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The efficiency of HEVC/H.265, AV1, and VVC/H.266 in Terms of Performance Compression and Video Content

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ABSTRACT

In recent times, there has been a significant focus on digital compression. The purpose of this study is to undertake a comparative evaluation and examination of the efficacy of the latest standards, namely HEVC, AVI, and its successor VVC. The determination of which standard to utilize relies heavily on factors such as the inherent characteristics of the video, its functionalities, quantization parameters, image quality, as well as the size and video content, this latter, is often classified by spatio-temporal complexity using spatial and temporal information (SI/TI). In reality, they are mostly used for original video sources. The efficiency of encoding original video sources is unknown. The results show that each standard has characteristics that sometimes make it superior to others. In addition, We observe that By understanding how SI and TI affect encoding efficiency, we will be able to better optimize the encoding process and reduce the amount of data that needs to be stored, transmitted, and processed. This could help to reduce the amount of time and energy required to encode video content, as well as reduce the amount of storage space needed to store it. Compared to H.265/HEVC, AV1 is more efficient at compressing HD and FHD video, and more efficient for SD video. In addition, experiments show that VVC/H.266 has higher compression efficiency.

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1. INTRODUCTION

Nowadays, video is considered one of the things that are taken for granted in reality, as it has come to dominate all aspects of the display of moving pictures. Video is one of the most important media for communications, entertainment, and many other applications [1].

We might spend most of our days watching videos in front of the Internet, from TIk TOK videos to YouTube to facebook watch. In the midst of this development, we ask today about video compression technologies that help us transfer these videos to you to view [1-2]. The evolution of new digital techniques and technologies has led to the digitization of this type of content and has allowed us to have high-quality and high-definition videos. The video compression format is a content representation format for storing or transmitting digital video content (such as in a data file or bitstream). It usually uses the standard video compression algorithm. The idea of digital video compression is intended to obtain a smaller file size for the video, making the required field for broadcasting smaller without reducing its size, and with the least possible impact on the quality of what is disf played. However, such distribution under IP is fraught with many difficulties and disadvantages [2-4] [5].

Firstly, video quality is defined by the lossy compression given by the encoder causes source distortion and associated distortion on the images that make up the video; these have a direct impact on the user's perception of the video. In fact, since the late 1970s, video resolution has consistently escalated from several hundred kilopixels per frame to numerous tens of megapixels per frame, exemplified by formats such as High Definition (HD) or Full HD, etc. This advancement has been accompanied by an overwhelming volume of digital data that necessitates processing, transmission, and storage across various platforms, including desktops, smartphones, tablets, and other electronic devices. Therefore, video codecs play a fundamental role in compressing video sequences with large frame sizes and high frame rates into comparatively small bit streams while maintaining an acceptable level of perceptual quality.

In addition, with the increase in Internet video streaming on popular sites like Netflix and YouTube, and the increase in camera resolution, a lot of storage space and bandwidth are required. As 4K and 8K Ultra HD content became mainstream, advanced video compression standards (also known as video codecs) emerged to provide better video quality and lower bandwidth costs. The most efficient codecs today are the HEVC/H.265 (High Efficiency Video Coding) and AOMediaVideo 1 (AV1) standards. Recently, a new video coding standard called Versatile Video Coding (VVC)/H.266 was introduced, also known as MPEG-I Part 3 or H.266[6], which improves coding efficiency by about 50% compared to H.265/HEVC.

HEVC/H.265 is a video coding standard established by the Joint Collaborative Team on Video Coding (JCT-VC). This group is formed by two international organizations specified for video coding, ITU-T Video Coding Experts Group (VCEG) and ISO/IEC Moving Picture Experts Group (MPEG).

The first draft of H.265/HEVC was released in February 2012, and the final version was released in January 2013. It offers better performance than previously used standards. The source video is compressed using the HEVC encoder. It creates and stores a compressed bitstream that can be decoded into a sequence of images using a video decoder. HEVC is similar to earlier H264/AVC and MPEG-2, but with significant improvements. A video is compatible if it meets the requirements of the compressed format and can be easily decoded. You can save HEVC videos as files, transfer them or stream them over the Internet. The main goal of HEVC is to increase compression 50% more efficient than H.264/AVC encoding [4,7-10], and Support for screen resolutions up to 8192 x 4320 and improved network transfers.

