Subjective evaluation of H.265/HEVC based dynamic adaptive video streaming over HTTP (HEVC-DASH)

Iheanyi Irondi*[a], Qi Wang [a], Christos Grecos[a]
[a]Centre for Audio Visual Communications and Networks, School of Computing, University of the West of Scotland, Paisley PA1 2BE, United Kingdom.

ABSTRACT

The Dynamic Adaptive Streaming over HTTP (DASH) standard is becoming increasingly popular for real-time adaptive HTTP streaming of internet video in response to unstable network conditions. Integration of DASH streaming techniques with the new H.265/HEVC video coding standard is a promising area of research. The performance of HEVC-DASH systems has been previously evaluated by a few researchers using objective metrics, however subjective evaluation would provide a better measure of the user's Quality of Experience (QoE) and overall performance of the system.

This paper presents a subjective evaluation of an HEVC-DASH system implemented in a hardware testbed. Previous studies in this area have focused on using the current H.264/AVC (Advanced Video Coding) or H.264/SVC (Scalable Video Coding) codecs and moreover, there has been no established standard test procedure for the subjective evaluation of DASH adaptive streaming. In this paper, we define a test plan for HEVC-DASH with a carefully justified data set employing longer video sequences that would be sufficient to demonstrate the bitrate switching operations in response to various network condition patterns. We evaluate the end user's real-time QoE online by investigating the perceived impact of delay, different packet loss rates, fluctuating bandwidth, and the perceived quality of using different DASH video stream segment sizes on a video streaming session using different video sequences. The Mean Opinion Score (MOS) results give an insight into the performance of the system and expectation of the users. The results from this study show the impact of different network impairments and different video segments on users' QoE and further analysis and study may help in optimizing system performance.

Keywords: H.265/HEVC, QoE, video streaming, DASH, Subjective evaluation, MOS.

1. INTRODUCTION

With the surge in internet traffic video traffic, there has been a high demand for various multimedia applications. Cisco predicts[1] that by 2018, 80% to 90% of global consumer traffic will be video. They[1] also estimated that traffic generated by video on demand (VoD) will be equivalent to 6 billion DVDs per month while over 50% of internet video traffic will be delivered through content delivery networks (CDN) by 2018. This sharing of rich media content over the internet comes with a lot of challenges considering the limited availability of the bandwidth and the unreliable nature of the internet. The sharing of video streams will involve streaming video across different servers, platforms and media devices. Interoperability between servers from different vendors and various media devices also poses another challenge[2]. Several techniques and protocols also exist for streaming of video including progressive download, traditional streaming and adaptive streaming. The Real-time streaming protocol (RTSP) is a traditional streaming technique and has some draw backs like the use of specialized streaming server and not firewall friendly. Progressive download employ HTTP protocol but wastes bandwidth[2]. Adaptive streaming is designed to overcome the drawbacks of progressive download and traditional streaming[2]. MPEG-Dynamic adaptive streaming over HTTP (DASH) is an ISO/IEC adaptive streaming standard that enables live, on demand, dynamic and streaming of video in response to clients network conditions. In the MPEG-DASH technique, a video stream is encoded into several bitrates, segmented into chunks and stored on a HTTP server and accessed using a dash client. In DASH, the streaming session is controlled by the client in response to the client's bandwidth condition and CPU capacity.

*Iheanyi.irondi@uws.ac.uk

MPEG-DASH runs on the popular HTTP stateless protocol over TCP and addresses the limitations posed by streaming techniques like RTP/RTSP and progressive download. HTTP streaming supports popular content delivery networks (CDN) which provide localized edge caches unlike RTP[2]. HTTP streams transverse firewalls and also make use of existing internet infrastructures like servers and caches making them more scalable and cost effective. Different commercial HTTP adaptive streaming solutions have been proposed by Adobe, Apple and Microsoft and have adopted similar design[2] approach; however the MPEG-DASH standard has an advantage in that it provides interoperability between servers and media clients from different vendors when compared to commercial deployments[2].

Integration of the MPEG-DASH with the new video coding standard HEVC/H.265 is a new and promising area of research. Initial delay, buffering, and freezing are issues associated with video streaming. DASH also comes with its own additional costs such as quality fluctuations caused by quality switching. The performance of DASH systems can be evaluated by using objective metrics like PSNR, VQM and SSIM. However to evaluate the QoE as perceived by users, subjective testing methods are used. Muller et al[5] compared the performance of Apple, Adobe and Microsoft smooth streaming techniques under real world network conditions. HEVC/H.265 based DASH systems have been studied by Irondi et al[4] using objective metrics. Nightingale et al[3] carried out a subjective evaluation of the impact of different network conditions on HEVC/H.265 video streaming.

