|  |  |
| --- | --- |
| **Joint Collaborative Team on Video Coding (JCT-VC)**  **of ITU-T SG16 WP3 and ISO/IEC JTC1/SC29/WG11**  4th Meeting: Daegu, KR, 20-28 January, 2011 | Document: JCTVC-D060  WG11 Number: m18807 |

|  |  |  |  |
| --- | --- | --- | --- |
| *Title:* | Evaluation results on Residual Quad Tree (RQT) | | |
| *Status:* | Input Document to JCT-VC | | |
| *Purpose:* | Request for Study | | |
| *Author(s) or Contact(s):* | Minhua Zhou Texas Instruments Inc., USA  Ali Tabatabai Sony Electronics USA | Tel: Email:  Tel: Email: | +1-214-480-3816 [zhou@ti.com](mailto:zhou@ti.com)  +1 408-352 - 4715 [ali.tabatabai@am.sony.com](mailto:ali.tabatabai@am.sony.com) |
| *Source:* | Texas Instruments Inc. Sony Electronics | | |

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

# Abstract

This document reports the evaluation results of the residual quadtree (RQT) adopted in the first version of HEVC test model (HM1). When compared to two-level method used in TMuC-0.7, the RQT provides marginal gain only in the luma component of high efficiency configurations, but leads to loss in other configurations, especially in the chroma component parts in which the significant loss is observed. The RQT performance with respect to encoder complexity is also investigated in this report. It is concluded that the current RQT design needs further improvement given both the complexity and coding efficiency performances tested and verified, and recommended to set up an ad-hoc group for the development of improved TU tree representation methods which would simply both the encoder and decoder design.

# Introduction

In the first version of the HEVC test model (HM1), residual quad tree (RQT) [1] was adopted for the purpose of coding efficiency improvement. The RQT is an independent tree which signals the transform unit (TU) partitioning structure for each coding unit (CU). On the encoder side, it requires separate RDO processing to determine the optimal TU tree structure. The RQT is very challenging for the encoder design from the computational complexity and throughput point of view.

**split\_transform\_flag**

**QT CBF U**

**QT CBF V**

**Root CBF (one flag for YUV)**

**QT CBF Y**

**QT CBF U, QT CBF V (conditional)**

**split\_transform\_flag**

**INTRA**

**INTER**

**QT CBF Y, QT CBF U, QT CBF V**

**Figure 1 Diagram of Residual Quad Tree (RQT) for intra and inter coded CU**

Figure 1 depicts the diagram of RQT based on our understanding of the TMuC0.9 software. For an Intra-coded CU, the RQT consists of recursive **split\_transform\_flags** followed by the leaf QT CBF flags**.**  The TU size cannot be larger than PU size and cannot go across PU boundaries; For an inter-coded CU, the RQT is made up of a root CBPF flag, recursive **split\_transform\_flags** and **chroma CBF flags** followed by the leaf CBF flags**.** Here the TU tree is totally independent of the PU partitioning tree, the TU size can be larger than the PU size and can go across PU boundaries.

In this document the coding performance of the RQT is compared against the TMuC-0.7 two-level method by using the TMuC0.9 software. Also analyzed is the RQT performance with respect to the encoder complexity by turning off the RQT inter-frame speedup in the TMuc0.9 software, and by decreasing the maximum RQT TU depths allowed for intra and inter CUs.

# Test Conditions

The TMuC0.9 software is used for the evaluation, the common test conditions and reference configurations specified in [2] are followed. The simulation platform used by Texas Instruments is LSF equipped with Intel(R) Xeon(R) CPU X5570@2.93GHz 64 bits Linux machines. The simulation platform used by SONY for HE was on Intel Core i7 965 @ 3.2Ghz, 4 cores and 12GB RAM. The LC experiments were run on Intel Core i7 940 @ 2.93Ghz, 4 cores and 6GB RAM.

The TMuC0.9 software is configured into the following three settings:

1. RQT on **with** inter-frame speed up: use the TMuC0.9 software as is
2. Set the following macros in typeDef.h to zero to switch on TMuC-0.7 two-level method and disable RQT in TMuC0.9 software, i.e.

