ï»¿

Internet Engineering Task Force (IETF)
Request for Comments: 9328
Category: Standards Track
ISSN: 2070-1721

S. Zhao
Intel
S. Wenger
Tencent
Y. Sanchez
Fraunhofer HHI
Y.-K. Wang
Bytedance Inc.
M. M Hannuksela
Nokia Technologies

December 2022

RTP Payload Format for Versatile Video Coding (VVC)

Abstract

This memo describes an RTP payload format for the Versatile Video Coding (VVC) specification, which was published as both ITU-T Recommendation H.266 and ISO/IEC International Standard 23090-3. VVC was developed by the Joint Video Experts Team (JVET). The RTP payload format allows for packetization of one or more Network Abstraction Layer (NAL) units in each RTP packet payload, as well as fragmentation of a NAL unit into multiple RTP packets. The payload format has wide applicability in videoconferencing, Internet video streaming, and high-bitrate entertainment-quality video, among other applications.

Status of This Memo

This is an Internet Standards Track document.

This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Further information on Internet Standards is available in Section 2 of RFC 7841.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at https://www.rfc-editor.org/info/rfc9328.

Table of Contents

1. Introduction

The Versatile Video Coding specification was formally published as both ITU-T Recommendation H.266 [VVC] and ISO/IEC International Standard 23090-3 [ISO23090-3]. VVC is reported to provide significant coding efficiency gains over High Efficiency Video Coding [HEVC], also known as H.265, and other earlier video codecs.

This memo specifies an RTP payload format for VVC. It shares its basic design with the NAL-unit-based RTP payload formats of Advanced Video Coding (AVC) [RFC6184], Scalable Video Coding (SVC) [RFC6190], and High Efficiency Video Coding (HEVC) [RFC7798], as well as their respective predecessors. With respect to design philosophy, security, congestion control, and overall implementation complexity, it has similar properties to those earlier payload format specifications. This is a conscious choice, as at least [RFC6184] is widely deployed and generally known in the relevant implementer communities. Certain scalability-related mechanisms known from [RFC6190] were incorporated into this document, as VVC version 1 supports temporal, spatial, and signal-to-noise ratio (SNR) scalability.

1.1. Overview of the VVC Codec

VVC and HEVC share a similar hybrid video codec design. In this memo, we provide a very brief overview of those features of VVC that are, in some form, addressed by the payload format specified herein. Implementers have to read, understand, and apply the ITU-T/ISO/IEC specifications pertaining to VVC to arrive at interoperable, well-performing implementations.

Conceptually, both VVC and HEVC include a Video Coding Layer (VCL), which is often used to refer to the coding-tool features, and a NAL, which is often used to refer to the systems and transport interface aspects of the codecs.

1.1.1. Coding-Tool Features (Informative)

Coding-tool features are described below with occasional reference to the coding-tool set of HEVC, which is well known in the community.

Similar to earlier hybrid-video-coding-based standards, including HEVC, the following basic video coding design is employed by VVC. A prediction signal is first formed by either intra- or motion-compensated prediction, and the residual (the difference between the original and the prediction) is then coded. The gains in coding efficiency are achieved by redesigning and improving almost all parts of the codec over earlier designs. In addition, VVC includes several tools to make the implementation on parallel architectures easier.

Finally, VVC includes temporal, spatial, and SNR scalability, as well as multiview coding support.

Coding blocks and transform structure
: Among major coding-tool differences between HEVC and VVC, one of the important improvements is the more flexible coding tree structure in VVC, i.e., multi-type tree. In addition to quadtree, binary and ternary trees are also supported, which contributes significant improvement in coding efficiency. Moreover, the maximum size of a coding tree unit (CTU) is increased from 64x64 to 128x128. To improve the coding efficiency of chroma signal, luma-chroma-separated trees at CTU level may be employed for intra slices. The square transforms in HEVC are extended to non-square transforms for rectangular blocks resulting from binary and ternary tree splits. Besides, VVC supports multiple transform sets (MTSs), including DCT-2, DST-7, and DCT-8, as well as the non-separable secondary transform. The transforms used in VVC can have different sizes with support for larger transform sizes. For DCT-2, the transform sizes range from 2x2 to 64x64, and for DST-7 and DCT-8, the transform sizes range from 4x4 to 32x32. In addition, VVC also support sub-block transform for both intra- and inter-coded blocks. For intra-coded blocks, intra sub-partitioning (ISP) may be used to allow sub-block-based intra prediction and transform. For inter blocks, sub-block transform may be used assuming that only a part of an inter block has non-zero transform coefficients.

Entropy coding
: Similar to HEVC, VVC uses a single entropy-coding engine, which is based on context adaptive binary arithmetic coding [CABAC] but with the support of multi-window sizes. The window sizes can be initialized differently for different context models. Due to such a design, it has more efficient adaptation speed and better coding efficiency. A joint chroma residual coding scheme is applied to further exploit the correlation between the residuals of two color components. In VVC, different residual coding schemes are applied for regular transform coefficients and residual samples generated using transform-skip mode.

In-loop filtering
: VVC has more feature support in loop filters than HEVC. The deblocking filter in VVC is similar to HEVC but operates at a smaller grid. After deblocking and sample adaptive offset (SAO), an adaptive loop filter (ALF) may be used. As a Wiener filter, ALF reduces distortion of decoded pictures. Besides, VVC introduces a new module called luma mapping with chroma scaling to fully utilize the dynamic range of signal so that rate-distortion performance of both Standard Dynamic Range (SDR) and High Dynamic Range (HDR) content is improved.

Motion prediction and coding
: Compared to HEVC, VVC introduces several improvements in this area. First, there is the adaptive motion vector resolution (AMVR), which can save bit cost for motion vectors by adaptively signaling motion vector resolution. Then, the affine motion compensation is included to capture complicated motion-like

zooming and rotation. Meanwhile, prediction refinement with the optical flow (PROF) with affine mode is further deployed to mimic affine motion at the pixel level. Thirdly, the decoder-side motion vector refinement (DMVR) is a method to derive the motion vector at the decoder side based on block matching so that fewer bits may be spent on motion vectors. Bidirectional optical flow (BDOF) is a similar method to PROF. BDOF adds a sample-wise offset at the 4x4 sub-block level that is derived with equations based on gradients of the prediction samples and a motion difference relative to coding-unit (CU) motion vectors. Furthermore, merge with motion vector difference (MMVD) is a special mode that further signals a limited set of motion vector differences on top of merge mode. In addition to MMVD, there are another three types of special merge modes, i.e., sub-block merge, triangle, and combined intra/inter prediction (CIIP). The sub-block merge list includes one candidate of sub-block temporal motion vector prediction (SbTMVP) and up to four candidates of affine motion vectors. Triangle is based on triangular block motion compensation. CIIP combines intra and inter predictions with weighting. Adaptive weighting may be employed with a block-level tool called bi-prediction with CU-based weighting (BCW), which provides more flexibility than in HEVC.

Intra prediction and intra coding

To capture the diversified local image texture directions with finer granularity, VVC supports 65 angular directions instead of 33 directions in HEVC. The intra mode coding is based on a 6-most-probable-modes scheme, and the 6 most probable modes are derived using the neighboring intra prediction directions. In addition, to deal with the different distributions of intra prediction angles for different block aspect ratios, a wide-angle-intra-prediction (WAIP) scheme is applied in VVC by including intra prediction angles beyond those present in HEVC. Unlike HEVC, which only allows using the most adjacent line of reference samples for intra prediction, VVC also allows using two further reference lines, known as multi-reference-line (MRL) intra prediction. The additional reference lines can be only used for the 6 most probable intra prediction modes. To capture the strong correlation between different color components, in VVC, a cross-component linear mode (CCLM) is utilized, which assumes a linear relationship between the luma sample values and their associated chroma samples. For intra prediction, VVC also applies a position-dependent prediction combination (PDPC) for refining the prediction samples closer to the intra prediction block boundary. Matrix-based intra prediction (MIP) modes are also used in VVC, which generates an up to 8x8 intra prediction block using a weighted sum of downsampled neighboring reference samples, and the weights are hard-coded constants.

Other coding-tool features

VVC introduces dependent quantization (DQ) to reduce quantization error by state-based switching between two quantizers.

1.1.2. Systems and Transport Interfaces (Informative)

VVC inherits the basic systems and transport interface designs from HEVC and AVC. These include the NAL-unit-based syntax structure, the hierarchical syntax and data unit structure, the supplemental enhancement information (SEI) message mechanism, and the video buffering model based on the hypothetical reference decoder (HRD). The scalability features of VVC are conceptually similar to the scalable extension of HEVC, known as SHVC. The hierarchical syntax and data unit structure consists of parameter sets at various levels (i.e., decoder, sequence (pertaining to all), sequence (pertaining to a single), and picture), picture-level header parameters, slice-level header parameters, and lower-level parameters.

A number of key components that influenced the network abstraction layer design of VVC, as well as this memo, are described below

Decoding capability information

The decoding capability information (DCI) includes parameters that stay constant for the lifetime of a VVC bitstream in the duration of a video conference, continuous video stream, and similar, i.e., any video that is processed by a decoder between setup and teardown. For streaming, the requirement of constant parameters pertains through splicing. Such information includes profile, level, and sub-profile information to determine a maximum capability interop point that is guaranteed to never be exceeded, even if splicing of video sequences occurs within a session. It further includes constraint fields (most of which are flags), which can optionally be set to indicate that the video bitstream will be constrained in the use of certain features, as indicated by the values of those fields. With this, a bitstream can be labeled as not using certain tools, which allows, among other things, for resource allocation in a decoder implementation.

Video parameter set

The video parameter set (VPS) pertains to one or more coded video sequences (CVSs) of multiple layers covering the same range of access units and includes, among other information, decoding dependency expressed as information for reference-picture-list construction of enhancement layers. The VPS provides a "big picture" of a scalable sequence, including what types of operation points are provided; the profile, tier, and level of the operation points; and some other high-level properties of the bitstream that can be used as the basis for session negotiation and content selection, etc. One VPS may be referenced by one or more sequence parameter sets.

Sequence parameter set

The sequence parameter set (SPS) contains syntax elements pertaining to a coded layer video sequence (CLVS), which is a group of pictures belonging to the same layer, starting with a random access point, and followed by pictures that may depend on each other until the next random access point picture. In MPEG-2, the equivalent of a CVS was a group of pictures (GOP), which normally started with an I frame and was followed by P and B frames. While more complex in its options of random access points, VVC retains this basic concept. One remarkable difference of VVC is that a CLVS may start with a Gradual Decoding Refresh (GDR) picture without requiring presence of traditional random access points in the bitstream, such as instantaneous decoding refresh (IDR) or clean random access (CRA) pictures. In many TV-like applications, a CVS contains a few hundred milliseconds to a few seconds of video. In video conferencing (without switching Multipoint Control Units (MCUs) involved), a CVS can be as long in duration as the whole session.

Picture and adaptation parameter set

The picture parameter set (PPS) and the adaptation parameter set (APS) carry information pertaining to zero or more pictures and zero or more slices, respectively. The PPS contains information that is likely to stay constant from picture to picture, at least for pictures for a certain type, whereas the APS contains information, such as adaptive loop filter coefficients, that are likely to change from picture to picture or even within a picture. A single APS is referenced by all slices of the same picture if that APS contains information about luma mapping with chroma scaling (LMCS) or a scaling list. Different APSs containing ALF parameters can be referenced by slices of the same picture.

Picture header

A picture header (PH) contains information that is common to all slices that belong to the same picture. Being able to send that information as a separate NAL unit when pictures are split into several slices allows for saving bitrate, compared to repeating the same information in all slices. However, there might be scenarios where low-bitrate video is transmitted using a single slice per picture. Having a separate NAL unit to convey that information incurs in an overhead for such scenarios. For such scenarios, the picture header syntax structure is directly

included in the slice header, instead of its own NAL unit. The mode of the picture header syntax structure being included in its own NAL unit or not can only be switched on/off for an entire CLVS and can only be switched off when, in the entire CLVS, each picture contains only one slice.

Profile, tier, and level
: The profile, tier, and level syntax structures in DCI, VPS, and SPS contain profile, tier, and level information for all layers that refer to the DCI, for layers associated with one or more output layer sets specified by the VPS, and for any layer that refers to the SPS, respectively.

Sub-profiles
: Within the VVC specification, a sub-profile is a 32-bit number, coded according to ITU-T Recommendation T.35, that does not carry semantics. It is carried in the profile_tier_level structure and hence is (potentially) present in the DCI, VPS, and SPS. External registration bodies can register a T.35 codepoint with ITU-T registration authorities and associate with their registration a description of bitstream restrictions beyond the profiles defined by ITU-T and ISO/IEC. This would allow encoder manufacturers to label the bitstreams generated by their encoder as complying with such sub-profile. It is expected that upstream standardization organizations (such as Digital Video Broadcasting (DVB) and Advanced Television Systems Committee (ATSC)), as well as walled-garden video services, will take advantage of this labeled system. In contrast to "normal" profiles, it is expected that sub-profiles may indicate encoder choices traditionally left open in the (decoder-centric) video coding specifications, such as GOP structures, minimum/maximum Quantizer Parameter (QP) values, and the mandatory use of certain tools or SEI messages.

General constraint fields
: The profile_tier_level structure carries a considerable number of constraint fields (most of which are flags), which an encoder can use to indicate to a decoder that it will not use a certain tool or technology. They were included in reaction to a perceived market need to label a bitstream as not exercising a certain tool that has become commercially unviable.

Temporal scalability support
: VVC includes support of temporal scalability, by the inclusion of the signaling of TemporalId in the NAL unit header, the restriction that pictures of a particular temporal sublayer cannot be used for inter prediction reference by pictures of a lower temporal sublayer, the sub-bitstream extraction process, and the requirement that each sub-bitstream extraction output be a conforming bitstream. Media-Aware Network Elements (MANEs) can utilize the TemporalId in the NAL unit header for stream adaptation purposes based on temporal scalability.

Reference picture resampling (RPR)
: In AVC and HEVC, the spatial resolution of pictures cannot change unless a new sequence using a new SPS starts, with an intra random access point (IRAP) picture. VVC enables picture resolution change within a sequence at a position without encoding an IRAP picture, which is always intra coded. This feature is sometimes referred to as reference picture resampling (RPR), as the feature needs resampling of a reference picture used for inter prediction when that reference picture has a different resolution than the current picture being decoded. RPR allows resolution change without the need of coding an IRAP picture and hence avoids a momentary bit rate spike caused by an IRAP picture in streaming or video conferencing scenarios, e.g., to cope with network condition changes. RPR can also be used in application scenarios wherein zooming of the entire video region or some region of interest is needed.

Spatial, SNR, and multiview scalability
: VVC includes support for spatial, SNR, and multiview scalability.

Scalable video coding is widely considered to have technical benefits and enrich services for various video applications. Until recently, however, the functionality has not been included in the first version of specifications of the video codecs. In VVC, however, all those forms of scalability are supported in the first version of VVC natively through the signaling of the nuh_layer_id in the NAL unit header, the VPS that associates layers with the given nuh_layer_id to each other, reference picture selection, reference picture resampling for spatial scalability, and a number of other mechanisms not relevant for this memo.

