

Title: Improved low complexity entropy coding for transform coefficients
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Author(s) or Contact(s): Gisle Bjontegaard
Telenor Plus
P.O.Box 6914 St.Olavs plass
N-0130 Oslo, Norway
Tel: +47 23 13 83 81
Email: gisle.bjontegaard@telenor.com
gisleb@real.com
Source: RealNetworks, Inc.

1 Background

TML specifies two different ways of entropy coding:

- Use of one single VLC (UVLC) for all parameters. This has a reasonably good performance and is considered to have low implementation complexity
- CABAC (Context-based Adaptive Binary Arithmetic Coding). This method represents considerable coding gain (typically in the range (5-10)% reported in VCEG-O42). However, it is also significantly more complex

It is assumed that it is within the scope of H.26L to define different entropy coding methods to serve different applications and needs. One low complexity and one high efficiency entropy coding method therefore seems to be a good solution.

The present paper proposes to replace the low complexity method (UVLC). The described method represents improved coding gain. At the same time the complexity is still low - it is in many ways similar to the UVLC coding.

We are in the process of implementing the coding method in the TML software. Unfortunately this will not be ready before this meeting. It can be made available sometimes between the Geneva and Fairfax meetings. However, considering that we are late in the standardization process we have decided to present results based on a different version of TML software which is very similar to the official TML software. CABAC is not implemented in this software. That is why the TML software is used for comparison between UVLC and CABAC entropy coding in section 3

2 Description of the method

The method is used for luma coefficients only. The rest of the parameters are still UVLC coded. The basic idea is to make the method more self adaptive and hence more efficient. An overview of the method will be given below.

Coding of coefficients in an 8x8 block

Coding of CBP stays unchanged. Let us consider the coding of an 8x8 block as depicted below. If the CBP indicate 'no coefficients for the 8x8 block', no more information is needed.

a	b
c	d

UVLC coding:

If CBP indicates that there are coefficients in the 8x8 block, UVLC coding sends information connected to each of the 4x4 blocks **a,b,c,d**. If some of the 4x4 blocks contain no coefficients, only EOB is produced - that is 1 bit in case of single scan, 2 bits in case of double scan.

Proposed method:

The proposed method uses only single scan. Three elements are used to code the 8x8 block:

1:

One bit each for **a,b,c,d** to indicate if there are coefficients or not.

2:

If there are coefficients (signalled by the 1 bit above), the number of coefficients is coded.

3:

Lastly the combinations of (Run, Level) are coded for each coefficient. The VLCs for this purpose are similar to the UVLC. No codeword for EOB is needed since the number of coefficients is already known.

2.1 Adaptivity

Additional adaptivity is included with the coding of number-of-coefficients and (Run,Level) coding.

2.1.1 Number-of-coefficients (NumCof)

Code tables of 16 codewords are used. Different tables are used depending on:

- How many of the 4x4 blocks **a,b,c,d** have coefficients and (M)
- How many coefficients the last coded 4x4 block had (N)

There are 4 different VLCs with the following bit assignments:

Number of coefficients in a 4x4 block:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Bits to signal NumCof with VLC 1:	6	1	2	3	4	5	7	8	9	10	11	12	13	14	15	15
Bits to signal NumCof with VLC 2:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	15
Bits to signal NumCof with VLC 3:	2	2	3	3	4	4	5	5	6	6	7	7	8	8	8	8
Bits to signal NumCof with VLC 4:	4	3	3	3	3	4	4	4	4	5	5	5	5	5	6	6

The rule for assignment of VLC table:

VLC1: M = 1 (for intra MBs VLC2 is used instead)
VLC2: M = 2 or M > 2 and N < 3
VLC3: M > 2 and (N = 3 or N = 4)
VLC4: M > 2 and N > 4

VLC1 uses 6 bits to signal 1 coefficient. The reason for this long codeword is that "Elimination of single coefficients in inter macroblocks" is applied (I.3 of TML-9). As a result, 1 coefficient in an 8x8 block is a rare event.