AV1 is being touted as a new web video format to replace the well-known and trusted MPEG format. The AV1 codec is a clever combination of Google's VP10, Mozilla's Daala, and Cisco's Thor [11] codecs. The codec is especially useful for video conferencing with low complexity. They all have the same goal: to develop the next generation of video codecs to make online video sharing faster, easier, and most importantly, more affordable. In 2015, everyone decided to unite under AOMedia. The AV1 codec is a product of this alliance. In particular, it's based on Google's VP9 codec, but also leverages tools and techniques from the Daala, Thor, and VP10 codecs. As of 2018, Google Chrome and Mozilla Firefox, two of the most widely used browsers in the world, support AV1 [12]. The general architecture of AV1 is similar to the HEVC approach. Implementations must balance software and hardware capabilities. Open benchmarks are possible, mostly for 1080p and 4k data. [12]

H.266/VVC, is a video codec released on July 6, 2020, by the Joint Video Experts Team (JVET). The Fraunhofer Institute developed it in cooperation with industry. It is advertised as twice the compression rate of H.265/HEVC with the same quality. VVC is suitable for Ultra HD, 4k, 8k, HDR or 360° video on future TVs and other devices [13]. Thus, it can convert large movie files. A 1-hour 1080p 24GB movie at an average speed of 25 FPS is stored and streamed at a smaller file size with less bandwidth. Fraunhofer Heinrich-Hertz said: "The use of video will continue to increase worldwide due to the leap in coding efficiency offered by H.266/VVC. Furthermore, the increased versatility of H.266/VVC makes it ideal for use in video transmission and storage, more attractive in related broader applications" [13]. This means that the H.266 standard will be the most usable standard in the world due to its efficient transmission and minimal storage [13].

In recent times, Spatial Information (SI) and Temporal Information (TI) serve as two metrics to quantify the complexity of a video source in terms of its spatiotemporal (S/T) characteristics [14]. The Video Quality Experts Group has made a concerted effort to reexamine the subject matter of SI and TI and deliberate their suitability for various use cases, transcending the mere demonstration of dataset coverage within a specific S/T complexity range. Especially for different types of video definition corresponds to the number of horizontal and vertical pixels that form the image like SD, HD, Full HD. To assess the necessary bandwidth, it is imperative to ascertain the appropriate dimensions for your IPTV service. This entails establishing precise definitions for both SD and HD television.

In this paper, a comparison of current digital video compression methods and standards, and how it's possible to significantly reduce video size without major loss of quality or detail. We will compare these standards, HEVC, AV1 and VVC, making comparisons in terms of video content like SI/TI, bitrates, and encoding quality. PSNR (Peak Signal-to-Noise Ratio), VMAF (Video Multi-Method Assessment Fusion) and QP (Quantization Parameter) are used to measure video quality. The analysis of SI/TI for video with a bit depth of 10 has been conducted, with due consideration given to the impact of encoder selection and resolution scaling on the outcomes for different video difinition. For example, in IPTV service, it is necessary to set the video definitions of SD, HD, and full HD TVs.

2. PROPOSED ARCHITECTURE

In this paper, the utilization of various video content types and distinct QP values is employed for emulating the impact of the HEVC, AV1, and VVC encoding process in different test scenarios. JCT-VC [15][16] recommends encoding video sequences using the full QP range (13, 17, 22, 27, 32, and 40). QP regulates the rate/size of the content and therefore the level of distortion. In effect, for a small rate, the QP should be more high and the more visible artifacts of the disturbance. On the contrary, small QP values limit the distortion but increase the content rate/size. Additionally, the QP has a direct influence on the visual quality and compresses videos[17].

We used video compression standards:

- HEVC / H.265: x265 codec (FFmpeg [18].).
- AV1: AOM codec (Alliance for Open Media).
- VVC: VTM reference software codec (Versatile video coding Test Model).

These encoders require an uncompressed (raw) YUV video file and a specific configuration file. The video compression standards HEVC, AV1, and VVC test conditions aim to obtain various objective metrics, such as PSNR, VMAF, etc.

PSNR (Peak signal-to-noise ratio) represents the ratio between the maximum possible power of a signal and the power of the noise that affects the accuracy of its representation [19]. The PSNR is typically measured in decibels (dB). It provides a rough estimate of how well humans perceive the quality of a reconstructed signal. Generally, a higher PSNR indicates better quality in image compression.

The PSNR is calculated by comparing the mean square error (MSE) to the maximum possible value of luminance (usually 255 for an 8-bit value).

$$MSE = \frac{\sum_{I=1}^{M}\sum_{i=1}^{N}[(f(i,j)-F(i,j)]^2}{M.N} \quad (1)$$

$$PSNR = 20.\log_{10}\left(\frac{255}{\sqrt{MSE}}\right) \quad (2)$$

This calculation involves the original signal at a specific pixel (i, j), the reconstructed signal at the same pixel (i, j), and the size of the image (M x N). Despite the development of various objective models for assessing video quality over the past two decades, PSNR remains the most widely used method for comparing the quality of frames.

