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| *Title:* | **Non-CE1: Accurate initialization and conditional probability for CABAC performance improvement** | | |
| *Status:* | Input Document to JCT-VC | | |
| *Purpose:* | Proposal | | |
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# Abstract

Two possible ways for CABAC performance improvement are studied in this contribution. First takes into account conditional probability while updating entropy code state. Second one changes probability initialization taking into account hierarchical encoding structure. Both algorithms implemented on top of multi-parameter probability up-date, studied in CE1, and provide additionally 0.2% BD-rate.

# Introduction

Context-Based Adaptive Binary Arithmetic Coding (CABAC) is one of the most efficient entropy coding scheme and so was chosen as unified entropy coder for HEVC. CABAC encoding process is based on of interval subdivision which is realized in integer arithmetic. Nevertheless performance of this scheme is close to entropy limit.

Probability of current bin is not known in advance and should be estimated during encoding/decoding process. As probability in CABAC depends on context it is already conditional probability. However inside every context model we can introduce dependency from prior encoded bin. ***Conditional probability estimation for CABAC*** is described in Section 2.

After each probability update two conditional probabilities are estimated. Namely probability that next symbol will be “1” if previous encoded bin is known to be “1” and probability that next symbol will be “1” if previous encoded bin is “0”. This idea was synchronized with multi-parameter probability up-date technique proposed for CABAC [1]. Proposed method allows more precise probability estimation for current bin.

Another possible way for CABAC performance improvement is ***more accurate initialization, taking into account hierarchical encoding structure*** of HM. This opportunity is demonstrated in Section 3.

# Conditional Probabilities Up-date.

Let’s assume that probability that next bin will be “1” is *p*, conditional probability *p*11 is probability that next bin will be “1” if previous encoded bin is known to be “1”and conditional probability *p*10 is probability of “1” if previous bin is “0”. Then these probabilities met following equation

*p*= *p*⋅*p*11+(1-*p*) *p*10. (1)

Let’s introduce discrete random variable ***ζ*** which equal to 1 if current bin equal to previous bin and 0 if bin value was changed (refer Table 1)

**Table1.** Discrete random variable ***ζ****.*

|  |  |  |
| --- | --- | --- |
| Current bin | Previous bin | ***ζ*** |
| 1 | 1 | 1 |
| 1 | 0 | 0 |
| 0 | 1 | 0 |
| 0 | 0 | 1 |

Suppose that expectation value of discrete random variable ***ζ*** is ***.*** So is a probability that next symbol will be same that previous one.

. (2)

Using formulas (1)-(2) we obtain

(3)

Both values *p* and are unknown, but can be easily estimated during encoding/decoding process using exponential smoothing of content.

The main idea of proposed technique is to use one of the conditional probabilities *p*10 or*p*11 instead of *p.*

Calculations in formula for each probability and *p* are independent and can be done in parallel.

**2.1 Two-probabilities update model**.

Multi-parameter probability estimation was proposed in [1] and tested in CE1 [2]. It combines probability estimated using short and long distance prediction. In integer realization it looks as follows:

P0 = (Y>>4) + P0 – (P0>>4), (4)

P1 = (Y>>7) + P1 – (P1>>7). (5)

Here P0 and P1 are two probabilities of “1” scaled by S bits and estimated independently with two different parameters, Y = 2S if currently coding bin is “1” and Y=0 if last coding bin is “0”, “>>M” is right arithmetic shift for M bits. In [2] S=15 was used. But without noticeable performance degradation S can be reduced to 12.

For short transition period after entropy reset short-distance probability estimation is used; and then updates probability estimation switches too semi-sum:

(6)

Here counter measures the number of updates since initialization. In [2] Threshold=50 was used.

Let P2 bescaled with S bitsprobability that next symbol will not change. Let’s estimate it using long distance prediction:

P2 = (Y2>>7) + P2 – (P2>>7) (7)

Here Y2 = 2S if current coding bin is equal to previous and Y2=0 if current coding bin is different from previous one. Formula (3) in integer S=15 bits precision representation looks like

(8)

Here P3 is scaled by 2S conditional probability of “1” and is previous bin value. The calculation by formula (8) uses division which can be substituted by look-up table.

