Energy Efficient Video Decoding for VVC Using a Greedy Strategy Based Design Space Exploration

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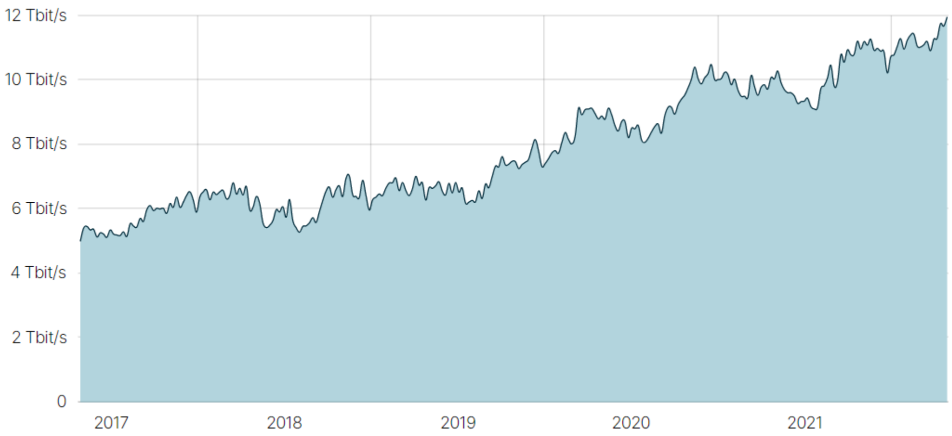
Motivation

- Increase of IP traffic at Frankfurt internet exchange node by 140% in the last five years (5 Tbit/s → 12 Tbit/s) [1]

  → Compound annual growth rate of ≈20%

- Rising demand for video streaming and higher quality video content

  → Requirement for better compression



[1] https://www.de-cix.net/en/locations/frankfurt/statistics [01.05.2022]

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- Versatile Video Coding (VVC): 50% bit rate reduction with equal subjective quality in relation to HEVC

  → Increased complexity of codec

- Goal: Reduction of decoding energy demand

	Random access Main10				
	VTM 11.0 Over HM 16.22				
	Y	U	V	EncT	DecT
Class A1	-41,67%	-43,42%	-49,16%	675%	157%
Class A2	-47,76%	-46,20%	-44,93%	752%	170%
Class B	-41,72%	-53,65%	-51,59%	754%	155%
Class C	-34,68%	-37,88%	-39,61%	1033%	163%
Class E					
Overall	**-41,04%**	**-45,91%**	**-46,58%**	**802%**	**161%**
Class D	-30,84%	-33,63%	-33,40%	1161%	164%
Class F	-48,00%	-50,91%	-51,69%	572%	137%

[2]

[1] https://www.de-cix.net/en/locations/frankfurt/statistics [01.05.2022]
[2] F. Bossen *et al.*, "JVET AHG report: Test model software development (AHG3)," JVET-U0003, Jan. 2021

Outline

- Motivation
- **Metrics & Setup**
- Greedy Strategy Based Design Space Exploration
- Evaluation of DSE
- Conclusion

Metrics & Setup

Energy measurement setup:

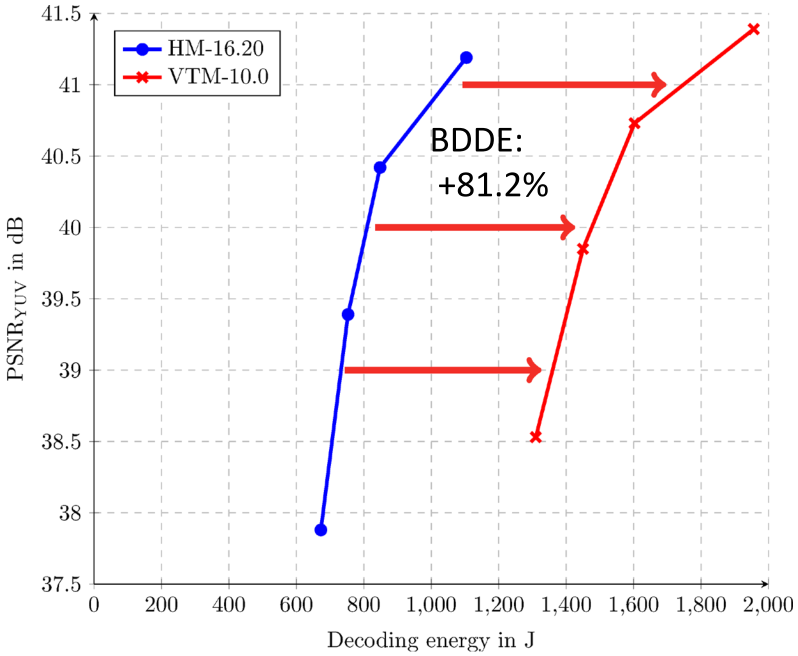
- Desktop PC: Intel i7-8700 CPU
- Integrated power meter of CPU (RAPL)
- Measurements are validated with confidence interval test