**#define HHI\_RQT 0**

**#define HHI\_RQT\_INTRA 0**

**#define HHI\_RQT\_ROOT 0**

**And**

**MaxTrSize : 32**

is added to the configuration files to disable 64x64 transform

1. RQT on **without** inter-frame speed up: in TEncCu.cpp of TMuC0.9 software, replace

**#if 1 // speedup for inter frames**

With

**#if 0 // speedup for inter frames**

# Test Results

## Performance comparison of RQT with inter-frame speedup against TMuC-0.7 two-level method

As shown in the table 1 below, for HE cases RQT shows marginal performance (0.1 ~ 0.5%) improvement in Luma, in all other cases turning on the RQT actually leads to quality loss, ranging from 0.3% (in low-delay and intra LoCo configurations) to 0.9% (in low delay LoCo). It is worth to notice that the RQT is causing quality loss in chroma components of almost all the configurations.

However, RQT with inter-frame speedup appears to be faster than TMuC-0.7 method. For example, in Random access and low-delay configurations the RQT is about 10% faster.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Intra | | | Intra LoCo | | |
| Y BD-rate | U BD-rate | V BD-rate | Y BD-rate | U BD-rate | V BD-rate |
| Class A | 0.3 | 0.1 | -1.8 | -0.4 | -2.0 | -4.1 |
| Class B | 0.5 | -1.3 | -2.0 | -0.5 | -1.4 | -2.8 |
| Class C | 0.6 | -0.6 | -1.1 | -0.2 | -1.7 | -2.2 |
| Class D | 0.3 | -0.7 | -0.9 | -0.1 | -2.1 | -2.2 |
| Class E | 0.6 | -2.7 | -2.2 | -0.2 | -7.8 | -5.8 |
| All | 0.5 | -1.1 | -1.6 | -0.3 | -2.8 | -3.2 |
| Enc Time[%] | 97% | | | 108% | | |
| Dec Time[%] | 94% | | | 93% | | |
|  |  |  |  |  |  |  |
|  |  | Random access |  |  | Random access LoCo |  |
| Y BD-rate | U BD-rate | V BD-rate | Y BD-rate | U BD-rate | V BD-rate |
| Class A | 0.1 | 1.1 | -1.7 | -0.7 | -0.5 | -2.2 |
| Class B | 0.5 | -0.7 | -2.4 | -0.6 | 0.1 | -0.5 |
| Class C | 0.3 | -0.5 | -1.2 | -0.5 | -0.1 | -0.4 |
| Class D | 0.3 | -0.3 | -0.6 | -0.5 | -0.3 | -0.2 |
| Class E |  |  |  |  |  |  |
| All | 0.4 | -0.3 | -1.5 | -0.6 | -0.1 | -0.6 |
| Enc Time[%] | 111% | | | 129% | | |
| Dec Time[%] | 95% | | | 97% | | |
|  |  |  |  |  |  |  |
|  | Low delay | | | Low delay LoCo | | |
|  | Y BD-rate | U BD-rate | V BD-rate | Y BD-rate | U BD-rate | V BD-rate |
| Class A |  |  |  |  |  |  |
| Class B | 0.3 | 0.9 | -2.3 | -1.1 | 0.2 | 0.8 |
| Class C | 0.0 | -0.4 | -2.0 | -1.0 | 0.0 | 0.4 |
| Class D | 0.0 | -0.8 | -1.4 | -1.1 | 0.3 | -0.4 |
| Class E | 0.1 | -3.5 | -3.1 | -0.4 | -2.1 | -1.1 |
| All | 0.1 | -0.7 | -2.1 | -0.9 | -0.3 | 0.1 |
| Enc Time[%] | 110% | | | 123% | | |
| Dec Time[%] | 99% | | | 100% | | |

**Table 1 Comparison results (TMuC-0.9 RQT w/ inter-frame speedup vs. TMuC-0.7 two-level method)**

Texas Instruments and SONY have both run the simulation for the tests of this section, and got identical results for the performance comparison between the RQT and TMuC-0.7 two-level method. (see TMuC0.9-anchor\_vs.TMuC0.7TwoLevel.xls from Texas Instruments and TMuC0.9-anchor-xcheck-v4-SONY.xls)

## Performance comparison of RQT without inter-frame speedup against TMuC-0.7 two-level method

As shown in the table 2 below, when the RQT inter-frame speedup is turned off, the RQT performance is improved. The gain for HE luma components are increased from 0.1% - 0.5% (see Table 1) to 0.4% - 0.6% (Table 2) when compared to the TMuC0.7 method. Loss is still observed for LOCO configurations, ranging from 0.3% (in intra LoCo) to 0.7% (in low delay LoCo). Loss in chroma components has been reduced, but significant loss in chroma component is still seen in high-efficiency configurations.

