
**Information technology — MPEG video
technologies —**

Part 8:
**Working practices using objective
metrics for evaluation of video coding
efficiency experiments**

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Contents

| | Page |
|---|-----------|
| Foreword | iv |
| 1 Scope | 1 |
| 2 Normative references | 1 |
| 3 Terms and definitions | 1 |
| 4 Abbreviated terms | 1 |
| 5 Video coding experiments using Bjøntegaard delta bit rate (BD-rate) measurements | 2 |
| 6 The PSNR-based BD-rate concept | 3 |
| 7 PSNR-based BD-rate calculation | 4 |
| 7.1 General | 4 |
| 7.2 Calculation of PSNR for individual frames | 4 |
| 7.3 Calculation of sequence PSNR and bit rate numbers for each QP value | 5 |
| 7.4 Calculation of sequence BD-rate number | 5 |
| 7.5 Consideration of chroma fidelity | 8 |
| 7.6 Calculation of aggregate BD-rate value for all sequences | 9 |
| 8 BD-rate calculation for HDR material | 9 |
| 9 BD-rate calculation for 360° video | 9 |
| Bibliography | 11 |

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Foreword

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Information technology — MPEG video technologies —

Part 8:

Working practices using objective metrics for evaluation of video coding efficiency experiments

1 Scope

This document provides general information about coding efficiency measurement practices for video coding. This document does not provide recommendations for evaluating video quality; it describes the practices that have recently been followed for coding efficiency experiments conducted during work to develop video coding standards.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following term and definition apply:

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1

Bjontegaard delta bit rate

BD-rate

average percentage bit rate difference at equal measured distortion, integrated across a range of bit rates in the log domain

Note 1 to entry: The Bjontegaard delta bit rate measurement method was originally specified in VCEG-M33^[1].

4 Abbreviated terms

| | |
|---------|--|
| AVC | advanced video coding (Rec. ITU-T H.264 ISO/IEC 14496-10) |
| BD-rate | Bjontegaard delta bit rate |
| HDR | high dynamic range |
| HEVC | high efficiency video coding (Rec. ITU-T H.265 ISO/IEC 23008-2) |
| HLG | hybrid log gamma |
| JCT-VC | joint collaborative team on video coding (for development of HEVC) |
| JVET | joint video experts team (for development of VVC) |

| | |
|--------------|--|
| MPEG | moving picture experts group |
| MS-SSIM | multi-scale structural similarity |
| MSE | mean square error |
| PQ | perceptual quantizer (as defined in SMPTE ST 2084 ^[10] and Rec. ITU-R BT.2100 ^[11]) |
| PSNR | peak signal-to-noise ratio |
| QP | quantization parameter |
| SDR | standard dynamic range |
| SSIM | structural similarity |
| VCEG | visual coding experts group |
| VMAF | video multimethod assessment fusion |
| VVC | versatile video coding (Rec. ITU-T H.266 ISO/IEC 23090-3) |
| WCG | wide colour gamut |
| WVGA | wide video graphics array |
| $Y'_{CB}C_R$ | colour space representation commonly used for video/image distribution, also written as YUV |
| YUV | colour space representation commonly used for video/image distribution, also written as $Y'_{CB}C_R$ |

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5 Video coding experiments using Bjøntegaard delta bit rate (BD-rate) measurements

This document provides general information about coding efficiency measurement practices that have been used for video coding experiments for the development of video coding standards in the ITU-T SG 16 VCEG and ISO/IEC JTC 1/SC 29 MPEG communities. Such work has often been conducted together in the JVET and JCT-VC joint collaborative teams. In particular, the document describes the use of Bjøntegaard delta bit rate (BD-rate) measurements. It provides a concept-level overview of recent practices and provides references to other works that describe further details. It includes comments on why some of the choices were made and indicates situations where caution is needed when interpreting the results.

For comparing different encodings, often it is helpful to control the encodings so that similar types and degrees of encoder optimization are applied, except for the aspects to be tested.

When there are large differences between the coding technologies being tested, and especially when there can be a substantial difference between the resulting subjective quality, subjective testing (i.e. using humans to measure the visual quality) is the appropriate action. There are also cases where the quality difference is expected to be primarily a matter of subjective effect – for example, when measuring the effects of deblocking filters.