Visual quality metric:

- YUV-PSNR

Bjøntegaard-delta metrics:

- BD bit rate (BDR)
- BD decoding energy (BDDE)



Metrics & Setup

Setup:

- Encoding:
  - According to common test conditions of JVET-N1010 [3]
  - VVC: VTM
  - HEVC: HM
- Decoding:
  - VVC: VTM, VVdeC
  - HEVC: HM, openHEVC
- Test sequence sets:
  - JVET [3]: Class A1-F
  - UVG [4]: 4K & FHD sequences

Sequence	Resolution	Frames	Rate	Bit Depth
UVG1				
Beauty	3840×2160	600	120	10
Bosphorus	3840×2160	600	120	10
HoneyBee	3840×2160	600	120	10
Jockey	3840×2160	600	120	10
ReadySetGo	3840×2160	600	120	10
ShakeNDry	3840×2160	300	120	10
YachtRide	3840×2160	600	120	10
Lips	3840×2160	600	120	10
UVG2				
CityAlley	3840×2160	600	50	10
FlowerFocus	3840×2160	600	50	10
FlowerKids	3840×2160	600	50	10
FlowerPan	3840×2160	600	50	10
RaceNight	3840×2160	600	50	10
RiverBank	3840×2160	600	50	10
SunBath	3840×2160	300	50	10
Twilight	3840×2160	600	50	10
UVG3				
Beauty	1920×1080	600	120	8
Bosphorus	1920×1080	600	120	8
HoneyBee	1920×1080	600	120	8
Jockey	1920×1080	600	120	8
ReadySetGo	1920×1080	600	120	8
ShakeNDry	1920×1080	300	120	8
YachtRide	1920×1080	600	120	8

[3] F. Bossen *et al.*, "JVET common test conditions and software reference configurations for SDR video," JVET-N1010, Mar. 2019
[4] A. Mercat *et al.*, "UVG dataset: 50/120fps 4K sequences for video codec analysis and development," in Proc. ACM Multimedia Systems Conference, Istanbul, Turkey, Jun. 2020.

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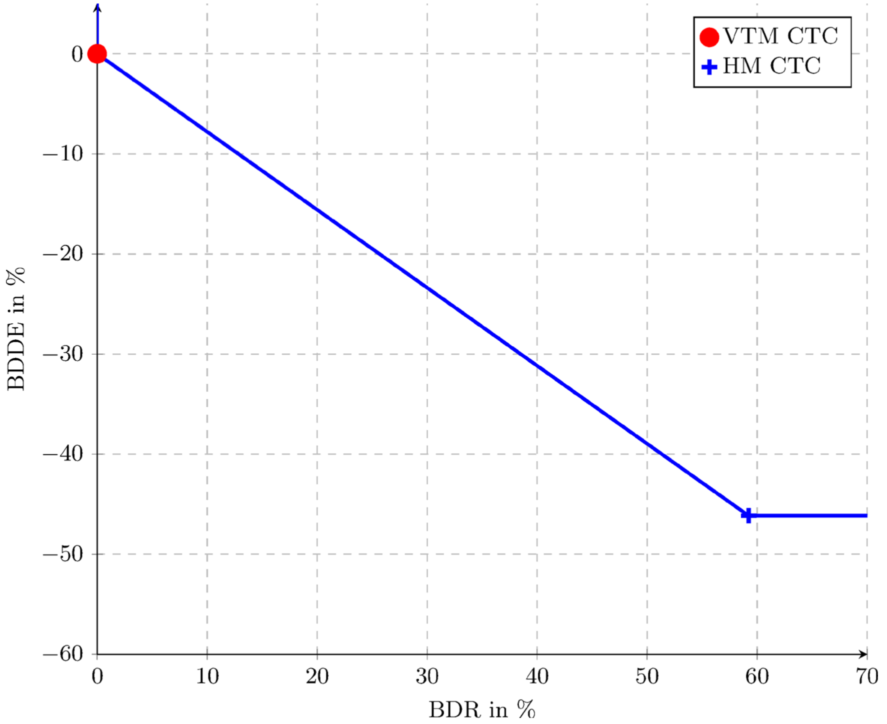
Greedy Strategy Based Design Space Exploration