Spatial scalability
With the existence of reference picture resampling (RPR), the additional burden for scalability support is just a modification of the high-level syntax (HLS). The inter-layer prediction is employed in a scalable system to improve the coding efficiency of the enhancement layers. In addition to the spatial and temporal motion-compensated predictions that are available in a single-layer codec, the inter-layer prediction in VVC uses the possibly resampled video data of the reconstructed reference picture from a reference layer to predict the current enhancement layer. The resampling process for inter-layer prediction, when used, is performed at the block level, reusing the existing interpolation process for motion compensation in single-layer coding. It means that no additional resampling process is needed to support spatial scalability.

SNR scalability
SNR scalability is similar to spatial scalability except that the resampling factors are 1:1. In other words, there is no change in resolution, but there is inter-layer prediction.

Multiview scalability
The first version of VVC also supports multiview scalability, wherein a multi-layer bitstream carries layers representing multiple views, and one or more of the represented views can be output at the same time.

SEI messages
Supplemental enhancement information (SEI) messages are information in the bitstream that do not influence the decoding process as specified in the VVC specification but address issues of representation/rendering of the decoded bitstream, label the bitstream for certain applications, and other, similar tasks. The overall concept of SEI messages and many of the messages themselves has been inherited from the AVC and HEVC specifications. Except for the SEI messages that affect the specification of the hypothetical reference decoder (HRD), other SEI messages for use in the VVC environment, which are generally useful also in other video coding technologies, are not included in the main VVC specification but in a companion specification [VSEI].

1.1.3. High-Level Picture Partitioning (Informative)

VVC inherited the concept of tiles and wavefront parallel processing (WPP) from HEVC, with some minor to moderate differences. The basic concept of slices was kept in VVC but designed in an essentially different form. VVC is the first video coding standard that includes subpictures as a feature, which provides the same functionality as HEVC motion-constrained tile sets (MCTSs) but designed differently to have better coding efficiency and to be friendlier for usage in application systems. More details of these differences are described below.

Tiles and WPP
Same as in HEVC, a picture can be split into tile rows and tile columns in VVC, in-picture prediction across tile boundaries is disallowed, etc. However, the syntax for signaling of tile

partitioning has been simplified by using a unified syntax design for both the uniform and the non-uniform mode. In addition, signaling of entry point offsets for tiles in the slice header is optional in VVC, while it is mandatory in HEVC. The WPP design in VVC has two differences compared to HEVC: i) the CTU row delay is reduced from two CTUs to one CTU, and ii) signaling of entry point offsets for WPP in the slice header is optional in VVC while it is mandatory in HEVC.

Slices

In VVC, the conventional slices based on CTUs (as in HEVC) or macroblocks (as in AVC) have been removed. The main reasoning behind this architectural change is as follows. The advances in video coding since 2003 (the publication year of AVC v1) have been such that slice-based error concealment has become practically impossible due to the ever-increasing number and efficiency of in-picture and inter-picture prediction mechanisms. An error-concealed picture is the decoding result of a transmitted coded picture for which there is some data loss (e.g., loss of some slices) of the coded picture or a reference picture, as at least some part of the coded picture is not error-free (e.g., that reference picture was an error-concealed picture). For example, when one of the multiple slices of a picture is lost, it may be error-concealed using an interpolation of the neighboring slices. While advanced video coding prediction mechanisms provide significantly higher coding efficiency, they also make it harder for machines to estimate the quality of an error-concealed picture, which was already a hard problem with the use of simpler prediction mechanisms. Advanced in-picture prediction mechanisms also cause the coding efficiency loss due to splitting a picture into multiple slices to be more significant. Furthermore, network conditions become significantly better while, at the same time, techniques for dealing with packet losses have become significantly improved. As a result, very few implementations have recently used slices for maximum-transmission-unit-size matching. Instead, substantially all applications where low-delay error resilience is required (e.g., video telephony and video conferencing) rely on system/transport-level error resilience (e.g., retransmission or forward error correction) and/or picture-based error resilience tools (e.g., feedback-based error resilience, insertion of IRAPs, scalability with a higher protection level of the base layer, and so on). Considering all the above, nowadays, it is very rare that a picture that cannot be correctly decoded is passed to the decoder, and when such a rare case occurs, the system can afford to wait for an error-free picture to be decoded and available for display without resulting in frequent and long periods of picture freezing seen by end users.

Slices in VVC have two modes: rectangular slices and raster-scan slices. The rectangular slice, as indicated by its name, covers a rectangular region of the picture. Typically, a rectangular slice consists of several complete tiles. However, it is also possible that a rectangular slice is a subset of a tile and consists of one or more consecutive, complete CTU rows within a tile. A raster-scan slice consists of one or more complete tiles in a tile raster-scan order; hence, the region covered by raster-scan slices need not but could have a non-rectangular shape, but it may also happen to have the shape of a rectangle. The concept of slices in VVC is therefore strongly linked to or based on tiles instead of CTUs (as in HEVC) or macroblocks (as in AVC).

Subpictures

VVC is the first video coding standard that includes the support of subpictures as a feature. Each subpicture consists of one or more complete rectangular slices that collectively cover a rectangular region of the picture. A subpicture may be either specified to be extractable (i.e., coded independently of other subpictures of the same picture and of earlier pictures in decoding order) or not extractable. Regardless of whether a subpicture is extractable or not, the encoder can control whether

in-loop filtering (including deblocking, SAO, and ALF) is applied across the subpicture boundaries individually for each subpicture.

Functionally, subpictures are similar to the motion-constrained tile sets (MCTSs) in HEVC. They both allow independent coding and extraction of a rectangular subset of a sequence of coded pictures for use cases like viewport-dependent 360-degree video streaming optimization and region of interest (ROI) applications.

There are several important design differences between subpictures and MCTSs. First, the subpictures featured in VVC allow motion vectors of a coding block to point outside of the subpicture, even when the subpicture is extractable by applying sample padding at the subpicture boundaries, in this case, similarly as at picture boundaries. Second, additional changes were introduced for the selection and derivation of motion vectors in the merge mode and in the decoder-side motion vector refinement process of VVC. This allows higher coding efficiency compared to the non-normative motion constraints applied at the encoder-side for MCTSs. Third, rewriting of slice headers (SHs) (and PH NAL units, when present) is not needed when extracting one or more extractable subpictures from a sequence of pictures to create a sub-bitstream that is a conforming bitstream. In sub-bitstream extractions based on HEVC MCTSs, rewriting of SHs is needed. Note that, in both HEVC MCTSs extraction and VVC subpictures extraction, rewriting of SPSs and PPSs is needed. However, typically, there are only a few parameter sets in a bitstream, whereas each picture has at least one slice; therefore, rewriting of SHs can be a significant burden for application systems. Fourth, slices of different subpictures within a picture are allowed to have different NAL unit types. Fifth, VVC specifies HRD and level definitions for subpicture sequences, thus the conformance of the sub-bitstream of each extractable subpicture sequence can be ensured by encoders.

1.1.4. NAL Unit Header

VVC maintains the NAL unit concept of HEVC with modifications. VVC uses a two-byte NAL unit header, as shown in Figure 1. The payload of a NAL unit refers to the NAL unit excluding the NAL unit header.

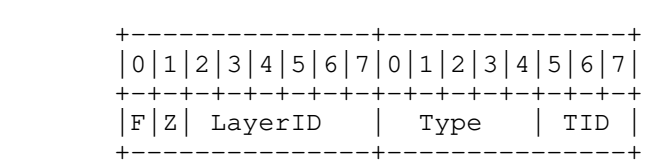


Figure 1: The Structure of the VVC NAL Unit Header

The semantics of the fields in the NAL unit header are as specified in VVC and described briefly below for convenience. In addition to the name and size of each field, the corresponding syntax element name in VVC is also provided.

F: 1 bit
forbidden_zero_bit. This field is required to be zero in VVC. Note that the inclusion of this bit in the NAL unit header was to enable transport of VVC video over MPEG-2 transport systems (avoidance of start code emulations) [MPEG2S]. In the context of this payload format, the value 1 may be used to indicate a syntax violation, e.g., for a NAL unit resulted from aggregating a number of fragmented units of a NAL unit but missing the last fragment, as described in the last sentence of Section 4.3.3.

Z: 1 bit
nuh_reserved_zero_bit. This field is required to be zero in VVC, and reserved for future extensions by ITU-T and ISO/IEC.
This memo does not overload the "Z" bit for local extensions a) because overloading the "F" bit is sufficient and b) in order to preserve the usefulness of this memo to possible future versions of [VVC].

LayerId: 6 bits
: nuh_layer_id. This field identifies the layer a NAL unit belongs to, wherein a layer may be, e.g., a spatial scalable layer, a quality scalable layer, a layer containing a different view, etc.

Type: 5 bits
: nal_unit_type. This field specifies the NAL unit type, as defined in Table 5 of [VVC]. For a reference of all currently defined NAL unit types and their semantics, please refer to Section 7.4.2.2 in [VVC].

TID: 3 bits
: nuh_temporal_id_plus1. This field specifies the temporal identifier of the NAL unit plus 1. The value of TemporalId is equal to TID minus 1. A TID value of 0 is illegal to ensure that there is at least one bit in the NAL unit header equal to 1 in order to enable the consideration of start code emulations in the NAL unit payload data independent of the NAL unit header.

1.2. Overview of the Payload Format

This payload format defines the following processes required for transport of VVC coded data over RTP [RFC3550]:

* usage of the RTP header with this payload format

* packetization of VVC coded NAL units into RTP packets using three types of payload structures: a single NAL unit packet, aggregation packet, and fragment unit

* transmission of VVC NAL units of the same bitstream within a single RTP stream

* media type parameters to be used with the Session Description Protocol (SDP) [RFC8866]

* usage of RTCP feedback messages

2. Conventions

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

3. Definitions and Abbreviations

3.1. Definitions

This document uses the terms and definitions of VVC. Section 3.1.1 lists relevant definitions from [VVC] for convenience. Section 3.1.2 provides definitions specific to this memo. All the used terms and definitions in this memo are verbatim copies from the [VVC] specification.

3.1.1. Definitions from the VVC Specification

Access unit (AU):
: A set of PUs that belong to different layers and contain coded pictures associated with the same time for output from the DPB.

Adaptation parameter set (APS):
: A syntax structure containing syntax elements that apply to zero or more slices as determined by zero or more syntax elements found in slice headers.

Bitstream:
: A sequence of bits, in the form of a NAL unit stream or a byte stream, that forms the representation of a sequence of AUs forming one or more coded video sequences (CVSs).

Coded picture:
   A coded representation of a picture comprising VCL NAL units with a particular value of nuh_layer_id within an AU and containing all CTUs of the picture.

Clean random access (CRA) PU:
   A PU in which the coded picture is a CRA picture.

Clean random access (CRA) picture:
   An IRAP picture for which each VCL NAL unit has nal_unit_type equal to CRA_NUT.

Coded video sequence (CVS):
   A sequence of AUs that consists, in decoding order, of a CVSS AU, followed by zero or more AUs that are not CVSS AUs, including all subsequent AUs up to but not including any subsequent AU that is a CVSS AU.

Coded video sequence start (CVSS) AU:
   An AU in which there is a PU for each layer in the CVS and the coded picture in each PU is a CLVSS picture.

Coded layer video sequence (CLVS):
   A sequence of PUs with the same value of nuh_layer_id that consists, in decoding order, of a CLVSS PU, followed by zero or more PUs that are not CLVSS PUs, including all subsequent PUs up to but not including any subsequent PU that is a CLVSS PU.

Coded layer video sequence start (CLVSS) PU:
   A PU in which the coded picture is a CLVSS picture.

Coded layer video sequence start (CLVSS) picture:
   A coded picture that is an IRAP picture with NoOutputBeforeRecoveryFlag equal to 1 or a GDR picture with NoOutputBeforeRecoveryFlag equal to 1.

Coding Tree Block (CTB):
   An NxN block of samples for some value of N such that the division of a component into CTBs is a partitioning.

Coding tree unit (CTU):
   A CTB of luma samples, two corresponding CTBs of chroma samples of a picture that has three sample arrays, or a CTB of samples of a monochrome picture or a picture that is coded using three separate colour planes and syntax structures used to code the samples.

Coding Unit (CU):
   A coding block of luma samples, two corresponding coding blocks of chroma samples of a picture that has three sample arrays in the single tree mode, or a coding block of luma samples of a picture that has three sample arrays in the dual tree mode, or two coding blocks of chroma samples of a picture that has three sample arrays in the dual tree mode, or a coding block of samples of a monochrome picture, and syntax structures used to code the samples.

Decoding Capability Information (DCI):
   A syntax structure containing syntax elements that apply to the entire bitstream.

Decoded picture buffer (DPB):
   A buffer holding decoded pictures for reference, output reordering, or output delay specified for the hypothetical reference decoder.

Gradual decoding refresh (GDR) picture:
   A picture for which each VCL NAL unit has nal_unit_type equal to GDR_NUT.

Instantaneous decoding refresh (IDR) PU:

A PU in which the coded picture is an IDR picture.

Instantaneous decoding refresh (IDR) picture:
An IRAP picture for which each VCL NAL unit has nal_unit_type equal to IDR_W_RADL or IDR_N_LP.

Intra random access point (IRAP) AU:
An AU in which there is a PU for each layer in the CVS and the coded picture in each PU is an IRAP picture.

Intra random access point (IRAP) PU:
A PU in which the coded picture is an IRAP picture.

Intra random access point (IRAP) picture:
A coded picture for which all VCL NAL units have the same value of nal_unit_type in the range of IDR_W_RADL to CRA_NUT, inclusive.

Layer:
A set of VCL NAL units that all have a particular value of nuh_layer_id and the associated non-VCL NAL units.

Network abstraction layer (NAL) unit:
A syntax structure containing an indication of the type of data to follow and bytes containing that data in the form of an RBSP interspersed as necessary with emulation prevention bytes.

Network abstraction layer (NAL) unit stream:
A sequence of NAL units.

Output Layer Set (OLS):
A set of layers for which one or more layers are specified as the output layers.

Operation point (OP):
A temporal subset of an OLS, identified by an OLS index and a highest value of TemporalId.

Picture Header (PH):
A syntax structure containing syntax elements that apply to all slices of a coded picture.

Picture parameter set (PPS):
A syntax structure containing syntax elements that apply to zero or more entire coded pictures as determined by a syntax element found in each slice header.

Picture unit (PU):
A set of NAL units that are associated with each other according to a specified classification rule, are consecutive in decoding order, and contain exactly one coded picture.

Random access:
The act of starting the decoding process for a bitstream at a point other than the beginning of the bitstream.

Raw Byte Sequence Payload (RBSP):
A syntax structure containing an integer number of bytes that is encapsulated in a NAL unit and is either empty or has the form of a string of data bits containing syntax elements followed by an RBSP stop bit and zero or more subsequent bits equal to 0.

Sequence parameter set (SPS):
A syntax structure containing syntax elements that apply to zero or more entire CLVSs as determined by the content of a syntax element found in the PPS referred to by a syntax element found in each picture header.

Slice:
An integer number of complete tiles or an integer number of consecutive complete CTU rows within a tile of a picture that are exclusively contained in a single NAL unit.

