the main quality assessment methods and brake them down into those of objective and subjective ones. The next section describes the measurement environment, some scenarios and a set of video formats used in the research. Then, the results of objective and subjective video quality assessment are presented. The authors discuss the ability of using different codecs for video transmission in a real-time- and non-real-time modes, i.e. in IPTV and streaming transmission over HTTP, respectively. The results of both objective and subjective evaluation tests are discussed. The last section presents some conclusions, where the authors give

This work was supported by grant No. 049U/0032/19, ”A development of modern IT technologies”, financed from the Ministry of Science and Higher Education fund and carried out at Wroclaw University of Science and Technology and the Maritime University of Szczecin, Poland.

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advice regarding video formats and codecs that can be used for video transmission over the public IP network.

II. Quality assessment methods

The methods may be described by three video quality estimation models, depending on the required input signals, and are categorized as full reference (FR), reduced reference (RR) and no reference (NR). In order to assess the video quality using the FR model, the unimpaired reference and the processed video sequence is required. In the case of the RR model features extracted from the reference video sequence and the processed video sequence are needed. The NR model requires the processed video sequence only [9]–[11]. Therefore, the main groups of methods for measuring the quality of services are as follows: two-sided and one-sided [12]. In the first case, a reference signal is sent by the sender and, after reaching the recipient, is returned to the sender (often as a distorted signal) and is then compared with the original reference signal. This comparison can be carried out objectively with the algorithms (QoS) defined for that purpose or with groups of testers (QoE), who can assess the quality in a subjective way.

A. *Objective video quality assessment*

The most popular methods of the objective perceptual measurement of the video service are PEVQ (ITU-T J.247) [13] and VQuad-HD (ITU-T J.341) [14]. They are very accurate, but also licensed, making them expensive to use. In the second case (i.e. one-sided methods), the received signal is analysed using parametric models specially created for this purpose. Of course, not only the service parameters, such as the type of codec used, the size of the coded data stream, the coding rate, the signal-to-noise ratio, etc., play an important role in this kind of model, but also network parameters such as the probability of packet loss, number of reordered packets, jitter and delay. These methods are less accurate when compared with the two-way methods, but they are quick to use and can usually be used without a license. One of the most popular one-sided methods of video service quality assessment is PSNR (ITU-T J.340) [15]. On the other hand one can find more sophisticated hybrid models for objective video quality measurement, as described in ITU-T J.343 [9]. These models are not in the scope of this paper.

B. *Subjective video quality assessment*

Provisioning 'good quality' services by ensuring the proper level of their parameters, which can be objectively measured, does not guarantee a good quality experienced by the users - known as Quality of Experience (QoE). QoE not only takes into account technical parameters, but also human factors, like emotions, experience with previous similar services, user expectations, etc., which are of a subjective nature. From the users' side, this kind of quality is even more important, so it is also worth developing the subjective quality assessment methods. Among the most common subjective quality assessment methods the Absolute Category Rating (ACR) and Degradation Category Rating (DCR) should be highlighted [18]. ACR is a one-side, also known as a single stimulus, method. Here, the test sequences presented to the users are independently assessed by them on a category scale. After each presentation of a test video sequence (presentation time ca. 10 s) the subjects (test users) are asked to evaluate the quality of the sequence shown (judgement time up to 10 s). The presentation time may be changed according to the content of the test material. A five-level scale for rating overall quality is used (1 – Bad, 2 – Poor, 3 – Fair, 4 – Good, 5 – Excellent).

The main problem that may occur during the classical single-stimulus method, e.g. ACR, is a lack of reference point while evaluating. If the testers do not know the reference material (of the best quality), they are less likely to give good grades, which is due to the fact that they are prepared for potentially better material that might occur. DCR methods omit these problems. In the DCR method the test sequences are presented in pairs. The first one is always a reference material, while the second stimulus in the pair is the same material after passing through the system (or examined network). Thus, the method is classified as a double stimulus one. The users evaluate the impairments of the second stimulus in relation to the reference material. In order to carry out the subjective video quality assessment, the authors implemented a solution based on the classical DCR method.