Netflix specifically developed VMAF (Video Multimethod Assessment Fusion) with the primary goal of establishing a strong correlation with subjective MOS scores. Utilizing advanced machine learning techniques, a substantial collection of MOS scores was employed as a reference point to effectively train a model for estimating video quality. VMAF represents a comprehensive full-reference perceptual video quality metric, which seeks to closely approximate the human perception of video quality. This metric places significant emphasis on the degradation of quality resulting from compression and rescaling processes. VMAF, to evaluate the perceived quality score, employs the calculation of scores generated by various quality assessment algorithms and combines them utilizing a support vector machine (SVM)[20] [21].

At present, three image fidelity metrics, along with a temporal signal, have been selected as the features utilized within the SVM:

- Mean Co-Located Pixel Difference (MCPD),
- Detail Loss Metric (DLM),
- Visual Information Fidelity (VIF) [13] [20].

The expected scenario is shown in Figure 1.

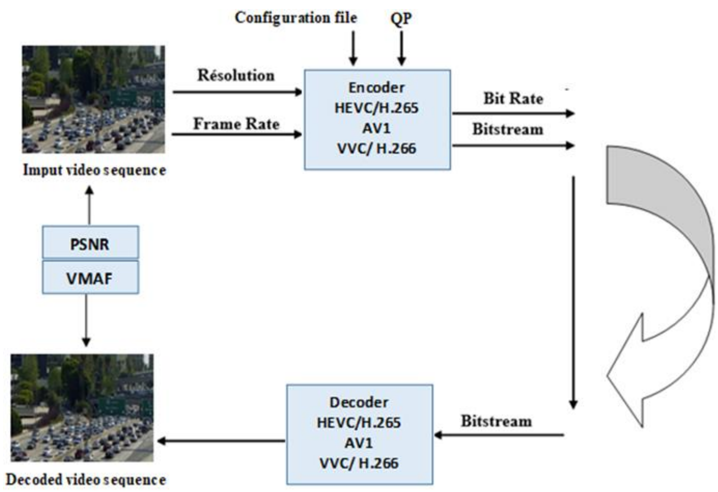

Figure 1. Scheme assessment of different video sequence.

The video quality assessment method is divided into four steps:

1. Selection of reference video (YUV).
2. Video compression standards (HEVC/AV1/VCC).
3. Refer to video decompression.
4. Evaluate the video sequence.

We used six videos with distinct characteristics. Table 1 shows the video sequences parameters and Figure 2 presents the video that were used in the experiments.

Table 1. Video sequences

Sequence	Format	Resolution	FPS	Frames
Crowdrun	SD	704x576	25	250
Harbour	SD	704x576	30	300
DuckStakeoff	SD	704x576	25	250
Basketball drill	SD	832x480	50	500
Johhny	HD	1280x720	60	600
Traffic	Full HD	2560x1600	30	150


Traffic Johnny Basketball drill Crowdrun Harbour Duckstakeoff

Figure 2. Illustrations of video sequences.

SI and TI are used to evaluate video content diversity using selected test sequences, which is recommended by the ITU. ITU-T Rec. P.910 [22] [23] defines SI of an entire sequence in accordance with Equation 3 as:

$$SI = max_{time}\{std_{space}[Sobel\,(F_n)]\}, \quad (3)$$

The frame n, denoted as Fn, serves as the basis for our analysis. The gradient magnitude of the 3 × 3 Sobel operator, known as Sobel, is then calculated by considering both the vertical and horizontal components of the image. Following this, the standard deviation over space is computed for each frame. The term TI represents the maximum value obtained by considering the standard deviation of the difference between the pixel values of consecutive frames over time. For a more comprehensive understanding, we recommend referring to ITU-T Rec. P.910 [24]. Furthermore, machine-learning based video quality metrics have also incorporated the features SI and TI.

It is worth noting that the SI and TI indices of the selected video content range from relatively small to relatively large, SI increases with the amount of spatial detail, while TI increases with the amount of motion in the sequence.

Coordinates SI and TI in Figure 3 represent the six test video sequences. Crowdrun, Duckstakeoff, Basketball Drill, and Harbour in SD (standard definition), Johnny in HD, and traffic video sequence in UHD.

