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| *Title:* | **Report of Results of the Joint Call for Proposals on Scalable High Efficiency Video Coding (SHVC)** | | |
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# Abstract

This report summarizes the result of the Joint Call for Proposals on Scalable Video Coding Extensions of High Efficiency Video Coding (HEVC). Twenty responses to the Joint Call for Proposals were received during the October meetings of ITU-T SG 16/Q.6 (VCEG), ISO/IEC JTC 1/SC 29/WG 11 (MPEG) and the Joint Collaborative Team on Video Coding (JCT-VC) in Shanghai, China. Results from the responses showed substantial gains in coding efficiency without undue complexity increase. As a result, it was concluded that the responses provided justification for launching a standardization effort on a scalable extension for HEVC, which will be informally referred to as SHVC.

# Introduction

Technical responses to the Joint Call for Proposals on Scalable Video Coding Extensions were evaluated during the October 10–19, 2012, meeting in Shanghai, China. The Joint Call for Proposals had been issued by the JCT-VC parent bodies at their meetings of July 2012 in Stockholm, Sweden [1].

Twenty responses to the Joint Call for Proposals were received and evaluated [5–24]. Some organizations collaborated on joint proposals and/or submitted multiple responses. A total of 20 unique organizations provided technical information: Canon, ETRI, Fraunhofer HHI, Ghent University – IBBT, Huawei, Intel, InterDigital Communications, KDDI Corporation, Kwangwoon University, LG Electronics, MediaTek, Nokia, Qualcomm, Samsung, Sharp Corporation, Texas Instruments, University of Southern California, University of Science and Technology of China, Vidyo, and Waseda University.

The Joint Call for Proposals requested information in four categories. Each category was optional, in the sense that respondents were invited to respond to any individual category or multiple categories within the Joint Call for Proposals. The number of responses for each category is listed in the table below.

**Table 1: Number of responses to joint CfP in each scalability category**

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| **Scalability category** | **Number of responses** |
| Spatial Scalability (2x and 1.5x) | 19 |
| Intra-only Spatial Scalability (2x and 1.5x) | 16 |
| SNR Scalability | 15 |
| Coding Standard Scalability | 8 |

During the Shanghai meeting, the JCT-VC studied the responses to the Joint Call for Proposals [2, 3]. Four major study activities were conducted, consisting of: (i) identifying and summarizing the tools proposed within each response, (ii) determining the coding efficiency and indicated complexity of the responses, (iii) verifying bitstreams, and (iv) performing informal viewing. The following sections reports on these study activities.

# Tool summary

The study of tools showed that 19 of the 20 responses proposed a multi-loop decoder design. Here, a multi-loop decoder design is one that requires reconstruction of the base layer picture content (including inter-picture prediction processing) prior to predicting and reconstructing the enhancement layer representation.

Given the similarity in high level design, it was possible to further categorize the tools within each response. Six distinct categories were identified and included:

* Adaptive or switched upsampling filters
* Inter-layer texture prediction signalling
* Combined mode prediction
* Inter-layer filtering
* Inter-layer syntax prediction
* Single-layer coding tools applied to the enhancement layer.

These categories are further discussed in the remainder of this section.

The first category, adaptive or switched upsampling filters tools, appeared in six responses. In general, these technologies consisted of some combination of transmitting upsampling filter coefficients from the encoder to the decoder and/or switching between different sets of upsampling filter coefficients.

The second category, inter-layer prediction signalling, appeared in all proposals. This technology is used to identify the base layer samples as a prediction for the enhancement layer. Here, the study revealed that 17 responses used an additional syntax element to signal prediction from the base layer, while three proposals employed an approach of providing upsampled base layer sample data as an additional reference frame for prediction.

The third category, combined mode prediction, was used in 18 responses. This category included technology that generates a prediction at the enhancement layer from both reconstructed enhancement layer and base layer samples. Sub-categories of such approaches included (i) difference mode coding for intra, (ii) weighted averaging of reconstructed data for intra, (iii) difference mode coding for inter, (iv) weighted averaging of reconstructed data for inter, (v) residual prediction, and (vi) generalized residual prediction.

The fourth category, inter-layer filtering, was used in seven responses. This category included technology that alters the base layer reconstructed sample data after upscaling. Sub-categories of approaches included (i) inter-layer deblocking, (ii) inter-layer sample adaptive offset, and (iii) inter-layer adaptive loop filtering. It was noted during the study that there is some overlap in functionality between tools in this category and the adaptive or switched upsample filtering methods.

The fifth category, inter-layer syntax prediction, was used in 18 responses. In general, this category included methods that conditioned the coding of enhancement layer syntax on base layer syntax. Sub-categories include (i) enhancement layer merge or AMVP list modification, (ii) partition mode and (iii) intra-mode syntax prediction. Additionally, a fourth sub-category of AVC based (i.e. Rec. ITU-T H.264 | ISO/IEC 14496-10) syntax prediction was identified among the responses that considered the "Coding Standard Scalability" category. We note that of the 18 responses in this category, all included modifications to the enhancement layer merge or AMVP list modification processes.

