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QoE Assessment of Video Codecs for Video Streaming over 5G Networks

Georgios Minopoulos, Konstantinos E. Psannis
Department of Applied Informatics
University of Macedonia
Thessaloniki, Greece
e-mail: gminopoulos@uom.edu.gr, kpsannis@uom.edu.gr

Georgios Kokkonis
Department of Business Administration
University of Western Macedonia
Grevena, Greece
e-mail: gkokkonis@uowm.gr

Yutaka Ishibashi
Graduate School of Engineering
Nagoya Institute of Technology
Nagoya, Japan
e-mail: ishibasi@nitech.ac.jp

***Abstract*—Nowadays, the need for more efficient video compression algorithms is growing, due to the increasing consumption of video content in higher resolutions. Thus, it is obvious that video compression technologies play a key role in the distribution of video content in broadcasting. In this paper, a comparative analysis and QoE assessment over the most recent video codecs in terms of video transmission over 5G networks are presented. The video compression comparison takes into account performance metrics considering the bitrate savings versus the image quality, in order to provide evidence about their adaptation under real-time streaming conditions. The video test sequences used in our experiments were retrieved from miscellaneous sources and their common characteristic is that they have High, Full or Ultra High Definition resolution. Video codecs' performance was tested by using commercial coding libraries and reference software of the coding standards.**

Keywords-fifth generation; high definition; mobile networks; video codecs; video streaming

I. INTRODUCTION

Various industrial studies and reports have predicted the drastic increase of video traffic in the Internet. IP video traffic will reach 82% of all IP traffic by 2022 worldwide. Live Internet video will approach 17% of Internet video traffic, while mobile video traffic now reaches nearly more than 50% of total mobile data traffic. Predictions show that this number will jump to 79% by 2022 [1]. Moreover, video traffic in mobile networks is forecast to grow by around 30% annually through 2025 [2].

Today's popular video coding standards, are widely used to encode video into bit streams for storage and transmission. The most common resolution for video streaming over cellular networks has been estimated to be the Standard Definition (SD). With smartphones and networks improving constantly, streaming of 1280x720 High Definition (HD), 1920x1080 Full High Definition (FHD) and 3840x2160 Ultra High definition (UHD) videos is becoming more common, and according to a streaming media survey, by the end of 2020, close to 40% of all video distributions will be 4K or higher resolutions [3]. The explosive growth of various video applications makes the recent video codecs not to fully satisfy their requirements anymore. Thus, the implementation of high compression efficiency and low complexity video coding standards is imperative.

The introduction of the Fifth Generation (5G) mobile networks is likely to increase the demand for mobile video consumption of 720p, 1080p and 4K resolution videos. 5G networks are considered as the communication technology of the future. On a global level, 5G network deployments are expected to dominate during the next years, building the foundation for massive adoption of 5G subscriptions. Over the next six years, 5G subscription uptake is expected to be significantly faster than that of 4G. According to estimations, the number of 5G connections will reach 2.6 billion by the end of 2025, covering up to 65% of the world's population, and generating 45% of the world's total mobile data traffic, making it the fastest developing mobile communication technology to have ever been rolled out on a global scale [2]. In Europe 5G is expected to reach about 30% of connections, which translates into 217 million connections [4].

5G technology is designed to interconnect not only people, but also a massive number of devices. By doing so, 5G paves the way for the Internet of Things (IoT) and Smart Cities [5]. This emerging technology is going to play a vital role in the evolution of today's applications that still need improvements, like video streaming. 5G is expected to be 100 times faster than 4G [6], allowing high resolution video transmission in a matter of seconds. The enhanced Mobile Broadband (eMBB) 5G services target applications with an aggregated data rate of more than 10 Gbps. An e-streaming sports event in multi-view could consume about 7 GB per hour, Virtual Reality (VR) or Augmented Reality (AR) applications are anticipated to demand a few Gbps capabilities as a high quality VR/AR stream with a bitrate of 25 Mbps would consume as much as 12GB per hour and an 8K UHD streaming should require a capacity of higher than 100 Mbps for a single user [7].

The rest of the paper is organized as follows: Section 2 mentions the specifications of 5G networks and their

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significance for video transmission. In Section 3 the most popular MPEG video coding standards are presented, while Section 4 presents the video coding standards implemented recently by AOMedia. In Section 5 the results of the video codecs comparisons are presented. Finally, Section 6 concludes the paper and indicates some future perspectives.