We present a subjective evaluation of the HEVC/H.265 based DASH system using a realistic test bed. Previous studies in this area have focused on H.264/AVC or SVC based DASH systems and QoE of HEVC/H.265 DASH has hardly been considered. Moreover, there is no established standard test procedure for subjective evaluation of MPEG-DASH adaptive streaming. We evaluated the QoE of an HEVC/H.265 based DASH system by investigating the impact of various packet loss ratio, various delay values, and different segment sizes using MOS. This subjective evaluation was carried out in a controlled environment in real-time while the impairments were added on the fly with subjects scoring the video after each test video. Impact of different segment sizes have been studied by Ognenski[6] using objective metrics using objective metrics while this paper used subjective scores. Impact of longer sequences on QoE has been studied by Staelens et al[7] by using tablets in non controlled environments while we conducted our test in a controlled environment with additional parameters. The results presented here will provide an insight into the performance of HEVC-DASH system and will help in establishing optimal operating conditions for HEVC/H.265 based DASH system.

The remainder of this paper is organized as follows. Section 2 gives further review of related literature. Section 3 gives a brief overview of the MPEG-DASH and HEVC/H.265 codec. Section 4 describes the test methodology and experiment. Section 5 presents the result and analysis. The final section concludes the paper.

2. RELATED WORK

Ognenoski et al[6]studied the performance of small and large segment sizes of encoded videos and results showed that the small segment sizes increase the probability of empty buffer while large segment sizes decrease the probability of empty buffer. Further analysis[6] in their result showed that increasing the client's buffer size and choosing appropriate segment size further improves the performance of the system. To mimic realistic viewing conditions[7], Staelens et al[7] carried out subjective evaluation of adaptive streaming using longer segment video sequences in a non controlled environment and results showed that the number of quality switches and video content affects picture quality and also switching between quality levels are more in high motion videos. Their results[7] also deviated less from experiments carried out in controlled environments. Subjective evaluation using long video sequences in order to emulate realistic environment was carried out by Tavakoli et al[8] by investigating the impact of different adaptation strategies/pattern on QoE, their results showed that content type and its spatio-temporal information have a huge impact on QoE.

Vankeirsbilck et al[9]studied the real-time evaluation of interactive video contents by adding various network impairments that affect QoE on the fly, also investigated was the impact of frame rate on QoE[9]. The impacts of fluctuating bandwidth, stalling and initial delay[10] on QoE were studied by Liu et al[10], the impact of timing and distribution of stalling on QoE[10] were also further investigated. Akhshabi et al[11] conducted an experimental evaluation of the rate adaption techniques of Netflix, smooth streaming and Adobe OSMF by investigating their reaction to persistent and brief variations in available network bandwidth. The performance of adaptive systems and traditional streaming systems under various network conditions were compared by Alvarez et al[12] and their results[12] showed that adaptive streaming of video improves QoE compared to traditional video streaming. Hossfeld et al[13] carried out the subjective evaluation of the impact of initial delay for different application scenarios and also compared the influence of initial delay and stalling. A QoE model for High definition video streaming which evaluates the impact of different patterns of packet loss was proposed[14]. Seyedebrahimi et al[15] proposed a non-reference objective metric for video streaming, and their results showed the impact of packet loss on duration and frequency of pause. The results from the proposed metric[15] was compared to subjective scores obtained using various video sequences and they appeared to be closely correlated. The impact of user device on QoE was studied for tablet devices[16].

3. BACKGROUND

3.1 Overview of the HEVC/H.265 (High Efficiency Video Coding)

HEVC/H.265 is the latest video compression standard jointly developed by ISO/IEC Moving Picture Experts Group (MPEG) and ITU-T Video Coding Experts Group (VCEG). This new standard promises to reduce the bandwidth requirement by 50% at the same video quality compared to its predecessor H.264/AVC[17]. This standard is designed to support parallel processing and increasing demand for systems with high bandwidth requirements like 4k UHD and 8k.

HEVC/H.265 employs a hybrid coding scheme similar to H.264/AVC but the difference is that in H.264/AVC, the core coding layer is the 16x16 pixel macroblock while HEVC/H.265 introduces a larger block structure called Coding Tree Unit (CTU) with sizes ranging from 16x16 to 64x64 pixels. This larger block structure employed by H.265/HEVC helps in achieving better compression efficiency. Ohm et al[18] studied the effect of using different CTU sizes and results showed that the higher the size the better the compression efficiency and that the larger block sizes are more suited for higher resolution systems.

The CTU is the basic processing unit of the HEVC and has an adaptive quadtree structure. The CTU is split into CU and then the CU is in turn split into PU and TU. The CUs are the basic unit for intra and inter coding; the PU is the basic unit for prediction while the TU is the basic unit for Transform and Quantization process[17].

In HEVC/H.265 two loop filters are specified and applied sequencially[17]. The first filter applied is the Deblocking filter (DBF) and similar to the one applied to its predecessor H.264/AVC but with a simpler design and is more suitable for parallel processing[17]. The second loop filter added after DBF is the Sample Adaptive Offset (SAO) and this filter provides better reconstruction of the original signal amplitudes[18]. Slices are used to support parallel processing and error resilience in H.264/AVC and have also been retained in HEVC/H.265. To increase support for parallel processing in HEVC/H.265, tiles and wavefront were also introduced.

