APPS015-Codensity T408™ BD-rate Calculation Application Note

V2.0

2021-12-20

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1 Table of Abbreviations

Abbreviation:	Full Form:
BD-rate	Bjontegaard rate
PCHIP	piecewise cubic hermite interpolating polynomial
AI	Artificial Intelligence
API	Application Programming Interface
AUD	Access Unit Delimiters
AV	Audio Video
AV1	Alliance Open Media Video 1 Codec
CABAC	Context Adaptive Binary Arithmetic Coding
CBR	Constant Bit Rate
CPU	Central Processing Unit
CRF	Constant Rate Factor
DSP	Digital Signal Processing
EOF	End Of File
FIXQB	Fixed Quantization Parameter
FF	Form Factor
FPS	Frames Per Second
GOP	Group of pictures
HDR	High Dynamic Range
HHHL	Half Height, Half Length
HHFL	Half Height, Full Length
HLG	Hybrid Log Gamma
HRD	Hypothetical Reference Decoder
IE	Inference Engine
Mbps	Mega Bit per second
MBps	Mega Byte per second
NLP	Natural Language Processing
NPU	Neural Processing Unit
NVMe	Non-Volatile Memory express
PCIe	Peripheral Component Interconnect express
PPS	Picture Parameter Set
QP	Quoted Printable
RGB	Red Green Blue
RGBA	Red Green Blue Alpha
RDO	Optimization

ROI	Region of interest
SDK	Software Development Kit
SEI	Supplemental Enhancement Information
SRIOV	Single Root I/O Virtualization
SPS	Sequence Parameter Set
VBR	Variable Bit Rat
VCL	Video Coding Layer
VPS	Video Parameter Set
VUI	Video Usability Information

2 References

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3 Background

The Bjontegaard rate difference, also known as BD-rate, allows the measurement of the bitrate reduction offered by a codec or codec feature, while maintaining the same quality as measured by objective metrics. The rate change is computed as the average percent difference in rate over a range of qualities. Metric score ranges are not static - they are calculated either from a range of bitrates of the reference codec, or from quantizers of a third, anchor codec.

It is found the open source excel spreadsheet (https://github.com/tbr/bjontegaard_etro , Tim Bruylants, ETRO, Vrije Universiteit Brussel) which is commonly used by the video decoder evaluation uses a polynomial interpolation which may have large error on some cases. A more precise PCHIP (piecewise cubic hermite interpolating polynomial) interpolation is evaluated in this document which can provide much more accurate result.

4 BD-rate Introduction

4.1 Bjontegaard rate

BD-rate is introduced in ITU - Telecommunications Standardization Sector STUDY GROUP 16 Question 6 Video Coding Experts Group (VCEG), document VCEG-M33.

When we want to compare the encoding efficiency of two encoders, we usually encode the sample source with these two encoders and evaluate the objective quality index such as PSNR, SSIM and VMAF under different bitrate. In Figure 1, we assume we are going to evaluate two encoders: The “encoder RED” and the “encoder GREEN”. For each of the encoders, we tested 5 different bitrates and calculate their quality. These 5 different samples are noted as 1~5 in the plot.

