avtcore
Internet-Draft
Intended status: Standards Track
Expires: May 6, 2021

S. Zhao
S. Wenger
Tencent
Y. Sanchez
Fraunhofer HHI
Y. Wang
Bytedance Inc.

November 02, 2020

RTP Payload Format for Versatile Video Coding (VVC)
draft-ietf-avtcore-rtp-vvc-05

Abstract

This memo describes an RTP payload format for the video coding standard ITU-T Recommendation H.266 and ISO/IEC International Standard 23090-3, both also known as Versatile Video Coding (VVC) and 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 Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute working documents as Internet-Drafts. The list of current Internet-Drafts is at https://datatracker.ietf.org/drafts/current/.

Internet-Drafts are draft documents valid for a maximum of six months and may be updated, replaced, or obsoleted by other documents at any time. It is inappropriate to use Internet-Drafts as reference material or to cite them other than as "work in progress."

This Internet-Draft will expire on May 6, 2021.

Table of Contents

1. Introduction

The Versatile Video Coding [VVC] specification, formally published as both ITU-T Recommendation H.266 and ISO/IEC International Standard 23090-3, is currently in the ITU-T publication process and the ISO/IEC approval process. VVC is reported to provide significant coding efficiency gains over HEVC [HEVC] as 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 (Network Abstraction Layer) unit-based RTP payload formats of, H.264 Video Coding [RFC6184], Scalable Video Coding (SVC) [RFC6190], High Efficiency Video Coding (HEVC) [RFC7798] and 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 RFC 6184 is widely deployed and generally known in the relevant implementer communities. Certain mechanisms known from [RFC6190] were incorporated in VVC, 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 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 (MTS), 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 before deblocking called luma mapping with chroma scaling to fully utilize the dynamic range of signal so that rate-distortion performance of both SDR and 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 with affine mode (PROF) is further deployed to mimic affine motion at the pixel level. Thirdly the decoder side motion vector refinement (DMVR) is a method to derive MV vector at decoder side based on block matching so that fewer bits may be spent on motion vectors. Bi-directional optical flow (BDOF) is a similar method to PROF. BDOF adds a sample wise offset at 4x4 sub-block level that is derived with equations based on gradients of the prediction samples and a motion difference relative to CU motion vectors. Furthermore, merge with motion vector difference (MMVD) is a special mode, which 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). 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-mode 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, as 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 colour 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 hardcoded constants.

Other coding-tool feature

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 interfaces designs from HEVC and H.264. 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 variant of HEVC known as SHVC. The hierarchical syntax and data unit structure consists of parameter sets at various levels (decoder, sequence (pertaining to all), sequence (pertaining to a single), 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 includes parameters that stay constant for the lifetime of a Video Bitstream, which in IETF terms can translate to the lifetime of a session. Such information includes profile, level, and sub-profile information to determine a maximum capability interop point that is guaranteed to be never 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 constraint in the use of certain features as indicated by the values of those fields. With this, a bitstream can be labelled as not using certain tools, which allows among other things for resource allocation in a decoder implementation.

Video parameter set

The ideo parameter set (VPS) pertains to a coded video sequences (CVS) 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 MPGEG-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 MCUs involved), a CVS can be as long in duration as the whole session.

Picture and adaptation parameter set

The picture parameter set and the adaptation parameter set (PPS and APS, respectively) 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 scaling list. Different APSs containing ALF parameters can be referenced by slices of the same picture.

Picture header

A Picture Header 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 in 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, 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 Rec. T.35, that does not carry a semantics. It is carried in the profile_tier_level structure and hence (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: DVB and ATSC), as well as walled-garden video services will take advantage of this labelling 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 specs, such as GOP structures, minimum/maximum 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 for labelling a bitstream as not exercising a certain tool that has become commercially unviable.

Temporal scalability support

VVC includes support of temporal scalability, by 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 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, which causes a momentary bit rate spike 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 layer_id in the NAL unit header, the VPS which associates layers with given layer_ids 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

Supplementary enhancement information (SEI) messages are information in the bitstream that do not influence the decoding process as

specified in the VVC spec, but address issues of representation/ rendering of the decoded bitstream, label the bitstream for certain applications, among other, similar tasks. The overall concept of SEI messages and many of the messages themselves has been inherited from the H.264 and HEVC specs. 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; 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 for 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, forward error correction) and/or picture-based error resilience tools (feedback-based error resilience, insertion of IRAPs, scalability with 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 a 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

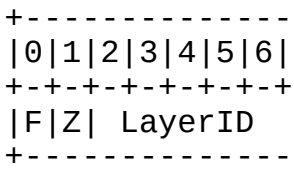
extractable. Regardless of whether a subpicture is extractable or not, the encoder can control whether in-loop filtering (including deblocking, SAO, and ALF) is applied across the subpicture boundaries individually for each subpicture.

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 360o video streaming optimization and region of interest (ROI) applications.

There are several important design differences between subpictures and MCTSs. First, the subpictures feature in VVC allows motion vectors of a coding block pointing outside of the subpicture even when the subpicture is extractable by applying sample padding at 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 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, while 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.



The Structure of the VVC NAL Unit Header.

Figure 1

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. 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 memo 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 Section TBD.

Z: 1 bit

nuh_reserved_zero_bit. 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, as a) overloading the "F" bit is sufficient and b) to preserve the usefulness of this memo to possible future versions of [VVC].

LayerId: 6 bits

nuh_layer_id. Identifies the layer a NAL unit belongs to, wherein a layer may be, e.g., a spatial scalable layer, a quality scalable layer .

Type: 5 bits

nal_unit_type. This field specifies the NAL unit type as defined in Table 7-1 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, so to enable independent considerations of start code emulations in the NAL unit header and in the NAL unit payload data.

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 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) [RFC4566]
- Frame-marking mapping [FrameMarking]

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 above.

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.

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 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.

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.

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

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 stream.

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: An 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.

Editor Notes: the following informative needs to be updated along with frame marking update

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.

NAL unit output order: A NAL unit order in which NAL units of different access units are in the output order of the decoded pictures corresponding to the access units, as specified in [VVC], and in which NAL units within an access unit are in their decoding order.