II. 5G SPECIFICATIONS

5G systems are anticipated to embrace and integrate existing or new innovative technologies, bringing small cells, MIMO, beam forming, true in-band full duplex (IBFD), edge computing together and extend spectrum support to both low band (600 MHz) and high band millimeter wavelength (26, 28, 38 and 60 GHz) in order to be able to support the standardization requirements. Moreover, it is estimated to foster the digitization of the economy like cloud based services, next generation transactions (e.g. block chain), big data, virtual reality, augmented reality, artificial intelligence and tactile internet due to its ability to manage, in real-time, large amount of data with low latency [8].

ITU IMT-2020 standard outlines eight criteria for mobile networks, which should be fulfilled in order to qualify as 5G [9]:

- 10 Gbps maximum achievable data rate.
- 10 (Mbit/s)/m^2 traffic capacity across coverage area.
- 1 ms latency.
- 10^6/km^2 total number of connected devices.
- 3 times higher spectrum efficiency compared to 4G.
- Full (100%) network coverage.
- Mobility up to 500 km/h with acceptable Quality of Services.
- 100 times lower network energy usage compared to 4G.

The increasing requirement of UHD videos is obvious because not only televisions, but also portable devices embed UHD resolution displays, as well [10]. Thus, it is important to mention the data rate capacity of such a video. The needed bandwidth for a video is calculated as follows:

$$bandwidth = x * y * p * fps \, / \, 1024 \ (Gbps) \qquad (1)$$

where: x and y indicate the resolution of the image; p is the bit value of a pixel, which consists of 3 bits; and fps is the frames per second. For example, for an 8K UHD clip with a hypothetical framerate of 120 fps, equation (1) gives: 7680 * 4320 * 24 * 120 / 1024 = 93.3 Gbps as necessary bandwidth.

Therefore, it is clear that the transition to UHD video streaming is not feasible under neither the present cellular 4G networks, as they can barely achieve a maximum bandwidth of almost 45 Mbps in well-developed countries [11], nor with the existing video compression algorithms. As uninterrupted video transmission over mobile networks will bring novel applications such as telesurgery or surveillance, the development of new video codecs, which can support excellent image quality with less bitrate, should be the main aim of video coding vendors and not only. The immersive demand for efficient video codecs seems to be more imperative than ever before. The introduction of 5G networks will boost the video data traffic and promise an excessive Quality of Experience (QoE) for the users.

III. MPEG CODING STANDARDS

The Video Coding Experts Group (VCEG) of the International Telecommunication Union (ITU-T) is responsible for standardization of the H.26x series of coding standards, including H.120, H.261, H.263 and H.263+. Then the Moving Picture Experts Group (MPEG) under the International Standards Organization (ISO) and International Electrotechnical Commission (IEC) developed the popular MPEG-1 and MPEG-4 standards. In 1995 ITU and ISO/IEC collaborated and jointly developed H.262/MPEG-2. In 2001, these two groups formed the Joint Video Team (JVT) and cooperated in the development of H.264/MPEG-4. In 2003, the Joint Collaborative Team on Video Coding (JCT-VC) developed the new generation video coding standard H.265. Finally, MPEG plans to launch 3 different codecs in 2020.

A. AVC

H.264/MPEG-4 or Advanced Video Coding (AVC) is the most widely adopted video coding standard nowadays. AVC covers a wide range of applications with satisfactory results, such as videoconferencing, video streaming, and video transmission over fixed and wireless networks with different transport protocols among others. H.264 can support 4K resolution, while 6K and 8K videos are obviously out of the scope of H.264 [12].

B. HEVC

H.265/MPEG-H or High Efficiency Video Coding (HEVC) presents significantly better compression performance, allowing 4K video view with about half bandwidth less retaining the same video quality, compared to its predecessor H.264/MPEG-4 standard, while it supports 6K and 8K resolutions [13], [14]. HEVC is still not widely adopted because it requires almost 50% more computing power for decoding than AVC [15]. However, if a computer can handle off the computational load, the processing could become much faster and more energy efficient. Thus, it would gain higher popularity as more hardware markets adopt it [16].

