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Performance Comparison of HEVC and H.264/AVC Standards in Broadcasting Environments

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Abstract

High Efficiency Video Coding (HEVC) is the most recent video codec standard of the ITU-T Video Coding Experts Group and the ISO/IEC Moving Picture Experts Group. The main goal of this newly introduced standard is for catering to high-resolution video in low bandwidth environments with a higher compression ratio. This paper provides a performance comparison between HEVC and H.264/AVC video compression standards in terms of objective quality, delay, and complexity in the broadcasting environment. The experimental investigation was carried out using six test sequences in the random access configuration of the HEVC test model (HM), the HEVC reference software. This was also carried out in similar configuration settings of the Joint Scalable Video Module (JSVM), the official scalable H.264/AVC reference implementation, running on a single layer mode. According to the results obtained, the HM achieves more than double the compression ratio compared to that of JSVM and delivers the same video quality at half the bitrate. Yet, the HM encodes two times slower (at most) than JSVM. Hence, it can be concluded that the application scenarios of HM and JSVM should be judiciously selected considering the availability of system resources. For instance, HM is not suitable for low delay applications, but it can be used effectively in low bandwidth environments.

Keywords

Complexity, Compression Efficiency, HEVC, H.264/AVC, Latency

1. Introduction

With the advancements in the video capturing and recording architectures, the demand for high quality video services has increased. This imposes an immense challenge on today's transmission networks due to a scarcity of resources. It demands a coding efficiency that is beyond the capacity of existing video coding standards.

H.264 Advanced Video Coding (H.264/AVC) is the most popular video compressing standard at present [1]. It is a mature video compression standard, where the final drafting of the first version was completed in May 2003 [2]. This technology is widely used in streaming Internet sources, web application software, and many others. It was reported that the bitrate saving of H.264 was nearly double to that of the MPEG-2 standard when applied to a high-definition television (HDTV) broadcast and a digital cinema format, which uses lossless coding [3].

For example, H.264 provides the same digital satellite TV quality at 1.5 Mbps in comparison to the

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MPEG-2 codec, which achieves the same quality at around 3.5 Mbps [1]. In a broader sense it has three profiles, namely; a baseline profile, main profile, and high profile for 2D video coding, and these three key profiles can be further configured to obtain 17 sub-profiles [1]. The Joint Scalable Video Model (JSVM) codec is the reference software for the H.264/AVC standard, where the scalability is allowed [4].

Many services in today's video communication market employ the H.264 in their video-related applications over the older video compressing standards. However, with the diversification of video related services, the growing popularity of high-definition (HD) video, mobile computing, and the outcropping beyond HD formats have created the requirement for a more advanced video compression standard to cater to the limited bandwidth associated with the transmission and storage environments. The main focus of the emerging video compression standards is to provide high-resolution videos in low bandwidth environments. As a solution for the above requirement, the Joint Collaborative Team on Video Coding (JCT-VC), which is a joint partnership of the ITU-T Video Coding Experts Group (VCEG) and the ISO/IEC Moving Picture Experts Group (MPEG) standardization organizations [5], have proposed the high-efficiency video coding (HEVC) standard. The first edition of the HEVC standard was finalized in January 2013 [6]. It was designed to cater to almost all existing application scenarios of the H.264/AVC video standard. At the same time, it mainly focuses on improved features, such as increasing bitrate saving, handling videos with higher resolutions, and parallel processing architectures. According to Ohm et al. [7] HEVC is aimed at a 50% bitrate reduction that is relative to the H.264 standard. The HEVC reference codec is called the HEVC test model (HM) [8]. It includes four pre-defined coding structures, namely: all intra, low delay P, low delay BL, and random access (RA). In the RA configuration, intra coded pictures are inserted at a regular interval to provide clean random access (CRA) to the video stream.

There are a few papers that compare the performance of these two standards, HEVC and H.264/AVC. For instance, Nightingale et al. [9] evaluate the performance of the HEVC standard in loss-prone networks, Zeng et al. [10] present a comparison between the coding gain predicted by objective video quality assessment models for the two standards, Vanne et al. [11] analyze the rate distortion complexity of the HEVC codec, Milicevic and Bojkovic [12] investigate the general performance of HEVC, and the implementation and complexity analysis for HEVC is presented by Bossen et al. [13] and Correa et al. [14].