The video coding community has typically used formal subjective testing at the call for proposals and verification testing stages of projects for standardization (i.e. at the beginning and the end of the work). For measuring smaller effects and where formal subjective testing is not feasible, it is necessary to use objective measurements. Since objective measurements are collected at multiple operational points, and to better understand coding behaviour across all these points, what has commonly been used in this community is the technique known as the BD-rate (Bjøntegaard delta bit rate) comparison.^[1]

Encoding for video distribution is ordinarily performed in the $Y'CbCr$ domain (YUV). For typical multimedia applications, it is well known that the human visual system is most sensitive to the fidelity of the Y component. The Y component also tends to use most of the bit rate, so it is natural to focus primarily on the Y component. However, it is advised to measure and report the fidelity of all three components and review the balance between luma and chroma fidelity when interpreting the results. This practice can help avoid situations where luma gain can be achieved at a significant cost of chroma fidelity.

To calculate the Bjøntegaard delta bit rate, a distortion metric needs to be used. For standard-dynamic range video, the distortion metric primarily used in the video coding standardization community has been the peak signal to noise ratio (PSNR). There are certainly some weaknesses to the PSNR-based BD-rate measure in terms of its correspondence with human perception of fidelity. Some other objective distortion metrics which have been asserted to have a better relationship with human perception, such as structural similarity (SSIM) index,^[12] multi-scale SSIM (MS-SSIM),^[13] and video multimethod assessment fusion (VMAF),^[14] have also been considered with the BD-rate measurement process. However, the use of PSNR-based BD-rate measures is the most prevalent in the video coding standardization community. In this document, BD-rate is used to denote PSNR-based BD-rate unless a different distortion metric is explicitly mentioned.

This document is based on JVET-Q0826^[15] and JVET-R2016^[16].

6 The PSNR-based BD-rate concept

When developing a video coding standard, it is important to have a uniform way of reporting the compression results so that different contributions can be compared against each other.

The PSNR metric is based on the squared error of individual sample values and does not take into account how the human visual system works. A relevant question is therefore whether the PSNR metric is a good predictor of subjective quality. The answer depends at least partly on how different the encoding methods being compared are to each other. If the two methods differ greatly, their artefacts can be very different, and the perceived subjective quality will depend heavily on which type of artefact is psychovisually more disturbing. BD-rate measurements are most often used to compare between two versions of the same video encoder that only differ in that in one of them one tool has been turned on or has been modified versus the other. In this scenario it is much more likely that the BD-rate score between these two versions will correlate with a difference in subjective quality. A clear exception is when tools are considered that are only (or primarily) expected to affect subjective quality, such as deblocking filters. Here, decisions are almost always based on a subjective test or expert viewing, and BD-rate numbers are provided more as an assurance that the tool has not caused some unexpected problem.

An advantage with using PSNR is that it is mathematically simple and therefore straightforward to optimize for. As an example, if a tool depends on filter coefficients or other parameters, the reference encoder can search for the parameter value that minimizes mean square error (MSE) and thus optimizes PSNR, and this type of optimization is often straightforward to analyse and implement. The idea is that a real encoder can optimize for a different distortion metric that is psychovisually more relevant but where the parameter search can be a lot more complicated to implement. By choosing PSNR as the distortion metric in the BD-rate calculations, the work can concentrate on creating coding tools instead of spending time developing encoder optimizations for advanced distortion metrics. However, it is also possible to compute BD-rate measurements using other objective distortion metrics or subjective mean-opinion scores.

For high-dynamic range (HDR)/wide colour gamut (WCG) material and 360° video material, there are additional aspects that influence the usability of BD-rate calculations; these are addressed in [Clauses 7](#) and [8](#), respectively. The JVET common test conditions also specify a separate category for screen content material (i.e. material that has not been captured by a camera). However, in the context of standardization development, a need for a special metric instead of PSNR-based BD-rate has not been identified for this category.

7 PSNR-based BD-rate calculation

7.1 General

There are several steps in the BD-rate calculation process, where the result in each step is calculated from the result obtained in the previous step:

- a) Calculation of PSNR for individual frames.
- b) Calculation of per-sequence PSNR and bit rate values for each quantization parameter (QP) value. The QP value influences the resulting bit rate. Hence, compressing the sequence several times with different QPs ensures that the final BD-rate measurement will reflect the performance at many different bit rates.
- c) Calculation of per-sequence BD-rate values.
- d) Calculation of an aggregate BD-rate value for all sequences.