Slice header (SH):
A part of a coded slice containing the data elements pertaining to all tiles or CTU rows within a tile represented in the slice.

Sublayer:
A temporal scalable layer of a temporal scalable bitstream consisting of VCL NAL units with a particular value of the TemporalId variable, and the associated non-VCL NAL units.

Subpicture:
A rectangular region of one or more slices within a picture.

Sublayer representation:
A subset of the bitstream consisting of NAL units of a particular sublayer and the lower sublayers.

Tile:
A rectangular region of CTUs within a particular tile column and a particular tile row in a picture.

Tile column:
A rectangular region of CTUs having a height equal to the height of the picture and a width specified by syntax elements in the picture parameter set.

Tile row:
A rectangular region of CTUs having a height specified by syntax elements in the picture parameter set and a width equal to the width of the picture.

Video coding layer (VCL) NAL unit:
A collective term for coded slice NAL units and the subset of NAL units that have reserved values of nal_unit_type that are classified as VCL NAL units in this Specification.

3.1.2. Definitions Specific to This Memo

Media-Aware Network Element (MANE):
A network element, such as a middlebox, selective forwarding unit, or application-layer gateway that is capable of parsing certain aspects of the RTP payload headers or the RTP payload and reacting to their contents.

> Informative note: The concept of a MANE goes beyond normal routers or gateways in that a MANE has to be aware of the signaling (e.g., to learn about the payload type mappings of the media streams), and in that it has to be trusted when working with Secure RTP (SRTP). The advantage of using MANEs is that they allow packets to be dropped according to the needs of the media coding. For example, if a MANE has to drop packets due to congestion on a certain link, it can identify and remove those packets whose elimination produces the least adverse effect on the user experience. After dropping packets, MANEs must rewrite RTCP packets to match the changes to the RTP stream, as specified in Section 7 of [RFC3550].

NAL unit decoding order:
A NAL unit order that conforms to the constraints on NAL unit order given in Section 7.4.2.4 in [VVC], follow the order of NAL units in the bitstream.

RTP stream (see [RFC7656]):
Within the scope of this memo, one RTP stream is utilized to transport a VVC bitstream, which may contain one or more layers, and each layer may contain one or more temporal sublayers.

Transmission order:
The order of packets in ascending RTP sequence number order (in modulo arithmetic). Within an aggregation packet, the NAL unit

transmission order is the same as the order of appearance of NAL units in the packet.

3.2. Abbreviations

AU	Access Unit
AP	Aggregation Packet
APS	Adaptation Parameter Set
CTU	Coding Tree Unit
CVS	Coded Video Sequence
DPB	Decoded Picture Buffer
DCI	Decoding Capability Information
DON	Decoding Order Number
FIR	Full Intra Request
FU	Fragmentation Unit
GDR	Gradual Decoding Refresh
HRD	Hypothetical Reference Decoder
IDR	Instantaneous Decoding Refresh
IRAP	Intra Random Access Point
MANE	Media-Aware Network Element
MTU	Maximum Transfer Unit
NAL	Network Abstraction Layer
NALU	Network Abstraction Layer Unit
OLS	Output Layer Set
PLI	Picture Loss Indication
PPS	Picture Parameter Set
RPSI	Reference Picture Selection Indication
SEI	Supplemental Enhancement Information
SLI	Slice Loss Indication
SPS	Sequence Parameter Set
VCL	Video Coding Layer
VPS	Video Parameter Set

4. RTP Payload Format

4.1. RTP Header Usage

The format of the RTP header is specified in [RFC3550] (reprinted as Figure 2 for convenience). This payload format uses the fields of the header in a manner consistent with that specification.

The RTP payload (and the settings for some RTP header bits) for aggregation packets and fragmentation units are specified in Sections 4.3.2 and 4.3.3, respectively.

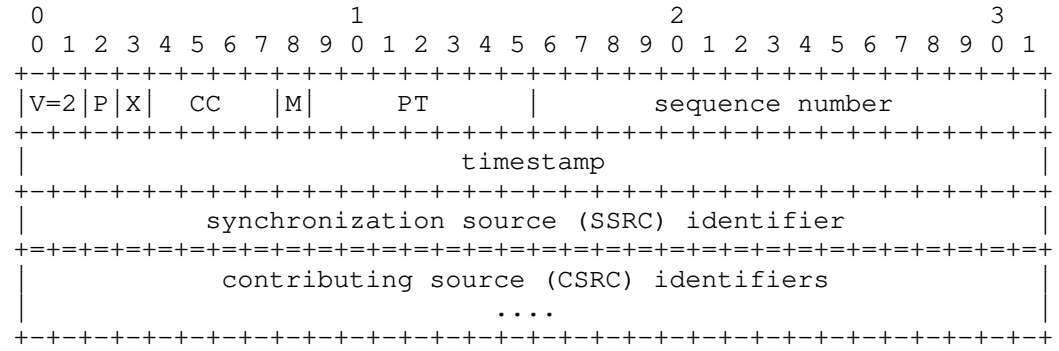


Figure 2: RTP Header According to RFC 3550

The RTP header information to be set according to this RTP payload format is set as follows:

Marker bit (M): 1 bit
Set for the last packet, in transmission order, among each set of packets that contain NAL units of one access unit. This is in line with the normal use of the M bit in video formats to allow an efficient playout buffer handling.

Payload Type (PT): 7 bits
The assignment of an RTP payload type for this new packet format is outside the scope of this document and will not be specified here. The assignment of a payload type has to be performed either through the profile used or in a dynamic way.

Sequence Number (SN): 16 bits
Set and used in accordance with [RFC3550].

Timestamp: 32 bits
The RTP timestamp is set to the sampling timestamp of the content. A 90 kHz clock rate MUST be used. If the NAL unit has no timing properties of its own (e.g., parameter set and SEI NAL units), the RTP timestamp MUST be set to the RTP timestamp of the coded pictures of the access unit in which the NAL unit (according to Section 7.4.2.4 of [VVC]) is included. Receivers MUST use the RTP timestamp for the display process, even when the bitstream contains picture timing SEI messages or decoding unit information SEI messages, as specified in [VVC].

> Informative note: When picture timing SEI messages are present, the RTP sender is responsible to ensure that the RTP timestamps are consistent with the timing information carried in the picture timing SEI messages.

Synchronization source (SSRC): 32 bits
Used to identify the source of the RTP packets. A single SSRC is used for all parts of a single bitstream.

4.2. Payload Header Usage

The first two bytes of the payload of an RTP packet are referred to as the payload header. The payload header consists of the same fields (F, Z, LayerId, Type, and TID) as the NAL unit header shown in Section 1.1.4, irrespective of the type of the payload structure.

The TID value indicates (among other things) the relative importance of an RTP packet, for example, because NAL units belonging to higher temporal sublayers are not used for the decoding of lower temporal sublayers. A lower value of TID indicates a higher importance. More important NAL units MAY be better protected against transmission losses than less-important NAL units.

4.3. Payload Structures

Three different types of RTP packet payload structures are specified. A receiver can identify the type of an RTP packet payload through the

Type field in the payload header.

The three different payload structures are as follows:

* Single NAL unit packet: Contains a single NAL unit in the payload, and the NAL unit header of the NAL unit also serves as the payload header. This payload structure is specified in Section 4.3.1.

* Aggregation Packet (AP): Contains more than one NAL unit within one access unit. This payload structure is specified in Section 4.3.2.

* Fragmentation Unit (FU): Contains a subset of a single NAL unit. This payload structure is specified in Section 4.3.3.

4.3.1. Single NAL Unit Packets

A single NAL unit packet contains exactly one NAL unit and consists of a payload header, as defined in Table 5 of [VVC] (denoted here as PayloadHdr), following with a conditional 16-bit DONL field (in network byte order), and the NAL unit payload data (the NAL unit excluding its NAL unit header) of the contained NAL unit, as shown in Figure 3.

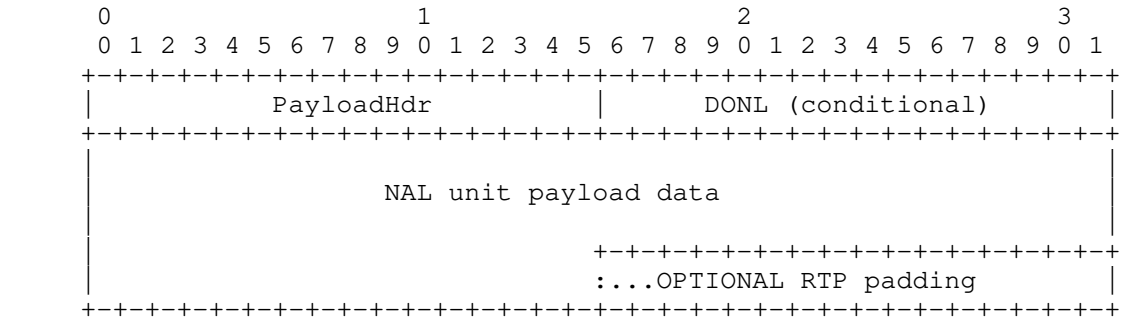


Figure 3: The Structure of a Single NAL Unit Packet

The DONL field, when present, specifies the value of the 16 least significant bits of the decoding order number of the contained NAL unit. If sprop-max-don-diff (defined in Section 7.2) is greater than 0, the DONL field MUST be present, and the variable DON for the contained NAL unit is derived as equal to the value of the DONL field. Otherwise (sprop-max-don-diff is equal to 0), the DONL field MUST NOT be present.

4.3.2. Aggregation Packets (APs)

Aggregation packets (APs) can reduce packetization overhead for small NAL units, such as most of the non-VCL NAL units, which are often only a few octets in size.

An AP aggregates NAL units of one access unit, and it MUST NOT contain NAL units from more than one AU. Each NAL unit to be carried in an AP is encapsulated in an aggregation unit. NAL units aggregated in one AP are included in NAL-unit-decoding order.

An AP consists of a payload header, as defined in Table 5 of [VVC] (denoted here as PayloadHdr with Type=28), followed by two or more aggregation units, as shown in Figure 4.

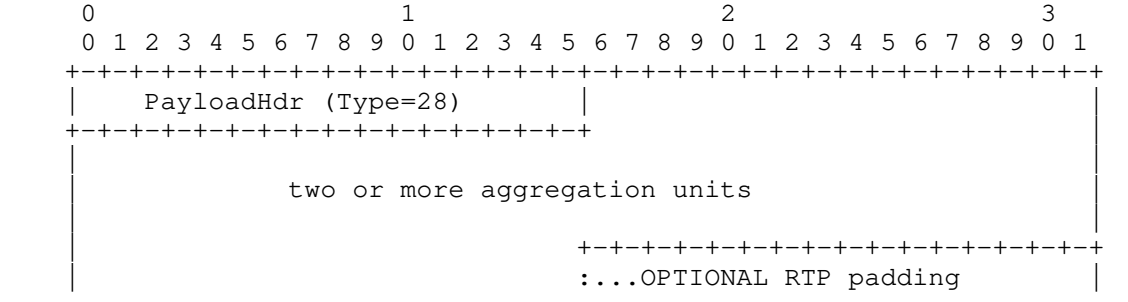


Figure 4: The Structure of an Aggregation Packet

The fields in the payload header of an AP are set as follows. The F bit MUST be equal to 0 if the F bit of each aggregated NAL unit is equal to zero; otherwise, it MUST be equal to 1. The Type field MUST be equal to 28.

The value of LayerId MUST be equal to the lowest value of LayerId of all the aggregated NAL units. The value of TID MUST be the lowest value of TID of all the aggregated NAL units.

> Informative note: All VCL NAL units in an AP have the same TID value since they belong to the same access unit. However, an AP may contain non-VCL NAL units for which the TID value in the NAL unit header may be different than the TID value of the VCL NAL units in the same AP.

> Informative note: If a system envisions subpicture-level or picture-level modifications, for example, by removing subpictures or pictures of a particular layer, a good design choice on the sender's side would be to aggregate NAL units belonging to only the same subpicture or picture of a particular layer.

An AP MUST carry at least two aggregation units and can carry as many aggregation units as necessary; however, the total amount of data in an AP obviously MUST fit into an IP packet, and the size SHOULD be chosen so that the resulting IP packet is smaller than the MTU size in order to avoid IP layer fragmentation. An AP MUST NOT contain the FUs specified in Section 4.3.3. APs MUST NOT be nested, i.e., an AP cannot contain another AP.

The first aggregation unit in an AP consists of a conditional 16-bit DONL field (in network byte order), followed by 16 bits of unsigned size information (in network byte order) that indicate the size of the NAL unit in bytes (excluding these two octets but including the NAL unit header), followed by the NAL unit itself, including its NAL unit header, as shown in Figure 5.

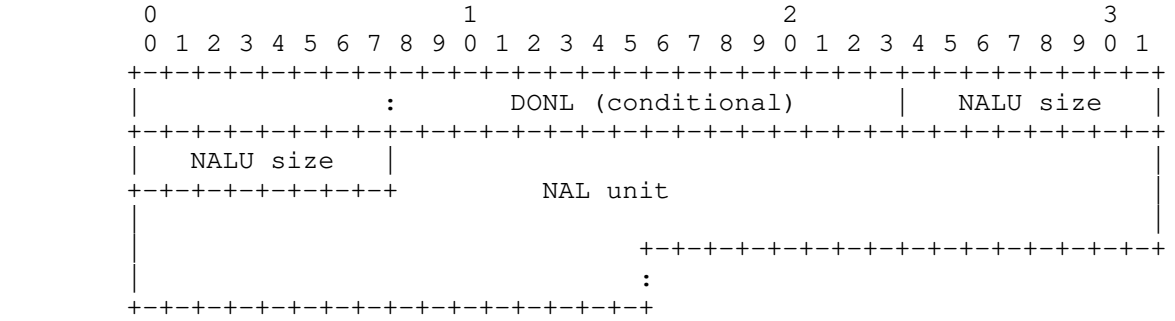


Figure 5: The Structure of the First Aggregation Unit in an AP

> Informative note: The first octet of Figure 5 (indicated by the first colon) belongs to a previous aggregation unit. It is depicted to emphasize that aggregation units are octet aligned only. Similarly, the NAL unit carried in the aggregation unit can terminate at the octet boundary.

The DONL field, when present, specifies the value of the 16 least significant bits of the decoding order number of the aggregated NAL unit.

If sprop-max-don-diff is greater than 0, the DONL field MUST be present in an aggregation unit that is the first aggregation unit in an AP, and the variable DON for the aggregated NAL unit is derived as equal to the value of the DONL field, and the variable DON for an aggregation unit that is not the first aggregation unit in an AP-aggregated NAL unit is derived as equal to the DON of the preceding

aggregated NAL unit in the same AP plus 1 modulo 65536. Otherwise (sprop-max-don-diff is equal to 0), the DONL field MUST NOT be present in an aggregation unit that is the first aggregation unit in an AP.

An aggregation unit that is not the first aggregation unit in an AP will be followed immediately by 16 bits of unsigned size information (in network byte order) that indicate the size of the NAL unit in bytes (excluding these two octets but including the NAL unit header), followed by the NAL unit itself, including its NAL unit header, as shown in Figure 6.