Design Space Exploration (DSE) [5]:

- Trade-off between compression and energy efficiency



[5] M. Kränzler *et al.*, “Energy Efficient Video Decoding for VVC Using a Greedy Strategy Based Design Space Exploration,” in IEEE Transactions on Circuits and Systems for Video Technology, vol. 32, no. 7, pp. 4696-4709, Jul. 2022.

Greedy Strategy Based Design Space Exploration

Design Space Exploration (DSE) [5]:

- Trade-off between compression and energy efficiency
- Definition of a coding tool profile (CTP):

$$\boldsymbol{u} = \begin{pmatrix} u(1) \\ \vdots \\ u(\nu) \\ \vdots \\ u(N) \end{pmatrix}$$

	Tool	AI	LB	RA
Intra	CCLM	✓	✓	✓
	ISP	✓	✓	✓
	MIP	✓	✗	✓
	MRLP	✓	✓	✓
Inter	AFFINE	-	✓	✓
	AMVR	-	✓	✓
	BCW	-	✓	✓
	BDOF	-	-	✓
	CIIP	-	✓	✓
	DMVR	-	-	✓
	GPM	-	✓	✓
	MMVD	-	✓	✓
	PROF	-	✓	✓
	SbTMVP	-	✓	✓
	SMVD	-	-	✓

	Tool	AI	LB	RA
Transform. Quant.	DQ	✓	✓	✓
	JCCR	✓	✓	✓
	LFNST	✓	✗	✓
	MTS	✓	✓	✓
	SBT	-	✓	✓
In-Loop Filter	ALF	✓	✓	✓
	CCALF	✓	✓	✓
	DBF	✓	✓	✓
	LMCS	✓	✓	✓
	SAO	✓	✓	✓
Others	BDPCM	✗	✗	✗
	IBC	✗	✗	✗
	CST	✓	✓	✓

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- Trade-off between compression and energy efficiency
- Definition of a coding tool profile (CTP):

$$\boldsymbol{u} = \begin{pmatrix} u(1) \\ \vdots \\ u(\nu) \\ \vdots \\ u(N) \end{pmatrix}$$

- Goal: Optimization of energy efficiency

$$\min_{\boldsymbol{u}} \ \mathrm{BDDE} = \min_{\boldsymbol{u}} \ f(\boldsymbol{u})$$

```
Initialize u_{1,0} ;
i = 1 ;
while u_{i,0} ≠ u_{i+1,0} do
    PSNR_{i,0}, Energy_{i,0} ← Analyze (u_{i,0});
    for ν ← 1, 2, ..., N do
        u_{i,ν} = u_{i,0};
        if u_{i,0} (ν) == 0 then
            u_{i,ν} (ν) = 1;
        else
            u_{i,ν} (ν) = 0;
        end
        PSNR_{i,ν}, Energy_{i,ν} ← Analyze (u_{i,ν});
        Calculate BDDE (u_{1,0}, u_{i,ν});
        if BDDE (u_{1,0}, u_{i,ν}) < BDDE (u_{1,0}, u_{i,0}) then
            u_{i+1,0} (ν) = u_{i,ν} (ν);
        end
    end
    if BDDE (u_{1,0}, u_{i,ν}) ≥ BDDE (u_{1,0}, u_{i−1,0}) ∀ν then
        Break;
    end
    i = i + 1 ;
end
```

[5]

[5] M. Kränzler *et al.*, "Energy Efficient Video Decoding for VVC Using a Greedy Strategy Based Design Space Exploration," in IEEE Transactions on Circuits and Systems for Video Technology, vol. 32, no. 7, pp. 4696-4709, Jul. 2022.

