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HEVC in Wireless Environments

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Abstract The increasing demand for real-time applications with high and ultra high definition video urged the ITU-T and the ISO/IEC to join their forces to develop the next-generation video coding standard. The new coding standard that has been produced is known as High Efficiency Video Coding (HEVC). The proposed HEVC standard fulfilled its target to achieve more than 50% improvement in video compression over the existing H.264 Advanced Video Coding standard, keeping comparable image quality, at the expense of increased computational complexity. Advances in wireless communications and mobile networking have dramatically increased the popularity of video services for mobile users, with video delivery at their fingertips. Delivering high perceptual quality video over wireless environments is challenging due to the changing channel quality and the variations in the importance of one source packet to the next for the end-user's quality of experience. The main objective of this paper is to provide an overview over the new characteristics which are likely to be used in HEVC in wireless environments and discusses several research challenges. Experimental results demonstrate that for low-delay wireless video communications the HEVC codec is more effective compare to previous H.264 codec and shows better overall performance. Both subjective and objective visual quality comparative study has been also carried out in order to validate the proposed approach.

Keywords, HEVC, High Efficiency Video Coding, Algorithm, Wireless video, Error resilient, Algorithm,

1 Introduction

Nowadays, High Efficiency Video Coding, known as HEVC, is the latest compression standard, which was officially approved in January 2013, and became the successor of H.264/MPEG-4 or AVC (Advanced Video Coding) standard.
The HEVC standard design has the features to be easily adaptable to about all the current existing H.264/MPEG-AVC applications, and emphasizes mainly on the capability of Ultra-High-Definition (UHD) video view without much bandwidth consumption [1], [2].

The fundamental goal of the HEVC codec standard is the fact that presents considerably better compression performance in comparison with the current existing standards, in the range of 50% bit-rate reduction for about the same video quality, compared to its predecessor, the H.264/MPEG-AVC standard. Moreover, it is designed to provide high-quality streaming media, even on low-bandwidth networks, due to the fact that it consumes only the half bandwidth, compared to AVC. Therefore, there are many benefits of using HEVC compression standard for media files compared to the predecessor H.264/MPEG-4 Advanced Video Coding (AVC) standard [1] - [4].

Since 1997, the ITU-T's Video Coding Experts Group (VCEG) has been working on a new video coding standard with the internal denomination H.26L. In late 2001, the Moving Picture Expert Group (MPEG) and VCEG decided to work together as a Joint Video Team (JVT), and to create a single technical design called H.264/AVC for a forthcoming ITU-T Recommendation H.264/AVC and for a new part of the MPEG-4 standard called AVC [1]. The primary goals of H.264/AVC are *improved coding efficiency* and *improved network adaptation.* The syntax of H.264/AVC typically permits a significant reduction in bit-rate [3] compared to all previous standards such as ITU-T Rec. H.263 and ISO/IEC JTC 1 MPEG-4 at the same quality level [2] - [5]. It should be emphasized that HEVC codec has specific complexity [4], and implementation [5], and it is being integrated into media systems and protocols [6], while constitutes the current codec for resolutions beyond HDTV [7] for real-time streaming of video files [8].

In addition, HEVC presents more effective rate-distortion (R-D) performance, by using specific algorithms [9]. The HEVC standard fulfilled its target to achieve more than 50% improvement in video compression over the existing H.264 Advanced Video Coding standard, keeping comparable image

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quality, at the expense of increased computational complexity. HEVC targets a wide variety of high definition video applications such as the 4k television with screen resolution of 4096 × 2160 and the Ultra High Definition Television (UHDTV) with screen resolutions of up to 7680x4320. [10] - [17].

Nowadays, users are demanding continuous delivery of increasingly higher quality videos over the Internet, in both wired and wireless networks. Due to its real-time nature, video delivery typically has bandwidth, delay and loss requirements. However, for wireless video delivery, especially delay-bounded real-time video delivery, higher data rate could lead to higher packet loss rate, thus degrading the users Quality of Experience (QoE). Moreover video delivery has the properties of real-time, continuity and data dependency. The generic characteristics of wireless networks are time-varying and their performance is generally inferior to those of wired networks. Therefore, it is still a challenging problem to efficiently provide a video delivery service of high quality over wireless environments [18] - [23]. This paper provides an overview over the new characteristics which are likely to be used in HEVC in wireless environments and discusses several research challenges.