This paper presents the performance comparison between H.264/AVC and HEVC video compression standards in the broadcasting environment, where random access is available, based on the objective quality, bitrate saving, and latency measurement. The authors hope that this paper will fill the gap created due to the lack of literature on this topic. The rest of this paper is organized as follows: Section 2 provides a very brief comparison between the two video coding standards, while Section 3 outlines the experimental setup. Results and analyses are given in Section 4 and Section 5 concludes the paper.

2. Brief Comparison between HEVC and H.264 Standards

The HEVC standard is designed to take over almost all the applications of older video coding standards. In particular, major emphasis is placed on the two key features; high-resolution video and parallel processing. When comparing these two major video compression standards in terms of the technological approach, it can be seen that the HEVC standard follows enhanced state of the art video coding techniques as compared to H.264. At the same time, most of the syntaxes used by both standards follow a similar format. Some of the key structural similarities and differences between the two coding standards can be summarized as below (for a more in-depth description, refer to [15,16]).

Intra prediction is one of the most important mechanisms of video compression. Both HEVC and H.264 use intra prediction, but HEVC uses over 35 directions and H.264 only uses nine prediction directions, as illustrated in Fig. 1. This contributes immensely to the high compression efficiency of the intra frame compression of the HEVC standard. It does so by increasing the potential reference blocks for the block matching algorithm.

Furthermore, both standards use coding tree blocks (CTBs). Specifically, H.264 uses macro blocks (MB) with a maximum size of 16 × 16 pixels and HEVC uses the quadtree coding structure as a CTB, with a maximum size of 64 × 64 pixels. The quadtree structure, illustrated in Fig. 2, is well known as a pruning based algorithm and it works more efficiently with larger block sizes, when encoding larger frame sizes, like 4 K.

Another major improvement of HEVC compared to H.264 is in regards to motion prediction techniques. The H.264 uses the Motion Vector Prediction (MVP) approach, whereas, HEVC uses the Advanced Motion Vector Prediction (AMVP) method, where several of the most probable candidate vectors are estimated. Furthermore, the direct mode and skip mode estimation techniques of HEVC are better than those of the H.264 standard.

One of the focus points of HEVC is the introduction of parallel processing. Although H.264/AVC attempts to address parallel processing through slices, which have been introduced as an error resilience mean, it faces several problems in terms of coding loss and real time performance. The HEVC standard approaches parallelization through tiles and wavefront parallel processing (WPP). Tiles, which are rectangle regions of the picture, are independently decodable and hence, allow for parallelism. WPP creates slices with rows of CTUS, which can be decoded in parallel with a lot less dependency and without incurring a high coding loss.

One of the minor differences between the two standards is the resolution levels that are supported. HEVC supports a vast variety of resolution levels that range from 176 × 144 to 8,192 × 4,320 pixel levels, whereas, the H.264 standard only recognizes resolutions up to 4,096 × 2,160 pixel levels.

Some of the high level syntaxes of the HEVC standard are similar to that of H.264/AVC. For instance, both systems use Sequence Parameter Set (SPS), Picture Parameter Set (PPS), Network Abstraction Layer (NAL), Supplemental Enhancement Information (SEI) metadata, and Video Usability Information (VUI) metadata.

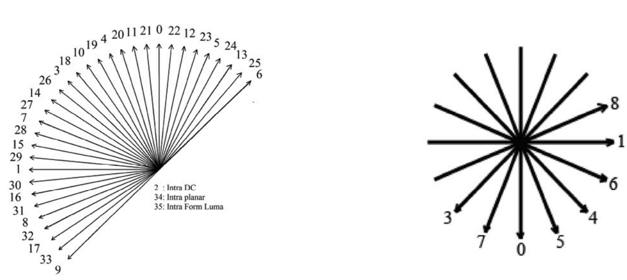

Fig. 1. Comparison between H.264 Advanced Video Coding (H.264/AVC) and High Efficiency Video Coding (HEVC) intra prediction directions.

The aim of this study is to compare the performance differences between the newly introduced HEVC standard and the matured H.264 standard in terms of bit savings, latency, and delay in broadcasting environment. We hope that the results presented in this paper will help in the future development of HEVC. Also, our findings can be employed when selecting the most suitable codec for different applications with respect to quality, real time usage, and memory constraints.