Following [F-254] for short transition period we use only short distance prediction P0. But after stabilization near optimal value two-probabilities combination is used:

(9)

Proposed modification of multi-parameter probability up-date is shown on Figure 1.



**Fig. 1.** Multi-parameter probability up-date diagram (with conditional probabilities model).

**2.2 Initialization for and** P2.

Suppose that in the beginning of each slice probabilities P0 and P1 areinitialized by value iP.

Then for initialization is obvious:

= (iP>2S-1)? 1: 0

Using formula (2) and simplifying assumption:

*p*=*p*11= *p*10.

For probability P2 following initialization value was obtained:

P2=2S -(iP<<1)+((iP\*iP)>>(S-1)).

# CABAC Initialization

**3.1. Motivation** HM5.0 use hierarchical structure schematically shown on Figure 3 for RA-test case (not all references are shown). We identify 5 groups of frame: I, B1, B2, B3 and b4. These groups of frames uses different prediction type (only Intra or mixture of Intra and Inter). For Inter-frames the distance to nearest reference frame is different each group. Group b4 is not use as reference in MC in opposite to other groups. In HM5.0 these group of frames are encoded with different QP. Because of listed factors we may expect different statistics for symbols in each group.



**Fig. 3.** Hierarchical structure in RA test case.

Both in AVC and in HM5.0 during entropy reset probability is set to predetermined value. Initial probability value for every context model linearly depends on QP:

Pinit = *Slope*[SliceType]⋅Qp + *Intersect*[SliceType]⋅ (10)

Parameters of linear dependency *Slope, Intersect* in HM5.0 are different for 3 different Slice Types: Intra, InterP or InterB. So groups B1, B2, B3 and b4 (Figure 3) use the same probability initialization; initialization for group I is different from B1, B2, B3 and b4.

Figures 4 (a-d) show probability (scaled by 2S,S=15) of “1” for several context models depending on QP. This statistics was collected for B-slices during random access (RA) test. Context model buffer for each graph on Figure 4 is indicated in upper-left corner.

The paradigm embedded to CABAC state initialization in HM5.0 assumes that all these points belong to one line. But this is obviously not true. A similar phenomenon was observed for low delay-B (LB) and low delay-P (LP) tests.

We grouped point on Figures 4 follow the same principle as on Figures 3. Actual symbol probability for different groups is show by different color. This is easy to approximate by linear function point form one group. But if we try to draw one line approximating all point on each figure we have very poor accuracy.

In some cases such as Figures 4.(a) B2 and B2, Figures 4 ( b) B4 groups, linear approximation for probability dependence on QP seems to be not a good choice. Quadratic function for this dependency approximation is more reasonable.

|  |  |
| --- | --- |
| 1. INIT\_SIG\_FLAG\_CHROMA      1. INIT\_PRED\_MODE | 1. INIT\_QT\_CBF      1. INIT\_REF\_PIC |

**Fig.4.** Statistics of symbols for different context models.

**3.2. Algorithm description**. We keep linear dependency of initial probability value on QP (10) but introduce more detailed slice type classification during CABAC initialization. Introduced slice classification and relation with HM5.0 slice types is shown in Table 1.

**Table 1.** Slice Type classification for CABAC initialization.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| HM5.0 | I | P | | | B | | | | | | |
| Proposed | I | LP1 | LP2 | LP3 | B1 | B2 | B3 | B4 | LB1 | LB2 | LB3 |

*Slope* and *Intersect* parameters in (10) were adjusted for each slice group.

Proposed probability initialization can be applied for HM5.0 CABAC as well.

# Test results

Proposed concepts were implemented on top of multi-parameter probability up-date algorithm studied in CE1 [2] and tested according to [3]. Test results are summarized in Table 2: first column shows [2] performance.

The second column shows performance if high precision probability in [2] was initialized according to proposed slice grouping. In average proposed initialization modification provides 0.1 % performance improvement for [2].