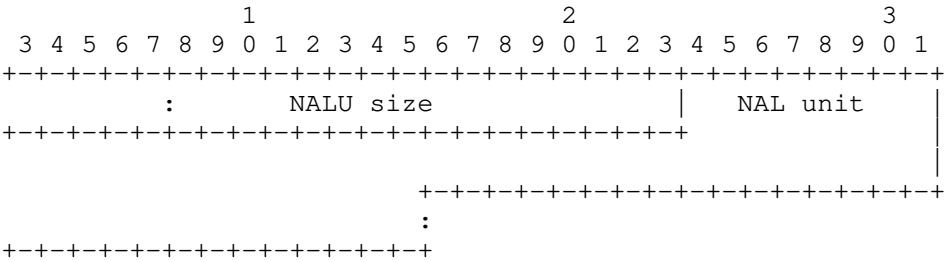


Figure 6: The Structure of an Aggregation Unit That Is Not the First Aggregation Unit in an AP

> Informative note: The first octet of Figure 6 (indicated by the first colon) belongs to a previous aggregation unit. It is depicted to emphasize that aggregation units are octet aligned only. Similarly, the NAL unit carried in the aggregation unit can terminate at the octet boundary.

Figure 7 presents an example of an AP that contains two aggregation units, labeled as 1 and 2 in the figure, without the DONL field being present.

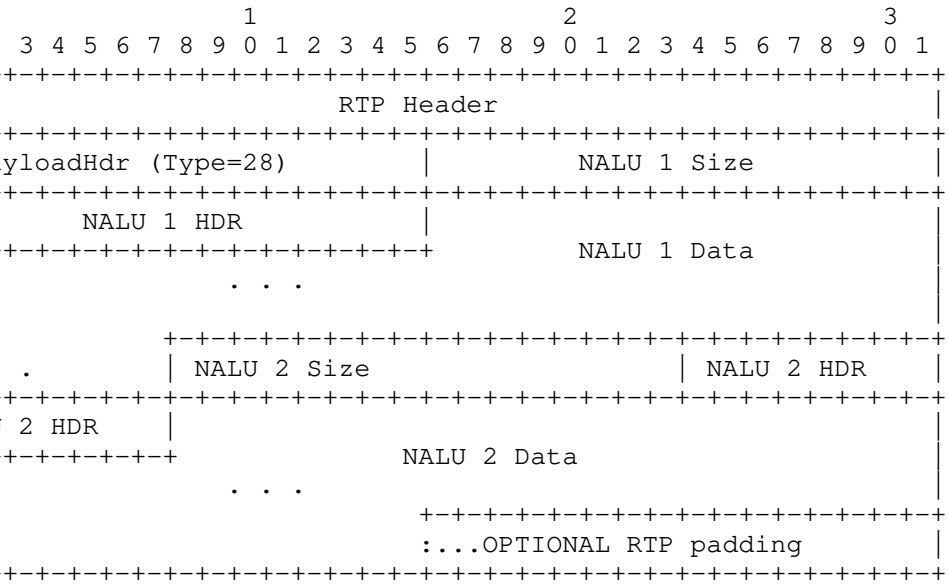
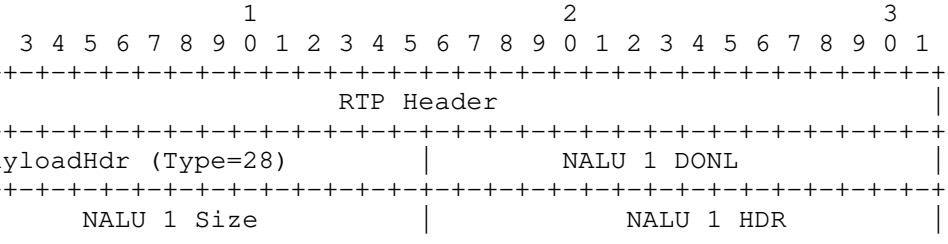


Figure 7: An Example of an AP Packet Containing Two Aggregation Units without the DONL Field

Figure 8 presents an example of an AP that contains two aggregation units, labeled as 1 and 2 in the figure, with the DONL field being present.



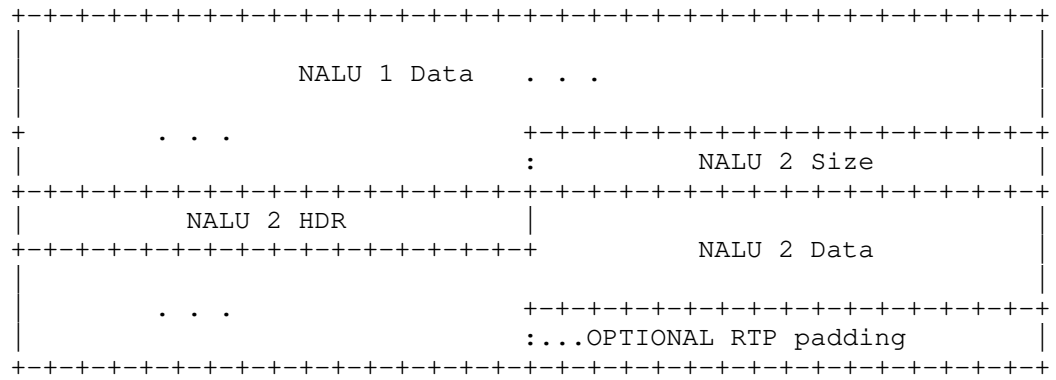


Figure 8: An Example of an AP Containing Two Aggregation Units with the DONL Field

4.3.3. Fragmentation Units

Fragmentation Units (FUs) are introduced to enable fragmenting a single NAL unit into multiple RTP packets, possibly without cooperation or knowledge of the [VVC] encoder. A fragment of a NAL unit consists of an integer number of consecutive octets of that NAL unit. Fragments of the same NAL unit MUST be sent in consecutive order with ascending RTP sequence numbers (with no other RTP packets within the same RTP stream being sent between the first and last fragment).

When a NAL unit is fragmented and conveyed within FUs, it is referred to as a fragmented NAL unit. APs MUST NOT be fragmented. FUs MUST NOT be nested, i.e., an FU cannot contain a subset of another FU.

The RTP timestamp of an RTP packet carrying an FU is set to the NALU-time of the fragmented NAL unit.

An FU consists of a payload header as defined in Table 5 of [VVC] (denoted here as PayloadHdr with Type=29), an FU header of one octet, a conditional 16-bit DONL field (in network byte order), and an FU payload (as shown in Figure 9).

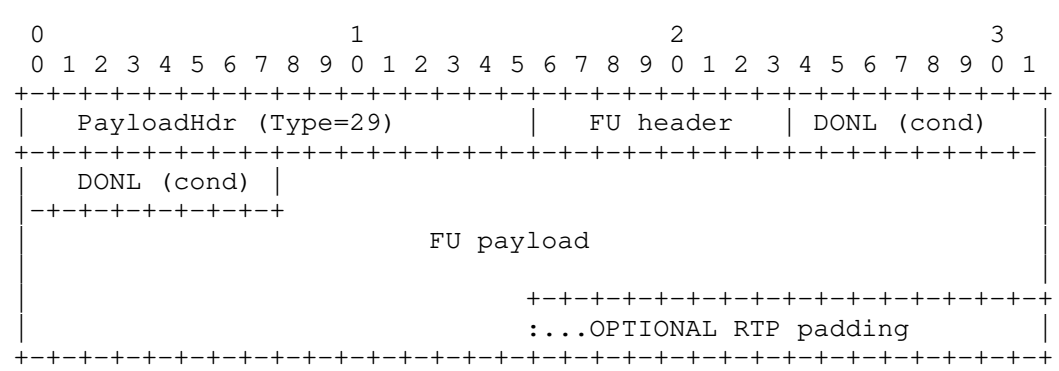


Figure 9: The Structure of an FU

The fields in the payload header are set as follows. The Type field MUST be equal to 29. The fields F, LayerId, and TID MUST be equal to the fields F, LayerId, and TID, respectively, of the fragmented NAL unit.

The FU header consists of an S bit, an E bit, an R bit, and a 5-bit FuType field, as shown in Figure 10.

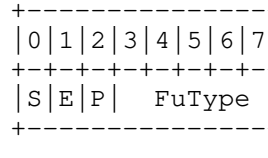


Figure 10: The Structure of the FU Header

The semantics of the FU header fields are as follows:

S: 1 bit
When set to 1, the S bit indicates the start of a fragmented NAL unit, i.e., the first byte of the FU payload is also the first byte of the payload of the fragmented NAL unit. When the FU payload is not the start of the fragmented NAL unit payload, the S bit MUST be set to 0.

E: 1 bit
When set to 1, the E bit indicates the end of a fragmented NAL unit, i.e., the last byte of the payload is also the last byte of the fragmented NAL unit. When the FU payload is not the last fragment of a fragmented NAL unit, the E bit MUST be set to 0.

P: 1 bit
When set to 1, the P bit indicates the last FU of the last VCL NAL unit of a coded picture, i.e., the last byte of the FU payload is also the last byte of the last VCL NAL unit of the coded picture. When the FU payload is not the last fragment of the last VCL NAL unit of a coded picture, the P bit MUST be set to 0.

FuType: 5 bits
The field FuType MUST be equal to the field Type of the fragmented NAL unit.

The DONL field, when present, specifies the value of the 16 least significant bits of the decoding order number of the fragmented NAL unit.

If sprop-max-don-diff is greater than 0, and the S bit is equal to 1, the DONL field MUST be present in the FU, and the variable DON for the fragmented NAL unit is derived as equal to the value of the DONL field. Otherwise (sprop-max-don-diff is equal to 0, or the S bit is equal to 0), the DONL field MUST NOT be present in the FU.

A non-fragmented NAL unit MUST NOT be transmitted in one FU, i.e., the Start bit and End bit must not both be set to 1 in the same FU header.

The FU payload consists of fragments of the payload of the fragmented NAL unit so that, if the FU payloads of consecutive FUs, starting with an FU with the S bit equal to 1 and ending with an FU with the E bit equal to 1, are sequentially concatenated, the payload of the fragmented NAL unit can be reconstructed. The NAL unit header of the fragmented NAL unit is not included as such in the FU payload, but rather the information of the NAL unit header of the fragmented NAL unit is conveyed in the F, LayerId, and TID fields of the FU payload headers of the FUs and the FuType field of the FU header of the FUs. An FU payload MUST NOT be empty.

If an FU is lost, the receiver SHOULD discard all following fragmentation units in transmission order, corresponding to the same fragmented NAL unit, unless the decoder in the receiver is known to be prepared to gracefully handle incomplete NAL units.

A receiver in an endpoint or in a MANE MAY aggregate the first n-1 fragments of a NAL unit to an (incomplete) NAL unit, even if fragment n of that NAL unit is not received. In this case, the forbidden_zero_bit of the NAL unit MUST be set to 1 to indicate a syntax violation.

4.4. Decoding Order Number

For each NAL unit, the variable AbsDon is derived, representing the decoding order number that is indicative of the NAL unit decoding order.

Let NAL unit n be the n-th NAL unit in transmission order within an RTP stream.

If sprop-max-don-diff is equal to 0, AbsDon[n], the value of AbsDon for NAL unit n, is derived as equal to n.

Otherwise (sprop-max-don-diff is greater than 0), AbsDon[n] is derived as follows, where DON[n] is the value of the variable DON for NAL unit n:

* If n is equal to 0 (i.e., NAL unit n is the very first NAL unit in transmission order), AbsDon[0] is set equal to DON[0].

* Otherwise (n is greater than 0), the following applies for derivation of AbsDon[n]:

```
If DON[n] == DON[n-1],
   AbsDon[n] = AbsDon[n-1]

If (DON[n] > DON[n-1] and DON[n] - DON[n-1] < 32768),
   AbsDon[n] = AbsDon[n-1] + DON[n] - DON[n-1]

If (DON[n] < DON[n-1] and DON[n-1] - DON[n] >= 32768),
   AbsDon[n] = AbsDon[n-1] + 65536 - DON[n-1] + DON[n]

If (DON[n] > DON[n-1] and DON[n] - DON[n-1] >= 32768),
   AbsDon[n] = AbsDon[n-1] - (DON[n-1] + 65536 - DON[n])

If (DON[n] < DON[n-1] and DON[n-1] - DON[n] < 32768),
   AbsDon[n] = AbsDon[n-1] - (DON[n-1] - DON[n])
```

For any two NAL units (m and n), the following applies:

* When AbsDon[n] is greater than AbsDon[m], this indicates that NAL unit n follows NAL unit m in NAL unit decoding order.

* When AbsDon[n] is equal to AbsDon[m], the NAL unit decoding order of the two NAL units can be in either order.

* When AbsDon[n] is less than AbsDon[m], this indicates that NAL unit n precedes NAL unit m in decoding order.

> Informative note: When two consecutive NAL units in the NAL unit decoding order have different values of AbsDon, the absolute difference between the two AbsDon values may be greater than or equal to 1.

> Informative note: There are multiple reasons to allow for the absolute difference of the values of AbsDon for two consecutive NAL units in the NAL unit decoding order to be greater than one. An increment by one is not required, as at the time of associating values of AbsDon to NAL units, it may not be known whether all NAL units are to be delivered to the receiver. For example, a gateway might not forward VCL NAL units of higher sublayers or some SEI NAL units when there is congestion in the network. In another example, the first intra-coded picture of a pre-encoded clip is transmitted in advance to ensure that it is readily available in the receiver, and when transmitting the first intra-coded picture, the originator does not exactly know how many NAL units will be encoded before the first intra-coded picture of the pre-encoded clip follows in decoding order. Thus, the values of AbsDon for the NAL units of the first intra-coded picture of the pre-encoded clip have to be estimated when they are transmitted, and gaps in values of AbsDon may occur.

5. Packetization Rules

The following packetization rules apply:

* If sprop-max-don-diff is greater than 0, the transmission order of NAL units carried in the RTP stream MAY be different than the NAL unit decoding order. Otherwise (sprop-max-don-diff is equal to 0), the transmission order of NAL units carried in the RTP stream

MUST be the same as the NAL unit decoding order.

* A NAL unit of a small size SHOULD be encapsulated in an aggregation packet together with one or more other NAL units in order to avoid the unnecessary packetization overhead for small NAL units. For example, non-VCL NAL units, such as access unit delimiters, parameter sets, or SEI NAL units, are typically small and can often be aggregated with VCL NAL units without violating MTU size constraints.

* Each non-VCL NAL unit SHOULD, when possible from an MTU size match viewpoint, be encapsulated in an aggregation packet together with its associated VCL NAL unit, as typically a non-VCL NAL unit would be meaningless without the associated VCL NAL unit being available.

* For carrying exactly one NAL unit in an RTP packet, a single NAL unit packet MUST be used.

6. De-packetization Process

The general concept behind de-packetization is to get the NAL units out of the RTP packets in an RTP stream and pass them to the decoder in the NAL unit decoding order.

The de-packetization process is implementation dependent. Therefore, the following description should be seen as an example of a suitable implementation. Other schemes may be used as well, as long as the output for the same input is the same as the process described below. The output is the same when the set of output NAL units and their order are both identical. Optimizations relative to the described algorithms are possible.