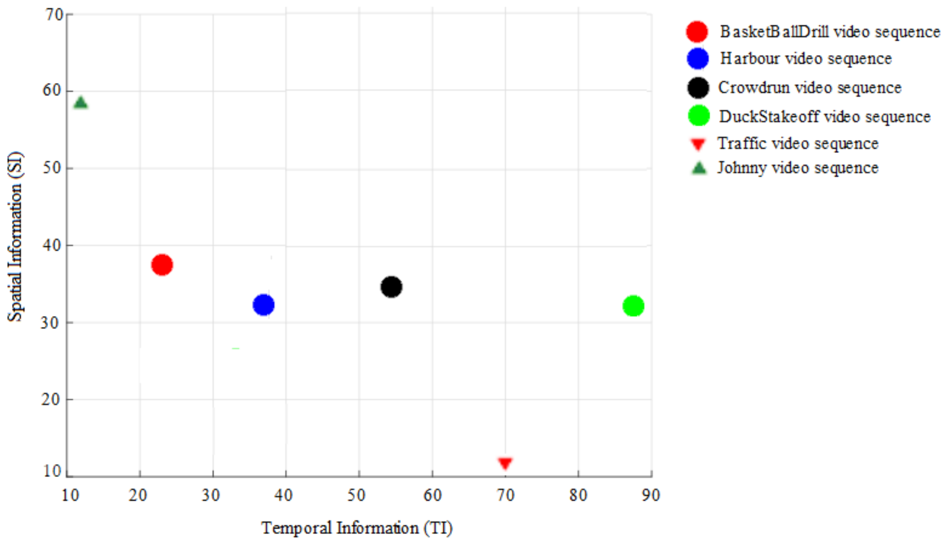

Figure 3. Perceptual spatial information (SI) and perceptual temporal information (TI)

It is observed that video has the highest SI value, indicating that it is the highest in terms of spatial detail, whereas Traffic sequence has the lowest SI, despite having a higher TI, indicating that it is the highest in terms of motion, with a few regular spatial details. The videos "Johnny" and "BasketballDrill" have the highest SI values, which means they have the highest amount of spatial detail. In addition, the DuckStakeoff in SD format is the highest in terms of motion.

Figure 1 shows the process of encoding a video signal. A raw video is acquired by a recording device and converted by the encoder into a bitstream composed of binary symbols (bits). The size of the bitstream for a given time interval is called bitrate [bits/s]. The rate is often expressed in bits per second (the amount of digital data transmitted per second). The decoder then processes the bitstream, and the decoded video signal is displayed on the user's screen. The quality of the decoded video is evaluated either by a distortion metric, a rate-distortion metric, or by a subjective quality metric. [13].

The distortion measures the distance between the raw video signal and the decoded video signal, and hence requires the raw video signal as a reference to calculate. The objective parameters PSNR and VMAF are most commonly used.

3. RESULTS AND DISCUSSION

Two-pass or multi-pass rate control encoding [25] is a commonly employed technique in video encoding to enhance the efficiency and excellence of the resultant bitstream. This methodology involves the execution of the encoding process multiple times, whereby each pass modifies the encoding parameters in accordance with the outcomes of the prior pass. In the initial pass, the encoder examines the input video and generates a statistical synopsis of the content in the form of a log file. This log file is then utilized to inform the encoding decisions in the subsequent pass. The summary encapsulates various facets, such as the distribution of colors, edges, and motion vectors within the video, as well as the relative significance of distinct sections of the frame. In subsequent passes, this log file is employed to precisely adjust the encoding parameters in order to attain the desired equilibrium between file size and video quality. Consequently, it adapts the quantization level of different segments of the frame based on their intricacy and significance.

To conduct comparative studies involving two-pass encoding, a selection of software implementations was made. This selection included x265 for HEVC, AOM for AV1, as well as VTM for VVC. The criteria for choosing these software implementations were their extensive usage and popularity, as well as their advanced functionalities and capabilities. The encoder configurations are fully described in Table 2.

Table 2. The encoder’s configurations

Norms	Codec	Parametrs
H.265/HEVC	X265 (FFmpeg) v2.8	Similar to HM configuration file -profile main -tune psnr -ref 4 ±merange 64 -keyint -1 -min-keyint 99999 ±bframes 0 -b-adapt 0 -no-b-pyramid -no-weightb -aq-mode 0 -no-cutree -QP $QP -tskip-fast -tskip -rect -amp -pass $P
AV1	AOM v1.0.0	-cpu-used=0 ±threads=0 ±profile=0 ±lag-in-frames=0 ±min-q=$QP ±max-q=$QP -auto-alt-ref=1 ±passes=$P ±kf-max-dist=9999 ±kf-min-dist=9999 ±drop-frame=0 -static-thresh=0 ±arnr-maxframes=7 ±arnr-strength=5 ±sharpness=0 undershootpct=100- overshoot-pct=100 ±frame-parallel=0 ±tile-columns=0 ±end-usage=q ±cqlevel=$QP-tune=psnr
H.266/VVC	VTM v3.2	Default low-delay P configuration file.