The third column shows performance if additionally conditional probability is taken into account according to (9). This part of our contribution provides 0.1 % additional performance improvement..

Table 2(a). Performance test results vs HM5.0 (Luma BD-rate for mandatory tests is reported).

|  |  |  |  |
| --- | --- | --- | --- |
| Tested Method | 1 | 2 | 3 |
| Multi-parameter probability estimation | Method 1 + proposed CABAC initialization | Method 2 + proposed condition probability estimation |
| AI-HE | -0.77% | -0.78% | -0.86% |
| AI-LC | -0.75% | -0.75% | -0.88% |
| RA-HE | -0.66% | -0.78% | -0.91% |
| RA-LC | -0.67% | -0.73% | -0.86% |
| RA-HE10 | -0.75% | -0.83% | -0.95% |
| LB-HE | -0.52% | -0.73% | -0.80% |
| LB-LC | -0.58% | -0.75% | -0.80% |
| ALL | **-0.69%** | **-0.78%** | **-0.88%** |

Table 2(b). Performance test results vs HM5.0 (Luma BD-rate in all test is reported).

|  |  |  |  |
| --- | --- | --- | --- |
| Tested Method | 1 | 2 | 3 |
| Multi-parameter probability estimation | Method 1 + proposed CABAC initialization | Method 2 + proposed condition probability estimation |
| AI-HE | -0.74% | -0.75% | -0.86% |
| AI-LC | -0.76% | -0.76% | -0.89% |
| AI-HE10 | -0.74% | -0.73% | -0.85% |
| RA-HE | -0.66% | -0.77% | -0.93% |
| RA-LC | -0.64% | -0.68% | -0.87% |
| RA-HE10 | -0.60% | -0.70% | -0.86% |
| LB-HE | -0.51% | -0.72% | -0.85% |
| LB-LC | -0.55% | -0.71% | -0.80% |
| LB-HE10 | -0.50% | -0.75% | -0.83% |
| LP-HE | -0.52% | -0.72% | -0.83% |
| LP-LC | -0.50% | -0.67% | -0.79% |
| LP-HE10 | -0.57% | -0.79% | -0.91% |
| ALL | **-0.61%** | **-0.73%** | **-0.86%** |

More details about test results can be found in Appendix (Tables 3, 4) and excel spreadsheets attached to this contribution.

# Conclusions

**Based on reported performance for multi-parameter probability estimation:**

**-0.7% Luma BD-rate and -0.4% Chroma BD-rate**

**and shown potential for further improvement**

**-0.9% Luma BD-rate and -0.6% Chroma BD-rate**

**Samsung proposes to adopt CABAC multi-parameter probability estimation to WD and HM6.0**.

# References

1. Alexander Alshin, Elena Alshina “Multi-parameter probability up-date for CABAC”, JCTVC-F254, Torino, ITA, July 2011
2. A. Alshin, E. Alshina, J.H. Park “CE1, subtest C4: Multi-parameter probability estimation for CABAC,” Document of Joint Collaborative Team on Video Coding, JCTVC-H0112, February 2012
3. F. Bossen, “Common HM test conditions and software reference configurations,” Document of Joint Collaborative Team on Video Coding, JCTVC-G1200, November 2011.

# Patent rights declaration(s)

**Samsung Electronics Co., Ltd. may have current or pending patent rights relating to the technology described in this contribution and, conditioned on reciprocity, is prepared to grant licenses under reasonable and non-discriminatory terms as necessary for implementation of the resulting ITU-T Recommendation | ISO/IEC International Standard (per box 2 of the ITU-T/ITU-R/ISO/IEC patent statement and licensing declaration form).**