RTP stream: See [RFC7656]. Within the scope of this memo, one RTP stream is utilized to transport 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
CTU	Coding Tree Unit

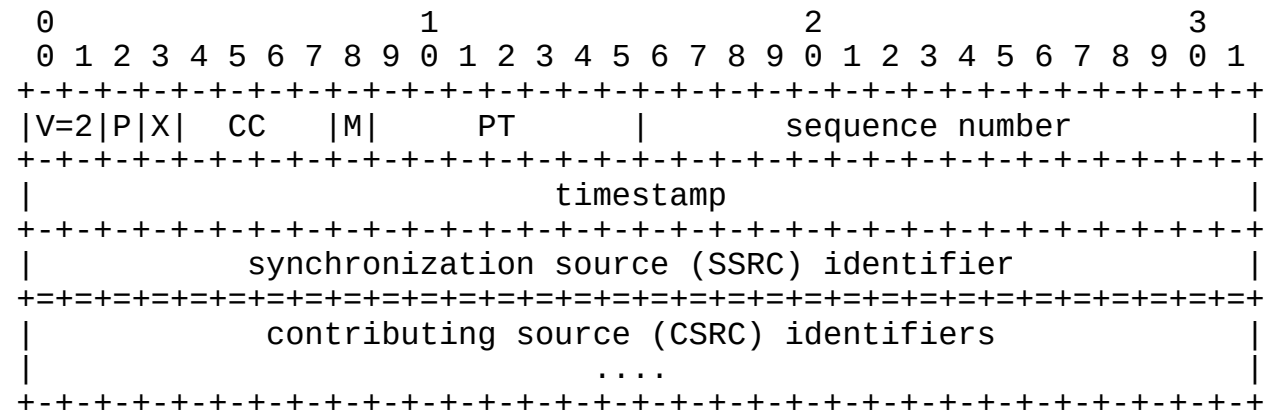
CVS	Coded Video Sequence
DPB	Decoded Picture Buffer
DCI	Decoding capability information
DON	Decoding Order Number
FIR	Full Intra Request
FU	Fragmentation Unit
HRD	Hypothetical Reference Decoder
IDR	Instantaneous Decoding Refresh
MANE	Media-Aware Network Element
MTU	Maximum Transfer Unit
NAL	Network Abstraction Layer
NALU	Network Abstraction Layer Unit
PLI	Picture Loss Indication
PPS	Picture Parameter Set
RPS	Reference Picture 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 Section 4.3.2 and Section 4.3.3, respectively.



RTP Header According to {{RFC3550}}

Figure 2

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 of the access unit, carried in the current RTP stream. This is in line with the normal use of the M bit in video formats to allow an efficient playout buffer handling.

Editor notes: The informative note below needs updating once the NAL unit type table is stable in the [VVC] spec.

> Informative note: The content of a NAL unit does not tell whether or not the NAL unit is the last NAL unit, in decoding order, of an access unit. An RTP sender implementation may obtain this information from the video encoder. If, however, the implementation cannot obtain this information directly from the encoder, e.g., when the bitstream was pre-encoded, and also there is no timestamp allocated for each NAL unit, then the

sender implementation can inspect subsequent NAL units in decoding order to determine whether or not the NAL unit is the last NAL unit of an access unit as follows. A NAL unit is determined to be the last NAL unit of an access unit if it is the last NAL unit of the bitstream. A NAL unit naluX is also determined to be the last NAL unit of an access unit if both the following conditions are true: 1) the next VCL NAL unit naluY in decoding order has the high-order bit of the first byte after its NAL unit header equal to 1 or nal_unit_type equal to 19, and 2) all NAL units between naluX and naluY, when present, have nal_unit_type in the range of 13 to17, inclusive, equal to 20, equal to 23 or equal to 26.

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 picture of the access unit in which the NAL unit (according to Annex D 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.

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 as 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.

For Discussion: quite possibly something similar can be said for the Layer_id in layered coding, but perhaps not in multiview coding. (The relevant part of the spec is relatively new, therefore the soft language). However, for serious layer pruning, interpretation of the VPS is required. We can add language about the need for stateful interpretation of LayerID vis-a-vis stateless interpretation of TID later.

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 4.4.1.

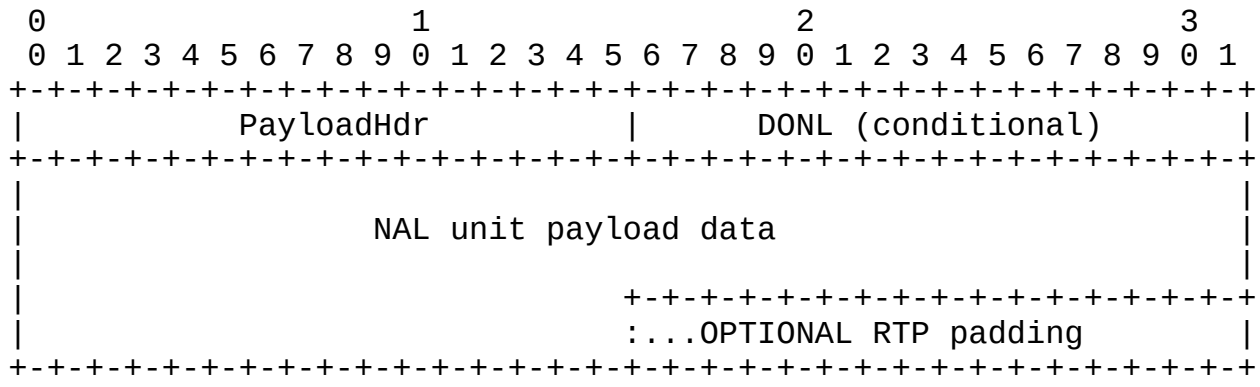
- Aggregation Packet (AP): Contains more than one NAL unit within one access unit. This payload structure is specified in Section 4.3.2.

- 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

Editor notes: its better to add a section to describe DONL and sprop-max_don_diff. sprop-max_don_diff is used but not specified as parameters in section 7 are not yet specified. A value of sprop-max_don_diff greater than 0 indicates that the transmission order may not correspond to the decoding order and that the DON is is included in the payload header.

A single NAL unit packet contains exactly one NAL unit, and consists of a payload header (denoted as PayloadHdr), 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.



