Objective quality comparison of 4K UHD and up-scaled 4K UHD videos	**So sánh độ trung thực của các video UHD 4Kvà video UHD tăng cường độ phân giải đến 4K** objective quality: chất lượng khách quan, độ trung thực
Abstract—In this paper, we perform objective quality com-parison between 4K ultra-high definition (UHD) and up-scaled 4K UHD videos. We aim at investigating added values of 4K UHD over high definition (HD). We examine	Tóm tắt-Trong bài báo này, chúng tôi tiến hành so sánh độ trung thực giữa các video độ nét siêu cao (UHD) và các video UHD tăng cường độ phân giải đến 4K. Mục đích của chúng tôi là khảo sát giá trị gia tăng của UHD

the quality of the two types of videos at the same bitrate conditions for two compression standards, AVC and HEVC. Using our own 4K UHD video data, we generate test sequences having various quality levels and bitrates using AVC and HEVC. Objective quality comparison is performed using multi-scale structural similarity (MS-SSIM), visual information fidelity (VIF), and visual signal-to-noise ratio (VSNR) metrics. The results show that superiority between the two UHD versions changes according to the bitrate, where content characteristics and the codec also have notable influences.	4K so với video phân giải cao (HD). Chúng tôi phân tích chất lượng của hai loại video ở cùng điều kiện tốc độ bit với 2 chuẩn nén, AVC và HEVC. Bằng cách sử dụng các dữ liệu video UHD 4K của riêng mình, chúng tôi tạo ra các chuỗi thử nghiệm với cấp độ chất lượng và tốc độ bit khác nhau khi dùng chuẩn nén AVC và HEVC. Chúng tôi tiến hành so sánh độ trung thực bằng cách sử dụng các số liệu thống kê Đồng dạng cấu trúc đa quy mô (MS-SSIM), độ trung thực thông tin hình ảnh (VIF) và tỷ lệ tín hiệu hình ảnh nhiễu (VSNR). Kết quả cho thấy rằng sự vượt trội giữa hai phiên bản UHD thay đổi theo tốc độ bit vốn cũng chịu ảnh hưởng đáng kể từ đặc điểm nội dung và chuẩn nén.
I. INTRODUCTION With the growth of the video technology, high quality videos have been popular and familiar with us. Following the success of high definition (HD) services, 4K ultra-high definition (UHD) resolution (3840x2160 pixels) videos have been becoming popular increasingly. UHD is expected to enhance visual experience beyond HD by having a wide field of view with appropriate screen sizes [1]. The display industry and film industry have paid attention to the 4K resolution. And, video services over networks, e.g., YouTube, Netflix, etc., provide high quality videos and the representative video website, YouTube, now supports 4K videos.	**I. GIỚI THIỆU** [redacted]
We expect enhanced quality when watching 4K UHD videos. The 4K UHD resolution is four times the full	[redacted]

high definition (FHD) resolution (1920 x 1080 pixels) and a higher resolution in the same screen gives more information and impressive experiences to viewers. However, larger storage and bandwidth are needed to store and transmit 4K video contents. Thus, there exists trade-off relationship between the amount of data and visual quality.	[redacted]
Compression is an essential step in most video applications for efficiency. The new video compression standard, high efficiency video coding (HEVC), is known to be particularly effective for 4K UHD videos than the popular H.264/AVC. Recent researches have been performed to investigate quality of 4K UHD videos in relation to compression using the two types of codec, AVC and HEVC. A significant difference in compression performance was observed between HEVC and AVC from similar bitrate conditions from subjective quality evaluation using 4K UHD videos [2]. In the study of subjective and objective quality evaluation of 4K videos in [3], the bitrate ranges for acceptable compression quality were investigated, e.g., above 5 Mbps for AVC and 1 Mbps for HEVC. Because of limited resources for transmission and decoding and lack of 4K UHD video contents, there would be situations where watching FHD video contents with up-scaling to 4K UHD is preferred to watching 4K UHD contents, just like what happened during the transition from standard definition (SD) to HD. Pitrey et al. [4]	[redacted]

performed subjective quality assessment to compare original FHD videos to FHD videos generated from intermediate formats (e.g., SD) using possible scenarios such as up-scaling. It was shown that the HD video stream with up-scaling to FHD is preferred to the directly coded FHD video stream at the same bitrate when AVC was used. Similarly, for efficient services, it will be important to study the aforementioned trade-off relationship and understand in which cases 4K UHD can create added values over HD in spite of the additional cost due to the increased amount of data.

