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AVT WG
Ladan Gharai
Colin Perkins
USC/ISI

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RTP Payload Format for Uncompressed Video

Status of this Memo

Abstract

This memo specifies a packetization scheme for encapsulating uncompressed video into a payload format for the Real-time Transport Protocol, RTP. It supports a range of standard- and high-definition video formats, including common television formats such as ITU BT.601, SMPTE 274M and SMPTE 296M. The format is designed to be extensible as new video formats are developed.

1. Introduction

[Note to RFC Editor: All references to RFC XXXX are to be replaced with the RFC number of this memo, when published]

This memo defines a scheme to packetize uncompressed, studio-quality, video streams for transport using RTP [RTP]. It supports a range of standard and high definition video formats, including ITU-R BT.601 [601], SMPTE 274M [274] and SMPTE 296M [296].

Formats for uncompressed standard definition television are defined by ITU Recommendation BT.601 [601] along with bit-serial and parallel interfaces in Recommendation BT.656 [656]. These formats allow both 625 line and 525 line operation, with 720 samples per digital active line, 4:2:2 color sub-sampling, and 8- or 10-bit digital representation.

The representation of uncompressed high definition television is specified in SMPTE standards 274M [274] and 296M [296]. SMPTE 274M defines a family of scanning systems with an image format of 1920x1080 pixels with progressive and interlaced scanning, while SMPTE 296M standard defines systems with an image size of 1280x720 pixels and only progressive scanning. In progressive scanning, scan lines are displayed in sequence from top to bottom of a full frame. In interlaced scanning, a frame is divided into its odd and even scan lines (called fields) and the two fields are displayed in succession.

SMPTE 274M and 296M define images with aspect ratios of 16:9, and define the digital representation for RGB and YCbCr components. In the case of YCbCr components, the Cb and Cr components are horizontally sub-sampled by a factor of two (4:2:2 color encoding).

Although these formats differ in their details, they are structurally very similar. This memo specifies a payload format to encapsulate these, and other similar, video formats for transport within RTP.

2. Conventions Used in this Document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119[2119].

3. Payload Design

Each scan line of digital video is packetized into one or more (depending on the network MTU) RTP packets. A single RTP packet MAY also contain data for more than one scan line. Only the active samples are

included in the RTP payload, inactive samples and the contents of horizontal and vertical blanking SHOULD NOT be transported. Scan line numbers are included in the RTP payload header, along with a field identifier for interlaced video.

> For SMPTE 296M format video, valid scan line numbers are from 26 through 745, inclusive. For progressive scan SMPTE 274M format video, valid scan lines are from scan line 42 through 1121 inclusive. For interlaced scan, valid scan line numbers for field one (F=0) are from 21 to 560 and valid scan line numbers for the second field (F=1) are from 584 to 1123. For ITU-R BT.601 format video, the blanking intervals defined in BT.656 are used: for 625 line video, lines 24 to 310 of field one (F=0) and 337 to 623 of the second field (F=1) are valid; for 525 line video, lines 21 to 263 of the first field, and 284 to 525 of the second field are valid. Other formats (e.g. [372]) may define different ranges of active lines.

The payload header contains a 16 bit extension to the standard 16 bit RTP sequence number, thereby extending the sequence number to 32 bits and enabling RTP to accommodate high data rates. This is necessary as the 16 bit RTP sequence number will roll-over very quickly for high data rates. For example, for a 1 Gbps video stream with packet sizes of at least one thousand octets, the standard RTP packet will roll-over in 0.5 seconds, which can be a problem for detecting loss and out of order packets particularly in instances where the round trip time is greater than half a second. The extended 32 bit number allows for a longer wrap-around time of approximately nine hours.

It is desirable for the video to be both octet aligned when packetized, and to adhere to the principles of application level framing [ALF] by ensuring that the samples relating to a single pixel are not fragmented across two packets.

Samples may be transfered as 8, 10, 12 or 16 bit values. For 10 bit and 12 bit payloads, care must be taken to pack an appropriate number of samples per packet, such that the payload is also octet aligned. For RGB video, it is desirable that the samples corresponding to a single pixel are not fragmented across packets. Similarly, for YCrCb video, it is desirable that luminance and chrominance values are not fragmented across packets.

