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**Abstract**

The Versatile Video Coding (VVC) standard, standardized in ITU-T as Recommendation H.266 and in ISO/IEC as International Standard 23090-3, is the most recent international video coding standard. It was developed by the Joint Video Experts Team (JVET) of the ITU-T Video Coding Experts Group (VCEG) and the ISO/IEC Moving Picture Experts Group (MPEG) to serve the ever-growing need for improved digital video compression as well as to support a wider variety of today’s media content and emerging applications. VVC delivers this by providing approximately 50% bit-rate savings over its predecessor, the High Efficiency Video Coding (HEVC) standard. In the development of the VVC standard, an emphasis was put on video with high- and ultra high-definition resolutions and beyond, high dynamic range, wide colour gamut and 10-bit sample precision per colour component.

The standard was also developed with a mission of very broad application versatility, as reflected in specific coding tools and systems functionalities that have been included in the design. The VVC includes six profiles to serve as conformance points for applications with up to 10 bits per colour component sample: the Main 10 Profile, Multilayer Main 10 Profile and Main 10 Still Picture Profile for 4:2:0 and monochrome formats and three corresponding profiles that additionally support 4:2:2 and 4:4:4 chroma formats.

The Versatile Supplemental Enhancement Information (VSEI) standard Rec. ITU-T H.274 | ISO/IEC 23002-7 was developed and approved together with VVC. It specifies the video usability information (VUI) and some of the supplemental enhancement information (SEI) messages used with VVC bitstreams. For previous standards such as HEVC and AVC, these aspects are specified directly within the same video coding standard that specifies the coding tools.

This white paper has been written to provide a brief introduction to the standard and guidance to readers on where additional resources relating to the VVC and VSEI standards can be found.

**Introduction to the VVC standard**

The VVC standard (formalized as Rec. ITU-T H.266 and ISO/IEC 23090-3) [1] was finalized in July 2020. In ITU-T it was approved in August 2020 and formally published “in force” in November 2020. In ISO/IEC, its final approval ballot was completed in January 2021 and the standard published in February 2021. A journal article with an overview of the new standard and a historical perspective on the evolution of its features has been published in the Proceedings of the IEEE [2], and another journal article with an overview of the standard and discussion of its applications and early implementations has been published in the IEEE Transactions on Circuits and Systems for Video Technology [3]. These are available as “open access” publications available to the public for download without cost. A video tutorial [4] and an overview slide presentation [5] are also available. Web sites with further information about the new standard are found at [6][7][8].

The compelling advantage of VVC is that it can achieve roughly double the compression efficiency of the previous flagship ITU-T and ISO/IEC High Efficiency Video Coding (HEVC) standard (Rec. ITU-T H.265 and ISO/IEC 23008-2) and about four times the compression efficiency of the previously-dominant H.264/MPEG-4 AVC standard (Rec. ITU-T H.264 and ISO/IEC 14496-10) – enabling, e.g., storage of more video content in the same storage space with the same video quality, sending more channels in a broadcasting service, reducing the bit rate needed for sending video on a network, or alternatively providing a major increase in video frame quality, frame rate, or picture resolution (when using a sufficiently powerful encoder). The need for maximal compression efficiency for video is pressing and urgent, since about 80% of the data transmitted on world-wide networks is video, and that percentage has been steadily growing and is projected to continue to grow further [9][10].[[1]](#footnote-1) The introduction of Ultra High Definition (UHD), High Dynamic Range (HDR), Wide Colour Gamut (WCG), and High Frame Rate (HFR) video services have increased the challenge with their use of larger frame sizes, faster refresh rates for progressive-scan video, and greater pixel bit depth. For example, by 2023, it is projected that about two-thirds of installed flat-panel television will support UHD resolution (up from one third in 2018) [11].

The complexity requirements for implementation of VVC decoders are relatively modest (less than twice the complexity of a comparable HEVC decoder and less than four times the complexity of a comparable AVC decoder), and VVC encoders, while being somewhat more of a challenge, are also quite feasible and are vendor-customizable and generally less cost-sensitive.

In addition to providing a large improvement in compression efficiency capability, the VVC standard has been designed to address a very broad range of applications, including new and emerging use cases, and hence the inclusion of “versatile” in the name of the standard. Figure 1 summarizes these two primary characteristics. The capabilities built into the finalized VVC standard include features designed to address HDR, WCG, resolution-adaptive multi-rate video streaming services, 360-degree immersive video, bitstream extraction and merging, temporal scalability, gradual decoding refresh, and multilayer coding to deliver layered video content to support application features such as multiview, alpha maps, depth maps, and spatial and quality scalability.