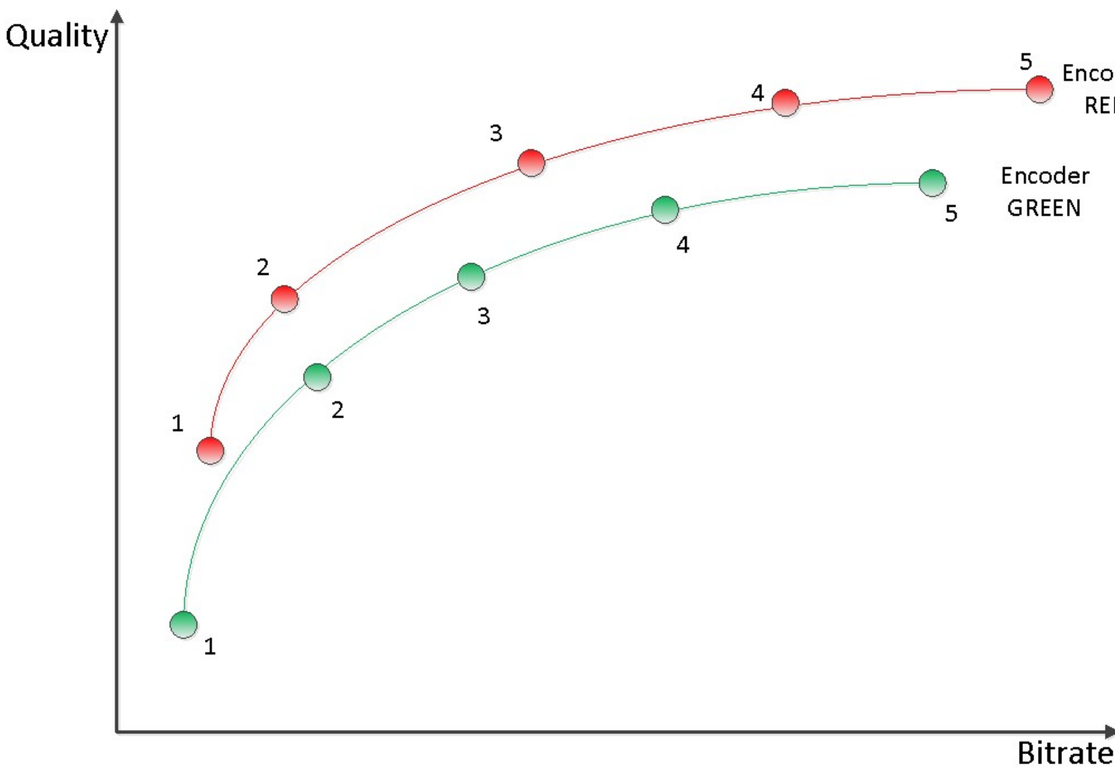

Figure 1 two encoder bitrate vs quality curve

The BD-rate compares the common part of two curves. So we need to find the minimum and maximum range first.

In Figure 2, the “MIN” and “MAX” boundary are found for the two encoders. The BD-rate on same bitrate is defined as the ratio of two areas of two curves. In this case, the RED encoder has larger area, i.e. it has extra orange area compare the green area covered by GREEN encoder. Assume the area of orange is 15% of the GREEN area, then we can say the RED encoder has 15% better quality when they encode with the same bitrate.

Usually, we compare the BD-RATE in a different way: instead of finding the common bitrate range, we find the common Quality index range. Like in Figure 3, we can find the common area in Quality axis. Now the physical meaning of BD-rate is: with the same quality, RED encoder can save xx% bitrate than GREEN encoder. The smaller, the better.

In practice, the bitrate axis is usually in logarithmic scale, since we want the high bitrate area takes same weight with low bitrate area. For details, please check document VCEG-M33.

We can also know from the plot, to compare the BD-RATE, the two curves must have overlapping on X-axis or Y-axis.

These links covers a few useful topics on using BD-rate for encoder quality comparison:

https://netflixtechblog.com/performance-comparison-of-video-coding-standards-an-adaptive-streaming-perspective-d45d0183ca95

https://euclidiq.com/blog/blog-post-title-one-xjy6b

Define the function of encoder RED as:

$$f_{red}(x)$$

Define the function of encoder GREEN as:

$$f_{green}(x)$$

Then the BD-RATE is defined as:

$$BD-RATE = \int_{min}^{max} f_{red}(x)dx \, / \int_{min}^{max} f_{green}(x)dx - 1$$

According to Newton-Leibniz formula:

$$\int_{a}^{b} f(x)dx = F(b) - F(a), where\ F(x) is\ the\ primitive\ function\ of\ f(x)$$

F(x) is defined as:

$$F(x) = \int f(x)dx + C, where\ C\ is\ a\ contant\ number$$

We are going to use polynomial function to approach f(x), for polynomial function, we have:

$$\frac{1}{n}x^{n+1} = \int x^n dx$$

For a 3rd order polynomial function:

$$f(x) = bx^3 + cx^2 + dx + a$$

F(x):

$$F(x) = \frac{1}{4}bx^4 + \frac{1}{3}cx^3 + \frac{1}{2}dx^2 + ax + C$$

Equation 1

The integration of Encoder RED will be:

Area(1-2)+Area(2-3)+Area(3-4)+Area(4-max)

The integration of Encoder GREEN will be:

Area(min-2)+Area(2-3)+Area(3-4)+Area(4-5)

The function in each area is different.