For example, in YCrCb video with 4:1:1 color subsampling, each group of 4 pixels is represented by 6 values, Y1 Y2 Y3 Y4 Cr Cb. These should be packetized such that these values are not fragmented across a packet boundary. With 10 bit words this is a 60 bit value which is not octet

aligned. To be both octet aligned, and appropriately framed, pixels must be framed in 2 groups of 4 pixels, thereby becoming octet aligned on a 15 octet boundary. This length is referred to as the pixel group ("pgroup"), and it is conveyed in the SDP parameters. Tables 1 to 4 display the pgroup values, in octets, for a range of color samplings and word lengths.

When packetizing digital active line content, video data MUST NOT be fragmented within a pgroup.

Video content is almost always associated with additional information such as audio tracks, time code, etc. In professional digital video applications this data is commonly embedded in non-active portions of the video stream (horizontal and vertical blanking periods) so that precise and robust synchronization is maintained. This payload format requires that applications using such synchronized ancillary data MUST deliver it in separate RTP sessions which operate concurrently with the video session. The normal RTP mechanisms SHOULD be used to synchronize the media.

Color Subsampling	Pixels		8 bit words #words	octet alignment	#samples	pgroup octets
monochrome	1	P/I	1x8	8/8 = 1	1	1
4:1:1	4	P/I	6x8	6x8/8 = 6	6	6
4:2:0	4	P	6x8	6x8/8 = 6	6	6
4:2:0	4	I	4x8	4x8/8 = 6	4	4
4:2:2	2	P/I	4x8	4x8/8 = 8	4	4
4:4:4	1	P/I	3x8	3x8/8 = 3	3	3
4:4:4:4	1	P/I	4x8	4x8/8 = 4	4	4

Table 1: pgroup values for 8 bit sampling

Color Subsampling	Pixels		10 bit words #words	octet alignment	#samples	pgroup octets
monochrome	4	P/I	4x10	40/8 = 5	4	5
4:1:1	4	P/I	6x10	2x60/8 = 15	12	15
4:2:0	4	P	6x10	2x60/8 = 15	12	15
4:2:0	4	I	4x10	40/8 = 5	4	5
4:2:2	2	P/I	4x10	40/8 = 5	4	5
4:4:4	1	P/I	3x10	4x30/8 = 15	12	15
4:4:4:4	1	P/I	4x10	40/8 = 5	4	5

Table 2: pgroup values for 10 bit sampling

Color Subsampling	Pixels		12 bit words #words	octet alignment	#samples	pgroup octets
monochrome	2	P/I	2x12	2x12/8 = 3	2	3
4:1:1	4	P/I	6x12	72/8 = 9	6	9
4:2:0	4	P	6x12	72/8 = 9	6	9
4:2:0	4	I	4x12	48/8 = 6	4	6
4:2:2	2	P/I	4x12	48/8 = 6	4	6
4:4:4	2	P/I	6x12	2x36/8 = 9	6	9
4:4:4:4	1	P/I	4x12	48/8 = 6	4	6

Table 3: pgroup values for 12 bit sampling

Color Subsampling	Pixels		16 bit words #words	octet alignment	samples	pgroup octets
monochrome	1	P/I	1x16	16/8 = 2	1	2
4:1:1	4	P/I	6x16	6x16/8 = 12	6	12
4:2:0	4	P	6x16	6x16/8 = 12	6	12
4:2:0	4	I	4x16	4x16/8 = 8	4	8
4:2:2	2	P/I	4x16	4x16/8 = 8	4	8
4:4:4	1	P/I	3x16	3x16/8 = 6	3	6
4:4:4:4	1	P/I	4x16	4x16/8 = 8	4	8

Table 4: pgroup values for 16 bit sampling

4. RTP Packetization

The standard RTP header is followed by a 4 octet payload header that extends the RTP Sequence Number, and by a 6 octet payload header for each line (or partial line) of video included. One or more lines, or partial lines, of video data follow. This format makes the payload header 32 bit aligned in the common case, where one scan line (fragment) of video is included in each RTP packet.