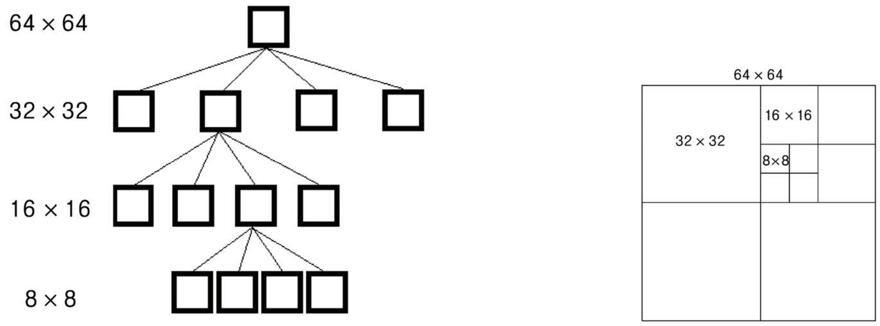

Fig. 2. The quadtree coding structure of High Efficiency Video Coding (HEVC) standard.

3. Experimental Setup

As stated in Section 2, the HEVC standard introduces many coding tools to improve overall coding efficiency. However, these techniques increase the complexity of the encoder as well. The research presented here has been carried out to evaluate the performance of the HEVC standard compared to the H.264 standard in the broadcasting environment where random access to the streaming is facilitated. For the experiments presented in this paper, the latest available version and the stable codecs of each standard were used. The HEVC coder, HM version 10.0 [8] and scalable H.264/AVC coder, JSVM version 8.7 [4] were employed during the experimental simulations. The JSVM encoder is configured to run in a single-layer coding mode, with parameter MVCMode set to 1. When the JSVM encoder is run in a single-layer mode, an H.264/AVC compatible bit-stream is generated.

To analyze the performance of the HEVC codec, HM, in a broadcasting environment where random access to the users is facilitated, the RA configuration of the HM codec was used [13]. A subset of six video sequences was selected from the list of sequences given in common test conditions for HM [17]. These six video sequences were selected from three classes, such that two sequences from each class, namely Class B, Class C, Class D [7]. The sequences were grouped into classes based on their temporal dynamics, frame rate, bit depth, resolution, and texture characteristics. Detailed descriptions of the sequences are given in the Table 1.

Since the RA configuration of HEVC is used during encoding, the configuration settings of the JSVM were tuned to match the RA structure of the HM. All of the sequences were encoded for 100 frames. The group of picture (GOP) size was set to 8 and the intra period was set to four times the GOP size (every 32 frames) throughout all the simulations.

The performances of the two codecs were analyzed in terms of the peak signal-to-noise ratio (PSNR), bitrate (kbps), and delay introduced by the system (s) under several quantization parameter (QP) values (i.e., at QPs of 10, 15, 25, 35, and 45). The tests were carried out on an Intel Core i5-3470 CPU, 3.2 GHz, 4 GB RAM computer.

Eq. (1) was utilized to evaluate the bitrate saving achieved by the HEVC codec, while Eq. (2) was used to find the average amount of time saved by the H.264 in comparison to the HEVC codec.

$$BitSaving = \frac{\left(bitrate\,(H.264) - bitrate\,(HEVC)\right)}{bitrate\,(H.264)} \times 100 \tag{1}$$

$$TimeSaving = \frac{\left(time\,(HEVC) - time\,(H.264)\right)}{time\,(HEVC)} \times 100 \tag{2}$$

Table 1. Details of the sequences used for the simulations

Class	Sequence	Resolution (pixel)	Frame rate (fps)
D	RaceHorses	416×240	30
	BasketballPass	416×240	30
C	RaceHorses	832×480	30
	BasketballDrill	832×480	30
B	Kimono1	1920×1080	30
	ParkScene	1920×1080	30

4. Results and Discussion

This section presents the output results of the performance analysis, in terms of PSNR, bitrate, delay, and latency for the six sequences listed in Table 1. The results are summarized in Tables 2 and 3, and Figs. 3–8.

The purpose of the JSVM and the HM codec is to provide a common reference implementation of the two standards, which can be used as a test bed for research purposes. It should be noted that the codecs which are developed in the C++ environment, are not aimed at providing a real-world example of implementation of the two standards. Furthermore, the HM codec used is still in the development stage. However, the core concepts of the standard are very unlikely to undergo drastic changes. As such, most of the conclusions made in this paper will remain valid.