All normal RTP mechanisms related to buffer management apply. In particular, duplicated or outdated RTP packets (as indicated by the RTP sequence number and the RTP timestamp) are removed. To determine the exact time for decoding, factors, such as a possible intentional delay to allow for proper inter-stream synchronization, MUST be factored in.

NAL units with NAL unit type values in the range of 0 to 27, inclusive, may be passed to the decoder. NAL-unit-like structures with NAL unit type values in the range of 28 to 31, inclusive, MUST NOT be passed to the decoder.

The receiver includes a receiver buffer, which is used to compensate for transmission delay jitter within individual RTP streams and to reorder NAL units from transmission order to the NAL unit decoding order. In this section, the receiver operation is described under the assumption that there is no transmission delay jitter within an RTP stream. To make a difference from a practical receiver buffer that is also used for compensation of transmission delay jitter, the receiver buffer is hereafter called the de-packetization buffer in this section. Receivers should also prepare for transmission delay jitter, that is, either reserve separate buffers for transmission delay jitter buffering and de-packetization buffering or use a receiver buffer for both transmission delay jitter and de-packetization. Moreover, receivers should take transmission delay jitter into account in the buffering operation, e.g., by additional initial buffering before starting of decoding and playback.

The de-packetization process extracts the NAL units from the RTP packets in an RTP stream as follows. When an RTP packet carries a single NAL unit packet, the payload of the RTP packet is extracted as a single NAL unit, excluding the DONL field, i.e., third and fourth bytes, when sprop-max-don-diff is greater than 0. When an RTP packet carries an aggregation packet, several NAL units are extracted from the payload of the RTP packet. In this case, each NAL unit corresponds to the part of the payload of each aggregation unit that follows the NALU size field, as described in Section 4.3.2. When an RTP packet carries a Fragmentation Unit (FU), all RTP packets from

the first FU (with the S field equal to 1) of the fragmented NAL unit up to the last FU (with the E field equal to 1) of the fragmented NAL unit are collected. The NAL unit is extracted from these RTP packets by concatenating all FU payloads in the same order as the corresponding RTP packets and appending the NAL unit header with the fields F, LayerId, and TID set to equal the values of the fields F, LayerId, and TID in the payload header of the FUs, respectively, and with the NAL unit type set equal to the value of the field FuType in the FU header of the FUs, as described in Section 4.3.3.

When sprop-max-don-diff is equal to 0, the de-packetization buffer size is zero bytes, and the NAL units carried in the single RTP stream are directly passed to the decoder in their transmission order, which is identical to their decoding order.

When sprop-max-don-diff is greater than 0, the process described in the remainder of this section applies.

There are two buffering states in the receiver: initial buffering and buffering while playing. Initial buffering starts when the reception is initialized. After initial buffering, decoding and playback are started, and the buffering-while-playing mode is used.

Regardless of the buffering state, the receiver stores incoming NAL units in reception order into the de-packetization buffer. NAL units carried in RTP packets are stored in the de-packetization buffer individually, and the value of AbsDon is calculated and stored for each NAL unit.

Initial buffering lasts until the difference between the greatest and smallest AbsDon values of the NAL units in the de-packetization buffer is greater than or equal to the value of sprop-max-don-diff.

After initial buffering, whenever the difference between the greatest and smallest AbsDon values of the NAL units in the de-packetization buffer is greater than or equal to the value of sprop-max-don-diff, the following operation is repeatedly applied until this difference is smaller than sprop-max-don-diff:

> The NAL unit in the de-packetization buffer with the smallest value of AbsDon is removed from the de-packetization buffer and passed to the decoder.

When no more NAL units are flowing into the de-packetization buffer, all NAL units remaining in the de-packetization buffer are removed from the buffer and passed to the decoder in the order of increasing AbsDon values.

7. Payload Format Parameters

This section specifies the optional parameters. A mapping of the parameters with Session Description Protocol (SDP) [RFC8866] is also provided for applications that use SDP.

Parameters starting with the string "sprop" for stream properties can be used by a sender to provide a receiver with the properties of the stream that is or will be sent. The media sender (and not the receiver) selects whether, and with what values, "sprop" parameters are being sent. This uncommon characteristic of the "sprop" parameters may not be intuitive in the context of some signaling protocol concepts, especially with offer/answer. Please see Section 7.3.2 for guidance specific to the use of sprop parameters in the offer/answer case.

7.1. Media Type Registration

The receiver MUST ignore any parameter unspecified in this memo.

Type name: video

Subtype name: H266

Required parameters: N/A

Optional parameters: profile-id, tier-flag, sub-profile-id, interop-constraints, level-id, sprop-sublayer-id, sprop-ols-id, recv-sublayer-id, recv-ols-id, max-recv-level-id, sprop-dci, sprop-vps, sprop-sps, sprop-pps, sprop-sei, max-lsr, max-fps, sprop-max-don-diff, sprop-depack-buf-bytes, depack-buf-cap (refer to Section 7.2 for definitions).

Encoding considerations: This type is only defined for transfer via RTP [RFC3550].

Security considerations: See Section 9 of RFC 9328.

Interoperability considerations: N/A

Published specification: Please refer to RFC 9328 and VVC coding specification [VVC].

Applications that use this media type: Any application that relies on VVC-based video services over RTP

Fragment identifier considerations: N/A

Additional information: N/A

Person & email address to contact for further information: Stephan Wenger (stewe@stewe.org)

Intended usage: COMMON

Restrictions on usage: N/A

Author: See Authors' Addresses section of RFC 9328.

Change controller: IETF <avtcore@ietf.org>

7.2. Optional Parameters Definition

profile-id, tier-flag, sub-profile-id, interop-constraints, and level-id:
: These parameters indicate the profile, the tier, the default level, the sub-profile, and some constraints of the bitstream carried by the RTP stream, or a specific set of the profile, the tier, the default level, the sub-profile, and some constraints the receiver supports.

  The subset of coding tools that may have been used to generate the bitstream or that the receiver supports, as well as some additional constraints, are indicated collectively by profile-id, sub-profile-id, and interop-constraints.

  > Informative note: There are 128 values of profile-id. The subset of coding tools identified by profile-id can be further constrained with up to 255 instances of sub-profile-id. In addition, 68 bits included in interop-constraints, which can be extended up to 324 bits, provide means to further restrict tools from existing profiles. To be able to support this fine-granular signaling of coding-tool subsets with profile-id, sub-profile-id, and interop-constraints, it would be safe to require symmetric use of these parameters in SDP offer/answer unless recv-ols-id is included in the SDP answer for choosing one of the layers offered.

  The tier is indicated by tier-flag. The default level is indicated by level-id. The tier and the default level specify the limits on values of syntax elements or arithmetic combinations of values of syntax elements that are followed when generating the bitstream or that the receiver supports.

In SDP offer/answer, when the SDP answer does not include the recv-ols-id parameter that is less than the sprop-ols-id parameter in the SDP offer, the following applies:

* The tier-flag, profile-id, sub-profile-id, and interop-constraints parameters MUST be used symmetrically, i.e., the value of each of these parameters in the offer MUST be the same as that in the answer, either explicitly signaled or implicitly inferred.

* The level-id parameter is changeable as long as the highest level indicated by the answer is either equal to or lower than that in the offer. Note that the highest level higher than level-id in the offer for receiving can be included as max-recv-level-id.

In SDP offer/answer, when the SDP answer does include the recv-ols-id parameter that is less than the sprop-ols-id parameter in the SDP offer, the set of tier-flag, profile-id, sub-profile-id, interop-constraints, and level-id parameters included in the answer MUST be consistent with that for the chosen output layer set as indicated in the SDP offer, with the exception that the level-id parameter in the SDP answer is changeable as long as the highest level indicated by the answer is either lower than or equal to that in the offer.

More specifications of these parameters, including how they relate to syntax elements specified in [VVC], are provided below.

profile-id:
When profile-id is not present, a value of 1 (i.e., the Main 10 profile) MUST be inferred.

When used to indicate properties of a bitstream, profile-id is derived from the general_profile_idc syntax element that applies to the bitstream in an instance of the profile_tier_level( ) syntax structure.

VVC bitstreams transported over RTP using the technologies of this memo SHOULD contain only a single profile_tier_level( ) structure in the DCI, unless the sender can assure that a receiver can correctly decode the VVC bitstream, regardless of which profile_tier_level( ) structure contained in the DCI was used for deriving profile-id and other parameters for the SDP offer/answer exchange.

As specified in [VVC], a profile_tier_level( ) syntax structure may be contained in an SPS NAL unit, and one or more profile_tier_level( ) syntax structures may be contained in a VPS NAL unit and in a DCI NAL unit. One of the following three cases applies to the container NAL unit of the profile_tier_level( ) syntax structure containing syntax elements used to derive the values of profile-id, tier-flag, level-id, sub-profile-id, or interop-constraints:

1. The container NAL unit is an SPS, the bitstream is a single-layer bitstream, and the profile_tier_level( ) syntax structures in all SPSs referenced by the CVSs in the bitstream have the same values respectively for those profile_tier_level( ) syntax elements.

2. The container NAL unit is a VPS, the profile_tier_level( ) syntax structure is the one in the VPS that applies to the OLS corresponding to the bitstream, and the profile_tier_level( ) syntax structures applicable to the OLS corresponding to the bitstream in all VPSs referenced by the CVSs in the bitstream have the same values respectively for those profile_tier_level( ) syntax elements.

3. The container NAL unit is a DCI NAL unit, and the

profile_tier_level( ) syntax structures in all DCI NAL units in the bitstream have the same values respectively for those profile_tier_level( ) syntax elements.

[VVC] allows for multiple profile_tier_level( ) structures in a DCI NAL unit, which may contain different values for the syntax elements used to derive the values of profile-id, tier-flag, level-id, sub-profile-id, or interop-constraints in the different entries. However, herein defined is only a single profile-id, tier-flag, level-id, sub-profile-id, or interop-constraints. When signaling these parameters and a DCI NAL unit is present with multiple profile_tier_level( ) structures, these values SHOULD be the same as the first profile_tier_level structure in the DCI, unless the sender has ensured that the receiver can decode the bitstream when a different value is chosen.

tier-flag, level-id:
The value of tier-flag MUST be in the range of 0 to 1, inclusive. The value of level-id MUST be in the range of 0 to 255, inclusive.

If the tier-flag and level-id parameters are used to indicate properties of a bitstream, they indicate the tier and the highest level the bitstream complies with.

If the tier-flag and level-id parameters are used for capability exchange, the following applies. If max-recv-level-id is not present, the default level defined by level-id indicates the highest level the codec wishes to support. Otherwise, max-recv-level-id indicates the highest level the codec supports for receiving. For either receiving or sending, all levels that are lower than the highest level supported MUST also be supported.

If no tier-flag is present, a value of 0 MUST be inferred; if no level-id is present, a value of 51 (i.e., level 3.1) MUST be inferred.

> Informative note: The level values currently defined in the VVC specification are in the form of "majorNum.minorNum", and the value of the level-id for each of the levels is equal to majorNum * 16 + minorNum * 3. It is expected that, if any levels are defined in the future, the same convention will be used, but this cannot be guaranteed.

When used to indicate properties of a bitstream, the tier-flag and level-id parameters are derived respectively from the syntax element general_tier_flag, and the syntax element general_level_idc or sub_layer_level_idc[j], that apply to the bitstream in an instance of the profile_tier_level( ) syntax structure.

If the tier-flag and level-id are derived from the profile_tier_level( ) syntax structure in a DCI NAL unit, the following applies:

* tier-flag = general_tier_flag

* level-id = general_level_idc

Otherwise, if the tier-flag and level-id are derived from the profile_tier_level( ) syntax structure in an SPS or VPS NAL unit, and the bitstream contains the highest sublayer representation in the OLS corresponding to the bitstream, the following applies:

* tier-flag = general_tier_flag

* level-id = general_level_idc

Otherwise, if the tier-flag and level-id are derived from the profile_tier_level( ) syntax structure in an SPS or VPS NAL unit, and the bitstream does not contain the highest sublayer representation in the OLS corresponding to the bitstream, the

following applies, with j being the value of the sprop-sublayer-id parameter:

* tier-flag = general_tier_flag

* level-id = sub_layer_level_idc[j]

sub-profile-id:
The value of the parameter is a comma-separated (',') list of data using base64 encoding (Section 4 of [RFC4648]) representation without "==" padding.

When used to indicate properties of a bitstream, sub-profile-id is derived from each of the ptl_num_sub_profiles general_sub_profile_idc[i] syntax elements that apply to the bitstream in a profile_tier_level( ) syntax structure.

interop-constraints:
A base64 encoding (Section 4 of [RFC4648]) representation of the data that includes the ptl_frame_only_constraint_flag syntax element, the ptl_multilayer_enabled_flag syntax element, and the general_constraints_info( ) syntax structure that apply to the bitstream in an instance of the profile_tier_level( ) syntax structure.

If the interop-constraints parameter is not present, the following MUST be inferred:

* ptl_frame_only_constraint_flag = 1

* ptl_multilayer_enabled_flag = 0

* gci_present_flag in the general_constraints_info( ) syntax structure = 0

Using interop-constraints for capability exchange results in a requirement on any bitstream to be compliant with the interop-constraints.

sprop-sublayer-id:
This parameter MAY be used to indicate the highest allowed value of TID in the bitstream. When not present, the value of sprop-sublayer-id is inferred to be equal to 6.

The value of sprop-sublayer-id MUST be in the range of 0 to 6, inclusive.

sprop-ols-id:
This parameter MAY be used to indicate the OLS that the bitstream applies to. When not present, the value of sprop-ols-id is inferred to be equal to TargetOlsIdx, as specified in Section 8.1.1 of [VVC]. If this optional parameter is present, sprop-vps MUST also be present or its content MUST be known a priori at the receiver.

The value of sprop-ols-id MUST be in the range of 0 to 256, inclusive.

> Informative note: VVC allows having up to 257 output layer sets indicated in the VPS, as the number of output layer sets minus 2 is indicated with a field of 8 bits.

recv-sublayer-id:
This parameter MAY be used to signal a receiver's choice of the offered or declared sublayer representations in sprop-vps and sprop-sps. The value of recv-sublayer-id indicates the TID of the highest sublayer that a receiver supports. When not present, the value of recv-sublayer-id is inferred to be equal to the value of the sprop-sublayer-id parameter in the SDP offer.

The value of recv-sublayer-id MUST be in the range of 0 to 6,

inclusive.

recv-ols-id:
This parameter MAY be used to signal a receiver's choice of the offered or declared output layer sets in sprop-vps. The value of recv-ols-id indicates the OLS index of the bitstream that a receiver supports. When not present, the value of recv-ols-id is inferred to be equal to the value of the sprop-ols-id parameter inferred from or indicated in the SDP offer. When present, the value of recv-ols-id must be included only when sprop-ols-id was received and must refer to an output layer set in the VPS that includes no layers other than all or a subset of the layers of the OLS referred to by sprop-ols-id. If this optional parameter is present, sprop-vps must have been received or its content must be known a priori at the receiver.

The value of recv-ols-id MUST be in the range of 0 to 256, inclusive.

max-recv-level-id:
This parameter MAY be used to indicate the highest level a receiver supports.