*Figure 1: The two primary design characteristics of the Versatile Video Coding standard.*

For gaming and screen sharing, coding tools designed to more efficiently compress computer-rendered or screen-captured content are available. For immersive media applications, new 360° video projection handling features were included. To enable more efficient video streaming, adaptive resolution changes and new random access and splicing features are supported. Ultralow latency applications are facilitated by gradual decoding refresh capability. To exploit the full potential of parallel processing, the concepts of tiles, slices and wavefronts from HEVC are developed further in VVC. Bitstream extraction and merging, e.g. as used in tile-based streaming of 360° video, is facilitated by using independent sub-pictures for easily region extraction. Multilayer coding is also supported already in the first edition of VVC, supporting temporal, spatial, view and quality scalability.

The VVC standard includes six profiles to serve as conformance points for applications with up to 10 bits per colour component sample: the Main 10 Profile, Multilayer Main 10 Profile and Main 10 Still Picture Profile for 4:2:0 and monochrome formats and three corresponding profiles that additionally support 4:2:2 and 4:4:4 chroma formats. In addition to the specified profiles, VVC offers the possibility to impose restrictions on the existing profiles either by externally defining a sub-profile indicator or by setting general constraint indicators defined in the VVC specification.

Along with the VVC standard itself, an accompanying standard known as Versatile Supplemental Enhancement Information (VSEI) has also been developed (formalized as Rec. ITU-T H.274 and ISO/IEC 23002-7) [12]. The VSEI specification defines supplemental metadata in a generalized way that can be used with VVC and also with systems specifications and possibly with other video coding standards as well. Like VVC, the VSEI standard was finalized in July 2020, and its final approval and publication had a very similar timeline. Both of these standards were produced by a joint collaborative team containing experts of ITU-T Study Group 16 and ISO/IEC JTC 1/SC 29 that is known as the Joint Video Experts Team (JVET). The JVET document archive is available in [13].

Further work on a second edition of the VVC and VSEI standards is also being conducted in the JVET. The second edition of VVC will contain additional profiles for support of higher bit depths and higher bit rates and will also specify additional SEI messages. The work on the second edition of these standards reached the CDAM stage of the ISO/IEC approval process in April 2021 and the DIS stage in July 2021 (with ballots issued to close on 2021-12-27) [14][15].

**Profiles, tiers and levels of the standard**

The VVC standard contains six profiles, which have straightforward relationships to each other as illustrated in Figure 2:

Three profiles that support only the 4:2:0 and monochrome chroma formats:

Main 10 profile, supporting video formats of 8–10 bits per colour component sample

Multilayer Main 10 profile, additionally supporting layered coding for such applications as multilayer scalability, multiview coding, and auxiliary pictures

Main 10 Still Picture profile, for compatible picture coding applications, with the only difference compared to the Main 10 profile being that the bitstream can only contain one picture

Three similar profiles that additionally support the 4:2:2 and 4:4:4 chroma formats (the Main 10 4:4:4 profile, Multilayer Main 10 4:4:4 profile, and Main 10 4:4:4 Still Picture profile)

Each of these profiles has a complete set of tiers and levels to support a wide range of bit rates and picture resolutions. Additional work is under way to develop profiles supporting higher bit depth precision.

Main 10 4:4:4 Still Picture

Main 10

Main 10 Still Picture

Main 10 4:4:4

Multilayer Main 10

Multilayer

Main 10 4:4:4

*Figure 2: The six profiles of the Versatile Video Coding standard and their relationships.*

**Additional publicly available information and resources**

JVET has developed the VVC Test Model (VTM) as its reference software encoder and decoder codebase [7]. It is intended primarily to demonstrate coding efficiency capability and proper interpretation of the syntax and decoding process specified in the standard (but not as a speed-optimized implementation), and is intended to be usable as a starting basis for product implementations. The software is available under a BSD copyright licence. The reference software is under development by JVET as H.266.2 (ex H.VVC.2) and ISO/IEC 23090-16. It reached the CD stage of the ISO/IEC approval process in October 2020 and the DIS stage in January 2021 (with a ballot issued to close on 2021-09-30). A description of the encoding algorithms in the test model is also maintained and made available by JVET [16].