4.1 Rate Distortion Analysis

Fig. 3–5 depict the rate-distortion (RD) curves that were taken for the video sequences of Class B, Class C, and Class D. The results were presented for two pre-selected sequences from each of the three classes. The results were taken for QP values ranging from 10–45 at every 5-point increment. According to Fig. 3–5, it is evident that the HEVC codec provides a better bitrate savings than H.264. HEVC achieves a similar objective quality in terms of PSNR as H.264, with more than a 60% bitrate reduction on average for the RA environment. However, at lower PSNR levels the bitrate variation between the outputs of the two codecs was less prominent compared to the coding efficiency improvement seen at higher PSNR levels with the HEVC codec. This phenomenon can be further observed through the results presented in Table 2.

Table 2 summarizes the bitrate savings achieved by the HM codec in comparison to the JSVM codec at average PSNR levels of 35 dB, 40 dB, and 45 dB. According to Table 2, the improvement in the coding efficiency is much more noticeable in a high-resolution video. This clearly illustrates that the HM codec satisfies one of the key design goals of HEVC standard, which is to optimize the compression ratio at higher resolutions with a lower bitrate than videos with lower resolutions.

In short, the coding efficiency improvement of HEVC is due to the advance coding tools employed in the HEVC standard, as stated in Section 2. Furthermore, the percentage of bitrate savings decreased with the increase in PSNR. This is because, as the PSNR increased, the QP used decreased and the amount of residual data transmitted increased. Although the HEVC provides advance motion search algorithms, the improvement achieved in terms of the residual coding was not that significant when compared to the enhancement attained through using the advanced motion vector coding technique at higher resolutions.

Table 2. Bitrate savings of HEVC compared to H.264/AVC for Class B, C and D sequences

Sequence	Resolution (pixel)	Bitrate saving (%)		
		35 dB	40 dB	45 dB
RaceHorses	416×240	60	54	48
BasketballPass	416×240	57	56	52
RaceHorses	832×480	62	51	39
BasketballDrill	832×480	62	61	58
Kimono1	1920×1080	91	86	74
ParkScene	1920×1080	87	84	73

HEVC=High Efficiency Video Coding, H.264/AVC= H.264 Advanced Video Coding.

4.2 Delay and Complexity Analysis

In theory, the time delay introduced by the codecs at the encoder can be used as a measure of latency and the complexity of the systems. When the rest of the simulation environment, which was comprised of a PC used for the simulations and the Central Processing Unit (CPU) load of the PC, was maintained at a constant level, the complexity of the two codecs that followed a similar encoding configuration could be compared using the number of CPU cycles used by each codec to encode the given sequence. Hence, the time taken to encode the given sequence was directly proportional to the number of CPU cycles and the clock frequency of the PC that was used. Therefore, to analyze the complexity and the latency of the encoders, the time taken to complete the encoding cycle can be utilized.

The reported time delay was gathered from the platform independent C++ codecs; HM 10, and JSVM 8.7. However, these results are only an approximation for actual hardware and software implementations.

The average delay and latency experienced by the HEVC codec in comparison to the JSVM codec is plotted in Figs. 6–8 for sequences of Classes B, C, and D, respectively, with respect to the selected PSNR values from the RD observations presented in Section 4.1. The bitrates corresponding to the selected PSNR values of each sequence can be estimated using the relevant RD curve from the graphs presented in Figs. 3–5. All video sequences exhibited a similar monotonic increase in complexity with the increase in PSNR, as seen in Figs. 6–8. However, with the increment of QP values, or decrement in the PSNR, the encoding time had reduced. This is due to the fact that the average cycle time reduces with the increment of QP, which in turn decreases the encoding delay [11].

Table 3 shows the percentage of time savings achieved by the JSVM codec over the HM codec. As seen in Table 3, it is clear that even though HEVC performs well in terms of bitrate savings, it requires a very high computational time. For instance, the delay introduced by HEVC is around 98% with reference to H.264 in low-resolution videos. Also, the computational cost of HEVC had slightly reduced with the increase in video resolution.