The Structure of a Single NAL Unit Packet

Figure 3

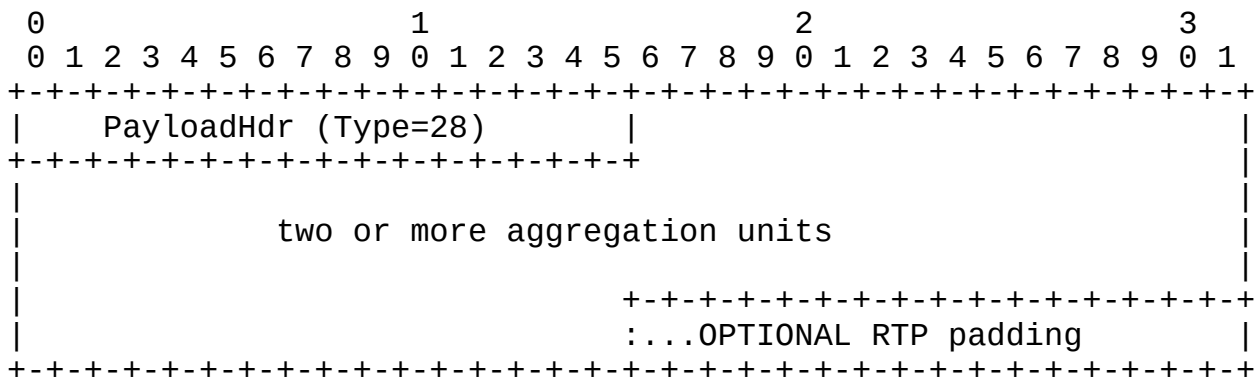
The DONL field, when present, specifies the value of the 16 least significant bits of the decoding order number of the contained NAL unit. If sprop-max-don-diff is greater than 0, the DONL field MUST be present, and the variable DON for the contained NAL unit is derived as equal to the value of the DONL 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 of 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. 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 (denoted as PayloadHdr) followed by two or more aggregation units, as shown in Figure 4.



The Structure of an Aggregation Packet

Figure 4

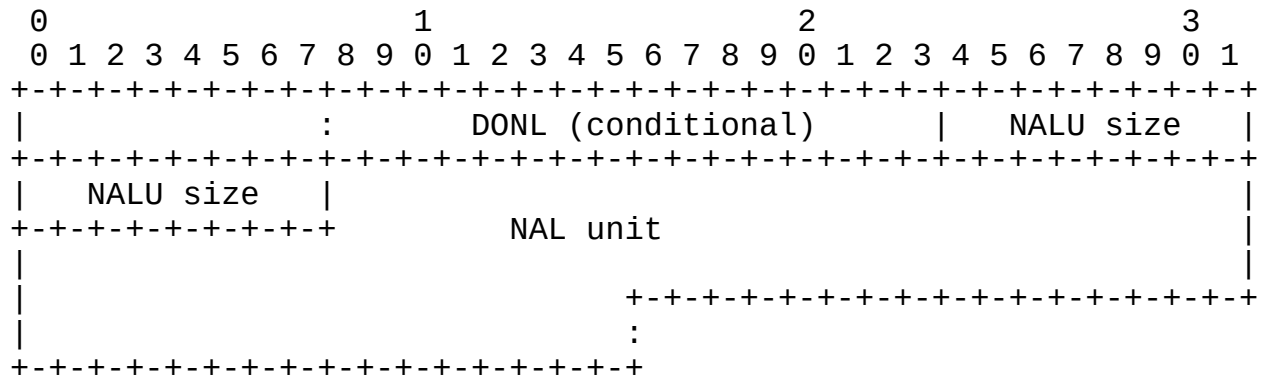
The fields in the payload header of an AP are set as follows. The F bit MUST be equal to 0 if the F bit of each aggregated NAL unit is equal to zero; otherwise, it MUST be equal to 1. The Type field MUST be equal to 28.

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.

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 so to avoid IP layer fragmentation. An AP MUST NOT contain FUs specified in Section 4.3.3. APs MUST NOT be nested; i.e., an AP can not contain another AP.

The first aggregation unit in an AP consists of a conditional 16-bit DONL field (in network byte order) followed by a 16-bit unsigned size information (in network byte order) that indicates 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.



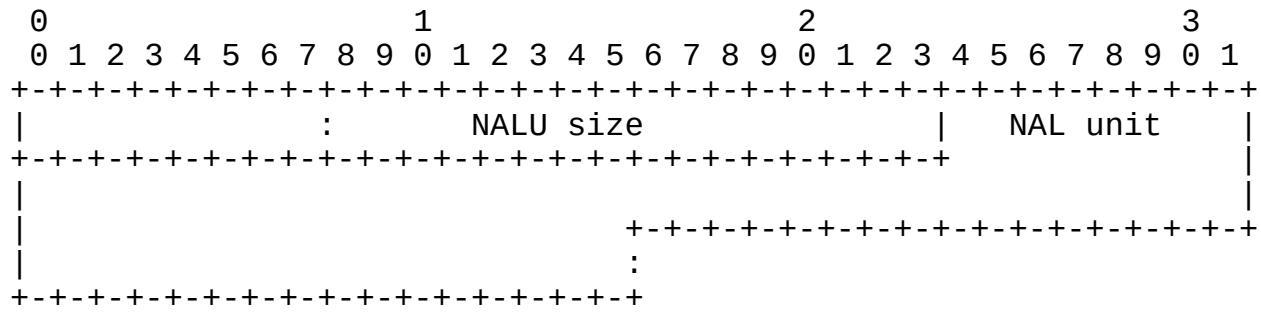
The Structure of the First Aggregation Unit in an AP

Figure 5

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. 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.

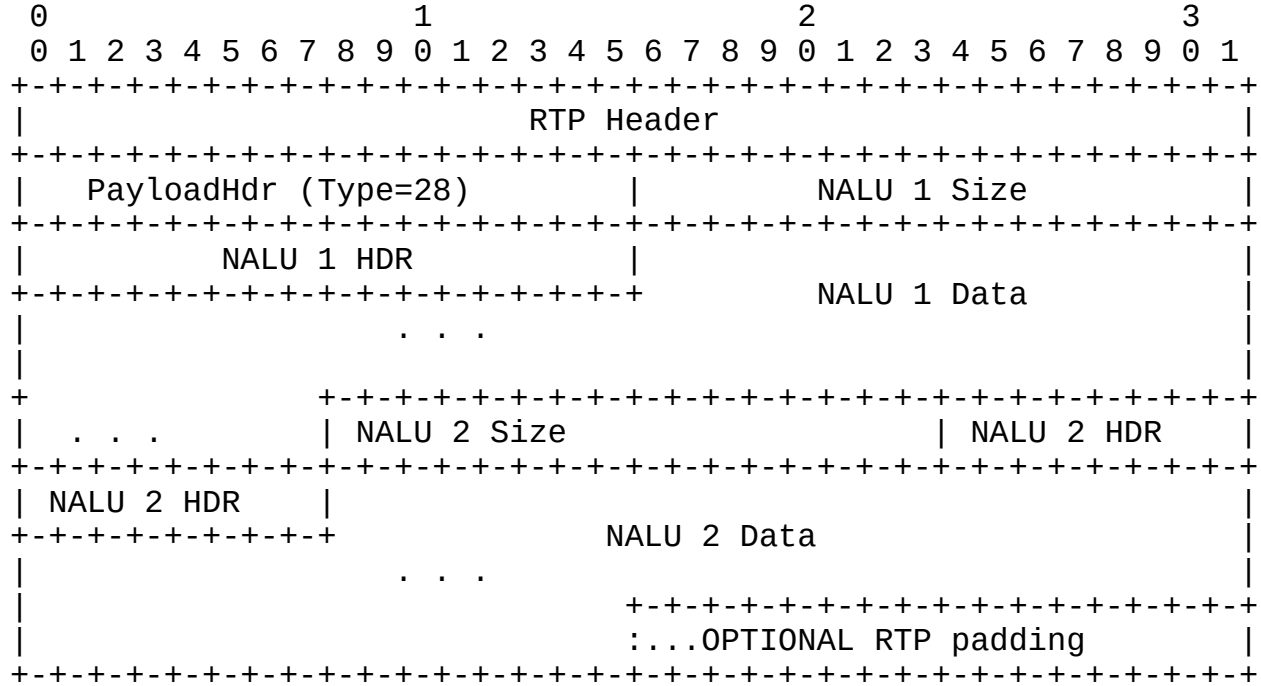
An aggregation unit that is not the first aggregation unit in an AP will be followed immediately by a 16-bit unsigned size information (in network byte order) that indicates the size of the NAL unit in bytes (excluding these two octets, but including the NAL unit header), followed by the NAL unit itself,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