C. VVC

H.266/MPEG-I Part 3 or Versatile Video Coding (VVC) will be the evolution of HEVC [17]. Compared to HEVC, VVC promises bitrate savings of 30% to 50% for the same level of video quality [18]. This means that VVC will require about half bandwidth less than HEVC, making it more efficient in fixed and especially in low-bandwidth networks, such as the mobile networks where data capacity is limited. VVC will enable high quality video services with resolutions from 4K to 16K and many emerging applications, such as 360-degree omnidirectional immersive multimedia and High Dynamic Range (HDR) videos [16]. The codec is intended to be rolled out by the end of 2020.

D. EVC

MPEG-5 Part 1 or Essential Video Coding (EVC) is another new codec that promises to become a viable alternative to AVC and HEVC, but with coding efficiency similar to HEVC. It can be looked at as a workaround to the complex HEVC licensing. MPEG decided to launch this new initiative around video coding, in order to provide a standardized video coding solution to address business needs in some use cases, such as video streaming, where existing ISO video coding standards have not been as widely adopted as might be expected from their purely technical characteristics [19]. MPEG aims to finalize the text of the standard within 2020.

E. LCEVC

MPEG-5 Part 2 or Low Complexity Enhancement Video Coding (LCEVC) takes an existing codec and improves the overall performance of the encoder. Actually, it is an add-on codec, not an alternative. The objective of LCEVC is to develop a data stream structure defined by two component streams, a base stream decodable by a hardware decoder, and an enhancement stream suitable for software processing implementation with sustainable power consumption. The enhancement stream will provide new features such as compression capability extension to existing codecs, lower encoding and decoding complexity, for on-demand and live streaming applications [20]. LCEVC, which is estimated to be finalized in mid-2020, creates a hybrid stream with one lower resolution stream containing the base codec, which can be any codec, and an enhanced stream that provides additional resolution and quality.

IV. AOMedia Coding Standards

In 2010 WebM Project launched VP8 as state-of-the-art video codec that is royalty-free. In 2013, a powerful sibling of VP8, VP9, was launched as a royalty-free alternative to HEVC. Even though the performance of VP9 is satisfactory, continued growth of the demand for high efficiency video applications, calls for more efficient video coding standards. In late 2015, the Alliance for Open Media (AOMedia), which is a forum of more than 30 leading tech companies, jointly develop a royalty-free codec called AOMedia Video 1 (AV1), which was released in 2018. The original plan for WebM Project was to release codecs every 5 years. Thus, AV2 is expected in 2023. The participation will be broader than in AV1 as invitations to Academia and partner companies were sent to work together towards AV2.

A. VP9

VP9 is now used on Google's video platform YouTube and serves billions of views every day. VP9 supports HDR videos and enables lossless compression. Furthermore, a VP9 bit stream is error resilient and the decoding process can be conducted in a parallel mode. It also allows both temporal spatial scalabilities [16]. VP9 encoder has a two-pass rate-control encoding option, which results in improved rate-distortion performance. This feature was enabled for VP9 as well as for its descendant AV1 in the multi-pass rate-control test case [21].

B. AV1

AV1 is an open, royalty-free video coding format designed for video transmissions over the Internet. It was developed as a successor to VP9. Its objective was to combine its members' technology and expertise to develop a royalty-free video format with high compression efficiency and suitable for use in browsers and on the web [22].

V. QoE Assessment

The video test sequences used in the experiments were retrieved by JVET common test conditions [23] or AOMedia's open test bench AWCY [24] and have been tested by using commercial coding libraries and reference software of the coding standards. The purpose of the reference implementations and tests models is to enable evaluation of new coding tools and to demonstrate one exemplary and straight-forward implementation of the corresponding standard. It is safe to assume that it is therefore unlikely that these reference implementations will be deployed in real-world products [25].

To assess the coding efficiency, objective QoE metrics such as PSNR (Peak Signal Noise Ratio), Video Multimethod Assessment Fusion (VMAF) and BD-Rates (Bjontegaard-Delta Rates) have been evaluated. BR-Rates reveal the average bitrate savings at the same objective quality for multiple operating points which differ in bitrate and quality. In such comparisons a negative BD-Rate means using less bits to achieve the same quality [25].