These steps are further described in subclauses [7.2](#) through [7.6](#).

7.2 Calculation of PSNR for individual frames

For an individual frame, the mean square error is calculated between the luma channel *decY* of the decoded output image and the luma channel *origY* of the original image according to [Formula \(1\)](#).

$$MSE_Y = \frac{1}{W*H} \sum_{y=0}^{H-1} \sum_{x=0}^{W-1} (decY(x,y) - origY(x,y))^2, \quad (1)$$

where

decY(*x*, *y*) and *origY*(*x*, *y*) are the luma sample values at position (*x*, *y*) of the decoded and original images at the same time instance, respectively;

W is the width of the luma component;

H is the height of the luma component.

A luma PSNR value for the frame can then be calculated using [Formula \(2\)](#).

$$PSNR_Y = 10 * \log_{10} \left(\frac{(255 \ll (bitDepth - 8))^2}{MSE_Y} \right), \quad (2)$$

where

bitDepth = 10 for 10-bit inputs;

\ll denotes a bitwise left-shift operation.

If *MSE_Y* = 0, i.e. if the decoded image exactly matches the original image, there is some adjustment applied to avoid a division by zero. Different implementations can use a different adjustment method. For example, the HEVC test model (HM) and VVC test model (VTM) software packages set the *PSNR_Y* value to 999.99. In this case, the AVC joint test model (JM) and HDRTools software packages impose a minimum MSE of $1 \div (W * H)$, and another approach could be to impose a minimum MSE of $1 \div 12$, since that is the MSE that would theoretically result from rounding large numbers to the nearest multiple of 1.

The use of $255 \ll (bitDepth - 8)$ instead of $2^{bitDepth} - 1$ in the numerator of the expression in [Formula \(2\)](#) is slightly unusual, but it provides a small adjustment so that if the same video content is coded using *bitDepth* = 8 or is coded by shifting it up by two bits and using a 10-bit encoder, and when any error is also just scaled up accordingly, there will be no difference in the resulting fidelity measurement. The

difference between the two types of measurement is just a constant offset of 0.0255 dB, so it is normally insignificant.

Three PSNR numbers are ordinarily calculated in this manner; one for luma ($PSNR_Y$), and two for chroma ($PSNR_U$ and $PSNR_V$).

7.3 Calculation of sequence PSNR and bit rate numbers for each QP value

The aggregate PSNR for a test sequence is calculated as the average of the PSNR values for the individual frames according to [Formula \(3\)](#).

$$PSNR_{Y_{sequence}} = \frac{1}{NumFrames} \sum_{k=0}^{NumFrames-1} PSNR_{Y_k}, \quad (3)$$

where

$PSNR_{Y_k}$ is the $PSNR_Y$ value for frame k calculated according to subclause [7.2](#);

$NumFrames$ is the number of frames in the sequence.

An alternative to averaging PSNR would be to average the MSE value and then use [Formula \(2\)](#) to calculate the aggregate PSNR for the sequence. That would avoid the issue with dividing by a zero MSE_Y value in [Formula \(2\)](#) when a single decoded frame matches the original perfectly. More generally, it would avoid the case where a single frame with very high fidelity has a large influence on the average. However, that would also mean that a single frame with very poor fidelity could influence the final number considerably, although it can arguably be difficult to notice, especially at high frame rates. It has been the typical practice to average the PSNR scores instead. The bit rate for the sequence is calculated in kilobits per second and is calculated from the number of frames per second (fps), the number of frames in the sequence, and the size of the file in bytes according to [Formula \(4\)](#).

$$BitRate = \frac{8 * FilesizeInBytes * fps}{NumFrames * 1000} \quad (4)$$

There is sometimes extra information in the bitstream, such as checksums, that is not necessary for decoding. This information is only used for bitstream validation and is not counted in $FilesizeInBytes$. Each test sequence is compressed using four different QP values (values 22, 27, 32 and 37 according to the JVET common test conditions). PSNR numbers and bit rate numbers are calculated for each QP.

For chroma, $PSNR_U_{sequence}$ and $PSNR_V_{sequence}$ are calculated in a similar fashion.