3.2 Overview of MPEG-DASH.

MPEG-DASH (Dynamic adaptive streaming over HTTP) is an ISO/IEC adaptive streaming standard for dynamic and adaptive delivery of high quality multimedia contents over the internet using conventional HTTP web servers. In DASH, video streams are encoded into several bit rate representations, segmented into chunks and then stored on the webserver to be accessed through DASH client using HTTP get or partial get methods while adapting the stream to the client’s network condition[2].

Different industry proprietary adaptive streaming solutions have been proposed by Adobe[2], Microsoft[2] and Apple[2] and they have all adopted similar design approach. A DASH system comprises of a webserver, a DASH client and a media description (MPD) an xml file that describes the contents of the media stored on the webserver. A client/server approach is employed in DASH where the streaming session is controlled by the client. The streaming session starts by the client making HTTP request to the server and receiving an xml as result of the request, upon receipt of the xml file it requests for its desired representation based on its network condition or CPU state. Adaptive streaming of encoded video chunks is illustrated in Figure 1 where it shows the encoded video chunks at four different bitrates and also the requested video chunks based on network conditions moving towards the client.

DASH runs on the popular HTTP stateless protocol over TCP and as such does not need specialized servers and makes use of existing internet infrastructure making it more scalable and cost effective. Also with the HTTP stateless protocol it can easily transverse firewalls making it more attractive when compared to traditional streaming protocols that use stateful protocols like Real-time Streaming Protocol (RTSP). The TCP protocol employed by DASH provides more reliability as result of its retransmission capability compared to UDP.

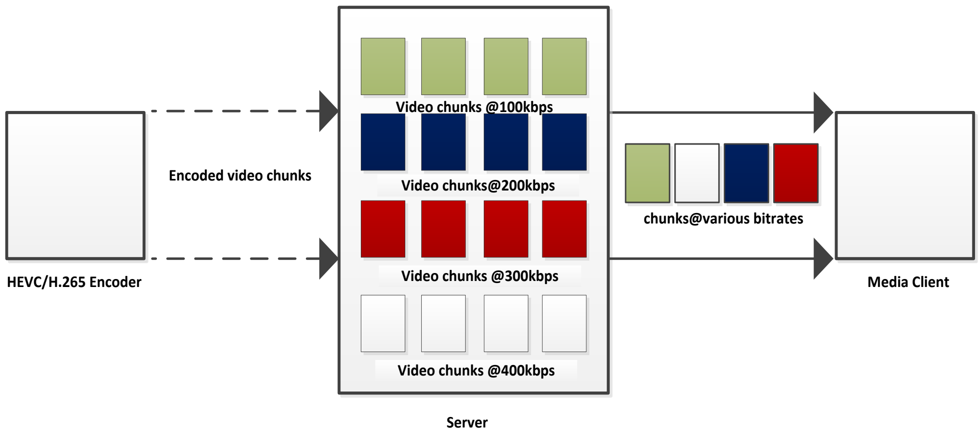

Figure 1. Adaptive streaming of video chunks

ISO/IEC PDTR 23009-3[19] recommends that the bitrate of the higher representation in adjacent representations should not be more than double that of the lower representation. This means that in DASH, the gap between different bitrate representations will not be too large and will avoid obvious changes in quality when switching which could add another dimension to the Quality of Experience (QoE). Different bitrate representations can be achieved during encoding by varying the resolution, frame rate, or QP of same video.

The HTTP syntax and video content packing are covered in the DASH standard, while the DASH content adaptation to the available bandwidth is beyond the scope of the DASH standard and can be addressed by client designers. It is required that each media segment will contain at least one Stream Access Point (SAP) during preparation of video segments. Three types of SAP have been highlighted in ISO/IEC PDTR 23009-3[19] namely SAP type 1, SAP type 2 and SAP type 3 respectively. The SAP type 1 can be implemented using the closed GoP (Group of Pictures) video structure, SAP type 2 can be implemented using a modified closed GoP video structure while the SAP type 3 can be implemented using the open GoP video structure[19].

4. DATA SET AND EXPERIMENT

4.1 Testbed

This section describes the testbed used in realizing the MPEG-DASH system. The testbed was implemented on a hardware testbed consisting of three main components: a webserver, emulator and a DASH client. The server is a standard apache web server running on an Intel core i5-2400 CPU @3.10GHz x 4, 500HDD, Ubuntu 12.10 operating system (OS), the client is an GPAC MP4Client[21] running on an Intel core i3-2100 CPU @ 3.10 GHz x 4, 500GB HDD, Ubuntu 12.04 OS, while the emulator is a NETEM based system with running on an i3-2100 CPU @ 3.10 GHz x 4, 500GB HDD, Ubuntu 12.04 OS. The testbed is illustrated in Figure 2 with a client/server approach with a network emulator in the middle. The user's QoE is evaluated online in real time.

