MOTION IMAGERY STANDARDS BOARD	MISB RP 0802.2
RECOMMENDED PRACTICE	
H.264/AVC Motion Imagery Coding	**27 February 2014**

1 Scope

This H.264/AVC (ITU-T Rec. H.264 | ISO/IEC 14496-10) motion imagery coding document provides recommendations and guidelines for the encoding of H.264/AVC compressed motion imagery that maintains interoperability and quality for motion imagery.

The document covers the encoding of H.264/AVC motion imagery for:

- operator-in-the-loop operations
- video exploitation and dissemination
- low bandwidth users

This document includes the guidelines on the structure of the encoding, and information that facilitates decoding to be included in the structure.

2 References

2.1 Normative References

The following references and the references contained therein are normative.

[1] ITU-T Rec. H.264 (04/2013), Advanced Video Coding for Generic Audiovisual Services, (ISO/IEC 14496-10:2012)

[2] ETSI TS 101 154 V1.11.1 (2012): Digital Video Broadcasting (DVB); Implementation guidelines for the use of Video and Audio Coding in Broadcasting Applications based on the MPEG-2 Transport Stream

[3] MISB ST 0604.3 Time Stamping Compressed Motion Imagery, Feb 2014

3 Acronyms

ASO	Arbitrary Slice Ordering
AU	Access Unit
AVC	Advanced Video Coding (H264)
CABAC	Context-Adaptive Binary Arithmetic Coding

CAVLC	Context-Adaptive Variable Length Coding
COTS	Commercial Off-The-Shelf
CPB	Coded Picture Buffer
DPB	Decoded Picture Buffer
DTS	Decoding Time Stamp
DVB	Digital Video Broadcast
FMO	Flexible Macroblock Ordering
GOP	Group of Pictures
HRD	Hypothetical Reference Decoder
IDR	Instantaneous Decoding Refresh
MP4	MPEG4
NAL	Network Abstraction Layer
PAT	Program Association Table
PCR	Program Clock Reference
PES	Packetized Elementary Stream
PMT	Program Map Table
POC	Picture Order Count
PPS	Picture Parameter Set
PTS	Presentation Time Stamp
PVR	Personal Video Recorder
RAP	Random Access Point
RTP	Real Time Protocol
SEI	Supplemental Enhancement Information
SPS	Sequence Parameter Set
VCL	Video Coding Layer
VUI	Video Usability Information

4 Revision History

Revision	Date	Summary of Changes
RP 0802.2	02/27/2014	• Promoted to a Recommended Practice • Revised to conform to EARS for requirements • Moved Transport information to ST 1402. • Revised references

5 Introduction

The H.264/AVC video coding standard [1] is capable of delivering significant compression increases over the earlier MPEG-2 video standard: for a given bandwidth H.264/AVC is capable of delivering double the resolution; for a given resolution it may require only half the bandwidth. There are many advantages for migrating systems to use H.264/AVC and over time it will replace MPEG-2 in many domains. It already forms the basis of the next generation of DVD, digital satellite broadcast, and Digital Video Broadcast (DVB) standards.

Because motion imagery application areas have quite different requirements, it is difficult to define a single set of H.264/AVC encoding and multiplexing guidelines which will meet the requirements for all users.

There are three application areas that this document addresses:

1) Motion imagery for operator-in-the-loop operations (low latency)
2) Motion imagery for exploitation and dissemination
3) Motion imagery for low bandwidth users

For operator-in-the-loop operations, the most important requirement is to be able to view the live stream with a very low end-to-end latency and consistent quality. Since the operator is reacting in real time to viewed imagery, it is critical that latency introduced by the motion imagery and communications systems be minimized. Studies show that the *glass-to-glass* latency needs to be less than 200 milliseconds. Typical operator activities include:

- Manually tracking a moving vehicle down a highway
- Driving an unmanned vehicle down a road
- Manipulating an explosive ordinance disposal robotic arm

For motion imagery exploitation[1] and dissemination, the most important requirements are image quality and the ability to support random access and PVR play modes, such as random access, frame stepping, fast forward, fast reverse and looping. Typical exploitation and dissemination activities include:

- Searching through and analyzing long motion imagery sequences
- Editing clips from a motion imagery sequence
- Creating files for distribution

For low bandwidth users, receiving real time imagery over the available bandwidth is the most important requirement. Typical low bandwidth user activities include:

- Target area observation
- Battle damage assessment

Because of the nature of the requirements for each application area, motion imagery encoded for one purpose may not always be suitable or even compatible with another. To help system designers and vendors create H.264/AVC compressed streams that best meets the needs of a specific purpose and to maximize compatibility with other users, this document presents a number of specific encoding and multiplexing guidelines.

First, a common profile is defined, which provides a minimal set of encoding guidelines suitable across all three application areas. While not optimal for any one area, these guidelines provide a reasonable compromise and maximize compatibility across all types of systems. This is particularly important when motion imagery is used for sensor control, downstream exploitation

[1] Phase 2 and Phase 3 exploitation

and low-bandwidth dissemination. Then, each application area is defined with its specific profile. For each of the three application areas, enhancements and changes from the common profile are described to further optimize a particular application area.