The main cause for this increased delay in HEVC is the low level brute force RD optimizations adopted by the codec itself [18]. Since HEVC has many more prediction modes than any other video compression standards, its dependency on rate distortion optimization is high. Also, fractional-pel search refinement in the motion compensation process and the computation of the sum of the absolute difference and other distortion estimation matrices, contributes to the computational complexity of the HEVC encoder. In other words, almost all of the advanced features of HEVC that increase the coding efficiency lead to an increase in the latency and complexity of the encoder as well. Because of this, the JSVM codec is more suitable for real time applications running on battery operated devices, which does not tolerate a considerable amount of delay and complexity in coding.

Table 3. The percentage of time saving achieved by JSVM compared to HM codec

Sequence	Resolution (pixel)	Avg. encoder delay (%)
RaceHorses	416×240	98.3
BasketballPass	416×240	97.8
RaceHorses	832×480	96.0
BasketballDrill	832×480	95.9
Kimono1	1920×1080	95.1
ParkScene	1920×1080	95.9

JSVM=Joint Scalable Video Model, HM=High Efficiency Video Coding test model.

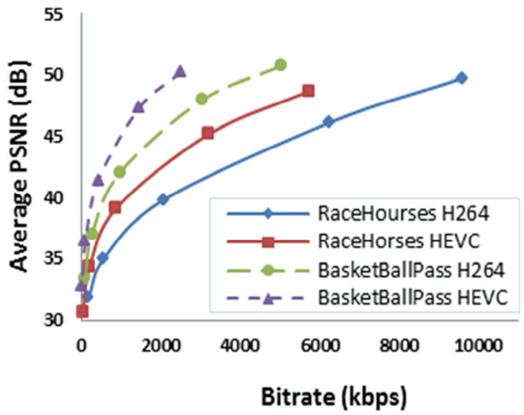

Fig. 3. Rate distortion curves for H.264 and High Efficiency Video Coding (HEVC) codecs for Class D sequences. PSNR=peak signal-to-noise ratio.

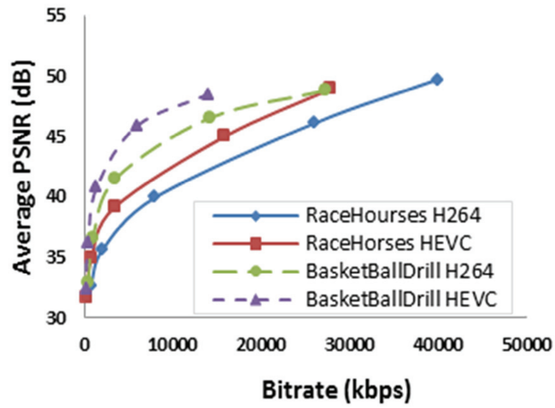

Fig. 4. Rate distortion curves for H.264 and High Efficiency Video Coding (HEVC) codecs for Class C sequences. PSNR=peak signal-to-noise ratio.

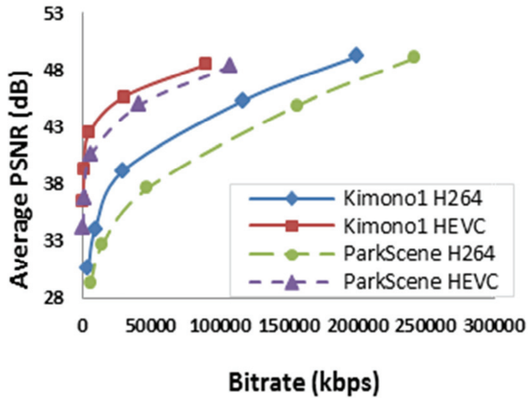

Fig. 5. Rate distortion curves for H.264 and High Efficiency Video Coding (HEVC) codecs for Class B sequences. PSNR=peak signal-to-noise ratio.

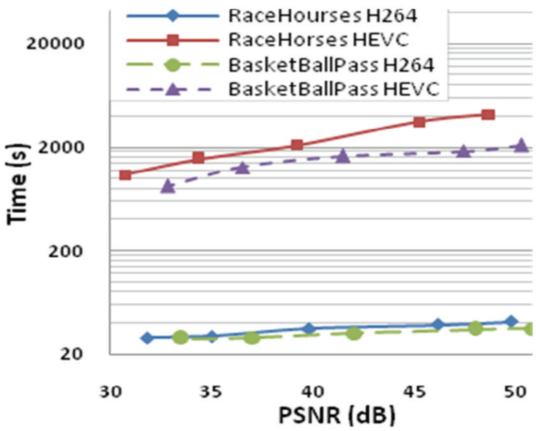

Fig. 6. Comparison of the fluctuation of encoding time with average PSNR for Class D sequences. PSNR=peak signal-to-noise ratio, HEVC=High Efficiency Video Coding.