**Appendix**.

**Table 3.** Performance test for Method 2: multi-parameter probability estimation with proposed initialization.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra HE** | | | **All Intra LC** | | | **All Intra HE-10** | | |
|  | Y | U | V | Y | U | V | Y | U | V |
| Class A | -0.9% | 0.0% | -0.1% | -0.8% | -0.6% | -0.6% | -0.9% | 0.1% | -0.1% |
| Class B | -0.8% | -0.8% | -0.7% | -0.8% | -0.9% | -0.9% | -0.8% | -0.8% | -0.7% |
| Class C | -0.7% | -0.8% | -0.6% | -0.7% | -0.8% | -0.8% | -0.7% | -0.7% | -0.6% |
| Class D | -0.8% | -0.4% | -0.4% | -0.7% | -0.8% | -0.8% | -0.8% | -0.5% | -0.4% |
| Class E | -0.7% | -0.6% | -0.5% | -0.7% | -0.8% | -0.8% | -0.7% | -0.6% | -0.6% |
| Class F | -0.6% | -0.5% | -0.3% | -0.6% | -0.4% | -0.6% | -0.6% | -0.4% | -0.3% |
| **Overall** | **-0.75%** | **-0.54%** | **-0.46%** | **-0.76%** | **-0.78%** | **-0.77%** | **-0.73%** | **-0.48%** | **-0.45%** |
|  | -0.7% | -0.5% | -0.4% | -0.8% | -0.8% | -0.8% | -0.7% | -0.5% | -0.4% |
| Enc Time[%] | 105% | | | 105% | | | 106% | | |
| Dec Time[%] | 100% | | | 100% | | | 101% | | |
|  |  |  |  |  |  |  |  |  |  |
|  | **Random Access HE** | | | **Random Access LC** | | | **Random Access HE-10** | | |
|  | Y | U | V | Y | U | V | Y | U | V |
| Class A | -1.0% | 0.3% | 0.0% | -0.8% | -0.7% | -0.4% | -0.9% | 0.5% | 0.5% |
| Class B | -0.8% | -0.6% | -0.5% | -0.7% | -0.8% | -1.1% | -0.8% | -0.8% | -0.6% |
| Class C | -0.8% | -0.6% | -0.4% | -0.7% | -1.0% | -0.8% | -0.7% | -0.5% | -0.6% |
| Class D | -0.7% | -0.5% | -0.1% | -0.7% | -0.6% | -0.8% | -0.7% | -0.8% | -0.3% |
| Class E |  |  |  |  |  |  |  |  |  |
| Class F | -0.6% | -0.4% | -0.4% | -0.5% | -0.7% | -0.6% | -0.4% | -0.4% | -0.1% |
| Overall | **-0.77%** | **-0.39%** | **-0.28%** | **-0.68%** | **-0.76%** | **-0.76%** | **-0.70%** | **-0.42%** | **-0.25%** |
|  | -0.8% | -0.4% | -0.3% | -0.7% | -0.8% | -0.8% | -0.7% | -0.4% | -0.2% |