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

Figure 6

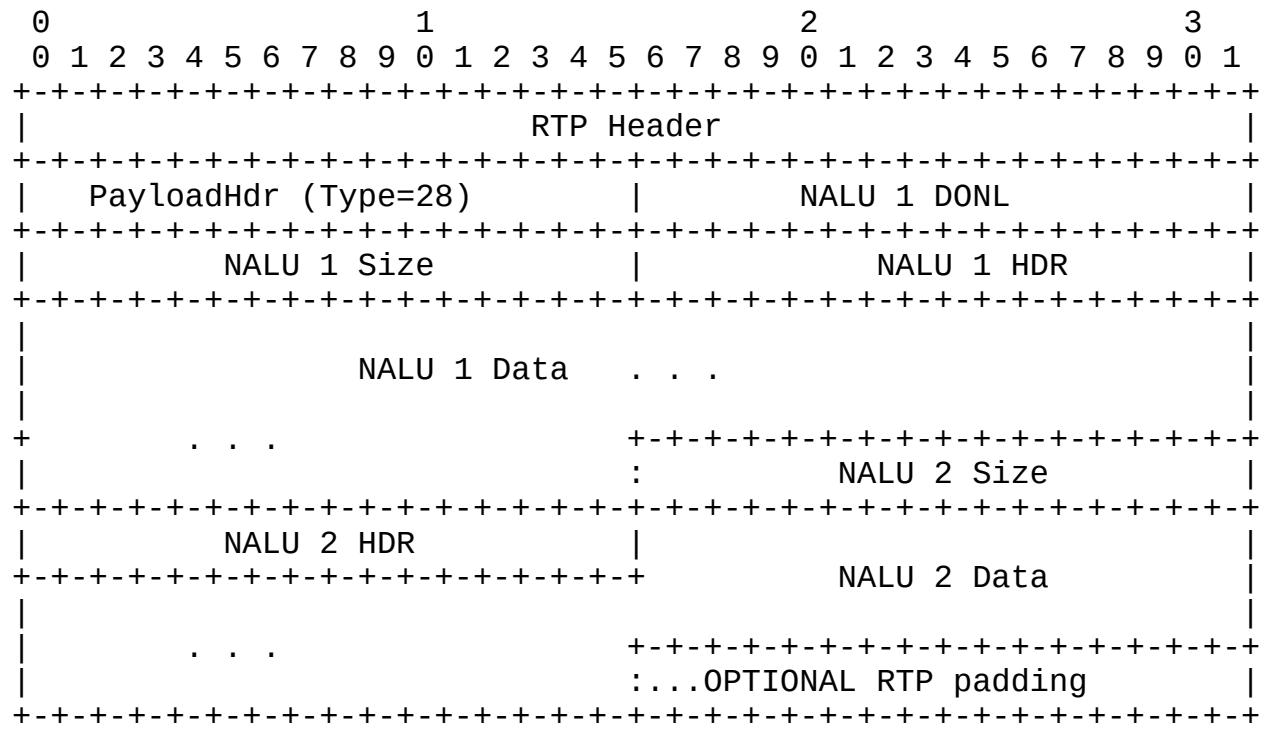
Figure 7 presents an example of an AP that contains two aggregation units, labeled as 1 and 2 in the figure, without the DONL field being present.



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

Figure 7

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.



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

Figure 8

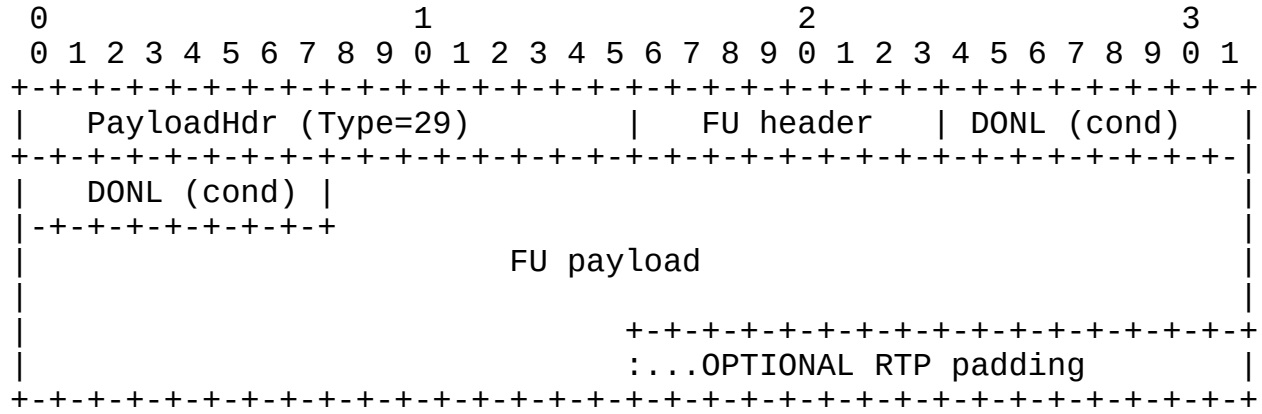
4.3.3. Fragmentation Units

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 can not 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 (denoted as PayloadHdr), 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.