The rest of the paper is organized as follows. Section 2 investigates the effects of temporal error propagation imposed by the variable wireless environments conditions. In Section 3 we present and analyze HEVC standard new characteristics regarding encoding complexity configurations and reference picture set (RPS) in order to detect reference picture losses reliably over variable wireless environments conditions. Section 4 includes the experimental results. Specifically, subjective and objective visual quality comparative study has been carried out. Finally section 5 identifies conclusions and future work.

2 Performance of HEVC under variable wireless environments conditions

In the last decade video compression technologies have evolved in the series of MPEG-1, MPEG-2, MPEG-4, H.264 and HEVC. Given a bandwidth of several hundred of kilobits per second, the recent codec, such as HEVC, can efficiently transmit quality video. A video stream comprises Intra (I)-frames, Predicted (P)-frames, and interpolated-Bidirectional (B)-frames. I-frames are the least compressible but don't require other video frames to decode. Moreover, P-frames can use data from previous frames to decompress and are more compressible than I-frames. On the other hand, B-frames can use both previous and forward frames for data reference to get the highest amount of data compression [13], [24].

According to HEVC, I- , P- and B-frames have been extended with new coding features, which lead to a significant increase in coding efficiency. For example, HEVC allows using more than one prior coded frame as a reference for P- and B-frames. Furthermore, in HEVC, P- frames and B-frames can use prediction for subsequent frames. These new features are described in detail in [1]. Moreover an HEVC coded video sequence is typically partitioned into small intervals called GOP (Group of Pictures). Encoded video data consists of frames with different level of importance in terms of frame types Intra (I), Predicted (P) and Bidirectional (B). In addition there is a complex dependency relationship across the different video frames, and lost packets have impact on the video quality. Since mobility is expected of the wireless client, there is typically significant packet loss. If the packet loss occurs on an I-frame, it would affect all the P- and B-frames in a GOP that are predicted from the I-frame [1-7, 24, 25].

In wireless environments, video quality is mainly impacted, in addition to the compression strategy at the source, by frame losses (evaluated in terms of Packet Loss Rate (PLR). Therefore, how to choose an accurate distortion model with respect to frame loss is an important design consideration. We adopt a modified version of the Decoded Frame Rate Metric [24] in order to assess the effect of the temporal error propagation imposed by streaming HEVC over wireless environments. The main modification is the use of the packet loss rate instead of frame loss for the different encoding schemes HEVC low delay configuration and H.264/AVC I-P structure.

Assume that N is the distance between two successive I-frames, defining a Group Of Pictures (GOP) and N_{GOP} is the total number of GOPs in the video sequence The extended successfully Decoded Frame Rate Metric (DFRM) can be defined as follows.

$$DFRM = \frac{F_{dec}}{N_{GOP} + N_{GOP} * (N-1)}, \quad 0 \le DFRM \le 1 \qquad (1)$$

where $Fdec$ is the summation of the successfully decoded I- and P-frames in the video sequence. $DFRM$ = 1 implies no quality degradation and $DFRM$ = 0 implies the most unpleasant case. The packet loss situation is simulated according to the channel conditions specified in [25]. Specifically we examined the packet loss rates from 5% up to 30% with step 5%. The simulations were carried out on the RaceHorses video sequence under different packet loss rates. Figure 1 depicts the Decoded Frame Rate Metric (DFRM) for the HEVC encoding scheme and the H.264/AVC under different packet loss rates (PLR).

From Figure I It can be observed that there is a significant increase in the successfully Decoded Frame Rate Metric (DFRM) for the HEVC encoding scheme compared to the conventional H.264/AVC encoding scheme for different packet loss rates. This is because the most important property to prevent temporal error propagation is the motion compensation reference frame.

Therefore, compensating for lossy wireless channels is a most important challenge. It is well known that predicatively encoded video is susceptible to bit errors. This is due in part to the use of variable-length coding in which a single bit error can cause the loss of entire blocks of data. In wireless environments, bit errors are usually dealt with using some form of error correction schemes. However, while too many errors can cause significant distortion to the end user, guaranteeing error-free wireless reception is pointless [24- 26].