III. Environment and measurement scenarios

To examine the quality of electronic services, two approaches can be used: a) measurements in an emulated environment and b) measurements in the real world.

In the first case, it is possible to repeat measurements in the selected scenario. Naturally, the results achieved here depend on the validity of the emulated environment. However, the repeatability and stability of measurement results can be seen to be a huge advantage of these methods.

In the second case, the measurements correspond to the real situation, but it is difficult, due to the changing traffic conditions in the network, to obtain stable measurement results. In order to overcome this problem the measurements must be repeated many times and then the statistical analysis should be done. Obviously, this kind of method requires the selection of test group, preparation of special measurement scenarios, the conducting of training sessions, etc.

A. *Objective approach*

In order to carry out an objective video quality assessment a numerical emulation tool QoSCalc (DASH), supplemented by a module implementing the MPEG-DASH (HTTP) technique, has been used [16]. This tool can be used to measure the quality of services in IP networks using various transport techniques and various codecs, which links to the subject of this work. The objective measurements presented in the paper encompass two scenarios.

The first test scenario concerns the MPEG2-TS transport stream with a "native RTP" protocol on the application layer, with reference to the H.265 and VP9 codecs. The parameters used here are the image coding rate and the packet loss in the network (binominal distribution). The reference signal used in the measurements is shown in Fig. 1. This video is 10

Fig. 1. The reference signal used in measurements.

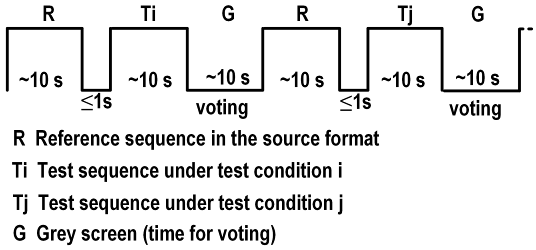

Fig. 2. The test sequence used for video QoE assessment.

seconds long, generates high traffic (622 Mbps), and at the same time presents a good range of colours (YUV: 4:2:0) at a resolution of 1920×1080 pixels (FullHD) and also has 25 full images per second. This signal is favoured by Opticom [17] for determining the quality of video service. The measuring techniques used here are J.247, J.341 and PSNR.

The second test scenario concerns the MPEG-DASH transport stream with RTP and HTTP protocols on the application layer, with reference to the H.265 and VP9 codecs. The variable parameters here are resolution, coding rate and packet loss in the network (binominal distribution). The emulation employs the most commonly used way of changing of the first parameter: the so-called "drop and rise" technique. This corresponds to the situation in the real network where, after the initial bandwidth limitation, the situation improves and the bandwidth increases. The authors use different reference signal formats with respect to the resolution and coding rate of the image. The measurement techniques used here are J.247, J.341 and PSNR.

B. *Subjective approach*

In order to perform a subjective video quality assessment, the authors prepared a test bed which emulates the behaviour of a real streaming service platform with implemented the MPEG-DASH mechanism. It consists of a video server, a network cloud and user equipment. The server contains a set of video clips divided into small chunks (10 s each). The video sequences are of different coding bitrates and spatial resolutions [20]. A LAN/WAN cloud implemented in the laboratory contains a network emulator that can emulate different issues which may happen in a real network, e.g. bottleneck, delay, jitter, packet loss, etc. Depending on the specific circumstances in the network, the client may receive a video chunk of the best possible quality at that moment. The video chunks were presented to the users in the following order: 1-2-3-4-5-4-3-2-1. The sequence order is the same as that presented in [20], where the objective methods of service quality assessment for video transport techniques in the IP networks were discussed [13]–[15]. It may illustrate a situation which could happen while watching a film on YouTube when a bottleneck in the IP network occurs [19]. In such a case, the DASH mechanism tries to change the video chunks to be less challenging, and when the network circumstances are getting better a more demanding video is transmitted and the video quality improves. The test scenario assumed utilisation of the modified DCR video quality assessment method (see Fig. 2), where the reference video (*R*) was alternated with the tested video chunks (*T*). After each '*R-T*' pair a 10-second grey screen (*G*) was displayed (time for voting). Thus, the final sequence presented to the user was as follows: R-T_1-G, R-T_2-G, R-T_3-G, R-T_4-G, R-T_5-G, R-T_4-G, R-T_3-G, R-T_2-G, R-T_1-G. The current test assumed a network with no impairments. The aim of the research was to assess the quality (QoE) of the H.264-encoded video chunks of different formats. The tests were performed in two versions, taking into account the different kinds of user equipment used, i.e.: Personal Computers – with 14-inch displays (FHD mode 1080p) and Smartphones – with 5.1-inch displays (FHD mode 1080p).