With the inter-frame speedup turned off, the RQT runs slower than TMuC-0.7 method for random access and low-delay configurations by 5 – 7%. Detailed results are provided in TMuC0.9-anchorNoInterSpeedup\_vs.TMuC0.7TwoLevel.xls.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Intra | | | Intra LoCo | | |
| Y BD-rate | U BD-rate | V BD-rate | Y BD-rate | U BD-rate | V BD-rate |
| Class A | 0.3 | 0.1 | -1.8 | -0.4 | -2.0 | -4.1 |
| Class B | 0.5 | -1.3 | -2.0 | -0.5 | -1.4 | -2.8 |
| Class C | 0.6 | -0.6 | -1.1 | -0.2 | -1.7 | -2.2 |
| Class D | 0.3 | -0.7 | -0.9 | -0.1 | -2.1 | -2.2 |
| Class E | 0.6 | -2.7 | -2.2 | -0.2 | -7.8 | -5.8 |
| All | 0.5 | -1.1 | -1.6 | -0.3 | -2.8 | -3.2 |
| Enc Time[%] | 99% | | | 108% | | |
| Dec Time[%] | 97% | | | 93% | | |
|  |  |  |  |  |  |  |
|  |  | Random access |  |  | Random access LoCo |  |
| Y BD-rate | U BD-rate | V BD-rate | Y BD-rate | U BD-rate | V BD-rate |
| Class A | 0.6 | 0.3 | -2.3 | -0.4 | -0.7 | -2.2 |
| Class B | 0.7 | -0.6 | -2.3 | -0.5 | 0.4 | -0.2 |
| Class C | 0.6 | 0.1 | -0.7 | -0.4 | 0.2 | 0.0 |
| Class D | 0.5 | -0.2 | -0.3 | -0.4 | 0.1 | 0.0 |
| Class E |  |  |  |  |  |  |
| All | 0.6 | -0.2 | -1.4 | -0.4 | 0.1 | -0.3 |
| Enc Time[%] | 93% | | | 108% | | |
| Dec Time[%] | 97% | | | 93% | | |
|  |  |  |  |  |  |  |
|  | Low delay | | | Low delay LoCo | | |
|  | Y BD-rate | U BD-rate | V BD-rate | Y BD-rate | U BD-rate | V BD-rate |
| Class A |  |  |  |  |  |  |
| Class B | 0.5 | 1.8 | -1.2 | -0.9 | 1.0 | 1.7 |
| Class C | 0.5 | 0.6 | -0.9 | -0.7 | 0.9 | 1.3 |
| Class D | 0.3 | 0.2 | -0.2 | -0.8 | 1.3 | 0.8 |
| Class E | 0.4 | -2.9 | -2.5 | -0.1 | -1.6 | -0.5 |
| All | 0.4 | 0.2 | -1.1 | -0.7 | 0.6 | 0.9 |
| Enc Time[%] | 95% | | | 107% | | |
| Dec Time[%] | 100% | | | 98% | | |

**Table 2 Comparison results (TMuC-0.9 RQT w/o inter-frame speedup vs. TMuC-0.7 two-level method)**

## Performance comparison of RQT with inter-frame speedup w.r.t RQT TU depth

The following two settings are tested for the high efficiency configurations against TMuC0.9 anchor which has

**QuadtreeTUMaxDepthInter : 3**

**QuadtreeTUMaxDepthIntra : 3**

The first setting is (setting 1)

**QuadtreeTUMaxDepthInter : 2**

**QuadtreeTUMaxDepthIntra : 2**

and the second setting is (setting 2)

**QuadtreeTUMaxDepthInter : 2**

**QuadtreeTUMaxDepthIntra : 1**

It has been observed that setting both **QuadtreeTUMaxDepthInter** and **QuadtreeTUMaxDepthIntra** to 1 in the high efficiency configurations leads to the same result as that of setting 2.