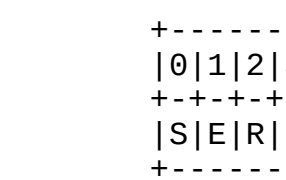


The Structure of an FU

Figure 9

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.



The Structure of FU Header

Figure 10

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.

Reserved: 1 bit

Placeholder

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 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:

- AbsDon[n] greater than AbsDon[m] 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.

- AbsDon[n] less than AbsDon[m] 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 and the NAL unit output order.

- A NAL unit of a small size SHOULD be encapsulated in an aggregation packet together 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 sequences 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 across RTP streams, 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 and across RTP streams. 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.

When sprop-max-don-diff is equal to 0, the de-packetization buffer size is zero bytes, and the process described in the remainder of this paragraph applies.
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 there are several NAL units of the same RTP stream with the same NTP timestamp, the order to pass them to the decoder is their transmission order.

> Informative note: The mapping between RTP and NTP timestamps is conveyed in RTCP SR packets. In addition, the mechanisms for faster media timestamp synchronization discussed in [RFC6051] may be used to speed up the acquisition of the RTP-to-wall-clock mapping.

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 condition A (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) or condition B (the number of NAL units in the de-packetization buffer is greater than the value of sprop-depack-buf-nalus) is true.

After initial buffering, whenever condition A or condition B is true, the following operation is repeatedly applied until both condition A and condition B become false:

- 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) [RFC4556] is also provided for applications that use SDP.

7.1. Media Type Registration

The receiver MUST ignore any parameter unspecified in this memo.

Type name: Video

Subtype name: H266

Required parameters: none

Optional parameters:

Editor’s notes: To be added

7.2. SDP Parameters

The receiver MUST ignore any parameter unspecified in this memo.

7.2.1. Mapping of Payload Type Parameters to SDP

The media type video/H266 string is mapped to fields in the Session Description Protocol (SDP) [RFC4566] 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.
- OPTIONAL PARAMETERS:

  Editor’s notes: To be dicussed here

profile-id, tier-flag, sub-profile-id, interop-constraints, and level-id:

These parameters indicate the profile, tier, default level, sub-profile, and some constraints of the bitstream carried by the RTP stream, or a specific set of the profile, tier, default level, 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 the profile-id can be further constrained with up to 255 sub-profile-ids. 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 signalling 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 or sprop-opi is included in the SDP answer for choosing one of the layers offered.

Editor’s notes: confirm when decided whether we use recv-ols-id or sprop-opi

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 either the recv-ols-id parameter that is less than the sprop-ols-id parameter in the SDP offer or the sprop-opi, the following applies:

Editor’s notes: confirm when decided whether we use recv-ols-id or sprop-opi for profile asymmetry - sub-layers cannot

+ 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 is indicated by level-id and max-recv-level-id together and a higher level than that in the offer 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 or includes the sprop-opi, 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.

Editor’s notes: confirm when decided whether we use recv-ols-id or sprop-opi for profile asymmetry - sub-layers cannot. The consistency of profiles is not yet in the text. I think this parts needs a bit of discussion

More specifications of these parameters, including how they relate 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 in the profile_tier_level( ) syntax structure in SPS, VPS or DCI NAL units as specified in [VVC]. When a VPS contains several profile_tier_level( ) syntax structures, the syntax structure corresponding to the OLS to which the bitstream applies is used.

Editor’s notes: What if the DCI contains several profile_tier_level( ) syntax structures and they are not onion shell?

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 numbers 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 level are defined in the future, the same convention will be used, but this cannot be guaranteed.

Editor’s notes: double check this informative note

When used to indicate properties of a bitstream, the tier-flag and level-id parameters are derived from the profile_tier_level( ) syntax structure in SPS, VPS or DCI NAL units as specified in [VVC] as follows.

If the tier-flag and level-id are derived from the profile_tier_level( ) syntax structure in the 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 the SPS or VPS NAL unit, and the bitstream contains the highest sub-layer 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 the SPS or VPS NAL unit, and the bitstream does not contains the highest sub-layer representation in the OLS corresponding to the bitstream, the following applies, with j being the value of the sprop-sub-layer-id parameter or the sub-layer representation indicated in the sprop-opi parameter:

+ tier-flag = general_tier_flag

+ level-id = sub_layer_level_idc[j]

Editor’s notes: double check this part above inherited from HEVC. What if more than one SPS, VPS and they have different general_leve_idcs or tier_flags? We would say it applies to all of them, i.e. to the highest one.

sub-profile-id:

The value of the parameter is a comma-separated (’,’) list of values.

Editor’s notes: What is the value? integer, base32?

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 in the profile_tier_level( ) syntax structure in SPS, VPS or DCI NAL units as specified in [VVC]. When a VPS contains several profile_tier_level( ) syntax structures, the syntax structure corresponding to the OLS to which the bitstream applies is used.

Editor’s notes: What if the DCI contains several profile_tier_level( ) syntax structures and they are not onion shell?

interop-constraints:

A base16 [RFC4648] (hexadecimal) representation of the data in the profile_tier_level( ) syntax structure in SPS, VPS or DCI NAL units as specified in [VVC], that include the syntax elements ptl_frame_only_constraint_flag and ptl_multilayer_enabled_flag and, when present, the general_constraints_info( ) syntax structure. When a VPS contains several profile_tier_level( ) syntax structures, the syntax structure corresponding to the OLS to which the bitstream applies is used.

Editor’s notes: What if the DCI contains several profile_tier_level( ) syntax structures and they are not equal?

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

+ ptl_frame_only_constraint_flag = 0

+ ptl_multilayer_enabled_flag = 1

+ gci_present_flag in the general_constraints_info( ) syntax structure = 1

Editor’s notes: Double check the default values. Currently, no constraints, but actually, with the Main 10 profile as default multi-layer not possible.

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

sprop-sub-layer-id:

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

The value of sprop-sub-layer-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 8.1.1 in [VVC].

The value of sprop-ols-id MUST be in the range of 0 to 257, inclusive.

Editor’s notes: Confirm this value

recv-sub-layer-id:

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

The value of recv-sub-layer-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 the 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 in the SDP offer.

The value of recv-ols-id MUST be in the range of 0 to 257, inclusive.

Editor’s notes: Confirm this value

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 a base64 [RFC4648] representations 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 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 sub-stream 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 [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 unit. 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 any decoder that conforms to the profile, tier, level, and constraints indicated by the 12 bytes of data starting from the syntax element general_profile_space to the syntax element general_level_idc, inclusive, in the first profile_tier_level( ) syntax structure in vpsA can decode any bitstream that conforms to the profile, tier, level, and constraints indicated by the 12 bytes of data starting from the syntax element general_profile_space to the syntax element general_level_idc, inclusive, in the first profile_tier_level( ) syntax structure in vpsB.