For example, if two lines of video are encapsulated, the payload format will be as shown in Figure 1.

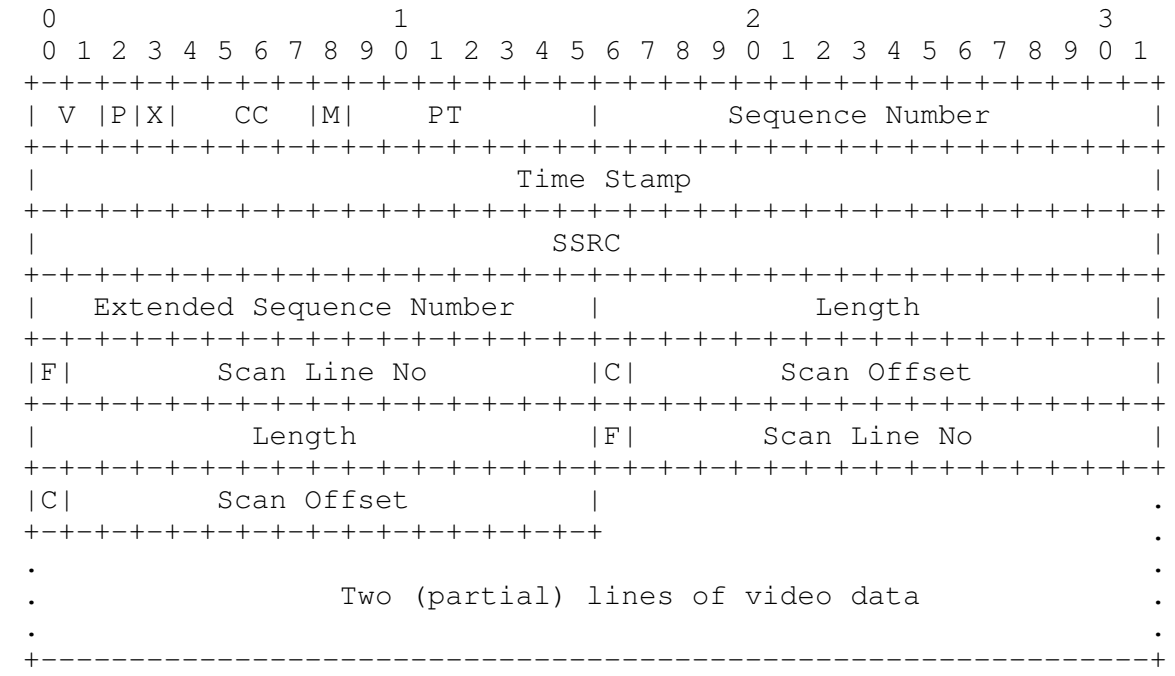

Figure 1: RTP Payload Format showing two (partial) lines of video

4.1. The RTP Header

The fields of the fixed RTP header have their usual meaning, with the following additional notes:

Payload Type (PT): 7 bits

A dynamically allocated payload type field which designates the payload as uncompressed video.

Timestamp: 32 bits

For progressive scan video, the timestamp denotes the sampling instant of the frame to which the RTP packet belongs. Packets MUST NOT include data from multiple frames, and all packets belonging to the same frame MUST have the same timestamp.

For interlaced video, the timestamp denotes the sampling instant of the field to which the RTP packet belongs. Packets MUST NOT include data from multiple fields, and all packets belonging to the same field MUST have the same timestamp. Use of field timestamps, rather than a frame timestamp and and field indicator bit, is needed to support reverse 3-2 pulldown.

A 90 kHz timestamp MUST be used in both cases. If the sampling instant does not correspond to an integer value of the clock (as may be the case when interleaving, the value SHALL be truncated to the next lowest integer).

Marker bit (M): 1 bit

The Marker bit denotes the end of a video frame, and MUST be set to 1 for the last packet of the video frame. It MUST be set to 0 for other packets.