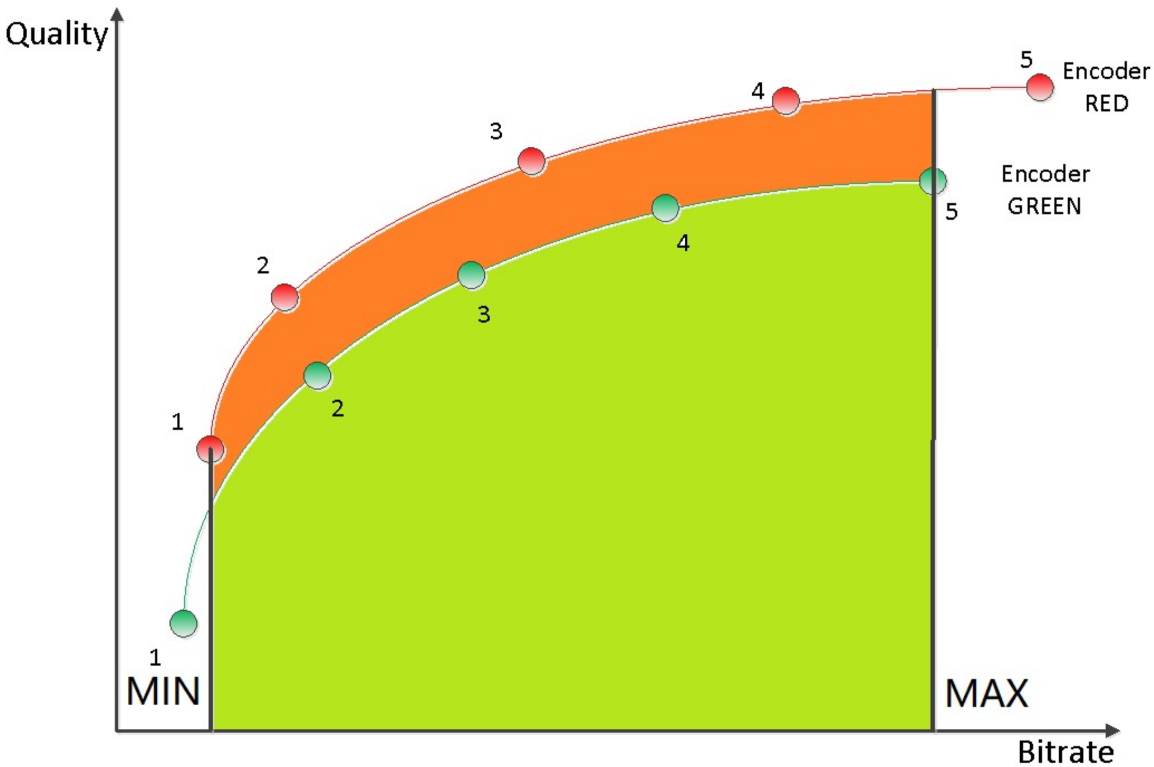

Figure 2 BD-RATE physical meaning, same bitrate

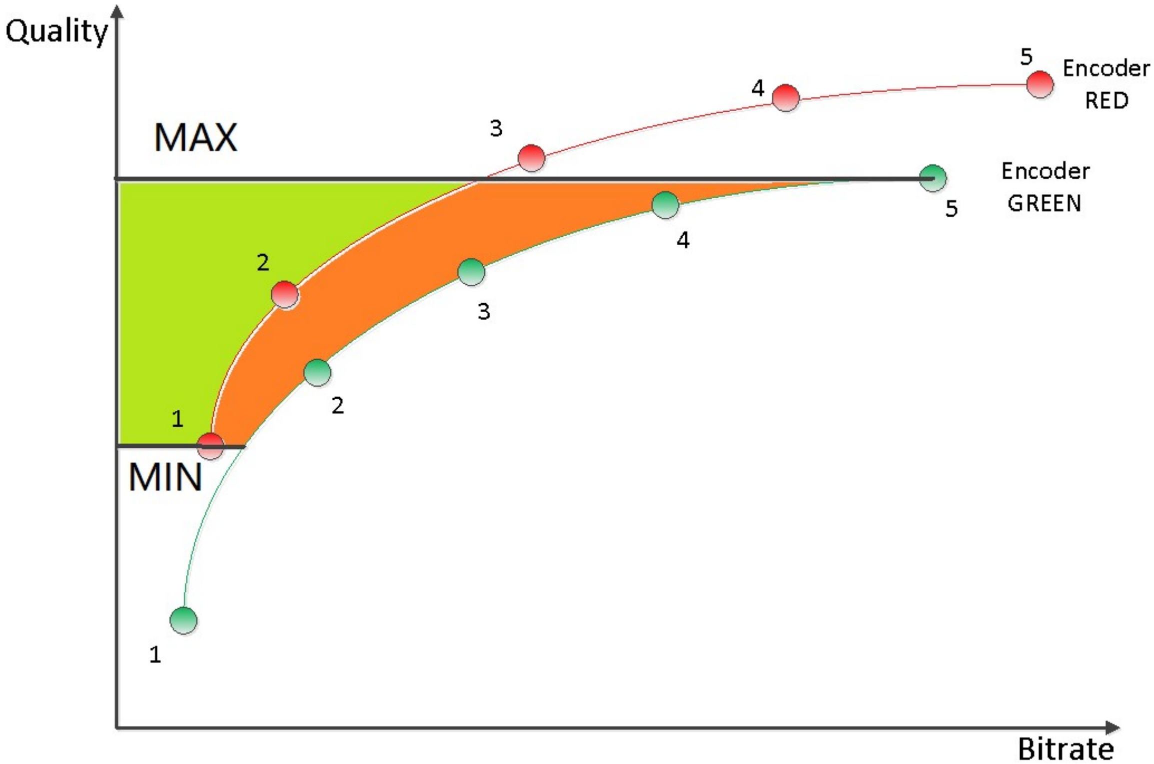

Figure 3 BD-RATE physical meaning, same Quality index

4.2 Interpolation

When we measure the quality of an encoder, we only get a few discrete points. For example, in the RED vs GREEN encoder comparison, we have 5 points for each encoder.

To calculate the BD-RATE, we need to find the function of each encoder and interpolate between these 5 points. A common way is to use polynomial functions to interpolate the samples. In VCEG-M33, a 3rd order polynomial function is suggested to approach the function of each RED and GREEN encoder.

In VCEG-M33, it suggested to use 3rd order polynomial function to approach sample points. 3rd order polynomial function requires at least 4 points.

Figure 4 shows different kinds of interpolation. “Linear” which is simply connect adjacent two samples. “Poly” use a polynomial function to approach all samples, but we can find it under/over shoots especially when the order is high. “pchip: stands for “piecewise cubic hermite interpolating polynomial” which is a shape-preserving, “visually pleasing” interpolant and was based on an old Fortran program by Fritsch and Carlson that is described by Kahaner, Moler, and Nash. Another piecewise cubic interpolating function is a cubic spline: ”spline”.

The difference between pchip and spline is pchip only keeps the first order of derivative continuous, but spline keeps 2nd order derivative also continuous. However, "spline" has more overshoots than pchip. It is recommended to use PCHIPs as the interpolation method for BD-RATE calculation.