Greedy Strategy Based Design Space Exploration

Example:

$$\boldsymbol{u}_{1,0} = \begin{pmatrix} u(A) = 1 \\ u(B) = 1 \\ u(C) = 1 \\ u(D) = 1 \end{pmatrix} \rightarrow BDDE(\boldsymbol{u}_{1,0}, \boldsymbol{u}_{1,0}) = 0$$

- First iteration:

$$\begin{matrix} \boldsymbol{u}_{1,1} = (0\ 1\ 1\ 1)^\mathsf{T} \\ \boldsymbol{u}_{1,2} = (1\ 0\ 1\ 1)^\mathsf{T} \\ \boldsymbol{u}_{1,3} = (1\ 1\ 0\ 1)^\mathsf{T} \\ \boldsymbol{u}_{1,4} = (1\ 1\ 1\ 0)^\mathsf{T} \end{matrix} \rightarrow \begin{matrix} BDDE(\boldsymbol{u}_{1,0}, \boldsymbol{u}_{1,1}) = \mathbf{-1.2\%} \\ BDDE(\boldsymbol{u}_{1,0}, \boldsymbol{u}_{1,2}) = 4.2\% \\ BDDE(\boldsymbol{u}_{1,0}, \boldsymbol{u}_{1,3}) = 0.3\% \\ BDDE(\boldsymbol{u}_{1,0}, \boldsymbol{u}_{1,4}) = \mathbf{-2\%} \end{matrix} \Rightarrow \boldsymbol{u}_{2,0} = \begin{pmatrix} \mathbf{0} \\ 1 \\ 1 \\ \mathbf{0} \end{pmatrix}$$