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 [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:

1) 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.

2) 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), the display orientation SEI message when the device is a handheld device (as the display orientation may change when the handheld device is turned around), or the filler payload SEI message (as there is no point in just having more bits in SDP).

sprop-opi:

Editor’s notes: VVC does not envision to provide the OPI by external means but this should not be a problem

This parameter MAY be used to convey an operating point information NAL unit of the bitstream for out-of-band transmission. The value of the parameter is a base64 [RFC4648] representations of the operating point information NAL unit as specified in Section 7.3.2.2 of [VVC].

max-lsr, max-lps, max-cpb, max-dpb, max-br, max-tr, max-tc:

These parameters MAY be used to signal the capabilities of a receiver implementation. These parameters MUST NOT be used for any other purpose. The highest level (specified by max-recv-level-id) MUST be the highest that the receiver is fully capable of supporting. max-lsr, max-lps, max-cpb, max-dpb, max-br, max-tr, and max-tc MAY be used to indicate capabilities of the receiver that extend the required capabilities of the highest level, as specified below.

When more than one parameter from the set (max-lsr, max-lps, max-cpb, max-dpb, max-br, max-tr, max-tc) is present, the receiver MUST support all signaled capabilities simultaneously. For example, if both max-lsr and max-br are present, the highest level with the extension of both the picture rate and bitrate is supported. That is, the receiver is able to decode bitstreams in which the luma sample rate is up to max-lsr (inclusive), the bitrate is up to max-br (inclusive), the coded picture buffer size is derived as specified in the semantics of the max-br parameter below, and the other properties comply with the highest level specified by max-recv-level-id.

Informative note: When the OPTIONAL media type parameters are used to signal the properties of a bitstream, and max-lsr, max-lps, max-cpb, max-dpb, max-br, max-tr, and max-tc are 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, tier, and level.

max-lsr:

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.

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 136 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 136 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 136 of [VVC] for the highest level.

max-lps:

The value of max-lps is an integer indicating the maximum picture size in units of luma samples. The max-lps parameter signals that the receiver is capable of decoding larger picture sizes than are required by the highest level. When max-lps is signaled, the receiver MUST be able to decode bitstreams that conform to the highest level, with the exception that the MaxLumaPs value in Table 135 of [VVC] for the highest level is replaced with the value of max-lps. Senders MAY use this knowledge to send larger pictures at a proportionally lower picture rate than is possible for the largest picture size for the highest level.

When not present, the value of max-lps is inferred to be equal to the value of MaxLumaPs given in Table 135 of [VVC] for the highest level.

The value of max-lps MUST be in the range of MaxLumaPs to 16 * MaxLumaPs, inclusive, where MaxLumaPs is given in Table 135 of [VVC] for the highest level.

max-cpb:

The value of max-cpb is an integer indicating the maximum coded picture buffer size in units of CpbVclFactor bits for the VCL HRD parameters and in units of CpbNalFactor bits for the NAL HRD parameters, where CpbVclFactor and CpbNalFactor are defined in Table 137 of [VVC]. The max-cpb parameter signals that the receiver has more memory than the minimum amount of coded picture buffer memory required by the highest level. When max-cpb is signaled, the receiver MUST be able to decode bitstreams that conform to the highest level, with the exception that the MaxCPB value in Table 135 of [VVC] for the highest level is replaced with the value of max-cpb. Senders MAY use this knowledge to construct coded bitstreams with greater variation

of bitrate than can be achieved with the MaxCPB value in Table 135 of [VVC].

When not present, the value of max-cpb is inferred to be equal to the value of MaxCPB given in Table 135 of [VVC] for the highest level.

The value of max-cpb MUST be in the range of MaxCPB to 16 * MaxCPB, inclusive, where MaxCPB is given in Table 135 of [VVC] for the highest level.

Informative note: The coded picture buffer is used in the hypothetical reference decoder (Annex C of [VVC]). The use of the hypothetical reference decoder is recommended in VVC encoders to verify that the produced bitstream conforms to the standard and to control the output bitrate. Thus, the coded picture buffer is conceptually independent of any other potential buffers in the receiver, including de-packetization and de-jitter buffers. The coded picture buffer need not be implemented in decoders as specified in Annex C of [VVC], but rather standard-compliant decoders can have any buffering arrangements provided that they can decode standard-compliant bitstreams. Thus, in practice, the input buffer for a video decoder can be integrated with de-packetization and de-jitter buffers of the receiver.

max-dpb:

The value of max-dpb is an integer indicating the maximum decoded picture buffer size in units decoded pictures at the MaxLumaPs for the highest level, i.e., the number of decoded pictures at the maximum picture size defined by the highest level. The value of max-dpb MUST be in the range of 1 to 16, respectively. The max-dpb parameter signals that the receiver has more memory than the minimum amount of decoded picture buffer memory required by default, which is maxDpbPicBuf as defined in [VVC] (equal to 8). When max-dpb is signaled, the receiver MUST be able to decode bitstreams that conform to the highest level, with the exception that the maxDpbPicBuff value defined in [VVC] as 8 is replaced with the value of max-dpb.

Consequently, a receiver that signals max-dpb MUST be capable of storing the following number of decoded pictures (MaxDpbSize) in its decoded picture buffer:

```
if( 2 \* PicSizeMaxInSamplesY  <=  ( MaxLumaPs   >>  2 ) )
   MaxDpbSize = 2 \* max-dpb
else if( 3 \* PicSizeMaxInSamplesY  <=  2 \* MaxLumaPs )
   MaxDpbSize = 3 \* max-dpb / 2
else
   MaxDpbSize = max-dpb
```

Wherein MaxLumaPs given in Table 135 of [VVC] for the highest level and PicSizeMaxInSamplesY is the maximum allowed picture size in units of luma samples as defined in [VVC].

Editor’s notes: I think that max-lps needs to be accounted for here.

The value of max-dpb MUST be greater than or equal to the value of maxDpbPicBuf (i.e., 8) as defined in [VVC]. Senders MAY use this knowledge to construct coded bitstreams with improved compression.

When not present, the value of max-dpb is inferred to be equal to the value of maxDpbPicBuf (i.e., 8) as defined in [VVC].

Informative note: This parameter was added primarily to complement a similar codepoint in the ITU-T Recommendation H.245, so as to facilitate signaling gateway designs. The decoded picture buffer stores reconstructed samples. There is no relationship between the size of the decoded picture buffer and the buffers used in RTP, especially de-packetization and de-jitter buffers.

max-br:

The value of max-br is an integer indicating the maximum video bitrate in units of BrVclFactor bits per second for the VCL HRD parameters and in units of BrNalFactor bits per second for the

NAL HRD parameters, where BrVclFactor and BrNalFactor are defined in Section A.4 of [VVC].