The value of max-recv-level-id MUST be in the range of 0 to 255, inclusive.

When max-recv-level-id is not present, the value is inferred to be equal to level-id.

max-recv-level-id MUST NOT be present when the highest level the receiver supports is not higher than the default level.

sprop-dci:
This parameter MAY be used to convey a decoding capability information NAL unit of the bitstream for out-of-band transmission. The parameter MAY also be used for capability exchange. The value of the parameter is a base64 encoding (Section 4 of [RFC4648]) representation of the decoding capability information NAL unit, as specified in Section 7.3.2.1 of [VVC].

sprop-vps:
This parameter MAY be used to convey any video parameter set to the NAL unit of the bitstream for out-of-band transmission of video parameter sets. The parameter MAY also be used for capability exchange and to indicate substream characteristics (i.e., properties of output layer sets and sublayer representations, as defined in [VVC]). The value of the parameter is a comma-separated (',') list of base64 encoding (Section 4 of [RFC4648]) representations of the video parameter set NAL units, as specified in Section 7.3.2.3 of [VVC].

The sprop-vps parameter MAY contain one or more than one video parameter set NAL units. However, all other video parameter sets contained in the sprop-vps parameter MUST be consistent with the first video parameter set in the sprop-vps parameter. A video parameter set vpsB is said to be consistent with another video parameter set vpsA if the number of OLSs in vpsA and vpsB are the same and any decoder that conforms to the profile, tier, level, and constraints indicated by the data starting from the syntax element general_profile_idc to the syntax structure general_constraints_info(), inclusive, in the profile_tier_level( ) syntax structure corresponding to any OLS with index olsIdx in vpsA can decode any CVS(s) referencing vpsB when TargetOlsIdx is equal to olsIdx that conforms to the profile, tier, level, and constraints indicated by the data starting from the syntax element general_profile_idc to the syntax structure general_constraints_info(), inclusive, in the profile_tier_level( ) syntax structure corresponding to the OLS with index TargetOlsIdx in vpsB.

sprop-sps:

This parameter MAY be used to convey sequence parameter set NAL units of the bitstream for out-of-band transmission of sequence parameter sets. The value of the parameter is a comma-separated (',') list of base64 encoding (Section 4 of [RFC4648]) representations of the sequence parameter set NAL units, as specified in Section 7.3.2.4 of [VVC].

A sequence parameter set spsB is said to be consistent with another sequence parameter set spsA if any decoder that conforms to the profile, tier, level, and constraints indicated by the data starting from the syntax element general_profile_idc to the syntax structure general_constraints_info(), inclusive, in the profile_tier_level( ) syntax structure in spsA can decode any CLVS(s) referencing spsB that conforms to the profile, tier, level, and constraints indicated by the data starting from the syntax element general_profile_idc to the syntax structure general_constraints_info(), inclusive, in the profile_tier_level( ) syntax structure in spsB.

sprop-pps:
This parameter MAY be used to convey picture parameter set NAL units of the bitstream for out-of-band transmission of picture parameter sets. The value of the parameter is a comma-separated (',') list of base64 encoding (Section 4 of [RFC4648]) representations of the picture parameter set NAL units, as specified in Section 7.3.2.5 of [VVC].

sprop-sei:
This parameter MAY be used to convey one or more SEI messages that describe bitstream characteristics. When present, a decoder can rely on the bitstream characteristics that are described in the SEI messages for the entire duration of the session, independently from the persistence scopes of the SEI messages, as specified in [VSEI].

The value of the parameter is a comma-separated (',') list of base64 encoding (Section 4 of [RFC4648]) representations of SEI NAL units, as specified in [VSEI].

> Informative note: Intentionally, no list of applicable or inapplicable SEI messages is specified here. Conveying certain SEI messages in sprop-sei may be sensible in some application scenarios and meaningless in others. However, a few examples are described below:
>
> In an environment where the bitstream was created from film-based source material, and no splicing is going to occur during the lifetime of the session, the film grain characteristics SEI message is likely meaningful, and sending it in sprop-sei, rather than in the bitstream at each entry point, may help with saving bits and allows one to configure the renderer only once, avoiding unwanted artifacts.
>
> Examples for SEI messages that would be meaningless to be conveyed in sprop-sei include the decoded picture hash SEI message (it is close to impossible that all decoded pictures have the same hashtag) or the filler payload SEI message (as there is no point in just having more bits in SDP).

max-lsr:
The max-lsr MAY be used to signal the capabilities of a receiver implementation and MUST NOT be used for any other purpose. The value of max-lsr is an integer indicating the maximum processing rate in units of luma samples per second. The max-lsr parameter signals that the receiver is capable of decoding video at a higher rate than is required by the highest level.

> Informative note: When the OPTIONAL media type parameters are used to signal the properties of a bitstream, and max-lsr is not present, the values of tier-flag, profile-id,

> sub-profile-id, interop-constraints, and level-id must always be such that the bitstream complies fully with the specified profile, sub-profile, tier, level, and interop-constraints.

When max-lsr is signaled, the receiver MUST be able to decode bitstreams that conform to the highest level, with the exception that the MaxLumaSr value in Table A.3 of [VVC] for the highest level is replaced with the value of max-lsr. Senders MAY use this knowledge to send pictures of a given size at a higher picture rate than is indicated in the highest level.

When not present, the value of max-lsr is inferred to be equal to the value of MaxLumaSr given in Table A.3 of [VVC] for the highest level.

The value of max-lsr MUST be in the range of MaxLumaSr to 16 * MaxLumaSr, inclusive, where MaxLumaSr is given in Table A.3 of [VVC] for the highest level.

max-fps:
The value of max-fps is an integer indicating the maximum picture rate in units of pictures per 100 seconds that can be effectively processed by the receiver. The max-fps parameter MAY be used to signal that the receiver has a constraint in that it is not capable of processing video effectively at the full picture rate that is implied by the highest level and, when present, max-lsr.

The value of max-fps is not necessarily the picture rate at which the maximum picture size can be sent; it constitutes a constraint on maximum picture rate for all resolutions.

> Informative note: The max-fps parameter is semantically different from max-lsr in that max-fps is used to signal a constraint, lowering the maximum picture rate from what is implied by other parameters.

The encoder MUST use a picture rate equal to or less than this value. In cases where the max-fps parameter is absent, the encoder is free to choose any picture rate according to the highest level and any signaled optional parameters.

The value of max-fps MUST be smaller than or equal to the full picture rate that is implied by the highest level and, when present, max-lsr.

sprop-max-don-diff:
If there is no NAL unit naluA that is followed in transmission order by any NAL unit preceding naluA in decoding order (i.e., the transmission order of the NAL units is the same as the decoding order), the value of this parameter MUST be equal to 0.

Otherwise, this parameter specifies the maximum absolute difference between the decoding order number (i.e., AbsDon) values of any two NAL units naluA and naluB, where naluA follows naluB in decoding order and precedes naluB in transmission order.

The value of sprop-max-don-diff MUST be an integer in the range of 0 to 32767, inclusive.

When not present, the value of sprop-max-don-diff is inferred to be equal to 0.

sprop-depack-buf-bytes:
This parameter signals the required size of the de-packetization buffer in units of bytes. The value of the parameter MUST be greater than or equal to the maximum buffer occupancy (in units of bytes) of the de-packetization buffer, as specified in Section 6.

The value of sprop-depack-buf-bytes MUST be an integer in the range of 0 to 4294967295, inclusive.

When sprop-max-don-diff is present and greater than 0, this parameter MUST be present and the value MUST be greater than 0. When not present, the value of sprop-depack-buf-bytes is inferred to be equal to 0.

> Informative note: The value of sprop-depack-buf-bytes indicates the required size of the de-packetization buffer only. When network jitter can occur, an appropriately sized jitter buffer has to be available as well.

depack-buf-cap:
This parameter signals the capabilities of a receiver implementation and indicates the amount of de-packetization buffer space in units of bytes that the receiver has available for reconstructing the NAL unit decoding order from NAL units carried in the RTP stream. A receiver is able to handle any RTP stream for which the value of the sprop-depack-buf-bytes parameter is smaller than or equal to this parameter.

When not present, the value of depack-buf-cap is inferred to be equal to 4294967295. The value of depack-buf-cap MUST be an integer in the range of 1 to 4294967295, inclusive.

> Informative note: depack-buf-cap indicates the maximum possible size of the de-packetization buffer of the receiver only, without allowing for network jitter.

7.3. SDP Parameters

The receiver MUST ignore any parameter unspecified in this memo.

7.3.1. Mapping of Payload Type Parameters to SDP

The media type video/H266 string is mapped to fields in the Session Description Protocol (SDP) [RFC8866] as follows:

* The media name in the "m=" line of SDP MUST be video.

* The encoding name in the "a=rtpmap" line of SDP MUST be H266 (the media subtype).

* The clock rate in the "a=rtpmap" line MUST be 90000.

* The OPTIONAL parameters profile-id, tier-flag, sub-profile-id, interop-constraints, level-id, sprop-sublayer-id, sprop-ols-id, recv-sublayer-id, recv-ols-id, max-recv-level-id, max-lsr, max-fps, sprop-max-don-diff, sprop-depack-buf-bytes, and depack-buf-cap, when present, MUST be included in the "a=fmtp" line of SDP. The fmtp line is expressed as a media type string, in the form of a semicolon-separated list of parameter=value pairs.

* The OPTIONAL parameters sprop-vps, sprop-sps, sprop-pps, sprop-sei, and sprop-dci, when present, MUST be included in the "a=fmtp" line of SDP or conveyed using the "fmtp" source attribute as specified in Section 6.3 of [RFC5576]. For a particular media format (i.e., RTP payload type), sprop-vps, sprop-sps, sprop-pps, sprop-sei, or sprop-dci MUST NOT be both included in the "a=fmtp" line of SDP and conveyed using the "fmtp" source attribute. When included in the "a=fmtp" line of SDP, those parameters are expressed as a media type string, in the form of a semicolon-separated list of parameter=value pairs. When conveyed in the "a=fmtp" line of SDP for a particular payload type, the parameters sprop-vps, sprop-sps, sprop-pps, sprop-sei, and sprop-dci MUST be applied to each SSRC with the payload type. When conveyed using the "fmtp" source attribute, these parameters are only associated with the given source and payload type as parts of the "fmtp" source attribute.

  > Informative note: Conveyance of sprop-vps, sprop-sps, and sprop-pps using the "fmtp" source attribute allows for out-of-

band transport of parameter sets in topologies like Topo-Video-switch-MCU, as specified in [RFC7667].

A general usage of media representation in SDP is as follows:

```
m=video 49170 RTP/AVP 98
a=rtpmap:98 H266/90000
a=fmtp:98 profile-id=1;
  sprop-vps=<video parameter sets data>;
  sprop-sps=<sequence parameter set data>;
  sprop-pps=<picture parameter set data>;
```

A SIP offer/answer exchange wherein both parties are expected to both send and receive could look like the following. Only the media codec-specific parts of the SDP are shown. Some lines are wrapped due to text constraints.

```
Offerer->Answerer:
      m=video 49170 RTP/AVP 98
      a=rtpmap:98 H266/90000
      a=fmtp:98 profile-id=1; level_id=83;
```

The above represents an offer for symmetric video communication using [VVC] and its payload specification at the main profile and level 5.1 (and as the levels are downgradable, all lower levels). Informally speaking, this offer tells the receiver of the offer that the sender is willing to receive up to 4Kp60 resolution at the maximum bitrates specified in [VVC]. At the same time, if this offer were accepted "as is", the offer can expect that the answerer would be able to receive and properly decode H.266 media up to and including level 5.1.

```
Answerer->Offerer:
      m=video 49170 RTP/AVP 98
      a=rtpmap:98 H266/90000
      a=fmtp:98 profile-id=1; level_id=67
```

With this answer to the offer above, the system receiving the offer advises the offerer that it is incapable of handing H.266 at level 5.1 but is capable of decoding 1080p60. As H.266 video codecs must support decoding at all levels below the maximum level they implement, the resulting user experience would likely be that both systems send video at 1080p60. However, nothing prevents an encoder from further downgrading its sending to, for example, 720p30 if it were short of cycles or bandwidth or for other reasons.

7.3.2. Usage with SDP Offer/Answer Model

This section describes the negotiation of unicast messages using the offer/answer model as described in [RFC3264] and its updates. The section is split into subsections, covering a) media format configurations not involving non-temporal scalability; b) scalable media format configurations; c) the description of the use of those parameters not involving the media configuration itself but rather the parameters of the payload format design; and d) multicast.

7.3.2.1. Non-scalable Media Format Configuration

A non-scalable VVC media configuration is such a configuration where no non-temporal scalability mechanisms are allowed. In [VVC] version 1, it is implied that general_profile_idc indicates one of the following profiles: Main 10, Main 10 Still Picture, Main 10 4:4:4, or Main 10 4:4:4 Still Picture, with general_profile_idc values of 1, 65, 33, and 97, respectively. Note that non-scalable media configurations include temporal scalability inline with VVC's design philosophy and profile structure.

The following limitations and rules pertaining to the media configuration apply:

* The parameters identifying a media format configuration for VVC

are profile-id, tier-flag, sub-profile-id, level-id, and interop-constraints. These media configuration parameters, except level-id, MUST be used symmetrically.

The answerer MUST structure its answer according to one of the following three options:

1. maintain all configuration parameters with the values remaining the same as in the offer for the media format (payload type), with the exception that the value of level-id is changeable as long as the highest level indicated by the answer is not higher than that indicated by the offer;

2. include in the answer the recv-sublayer-id parameter, with a value less than the sprop-sublayer-id parameter in the offer, for the media format (payload type), and maintain all configuration parameters with the values remaining the same as in the offer for the media format (payload type), with the exception that the value of level-id is changeable as long as the highest level indicated by the answer is not higher than the level indicated by sprop-sps or sprop-vps in offer for the chosen sublayer representation; or

3. remove the media format (payload type) completely (when one or more of the parameter values are not supported).

> Informative note: The above requirement for symmetric use does not apply for level-id and does not apply for the other bitstream or RTP stream properties and capability parameters, as described in Section 7.3.2.3 below.

* To simplify handling and matching of these configurations, the same RTP payload type number used in the offer SHOULD also be used in the answer, as specified in [RFC3264].

* The same RTP payload type number used in the offer for the media subtype H266 MUST be used in the answer when the answer includes recv-sublayer-id. When the answer does not include recv-sublayer-id, the answer MUST NOT contain a payload type number used in the offer for the media subtype H266 unless the configuration is exactly the same as in the offer or the configuration in the answer only differs from that in the offer with a different value of level-id. The answer MAY contain the recv-sublayer-id parameter if a VVC bitstream contains multiple operation points (using temporal scalability and sublayers) and sprop-sps or sprop-vps is included in the offer where information of sublayers are present in the first sequence parameter set or video parameter set contained in sprop-sps or sprop-vps, respectively. If sprop-sps or sprop-vps is provided in an offer, an answerer MAY select a particular operation point indicated in the first sequence parameter set or video parameter set contained in sprop-sps or sprop-vps, respectively. When the answer includes a recv-sublayer-id that is less than a sprop-sublayer-id in the offer, the following applies:

   1. When the sprop-sps parameter is present, all sequence parameter sets contained in the sprop-sps parameter in the SDP answer and all sequence parameter sets sent in-band for either the offerer-to-answerer direction or the answerer-to-offerer direction MUST be consistent with the first sequence parameter set in the sprop-sps parameter of the offer (see the semantics of sprop-sps in Section 7.1 of this document on one sequence parameter set being consistent with another sequence parameter set).