Low delay mode [26] is a specific configuration or mode used for prediction when encoding video using a video codec. The aim is to minimize the time between image capture and display, a feature that is particularly relevant in real-time applications such as video surveillance. In our study, we chose to predict the structure using IPPP. It should be noted that, to ensure a fair comparison, we stuck to a configuration similar to that described in Table. II for all software implementations.

III.1 HEVC, AV1, and VVC Performance

A. In terms of file size

The graphs below illustrate the size of three distinct types of video sequences, Traffic, Johnny and Basketball Drill, as well as the results produced after compressing them at different QP levels using three encoding technologies in succession: HEVC, AV1, and VVC.

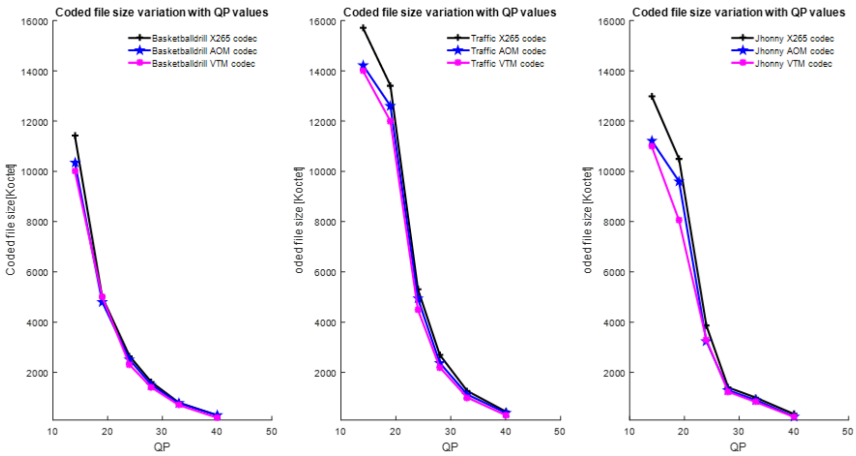

Figure 4. The graphs for Three video sequences compressed with HEVC, AV1, and VVC file size = F(QP).

B.In terms of PSNR and VMAF

The relationship between QP, PSNR and VMAF is important for whatever platform used for encoding. Using HEVC and AV1 compression standards, as well as VVC for video compression, as shown in Figures 5,6 and 7.

Furthermore, we note that for Duckstakeoff video sequence, HEVC is the best standard, AV1 and VVC have almost the same value, i.e. have the same efficiency. This was followed by the traffic video sequence, which has the same comment as Duckstakeoff. Unlike other video (Harbour, Crowdrun, Basketball Drill, and Johnny), AV1 and VVC are two standards that are a fraction above HEVC [1, 27]. From previous comments, we can say that although the HEVC standard is up to date, its performance sometimes makes it better than AV1 and VVC (table III). Among these performances, HEVC achieves better results in encoding videos with high TI values, such as duckstakeoff videos, whose Temporal Information (TI) is equal to 88, as shown in Figure.3, which is the maximum value, reported by video to others. This means that videos with high temporal detail are best encoded using HEVC. This improvement in coding results in an increase in the duration it takes to encode. Contrary to the AV1 and VVC standards, better results are obtained when encoding video with high SI values, like Basketball Drill ((SI) is equal to 40), and Johnny ((SI) is equal to 58) video sequences, which means is better to use both AV1 and VVC standards to encode videos that have a higher SI and TI, with priority to VVC. Furthermore, we observe that the overall benefits of codecs are attributed to the cost savings attained in low-motion scenes.

Table 3. PSNR values for Video sequences compressed with HEVC, AV1, and VVC.

