Comparison of Video Codecs Performance for Real-Time Transmission

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

Yutaka Ishibashi
Department of Computer Science
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, the video compression comparisons take into account the encoding or decoding time which is needed for each compression standard, 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 or Ultra High Definition resolution. Video codecs' performance was tested by using commercial coding libraries and reference software of the coding standards.**

Keywords-decoding; encoding; mobile networks; video codecs

I. INTRODUCTION

Globally, IP video traffic will reach 82% of all IP traffic by 2022. 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]. The introduction of the Fifth Generation (5G) mobile networks is likely to increase the demand for mobile video consumption of High Definition (HD) and Ultra High Definition (UHD) videos.

5G networks are considered as the communication technology of the future. The first 5G pilot networks have already been launched. According to estimations, the number of 5G connections will reach 1.4 billion by 2025, which means about 15% of the global total. 5G is expected to reach about 30% of connections in Europe, which translates into 217 million connections [2]. 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 [3]. 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 [4], 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. Virtual reality applications are anticipated to demand a few Gbps capabilities, whilst the generalization of 8K UHD streaming should require a capacity of higher than 100 Mbps for a single user [5].

The time taken to process the videos through the codec is an important measurement. Increased processing time means increased complexity, and therefore, more computational power is required. Video encoding normally occurs at a broadcast or streaming service with the resources to provide the required computational power. In addition, this could also be happened by home users who want to upload their videos to social media or send them to their friends. Reducing the complexity means that companies and individuals can save money and time by encoding faster, on cheaper and simpler devices [6].

Decoding happens when a video is received. This could occur in mobile phones, set-top boxes in the home, or almost in any device that receives and plays video. Decoding should be low in complexity and lightweight to keep user devices simple and cheap. This keeps decoding time low and helps to avoid juddering video [6].

The rest of the paper is organized as follows: Section II presents the latest related work which has been conducted on the new video compression standards. Section III cites the most popular video codecs, while Section IV describes the most known tools which are used for video coding. Section V presents the comparison of the video coding algorithms based on the current literature. Section VI concludes the paper and gives some potential future directions.

II. RELATED WORK

N. Barman and M. G. Martini [7] present a comparative analysis of H.264/MPEG or Advanced Video Coding (AVC), H.265/MPEG or High Efficiency Video Coding (HEVC) and VP9 encoders for live game video streaming applications as currently used by Twitch.tv and YouTube Gaming. For the encoding settings and the encoders used, in terms of BD-BR analysis, HEVC is found to provide the best compression efficiency but is 2.6 times slower than AVC. The magnitude of bitrate savings for VP9 compared to AVC is found to be highly dependent on the content type, with AVC resulting in higher average bitrate savings with an encoding speed 4 times faster than VP9.

J. Le Tanou and M. Blestel [8] present a thorough analysis of the emerging video codecs AOMedia Video 1 (AV1), Versatile Video Coding (VVC) and HEVC. Experimental results show that AV1 allows bitrate reduction of 10% in comparison to HEVC for the same PSNR and SSIM quality scores, while increasing encoding run-time by 55.5 times. However, it does not necessarily translate into gain in terms of subjective quality assessment. Additionally, the results highlight VVC as the best candidate for compression technology beyond HEVC.

M. Wien et al. [9] address an overview on recent and ongoing standardization status of immersive video coding with a focus on video signals, while it indicates the development timelines, summarizes the main technical details, and provides pointers to further points of reference.

P. Topiwala et al. [10] present a comparative analysis of the coding efficiency performance of VVC, AV1 and Essential Video Coding (EVC) video codecs. Their main conclusion from the assessment of objective metrics and subjective evaluation is that VVC seems to be superior to AV1 and EVC under both constant quality and target bitrate coding. However, compared to the popular codecs AVC and HEVC, this difference is moderate.

Finally, J. Aubié et al. [11] provide a deep comparative analysis of different codec technologies, such as AVC, HEVC, AV1 and VVC. The main scope of this research is to offer to the readers a better decision about which codec to use.

III. POPULAR VIDEO CODECS

A. AVC

H.264/MPEG-4 or AVC standard is a video codec that 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 [12].

B. HEVC

Today, H.265/MPEG-H or HEVC is the latest official compression standard for video streaming standardized by the Joint Collaborative Team on Video Coding (JCT-VC). HEVC presents significantly better compression performance, allowing UHD video view with about half bandwidth less retaining the same video quality, compared to its predecessor H.264/MPEG-4 standard [13], [14].

C. VVC

The next generation video coding standardization being developed by the Joint Video Experts Team (JVET), H.266/MPEG-I Part 3, known as VVC, is expected to be officially released by the end of 2020 and it will be the evolution of HEVC [15]. Compared to HEVC, VVC promises bitrate savings of 30% to 50% for the same level of video quality [16]. 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.

D. EVC

MPEG-5 Part 1 or EVC is another new codec that promises to become a viable alternative to HEVC. 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 [17]. MPEG aims to finalize the text of the standard in early 2020.