- Second iteration: $BDDE(\boldsymbol{u}_{1,0}, \boldsymbol{u}_{2,0}) = -2.6\%$

$$\begin{matrix} \boldsymbol{u}_{2,1} = (1\ 1\ 1\ 0)^\mathsf{T} \\ \boldsymbol{u}_{2,2} = (0\ 0\ 1\ 0)^\mathsf{T} \\ \boldsymbol{u}_{2,3} = (0\ 1\ 0\ 0)^\mathsf{T} \\ \boldsymbol{u}_{2,4} = (0\ 1\ 1\ 1)^\mathsf{T} \end{matrix} \rightarrow \begin{matrix} BDDE(\boldsymbol{u}_{1,0}, \boldsymbol{u}_{2,1}) = -2\% \\ BDDE(\boldsymbol{u}_{1,0}, \boldsymbol{u}_{2,2}) = -1.3\% \\ BDDE(\boldsymbol{u}_{1,0}, \boldsymbol{u}_{2,3}) = \mathbf{-2.9\%} \\ BDDE(\boldsymbol{u}_{1,0}, \boldsymbol{u}_{2,4}) = -1.2\% \end{matrix} \Rightarrow \boldsymbol{u}_{3,0} = \begin{pmatrix} 0 \\ 1 \\ \mathbf{0} \\ 0 \end{pmatrix}$$

```
Initialize u_{1,0} ;
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while u_{i,0} ≠ u_{i+1,0} do
    PSNR_{i,0}, Energy_{i,0} ← Analyze (u_{i,0});
    for ν ← 1, 2, ..., N do
        u_{i,ν} = u_{i,0};
        if u_{i,0} (ν) == 0 then
            u_{i,ν} (ν) = 1;
        else
            u_{i,ν} (ν) = 0;
        end
        PSNR_{i,ν}, Energy_{i,ν} ← Analyze (u_{i,ν});
        Calculate BDDE (u_{1,0}, u_{i,ν});
        if BDDE (u_{1,0}, u_{i,ν}) < BDDE (u_{1,0}, u_{i,0}) then
            u_{i+1,0} (ν) = u_{i,ν} (ν);
        end
    end
    if BDDE (u_{1,0}, u_{i,ν}) ≥ BDDE (u_{1,0}, u_{i−1,0}) ∀ν then
        Break;
    end
    i = i + 1 ;
end
```
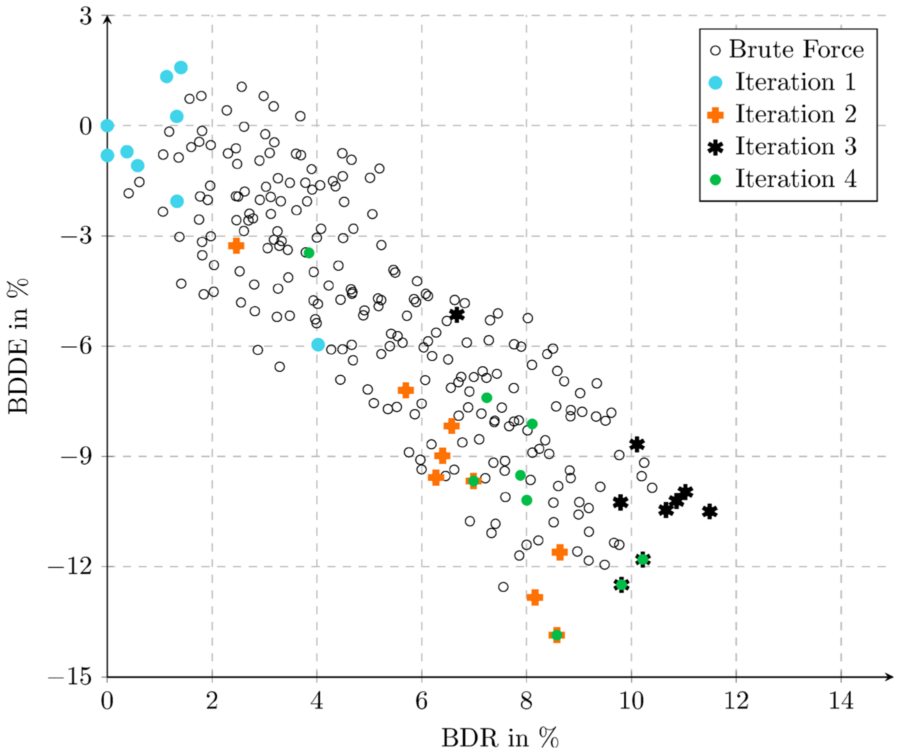

Greedy Strategy Based Design Space Exploration

Evaluation of optimality on a subset of 8 coding tools:

- Selected tools: ALF, Affine, CCLM, DQ, GPM, ISP, MTS, and SAO
- Encode and measure energy demand for each possible combination of coding tools
- Decoder & Encoder: VTM-8.0
- Sequence: Class C



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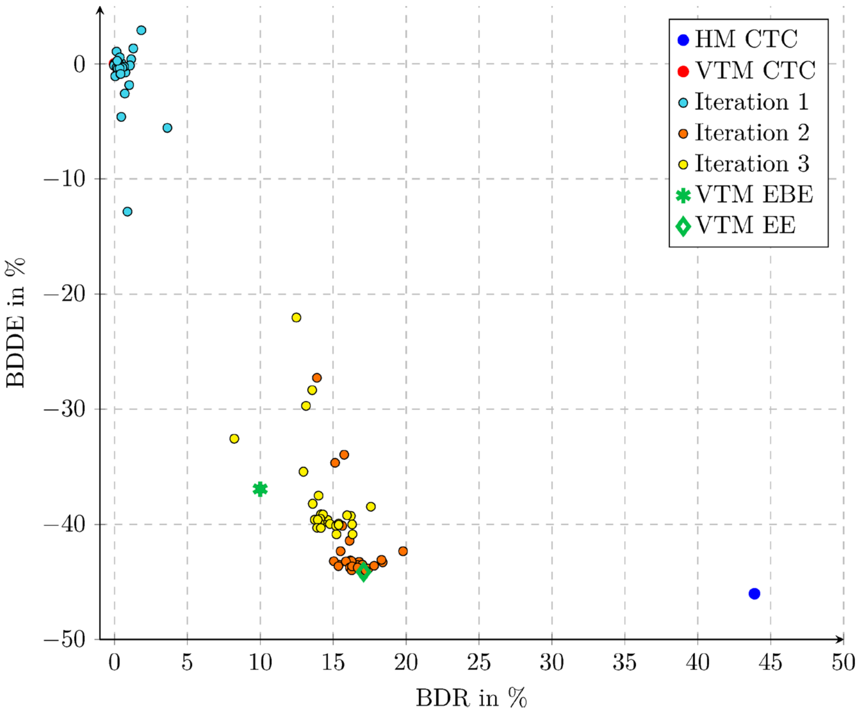
Evaluation of DSE