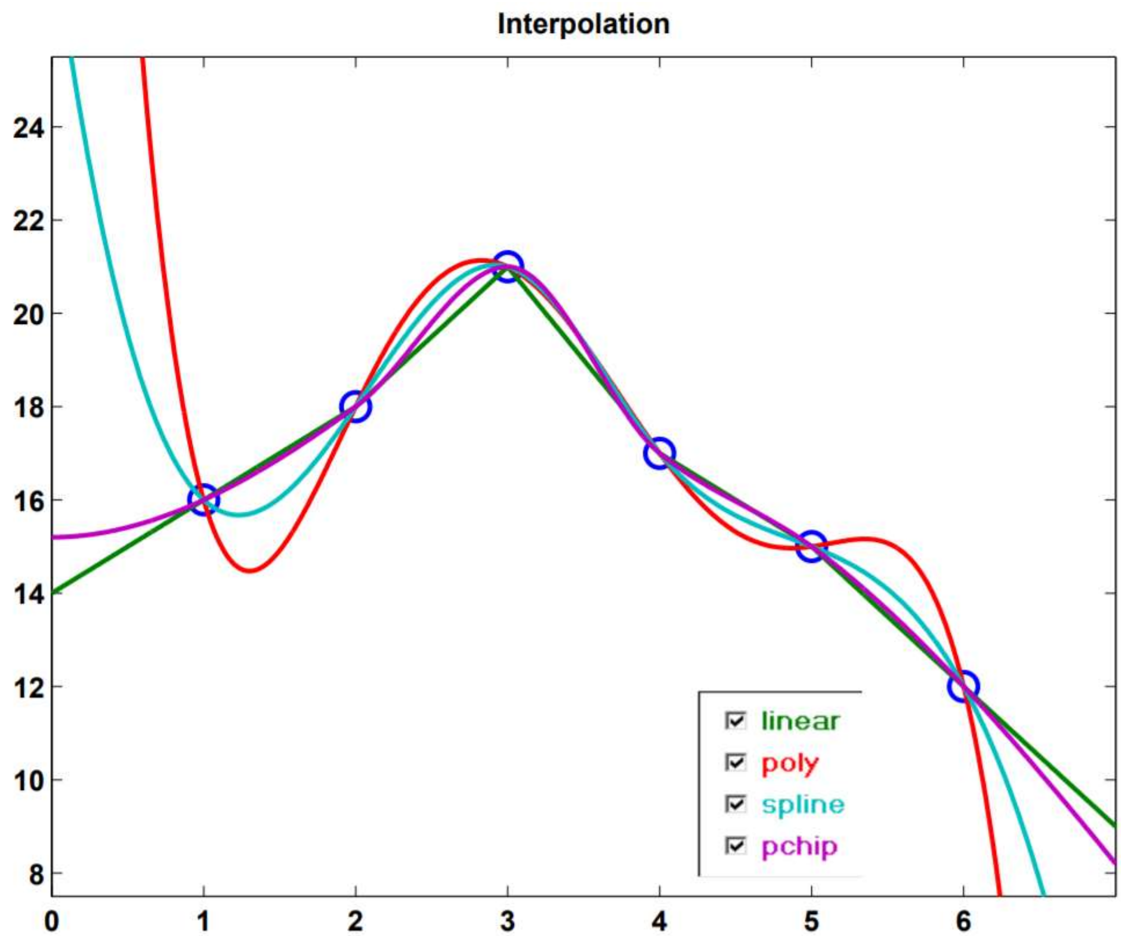

Figure 4 different kinds of interpolation from Numerical Computing with MATLAB, Clive Moler

For PCHIP calculation, take s=x-x_k where x is the new point we need to interpolate and x_k is a known sample. S is the distance between a new point to a known sample.

$$f(x) = y_k + sd_k + s^2 d_k + s^3 b_k$$

Where the coefficients of the quadratic and cubic terms are:

$$c_k = \frac{3\delta_k - 2d_k - d_{k+1}}{h}$$

$$b_k = \frac{d_k - 2\delta_k + d_{k+1}}{h^2}$$

Here δ_k is the slope at sample point k.

Once the f(x) is found, we can use Newton-Leibniz formula mentioned in Equation 1 to calculate the integration of the area.

5 Test Example

Different interpolation method could cause big difference on the BD-RATE result. Take a real test case as example.

Table 1 Measurement of two encoders and calculate the BD-RATE with Tim Bruylants's excel function

Encoder1			**Encoder2**			**B-DBR**
Bitrate	VMAF		Bitrate	VMAF		-4.71269
11240.05	99.40		16741.00	99.01		
5712.01	98.40		8582.08	96.56		
2829.91	93.93		4537.96	88.04		
1387.34	80.85		2406.87	71.96		

In Table 1, two encoders are tested with 4 different bitrates. The result is calculated with Tim Bruylants' excel spreadsheet. It shows the Encoder2 is better than encoder1, i.e., with the same VMAF score, encoder2 can save 4.71269% on bitrate.

But if we simply draw the bitrate vs VMAF curve of these two encoders (in Figure 5) with linear interpolation, we can easily find encoder1 is better than encoder2. With the same VMAF score, encoder2 always use more bits!

What caused this problem in the B-DBR function?

Take a close look at the VBA code used for B-DBR function, it uses a polynomial interpolation function from excel:

P = Application.WorksheetFunction.LinEst(Y, Application.Power(X, Application.WorksheetFunction.Transpose(powerArray)))

If we apply 3rd order polynomial interpolation to these two encoder curves, we can easily find the problem.

In Figure 6, the 3rd order polynomial function of encoder1 has huge overshoot so the integration of the overlapping area is even larger than encoder2! That's why the B-DBR function reach the wrong conclusion that encoder1 is worse than encoder2!

We have to point out, for most of the cases, if the samples are close to each other, the 3rd order polynomial interpolation used in Tim Bruylants' spreadsheet won't cause too much problem. In this example, the samples are spread too much so the interpolation cased large ringing.