Sequence Number: 16 bits

The low order bits for RTP sequence number. The standard 16 bit sequence number is augmented with another 16 bits in the payload header, in order avoid problems due to wrap-around when operating at high rate rates.

4.2. Payload Header

Extended Sequence Number : 16 bits

The high order bits of the extended 32 bit sequence number, in network byte order.

Scan Line No : 15 bits

Scan line number of encapsulated data, in network byte order. Successive RTP packets MAY contains parts of the same scan line (with an incremented RTP sequence number, but the same timestamp), if it is necessary to fragment a line.

Scan Offset : 15 bits

Scan offset of the first sample in the payload data. If YCrCb format data is being transported, this is the offset of the co-sited luminance sample and if RGB format data is being transported it is the offset of the red sample. The value is in network byte order, and the offset has a value of zero if the first sample in the payload corresponds to the start of the line.

Length: 16 bits

Number of octets of data included from this scan line, in network byte order. This MUST be a multiple of the pgroup value.

Field Identification (F): 1 bit

Identifies which field the scan line belongs to, for interlaced data. F=0 identifies the the first field and F=1 the second field. For progressive scan data (e.g. SMPTE 296M format video), F MUST always be set to zero.

Continuation (more lines) bit (C): 1 bit

Determines if an additional scan line header follows the current scan line header in the RTP packet. Set to 1 if an additional header follows, implying that the RTP packet is carrying data for more than one scan line. Set to 0 otherwise. An unlimited number of scan lines MAY be included, up to the path MTU limit. The only way to determine the number of scan lines included per packet is to parse the payload headers.

4.3. Payload Data

Depending on the video format, each RTP packet can include either a single complete scan line, a single fragment of a scan line, or one (or more) complete scan lines plus a fragment of a scan line. Every scan line or scan line fragment MUST begin at an octet boundary in the payload data. Scan lines SHOULD be fragmented so that the resulting RTP packet is smaller than the path MTU.

It is possible that the scan line length is not evenly divisible by the number of pixels in a pgroup, so the final pixel data of a scan line does not align to either an octet or pgroup boundary. Nonetheless the payload MUST contain a whole number of pgroups; the sender MUST fill the remaining bits of the final pgroup with zero and the receiver MUST ignore the fill data. (In effect, the trailing edge of the image is black-filled to a pgroup boundary.)

If the video is in YUV format, the packing of samples into the payload depends on the color sub-sampling used. For RGB format video, there is a single packing scheme.

For RGB format video, samples are packed in order Red-Green-Blue. All samples are the same bit size, which may be 8, 10, 12, or 16 bits. If 8 bit samples are used, the pgroup is 3 octets. If 10 bit samples are used, samples from adjacent pixels are packed with no padding, and the pgroup is 15 octets (4 pixels). Refer to Tables 1 thru 4.

For RGBA format video, samples are packed in order Red-Green-Blue-Alpha. All samples are the same bit size, which may be 8, 10, 12, or 16 bits. For pgroups refer to Tables 1 thru 4.

For YUV 4:4:4 format video, samples are packed in order Cb-Y-Cr for both interlaced and progressive frames. Each sample is either an 8, 10, 12 or 16 bit value. For relevant pgroups refer to Tables 1 to 4.

For YUV 4:2:2 format video, the Cb and Cr components are horizontally sub-sampled by a factor of two (each Cb and Cr samples corresponds to two Y components). Samples are packed in order Cb0-Y0-Cr0-Y1 for both interlaced and progressive scan lines. Samples are either an 8, 10, 12 or 16 bit value. For relevant pgroups refer to Tables 1 to 4.

For YUV 4:1:1 format video, the Cb and Cr components are horizontally sub-sampled by a factor of four (each Cb and Cr sample corresponds to four Y components). Samples are packed in order Cb0-Y0-Y1-Cr0-Y2-Y3 for both interlaced and progressive scan lines. Samples are either an 8, 10, 12 or 16 bit value. For relevant pgroups refer to Tables 1 to 4.