The relationship between the encoding parameters for each area can be shown using the Venn diagram in Figure 1. Each circle represents an application area for which certain parameters will best apply. The intersection of the three defines the common profile.

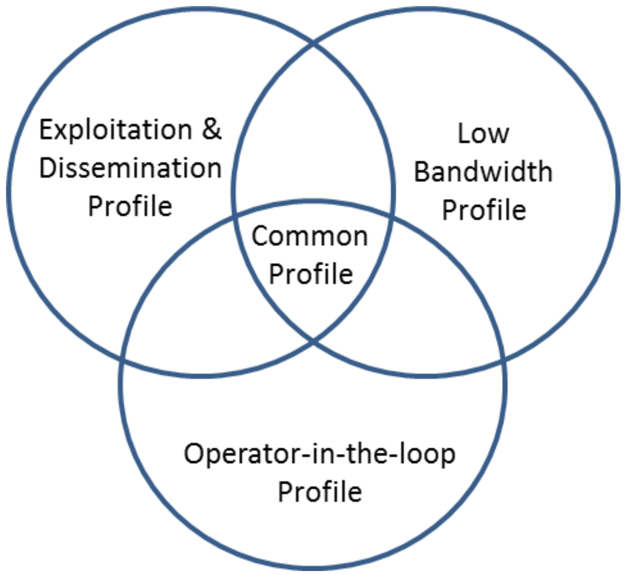


Figure 1: Application areas typically require different encoding parameters

The conflict of requirements among the three application areas can be explained using the triangle[2] of Quality, Bit rate and Latency as shown in Figure 2.

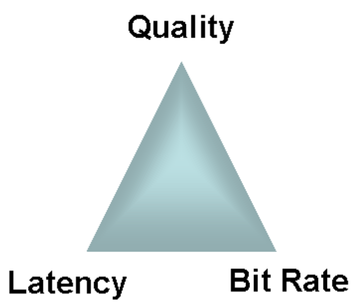


Figure 2: Application requirements require tradeoffs in Quality, Latency, and Bit Rate

For Operator-in-the-loop operations, the latency of the motion imagery is one of the most important considerations. Achieving low latency requires using encoding structures that are not

[2] The conflict in encoding parameters goes beyond a simple triangle representing three opposing areas, but a more detailed discussion is beyond the scope of this document.

the most efficient (e.g. no B frames and relatively fixed frame sizes). The tradeoff is less coding efficiency and less quality.

For Video Exploitation and Dissemination, image quality is one of the most important characteristics. To get the highest quality for a given bit rate requires using B frames (bi-directional) and a greater variation between frames sizes, both of which increase stream latency. Higher bit rates improve quality.

For the low bandwidth user, the bit rate of the motion imagery is the most important characteristic. To get the lowest bit rate requires using the most efficient encoding, which increases latency and reduces quality.

By presenting clear engineering guidelines, this document hopes to guide vendors in developing technologies and systems which are compatible with current and future systems.

6 Coding Guidelines

The minimum requirements motion imagery needs to satisfy to be compliant with the H.264/AVC standard only ensures there is enough information for every picture to be decodable in the right order. There are no specific requirements that mandate that information is carried to control the presentation or display of these pictures. The guidelines in the following sections are designed to maximize the usefulness of the encoded H.264/AVC video and increase its interoperability with other systems.

6.1 Common Profile

To create a H.264/AVC stream that is sufficiently low latency to meet operator in the loop requirements, has enough information to support random access and trick mode playback for exploitation, and can be delivered to bandwidth challenged users, requires making many compromises. The set of encoding guidelines below represents a reasonable set of compromises and will produce a stream that has the greatest amount of interoperability amongst systems.

Table 1: Common Profile

Guidelines	Reference Section
SPS and PPS occur before every IDR picture or the I picture at a recovery point	7.1
Random Access Points occur at least once a second	7.2
Fixed frame rate (piece-wise fixed)[3]	7.3
Fixed frame size (piece-wise fixed)	7.4
Picture Order Count (POC) equal to field number	7.6
IP coding structure (no B frames)	7.5
No long-term reference pictures	7.7

[3] Fixed frame rate or fixed frame size over a period of time, typically intended to be a number of seconds.

Use "picture not coded" when frames are dropped	7.9
Includes VUI parameters: *time_scale, num_units_in_ticks, fixed_frame_rate, num_reorder_frames, max_dec_frame_buffering*	7.10.1
Picture timing SEI message (ST 0604 [3])	7.10.3
Main or Constrained[4] Baseline Profile	7.8
User Data Unregistered (Precision Time Stamp) SEI message	MISB ST 0604[3]
Recommend inserting Commercial Time Stamp (optional only)	MISB ST 0604[3]

6.2 Operator-in-the-loop Profile

The most important requirement for sensor and vehicle operators is latency. Since low latency encoding is less efficient than normal encoding modes, maintaining image quality over a given bandwidth requires careful attention to the contents of the stream.