The sixth category, single layer coding tools, was included in 16 responses. This category denoted tools that could benefit a single layer coding system, in addition to a scalable coding system. Sub-categories include: (i) adaptive loop filtering, (ii) internal bit-depth increase, (iii) modified deblocking operations, (iv) additional transforms, (v) modified coefficient scanning, and (vi) modified entropy coding. Additionally, the study captured that seven proposals enabled asymmetrical motion partitions at the enhancement layer. This tool had been disabled in the software provided to create base layer representations for the Joint Call for Proposals, but the tool is supported in the draft HEVC Main Profile [4].

For a more detailed summary of the tools found each proposal, please see [2].

# Coding efficiency summary

The performance of the responses was measured in terms of coding efficiency (i.e. compression capability) and computational run-time. Information was collected for all configurations and is summarized below. The coding efficiency of the proposals was measured by PSNR measurements. Although PSNR is an imperfect measure of video quality, it provides tractable and precise measures that were deemed adequate for current purposes. With regard to subjective quality, please refer to section 5 of this report.

## Spatial scalability

Information describing spatial scalability was provided in 16 responses. This information considered random access conditions using both 2x and 1.5x spatial scalability configuration, where a 2x configuration describes an enhancement layer that has twice the resolution in both the vertical and horizontal dimensions relative to the base layer. Equivalently, a 1.5x configuration describes an enhancement layer with a ratio of 1.5 between the enhancement layer vertical/horizontal dimension and the base layer vertical/horizontal dimension.

The performance of the responses is summarized in Figures 1 and 2 below. Figure 1 reports the coding efficiency improvement of the responses for the 2x case, while Figure 2 reports the coding efficiency improvement of the responses for the 1.5x case. As can be seen in the figures, proposals achieved measured gains of between 35.8% and 7.7% for the 2x case. Similarly, proposals achieved measured gains of between 52.6% and 25.0% for the 1.5x case. We note that the median improvement of coding efficiency among the proposals was 31.5% and 47.7% for 2x and 1.5x cases, respectively. Please note that all coding efficiency results are relative to the actual bit rate of the proposals.

Figure 1: Coding efficiency improvement for responses for Spatial Scalability (2x) category.

Figure 2: Coding efficiency improvement for responses for Spatial Scalability (1.5x) category.

Combining the performance measurements with the tool summary above provides additional information about the responses. It was observed that all of the proposals with the highest coding efficiency enabled an adaptive loop filter (ALF) at the enhancement layer somewhat similar to that proposed previously for single-layer HEVC standardization (which had not been included in version 1 of HEVC due to complexity concerns). Figures 3 and 4 provide additional information about the responses. In the figures, the responses are denoted as either with ALF or without ALF. The proposals with ALF achieved gains of between 35.8% and 25.3% for the 2x case, while achieving gains of 33.2% to 7.7% without ALF. Similarly, proposals with ALF achieved gains of between 52.6% and 44.7% for the 1.5x case, while achieving gains of 50.2% to 25.0% without ALF.

Figure 3: Coding efficiency improvement for responses for the Spatial Scalability (2x) category. Responses are separated by the use of an adaptive loop filter.

Figure 4: Coding efficiency improvement for responses for the Spatial Scalability (1.5x) category. Responses are separated by the use of an adaptive loop filter.

## Intra-only spatial scalability

Information describing intra-only spatial scalability was provided in 16 responses. The performance of the responses is summarized in Figures 5 and 6 below. Figure 5 reports the coding efficiency improvement of the proposals for the 2x case, while Figure 6 reports the coding efficiency improvement of the responses for the 1.5x case. As can be seen in the figures, proposals achieved gains of between 37.6% and 13.8% for the 2x case. Similarly, proposals achieved gains of between 56.1% and 36.7% for the 1.5x case. We note that the median improvement of coding efficiency among the proposals was 35.6% and 54.6% for 2x and 1.5x cases, respectively.

Figure 5: Coding efficiency improvement for responses for All Intra Spatial Scalability (2x)

Figure 6: Coding efficiency improvement for responses for All Intra Spatial Scalability (1.5x).

## SNR scalability

Information describing SNR scalability was provided in 15 responses. The performance of the responses is summarized in Figure 7 below. As can be seen in the figure, proposals achieved gains of between 44.0% and 33.0% for the SNR case. The median improvement of coding efficiency among the proposals was 39.3%.

Figure 7: Coding efficiency improvement for responses for SNR scalability category.

## Coding standard scalability

The coding standard scalability category considered scalable extensions to HEVC that were compatible with the use of an AVC base layer. Eight responses were received. The performance for this category was reported relative to both AVC and HEVC references.