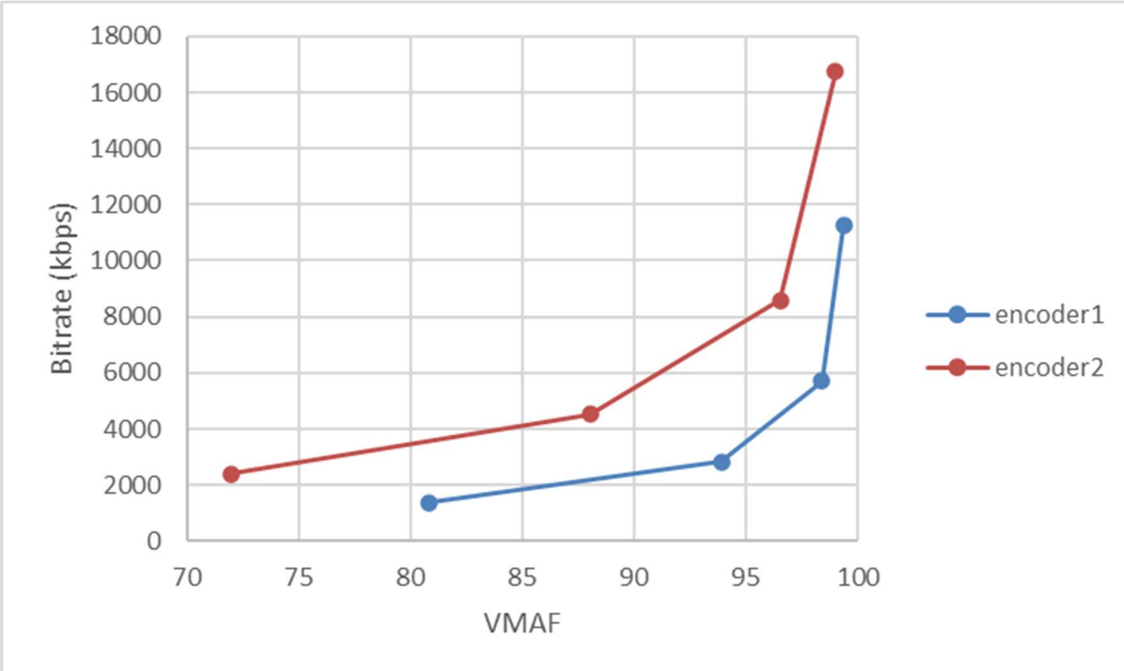

Figure 5 VMAF vs Bitrate plot of two encoders

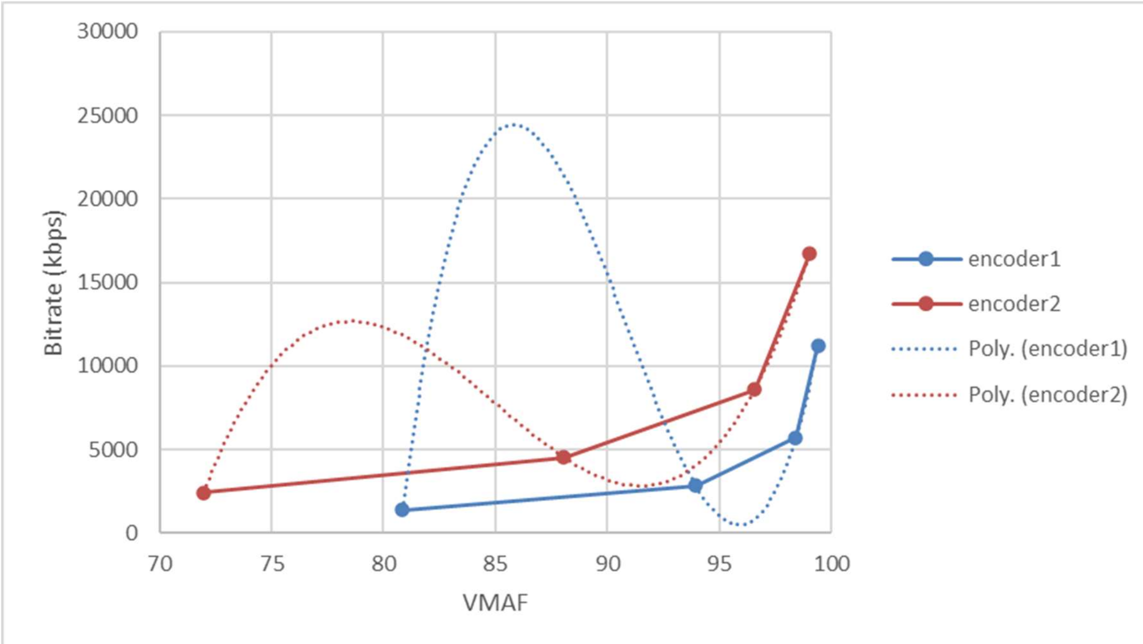

Figure 6 VMAF vs Bitrate plot of two encoders with trendline as 3rd order polynomial function