| Enc Time[%] | 103% | | | 102% | | | 103% | | |
| Dec Time[%] | 100% | | | 101% | | | 100% | | |
|  |  |  |  |  |  |  |  |  |  |
|  | **Low delay B HE** | | | **Low delay B LC** | | | **Low delay B HE-10** | | |
|  | Y | U | V | Y | U | V | Y | U | V |
| Class A |  |  |  |  |  |  |  |  |  |
| Class B | -0.8% | -0.6% | -0.4% | -0.8% | -1.1% | -0.5% | -0.7% | -0.7% | -0.5% |
| Class C | -0.7% | -0.9% | -0.4% | -0.8% | -0.9% | -1.0% | -0.8% | -0.7% | -0.4% |
| Class D | -0.7% | -0.7% | -1.0% | -0.8% | -0.9% | -1.7% | -0.8% | -1.1% | -0.9% |
| Class E | -0.7% | -1.6% | -1.3% | -0.6% | -1.1% | -1.2% | -0.8% | -2.2% | -0.6% |
| Class F | -0.7% | -0.8% | -0.5% | -0.6% | -1.8% | -1.3% | -0.7% | -0.3% | -0.2% |
| **Overall** | **-0.72%** | **-0.85%** | **-0.68%** | **-0.71%** | **-1.16%** | **-1.09%** | **-0.75%** | **-0.93%** | **-0.53%** |
|  | -0.7% | -0.9% | -0.7% | -0.7% | -1.1% | -1.0% | -0.8% | -0.8% | -0.5% |
| Enc Time[%] | 102% | | | 102% | | | 102% | | |
| Dec Time[%] | 100% | | | 102% | | | 100% | | |
|  |  |  |  |  |  |  |  |  |  |
|  | **Low delay P HE** | | | **Low delay P LC** | | | **Low delay P HE-10** | | |
|  | Y | U | V | Y | U | V | Y | U | V |
| Class A |  |  |  |  |  |  |  |  |  |
| Class B | -0.8% | -0.4% | -0.4% | -0.7% | -0.2% | -0.6% | -0.8% | -0.5% | -0.4% |
| Class C | -0.7% | -0.6% | -0.6% | -0.8% | -0.7% | -0.5% | -0.9% | -0.7% | -0.6% |
| Class D | -0.8% | -0.5% | -1.3% | -0.8% | -1.1% | -0.3% | -0.8% | -1.1% | -0.6% |
| Class E | -0.7% | -0.7% | -1.1% | -0.6% | -0.6% | -2.0% | -0.8% | -1.2% | -1.2% |
| Class F | -0.5% | -0.1% | 0.2% | -0.4% | -1.4% | -0.6% | -0.7% | -0.3% | 0.0% |
| **Overall** | **-0.72%** | **-0.43%** | **-0.60%** | **-0.67%** | **-0.78%** | **-0.73%** | **-0.79%** | **-0.71%** | **-0.54%** |
|  | -0.7% | -0.4% | -0.6% | -0.7% | -0.8% | -0.8% | -0.8% | -0.7% | -0.5% |
| Enc Time[%] | 103% | | | 103% | | | 103% | | |
| Dec Time[%] | 100% | | | 102% | | | 100% | | |