For YUV 4:2:0 video, the Cb and Cr components are sub-sampled by a factor of two both horizontally and vertically. Therefore chrominance values are shared between certain adjacent lines. Figure 2 illustrates the composition of luminance and chrominance values for 6x6 pixel grid in 4:2:0 YUV video.

```
      line 0:  Y00   Y01   Y02   Y03   Y04   Y05
               Cb00 Cr00   Cb01 Cr01   Cb02 Cr02
      line 1:  Y10   Y11   Y12   Y13   Y14   Y15

      line 2:  Y20   Y21   Y22   Y23   Y24   Y25
               Cb10 Cr10   Cb11 Cr11   Cb12 Cr12
      line 3:  Y30   Y31   Y32   Y33   Y34   Y35

      line 4:  Y40   Y41   Y42   Y43   Y44   Y45
               Cb20 Cr20   Cb21 Cr21   Cb22 Cr22
      line 5:  Y50   Y51   Y52   Y53   Y54   Y55
```

Figure 2: Chrominance and luminance compostion in 4:2:0 YUV video.

Transport of progressive scan 4:2:0 YUV video entails the transport of two scan lines together such that:

```
line 0,1:
Y00-Y01-Y10-Y11-Cb00-Cr00 Y02-Y03-Y12-Y13-Cb01-Cr01
                                    Y04-Y05-Y14-Y15-Cb02-Cr02

line 2,3:
Y20-Y21-Y30-Y31-Cb10-Cr10 Y22-Y23-Y32-Y33-Cb11-Cr11
                                    Y24-Y25-Y34-Y35-Cb12-Cr12

line 4,5:
Y40-Y41-Y50-Y51-Cb20-Cr20 Y42-Y43-Y52-Y53-Cb21-Cr21
                                    Y44-Y45-Y54-Y55-Cb22-Cr22
```

For interlaced transportm chrominance values are transported with every other line:

```
field 0:
   line 0: Y00-Y01-Cb00-Cr00 Y02-Y03-Cb01-Cr01 Y04-Y05-Cb02-Cr02
   line 2: Y20-Y21 Y22-Y23 Y24-Y25
   line 4: Y40-Y41-Cb20-Cr20 Y42-Y43-Cb21-Cr21 Y44-Y45-Cb22-Cr22

field 1:
   line 1: Y10-Y11 Y12-Y13 Y14-Y15
   line 3: Y30-Y31-Cb10-Cr10 Y32-Y33-Cb11 Cr11 Y34-Y35-Cb12-Cr12
   line 5: Y50-Y51 Y52-Y53 Y54-Y55
```

5. RTCP Considerations

RTCP SHOULD be used as specified in RFC1889 [RTP], which specifies two limits on the RTCP packet rate: RTCP bandwidth should be limited to 5% of the data rate, and the minimum for the average of the randomized intervals between RTCP packets should be 5 seconds. Considering the high data rate of many uncompressed video formats, the minimum interval is the governing factor in many cases.

It should be noted that the sender’s octet count in SR packets and the cumulative number of packets lost will wrap around quickly for high data rate streams. This means these two fields may not accurately represent octet count and number of packets lost since the beginning of transmission, as defined in RFC 1889. Therefore for network monitoring purposes other means of keeping track of these variables SHOULD be used.

6. IANA Considerations

6.1. MIME type registration

MIME media type name: video

MIME subtype name: raw

Required parameters:

rate: The RTP timestamp clock rate. Applications using this payload format MUST be 90000 for this format.

pgroup: The number of octets per the pixel group. See section 3 of RFC XXXX.

color-mode: Determines the color mode of the video stream. Valid values for this parameter are: RGB, RGBA, and YUV.

sub-sampling: Determines the type of color sub-sampling of the video stream. Valid values are: mono, 4:1:1, 4:2:0, 4:2:2, 4:4:4 and 4:4:4:4.

width: Determines the number of pixels per line. This is an integer between 1 and 32767.

height: Determines the number of lines per frame. This is an integer between 1 and 32767.

depth: Determines the number of bits per samples. This is a decimal integer; typical values include 8, 10, 12, and 16.

colorimetry: This parameter defines the set of colorimetric specfications and other transfer characteristics for the video source, by reference to an external specification. Valid values and their specification are:

BT601-5	ITU Recommendation BT.601-5 [601]
BT709-2	ITU Recommendation BT.709-2 [709]
SMPTE240M	SMPTE standard 240M [240M]
NTSC	The NTSC specification [NTSC]
PAL	The PAL specificaiton [PAL]

New values may be registered as described in section 6.2 of RFC XXXX.