Testing the upcoming VVC against AVC and HEVC under JVET common test conditions indicates their performance over high resolutions like 1080p and 4K, for which the recent coding algorithms are developed to support. VVC shows an average bitrate saving that reaches 65% against AVC in both classes, as depicted in Table I [26]. Additionally, VVC outperforms against HEVC, as well. In 4K resolution VVC shows an overall bitrate saving of about 39% and almost 35% in 1080p resolution, as depicted in Table II [27].

TABLE I. VVC vs AVC

Anchor: AVC		
	Resolution	PSNR-Y
VVC	4K	-65.0%
	1080p	-63.0%

TABLE II. VVC vs HEVC

Anchor: HEVC				
	Resolution	PSNR-Y	PSNR-U	PSNR-V
VVC	4K	-38.9%	-38.3%	-36.9%
	1080p	-34.3%	-41.2%	-41.3%

The aim of the recent developed EVC video codec is to replace AVC and HEVC keeping the positive elements of each algorithm and eliminating their drawbacks. As shown in Table III and Table IV, EVC shows a relatively better performance against the previous codecs in both FHD and UHD resolution. In 4K resolution EVC reaches 38% less bitrate that AVC and almost 30% less than HEVC. In 1080p it offers almost the same savings against AVC and HEVC of about 25% and 23% respectively [28].

TABLE III. EVC VS AVC

Anchor: AVC				
	Resolution	PSNR-Y	PSNR-U	PSNR-V
EVC	4K	-37.9%	-33.4%	-38.0%
	1080p	-24.8%	-28.0%	-27.2%

TABLE IV. EVC VS HEVC

Anchor: HEVC				
	Resolution	PSNR-Y	PSNR-U	PSNR-V
EVC	4K	-29.5%	-26.3%	-25.7%
	1080p	-22.9%	-24.4%	-21.2%

A comparison between the two emerging video codecs shows that EVC does not achieve the bitrate efficiency that VVC does, as depicted in Table V. VVC outperforms as it uses complex algorithms to achieve as much compression as possible. VVC is expected to be the successor of HEVC. In the first place, the aim of the EVC was to perform slightly better than HEVC, so it is obvious that it does not achieve the bitrate savings that the algorithm of VVC is developed to succeed. However, the less complexity that shows, make it a serious competitor for the succession of today's coding algorithms [29].

TABLE V. EVC VS VVC

Anchor: VVC				
		PSNR-Y	PSNR-U	PSNR-V
EVC	Overall	12.7%	21.1%	20.3%

The third coding standard that is expected to be finalized within 2020 is LCEVC. The main scope of this new approach is to reduce the computational complexity of coding algorithms and secondly to reduce the bitrate. Table VI depicts the numbers reported in its test submissions, which are impressive, including average bandwidth savings of 45%, 34% and more than 16% respectively as compared to AVC, HEVC and VVC [30].

TABLE VI. LCEVC VMAF BD-RATE

	AVC	HEVC	VVC
LCEVC	-44.9%	-34.2%	-16.5%

The difference of coding performance between VP9 and AV1, represented by BD-Rate, using 12 UHD clips and 7 HD clips of AOMedia's open test bench AWCY, is shown in Table VII. PSNR-Y, PSNR-Cb and PSNR-Cr are the objective metrics used to compute BD-Rate. Table VII indicates that AV1 substantially outperforms VP9 by almost 30% coding gain, when the main quality factor PSNR-Y is considered, in both HD and UHD resolution [31].

TABLE VII. AV1 VS VP9.

Anchor: VP9				
	Resolution	PSNR-Y	PSNR-Cb	PSNR-Cr
AV1	UHD	-26.8%	-31.3%	-31.1%
	HD	-28.2%	-25.4%	-27.9%

Finally, comparing MPEG's VVC against AOM's AV1, VVC performed almost 23% better than AV1 for HD sequences and 34% for UHD sequences, as shown in Table VIII [32].

TABLE VIII. VVC VS AV1

Anchor: AV1		
	Resolution	PSNR-Y
VVC	UHD	-34.0%
	HD	-22.9%

Figure 1 illustrates that the VVC algorithm produces consistently higher peak signal to noise values than AV1 for an equal bitrate, which means that the VVC decoded video is of better objective quality than the AV1 video.