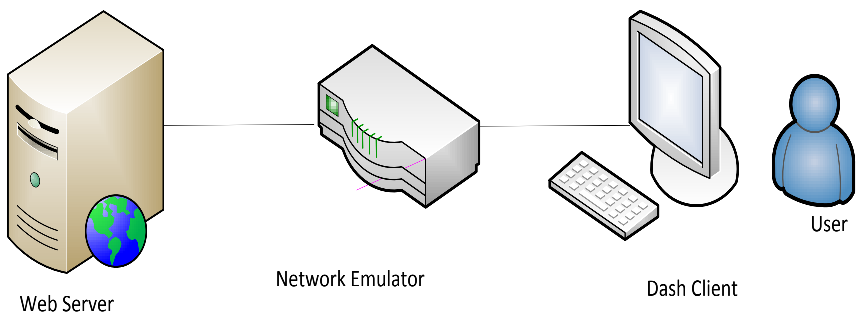

Figure 2. Experimental testbed.

4.2 Experiment and Implementation

To realize adaptive streaming of video streams, we chose the big buck bunny video clip[23] and the Elephants dream clip clip[23] for this experiment based on their temporal and spatial activity[20]. A longer video duration of 60s was chosen for this test in order to demonstrate the possible cyclical effect of the impairments being investigated and impact of a longer video chunk size. We avoided joining several video files in order get a 60s file which might add another dimension to our investigation by cutting out 60s clip from a very long raw video file The video sequences were encoded into 6 bitrate rate representations each using the HM reference software[22] by varying the Quantization parameter (QP) using the following QP values of 18, 23, 28, 33, 38, 43. The key frame interval was carefully chosen for segmentation at GOP boundaries and the video sequences were then segmented into chunks of 2s and 10s segments respectively for adaptive streaming considering the chunk size chosen by some commercial deployments and the need to investigate a short and long chunk size. The segmented video contents were stored on the webserver so that it can be accessed by the DASH Client using HTTP request. The parameters for the chosen video streams are shown in table 1.

Table 1. Video sequence parameters.

Video sequence	Frame rate (fps)	Spatial resolution (pixel)	Length (s)
Elephants dream	**24**	**1980x1080**	**60**
Big buck bunny	**24**	**1980x1080**	**60**

For this evaluation different network impairments that affect DASH have been identified during initial pilot test and review of related literatures and hence will be investigated. The impact of the following packet loss rates of 1%, 3% and 5%, will be added using NETEM and investigated. Delay values of 50ms, 100ms and 150ms will also be investigated. Furthermore, the network bandwidth will be shaped to 0.2Mbps, 0.5Mbps, 5Mbps and 8Mbps emulating different restrictions in bandwidth. We investigated the impact of these impairments for the 2 different sequences and different segment sizes.

The evaluation starts by making http request from the DASH client to the server, while different network impairments are introduced using the NETEM box. The subjective testing for our evaluation is carried out in real-time in order to capture how different issues like initial delay, stalling and flickering are being perceived by users. The frequency, duration and pattern of the mentioned issues were also monitored.

4.3 Subjective testing

The subjective testing was carried out in a controlled environment in the school laboratory. A 22” monitor was used in displaying the test sequences and the viewing conditions were as recommended in ITU-T P.910[20]. Ten volunteers took part in the subjective testing including both male and female. Their ages ranged from 18-52 years and were not involved in video quality evaluation research. All volunteers were screened for normal visual acuity[20] and normal colour vision. All volunteers appeared to be in good health at the time of test. The subjective scaling method selected for our evaluation was the Absolute category rating (ACR) [20]. The volunteers were educated on how to use the scale before the start of the experiments. The video sequences were randomly selected one at a time, played and rated independently. The ACR scale is as shown in figure 3.

5	**Excellent**
4	**Good**
3	**Fair**
2	**Poor**
1	**Bad**

Figure 3. ACR scale.

The video sequences are played randomly in real-time and rated independently using this five-level scale from 1-5 with 5 representing the highest quality. The volunteers were given frequent breaks considering the length of the video contents, and the number of scenarios where the entire subjective testing lasted over 2 weeks. The individual test scores were collected and a mean opinion score (MOS) was calculated. The MOS was then plotted graphically and further analyzed.

5. RESULTS AND ANALYSIS

This section describes the result obtained from our subjective experiment. The QoE is analyzed by investigating the impact of video chunk size, packet loss ratio and delay on received video using subjective scores. Individual test sequences with different network impairments were streamed randomly over the test bed and rated using the ACR scale by the subjects. The MOS was then calculated from the individual subjective scores and analyzed. The graph shows MOS v impairments and error bars with standard deviation. Figure 4 illustrates the impact of traffic shaping at 0.2Mbps, 0.5kbps, 2Mbps and 8Mbps representing very low, low, medium and High bandwidth respectively for 2s and 10s chunk sizes.