The H.264/AVC encoding guidelines for operator-in-the-loop operations take the Common Profile and make the following additions:

Table 2: Operator-in-the-Loop Profile

Guidelines	Reference Section
Frame rate (piece-wise fixed or variable)	7.3
No B frames (I & P only)	7.5
Use RAP > 1 second or Infinite GOPs (P frame only[5])	7.2, 7.5
Constrained Baseline, Main or High Profile	7.8

In addition to supporting piecewise continuous fixed frame rate, low latency encoders may also support non-fixed or variable frame rate. Non-fixed frame rate allows frames to be encoded and transmitted as fast as they can. Note: this mode is incompatible with current exploitation systems.

6.3 Exploitation and Dissemination Profile

The three main requirements for motion imagery for exploitation and dissemination are compatibility, image quality, and the ability to support 'trick mode' playback, which includes random access, fast forward and reverse.

The H.264/AVC encoding guidelines for exploitation and dissemination take the Common Profile and made the following additions:

[4] Constrained Baseline Profile provides tools that are common between Baseline and Main profile. It excludes any of the error resilience tools.

[5] Currently incompatible with exploitation systems

Table 3: Exploitation and Dissemination Profile

Guidelines	Reference Section
Use RAP < 1 second	7.2
Use B frames (IBP, IBBP or IBBBP[6])	7.5
Include HRD Parameters: *cpb_size_value_minus1*	7.10.2
Include buffering period SEI message	7.10.3
Main or High Profile	7.8

The use of bi-directionally predicted frames (B frames, which can be either reference or non-reference/disposable) improves the quality of the imagery for a given bit rate. Disposable B frames also help support variable speed playback as they can be easily dropped during decoding. Because B frames introduce a frame re-ordering delay and increase the buffering requirements for constant bit rate streams, they are not suited for low-latency streams.

Reducing the distance between Random Access Points improves random access navigation, frame-accurate random access, fast forward and fast reverse playback.

6.4 Low Bandwidth User Profile

Low bandwidth users over either reliable or un-reliable communication links are defined as users who have insufficient useable bandwidth to receive motion imagery and metadata at full frame rate and full resolution. To satisfy these requirements low bandwidth users have to trade off frame size, frame rate and the metadata frequency to fit the constraints of the available bandwidth.

The H.264/AVC encoding guidelines for low bandwidth users take the Common Profile and make the following additions:

Table 4: Low Bandwidth User Profile

Guidelines	Reference Section
Use B frames (IBP, IBBP or IBBBP[6])	7.5
RAP > 1sec or Infinite GOPs	7.2, 7.5
Error resilience tools	N/A
Constrained Baseline or Main Profile	7.8

Increasing the time between random access points using I or IDR frames can improve the quality of streams over lower bit rates, at the expense of longer times for decoders to open up and begin playing the stream, and longer times for error propagation.

[6] IBBBP refers to Hierarchical B frame encoding

Baseline profile provides a number of tools to provide error resilience which may be useful for low bandwidth users over error-prone networks.

For low power portable devices, it may be necessary to use baseline or simple baseline profile, where only CAVLC entropy coding is supported.

7 Coding Details

7.1 SPS and PPS occur before an IDR picture or the I picture at a recovery point

The H.264 Video Coding Layer (VCL), which consists of a hybrid of temporal and spatial prediction in conjunction with transform coding, is specified to efficiently represent the content of the data. The Network Abstraction Layer (NAL) is specified to format that data and provide header information in a manner appropriate for conveyance by the transport layers or storage media. All data are contained in NAL units, each of which contains an integer number of bytes. The NAL facilitates the ability to map H.264/AVC VCL data to transport layers such as:

- RTP/UDP for any kind of real-time wire-line and wireless Internet services (conversational and streaming)
- File formats, e.g. “MP4” for storage
- MPEG-2 systems for broadcasting services, etc.

A key concept of the NAL is parameter sets. A parameter set contains information that is expected to rarely change over time. There are two types of parameter sets: Sequence Parameter Sets (SPSs) apply to a series of consecutive coded video pictures; and Picture Parameter Sets (PPS), which apply to the decoding of one or more individual pictures. Inserting SPS and PPS headers before every IDR or I picture at a recovery point is essential to allow a decoder to begin playing from these points when they first connect to a stream. Without the information carried in these headers a decoder cannot begin decoding a sequence.

7.2 Random Access Points

The H.264/AVC standard specifies that each sequence have at least one IDR picture. The IDR (Instantaneous Decoder Refresh) picture provides a random access point from which a decoder can begin decoding.

When H.264/AVC video is streamed over a network, IDR pictures need to appear in the stream regularly to allow a decoder that connects to the stream to begin decoding. The time between IDR pictures determines the maximum time between connection to the stream and a decoder being able to begin decoding.

The international DVB standard [2] recommends that the random access points occur no less frequently than once every 5 seconds, and that for broadcast applications they occur at least once every 500 milliseconds. In practice, the application will determine the optimal GOP size, but it is recommended that a random access point occur at least once a second.