2.1.2 (Run,Level) coding

4 different 2D-VLCs are used. Moreover, the (Run,Level)s are coded in reverse order - starting from the last event. The reason for this is that the statistics for the last (Run,Level) is more consistent than the first one. If there is more than one coefficient in a block, switching between VLCs take place like this:

- Start with the VLC defined for the last coefficient (see below)
- If Level > 1 increase the number of the VLC table by 1 (clipped to the number of the highest VLC)

The 4 VLC tables represent:

1. The case where there is only one coefficient in a 4x4 block
2. The last (Run,Level) in blocks with more than 1 coefficient
3. The VLC number has been increased by 1 (see above)
4. The VLC number has been increased by more than 1 (see above)

2.2 Structure of the 2D-VLCs for (Run, Level) coding

The VLC tables are designed much in the same way as the UVLC. Low complexity and minimum memory requirement has been kept in mind when designing the tables. To illustrate how the tables are designed, the bit assignments of the lower parts the 4 tables are shown below. The red numbers indicate short code tables tailored to match the symbol statistics for the different tables. As part of this code table there is a 5-bit escape code (the same for all 4 code tables). All the remaining codewords are constructed similar to the UVLC:

```

1   y2 y1 y0
0 x0 1   y2 y1 y0
0 x1 0 x0 1   y2 y1 y0
0 x2 0 x1 0 x0 1   y2 y1 y0
0 x3 0 x2 0 x1 0 x0 1   y2 y1 y0
.....

```

Y₀ is used as the sign bit. Combined with the 5 bit escape code, this means that there are 8 9-bit words to represent 4 different levels, 16 11-bit words to represent 8 different levels etc. The codewords are filled into the 4 different 2D-VLC tables below in a similar way to the one defined in Table 5 of TML-9.

Example

I will try to make this clear with an example from the first bit assignment table below. Notice that at present this is just an example and little effort has been put into the real design of codewords. The relevant issue here is the number of bits which determines coding performance.

The red entries in the first table may have codewords ('s' is sign bit):

Run	Level	Codeword
0	1	1 s
1	1	0 1 1 s
2	1	0 1 0 s
0	2	0 0 1 1 1 s
3	1	0 0 1 1 0 s
4	1	0 0 1 0 1 s
5	1	0 0 1 0 0 s
6	1	0 0 0 1 1 1 s
7	1	0 0 0 1 1 0 s
8	1	0 0 0 1 0 1 s

9	1	000100s
0	3	0000111s
10	1	0000110s
11	1	0000101s
12	1	0000100s
Escape		00000

The remaining entries in the table are constructed in the following way:

Run	Level	Escape	'UVLC-part'	y ₂ y ₁ y ₀	Number of bits
1	2	00000	1	0 0 s	9
2	2	00000	1	0 1 s	9
13	1	00000	1	1 0 s	9
14	1	00000	1	1 1 s	9
0	4	00000	001	0 0 s	11
0	5	00000	001	0 1 s	11
etc...					

		L	E	V	E	L													
	R	2	6	8	11	11	13	15	15	17	17	17	17	19	19	19	19		
	4	9	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19		
	4	9	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19		
	U	6	11	13	15	15	17	17	17	19	19	19	19	19	19	19	19		
	6	11	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19		
	N	6	11	13	15	15	17	17	17	19	19	19	19	19	19	19	19		
	7	11	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19		
	7	11	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19		
	7	11	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19		
	7	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19		
	8	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19		
	8	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19		
	8	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19		
	9	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19		
	9	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19		
	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19	21		