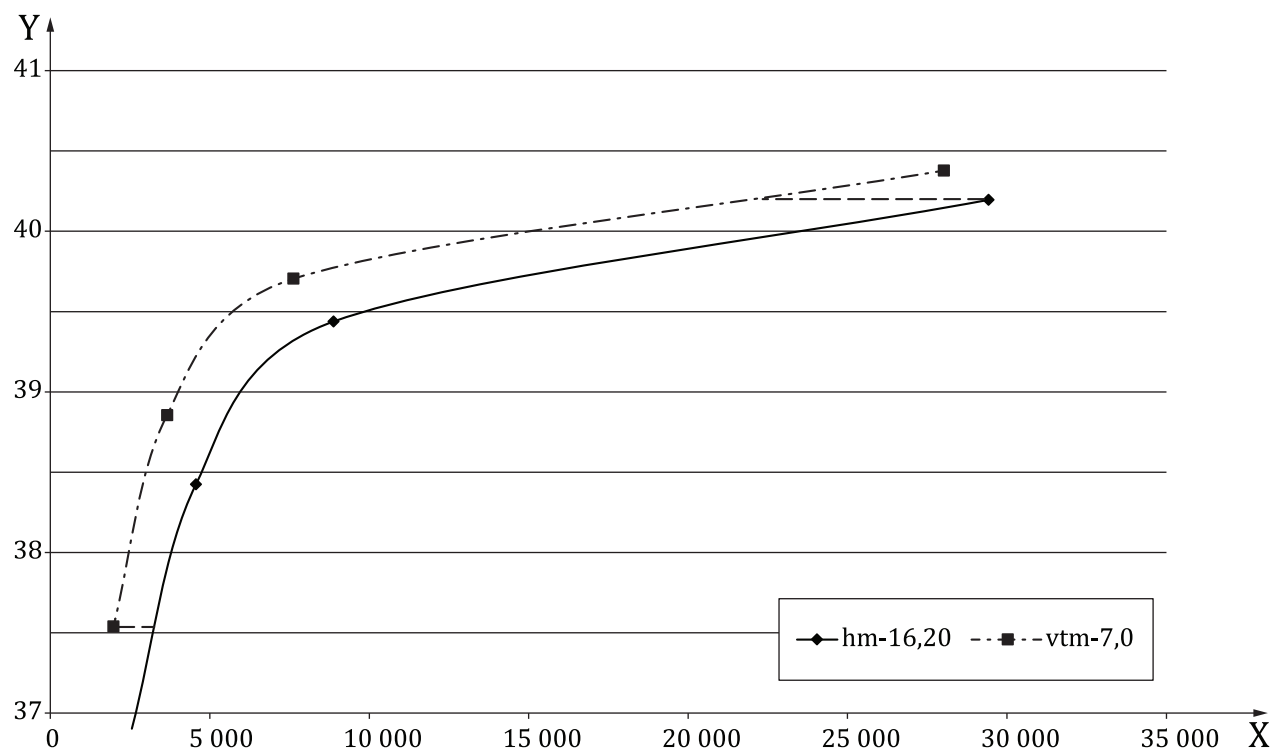
7.4 Calculation of sequence BD-rate number

Subclauses [7.2](#) and [7.3](#) have determined the PSNR values and bit rate values for each QP value, both for the anchor and for the tested method. The anchor here refers to the baseline that a tested method is compared against, such as the HEVC reference software HM-16.20, whereas the test is the tested method under investigation, for instance the VVC reference software VTM-7.0. [Table 1](#) presents one example of how the values can differ between the anchor and test scenarios:

Table 1 — Example bit rates and PSNR values for anchor and test

| QP value | Bit rate of anchor (kbps) | PSNR_Y anchor | Bit rate of test (kbps) | PSNR_Y test |
|----------|---------------------------|---------------|-------------------------|-------------|
| 22 | 29419.76 | 40.19 | 28020.45 | 40.38 |
| 27 | 8876.16 | 39.44 | 7622.83 | 39.70 |
| 32 | 4564.60 | 38.42 | 3661.62 | 38.86 |
| 37 | 2551.37 | 36.90 | 1979.02 | 37.54 |

The values in this table can be plotted as two curves as shown in [Figure 1](#) and [Figure 2](#).



Key
 X bit rate (kbps)
 Y PSNR_Y (dB)

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Figure 1 — Example of luma PSNR plotted as a function of bit rate for HM-16.20 (unbroken line) versus VTM-7.0 (dashed-dotted line)

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