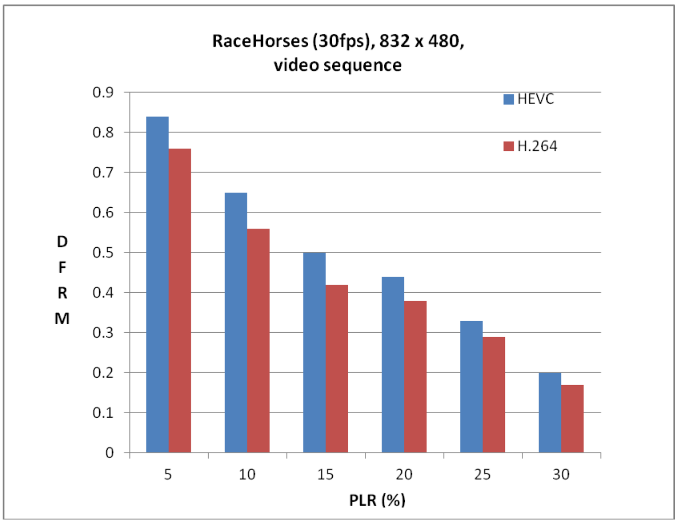


Fig. 1: Decoded Packet Rate Metric as a function of Packet Loss Rate for HEVC and H.264 compression technologies

Table 1 SSIM [27] vs BER for HEVC and H.264 Encoders

	RaceHorses (30fps), 832 x 480 (video sequences SSIM index	
BER	**HEVC**	**H.264**
10^{-6}	0.923	0.89
10^{-5}	0.912	0.87
10^{-4}	0.894	0.83
10^{-3}	0.710	0.625
10^{-2}	0.565	0.34
10^{-1}	0.345	0.09

The Structural SIMilarity (SSIM) index is a technique for measuring the similarity between two images [27]. Table 1 indicates the SSIM index of HEVC and H.264/AVC for increasing bit error rates (BER). This shows that, while wireless environments conditions can be extremely variable, in many cases we can simply ignore errors. This leads to an obvious tradeoff between the quality of the received video and the techniques used to reduce the BER**.** Below, we will discuss techniques at video encoder that can potentially accomplish this using the new characteristics of HEVC standard.

3 HEVC New Characteristics

The HEVC standard is designed to achieve multiple goals, including coding efficiency, ease of transport system integration and data loss resilience. Error resilience supported by the video codec is always an important feature, especially if the system layer uses unreliable transport as wireless environments scenarios [1-3].

HEVC's main target was to increase data compression by 50% over its predecessor H.264, while keeping the same image quality, at the expense of computational cost. Moreover HEVC offers many configurations modes, depending on the application scenario, for efficiency, computational complexity, processing delay, parallelization and error resilience techniques. The two main encoding complexity configurations are the "High Efficiency" and the "Low complexity" modes. The former offers a high efficiency encoding at the expense of computational cost while "Low complexity" offers reasonably high efficiency while trying to keep the encoder complexity as low as possible. As far as the temporal prediction structure is concerned, there are three prediction modes. The first mode is the "intra-only" configuration (Fig.2), where each picture is encoded independently and no temporal prediction is used. The second mode is the "Low-Delay configuration" (Fig. 3), where only the first picture of the video sequence will be used as an Instantaneous Decoder Refresh (IDR) coded picture, all the other pictures are encoded as Generalized P and B Pictures (GPB), in mandatory Low-Delay test condition, or as P Pictures, which is called non-normative Low-Delay condition. The third mode is the "Random-Access" mode (Fig.3) , where the first picture in a Group of Pictures (GOP), which lasts for approximately 1 sec, is encoded as IDR picture and all the other pictures inside the GOP are encoded as B or GPB pictures [4-9].

For multiple-reference picture management, a particular set of previously decoded pictures needs to be present in the decoded picture buffer (DPB) for the decoding of the remainder of the pictures in the bit-stream. To identify these pictures, a list of picture order count (POC) identifiers is transmitted in each slice header [1-3].