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In this study, therefore, we perform objective quality comparison between 4K UHD and up-scaled 4K UHD videos to investigate added values of 4K UHD over HD. Especially, we investigate which one provides better visual quality in various points of view, i.e., two standard codecs, various bitrates, and three popular objective metrics. We use our own video dataset composed of 4K UHD resolution contents with a variety of content types and complexity. From the raw 4K UHD and HD videos, we generate test sequences having various bitrates using AVC and HEVC codecs. Then, we measure and compare the quality of the test sequences using three state-of-the-art quality metrics, multi-scale structural similarity (MS-SSIM), visual information fidelity (VIF), and visual signal-to-noise ratio (VSNR).

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II. EXPERIMENT SETUP

A. Source videos

In our study, we considered six original sequences having virtually lossless quality from our own video contents captured by a RED Epic camera. These video contents have the 4K UHD resolution with a frame rate of 30 fps and Figure 1. Representative frames of the test sequences: (a) Park, (b) Lake, (c) Basketball, (d) Flowers, (e) Construction, and (f) Maples.

Figure 2. Spatial information (SI) and temporal information (TI) indexes of the contents.

length of 15 seconds. The example frames of the contents are given in Fig. 1. Fig. 2 shows their characteristics in terms of the spatial information (SI) and temporal information (TI) indexes computed on the luminance component [5]. It can be observed that the video data are representative of a wide variety of content types.

B. Test video sequences

The target stimuli are native 4K UHD and 4K UHD upscaled from FHD, where the latter assumes watching FHD videos at the 4K UHD resolution on a 4K UHD screen.

We obtained reference 4K UHD and FHD videos that have the same visual contents except for spatial resolutions; 4K UHD sources were down-scaled to FHD videos using the Lanczos kernel, which is a popular algorithm for down-/up-scaling.

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The two types of reference videos were encoded with AVC and HEVC using JM 18.5 and HM 10.0 reference softwares, respectively. The high profile with level 5.2 and main profile were used for AVC and HEVC, respectively. YUV 4:2:0 color sampling was used and the CABAC mode was enabled. The group of pictures (GOP) size was set to 8 and the intra period was set to 32. Hierarchical B-pictures with four temporal levels were used with an increase of quantization parameter (QP) by one between adjacent levels.

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We obtained the video sequences having various bitrates (low to high bitrates), which have various quality levels (low to high quality) according to the bitrates. For this, fixed QP values were used for encoding. From extensive preliminary experiments to map the QPs between the JM and the HM, we obtained appropriate QP values for them. For AVC, QPs are in the range of 16 to 42 with 6 levels, and those for HEVC are in the range of 22 to 46 with 5 levels.

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The encoded test sequences were decoded in their own spatial resolutions. For the FHD sequences, up-scaling to the 4K UHD resolution was conducted for each frame using the Lanczos resampling algorithm. Finally, we obtained two types of 4K UHD videos for quality evaluation, 4K UHD and up-scaled 4K UHD videos.

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C. Quality measurement

We performed quality measurement using three full- reference quality metrics, namely, MS-SSIM [6], VIF [7], and VSNR [8]. MS-SSIM is a popular metric to estimate perceptual quality of images and videos, whose reliability is proven through many previous researches [9]. VIF and VSNR are wavelet decomposition based algorithms estimating perceptual quality, which have shown high performance for HD videos [10]. These quality metrics also showed high performance for 4K UHD videos in [11]. When applying the metrics to the two types of videos, we used the original 4K UHD sequences as reference videos.