E. LCEVC

The objective of MPEG-5 Part 2 or Low Complexity Enhancement Video Coding (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 [18]. 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.

F. VP9

Google developed VP9 as a royalty-free alternative to HEVC. The 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 [19].

G. AV1

Apart from the forthcoming video encoding standards, a few other standards, which improve the bitrate savings of video compression and present significant meaning, have been developed recently. AV1 is an open, royalty-free video coding format designed for video transmissions over the Internet. It was developed as a successor to VP9 by the Alliance for Open Media (AOMedia), a consortium founded in 2015 [20]. Its initial release was in March 2018 and 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 [21].

H. XVC

The eXtreme Video Codec (XVC) is a novel video codec developed by Divideon, which was released in its first version in September 2017. The XVC codec is a software-defined video codec with conformance for bitstreams, decoders, and encoders, defined regarding the publicly available reference software. The XVC decoder is optimized for efficient software decoding on various platforms including mobile devices. Version 2.0 of XVC was released in July 2018. The new version provides improved compression efficiency compared to XVC 1.0 and includes a royalty-free baseline profile [22].

IV. Video Coding Tools

A. *x264 Codec Library*

The x264 is a free software library and application for encoding video streams into the H.264/AVC compression format. It provides best-in-class performance, compression, and features, which are necessary for many different applications, such as television broadcast, Blu-ray low-latency video applications, and web video [23].

B. *JM Reference Software*

The JM software is the reference implementation of the H.264/AVC standard. It provides both a reference software decoder and encoder used during the H.264 standardization process [24].

C. *x265 Codec Library*

The x265 software is an open-source encoder implementation based on the HEVC standard. Started in 2013, x265 has been built on-top of x264 software source code and implements most of the HEVC standard features. It implements an encoder only. The encoder defines various presets that match different trade-offs between compression efficiency and encoding run-time. Furthermore, it implements low level optimizations, parallel coding and multi-threading. Hence, x265 encoder can operate in real-time up to 4K 60fps, with a constrained coding efficiency, or down to multiple times the real-time with higher coding efficiency [25].

D. *HM Reference Software*

The HM software is the reference implementation of the HEVC standard. It provides both a reference software decoder and encoder used during the HEVC standardization process. The objective of this software is to provide a common and complete code base for conducting research and fair normative coding tools comparisons during the standardization process. It is single-thread only and it contains a limited number of low level optimizations. Code optimization and run-time performance were not the main focus of software design. Therefore, the encoding run-time is particularly slow and is count in minutes per frame [26].

E. *JEM and VTM Reference Software*

JEM is built above the HM software and includes 26 new normative, i.e. that implies decoder modification, coding tools which are candidates for VVC standard adoption. It provides a reference decoder and encoder, and is similar to the HM in its design and working principle. The continuous development of the VVC standard introduced a new reference software, known as VTM, which has been released along with the first draft of VVC specification. VTM version 1.0 consists of a reduced version of HEVC, removing elements that are not necessary, ineffective, or not suitable, but using new elements [27], [28].

F. *ETM Test Model*

ETM is the Test Model of EVC. It supports two major configurations: Baseline and Main configurations, each of which specifies a certain set of tools. The coding structure employs a quad-tree based coding structure which can use blocks up to 64x64 samples. ETM Test Model also includes bitstream merge service project which allows to merge several independently encoder bitstreams into the one joint valid bitstream [29].

G. *Libvpx Codec Library*

Libvpx is a free software video codec library from Google and AOMedia. It serves as the reference software implementation for the VP9 video coding formats. Libvpx offers an asymmetric codec – with encoding taking much longer than decoding – and options for configuring encoding expense independently from decoding complexity. A look ahead of up to 25 frames can be configured, which improves compression efficiency but introduces latency and thereby hurts real-time performance [30].

H. *AV1 Reference Software*

AV1 reference software provides both a reference decoder and encoder. AV1 reference encoder software is in the design and working principle similar to x265 software, but with less focused on encoding run-time optimization. Regarding run-time optimization, a number of level optimizations are implemented to speed-up the encoding time [21].

V. Comparison of Video Codecs

The aforementioned video compression tools were used to compare both the encoding and decoding time of each algorithm implementing similar parameters during simulations. The necessary time for encoding and decoding a video indicates whether an algorithm is appropriate for real-time broadcasting conditions, like surveillance of remote surgery. Furthermore, aspects of their video quality compression are examined in comparison with their encoding and decoding time.

A comparison of the most known video codecs, using several tests, is presented in order to provide evidence about their performance, as follows: 1) Comparison of the video codecs implemented by AOMedia (VP9 and AV1), 2) Comparison of the video codecs implemented by MPEG (AVC, HEVC, VVC, EVC, and LCEVC), 3) Comparison between AOMedia and MPEG codecs, and 4) Comparison of the Divideon codec versus a MPEG one (AVC).