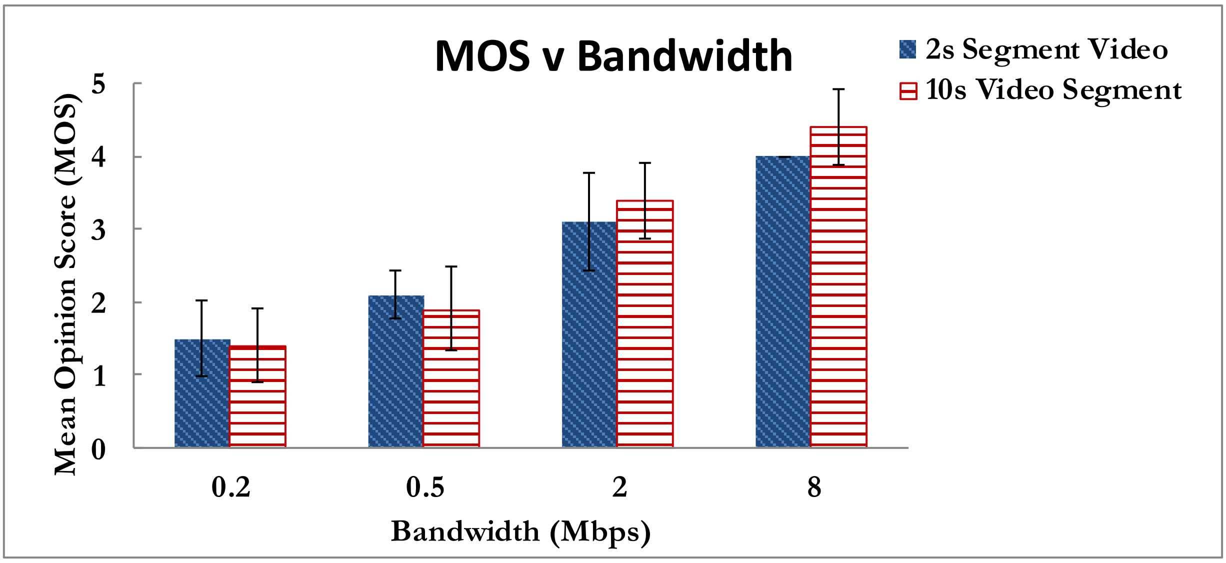

Figure 4. MOS of varying bandwidth sizes.

From Figure 4, at the 0.2Mbps, the MOS of the two segment sizes are very close and differ only by a value of 0.1, while at 8Mbps, the MOS for the 10s segment size is higher by a value of 0.4. The increase in bandwidth increases the MOS because the client switches to higher bitrate representation which provides a better picture quality thereby improving user's QoE. Also with improved network condition, the probability of empty playout buffer is reduced which improves the QoE. Figure 4 shows that at higher system bandwidth, the longer segment sizes have higher MOS than the shorter segment sizes. Longer segment sizes generally provide better compression because they have more temporal redundancy and reduced number of I-frames. The higher MOS of the shorter segment sizes at lower bandwidth in Figure 4 could be because a few subjects scored the video very low which could be very insignificant if the sample size was further increased.

The experiment was further investigated with a different video sequence in Figure 5 which showed a stable pattern of the longer video segments having a higher MOS than the shorter segment sizes. A further comparison with objective metrics will provide further insight. The impact of traffic shaping was investigated using the big buck bunny sequence in Figure 5, and it also showed the increase in MOS as the bandwidth increases and also the higher MOS of the longer video segment sizes compared the shorter segment sizes.

Figure 6 illustrates the impact of different delay values of 0ms, 50ms, 100ms and 150ms on 2s and 10s video segment sizes respectively, and shows that the MOS of the longer segment size was generally higher than that of the shorter segment size except at 50ms where the 2s segment size had a MOS of 2.6 while that of 10s has a MOS of 2.5 showing a difference in score of 0.10, the switch in pattern at 50ms might be because one of the subjects gave a very lower score and would have been insignificant with a larger sample size. During the test we observed that shorter segment sizes switched more quickly with sudden drop in network condition while it took the larger segment sizes more time to switch, but the longer segment sizes produced less flicker which the subjects preferred as they found the video more stable during playback.