IV. Measurement results

A. *Objective approach*

Figures 3 and 4 show selected, representative test results for the first scenario. The stream transfer technique used here is MPEG2-TS. This method is characteristic for real time services (IPTV, VToIP). It can be clearly seen from the diagrams that the increase in packet loss in the network has a very large impact on the QoE/QoS values. With packet loss of only about 3%, the quality of the service already drops by about 50%. At a value of packet loss exceeding 5%, the quality of the service is unacceptable, having fallen to the level of 1.5 on the MOS scale. The diagrams also show that the algorithm J.341 (VQuad-HD) is better suited to determining the quality of high-resolution video. The curves in Figs. 3 and 4 also confirm the high correlation of the quality

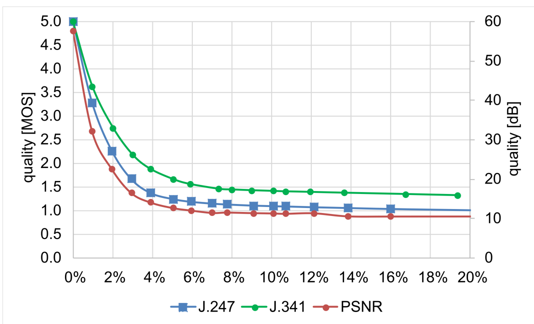

Fig. 3. QoE/QoS values as a function of packet loss for the H.265 codec; coding rate 6750 kbps.

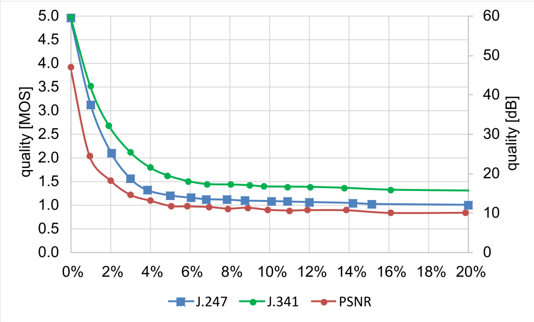

Fig. 4. QoE/QoS values as a function of packet loss for the VP9 codec; coding rate 6750 kbps.

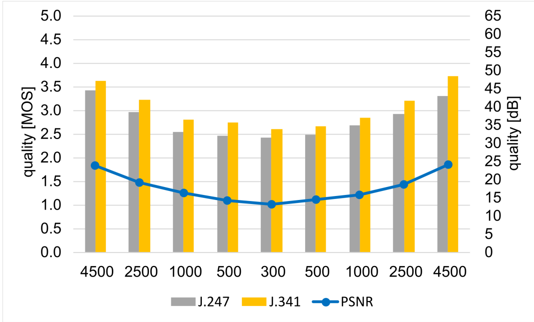

Fig. 6. QoE/QoS values as a function of the resolution and coding rate for the H.265 codec and 2% of the packet loss (RTP).