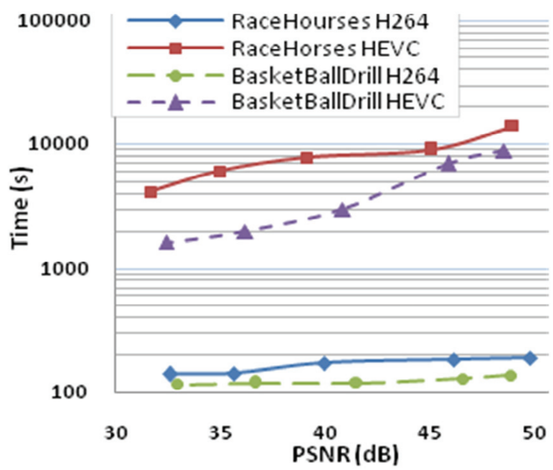

Fig. 7. Comparison of the fluctuation of encoding time with average PSNR for Class C sequences. PSNR=peak signal-to-noise ratio, HEVC=High Efficiency Video Coding.

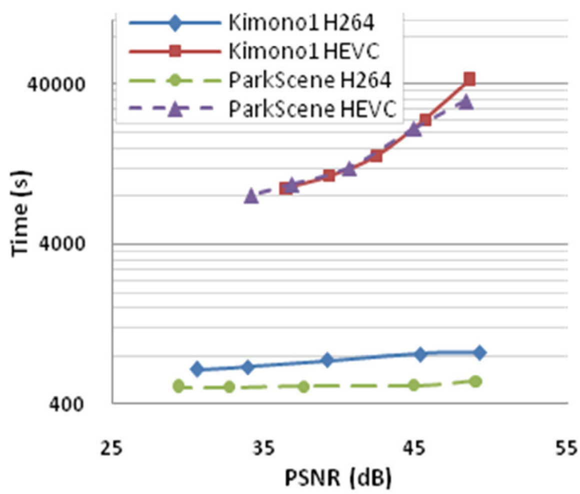

Fig. 8. Comparison of the fluctuation of encoding time with average PSNR for Class B sequences. PSNR=peak signal-to-noise ratio, HEVC=High Efficiency Video Coding.

5. Conclusions

In this paper, we evaluated the tradeoff between the coding gain, delay, and complexity of the HEVC encoder in the broadcasting environment using an RA configuration. The results show that both codecs have advantages and disadvantages depending on the application and the devices that are used. In terms of bit savings, the newly introduced HEVC codec yields a two-fold improvement compared to the H.264 codec. However, HEVC performs poorly in terms of encoding time and complexity. The delay introduced by the HEVC codec has increased by a considerable amount compared to preceding video compression standards. This is because it uses a brute force RD optimization technique and advanced video coding tools to improve the coding gain in high-resolution environments.

To achieve a similar quality level as the HEVC sequence, H.264 requires a higher bitrate (i.e., the coding gain achieved by HEVC is superior to H.264). For example, in Class D sequences, the coding gain achieved by HEVC in comparison to H.264 in a random access environment was around 84% at a PSNR level of 40 dB. Yet, HEVC also requires a very high computational time, which was around 98% with reference to H.264 in low-resolution videos. The HEVC performs better in high-resolution videos than in low-resolution videos meeting its design goals. Then, with the increment of QP values, the encoding time decreases. It can be concluded that HEVC is not mature enough to be used in broadcasting applications, where mobile devices with low-resolution video settings are used. Furthermore, a significant improvement in encoding time can be achieved by facilitating a low-level RD optimization for HEVC when employed in delay critical applications.

It is also clear that the application scenarios of JSVM and HM codecs, which use H.264/AVC and HEVC standards, respectively, should be selected judiciously. For instance, HM is not suitable for an application that requires a low delay, although, it can be used effectively in low bandwidth environments. When selecting the most suitable codec for a given application, facts such as the availability of system resources and the inherent characteristics of the application plays a major role.

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