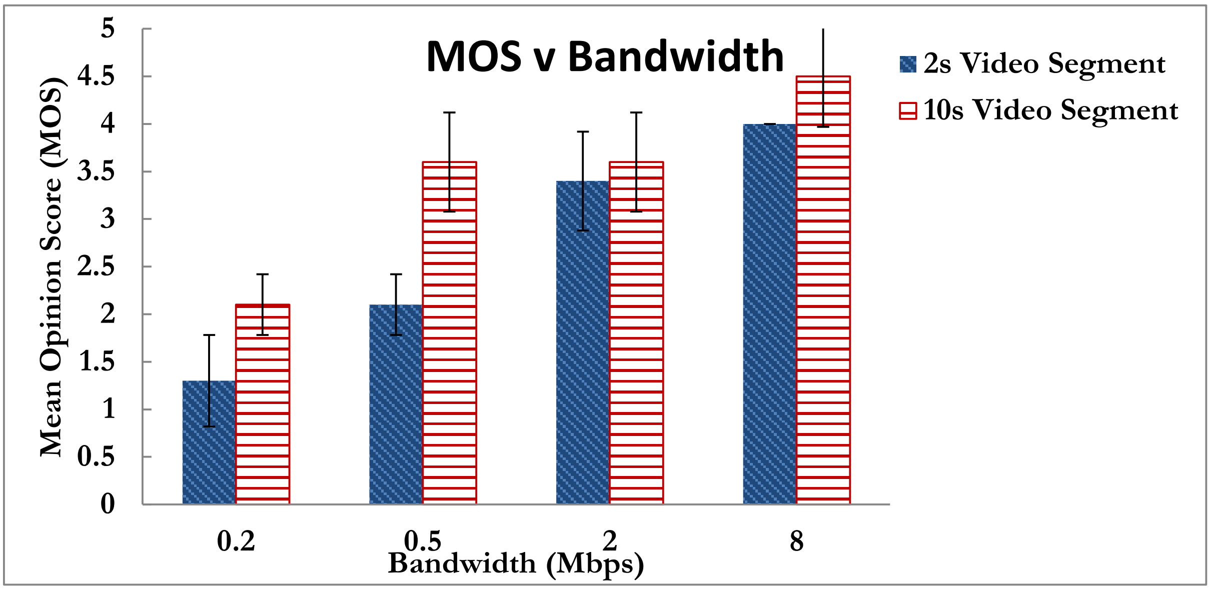

Figure 5. MOS of varying bandwidth sizes.

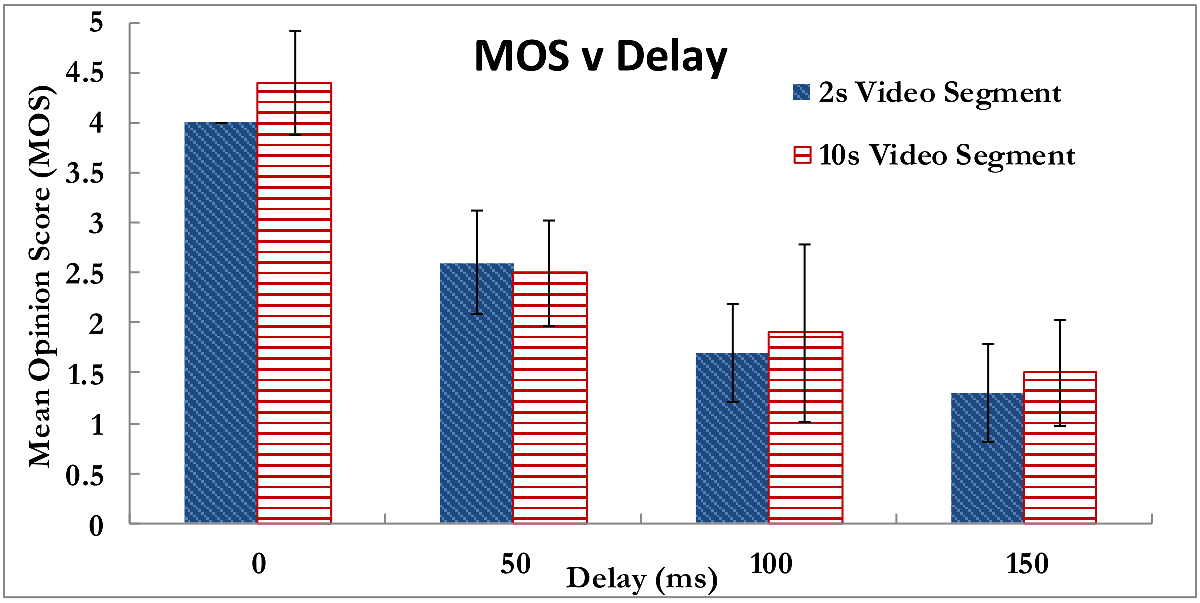

Figure 6. MOS of various delay sizes.

Also from Figure 6, at 150ms, the MOS is 1.30 and 1.50 for the 2s and 10s segment sizes respectively, from further statistically analysis the minimum scores for both segment sizes was 1 which reflects bad in the ACR scale, and maximum score is also 2 for the segment sizes representing poor which expresses the kind of QoE experienced at 150ms. These scores show that the subjects were not impressed with the videos hence the low scores. In summary as the value of the delay is increased, the MOS score decreases showing the effect of delay on QoE. The impact of various delay sizes was also investigated using a different video sequence in Figure 7 and showed similar impacts of delay on different segment sizes of encoded videos as illustrated in Figure 7.