A conformance test set is under development by JVET as H.266.1 (ex H.VVC.1) and ISO/IEC 23090-15 [17]. It reached the CD stage of the ISO/IEC approval process in October 2020 and the DIS stage in January 2021 (with a ballot issued to close on 2021-09-29).

Verification testing of the capabilities of the standard has been conducted using formal subjective assessment methodology, in consultation with ISO/IEC JTC 1/SC 29/AG 5 (MPEG Visual Quality Assessment) for a number of important application use cases, and further verification testing is being considered for 4:4:4 colour format, screen content, and multilayer video [18]. Verification tests that have been completed including the following types of video content:

Standard dynamic range (SDR) with ultra high definition (UHD) [19] (with the reference software test model showing an overall average bit-rate savings estimate of 43% and another publicly available encoder discussed in item 5 below showing 49%)

Standard dynamic range (SDR) with high definition (HD) [20] (with the reference software test model showing an overall average bit-rate savings estimate of 49% and another publicly available encoder discussed in item 5 below showing 51%)

360° immersive projection formats [20] (with the reference software test model showing an overall average bit-rate savings estimate of 50–56%, depending on the projection format)

High dynamic range (HDR) with high definition (HD) resolution [21] (with the reference software test model showing an overall average bit-rate savings estimate of 49–52%, depending on the HDR content type)

A review of the deployment status of the VVC standard is available as contribution document [JVET-W0021](https://jvet-experts.org/doc_end_user/current_document.php?id=10884) [22]. The document provides information about publicly available source code, software decoders, video services, encoding products, bitstream analysers and conformance test sets.

Fraunhofer HHI announced the VVenC encoder and VVdeC decoder open-source software (release 0.1) in September 2020 [3][23][24][25][26]. The encoder includes support for multithreading operation, single-pass rate control, perceptual QP adaptation, and motion-compensated temporal filtering (MCTF). The encoding software has four defined presets for quality/speed tradeoff (called “slow”, “medium”, “fast”, and “faster”). Subjective testing reported in October 2020 indicated that the VVenC encoder had about the same or better subjective compression performance as the VTM encoder when operating in its “medium” speed configuration (operating with MCTF and QP adaptation disabled in the VTM and enabled in VVenC and with rate control disabled in both) with encoding speed more than 100× that of the VTM, for 4K UHD SDR video content [3][19]. As of December 2020, a “slower” preset was added, along with an improved single-pass rate control and a new two-pass rate control [27]. The “slower” preset mode reportedly achieves approximately the same BD-rate coding efficiency as the VTM while providing a speedup of more than 8.6× for UHD and 5.2× for HD sequences relative to the VTM. As of December 2020, with release 0.2, the software is available under a BSD copyright licence. Release 0.3 of March 2021 includes substantial further speed and multithreading improvements [28]. Release 1.0.0 of the encoder released was declared in May 2021 with further coding efficiency and speed enhancements, encoding support for additional features, frame-level parallelism, and improved rate control [29]. The coding efficiency of the two-pass rate control is reportedly equivalent to that of fixed-QP operation. Release 1.1.2 of VVdeC was issued in July 2021 with support of subpictures (including support of nested SEI messages), improved conformance testing by checking of MD5 checksums, correction of picture output order and cropping [29].

Friedrich–Alexander University Erlangen–Nürnberg released an open-source bitstream analyser as an add-on for the VTM decoder [30][31]. The analyzer counts the occurrence of coding tools and coding modes used in a decoded bitstream and can be used for evaluating the decoding energy and time demands of VVC features. The software is available under a BSD copyright licence.

Eleven journal articles and an introductory editorial on the VVC design have been published in a Special Section of the IEEE Transactions on Circuits and Systems for Video Technology and are available in [3] and [32]–[42]. All of these papers are available to the public as “open access” publications for free download.

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1. “Globally, IP video traffic will be 82 percent of all IP traffic (both business and consumer) by 2022, up from 75 percent in 2017.” … “The implications of video growth are difficult to overstate.” … “Because of video consumption patterns, the Internet now has a much busier busy hour. Because video has a higher peak-to-average ratio than data or file sharing, and because video is gaining traffic share, peak Internet traffic will grow faster than average traffic.” – Cisco Systems, November 2018 [9]. [↑](#footnote-ref-1)