Evaluation of DSE for Randomaccess:

- Encoder & Decoder: VTM
- Sequences: Class C

- Energy efficient (EE) profile:
  - BDR: 17.08%
  - BDDE: -44.13%
- Energy and bit rate efficient (EBE) profile:
  - BDR: 9.99%
  - BDDE: -36.93%



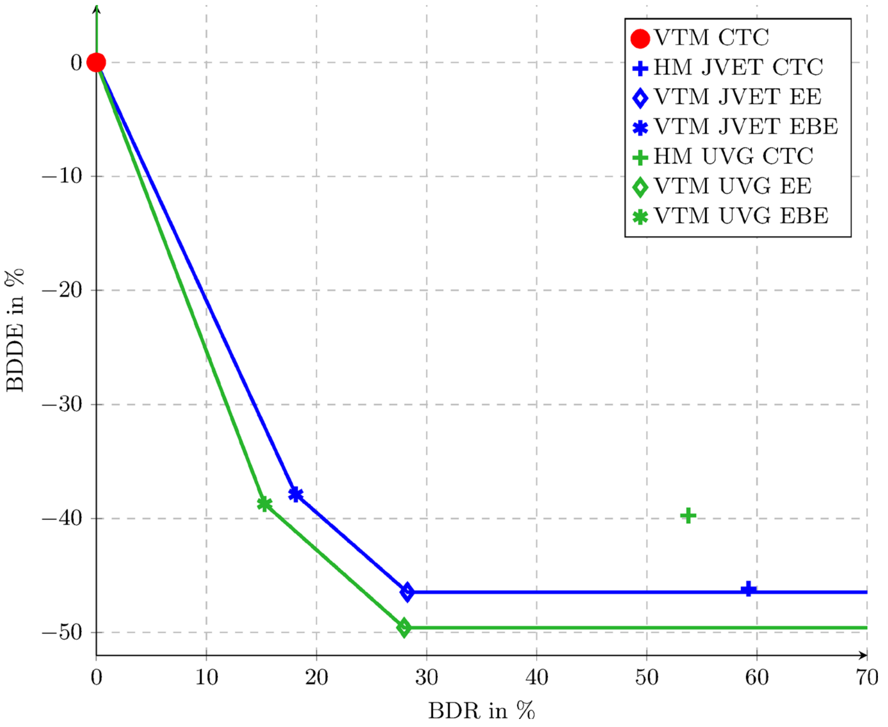
Evaluation of DSE

Validation of EE and EBE CTP for RA:

- Encoder: VTM-10.0 & HM-16.20
- Decoder: VTM-10.0 & HM-16.20
- Setups: JVET & UVG