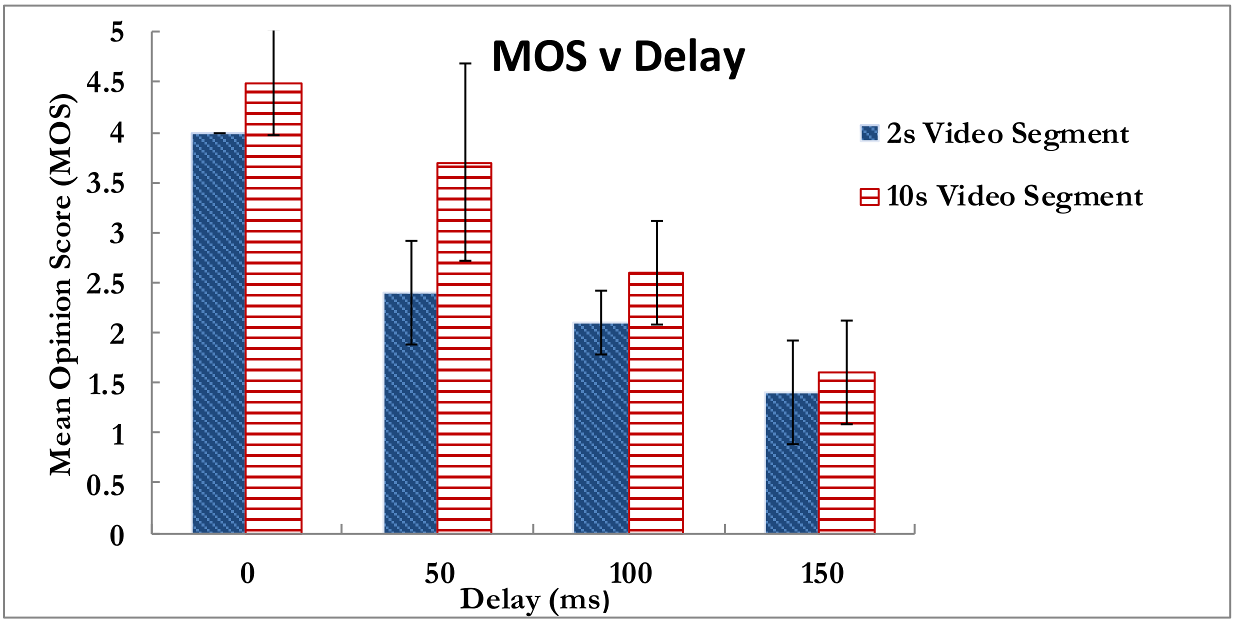

Figure 7. MOS of various delay sizes.

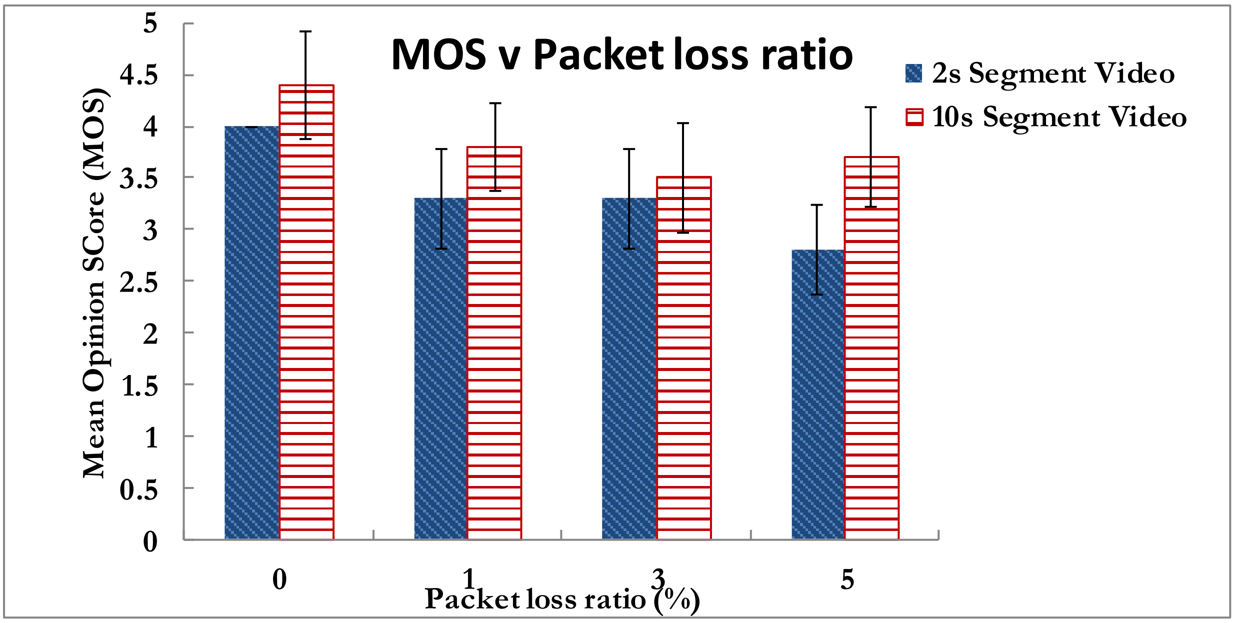

Figure 8. MOS of packet loss rates.