Optional parameters:

Interlace: If this optional parameter is present it indicates that the video stream is interlaced. If absent, progressive scan is implied.

Encoding considerations: Uncompressed video can be transmitted with RTP as specified in RFC XXXX. No file format is defined at this time.

Security considerations: See section 9 of RFC XXXX.

Interoperability considerations: NONE.

Published specification: RFC XXXX.

Applications which use this media type: Video communication.

Additional information: None

Magic number(s): None

File extension(s): None

Macintosh File Type Code(s): None

Person & email address to contact for further information:

Ladan Gharai <ladan@isi.edu>
IETF Audio/Video Transport working group.

Intended usage: COMMON

Author/Change controller: Ladan Gharai <ladan@isi.edu>

6.2. Parameter Registration

New values of the "colorimetry" parameter MAY be registered with the IANA provided they reference an RFC or other permanent and readily available specification (the Specification Required policy of RFC 2434 [2434]).

7. Mapping to SDP Parameters

Parameters are mapped to SDP [SDP] as in the following example:

```
m=video 30000 RTP/AVP 112
a=rtpmap:112 raw/90000
a=fmtp:112 color-mode=YUV; sub-sampling=4:2:2; width=1280; height=720;
           depth=10; colorimetry=BT.709-2
```

In this example, a dynamic payload type 111 is used for uncompressed video. The RTP sampling clock is 90kHz. Note that the "a=fmtp:" line has been wrapped to fit this page, and will be a single long line in the SDP file.

8. Security Considerations

RTP packets using the payload format defined in this specification are subject to the security considerations discussed in the RTP specification, and any appropriate RTP profile. This implies that confidentiality of the media streams is achieved by encryption.

This payload type does not exhibit any significant non-uniformity in the receiver side computational complexity for packet processing to cause a potential denial-of-service threat.

It is important to be note that uncompressed video can have immense bandwidth requirements (up 270 Mbps for standard definition video, and approximately 1 Gbps for high definition video). This is sufficient to cause potential for denial-of-service if transmitted onto most currently available Internet paths.

Accordingly, if best-effort service is being used, users of this payload format SHOULD monitor packet loss to ensure that the packet loss rate is within acceptable parameters. 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 the RTP flow is achieving. This condition can be satisfied by implementing congestion control mechanisms to adapt the transmission rate (or 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.

This payload format may also be used in networks which provide quality of service guarantees. If enhanced service is being used, receivers SHOULD monitor packet loss to ensure that the service that was requested is actually being delivered. If it is not, then they SHOULD assume that they are receiving best-effort service and behave accordingly.

9. Relation to RFC 2431

In comparison with RFC 2431 this memo specifies support for a wider variety of uncompressed video, in terms of frame size, color subsampling and sample sizes. While [BT656] can transport up to 4096 scan lines and 2048 pixels per line, our payload type can support up to 64k scan lines and pixels per line. Also, RFC 2431 only address 4:2:2 YUV data, while this memo covers YUV and RGB and most common color subsampling schemes. Given the variety of video types that we cover, this memo also assumes out-of-band signaling for sample size and data types (RFC 2431 uses in band signaling).

10. Relation to RFC YYYY

(tbd)

Relation [292RTP]

11. Full Copyright Statement

12. Acknowledgements

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13. Authors' Addresses

Ladan Gharai <ladan@isi.edu>
Colin Perkins <csp@csperkins.org>

USC Information Sciences Institute
3811 N. Fairfax Drive, #200
Arlington, VA 22203
USA

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[PAL] (tbd)