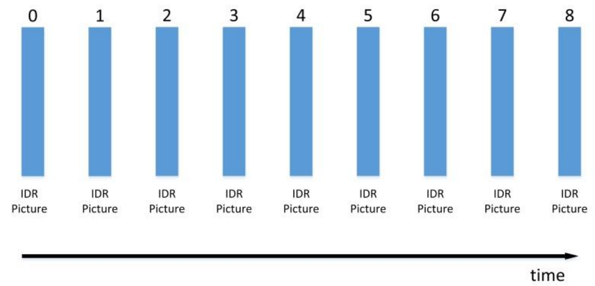


Fig. 2 Graphical presentation of Intra-only configuration

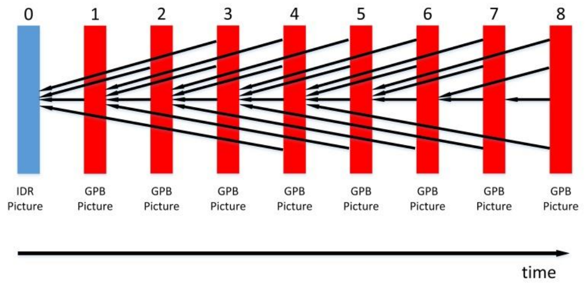


Fig. 3 Graphical presentation of Low-Delay configuration

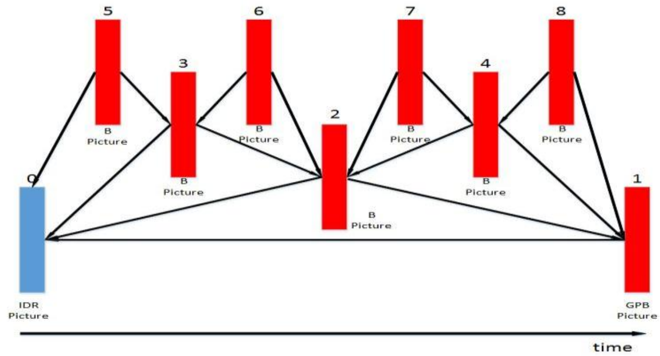


Fig. 4 Graphical presentation of Random-Access configuration

The set of retained reference pictures is called the reference picture set (RPS). The high-level syntax for identifying the RPS and establishing the reference picture lists for inter-picture prediction is more robust to data losses than in the prior H.264/MPEG-4 AVC design, and is more amenable to such operations as random access and trick mode operation (e.g., fast-forward, fast rewind, adaptive bit-stream switching) [1-3, 5-14] . Moreover the critical point for this enhancement is that the syntax is more explicit of the decoding process as it decodes the bit-stream picture by picture. In addition, the associated syntax for these aspects of the design is actually simpler than it had been for H.264/MPEG-4 AVC. Hence, in HEVC both encoders and decoders mandatorily apply the RPS feature for decoded reference picture marking. Consequently, HEVC decoders are always able to detect reference picture losses reliably [1-3]. In the following we investigate the performance of HEVC RPS feature under variable wireless environments.

4 Experiments

Experiments are conducted using HM 9.2 [28] and JCT-VC main configuration common conditions [29]. HEVC supports low-delay coding structures that usually provide an improved coding efficiency. The experiments reported here are conducted on test sequences of different characteristics. These sequences differ broadly from one another in terms of frame rate, bit depth, motion, and texture characteristics as well as spatial resolution. Sequences used in experiments are classified into four groups based on their resolution (class A, B, C, D). For low delay configuration class A sequences are not tested. This is consistent with the test conditions defined during the standardization process of HEVC [29]**.** Class B sequences correspond to full high definition (HD) sequences with a resolution of 1920x1080. Class C and Class D sequences correspond to WVGA and WQVGA resolutions of 832x480 and 416x240 respectively. For the experiments, Class B includes the Kimono (24fps), Basketball Drive (50fps) and BQTerrace (60fps) sequences**;** Class C includes the RaceHorses (30fps), PartyScene(50fps) and BQMall (60fps) sequences; and Class D includes the BasketballPass (50fps), BQSquare (60fps), and RaceHorses (30fps) sequences;