		L	E	V	E	L													
	R	3	6	8	9	11	13	15	15	17	17	17	19	19	19	19	19		
	4	8	11	13	15	15	17	17	17	19	19	19	19	19	19	19	19		
	4	8	11	13	15	15	17	17	17	19	19	19	19	19	19	19	19		
	U	4	9	13	15	15	17	17	17	19	19	19	19	19	19	19	19		
	4	9	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19		
	N	5	11	13	15	15	17	17	17	19	19	19	19	19	19	19	19		
	5	11	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19		
	6	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19		
	8	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19		
	8	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19		
	9	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19		
	11	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19		
	11	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19		
	11	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19		
	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19	21		
	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19	21		

		L	E	V	E	L													
	R	2	5	7	8	9	11	13	15	15	17	17	17	19	19	19	19		
	4	6	9	11	13	15	15	17	17	17	17	19	19	19	19	19	19		
	5	7	11	13	15	15	17	17	17	17	19	19	19	19	19	19	19		
	U	5	8	11	13	15	15	17	17	17	19	19	19	19	19	19	19		
	6	9	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19		
	N	6	11	13	15	15	17	17	17	19	19	19	19	19	19	19	19		
	8	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19		
	8	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19		
	9	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19		
	11	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19		
	11	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19		
	11	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19		
	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19	21		
	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19	21		
	13	15	15	17	17	19	19	19	19	19	19	19	19	21	21	21	21		
	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19	21		

		L	E	V	E	L													
	R	3	4	4	5	6	6	7	8	8	9	11	11	11	13	15	15		
	4	5	6	8	9	11	13	15	15	17	17	17	17	19	19	19	19		
	6	7	9	11	13	15	15	17	17	17	17	19	19	19	19	19	19		
	U	6	9	11	13	15	15	17	17	17	17	19	19	19	19	19	19		
	8	11	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19		
	N	11	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19		
	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19	21		
	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19	21		
	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19	21		
	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19	21		
	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19	21		
	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19	21		
	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19	21		
	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19	21		
	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19	21		
	13	15	15	17	17	17	17	19	19	19	19	19	19	19	19	19	21		

3 Simulation results

Simulations were run on the set of seven test sequences. Simulations were run using UVLC coefficient coding as well as the proposed method. Since only the entropy coding is different in the two cases, PSNRs are the same whereas bitrates differ. **Figure 1** and **Figure 2** show the bitrate reductions (positive values means reduced bitrate) for QPs in the range 10 to 28 for the different sequences. **Figure 1** includes whole sequences I,P coded, whereas

Figure 2 represent only the first frames in each sequence (Intra coding only).

Figure 3 and Figure 4 show similar comparisons using the TML software with UVLC and CABAC entropy coding. RDOptimization was turned off to be in line with the other simulations. This seemed to have little effect on comparison between UVLC and CABAC.