   2. When the sprop-vps parameter is present, all video parameter sets contained in the sprop-vps parameter in the SDP answer and all video parameter sets sent in-band for either the offerer-to-answerer direction or the answerer-to-offerer direction MUST be consistent with the first video parameter set in the sprop-vps parameter of the offer (see the semantics

of sprop-vps in Section 7.1 of this document on one video parameter set being consistent with another video parameter set).

3. The bitstream sent in either direction MUST conform to the profile, tier, level, and constraints of the chosen sublayer representation, as indicated by the profile_tier_level( ) syntax structure in the first sequence parameter set in the sprop-sps parameter or by the first profile_tier_level( ) syntax structure in the first video parameter set in the sprop-vps parameter of the offer.

> Informative note: When an offerer receives an answer that does not include recv-sublayer-id, it has to compare payload types not declared in the offer based on the media type (i.e., video/H266) and the above media configuration parameters with any payload types it has already declared. This will enable it to determine whether the configuration in question is new or if it is equivalent to configuration already offered, since a different payload type number may be used in the answer. The ability to perform operation point selection enables a receiver to utilize the temporal scalable nature of a VVC bitstream.

7.3.2.2. Scalable Media Format Configuration

A scalable VVC media configuration is such a configuration where non-temporal scalability mechanisms are allowed. In [VVC] version 1, it is implied that general_profile_idc indicates one of the following profiles: Multilayer Main 10 and Multilayer Main 10 4:4:4, with general_profile_idc values of 17 and 49, respectively.

The following limitations and rules pertaining to the media configuration apply. They are listed in an order that would be logical for an implementation to follow:

* The parameters identifying a media format configuration for scalable VVC are profile-id, tier-flag, sub-profile-id, level-id, interop-constraints, and sprop-vps. These media configuration parameters, except level-id, MUST be used symmetrically, except as noted below.

* The answerer MAY include a level-id that MUST be lower than or equal to the level-id indicated in the offer (either expressed by level-id in the offer or implied by the default level, as specified in Section 7.1).

* When sprop-ols-id is present in an offer, sprop-vps MUST also be present in the same offer and include at least one valid VPS so to allow the answerer to meaningfully interpret sprop-ols-id and select recv-ols-id (see below).

* The answerer MUST NOT include recv-ols-id unless the offer includes sprop-ols-id. When present, recv-ols-id MUST indicate a supported output layer set in the VPS that includes no layers other than all or a subset of the layers of the OLS referred to by sprop-ols-id. If unable, the answerer MUST remove the media format.

  > Informative note: If an offerer wants to offer more than one output layer set, it can do so by offering multiple VVC media with different payload types.

* The offerer MAY include sprop-sublayer-id, which indicates the highest allowed value of TID in the bitstream. The answerer MAY include recv-sublayer-id, which can be used to reduce the number of sublayers from the value of sprop-sublayer-id.

* When the answerer includes recv-ols-id and configuration parameters profile-id, tier-flag, sub-profile-id, level-id, and interop-constraints, it MUST use the configuration parameter values as signaled in the sprop-vps for the operating point with

the largest number of sublayers for the chosen output layer set, with the exception that the value of level-id is changeable as long as the highest level indicated by the answer is not higher than the level indicated by sprop-vps in offer for the operating point with the largest number of sublayers for the chosen output layer set.

7.3.2.3. Payload Format Configuration

The following limitations and rules pertain to the configuration of the payload format buffer management mostly and apply to both scalable and non-scalable VVC.

* The parameters sprop-max-don-diff and sprop-depack-buf-bytes describe the properties of an RTP stream that the offerer or the answerer is sending for the media format configuration. This differs from the normal usage of the offer/answer parameters; normally, such parameters declare the properties of the bitstream or RTP stream that the offerer or the answerer is able to receive. When dealing with VVC, the offerer assumes that the answerer will be able to receive media encoded using the configuration being offered.

  > Informative note: The above parameters apply for any RTP stream, when present, sent by a declaring entity with the same configuration. In other words, the applicability of the above parameters to RTP streams depends on the source endpoint. Rather than being bound to the payload type, the values may have to be applied to another payload type when being sent, as they apply for the configuration.

* The capability parameter max-lsr MAY be used to declare further capabilities of the offerer or answerer for receiving. It MUST NOT be present when the direction attribute is sendonly.

* The capability parameter max-fps MAY be used to declare lower capabilities of the offerer or answerer for receiving. It MUST NOT be present when the direction attribute is sendonly.

* When an offerer offers an interleaved stream, indicated by the presence of sprop-max-don-diff with a value larger than zero, the offerer MUST include the size of the de-packetization buffer sprop-depack-buf-bytes.

* To enable the offerer and answerer to inform each other about their capabilities for de-packetization buffering in receiving RTP streams, both parties are RECOMMENDED to include depack-buf-cap.

* The parameters sprop-dci, sprop-vps, sprop-sps, or sprop-pps, when present (included in the "a=fmtp" line of SDP or conveyed using the "fmtp" source attribute, as specified in Section 6.3 of [RFC5576]), are used for out-of-band transport of the parameter sets (DCI, VPS, SPS, or PPS, respectively).

* The answerer MAY use either out-of-band or in-band transport of parameter sets for the bitstream it is sending, regardless of whether out-of-band parameter sets transport has been used in the offerer-to-answerer direction. Parameter sets included in an answer are independent of those parameter sets included in the offer, as they are used for decoding two different bitstreams; one from the answerer to the offerer and the other in the opposite direction. In case some RTP packets are sent before the SDP offer/answer settles down, in-band parameter sets MUST be used for those RTP stream parts sent before the SDP offer/answer.

* The following rules apply to transport of parameter sets in the offerer-to-answerer direction.

  - An offer MAY include sprop-dci, sprop-vps, sprop-sps, and/or sprop-pps. If none of these parameters are present in the offer, then only in-band transport of parameter sets is used.

- If the level to use in the offerer-to-answerer direction is equal to the default level in the offer, the answerer MUST be prepared to use the parameter sets included in sprop-vps, sprop-sps, and sprop-pps (either included in the "a=fmtp" line of SDP or conveyed using the "fmtp" source attribute) for decoding the incoming bitstream, e.g., by passing these parameter set NAL units to the video decoder before passing any NAL units carried in the RTP streams. Otherwise, the answerer MUST ignore sprop-vps, sprop-sps, and sprop-pps (either included in the "a=fmtp" line of SDP or conveyed using the "fmtp" source attribute) and the offerer MUST transmit parameter sets in-band.

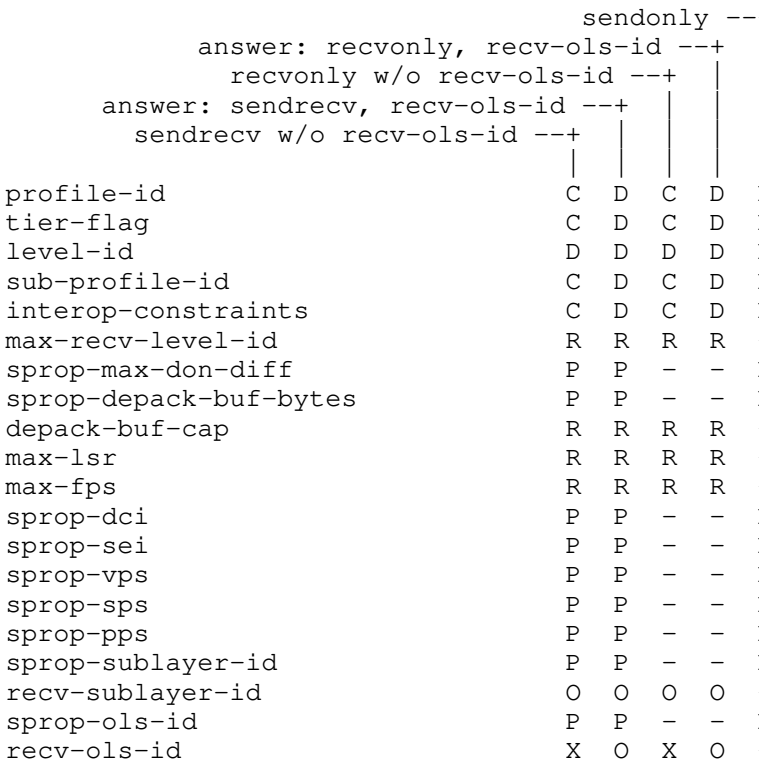
* The following rules apply to transport of parameter sets in the answerer-to-offerer direction.

  - An answer MAY include sprop-dci, sprop-vps, sprop-sps, and/or sprop-pps. If none of these parameters are present in the answer, then only in-band transport of parameter sets is used.

  - The offerer MUST be prepared to use the parameter sets included in sprop-vps, sprop-sps, and sprop-pps (either included in the "a=fmtp" line of SDP or conveyed using the "fmtp" source attribute) for decoding the incoming bitstream, e.g., by passing these parameter set NAL units to the video decoder before passing any NAL units carried in the RTP streams.

* When sprop-dci, sprop-vps, sprop-sps, and/or sprop-pps are conveyed using the "fmtp" source attribute, as specified in Section 6.3 of [RFC5576], the receiver of the parameters MUST store the parameter sets included in sprop-dci, sprop-vps, sprop-sps, and/or sprop-pps and associate them with the source given as part of the "fmtp" source attribute. Parameter sets associated with one source (given as part of the "fmtp" source attribute) MUST only be used to decode NAL units conveyed in RTP packets from the same source (given as part of the "fmtp" source attribute). When this mechanism is in use, SSRC collision detection and resolution MUST be performed as specified in [RFC5576].

Figure 11 lists the interpretation of all the parameters that MAY be used for the various combinations of offer, answer, and direction attributes.



Legend:

C: configuration for sending and receiving bitstreams
D: changeable configuration, same as C, except possible
   to answer with a different but consistent value (see the
   semantics of the six parameters related to profile, tier,
   and level on these parameters being consistent)
P: properties of the bitstream to be sent
R: receiver capabilities
O: operation point selection
X: MUST NOT be present
-: not usable, when present MUST be ignored

Figure 11: Interpretation of Parameters for Various Combinations of Offers, Answers, and Direction Attributes, with and without recv-ols-id.

Parameters used for declaring receiver capabilities are, in general, downgradable, i.e., they express the upper limit for a sender's possible behavior. Thus, a sender MAY select to set its encoder using only lower/lesser or equal values of these parameters.

When the answer does not include a recv-ols-id that is less than the sprop-ols-id in the offer, parameters declaring a configuration point are not changeable, with the exception of the level-id parameter for unicast usage, and these parameters express values a receiver expects to be used and MUST be used verbatim in the answer as in the offer.

When a sender's capabilities are declared with the configuration parameters, these parameters express a configuration that is acceptable for the sender to receive bitstreams. In order to achieve high interoperability levels, it is often advisable to offer multiple alternative configurations. It is impossible to offer multiple configurations in a single payload type. Thus, when multiple configuration offers are made, each offer requires its own RTP payload type associated with the offer. However, it is possible to offer multiple operation points using one configuration in a single payload type by including sprop-vps in the offer and recv-ols-id in the answer.

An implementation SHOULD be able to understand all media type parameters (including all optional media type parameters), even if it doesn't support the functionality related to the parameter. This, in conjunction with proper application logic in the implementation, allows the implementation, after having received an offer, to create an answer by potentially downgrading one or more of the optional parameters to the point where the implementation can cope, leading to higher chances of interoperability beyond the most basic interop points (for which, as described above, no optional parameters are necessary).

> Informative note: In implementations of previous H.26x payload formats, it was occasionally observed that implementations were incapable of parsing most (or all) of the optional parameters. As a result, the offer/answer exchange resulted in a baseline performance (using the default values for the optional parameters) with the resulting suboptimal user experience. However, there are valid reasons to forego the implementation complexity of implementing the parsing of some or all of the optional parameters, for example, when there is predetermined knowledge, not negotiated by an SDP-based offer/answer process, of the capabilities of the involved systems (walled gardens, baseline requirements defined in application standards higher up in the stack, and similar).

An answerer MAY extend the offer with additional media format configurations. However, to enable their usage, in most cases, a second offer is required from the offerer to provide the bitstream property parameters that the media sender will use. This also has the effect that the offerer has to be able to receive this media format configuration, not only to send it.

7.3.3. Multicast

For bitstreams being delivered over multicast, the following rules apply:

* The media format configuration is identified by profile-id, tier-flag, sub-profile-id, level-id, and interop-constraints. These media format configuration parameters, including level-id, MUST be used symmetrically; that is, the answerer MUST either maintain all configuration parameters or remove the media format (payload type) completely. Note that this implies that the level-id for offer/answer in multicast is not changeable.

* To simplify the handling and matching of these configurations, the same RTP payload type number used in the offer SHOULD also be used in the answer, as specified in [RFC3264]. An answer MUST NOT contain a payload type number used in the offer unless the configuration is the same as in the offer.

* Parameter sets received MUST be associated with the originating source and MUST only be used in decoding the incoming bitstream from the same source.

* The rules for other parameters are the same as above for unicast as long as the three above rules are obeyed.

7.3.4. Usage in Declarative Session Descriptions

When VVC over RTP is offered with SDP in a declarative style, as in Real Time Streaming Protocol (RTSP) [RFC7826] or Session Announcement Protocol (SAP) [RFC2974], the following considerations are necessary.

* All parameters capable of indicating both bitstream properties and receiver capabilities are used to indicate only bitstream properties. For example, in this case, the parameters profile-id, tier-id, and level-id declare the values used by the bitstream, not the capabilities for receiving bitstreams. As a result, the following interpretation of the parameters MUST be used:

  - Declaring actual configuration or bitstream properties:

    - profile-id
    - tier-flag
    - level-id
    - interop-constraints
    - sub-profile-id
    - sprop-dci
    - sprop-vps
    - sprop-sps
    - sprop-pps
    - sprop-max-don-diff
    - sprop-depack-buf-bytes
    - sprop-sublayer-id
    - sprop-ols-id
    - sprop-sei

  - Not usable (when present, they MUST be ignored):

- o max-lsr
- o max-fps
- o max-recv-level-id
- o depack-buf-cap
- o recv-sublayer-id
- o recv-ols-id

- A receiver of the SDP is required to support all parameters and values of the parameters provided; otherwise, the receiver MUST reject (RTSP) or not participate in (SAP) the session. It falls on the creator of the session to use values that are expected to be supported by the receiving application.

7.3.5. Considerations for Parameter Sets

When out-of-band transport of parameter sets is used, parameter sets MAY still be additionally transported in-band unless explicitly disallowed by an application, and some of these additional parameter sets may update some of the out-of-band transported parameter sets. An update of a parameter set refers to the sending of a parameter set of the same type using the same parameter set ID but with different values for at least one other parameter of the parameter set.