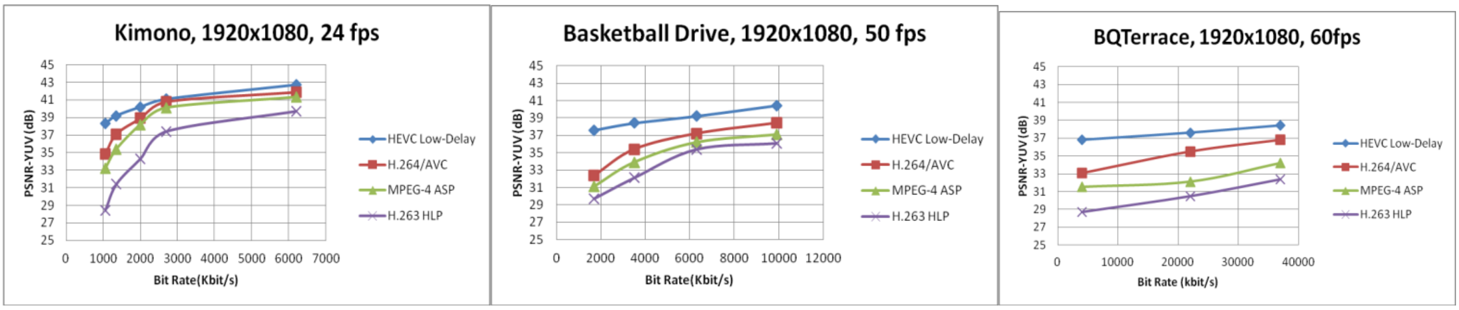
In Fig. 5, rate–distortion curves are depicted for two selected sequences, in which the PSNRYUV as defined in sec. IV.A is plotted as a function of the average bit rate. This figure additionally shows plots that illustrate the bit rate savings of HEVC relative to H.262/MPEG-2 MP, H.263 CHC, MPEG-4 ASP, and H.264/MPEG-4 AVC HP as a function of the PSNRYUV. In the diagrams, the PSNRYUV is denoted as YUVPSNR.

Table 2 (a)-(b) depicts the average Y-PSNR (dB) for Class B , Class C and Class D video sequences under the following packet loss rates (a), 0%, 10%, 20%, and (b) 30% and 40%. The packet loss situation is simulated according to the channel conditions specified in [24, 25]. The largest Y-PSNR value in each column is shown in bold font. From the results shown in Table 2 the follow observations can be derived. Applying HEVC coding pattern with Low-Delay configuration can enhance temporal error propagation for all the video traces and packet loss rates. All the cases with HEVC coding pattern outperform the conventional H.264/AVC, MPEG-4 ASP and H.263 HLP coding standards [7] with Intra(I) -Predicted (P) GOP pattern.

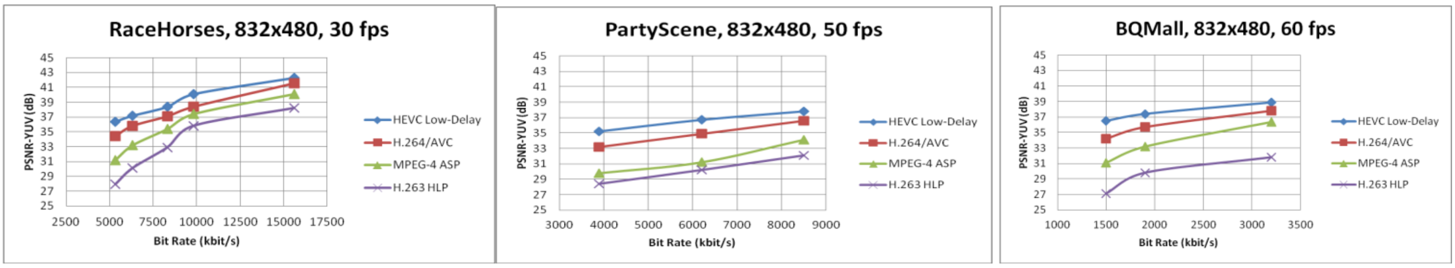
This is because the most important property to prevent temporal error propagation is the motion compensation reference frame. For instance, for packet loss rates 20-% to 40% HEVC low-delay coding pattern with reference picture set (RPS) feature noticeably outperforms all the other representations, the H.263 HLP, middle, MPEG-4 ASP, and the conventional H.264/AVC coding.

These results verify the effectiveness of the HEVC compared to conventional H.264/AVC standard under different packet loss rates. These results indicate that the emerging HEVC standard noticeably outperforms its predecessors in terms of coding efficiency, as well as, temporal error propagation optimization for all the video traces and packet loss rates for variable wireless video environments- applications.