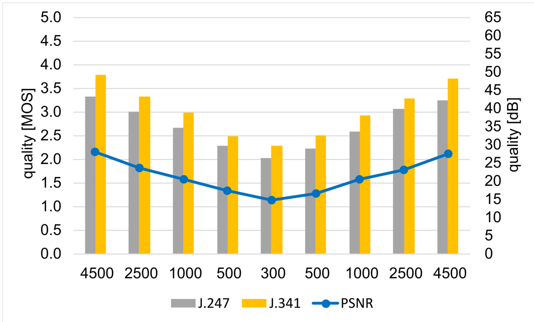

Fig. 7. QoE/QoS values as a function of the resolution and coding rate for the VP9 codec and 2% packet loss (RTP).

assessment methods QoE (J.247, J.341) and QoS (PSNR). The correlation coefficient determined here between these curves is at the level of 0.96. This is an important practical aspect because the PSNR method is much simpler and cheaper (without license) to use. The curves also show that both codecs indicate a comparable quality of video service. However, it should be noted that the VP9 codec needs less bandwidth in the network when compared to the H.265 codec. Further figures in this chapter show selected representative measurement results for the MPEG-DASH video transport using a ”drop and rise” technique. It assumes choosing video sequences of lower spatial resolutions and bitrates when a bottleneck in the network occurs and sending the video chunks of higher quality when the situation in the network recovers. Fig. 5 shows the quality of the video service in a lossless environment. Theoretically, the calculated QoE values for corresponding video chunks of the same resolutions and bitrates should be the same. The observed differences, which result from the limitations of calculation methods (starting points) used in the numerical tool. It can be seen here, that J.341 method is better fitted to FHD format than the J.247 method. Thus, the curves from Fig. 5 can be treated as a reference point for further analyses in a lossy environment. Fig. 6 shows the QoE/QoS values for the H.265 codec with packet loss set to 2% and with the RTP protocol on the application layer. There is clearly a significant decline in the quality of the video service. It should be added here that the received (distorted) signal was always compared to the highest resolution (HD) reference signal. If it was compared to the actual signal sent, i.e. with a reduced resolution and coding rate, a better quality of service would be expected. Further research in this direction would be worthwhile. Fig. 7 shows the QoE/QoS values for the VP9 codec for a 2% packet loss and with the RTP protocol. Here, a significant decrease in the quality of the video service is also evident. It is clear that the H.265 codec offers slightly better quality of service values when compared to the VP9 codec, especially when using low image resolution and coding rates. This can be explained by the various compression techniques used by the H.265 and VP9 codecs. Figures 8 and 9 show the QoE/QoS values for the H.265 and VP9 codecs, respectively, when using the HTTP protocol on the application layer (the case most often encountered in practice). It can be clearly seen

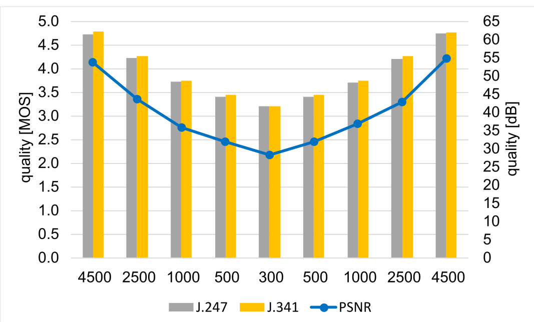

Fig. 5. QoE/QoS values as a function of the resolution and coding rate for the H.265 codec without packet loss (RTP).

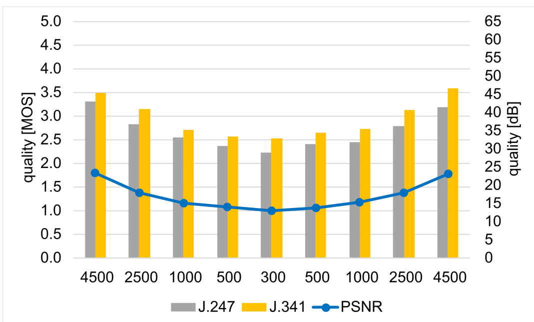

Fig. 8. QoE/QoS values as a function of the resolution and coding rate for the H.265 codec and 2% packet loss (HTTP).