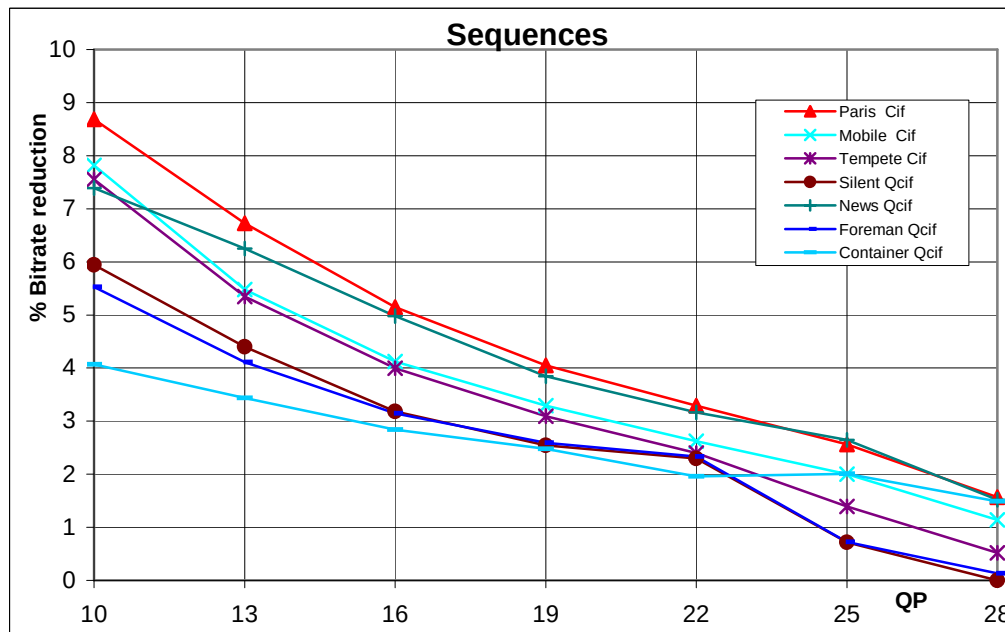


Figure 1 Comparison between the proposed method and UVLC coding of luma coefficients for sequences

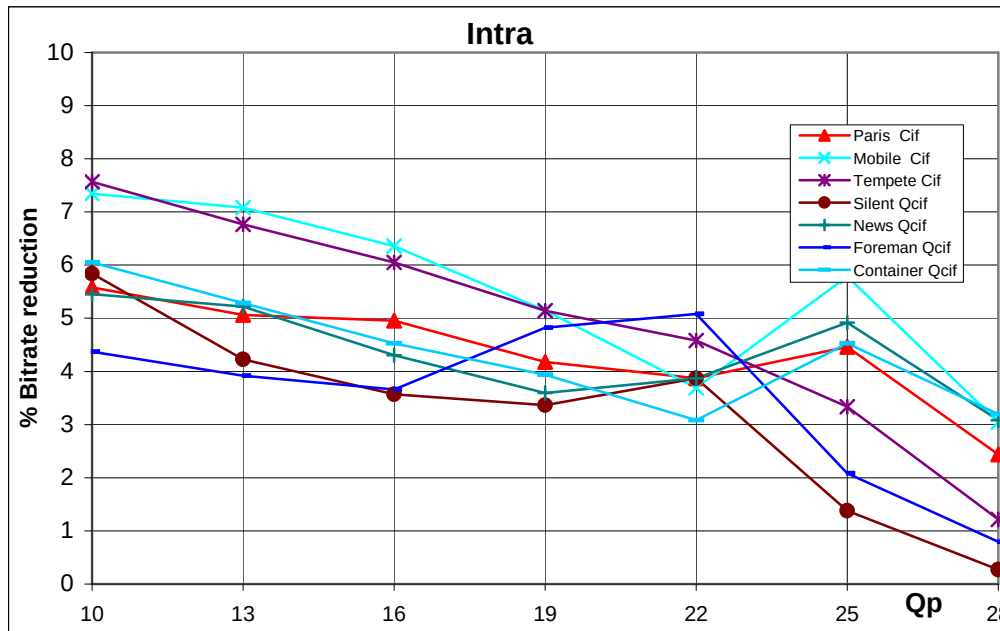


Figure 2 Comparison between the proposed method and UVLC coding of luma coefficients for first pictures (Intra)