The max-br parameter signals that the video decoder of the receiver is capable of decoding video at a higher bitrate than is required by the highest level.

When max-br is signaled, the video codec of the receiver MUST be able to decode bitstreams that conform to the highest level, with the following exceptions in the limits specified by the highest level:

+ The value of max-br replaces the MaxBR value in Table 136 of [VVC] for the highest level.

+ When the max-cpb parameter is not present, the result of the following formula replaces the value of MaxCPB in Table 135 of [VVC]:

(MaxCPB of the highest level) * max-br / (MaxBR of the highest level)

For example, if a receiver signals capability for Main 10 profile Level 2 with max-br equal to 2000, this indicates a maximum video bitrate of 2000 kbits/sec for VCL HRD parameters, a maximum video bitrate of 2200 kbits/sec for NAL HRD parameters, and a CPB size for VCL HRD of 2000000 bits (1500000 * 2000000 / 1500000).

Senders MAY use this knowledge to send higher bitrate video as allowed in the level definition of Annex A of [VVC] to achieve improved video quality.

When not present, the value of max-br is inferred to be equal to the value of MaxBR given in Table 136 of [VVC] for the highest level.

The value of max-br MUST be in the range of MaxBR to 16 * MaxBR, inclusive, where MaxBR is given in Table 136 of [VVC for the highest level.

Informative note: This parameter was added primarily to complement a similar codepoint in the ITU-T Recommendation H.245, so as to facilitate signaling gateway designs. The assumption that the network is capable of handling such bitrates at any given time cannot be made from the value of this parameter. In particular, no conclusion can be drawn that the signaled bitrate is possible under congestion control constraints.

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, one or more of the parameters max-lsr, max-lps, and max-br.

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, max-lps, max-cpb, max-dpb, max-br, max-tr, and max-tc 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, one or more of the parameters max-lsr, max-lps, and max-br.

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.

Editor's notes: sprop-depack-buf-nalus not included but mentioned in section 6 for startup in de-packetization process. We should decide on whether it needs to be included or not.