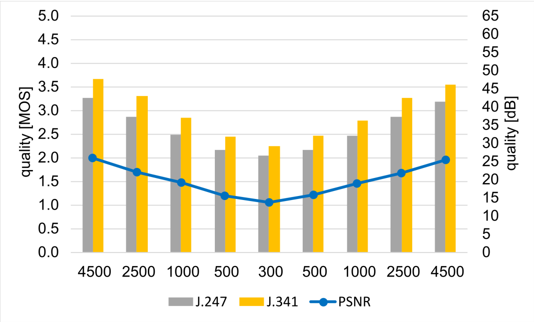

Fig. 9. QoE/QoS values as a function of the resolution and coding rate for the VP9 codec and 2% packet loss (HTTP).

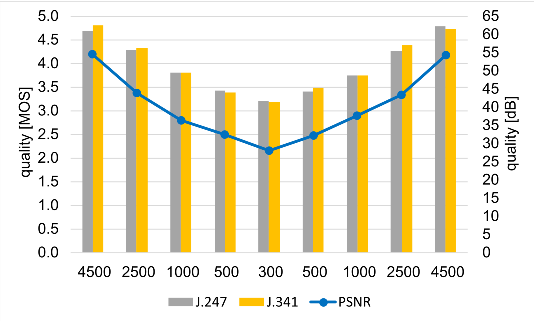

Fig. 10. QoE/QoS values as a function of the resolution and coding rate for the H.265 codec and 2% packet loss (HTTP) with a buffer of 500 ms.

here that the use of the HTTP protocol generates comparable QoE/QoS values to those achieved when the RTP protocol is used. This is because the studies did not use the buffer on the receiving side [23]. Therefore, lost and retransmitted data packets (according to the TCP protocol) cannot be included at the recipient. In this case we need to examine this scenario using the recipient's buffer. Fig. 10 shows the QoE/QoS values as a function of packet loss, using a 500 ms receiver buffer. The increase in the value of QoE/QoS using this type of buffer is evident. It is equally evident that a buffer of 500 ms is sufficient to accommodate the retransmission time incurred by packet loss. The differences between QoE values presented in Figs. 6 to 10 for the corresponding video chunks, on both sides of the figures, result from stochastic function of packet dropping (random events simulation), but still remain in the calculated 10% confidence interval (with error probability of 5%).

B. *Subjective approach*

In order to complement the set of the most popular video codecs, the authors also present the results of the evaluation of H.264 codec, which is used for the last several years in 'classic' broadcast TV or IPTV networks and end-user devices. The question about the ability of using this codec in Internet transmissions over the HTTP protocol seems to be interesting, especially in the case of user equipment that does support the new codecs presented above. Fig. 11 shows the results of the objectively measured video quality as a function of the video format for the H.264 codec. It should be noted

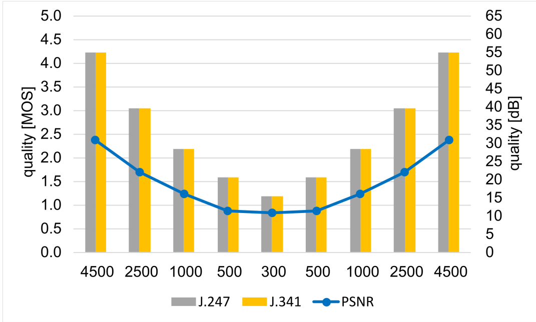

Fig. 11. QoE/QoS values as a function of the resolution and coding rate for the H.264 codec without packet loss (RTP).

that the quality of the video samples presented for the H.264 codec are significantly lower than the analogous values for the H.265 codec (see Fig. 5). Our objective quality assessment revealed that in order to provide an acceptable video quality level, i.e. three or higher on five-level scale, at most two from the five video formats, may be used. In most cases this acceptable quality level corresponds with a PSNR value of around 30 dB or higher [21], [22]. It would mean that such a set of video formats is not suitable for using the H.264 codec in video transmission over HTTP using the DASH technique. When looking for confirmation of these results, a subjective video quality assessment was conducted by the authors. The test environment and measurement scenarios were presented in Section II. The subjective video quality assessment was conducted on a group of over 40 testers (test users). Each video sample was assessed by every user and the mean value of the quality perceived by the users (in MOS scale) was then determined. There were two groups of tests, "PC" and "mobile", where the test groups were using different user equipment, i.e. personal computers (14-inch display) and smartphones (5.1-inch display), respectively. In order to determine whether the results are statistically significant, the nonparametric Kruskal-Wallis (K-W) test was performed. This test checks for significant differences on a dependent variable using a categorical independent variable with two