JVET	HM	EE	EBE
BDR in %	59.23	28.25	18.12
BDDE in %	-46.15	-46.46	-37.89

UVG	HM	EE	EBE
BDR in %	53.77	27.96	15.29
BDDE in %	-39.73	-49.57	-38.72



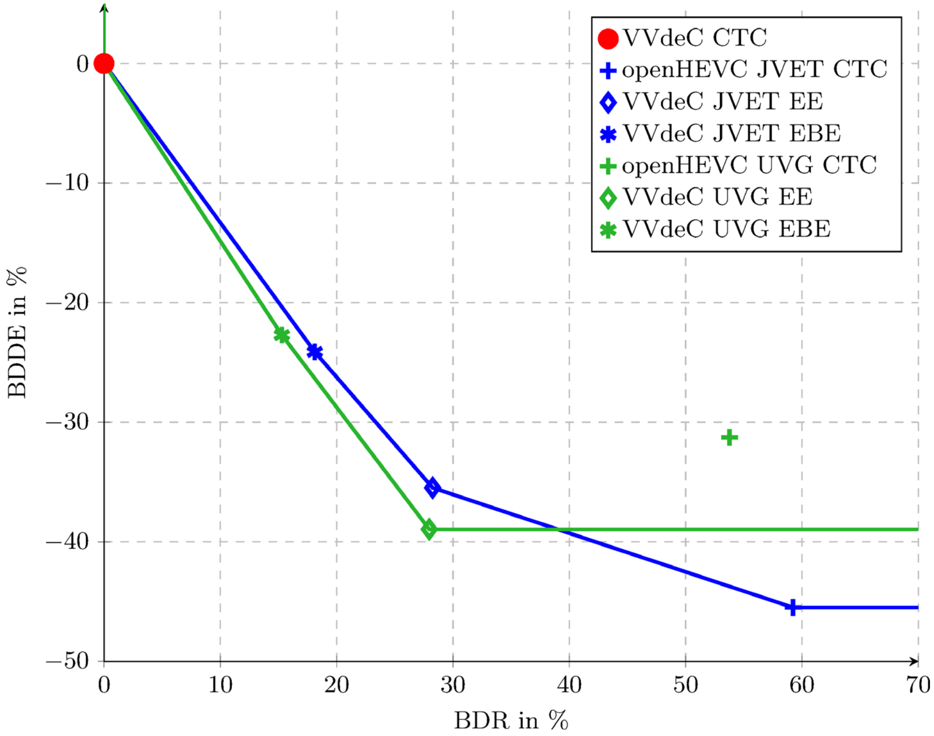
Evaluation of DSE

Validation of EE and EBE CTP for RA:

- Encoder: VTM-10.0 & HM-16.20
- Decoder: VVdeC-1.1.2 & openHEVC 2.0

JVET	openHEVC	EE	EBE
BDR in %	59.23	28.25	18.12
BDDE in %	-45.49	-35.48	-24.12

UVG	openHEVC	EE	EBE
BDR in %	53.77	27.96	15.29
BDDE in %	-31.27	-38.95	-22.71



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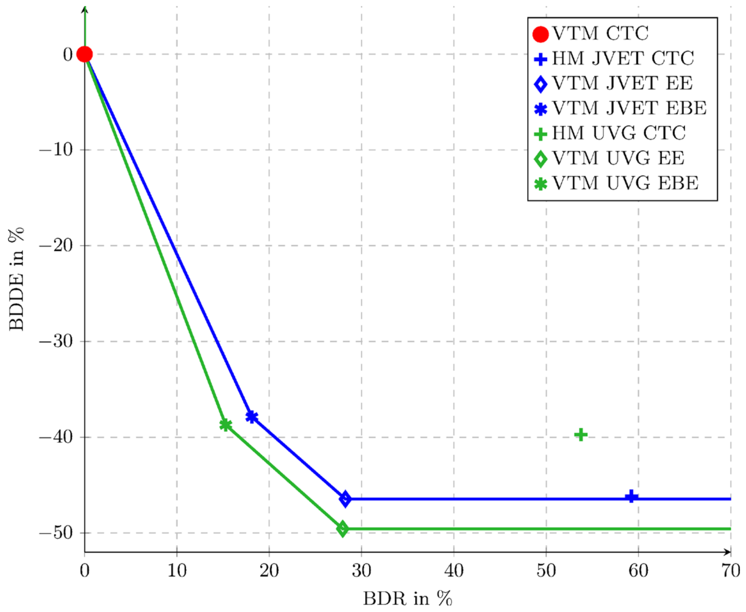
Conclusion

DSE for derivation of energy efficient profiles EE and EBE:

- EE CTP: Energy demand reduction of up to 50% with bit rate increase of 25%
- EBE CTP: 40% energy demand reduction with less than 15% additional bit rate



References

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Conclusion

Thank you for your attention!

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