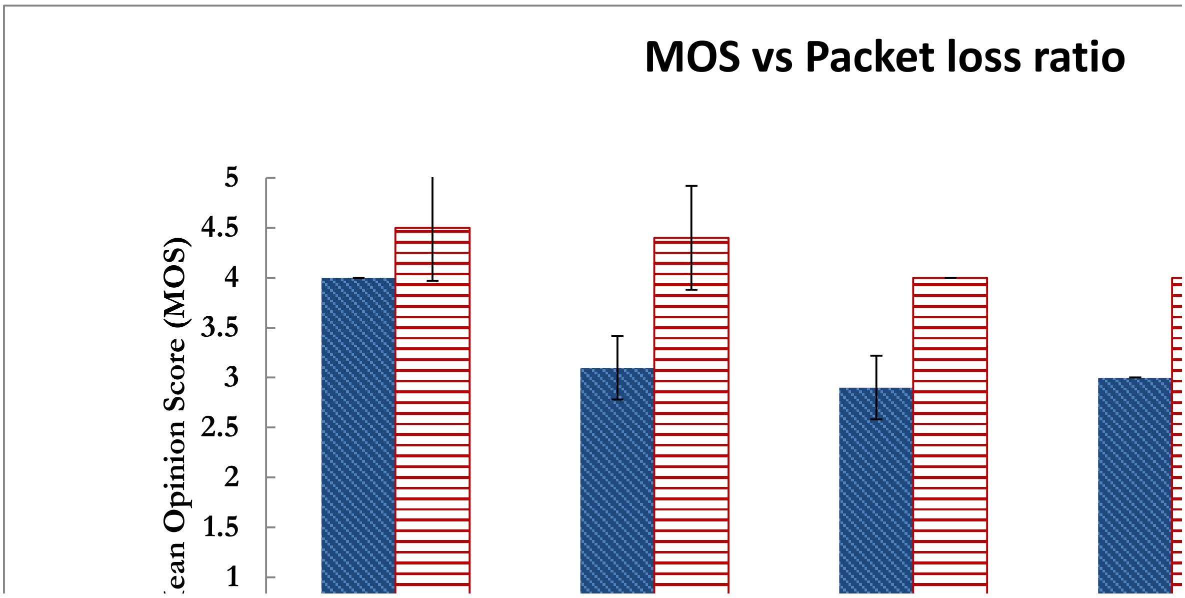

Figure 9. MOS of packet loss rates.

The different impacts of packet loss are illustrated in Figure 8. The 10s video segments have better MOS score when compared to the 2s segment size. At 0% packet loss, the MOS of the 10s video segment size is higher than the MOS of the 2s by a value of 0.40. For the 2s video segment size, there was no significant difference in the MOS from 1% to 3% packet loss ratio, but the MOS dropped by a value of 0.50 from 1% to 5% packet loss ratio. Considering 10s video segment size, the MOS dropped by a value of 0.10 from 1% to 5% packet loss ratio showing a better QoE when the packet loss is increased by a value 4%. Also at 5% packet loss ratio, the minimum subjective score was 3 and 2 for the 10s and 2s video segment sizes respectively.

The impact of packet loss on DASH is also shown in Figure 9 using a different video sequence, for the 10s video segment size, the MOS decreased by a value of 0.4 when the packet loss was increased from 1% to 5% and showed no difference in MOS when increased from 3% to 5% packet loss. Also from the Figure 9, for the 2s video segment size, there was no significant difference in MOS when the packet loss rate was increased. From the results in Figure 8 and Figure 9, the users had a better QoE with the longer video segment size when packet loss was introduced. Comparing Figure 8 and Figure 9 using different content types, user's perceived video quality was different because in Figure 9, there was no significant difference in MOS when the Packet loss ratio was increased from 3% to 5% while the change was obvious in Figure 8.

6. CONCLUSION

This paper presents the results of a real-time online subjective evaluation of MPEG-DASH system that employs H.265/HEVC, the latest video codec, to encode video streams. The impact of various network conditions on the users' perceived quality of experience or QoE was investigated using different video sequences and segment sizes. It was observed that DASH streaming is greatly affected by initial delay, playback interruption, and variation in picture quality, which influence the individual scores of subjects. The challenge is a trade-off between these three factors.

Based on our results, the larger segment sizes provided better QoE, but it cannot be stated that the larger segment sizes are generally better than shorter segment sizes because of the latter case's own merits. The shorter segment sizes usually switch more quickly between representations in case of sudden decline in the network condition. Considering their individual merits, different patterns of network conditions will present a further insight between the performances across segment sizes and hence establish a threshold. At 150ms delay, the MOS became very low, showing intolerable experience. We also observed during the test that subjects were tempted to abandon the viewing because of the long initial delay, duration and frequency of playback interruption. From the results, delay had the most significant effect on QoE and using a longer video sequence further demonstrates the recurrent effects of these impairments on QoE.

The results of this study can be combined with objective metrics to shed more light on the QoE of DASH systems and any correlation between the QoE results and the objective performance metrics will help designers in optimizing the performance of DASH systems.

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