Some encoder manufacturers prefer to use recovery point SEIs (Supplemental Enhancement Information) instead of IDRs to signal decoding after a random jump to an arbitrary point in the stream. Recovery points should begin with an I-picture. All pictures in display order after a recovery point should not reference pictures in decoding order prior to the recovery point. Pictures in display order prior to the recovery point may reference pictures in the previous GOP that are in display order after their own GOP's recovery point. Presence of an I-picture and a recovery point SEI will provide similar random access points as those provided by IDRs.

7.3 Fixed frame rate

The H.264/AVC standard allows the video frame rate to be fixed or variable. If fixed, the frame rate is constant for the duration of the sequence; this provides the greatest compatibility with existing systems.

If the video stream is being used for different types of tasks, such as both tracking and surveillance, allowing the frame rate to change in the stream from one rate to another provides advantages.

When the frame rate is changed, the change must be signaled with a new SPS, for example, switching from 30 frames-per-second to 15 frames-per-second.

For low latency modes, variable frame rate may be used at the expense of compatibility with current exploitation systems. Typical video encoding requires tradeoffs in picture quality, picture spatial resolution, temporal frame rate, and bit rate. Typically bit rate and spatial resolution are fixed. If frame rate is also fixed, the picture quality will vary depending on scene complexity and motion. In an attempt to maintain a constant picture quality, the frame rate can be allowed to vary as scene complexity and motion change. The latter mode has significant value in practical applications where picture quality is important; for example, in target recognition.

7.4 Fixed frame size

The H.264/AVC standard allows the video frame size (also known as video resolution) to change with a new SPS; for example, switching from 704x480 pixels to 352x240 pixels. Such a change may not be supported by some decoders.

7.5 Frame pattern

There are five main frame patterns used in H.264/AVC:

- I-frame only
- I-P which consists of just I and P frames
- I-B-P which includes I, B and P frames frequently using 2 B frames between each I or P in display order
- Hierarchical B, which may include more B frames between the I and P frames and additionally uses some B frames as references for other B frames
- Infinite GOP or P-frame only

I-frame only is the least efficient encoding pattern, but at high bit rates can provide the greatest encoding fidelity. It also allows fast random access and provides good error resilience, since errors do not propagate frame-to-frame.

I-P pattern is commonly used for low latency because it provides reasonable compression without introducing any frame re-ordering, since the encoding order is the same as the display order.

I-B-P pattern is widely used as it provides good compression, but incurs a frame-reordering delay during encoding and decoding.

Hierarchical B frames coding structure provides very good compression and is gaining wider support.

Infinite GOP or P-frame only structures use a technique known as rolling macroblock refresh to remove the need for I frames. Effectively, the I-frame is distributed over a number of P frames. Infinite GOP or P-frame only is not widely supported, but can provide the lowest latency form of encoding (along with I-frame only) because of the ability to use relatively fixed frame sizes and a constrained buffer model.

7.6 Picture Order Count (POC) equal to field number

Setting the Picture Order Count (POC) to equal the field number improves the ability for a file to be frame-accurately navigated and edited and is recommended.

7.7 No long-term reference pictures

While the use of long-term reference pictures can improve coding efficiency, they are not suitable for real-time streaming and largely prevent files from being randomly decoded and edited.

7.8 H.264 Profiles

H.264/AVC supports a number of different profiles, which are described in more detail in Appendix A. Of these, Constrained Baseline, Main and High profile are the most commonly supported:

- Constrained Baseline, Main and High profiles are recommended for low latency applications.
- Main and High profiles are recommended for exploitation and dissemination.
- Constrained Baseline and Main profiles are recommended for low bandwidth applications.

7.9 Picture Not Coded

This is done by setting the coding mode for each macroblock in a P picture to P_skip. Flags mb_skip_run (CAVLC entropy coding) and mb_skip_flag (CABAC entropy coding) indicate skipped macroblocks.

Definition of a skipped macroblock: A *macroblock* for which no data is coded other than an indication that the *macroblock* is to be decoded as "skipped". This indication may be common to several *macroblocks*.

If all macroblocks in a picture are skipped and, for example, CAVLC entropy coding mode is used, mb_skip_run can be set to the number of macroblocks in the entire picture indicating that all macroblocks in the picture are skipped. A frame coded in such a way will be coded using between 200 and 500 bits, depending on the format.

7.10 Additional syntax elements

This section contains additional information suggested to be carried in the compressed data stream. This information is useful for decoders, editors and exploitation systems that may need to process a compressed motion imagery stream.

7.10.1 VUI parameters

The H.264/AVC standard includes optional Video Usability Information (VUI) parameters. As its name implies, these parameters provide information that help makes the sequence useable beyond simple decoding. While it may be possible to deduce some of the information in these parameters from the motion imagery and transport layer through numerical and statistical analysis, the VUI parameters provide an explicit and more reliable mechanism.