8. Use with Feedback Messages

The following subsections define the use of the Picture Loss Indication (PLI) and Full Intra Request (FIR) feedback messages with [VVC]. The PLI is defined in [RFC4585], and the FIR message is defined in [RFC5104]. In accordance with this memo, unlike [HEVC], a sender MUST NOT send Slice Loss Indication (SLI) or Reference Picture Selection Indication (RPSI), and a receiver SHOULD ignore RPSI and treat a received SLI as a PLI.

8.1. Picture Loss Indication (PLI)

As specified in Section 6.3.1 of [RFC4585], the reception of a PLI by a media sender indicates "the loss of an undefined amount of coded video data belonging to one or more pictures". Without having any specific knowledge of the setup of the bitstream (such as use and location of in-band parameter sets, non-IRAP decoder refresh points, picture structures, and so forth), a reaction to the reception of a PLI by a VVC sender SHOULD be to send an IRAP picture and relevant parameter sets, potentially with sufficient redundancy so to ensure correct reception. However, sometimes information about the bitstream structure is known. For example, such information can be parameter sets that have been conveyed out of band through mechanisms not defined in this document and that are known to stay static for the duration of the session. In that case, it is obviously unnecessary to send them in-band as a result of the reception of a PLI. Other examples could be devised based on a priori knowledge of different aspects of the bitstream structure. In all cases, the timing and congestion control mechanisms of [RFC4585] MUST be observed.

8.2. Full Intra Request (FIR)

The purpose of the FIR message is to force an encoder to send an independent decoder refresh point as soon as possible while observing applicable congestion-control-related constraints, such as those set out in [RFC8082].

Upon reception of a FIR, a sender MUST send an IDR picture. Parameter sets MUST also be sent, except when there is a priori knowledge that the parameter sets have been correctly established. A typical example for that is an understanding between the sender and

receiver, established by means outside this document, that parameter sets are exclusively sent out of band.

9. Security Considerations

The scope of this section is limited to the payload format itself and to one feature of [VVC] that may pose a particularly serious security risk if implemented naively. The payload format, in isolation, does not form a complete system. Implementers are advised to read and understand relevant security-related documents, especially those pertaining to RTP (see the Security Considerations section in [RFC3550]) and the security of the call-control stack chosen (that may make use of the media type registration of this memo). Implementers should also consider known security vulnerabilities of video coding and decoding implementations in general and avoid those.

Within this RTP payload format, and with the exception of the user data SEI message as described below, no security threats other than those common to RTP payload formats are known. In other words, neither the various media-plane-based mechanisms nor the signaling part of this memo seem to pose a security risk beyond those common to all RTP-based systems.

RTP packets using the payload format defined in this specification are subject to the security considerations discussed in the RTP specification [RFC3550] and in any applicable RTP profile, such as RTP/AVP [RFC3551], RTP/AVPF [RFC4585], RTP/SAVP [RFC3711], or RTP/SAVPF [RFC5124]. However, as "Securing the RTP Framework: Why RTP Does Not Mandate a Single Media Security Solution" [RFC7202] discusses, it is not an RTP payload format's responsibility to discuss or mandate what solutions are used to meet the basic security goals, like confidentiality, integrity, and source authenticity for RTP in general. This responsibility lays on anyone using RTP in an application. They can find guidance on available security mechanisms and important considerations in "Options for Securing RTP Sessions" [RFC7201]. The rest of this section discusses the security impacting properties of the payload format itself.

Because the data compression used with this payload format is applied end to end, any encryption needs to be performed after compression. A potential denial-of-service threat exists for data encodings using compression techniques that have non-uniform receiver-end computational load. The attacker can inject pathological datagrams into the bitstream that are complex to decode and that cause the receiver to be overloaded. [VVC] is particularly vulnerable to such attacks, as it is extremely simple to generate datagrams containing NAL units that affect the decoding process of many future NAL units. Therefore, the usage of data origin authentication and data integrity protection of at least the RTP packet is RECOMMENDED but NOT REQUIRED based on the thoughts of [RFC7202].

Like HEVC [RFC7798], [VVC] includes a user data Supplemental Enhancement Information (SEI) message. This SEI message allows inclusion of an arbitrary bitstring into the video bitstream. Such a bitstring could include JavaScript, machine code, and other active content. [VVC] leaves the handling of this SEI message to the receiving system. In order to avoid harmful side effects of the user data SEI message, decoder implementations cannot naively trust its content. For example, it would be a bad and insecure implementation practice to forward any JavaScript a decoder implementation detects to a web browser. The safest way to deal with user data SEI messages is to simply discard them, but that can have negative side effects on the quality of experience by the user.

End-to-end security with authentication, integrity, or confidentiality protection will prevent a MANE from performing media-aware operations other than discarding complete packets. In the case of confidentiality protection, it will even be prevented from discarding packets in a media-aware way. To be allowed to perform such operations, a MANE is required to be a trusted entity that is included in the security context establishment. This on-path

inclusion of the MANE forgoes end-to-end security guarantees for the end points.

10. Congestion Control

Congestion control for RTP SHALL be used in accordance with RTP [RFC3550] and with any applicable RTP profile, e.g., AVP [RFC3551] or AVPF [RFC4585]. If best-effort service is being used, an additional requirement is that users of this payload format MUST monitor packet loss to ensure that the packet loss rate is within an acceptable range. Packet loss is considered acceptable if a TCP flow across the same network path and experiencing the same network conditions would achieve an average throughput, measured on a reasonable timescale, that is not less than all RTP streams combined are achieved. This condition can be satisfied by implementing congestion-control mechanisms to adapt the transmission rate, by implementing the number of layers subscribed for a layered multicast session, or by arranging for a receiver to leave the session if the loss rate is unacceptably high.

The bitrate adaptation necessary for obeying the congestion control principle is easily achievable when real-time encoding is used, for example, by adequately tuning the quantization parameter. However, when pre-encoded content is being transmitted, bandwidth adaptation requires the pre-coded bitstream to be tailored for such adaptivity. The key mechanisms available in [VVC] are temporal scalability and spatial/SNR scalability. A media sender can remove NAL units belonging to higher temporal sublayers (i.e., those NAL units with a high value of TID) or higher spatio-SNR layers until the sending bitrate drops to an acceptable range.

The mechanisms mentioned above generally work within a defined profile and level; therefore no renegotiation of the channel is required. Only when non-downgradable parameters (such as profile) are required to be changed does it become necessary to terminate and restart the RTP stream(s). This may be accomplished by using different RTP payload types.

MANEs MAY remove certain unusable packets from the RTP stream when that RTP stream was damaged due to previous packet losses. This can help reduce the network load in certain special cases. For example, MANEs can remove those FUs where the leading FUs belonging to the same NAL unit have been lost or those dependent slice segments when the leading slice segments belonging to the same slice have been lost, because the trailing FUs or dependent slice segments are meaningless to most decoders. MANE can also remove higher temporal scalable layers if the outbound transmission (from the MANE's viewpoint) experiences congestion.

11. IANA Considerations

A new media type has been registered with IANA; see Section 7.1.

12. References

12.1. Normative References

[ISO23090-3] International Organization for Standardization, "Information technology - Coded representation of immersive media - Part 3: Versatile video coding", ISO/IEC 23090-3:2022, September 2022, <https://www.iso.org/standard/73022.html>.

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <https://www.rfc-editor.org/info/rfc2119>.

[RFC3264] Rosenberg, J. and H. Schulzrinne, "An Offer/Answer Model with Session Description Protocol (SDP)", RFC 3264,

DOI 10.17487/RFC3264, June 2002,
<https://www.rfc-editor.org/info/rfc3264>.

[RFC3550] Schulzrinne, H., Casner, S., Frederick, R., and V. Jacobson, "RTP: A Transport Protocol for Real-Time Applications", STD 64, RFC 3550, DOI 10.17487/RFC3550, July 2003, <https://www.rfc-editor.org/info/rfc3550>.

[RFC3551] Schulzrinne, H. and S. Casner, "RTP Profile for Audio and Video Conferences with Minimal Control", STD 65, RFC 3551, DOI 10.17487/RFC3551, July 2003, <https://www.rfc-editor.org/info/rfc3551>.

[RFC3711] Baugher, M., McGrew, D., Naslund, M., Carrara, E., and K. Norrman, "The Secure Real-time Transport Protocol (SRTP)", RFC 3711, DOI 10.17487/RFC3711, March 2004, <https://www.rfc-editor.org/info/rfc3711>.

[RFC4585] Ott, J., Wenger, S., Sato, N., Burmeister, C., and J. Rey, "Extended RTP Profile for Real-time Transport Control Protocol (RTCP)-Based Feedback (RTP/AVPF)", RFC 4585, DOI 10.17487/RFC4585, July 2006, <https://www.rfc-editor.org/info/rfc4585>.

[RFC4648] Josefsson, S., "The Base16, Base32, and Base64 Data Encodings", RFC 4648, DOI 10.17487/RFC4648, October 2006, <https://www.rfc-editor.org/info/rfc4648>.

[RFC5104] Wenger, S., Chandra, U., Westerlund, M., and B. Burman, "Codec Control Messages in the RTP Audio-Visual Profile with Feedback (AVPF)", RFC 5104, DOI 10.17487/RFC5104, February 2008, <https://www.rfc-editor.org/info/rfc5104>.

[RFC5124] Ott, J. and E. Carrara, "Extended Secure RTP Profile for Real-time Transport Control Protocol (RTCP)-Based Feedback (RTP/SAVPF)", RFC 5124, DOI 10.17487/RFC5124, February 2008, <https://www.rfc-editor.org/info/rfc5124>.

[RFC5576] Lennox, J., Ott, J., and T. Schierl, "Source-Specific Media Attributes in the Session Description Protocol (SDP)", RFC 5576, DOI 10.17487/RFC5576, June 2009, <https://www.rfc-editor.org/info/rfc5576>.

[RFC8082] Wenger, S., Lennox, J., Burman, B., and M. Westerlund, "Using Codec Control Messages in the RTP Audio-Visual Profile with Feedback with Layered Codecs", RFC 8082, DOI 10.17487/RFC8082, March 2017, <https://www.rfc-editor.org/info/rfc8082>.

[RFC8174] Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words", BCP 14, RFC 8174, DOI 10.17487/RFC8174, May 2017, <https://www.rfc-editor.org/info/rfc8174>.

[RFC8866] Begen, A., Kyzivat, P., Perkins, C., and M. Handley, "SDP: Session Description Protocol", RFC 8866, DOI 10.17487/RFC8866, January 2021, <https://www.rfc-editor.org/info/rfc8866>.

[VSEI] ITU-T, "Versatile supplemental enhancement information messages for coded video bitstreams", ITU-T Recommendation H.274, May 2022, <https://www.itu.int/rec/T-REC-H.274>.

[VVC] ITU-T, "Versatile Video Coding", ITU-T Recommendation H.266, April 2022, <http://www.itu.int/rec/T-REC-H.266>.

12.2. Informative References

[CABAC] Sole, J., et al., "Transform coefficient coding in HEVC", IEEE Transactions on Circuits and Systems for Video

Technology, DOI 10.1109/TCSVT.2012.2223055, December 2012, <https://doi.org/10.1109/TCSVT.2012.2223055>.

[HEVC] ITU-T, "High efficiency video coding", ITU-T Recommendation H.265, August 2021, <https://www.itu.int/rec/T-REC-H.265>.

[MPEG2S] International Organization for Standardization, "Information technology - Generic coding of moving pictures and associated audio information - Part 1: Systems", ISO/IEC 13818-1:2022, September 2022.

[RFC2974] Handley, M., Perkins, C., and E. Whelan, "Session Announcement Protocol", RFC 2974, DOI 10.17487/RFC2974, October 2000, <https://www.rfc-editor.org/info/rfc2974>.

[RFC6184] Wang, Y.-K., Even, R., Kristensen, T., and R. Jesup, "RTP Payload Format for H.264 Video", RFC 6184, DOI 10.17487/RFC6184, May 2011, <https://www.rfc-editor.org/info/rfc6184>.

[RFC6190] Wenger, S., Wang, Y.-K., Schierl, T., and A. Eleftheriadis, "RTP Payload Format for Scalable Video Coding", RFC 6190, DOI 10.17487/RFC6190, May 2011, <https://www.rfc-editor.org/info/rfc6190>.

[RFC7201] Westerlund, M. and C. Perkins, "Options for Securing RTP Sessions", RFC 7201, DOI 10.17487/RFC7201, April 2014, <https://www.rfc-editor.org/info/rfc7201>.

[RFC7202] Perkins, C. and M. Westerlund, "Securing the RTP Framework: Why RTP Does Not Mandate a Single Media Security Solution", RFC 7202, DOI 10.17487/RFC7202, April 2014, <https://www.rfc-editor.org/info/rfc7202>.

[RFC7656] Lennox, J., Gross, K., Nandakumar, S., Salgueiro, G., and B. Burman, Ed., "A Taxonomy of Semantics and Mechanisms for Real-Time Transport Protocol (RTP) Sources", RFC 7656, DOI 10.17487/RFC7656, November 2015, <https://www.rfc-editor.org/info/rfc7656>.

[RFC7667] Westerlund, M. and S. Wenger, "RTP Topologies", RFC 7667, DOI 10.17487/RFC7667, November 2015, <https://www.rfc-editor.org/info/rfc7667>.

[RFC7798] Wang, Y.-K., Sanchez, Y., Schierl, T., Wenger, S., and M. M. Hannuksela, "RTP Payload Format for High Efficiency Video Coding (HEVC)", RFC 7798, DOI 10.17487/RFC7798, March 2016, <https://www.rfc-editor.org/info/rfc7798>.

[RFC7826] Schulzrinne, H., Rao, A., Lanphier, R., Westerlund, M., and M. Stiemerling, Ed., "Real-Time Streaming Protocol Version 2.0", RFC 7826, DOI 10.17487/RFC7826, December 2016, <https://www.rfc-editor.org/info/rfc7826>.

Acknowledgements

Dr. Byeongdoo Choi is thanked for the video-codec-related technical discussion and other aspects in this memo. Xin Zhao and Dr. Xiang Li are thanked for their contributions on [VVC] specification descriptive content. Spencer Dawkins is thanked for his valuable review comments that led to great improvements of this memo. Some parts of this specification share text with the RTP payload format for HEVC [RFC7798]. We thank the authors of that specification for their excellent work.

Authors' Addresses

Shuai Zhao
Intel
2200 Mission College Blvd

Santa Clara, 95054
United States of America
Email: shuai.zhao@ieee.org

Stephan Wenger
Tencent
2747 Park Blvd
Palo Alto, 94588
United States of America
Email: stewe@stewe.org

Yago Sanchez
Fraunhofer HHI
Einsteinufer 37
10587 Berlin
Germany
Email: yago.sanchez@hhi.fraunhofer.de

Ye-Kui Wang
Bytedance Inc.
8910 University Center Lane
San Diego, 92122
United States of America
Email: yekui.wang@bytedance.com

Miska M. Hannuksela
Nokia Technologies
HatanpÃ¤Ã¤n valtatie 30
FI-33100 Tampere
Finland
Email: miska.hannuksela@nokia.com