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III. RESULTS AND DISCUSSION

Fig. 3 shows the MS-SSIM, VIF, and VSNR scores vs. bitrates for all test sequences and two types of codecs. For most contents, in the case of AVC, quality is better for upscaled 4K UHD than 4K UHD when the bitrate is low. On the other hand, when the bitrate is sufficiently high, 4K UHD videos tend to have better quality than up-scaled 4K UHD videos. The sequences, (e) Construction and (f) Maples, show this trend when VIF is considered; however, for (a) Park, (b) Lake, (c) Basketball, and (d) Flowers, the two types of 4K UHD have similar quality at high bitrates. Using VSNR, 4K UHD videos tend to have better quality than up-scaled 4K UHD videos at high bitrates for all contents. However, in terms of MS-SSIM, the quality of the two types of 4K UHD is very similar when the bitrate is high for all contents.

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For the HEVC case, the trend that the 4K UHD is better than the up-scaled 4K UHD at high bitrates is more prominent in comparison to the AVC results. The sequences, (b) Lake, (c) Basketball, (e) Construction, and (f) Maples, show this trend for both VIF and VSNR. For the AVC results, for (a) Park and (d) Flowers, the two types of 4K UHD show similar quality at high bitrates.

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The trend that the superiority of 4K UHD over upscaled 4K UHD at high bitrates depends on the content can be largely explained based on the content complexity (particularly, spatial complexity) shown in Fig. 2. In other words, the former group of contents, i.e., (b) Lake, (c) Basketball, (e) Construction, and (f) Maples, have relatively large SI indexes, meaning that the visual scenes contain large amounts of fine details that are easily lost in the upscaled 4K UHD version, while this issue is less significant in the latter group of contents, i.e., (a) Park and (d) Flowers.

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These observations imply that, when we want to obtain higher quality and the bandwidth is sufficient, 4K UHD videos would be better than up-scaled 4K UHD videos. Especially, when the spatial complexity of a content is high, 4K UHD videos will provide better quality. However, when the bandwidth

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is relatively limited, it may be a better choice to deliver FHD videos and then up-scale them during display than to try to deliver 4K UHD videos.

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When HEVC and AVC are compared, HEVC shows overall higher quality and better coding efficiency than AVC for both 4K UHD and up-scaled 4K UHD videos. These results about improved efficiency of HEVC over AVC are consistent with the results of the aforementioned study [2]. Additionally, the quality gain by up-scaled 4K UHD against 4K UHD for HEVC at low bitrate conditions is much smaller than that for AVC. Therefore, the issue of choosing 4K UHD against up-scaled 4K UHD will not be so critical at low bitrates for HEVC. Moreover, the superiority of 4K UHD against up-scaled 4K UHD is kept at high bitrate conditions for HEVC. Therefore, preference of 4K UHD over up-scaled 4K UHD is stronger when HEVC is employed, whereas the choice highly depends on the bitrate and content for AVC.

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The considered three quality metrics produce consistent results overall, except that MS-SSIM does not distinguish quality difference at high bitrate conditions. MS-SSIM mainly measures distortion of the scene structure, to which the human visual system is sensitive, and structural information is well maintained in both 4K UHD and up-scaled 4K UHD cases at high bitrates as indicated by nearly perfect MS-SSIM scores. However, as observed from the results of the other two metrics, we can observe that there exists difference in the visual data between the results of the 4K UHD and up-scaled 4K UHD. In order to understand better how the difference affects the human perception, more thorough investigation including subjective quality assessment would be required, which will be our future work.

IV. CONCLUSION

In this paper, we have presented objective quality comparison of 4K UHD and up-sclaed 4K UHD after compression with the aim of investigating quality of the two types of videos with respect to the bitrate. For most cases, when the bitrate is low, quality of 4K UHD videos is worse than upscaled 4K UHD videos, which becomes less significant for HEVC in comparison to AVC. On the other hand, when the bitrate is sufficiently high, 4K UHD videos usually show better quality than up-scaled videos. For some contents having low spatial complexity, the quality of 4K UHD videos is similar to that of up-scaled 4K UHD videos at high bitrate conditions. It was confirmed that HEVC shows significantly better performance than AVC. In the future,

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we will perform subjective quality assessment using the test video sequences and more detailed analysis.	[redacted]