One of the more useful entries in the VUI parameters is the specification of frame rate using the time_scale and num_units_in_ticks variables and setting fixed_frame_rate_flag to 1.

MaxFPS = Ceil(time_scale / (2 x num_units_in_ticks)) [see EQ D-2 in [1]]

<u>Example:</u> if time_scale = 60 000 and num_units_in_ticks = 1001, then MaxFPS = 29.97 Hz.

The num_reorder_frames parameter provides crucial information to reduce DPB output delay. The difference with or without this parameter can be significant for low latency applications and frame accurate seeking/editing applications.

The max_dec_frame_buffering parameter specifies the required size of the DPB in units of frame buffers. Many encoders actually use a max_dec_frame_buffering less than MaxDpbSize; by providing this information, decoders can reduce Decoder Picture Buffer (DPB) size and latency (when num_reorder_frames is not present, its value is inferred to be equal to max_dec_frame_buffering).

Note: saving one frame’s worth of DPB is much more significant than one frame’s worth of CPB (Coded Picture Buffer) since the former is in raw, uncompressed format.

7.10.2 Use of HRD parameters

The HRD parameters define the buffer sizes and bit rates of the operation of the Hypothetical Reference Decoder (HRD) for the bit stream. These parameters are critical if the stream is to be multiplexed with other elementary streams.

The cpb_size_value_minus1 parameter is very important for editing and multiplexing procedures, because it directly affects the PCR/PTS gap in the resulting footage. In practice, most encoders choose the CPB buffer size to be much smaller than its maximum value restricted by level ([1] Annex A), in order to make their output playable on the widest range of hardware players.

7.10.3 Buffering period SEI message

The Buffering period SEI message occurs before each IDR and provides the initial buffering requirement, at random access points. The purpose of the initial buffering is to keep the encoder and decoder buffer levels complementary. The decoder ignores subsequent buffering period SEI messages once it begins decoding.

7.10.4 Other video parameters

Requirement	
RP 0802.2-01	The gaps_in_frame_num_value_allowed_flag shall be set to 0 (gaps not allowed).
RP 0802.2-02	The aspect_ratio_info_present_flag shall be set to 1.
RP 0802.2-03	The aspect_ratio_idc shall be correctly coded for the sample aspect ratio of the video content.

7.10.5 Picture timing SEI message

Reference MISB ST 0604 [3].

7.10.6 User Data Unregistered SEI message

Reference MISB ST 0604 [3].

8 Appendix A - Informative

This appendix includes additional topics related to different encoding options.

8.1 H.264/AVC Profiles and Levels

The H.264/AVC standard is designed to be generic in that it serves a wide range of applications, bit rates, resolutions, qualities, and services. As a result the standard consists of a common syntax which carries a large number of optional "tools" or syntax elements. These tools provide various compression and processing functions. Not every application needs, or can benefit from every tool. Nor is it practical for a decoder to implement and be able to support every tool. For this reason, limited subsets of the tools are grouped by means of "profiles" and "levels".

A "profile" is a subset of syntax elements, loosely grouped for an expected application. A "level" is a specified set of constraints imposed on values of the syntax elements in the bitstream.

A decoder that declares support for a specific profile and level must support all of the tools and constraints defined therein. An encoder that declares support for a specific profile and level may not utilize any tools from outside that profile, nor can it exceed the constraints on the tools that are allowed. However, an encoder need not utilize all of the tools, nor must it operate up to the limit of the constraints. An encoder is compliant as long as it generates a legal bitstream syntax within the profile and level that it is operating.

The following subsections discuss some of the features of the common profiles and levels.

8.1.1 Baseline Profile

The Baseline Profile contains the following restricted set of coding features.

- I and P Slices: Intra coding of macroblocks through the use of I slices; P slices add the option of Inter coding using one temporal prediction signal. Baseline profile does not support the use of B Slices.
- 4x4 Transform: The prediction residual is transformed and quantized using 4x4 blocks.
- CAVLC: The symbols of the coder (e.g. quantized transform coefficients, intra predictors, motion vectors) are entropy-coded using a variable length code.

In addition, the Baseline profile includes coding features which support error resilience useful for transmission in error prone environments. Care should be taken in specifying the use of these tools, since they may not be widely supported.

- Flexible Macroblock Ordering (FMO): This feature allows arbitrary sampling of the macroblocks within a slice.
- Arbitrary Slice Ordering (ASO): This feature allows arbitrary order of slices within a picture.
- Redundant Slices: This feature allows transmission of redundant slices that approximate the primary slice.

8.1.2 Constrained Baseline Profile

The Constrained Baseline Profile contains features that in are common between the Baseline and Main profiles.

8.1.3 Main Profile

Main Profile contains all features of Baseline Profile, except for FMO, ASO, and Redundant Slices, plus the following additional features:

- B Slices: Enhanced Inter coding using up to two temporal prediction signals that are superimposed for the predicted block.
- Weighted Prediction: Allowing the temporal prediction signal in P and B slices to be weighted by a factor.
- CABAC: Alternative entropy coding to CAVLC providing higher coding efficiency at higher complexity, which is based on context-adaptive binary arithmetic coding.
- Field Encoding: Field encoding provides for more efficient compression of interlaced video particularly in the presence of motion. While the goal is to move toward progressive sensors, there are and will continue to be interlaced sensors.