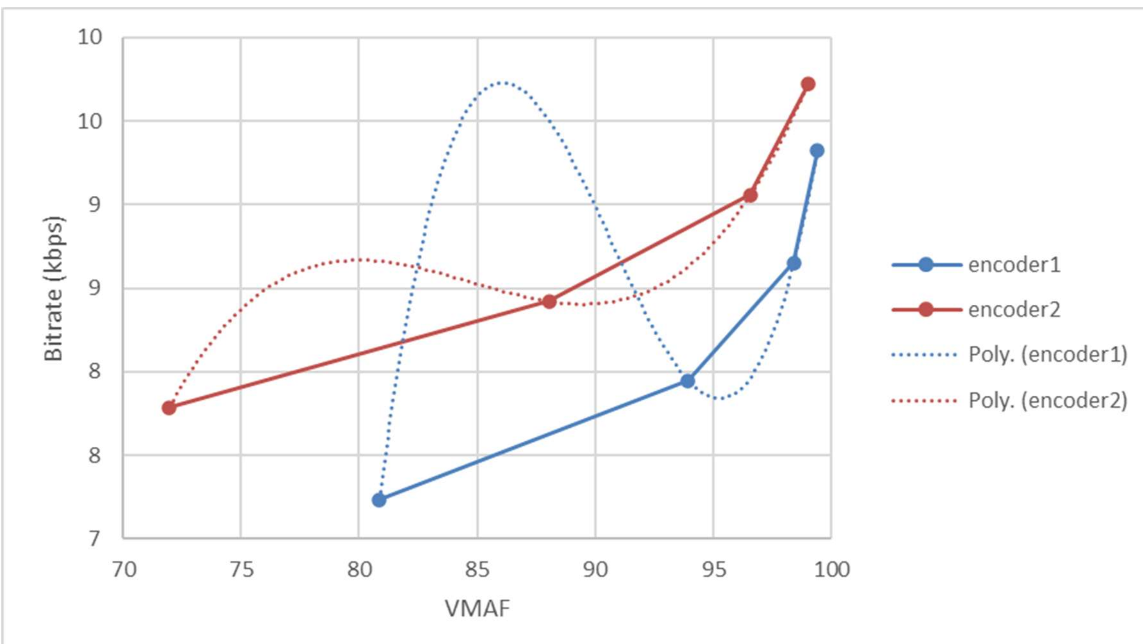

Figure 7 VMAF vs Bitrate plot of two encoders with trendline as 3rd order polynomial function(Y axis in LN())

Here is the PCHIP interpolation method based on the data of encoder1.

Table 2 PCHIP interpolation based on data of encoder1

bitrate	vmaf	k	log_rate	H(k)	delta(k)	d(k)	c(k)	b(k)
1387.34	80.85365	1	7.235144	13.07764	0.05451	0	0.005785	-0.00012
2829.91	93.93129	2	7.948	4.4737	0.15699	0.08788	0.000263	0.003394
5712.01	98.40499	3	8.650326	0.995491	0.679978	0.294036	0.679757	-0.29339
11240.05	99.40048	4	9.327239			0.775172		

K is the number of samples

Log_rate =Ln(bitrate)

H(k) is the slop on each sample.

Delta(k) is the interval of loga_rate

D(k),c(k) and b(k) are the parameters of 3^{rd} order polynomial function calculated according to PCHIP method.

Here is the PCHIP interpolation result with 100 new points, we can find the samples are matching with the original 4 samples very well and there is no overshoot or undershoot.

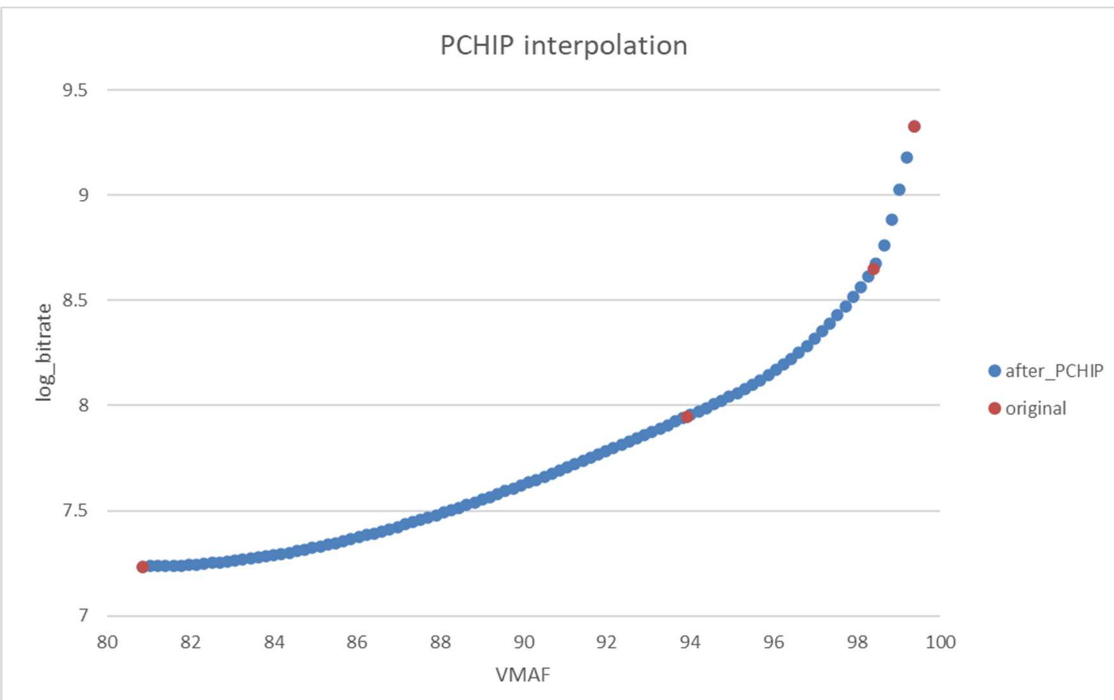

Figure 8 PCHIP interpolation method on 4 samples

The final BD-RATE calculation of encoder1 and encoder2 are:

	encoder2
Anchor : encoder1	VMAF
city_landscape_rotate_camera	140.7%
	140.7%

The encoder2 is 140.7% worse than encoder1!