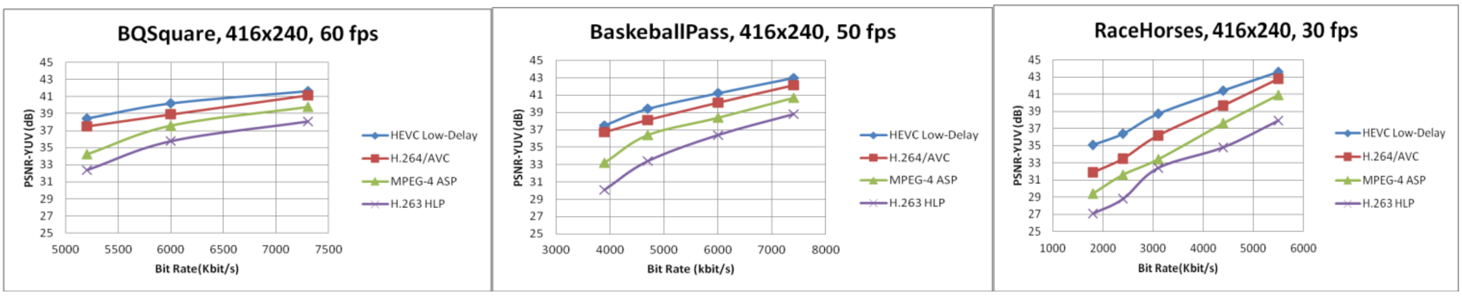
The SSIM index is a full reference metric, in other words, the measuring of image quality based on an initial uncompressed or distortion-free image as reference. SSIM is designed to improve on traditional methods like PSNR and MSE, which have proved to be inconsistent with human eye perception. SSIM is also commonly used as a method of testing the quality of various lossy video compression methods. The SSIM emphasizes that the Human Visual System (HVS) is highly adapted to extract structural information from visual scenes. Therefore, a measurement of structural similarity (or difference) should provide a good approximation to perceptual image quality.



(a)



(b)



(c)

Fig. 5 (a)-(c) Rate–Distortion (R-D) curves for

(a) Class B: Kimono (24fps), Basketball Drive (50fps), BQTerrace (60fps) video traces,
(b) Class C: RaceHorses (30fps), *PartyScene* (50fps), BQMall (60fps) video traces,
(c) Class D: BQSquare (60fps), BasketballPass (50fps), RaceHorses (30fps) video traces,

for the HEVC codec and the conventional H.264/AVC, MPEG-4 ASP, H.263 HLP, coding standards

Table 2 (a)-(b) Average Y-PSNR (dB) of
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Class D:BQSquare (60fps), BasketballPass (50fps), RaceHorses (30fps) video traces,
for the HEVC codec and the conventional H.264/AVC, MPEG-4 ASP, and H.263 HLP coding standards
under different packet loss rates (a) and (b).

(a)

Packet Loss	*0%*				*10%*				*20%*			
VideoSequence/ Coding pattern	*HEVC Low-Delay*	*H.264/ AVC*	*MPEG-4 ASP*	*H.263 HLP*	*HEVC Low-Delay*	*H.264/ AVC*	*MPEG-4 ASP*	*H.263 HLP*	*HEVC Low-Delay*	*H.264/ AVC*	*MPEG-4 ASP*	*H.263 HLP*
Kimono (24fps) 1920x1080(Class B)	**42.73**	41.9	41.3	39.7	**41.1**	40.8	40.1	37.4	**40.2**	38.9	38.2	34.3
BasketballDrive(50fps) 1920x1080 (Class B)	**41.43**	40.9	40.1	38.8	**40.4**	38.4	37.1	36.1	**39.2**	37.2	36.2	35.4

(b)

Packet Loss	*30%*				*40%*			
VideoSequence/ Coding pattern	*HEVC Low-Delay*	*H.264/AVC*	*MPEG-4 ASP*	*H.263 HLP*	*HEVC Low-Delay*	*H.264/AVC*	*MPEG-4 ASP*	*H.263 HLP*
Kimono (24fps) 1920x1080 (Class B)	**39.2**	37.1	36.4	31.4	**38.3**	34.8	33.2	28.4
BasketballDrive(50fps) 1920x1080 (Class B)	**38.4**	35.4	33.9	32.1	**37.6**	32.4	31.1	29.7
BQTerrace (60fps) 1920x1080 (Class B)	**37.6**	35.5	32.1	30.5	**36.8**	33.1	31.5	28.7
RaceHorses (30fps) 832 x 480 (Class C)	**37.2**	35.8	33.2	30.1	**36.4**	34.4	31.2	27.9
PartyScene (50fps) 832 x 480 (Class C)	**36.7**	34.9	31.2	30.2	**35.2**	33.2	29.8	28.4
BQMall (60fps) 832 x 480 (Class C)	**37.4**	35.7	33.2	29.8	**36.5**	34.2	31.1	27.1
BQSquare (60fps) 416 x 240 (Class D)	**37.1**	35.3	32.1	30.4	**35.8**	33.2	29.8	27.7
BasketballPass (50fps) 416 x 240 (Class D)	**37.5**	36.7	33.2	30.1	**36.4**	35.1	30.8	27.8
RaceHorses (30fps) 416 x 240 (Class D)	**36.4**	33.5	31.6	28.8	**35.1**	31.9	29.4	27.1