8.1.4 High Profile

High Profile contains all features of Main Profile and the following additional ones:

- 8x8 Transform: In addition to the 4x4 Transform, the encoder can choose to code the prediction residual using an 8x8 Transform.
- Quantization Matrices: The encoder can choose to apply different weights to the transform coefficients. This allows better alignment of quantization with human perception.
- Monochrome/single channel/4:0:0
- Larger allowable level prefix in CAVLC
- Separate C_b and C_r chroma QP control

8.1.5 High 10 Profile

High 10 Profile contains all of the features of High Profile with the addition of support for 9 and 10-bit pixel depths. Care should be taken in specifying the use of these tools, since they may not be widely supported.

8.1.6 High 4:2:2 Profile

High 4:2:2 Profile contains all of the features of High 10 Profile with the addition of support for 4:2:2 chroma sampling. Care should be taken in specifying the use of these tools, since they may not be widely supported.

8.1.7 High 4:4:4 Profile

High 4:4:4 Profile contains all of the features of High 4:2:2 Profile with the following additions:

- Support for up to 14-bit pixel depths.
- Support for 4:4:4 chroma sampling
- Residual color transform
- Predictive lossless coding

Care should be taken in specifying the use of these tools, since they may not be widely supported.

8.2 Levels

Levels typically constrain picture size, frame rate, and bitrate. Table 5, while not a complete definition of the levels, summarizes the key features for baseline, extended and main profile. Bit rates are for video coding layer.

Table 5: H.264 Baseline, Extended, and Main profile levels

Level Number	Typical Picture Size	Typical Frame Rate Maximum	Compressed Bit Rate Maximum
1	128x96p 176x144p	30 15	64 kbps
1b	176x144p	15	128 kbps
1.1	176x144p 352x288p	30 7.5	192 kbps
1.2	352x288p	15	384 kbps
1.3	352x288p	30	768 kbps
2	352x288p	30	2 Mbps
2.1	352x480p/i 352x576p/i	30 25	4 Mbps
2.2	720x480p/i 720x576p/i	15 12.5	4 Mbps
3	720x480p/i 720x576p/i	30 25	10 Mbps
3.1	1280x720p	30	14 Mbps
3.2	1280x720p	60	20 Mbps
4	1280x720p 1920x1080p	60 30	20 Mbps
4.1	1280x720p 1920x1080p	60 30	50 Mbps
4.2	1920x1080p	60	50 Mbps
5	2048x1024p	72	135 Mbps

5.1	2048x1024p 4096x2048p	120 30	240 Mbps

Table Notes: suffix "p" denotes progressive frame (i.e. 480p30 means 30 frames where each frame contains 480 lines imaged at a 30 Hz rate). Suffix "i" denotes interlaced frame (i.e. 480i30 means 30 complete frames per second constructed from pairs of fields taken at 60 fields per second). A 30 frames-per-second sequence constructed from pairs of 60 fields per second interlaced fields is *not* equivalent to a 30 frames per second progressive sequence (except in the simple case of imagery without any motion). The latter is imaged by the sensor as one complete frame, while the former is imaged as two separate fields displaced temporally in time by the field rate.

8.3 Group of Pictures (GOP) Length

A Group of Pictures (GOP) consists of all pictures from one I picture (represented by a random access point) to the picture just prior to the next I picture. The GOP length will represent a trade-off between the need for random access and error recovery versus bandwidth.

Smaller GOP lengths are desirable for fine grain random access. This is because random access to a picture, which occurs between random access points, must start at either the prior or the next random access point. Similarly, in streaming applications some decoders will discard pictures until it receives a random access point to begin decoding the stream. Some decoders will begin decoding and displaying video from the first frame received. If these are P-Frames, the picture will contain artifacts until sufficient I-macroblocks or an I-frame is received. This decoder behavior should be encouraged and is required in order to support infinite GOP streams.

Smaller GOP lengths are also desirable in error prone environments, since a video artifact caused by an error in the transmitted data stream will often persist in the decoded video until the next I picture.

Since I pictures are roughly 5-10 times larger than P pictures, reducing the number of I pictures will improve the efficiency of the compression and allow better quality video (assuming no transmission errors) at the same bandwidth. When video is transmitted over constant bitrate communications channels, as is the case in many radio links, GOP length will have a direct impact on video quality. Using a small GOP length will increase the number of I pictures, reducing video quality, while larger a GOP length will decrease the number of I pictures, increasing the video quality.

For low latency operator-in-the-loop applications, an infinite GOP length sequence can help reduce the latency at the expense of interoperability.