PSNR [dB]						
			HEVC			
QP	14	19	24	28	33	40
Crowdrun	40.34	35.96	33.57	31.94	29.79	26.49
Harbour	44.04	41.20	38.51	36.46	34.02	30.41
DuckStakeoff	39.55	34.52	31.00	29.05	27.03	24.15
Basketball drill	44.68	40.95	38.80	36.50	33.77	26.59
Johhny	45.60	43.07	41.00	39.37	36.12	31.55
Traffic	45.10	42.74	40.66	38.85	36.31	32.36
			AV1			
QP	14	19	24	28	33	40
Crowdrun	38.52	35.75	33.28	31.51	29.38	27.08
Harbour	47.39	43.99	41.18	39.09	36.58	32.96
DuckStakeoff	35.84	32.52	30.80	28.92	27.27	25.75
Basketball drill	46.29	43.78	41.12	39.09	36.47	32.87
Johhny	45.68	43.07	41.17	39.55	37.22	33.55
Traffic	45.84	43.57	41.29	39.13	36.30	32.02
			VVC			
QP	14	19	24	28	33	40
Crowdrun	39.00	35.80	34.00	31.90	29.50	28.20
Harbour	47.98	44.70	41.90	39.70	37.50	33.20
DuckStakeoff	36.00	33.80	31.00	28.50	27.50	26.20
Basketball drill	46.80	44.00	41.85	40.50	37.00	33.00
Johhny	46.90	44.50	42.00	40.90	37.54	33.50
Traffic	46.00	43.80	42.00	39.50	36.50	33.20

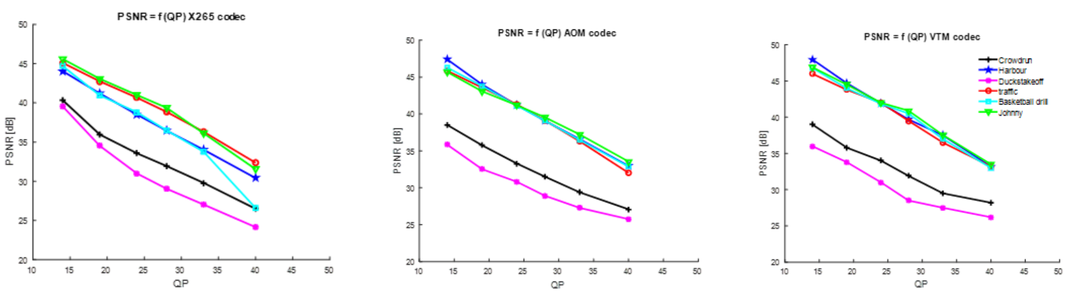

Figure 5. Video sequences compressed with HEVC, AV1, VVC

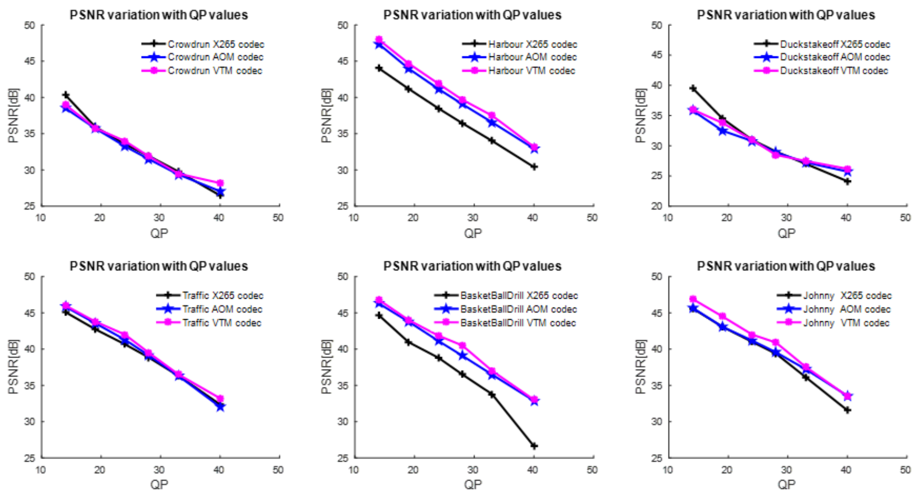

Figure 6. Graphs for different video sequences compressed with HEVC, AV1, and VVC (PSNR = F(QP)).