Table 3 Error burst with 10% frame loss for (a) Class B Kimono (24fps), Basketball Drive (50fps), BQTerrace (60fps) video traces, error burst with 20% frame loss for (b) Class C RaceHorses (30fps), *PartyScene (50fps)*, BQMall (60fps) video traces, error burst with 30% frame loss for (c) Class D BQSquare (60fps), BasketballPass (50fps), RaceHorses (30fps) video traces, for the HEVC codec and the conventional H.264/AVC coding.

(a)

CLASS B	***Structural SIMilarity (SSIM) index***	
1920x1080 video sequence	***H.264***	***HEVC***
Kimono (24fps)	0.817	0.933
Basketball Drive (50fps)	0.837	0.941
BQTerrace (60fps)	0.861	0.948

(b)

CLASS C	***Structural SIMilarity (SSIM) index***	
832 x 480 video sequence	***H.264***	***HEVC***
RaceHorses (30fps)	0.797	0.903
PartyScene (50fps)	0.777	0.918
BQMall (60fps)	0.754	0.922

(c)

CLASS D	***Structural SIMilarity (SSIM) index***	
416 x 240 video sequence	***H.264***	***HEVC***
BQSquare (60fps)	0.731	0.893
BasketballPass (50fps)	0.714	0.901
RaceHorses (30fps)	0.701	0.912

The SSIM index is defined as a product of luminance, contrast and structural comparison functions. The SSIM index is a decimal value between 0 and 1. A value of 0 would mean zero correlation with the original image, and 1 means the exact same image. Through this index, image and video compression methods can be effectively compared [24, 27].

The Class B video traces affected by burst error 10% frame loss for the Kimono (24fps), Basketball Drive (50fps) , and BQTerrace (60fps), the Class C video traces affected by burst error 20% frame loss for RaceHorses (30fps), PartyScene(50fps) and BQMall (60fps), the Class D video traces affected by burst error 30% frame loss for the BasketballPass (50fps), BQSquare (60fps), and RaceHorses (30fps) sequences. Table 3 (a)-(c) depicts the SSIM values for (a) Class B, (b) Class C, and (c) Class D video sequences under error burst with 10%, 20%, and 30% frame loss. It can be seen that for different burst error the HEVC codec outperforms the conventional H.264/AVC standard since it achieves better visual quality.

5. Conclusions

Wireless video communications are often afflicted by various forms of losses, such as burst packet loss or uniform packet loss. An understanding of the effect of packet loss on the reconstructed video quality, and developing accurate models for predicting the distortion for different loss events, is clearly very important for designing, analyzing, and operating video communications systems over lossy wireless environments. An important question is whether the expected distortion depends only on the average packet loss rate, or whether it also depends on the specific pattern of the loss. In this paper, we analyzed the constraints of temporal error propagation in error-prone wireless video environments.

Extensive experimental results demonstrated that the HEVC codec, under different packet loss rates, is more effective compare to previous video coding standards and shows better overall performance. Both subjective and objective visual quality comparative study demonstrated that the HEVC codec outperforms the conventional H.264/AVC standard.

Therefore, the HEVC codec promises some significant advances of standardized video coding in wireless environments. The new HEVC codec shows rather promising results as it manages to reduce the bit rate to 50% comparing to its predecessor H.264/AVC. Moreover the HEVC design is shown to be especially effective for low bit rates, high-resolution video content, and low-delay wireless communication applications. Future work will include the impact of the HEVC codec in the decoding efficiency, delay and random bit errors over combined networks from wired to wireless links. This is expected to be an active area of research in years to come.

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