In infinite GOP mode a single I picture is transmitted at the start of the sequence, and then all other pictures are coded as P pictures. In this mode, there are no random access points. The benefit of this mode is twofold: first, since all the coded pictures are roughly the same size (excluding the first I picture), there is a significant reduction in the buffering that is required in the encoder and the decoder during constant bitrate operation. This reduction in buffering translates into a reduction in latency, which is critical in many real time applications. Second, since no I pictures are transmitted, only more efficient P pictures are used. In addition to the loss of random access, this mode also is very susceptible to transmission errors, which could persist forever if unchecked. To correct this, intra refresh is used. In intra refresh, a small number of blocks are intra coded in each picture. The intra coded blocks are independently coded and not predicted from prior frames, correcting any transmission errors that may have occurred. By selecting the number of intra coded blocks per picture, the number of pictures over which the entire picture will be refreshed can be controlled. The SPS and PPS can still be sent periodically to aid decoders which receive the stream in mid sequence.

8.4 Slices

Slices provide resynchronization points within a picture. Because modern compression algorithms make heavy use of variable length coding, a single bit error can have a significant impact on artifacts. In some cases, this can corrupt the picture from the point of the error to the end of the frame. Slices provide resynchronization points within a frame, so that an error will only corrupt the picture to the end of the current slice.

While slices add additional overhead, they can be useful in high error environments. In normal operation a single slice contains the whole picture. Control of slices is usually done by specifying a slice size in bytes, or a slice size in macroblocks. Specifying the slice size in bytes allows the slice to be aligned with transport structures such as an RTP packet or a Forward Error Correction frame. Specifying the slice size in macroblocks aligns the slices to the picture structure.

8.5 Quantizer

The Quantizer controls the bitrate and image quality. The H.264/AVC encoder will typically vary the quantizer used throughout the picture in order to maintain the highest video quality while not exceeding the target data rate. Larger quantizer values generally cause more information to be discarded or reproduced less accurately. Lower quantizer values attempt to preserve information and reproduce it more accurately. Normally, the perceptually less important high frequency information is discarded first. This results in blurriness or fuzziness in the image. Preservation of the high frequency information results in improved detail and sharpness of edges.

To maintain higher quality at a given bitrate it is more effective to reduce frame rate rather than allow the quantizer value to increase, assuming lower frame rate is acceptable.

8.6 Frame Rate

Some encoders allow the user to encode at a frame rate lower than the input source rate. This is useful when picture quality is more important than motion reproduction or latency. By reducing the frame rate, the user is allowing the algorithm to allocate more bits to each picture, resulting in higher quality pictures.

8.7 B Frames

While P-Frames are predicted from the previous picture, B-Frames are predicted from both previous pictures and future pictures. B-Frames provide the most efficient way to encode a frame; however, this efficiency decreases with the frame distance of the B frame from its reference frame. In H.264/AVC, unlike in MPEG-2, B frames can also be used as reference frames for other B frames. An encoding structure called Hierarchical B-frame is increasingly popular as it increases the ratio of B frames to the less efficient I and P frames.

B frames however are usually not suitable for low latency encoding because their reference frames need to be transmitted before the current B frame itself can be coded, and the subsequent re-ordering of frames in the decoder also increases latency.

8.8 Field Encoding

The use of interlaced-scanned sensors is rejected by the MISP because interlaced scanning will introduce temporal artifacts into the imagery. However, when motion imagery from a legacy sensor is encoded, field encoding may produce better quality. Normally, the entire frame is treated as a single picture divided up into macroblocks for processing by the compression algorithm. This works well when the image is from a progressive camera which captures a complete frame at one time, or if the scene has little horizontal motion. If the sensor produces interlaced pictures, there may be artifacts introduced if there is motion. The interlaced artifacts result when a moving object is in one position during the capture of the first field and in a new position when the second field is captured. Viewed as one complete frame, the object edges appear to be torn or jagged since alternate lines (from two different fields) represent a large difference in time. This produces high frequency data, which is inefficient to compress. At lower spatial resolutions, where only a single field may be used this is not an issue.

Field encoding separates a frame into the two fields compressing them separately. This eliminates the high frequency data from interlaced artifacts and improves the compression efficiency.

There are two methods of field encoding with H.264/AVC: Macroblock Adaptive Frame/Field (MBAFF) and Picture Adaptive Frame/Field (PAFF). MBAFF makes the frame versus field encoding decision on a block-by-block basis throughout the picture, applying the most efficient method to each block as needed. PAFF makes the frame versus field encoding decision on a frame-by-frame basis coding the entire frame using the same method. Field encoding is not available in Baseline Profile.

8.9 Entropy Coding

Entropy coding is the last step in the compression process, where compression coefficients and other data are converted into an efficient format for transmission. H.264/AVC provides two methods of entropy coding: Context-adaptive variable-length coding (CAVLC) and Context-Based Adaptive Binary Arithmetic Coding (CABAC), which is only available in the Main and High Profiles. CABAC is noticeably more efficient than CAVLC, with an average bitrate reduction of 10-15%; however, it is more computationally intensive. CABAC may be especially useful at very low data rates (< 1Mbps). CABAC is not available in Baseline Profile.