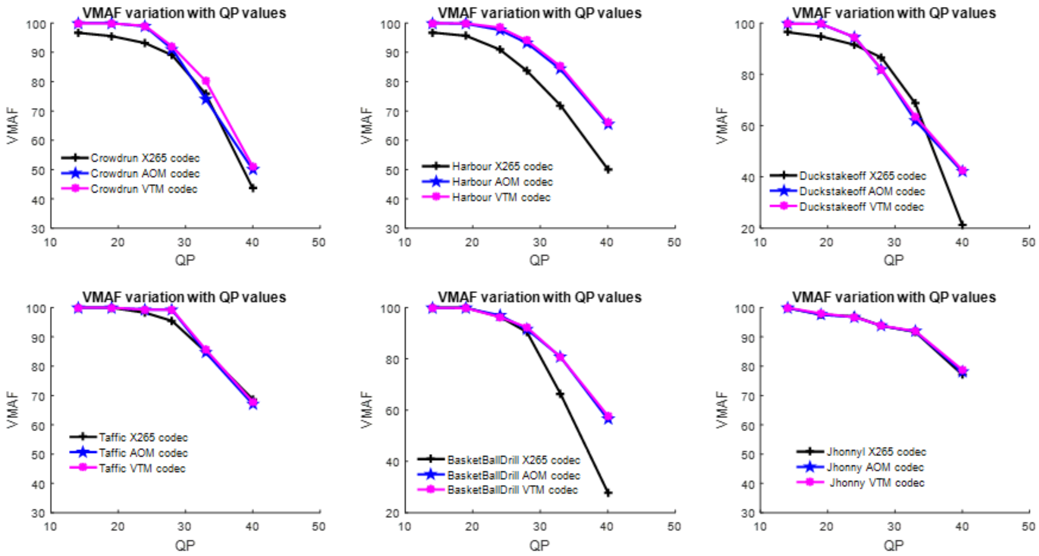

Figure 7. Graphs for different video sequences compressed with HEVC, AV1, and VVC (VMAF = F(QP

III.2 Comparison of PSNR according to Bitrate

Figure 8 and Figure 9 show the results of PSNR and VMAF methods. All figures show three video sequences encoded in SD (basketball drill), HD (Johnny), and FHD (traffic), knowing this and after extracting the results from Figure 6,

- SI equals 39 for SD (basketball drill), 58 for HD (Johnny), and 14 for FHD (traffic);
- TI equals 23 for SD (basketball drill), 10 for HD (Johnny), and TI = 70 for FHD (traffic).

As can be seen from Figures 5 and 6, video sequences with higher TI have lower PSNR values because their encoding is more complex. The videos Johnny (HD) and BasketballDrill (SD) have higher PSNR values for all three standards, also HEVC, AV1 and VVC; because of their reduced spatial SI information. Based on the resolution of the video sequence (width × height), BasketballDrill performs better than Johnny.

On the other hand, according to Figure 9, video sequences with higher SI have higher VMAF values, [15]. Due to the fact that VMAF gives little accurate information for videos with high TI and with the three standards. It can be observed that when using the same QP for video sequences, sequences with fast movement activities and high complexity (video content, frame size, frame rate, etc) tend to provide higher bitrates.

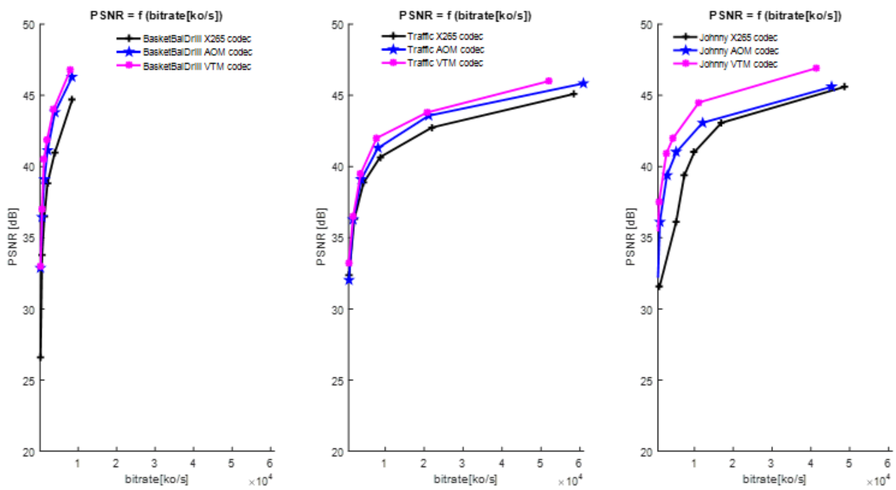

Figure 8. PSNR values as a function of Bitrate, for Basketball Drill Traffic and Johnny, compressed with HEVC, AV1 and VVC.