Table 4. Performance test results for Method 3: multi-parameter conditional probability estimation with proposed initialization.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra HE** | | | **All Intra LC** | | | **All Intra HE-10** | | |
|  | Y | U | V | Y | U | V | Y | U | V |
| Class A | -0.9% | 0.0% | -0.2% | -0.9% | -0.7% | -0.8% | -0.9% | -0.2% | -0.5% |
| Class B | -0.9% | -0.8% | -0.9% | -0.9% | -0.9% | -1.0% | -0.9% | -0.8% | -0.8% |
| Class C | -0.9% | -0.9% | -0.9% | -0.9% | -0.9% | -1.0% | -0.8% | -0.8% | -0.9% |
| Class D | -0.8% | -0.4% | -0.5% | -0.8% | -0.8% | -0.9% | -0.8% | -0.5% | -0.5% |
| Class E | -0.8% | -0.6% | -0.6% | -0.9% | -0.9% | -0.9% | -0.8% | -0.5% | -0.6% |
| Class F | -0.8% | -0.8% | -0.7% | -0.9% | -0.7% | -1.0% | -0.8% | -0.7% | -0.7% |
| **Overall** | **-0.86%** | **-0.59%** | **-0.65%** | **-0.89%** | **-0.85%** | **-0.92%** | **-0.85%** | **-0.60%** | **-0.68%** |
|  | -0.9% | -0.6% | -0.6% | -0.9% | -0.8% | -0.9% | -0.8% | -0.6% | -0.7% |
| Enc Time[%] | 108% | | | 111% | | | 108% | | |
| Dec Time[%] | 102% | | | 103% | | | 102% | | |
|  |  |  |  |  |  |  |  |  |  |
|  | **Random Access HE** | | | **Random Access LC** | | | **Random Access HE-10** | | |
|  | Y | U | V | Y | U | V | Y | U | V |
| Class A | -1.1% | 0.2% | 0.2% | -0.9% | -0.4% | -0.5% | -1.0% | 0.8% | 0.2% |
| Class B | -0.9% | -0.6% | -0.7% | -0.9% | -0.8% | -1.1% | -0.9% | -0.7% | -0.8% |
| Class C | -0.9% | -0.8% | -0.5% | -0.8% | -1.0% | -1.2% | -0.8% | -0.7% | -0.7% |
| Class D | -0.8% | -0.7% | -0.5% | -0.8% | -0.8% | -1.0% | -0.8% | -0.6% | -0.5% |
| Class E |  |  |  |  |  |  |  |  |  |
| Class F | -0.92% | -0.72% | -0.61% | -0.89% | -0.95% | -0.92% | -0.77% | -0.61% | -0.39% |
| Overall | **-0.93%** | **-0.52%** | **-0.42%** | **-0.87%** | **-0.78%** | **-0.94%** | **-0.86%** | **-0.37%** | **-0.46%** |
|  | -0.9% | -0.5% | -0.4% | -0.9% | -0.8% | -0.9% | -0.9% | -0.3% | -0.5% |
| Enc Time[%] | 103% | | | 104% | | | 104% | | |
| Dec Time[%] | 101% | | | 101% | | | 101% | | |
|  |  |  |  |  |  |  |  |  |  |
|  | **Low delay B HE** | | | **Low delay B LC** | | | **Low delay B HE-10** | | |
|  | Y | U | V | Y | U | V | Y | U | V |
| Class A |  |  |  |  |  |  |  |  |  |
| Class B | -0.8% | -0.6% | -0.3% | -0.9% | -0.8% | -0.4% | -0.8% | -0.8% | -0.3% |
| Class C | -0.8% | -0.9% | -0.7% | -0.9% | -0.8% | -1.1% | -0.8% | -1.0% | -0.5% |
| Class D | -0.8% | -1.1% | -0.8% | -0.7% | -0.4% | -1.0% | -0.8% | -0.8% | -0.4% |
| Class E | -0.7% | -1.1% | -1.1% | -0.7% | -1.0% | -0.6% | -0.8% | -2.1% | -1.4% |
| Class F | -1.1% | -1.2% | -0.8% | -0.8% | -1.2% | -1.0% | -0.9% | -0.5% | -0.9% |
| **Overall** | **-0.85%** | **-0.95%** | **-0.70%** | **-0.80%** | **-0.86%** | **-0.82%** | **-0.83%** | **-0.98%** | **-0.65%** |
|  | -0.9% | -1.0% | -0.7% | -0.8% | -0.9% | -0.8% | -0.8% | -1.0% | -0.7% |
| Enc Time[%] | 104% | | | 104% | | | 104% | | |
| Dec Time[%] | 101% | | | 102% | | | 101% | | |
|  |  |  |  |  |  |  |  |  |  |
|  | **Low delay P HE** | | | **Low delay P LC** | | | **Low delay P HE-10** | | |
|  | Y | U | V | Y | U | V | Y | U | V |
| Class A |  |  |  |  |  |  |  |  |  |
| Class B | -0.9% | -0.4% | -0.5% | -0.8% | -0.1% | -0.8% | -0.9% | -0.3% | -0.4% |
| Class C | -0.9% | -0.6% | -0.5% | -0.9% | -0.8% | -1.0% | -0.9% | -0.7% | -0.7% |
| Class D | -0.9% | -0.5% | -1.1% | -0.8% | -1.3% | -0.5% | -0.8% | -1.2% | 0.3% |
| Class E | -0.6% | -0.5% | -1.4% | -0.7% | -0.7% | -1.4% | -0.8% | -1.6% | -1.2% |
| Class F | -0.9% | -0.5% | -0.2% | -0.7% | -1.7% | -1.1% | -1.0% | -0.8% | -0.7% |
| **Overall** | **-0.83%** | **-0.51%** | **-0.69%** | **-0.79%** | **-0.88%** | **-0.94%** | **-0.91%** | **-0.85%** | **-0.50%** |
|  | -0.8% | -0.5% | -0.7% | -0.8% | -1.0% | -0.9% | -0.9% | -0.9% | -0.6% |
| Enc Time[%] | 106% | | | 106% | | | 105% | | |
| Dec Time[%] | 101% | | | 103% | | | 101% | | |