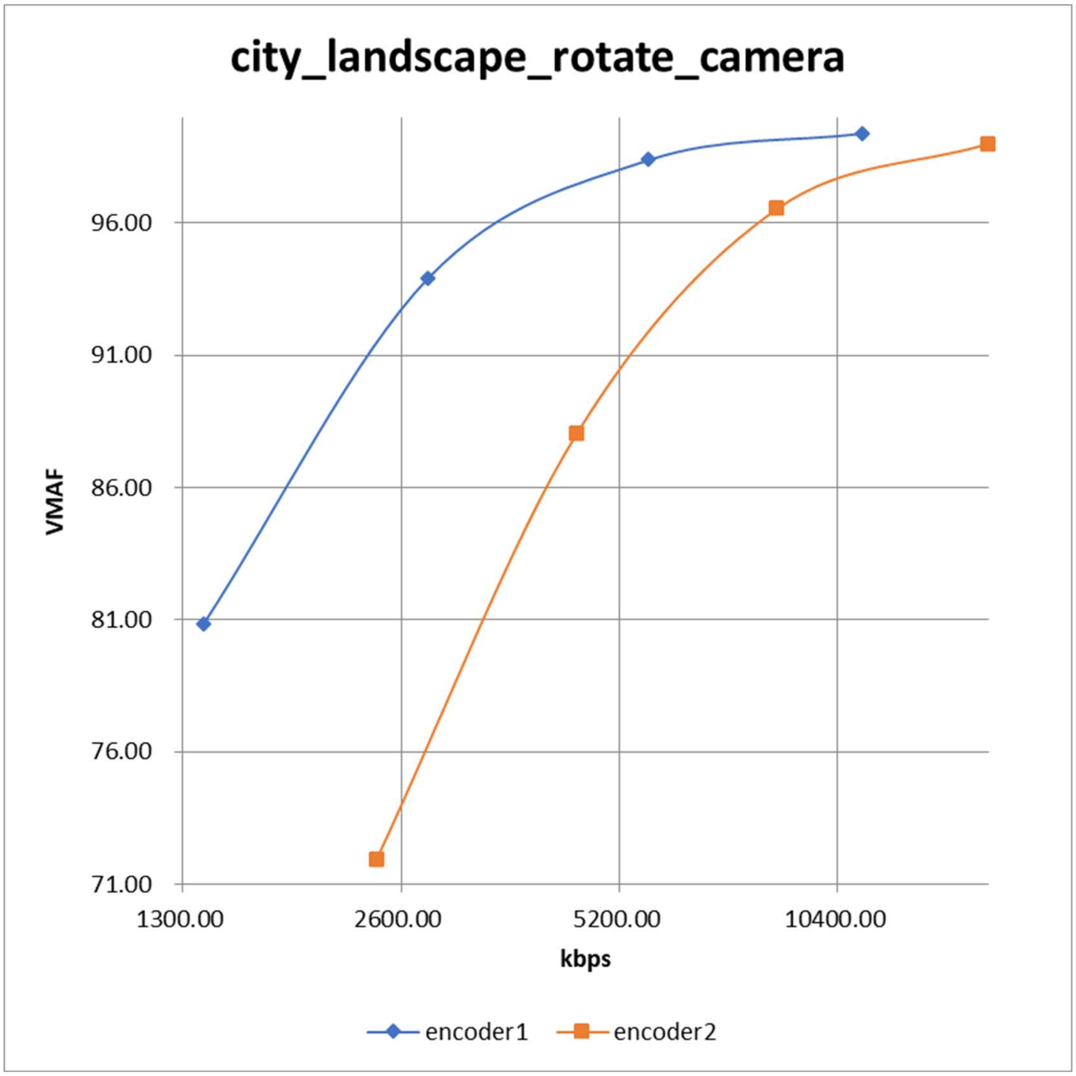

Figure 9 Plot of interpolated VMAF vs bitrate

6 Revision History

Version	Change	Create Date	Author
1.0	Document Created	Apr 23,2020	Tom Han
2.0	Update as per new app note template	December 20, 2021	Balwinder Sidhu

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