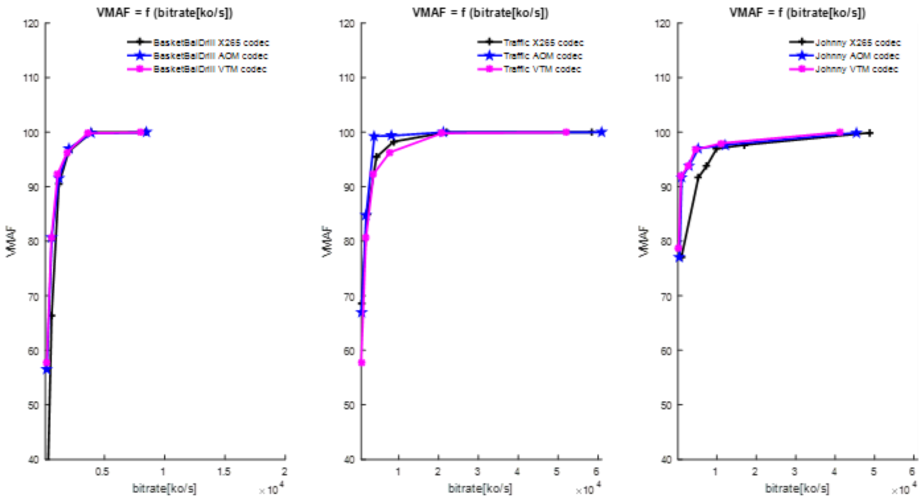

Figure 9. VMAF values as a function of Bitrate, for Basketball Drill Traffic and Johnny, compressed with HEVC, AV1 and VVC.

However, Basketball drill video achieves greater PSNR according to Bitrate in all three standards due to its unique characteristics (high spatial information and low temporal information as well as her difinition). Due to their complicated temporal characteristic, traffic video sequence produce the greatest VMAF values as a function of Bitrate in all three standards.

The comparison results show that the higher the QP value, the smaller the PSNR, as shown in the figures below. We also noticed that in harbour and basketball drill videos, the VVC standard outperformed the first two AV1 and HEVC, followed by AV1, yielding nearly identical results to those seen on VVC, then implemented in HEVC, but crowdrun and traffic videos results are almost identical. In Duckstakeoff, we found that HEVC outperformed each of the first two criteria in terms of QP score levels (14 and 19) and QP scores (from 24 to 36), and we saw nearly identical results for the three criteria and a value of 40. Then, we see that both standards VVC and AV1 lead to better quality. The graphes clearly show that VVC and AV1 generally perform significantly better than HEVC. The higher the resolution, the more important the difference seems to be.The Harbour video for example when QP =33; In VVC (PSNR=37.5dB) is higher than that of AV1 (PSNR=36.58dB) and HEVC (PSNR=34.02dB). Another example is the Traffic video, QP= 28; in standard VVC (PSNR = 39.5 dB), AV1 (PSNR = 39.1 dB) and HEVC (PSR = 38.85 dB). It is noted in this case that VVC and AV1 are the best and most similar encoding standards. We also note that HEVC has advantages over the other two standards VVC and AV1, for example in the case of video Duckstakeoff at specific values of QP.

To ensure a detailed and comprehensive comparison, we identify key metrics such as objective video quality. Selecting relevant papers with similar environments and calculating similar metrics under identical system conditions is important. We have chosen specific research papers to compare [1, 28-32]. In addition, these codecs have a notable impact on the compression rate and the visual quality of videos compared with H.264/AVC [7].

As a result, we can conclude that the perception of quality is not directly/linearly related to video motion. In addition, videos with different motion coefficients have different meaningful metrics. Therefore, the impact of video motion on perceived quality for different values of transmission impairments is presented [28].

We find that VVC outperforms both AV1 and HEVC standard. The two videos Johnny and Basketball Drill achieve lowest bitrate with higher PSNR. As for VMAF, we notice a very important change for the video traffic so that it is a much lower bitrate compared to the result of PSNR. Ultimately, we conclude that each standard has characteristics that sometimes make it superior to others [29-31], and this is due to the nature of video and its functionality.

4 CONCLUSIONS AND FUTURE WORK

This article conducts an analysis to examine the impact of various Video encoding factors such as video codec, video content type and different QP values on perceived video quality. The choice of compression parameters, including temporal and spatial activity, frame size, and frame rate, is a key factor in video encoding. Video size and video content type with different QP values mainly affect video quality. This method can achieve better results in PSNR and VMAF. There is undoubtedly a need for more comprehensive experiments covering the entire video resolution ladder (from low resolution to full HD).

Additionally, our tests show that AV1 compresses HD and FHD video more efficiently than HEVC/H.265. In addition, experiments show that VVC has higher compression efficiency than HEVC under the same perceived quality. Therefore, VVC and AV1 have very similar results and preferences to the high-definition HD and FHD videos widely used today. Therefore, VVC and AV1 are likely to largely replace H.265/HEVC in many networks in the near future.

As future work, end-to-end video quality over hybrid networks will be designed and encoded using HEVC, AV1 and VVC encoder schemes, which largely depends on the type of video content. Additionally, Quality of Service (QoS) is also taken into consideration when sending video encodings using different codecs on various networks (4G, 5G, etc). In addition to new applications such as 360° video encoding.

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