A. *VP9 vs AV1*

AV1 has been introduced as the successor of VP9, thus a comparison between them is meaningful. AV1 outperforms VP9 by 15.4% and 19.5% in bitrate savings for UHD and HD videos respectively. However, the AV1 encoder spends much more time to encode the videos. Particularly, the encoder run time of AV1 relative to VP9 is about 117.5 times slower. This means that the quite substantial bitrate savings for AV1 relative to VP9 require a huge amount of increase in computational complexity [31].

B. HEVC vs VVC

VVC is expected to replace the aforementioned video compression standards soon. So, a comparison between VVC and its predecessor HEVC is inevitable. The most recent reference software for VVC, VTM, achieves a 33.14% bitrate reduction but an encoding runtime of 6.71 times, and a decoding runtime of 1.03 times slower than HEVC reference software HM [32].

C. AVC, HEVC vs EVC

Another video codec that is expected to be finalized within 2020 is EVC. ETM is the test model of EVC and it was compared with both JM and HM, in order to evaluate its performance against AVC and HEVC. As depicted in Table I, EVC offers an average bitrate saving of 31.4% compared to AVC, but it needs more time for the encoding and the decoding process. Furthermore, EVC against HEVC provides average data rate savings of 26.5% and still needs much more time in order to complete the process, as shown in Table II [33].

TABLE I. EVC VS AVC

Anchor: ETM				
Simulation Tool	Resolution	Bitrate Savings	Encoding Time	Decoding Time
JM	UHD	-38%	46%	117%
	HD	-24.8%	39%	114%
	Average	-31.4%	42%	116%

TABLE II. EVC VS HEVC

Anchor: ETM				
Simulation Tool	Resolution	Bitrate Savings	Encoding Time	Decoding Time
HM	UHD	-30%	413%	167%
	HD	-23.1%	491%	142%
	Average	-26.5%	450%	154%

D. AVC, HEVC, VVC vs LCEVC

In parallel with EVC, MPEG is deploying the LCEVC, which runs as an enhancement of any other codec, in order to reduce its complexity. As depicted in Table III, LCEVC is significantly faster to encode than full resolution versions of AVC, HEVC and VVC. Specifically, LCEVC-AVC provides 2.4 times faster encoding speed that AVC, LCEVC-HEVC is 2.7 times faster than HEVC and LCEVC is 4.8 times faster than VVC. Moreover, LCEVC tests show an average bandwidth saving of 45% and 34% respectively as compared to AVC and HEVC [34].

TABLE III. LCEVC ENCODING PERFORMANCE

Simulation Tool	Encoding Time (sec)	Encoding Speed
AVC	74	-
LCEVC-AVC	31	2.4×
HEVC	736	-
LCEVC-HEVC	273	2.7×
VVC	1412882	-
LCEVC-VVC	294350	4.8×

E. AVC vs HEVC vs VP9 vs AV1

A comparison of the encoding time of AVC, HEVC, VP9 and AV1 standards using 4 different videos with 5 sec duration each one, shows their potential under real-time transmission. Implementing similar parameters in x264, x265, libvpx and AV1 tools the encoding time for the AV1 codec is by far the slowest. The AV1 encode took 147 times longer than the actual video duration. This measurement corresponds to about 12 minutes of encoding. The rest of the codecs show 58 times longer than real-time for HEVC, 45 times for VP9 and only 4 times for AVC, as shown in Table IV [35].

Regarding the decoding speed, AV1 decoded at 0.66 times of real-time, with HEVC at 8 times, VP9 at 10.5 times and AVC at 14 times, as depicted in Table IV. However, for these 4 video testing clips AV1 saved roughly 24% the data rate of HEVC while delivering the same quality, 33% from VP9, and 49% from AVC [36]

TABLE IV. ENCODING TIME FOR THE RESPECTIVE TECHNOLOGIES

Simulation Tool	Encoding Time (s)	Decoding Time (s)
AV1	736	3
x265	289	40
libvpx	226	53
x264	18	70

F. AVC vs XVC

Finally, the XVC decoder has been tested on different mobile devices to determine decoding capabilities. Most smartphones with at least four cores can run XVC software decoding of HD video in real-time. During the test, a Samsung Galaxy 8+ was able to decode 720p video with H.264 at 800 kbps for 8 hours 45 minutes and the XVC codec video at similar quality, at around 400 kbps for 7 hours [37].

VI. CONCLUSIONS AND FUTURE WORK

A comparison of video coding standards in terms of encoding and decoding time was presented, in order to evaluate their performance on real-time conditions. The comparison is based on the latest literature and includes both launched and non-launched, yet, video codecs. Experimental results show that each new video codec offers better video compression that its predecessor, but much complexity for its implementation. So, a real-time video transmission becomes impractical, due to the increased encoding times. The forthcoming video compression algorithms should focus to produce excellent image quality with low complexity, in order to reduce the encoding and decoding time. Future work may include experimental tests including simultaneous transmission of video, audio and haptic data over mobile wireless networks.

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