8.10 Rate Control

Rate Control defines the data rate characteristics of the generated compressed data. There are typically three rate control modes: Constant Bit Rate, Variable Bit Rate, and Constant Quality. In Constant Bit Rate (CBR) mode the encoder seeks to output an approximately constant number of bits over any short time period in order to not exceed the selected data rate. Fill data is added, if necessary, to avoid under running the selected data rate. This mode is typically used when transmitting video over a fixed data rate communications link.

In Variable Bit Rate (VBR) mode, the encoder maintains the data rate within some selected minimum and maximum values. The encoder allocates bits more flexibly, using fewer bits in less demanding scenes and more bits in difficult-to-encode scenes, resulting in higher video quality than the CBR mode for the same average bitrate. The disadvantages are that it may take more time to encode, as the process is more complex, and that some hardware might not be compatible with VBR data. This mode is useful in variable data rate communications links, such as an Ethernet network.

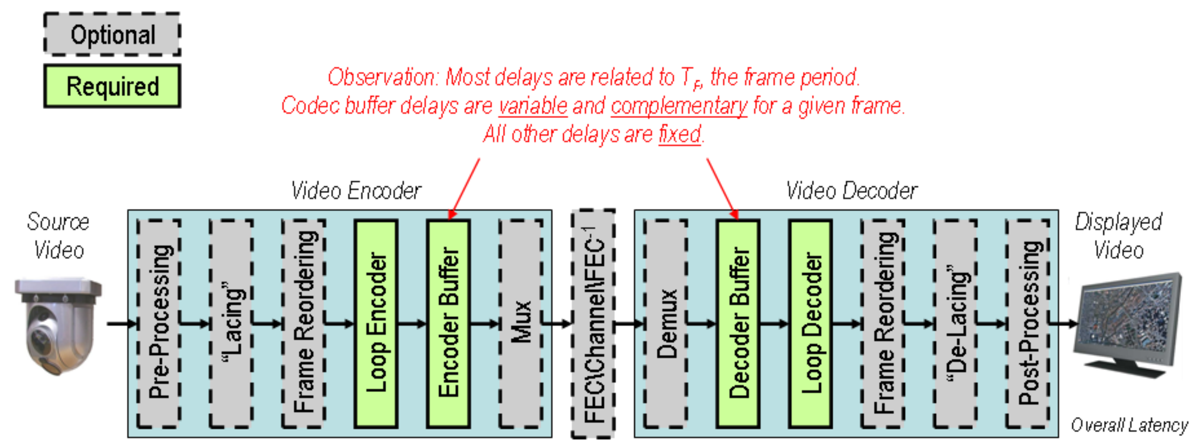
In Constant Quality (CQ), sometimes called unconstrained VBR mode, the encoder maintains the same quality for every frame. Quality is usually selected with the Quantizer parameter. This mode produces the same quality for all frames with no consideration how much data is generated. This mode is useful in variable data rate communications links, such as an Ethernet network.

In addition to the above rate control modes, there are also some encoders called Multi-Pass encoders. These encoders are not applicable to real time live encoding since they process the same sequence of frames several times. The benefit is that very high compression efficiencies are possible because in pass one the imagery is analyzed with more optimum compression techniques applied in successive passes. The penalty for this efficiency is a significant increase in latency. These encoders are very useful for offline compression.

9 Appendix B - Informative

Shown below is a theoretical model of the expected sources of latency in a video encoder and decoder to help understand how frame rate impacts latency, and the greatest contributors to latency in the encode/decode signal path. (Provided by Dr. Isnardi, Sarnoff Corp).

Contributions to Overall Latency



	Pre-Processing	"Lacing"	Frame Reordering	Loop Encoder	Encoder Buffer	Mux	FEC\Channel\FEC^{-1}	Demux	Decoder Buffer	Loop Decoder	Frame Reordering	"De-Lacing"	Post-Processing	Overall Latency
T_F (frame period)	≤2	≤0.5	≤3	≤1	≤0.5	≤0.5	fixed	≤0.5	1-15	≤1	≤1	≤0.5	≤2	
30i (msec)	≤66	≤16	≤100	≤33	≤16	≤16	≤50	≤16	33-728*	≤33	≤33	≤16	≤66	≤1.2 sec
60p (msec)	≤33	≤8	≤50	≤16	≤8	≤8	≤50	≤8	16-728*	≤16	≤16	≤8	≤33	≤1.0 sec
Example Systems														
30i (msec)	0	16**	0	33	0	16	50	16	33***	33	0	16**	0	213 msec
30i (msec)	0	16**	0	33	0	16	50	16	133****	33	0	16**	0	313 msec
60p (msec)	0	0	0	16	0	8	50	8	16***	16	0	0	0	114 msec
60p (msec)	0	0	0	16	0	8	50	8	116****	16	0	0	0	214 msec

*Assumes CBR transmission with 1 T_F lower limit. Upper limit is max VBV delay allowed by MPEG-2 Video spec

**Assumes frame picture coding. ***Assumes IIII / PPPP / Infinite GOP. ****Assumes IPPP GOP.