Figure 8 summarizes the performance for the 2x spatial scalability scenario. As can be seen from the figure, the responses provided a maximum gain in coding efficiency of 33.4% and 55.9% relative to HEVC and AVC references, respectively. The median measured gain in coding efficiency among the proposals was 26.8% and 51.8% compared to HEVC and AVC references, respectively.

Figure 8: Coding efficiency improvement for responses for Coding Standard Scalability (2x) category.

Figure 9 summarizes the performance for the 1.5x spatial scalability scenario. As can be seen from the figure, the responses provided a maximum gain in coding efficiency of 47.1% and 67.5% relative to HEVC and AVC references, respectively. The median measured gain in coding efficiency among the proposals was 42.0% and 64.7% compared to HEVC and AVC references, respectively.

## Complexity

The computational complexity of the responses was also studied by the JCT-VC. This was accomplished by summarizing the software run times of the encoder and decoder. It was recognized by the group that software run time may not be an accurate measurement of complexity for all implementation architectures and platforms.

The run time of the responses is summarized in Figure 9. In the figure, the decoder run time for each proposal is reported as a percentage of the time required to decode a single-layer bitstream. (The specific bitstream was defined in [1].)

Figure 9: Decoder run time of responses relative to a single layer HEVC decoder.

The median of the run times among the proposals is further summarized in the table below. As can be seen from the table, the responses provided a median run time of between 152% and 270% of a single layer decoder. This was judged to be reasonable and not an undue increase in complexity.

**Table 2: Median decoding run times of responses relative to single-layer HEVC**

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| **Category** | **Software Run Time** | |
| **1.5x** | **2x** |
| Spatial Scalability | 241% | 197% |
| Intra-only Spatial Scalability | 158% | 152% |
| SNR Scalability | 230% | |
| Coding Standard Scalability | 270% | 238% |

# Verification of compliance of responses to the CfP conditions

Verification of the responses consisted of two stages. The first stage was to confirm compliance of the response with conditions of the Joint Call for Proposals. During the verification, two responses were reported to contain bit rate violations, in which some actual sequence bit rates exceeded the maximum target bit rates. This was documented in the response Excel template.

The second stage was to confirm that bitstreams submitted by respondents matched the provided results. Two tests to confirm compliance were performed on the responses. The tests used two identified bitstreams from each response, each corresponding to a randomly selected anchor operation point. Using a decoder executable provided by each proponent, the two bitstreams were decoded.

First, it was confirmed that the required base layer was used in the experiments, by comparing the MD5sum calculations in the decoded picture hash SEI message of the base layer of the responses with the base layer of the selected anchor operation points.

Secondly, encoder/decoder mismatch detection was performed on the enhancement layer responses by comparing the encoder and decoder MD5sum values.

No compliance issues were found in the bitstreams submitted for verification.

# Informal subjective viewing

Informal subjective viewing was performed, in two 2-hour viewing sessions on October 14–15, 2012.. Approximately 70 participants participated in informal subjective viewing.

Three responses to the Call were selected, which were considered to be representative of three different classes of responses:

1. Use of only inter-layer texture prediction
2. Use of additional inter-layer coding tools
3. Use of additional inter-layer coding tools and single-layer coding tools

Two operation points were selected for inclusion in the viewing, for the 5 class B sequences, for each of the three representative responses at roughly equal target bit rates (corresponding to 30% and 50% lower bit rate for the enhancement layer than the bit rate of the single layer coding of the high-resolution anchor). The viewing was not blind; the sequences followed a fixed pattern, with titles indicating the class of the response.

Many of the viewers were unable to distinguish quality among the three different classes of responses, although several viewers indicated that they perceived small differences. It should be noted that the viewing conditions were not suitable for a formal subjective test. Several viewers expressed that they would have preferred for the viewing to have followed formal subjective test conditions. However, this was not feasible at the time.

The bit rates selected for inclusion in the viewing were intentionally chosen to be low enough that subjective artifacts would be visible. It was widely considered that the types of subjective artifacts seen in the scalable response were generally similar to the types of artifacts seen in single-layer HEVC coding, providing some evidence that many of the future Tool Experiments and Core Experiments can be performed using objective measures of bit rate and PSNR in their evaluations.

# Conclusions

The Joint Collaborative Team on Video Coding (JCT-VC) evaluated the technical responses to the Joint Call for Proposals on Scalable Video Coding Extensions during the October 10-19, 2012, meeting in Shanghai, China. Twenty responses to the Joint Call for Proposals were received and evaluated in the categories of Spatial Scalability, Intra-Only Scalability, SNR Scalability and Coding Standard Scalability. Evaluation included study of coding tools, coding efficiency and run time performance, bitstream verification and informal viewing. The quantity and quality of responses to the Joint Call for Proposals indicates significant interest among participants in launching an HEVC scalable extension project. The experimental results were deemed to provide sufficient evidence that substantial coding efficiency gains relative to simulcast are achievable and thus to justify proceeding with standardization of such extensions.

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