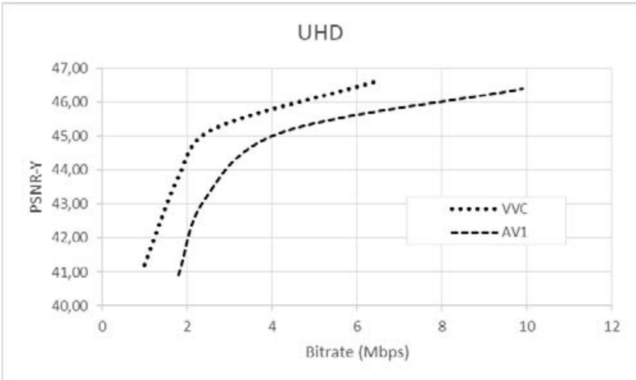

Figure 1. PSNR comparison between VVC and AV1.

VI. CONCLUSIONS

Video streaming through mobile networks is anticipated to play a vital role in the next few years. The number of mobile devices is growing in fast rates and so the demand for video data traffic is growing, as well. As high quality video streaming is not feasible under the current cellular systems, the next generation networks, 5G, will boost the video data transmission and provide an excessive QoE for the users. Video compression technologies play a key role in the distribution of video content in broadcasting. Emerging video codecs promise better image quality, while keeping lower bitrate. New algorithms provide better performance than the previous ones, but their complexity increase the video processing time. MPEG and AOMedia keep developing new codes in order to make them publicly available and replace current old-fashion ones. As future work, the examination of coding time in relation with the image quality they succeed seems as an open field for further improvement.

REFERENCES

[1] Cisco, "Cisco Visual Networking Index: Forecast and Trends," White Paper, Updated: February 2019. [Online] Available: https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-741490.html

[2] Ericsson, "Mobile traffic analysis by application". [Online] Available:

https://www.ericsson.com/en/mobility-report/reports/november-2017/mobile-traffic-analysisby-application

[3] Streaming Media, "Encoding 2020: Experts Predict the Future of Video Encoding," September 2015. [Online] Available: https://www.streamingmedia.com/Articles/Editorial/Featured-Articles/Encoding-2020-Experts-Predict-the-Future-of-Video-Encoding-106619.aspx

[4] GSMA, "New GSMA Study: 5G to Account for 15% of Global Mobile Industry by 2025 as 5G Network Launches Accelerate," February 2019. [Online] Available: https://www.gsma.com/newsroom/press-release/new-gsma-study-5g-to-account-for-15-of-global-mobile-industry-by-2025/

[5] V. A. Memos, K. E. Psannis, Y. Ishibashi, B-G. Kim and B.B. Gupta, "An Efficient Algorithm for Media-based Surveillance System (EAMSuS) in IoT Smart City Framework," Future Generation Computer Systems, vol. 83, pp. 619-628, 2018.

[6] ITU-R, "IMT Vision - Framework and overall objectives of the future development of IMT for 2020 and beyond," M-Series, Recommendation ITU-R M.2083-0, September 2015.

[7] G. Minopoulos, G. Kokkonis, K. E. Psannis and Y. Ishibashi, "A Survey on Haptic Data Over 5G Networks," International Journal of Future Generation Communication and Networking, vol. 12, no. 2, pp. 37-54, June 2019.

[8] K. Taga, R. Swinford and G. Peres, "5G deployment models are crystallizing - Opportunities for telecom operators to facilitate new business ecosystems," Arthur D. Little, June 2017. [Online] Available: https://www.adlittle.com/en/5Gdeployment

[9] ITU-R. "IMT Vision - Framework and overall objectives of the future development of IMT for 2020 and beyond," M Series, Recommendation ITU-R M.2083-0, September 2015.

[10] SONY, "Experience the world's first 4K HDR OLED screen," February 2019. [online] Available: https://www.sonymobile.com/global-en/products/phones/xperia-1/features/#display

[11] Opensignal, "The State of LTE", February 2018. [online] Available: https://www.opensignal.com/reports/2018/02/state-of-lte

[12] H. D. J. O. Dominguez, O. O. V. Villegas, V. G. C. Sanchez, E. D. G. Casas and K. R. Rao, "The H.264 Video Coding Standard," IEEE Potentials, vol. 33, no. 2, pp. 32-38, March-April 2014.