7.2.1.1. SDP Example

An example 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>
```

7.2.2. Usage with SDP Offer/Answer Model

When [VVC] is offered over RTP using SDP in an offer/answer model [RFC3264] for negotiation for unicast usage, the following limitations and rules apply:

Placeholder: To add limitations and considerations.

8. Use with Feedback Messages

The following subsections define the use of the Picture Loss Indication (PLI), Slice Lost Indication (SLI), Reference Picture Selection Indication (RPSI), and Full Intra Request (FIR) feedback messages with HEVC. The PLI, SLI, and RPSI messages are defined in [RFC4585], and the FIR message is defined in [RFC5104].

8.1. Picture Loss Indication (PLI)

As specified in RFC 4585, Section 6.3.1, 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 an 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, state could have been established outside of the mechanisms defined in this document that parameter sets are conveyed out of band only, and 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 RFC 4585 MUST be observed.

8.2. Slice Loss Indication (SLI)

For further study. Maybe remove as there are no known implementations of SDLI in [HEVC] based systems

8.3. Reference Picture Selection Indication (RPSI)

Feedback-based reference picture selection has been shown as a powerful tool to stop temporal error propagation for improved error resilience [Girod99] [Wang05]. In one approach, the decoder side tracks errors in the decoded pictures and informs the encoder side that a particular picture that has been decoded relatively earlier is correct and still present in the decoded picture buffer; it requests the encoder to use that correct picture-availability information when encoding the next picture, so to stop further temporal error propagation. For this approach, the decoder side should use the RPSI feedback message.

Encoders can encode some long-term reference pictures as specified in [VVC] for purposes described in the previous paragraph without the need of a huge decoded picture buffer. As shown in [Wang05], with a flexible reference picture management scheme, as in VVC, even a decoded picture buffer size of two picture storage buffers would work for the approach described in the previous paragraph.

The text above is copy-paste from RFC 7798. If we keep the RPSI message, it needs adaptation to the [VVC] syntax. Doing so shouldn’t be too hard as the [VVC] reference picture mechanism is not too different from the [HEVC] one.

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

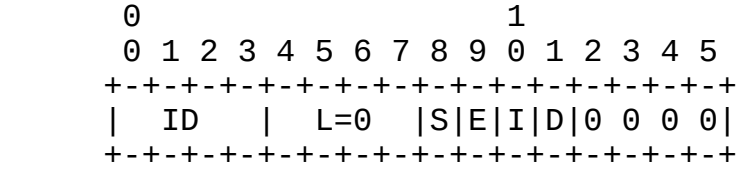
9. Frame Marking

[FrameMarking] provides an extension mechanism for RTP. The codec-agnostic meta-data in the [FrameMarking] header provides valuable video frame information. Its usage with [VVC] is defined in this section. Refer [FrameMarking] for any unspecified fields. Two header extensions are RECOMMENDED:

- The short extension for non-scalable streams.
- The long extension for scalable streams.

9.1. Frame Marking Short Extension

The fields for the short extension, as shown in Figure 11, are used as described in the following.



Short Frame Marking RTP Extension for [VVC]

Figure 11

The I bit MUST be 1 when the NAL unit type is 7-9 (inclusive), otherwise it MUST be 0.

The D bit MUST be 1 when the syntax element ph_non_ref_pic_flag for a picture is equal to 1, otherwise it MUST be 0.

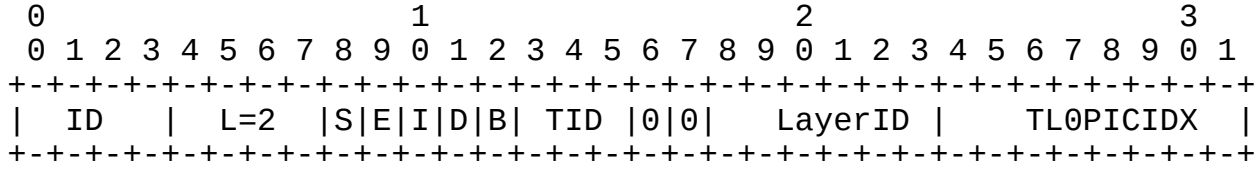
The S bit MUST be set to 1 if any of the following conditions is true and MUST be set to 0 otherwise:

- The RTP packet is a single NAL unit packet and it is the first VCL NAL unit, in decoding order, of a picture.
- The RTP packet is an AP, and the NAL unit in the first contained aggregation unit is the first VCL NAL unit, in decoding order, of a picture.
- The RTP packet is a FU with its S bit equal to 1 and the FU payload contains a fragment of the first VCL NAL unit, in decoding order, of a picture.

The E bit MUST be set to 1 if any of the following conditions is true and MUST be set to 0 otherwise:

- The RTP packet is a single NAL unit packet and it is the last VCL NAL unit, in decoding order, of a picture.
- The RTP packet is an AP and the NAL unit in the last contained aggregation unit is the last VCL NAL unit, in decoding order, of a picture.
- The RTP packet is a FU with its E bit equal to 1 and the FU payload contains a fragment of the last VCL NAL unit, in decoding order, of a picture.

9.2. Frame Marking Long Extension



Long Frame Marking RTP Extension for [VVC]

Figure 12

The fields for the long extension for scalable streams, as shown in Figure 12, are used as described in the following.

The LayerID (6 bits) and TID (3 bits) from the NAL unit header Section 1.1.4 are mapped to the generic LID and TID fields in [FrameMarking] as shown in Figure 12.

The I bit MUST be 1 when the NAL unit type is 7-9 (inclusive), otherwise it MUST be 0.

The D bit MUST be 1 when the syntax element ph_non_ref_pic_flag for a picture is equal to 1, otherwise it MUST be 0.

The S bit MUST be set to 1 if any of the following conditions is true and MUST be set to 0 otherwise:

- The RTP packet is a single NAL unit packet and it is the first VCL NAL unit, in decoding order, of a picture.
- The RTP packet is an AP, and the NAL unit in the first contained aggregation unit is the first VCL NAL unit, in decoding order, of a picture.

- The RTP packet is a FU with its S bit equal to 1 and the FU payload contains a fragment of the first VCL NAL unit, in decoding order, of a picture.

The E bit MUST be set to 1 if any of the following conditions is true and MUST be set to 0 otherwise:

- The RTP packet is a single NAL unit packet and it is the last VCL NAL unit, in decoding order, of a picture.
- The RTP packet is an AP and the NAL unit in the last contained aggregation unit is the last VCL NAL unit, in decoding order, of a picture.
- The RTP packet is a FU with its E bit equal to 1 and the FU payload contains a fragment of the last VCL NAL unit, in decoding order, of a picture.

10. Security Considerations

The scope of this Security Considerations 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, seems 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, for example, with SRTP [RFC3711] .

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 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.

11. Congestion Control

Congestion control for RTP SHALL be used in accordance with RTP [RFC3550] and with any applicable RTP profile, e.g., AVP [RFC3551]. 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 achieving. This condition can be satisfied by implementing congestion-control mechanisms to adapt the transmission rate, 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 (as indicated by interpreting the VPS) until the sending bitrate drops to an acceptable range.

The mechanisms mentioned above generally work within a defined profile and level and, 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. MANES can also remove higher temporal scalable layers if the outbound transmission (from the MANE’s viewpoint) experiences congestion.

12. IANA Considerations

Placeholder

13. 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.

14. References

14.1. Normative References

[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>.

[RFC4556] Zhu, L. and B. Tung, "Public Key Cryptography for Initial Authentication in Kerberos (PKINIT)", RFC 4556, DOI 10.17487/RFC4556, June 2006, <https://www.rfc-editor.org/info/rfc4556>.

[RFC4566] Handley, M., Jacobson, V., and C. Perkins, "SDP: Session Description Protocol", RFC 4566, DOI 10.17487/RFC4566, July 2006, <https://www.rfc-editor.org/info/rfc4566>.

[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>.

[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>.

[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>.

[VSEI] "ISO/IEC 23002-7 (ITU-T H.274) Versatile supplemental enhancement information messages for coded video bitstreams", 2020, <https://www.iso.org/standard/79112.html>.

[VVC] "ISO/IEC FDIS 23090-3 Information technology --- Coded representation of immersive media --- Part 3 - Versatile video coding", 2020, <https://www.iso.org/standard/73022.html>.

14.2. Informative References

[CABAC] Sole, J, . and . et al, "Transform coefficient coding in HEVC, IEEE Transactions on Circuts and Systems for Video Technology", DOI 10.1109/TCSVT.2012.2223055, December 2012.

[FrameMarking]
Berger, E, ., Nandakumar, S, ., and . Zanaty M, "Frame Marking RTP Header Extension", Work in Progress draft-berger-avtext-framemarking , 2015.

[Girod99] Girod, B, . and . et al, "Feedback-based error control for mobile video transmission, Proceedings of the IEEE", DOI 110.1109/5.790632, October 1999.

[HEVC] "High efficiency video coding, ITU-T Recommendation H.265", April 2013.

[MPEG2S] IS0/IEC, ., "Information technology - Generic coding ofmoving pictures and associated audio information - Part 1:Systems, ISO International Standard 13818-1", 2013.

[RFC6051] Perkins, C. and T. Schierl, "Rapid Synchronisation of RTP Flows", RFC 6051, DOI 10.17487/RFC6051, November 2010, <https://www.rfc-editor.org/info/rfc6051>.

[RFC6184] Wang, Y., 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., 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>.

[RFC7798] Wang, Y., Sanchez, Y., Schierl, T., Wenger, S., and 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>.

[Wang05] Wang, YK, ., Zhu, C, ., and . Li, H, "Error resilient video coding using flexible reference fames", Visual Communications and Image Processing 2005 (VCIP 2005) , July 2005.

Appendix A. Change History

draft-zhao-payload-rtp-vvc-00 ..... initial version

draft-zhao-payload-rtp-vvc-01 ..... editorial clarifications and corrections

draft-ietf-payload-rtp-vvc-00 ..... initial WG draft

draft-ietf-payload-rtp-vvc-01 ..... VVC specification update

draft-ietf-payload-rtp-vvc-02 ..... VVC specification update

draft-ietf-payload-rtp-vvc-03 ..... VVC coding tool introduction update

draft-ietf-payload-rtp-vvc-04 ..... VVC coding tool introduction update

Authors' Addresses

Shuai Zhao
Tencent
2747 Park Blvd
Palo Alto 94588
USA

Email: shuai.zhao@ieee.org

Stephan Wenger
Tencent
2747 Park Blvd
Palo Alto 94588
USA

Email: stewe@stewe.org

Yago Sanchez
Fraunhofer HHI
Einsteinufer 37
Berlin 10587
Germany

Email: yago.sanchez@hhi.fraunhofer.de

Ye-Kui Wang
Bytedance Inc.
8910 University Center Lane
San Diego 92122
USA

Email: yekui.wang@bytedance.com