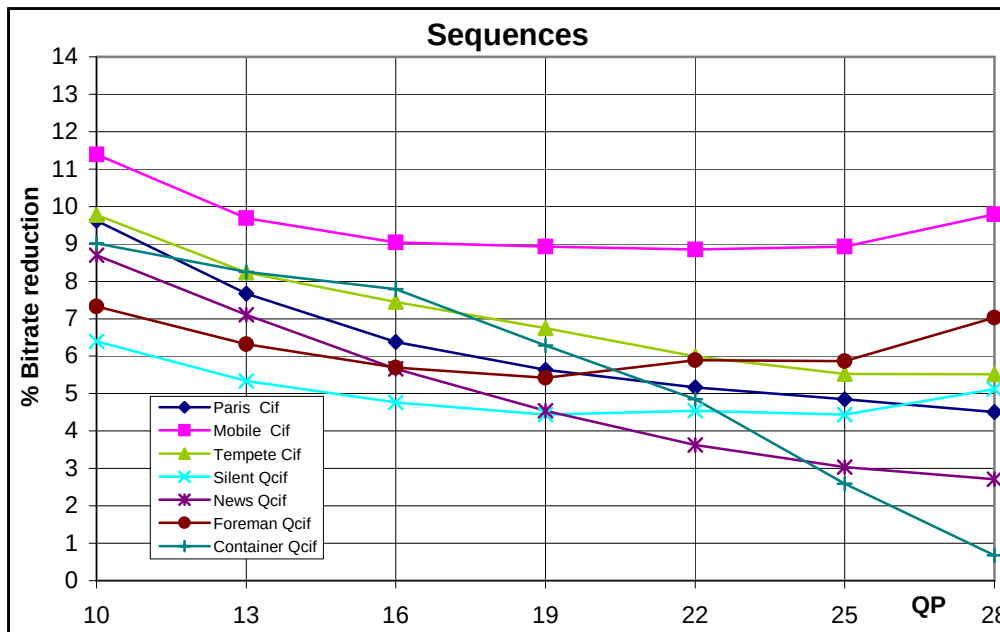


Figure 3 Comparisons using the TML software with UVLC and CABAC entropy coding for sequences

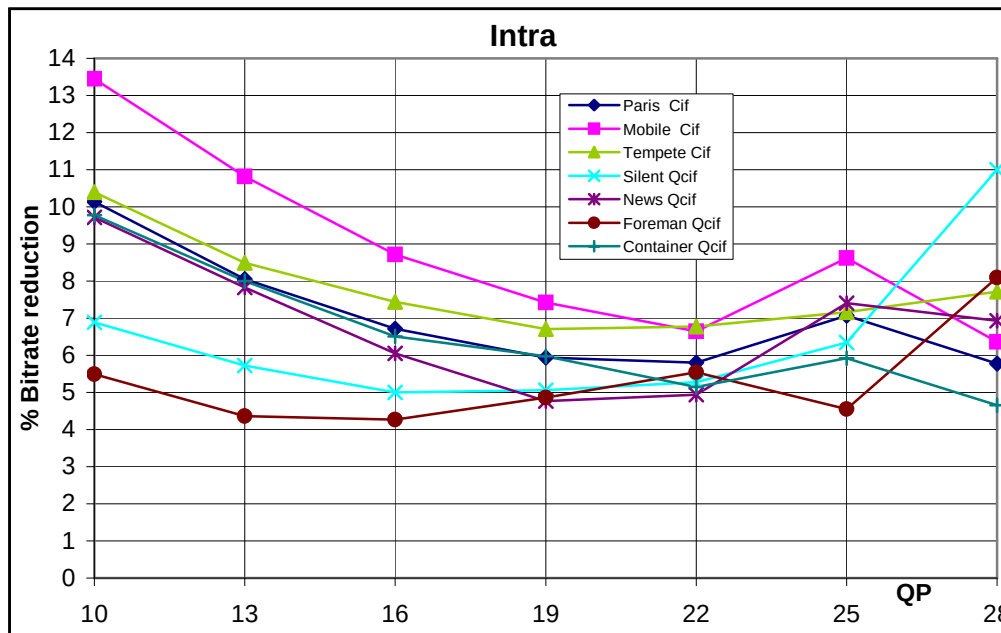


Figure 4 Comparisons using the TML software with UVLC and CABAC entropy coding for first pictures (Intra)

4 Conclusions

A low complexity entropy coding of transform coefficients is described. The performance of the new method is significantly better than UVLC - especially for low QP values. At the same time the performance is not as good as for CABAC. It is proposed that the presented method is considered for replacement of the UVLC method of transform coefficient coding.

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For purposes of this contribution, the terms of 2.2.1 above [and as detailed in document VCEG-O54 submitted by Gary Sullivan] are agreed to only as required to implement a “baseline” JVT video profile.