[13] J.R. Ohm, G.J. Sullivan, H. Schwarz, T.K. Tan and T. Wiegand, "Comparison of the coding efficiency of video coding standards—including high efficiency video coding (HEVC)," IEEE Transactions on circuits and systems for video technology, vol. 22, no.12, pp. 1669-1684, 2012.

[14] M. T. Pourazad, C. Doutre, M. Azimi and P. Nasiopoulos, "HEVC: the new gold standard for video compression, how does HEVC compare with H.264/AVC?," IEEE consumer electronics magazine, vol. 1, no. 3, pp. 36-46, 2012.

[15] G. Kokkonis, K. E. Psannis, M. Roumeliotis and Y. Ishibashi, "Efficient algorithm for transferring a real-time HEVC stream with haptic data through the internet," Journal of Real-Time Image Processing, vol. 12, no.2, pp. 343-355, August 2016.

[16] T. Zhang and S. Mao, "An overview of emerging video coding standards," GetMobile: Mobile Computing and Communications, vol. 22, no. 4, pp. 13-20, May 2019.

[17] Y. Sun, J. Lou, Y. Chao, H. Wang, V. Seregin and M. Karczewicz, "Analysis of Palette Mode on Versatile Video Coding," IEEE Conference on Multimedia Information Processing and Retrieval (MIPR), San Jose, CA, USA, pp. 455-458, March 2019.

[18] J. Krieger, "WDR and Fraunhofer HHI join forces for VVC/H.266," September 2019. [Online] Available: https://www.broadbandtvnews.com/2019/09/03/wdr-and-fraunhofer-hhi-join-forces-for-vvc-h-266/

[19] MPEG, "Text of ISO/IEC CD 23094-1 Essential Video Coding," N18568, Gothenburg, July 2019. [Online] Available: https://mpeg.chiariglione.org/standards/mpeg-5/essential-video-coding/text-isoiec-cd-23094-1-essential-video-coding

[20] MPEG, "Low Complexity Enhancement Video Coding," N18098, Macao, October 2018. [Online] Available: https://mpeg.chiariglione.org/standards/mpeg-5/low-complexity-enhancement-video-coding

[21] Chromium open-source browser project, VP9 source code. [Online] Available: http://git.chromium.org/gitweb/?p=webm/libvpx.git;a=tree;f=vp9;hb=aaf61dfbcab414bfacc3171501be17d191ff8506

[22] AOM, "The Alliance for Open Media Kickstarts Video Innovation Era with "AV1" Release," March 2018. [Online] Available: https://aomedia.org/the-alliance-for-open-media-kickstarts-video-innovation-era-with-av1-release/

[23] F. Bossen, J. Boyce, K. Suehring, X. Li and V. Seregin, "JVET Common Test Conditions and Software Reference Configurations for SDR Video," JVET-K1010, Ljubljana, Slovenia, July 2018.

[24] AWCY. [Online] Available: www.arewecompressedyet.com

[25] T. Laude, Y. G. Adhisantoso, , J. Voges, M. Munderloh and J. Ostermann, "A Comprehensive Video Codec Comparison," APSIPA Transactions on Signal and Information Processing, vol. 8, November 2019.

[26] T. Fautier, "Codecs comparison from TCO and compression efficiency perspective," Harmonic Inc. 2018.

[27] S. Ma, "AVS3: The 3rd Generation AVS Video Coding Standard," Peking University.

[28] K. Choi, "MPEG-5 Essential Video Coding," Samsung Electronics.

[29] Y. Chen, E. François, F. Galpin, R. Jullian and M. Kerdranvat, "Comparative study of video coding solutions VVC, AV1, EVC versus HEVC," JVET-N0605r1

[30] G. Meardi, "Introducing MPEG-5 Part 2 LCEVC: A codec to improve other codecs," ITU Workshop on the Future of Media, Geneva, October 2019.

[31] Y. Chen, D. Murherjee, J. Han, A. Grange, Y. Xu, Z. Liu, ... and C. H. Chiang, "An overview of core coding tools in the AV1 video codec," IEEE Picture Coding Symposium (PCS) San Francisco, CA, USA, pp. 41-45, June 2018.

[32] BBC Research and Development, "Testing AV1 and VVC". [online] Available: https://www.bbc.co.uk/rd/blog/2019-05-av1-codec-streaming-processing-hevc-vvc