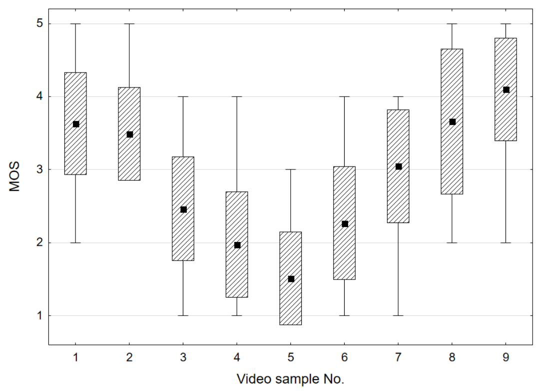

Fig. 12. QoE determined in PC test as a function of the resolution and coding rate for the H.264 codec without packet loss (RTP).

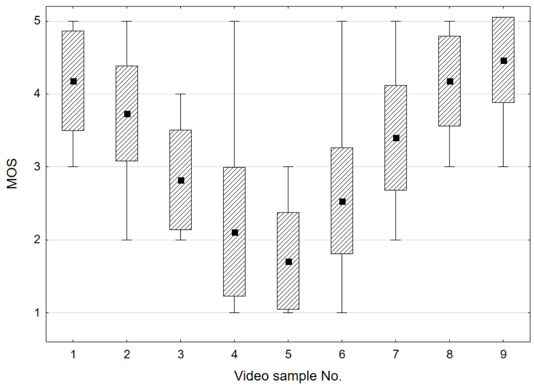

Fig. 13. QoE determined in mobile test as a function of the resolution and coding rate for the H.264 codec without packet loss (RTP).

or more groups (here: MOS value and video sample number, respectively), and does not require normal distribution of the residuals. In both groups of tests the statistical significance of the results was positively confirmed by the K-W test. The QoE values as a function of video resolution and codec bitrate are presented in Fig. 12 and Fig. 13, respectively. The results obtained from the mobile test were somewhat higher than from the PC test and the changes of video formats (spatial resolutions and coding bitrates) were more visible in the case of larger displays (i.e. PC tests). These changes were not so visible on smartphones. More detailed analysis of the medians of the subjective quality results revealed statistically non-significant differences between the quality perceived by the users for the adjacent video test samples, i.e. 1-2, 2-3, 3-4, etc. A bigger and statistically significant difference was observed between the non-adjacent videos. This justifies the way of changing the video chunks when the network circumstances change. It is worth changing the video chunk into an adjacent smaller one when the network throughput decreases, because then the QoE deterioration is almost imperceptible by many users. A more radical bitrate reduction (i.e. sending non-consecutive video chunks) makes the decrease in video quality more noiticeable for the users. The obtained results of the subjective quality assessment are convergent with the results of the objective measurements, and both indicate that the set of tested video formats does not fulfil quality requirements in the case of using H.264 encoded material.

V. Conclusion

A comparative study of the work of various transport techniques for video services in relation to modern motion video codecs was presented in the paper. It was found that both the presented transport techniques are highly sensitive to packet loss in the network. There were no significant differences in quality delivered by the codecs H.265 and VP9. Both of them may be used for streaming purposes when taking into account the proposed video formats. On the other hand, the H.264 codec seems to be inappropriate in such situations because of the too low video quality obtained during the tests. The study has confirmed that the use of the HTTP protocol, together with the MPEG-DASH technique in conjunction with a properly sized receiving buffer, can significantly increase the quality of the video service when compared to the RTP protocol.

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