As shown in Table 3 below, reducing the RQT maximum TU depth (encoder complexity) leads to quality loss. When compared to TMuC0.9 anchor the loss is around 0.2% to 0.3% for setting 1, and 0.3% to 0.6% for setting 2, respectively. Detailed results are provided in TMuC0.9-anchor\_vs.RQTDepth22.xls and TMuC0.9-anchor\_vs.RQTDepth21.xls.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **QuadtreeTUMaxDepthInter : 2**  **QuadtreeTUMaxDepthIntra : 2** | | | ***QuadtreeTUMaxDepthInter : 2***  ***QuadtreeTUMaxDepthIntra : 1*** | | |
| Intra | | | *Intra* | | |
| Y BD-rate | U BD-rate | V BD-rate | Y BD-rate | U BD-rate | *V BD-rate* |
| Class A | 0.2 | 0.2 | 0.2 | 0.5 | 0.4 | *0.3* |
| Class B | 0.3 | 0.2 | 0.2 | 0.6 | 0.4 | *0.4* |
| Class C | 0.2 | 0.2 | 0.2 | 0.7 | 0.6 | *0.6* |
| Class D | 0.1 | 0.1 | 0.1 | 0.5 | 0.4 | *0.4* |
| Class E | 0.2 | 0.3 | 0.2 | 0.7 | 0.6 | *0.5* |
| All | 0.2 | 0.2 | 0.2 | 0.6 | 0.5 | *0.5* |
| Enc Time[%] | 94% | | | *88%* | | |
| Dec Time[%] | 100% | | | *100%* | | |
|  |  | Random access |  |  | Random access |  |
| Y BD-rate | U BD-rate | V BD-rate | Y BD-rate | U BD-rate | *V BD-rate* |
| Class A | 0.3 | 0.4 | 0.4 | 0.4 | 0.2 | *0.3* |
| Class B | 0.4 | 0.3 | 0.4 | 0.6 | 0.3 | *0.3* |
| Class C | 0.3 | 0.1 | 0.2 | 0.5 | 0.4 | *0.2* |
| Class D | 0.2 | 0.1 | 0.3 | 0.4 | 0.4 | *0.5* |
| Class E |  |  |  |  |  |  |
| All | 0.3 | 0.2 | 0.3 | 0.5 | 0.3 | *0.4* |
| Enc Time[%] | 86% | | | *86%* | | |
| Dec Time[%] | 101% | | | *100%* | | |
|  | Low delay | | | *Low delay* | | |
|  | Y BD-rate | U BD-rate | V BD-rate | Y BD-rate | U BD-rate | *V BD-rate* |
| Class A |  |  |  |  |  |  |
| Class B | 0.2 | 0.9 | 1.3 | 0.3 | 1.1 | *1.2* |
| Class C | 0.3 | 0.4 | 0.3 | 0.3 | 0.6 | *0.6* |
| Class D | 0.3 | 0.0 | 0.5 | 0.3 | -0.2 | *0.3* |
| Class E | 0.0 | -0.2 | -0.6 | 0.2 | 0.6 | *-0.5* |
| All | 0.2 | 0.3 | 0.5 | 0.3 | 0.5 | *0.5* |
| Enc Time[%] | 88% | | | *87%* | | |
| *Dec Time[%]* | *105%* | | | *101%* | | |

**Table 3 RQT results (w/ inter-frame speedup) w.r.t. maximum TU depth for the high efficiency configurations**

Results in Table 4 also reveal that the RQT leads to 0.1% to 0.2% loss in the luma compenent of HE configurations when the TU depth setting is same as the one in the low-complexity complexity settings. (i.e. 2 for inter and 1 for intra). Please refer to TMuC0.9-RQTDepth21\_vs.TMuC0.7TwoLevel.xls for detail.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Intra | | | Intra LoCo | | |
| Y BD-rate | U BD-rate | V BD-rate | Y BD-rate | U BD-rate | V BD-rate |
| Class A | -0.2 | -0.3 | -2.1 | -0.4 | -2.0 | -4.1 |
| Class B | -0.1 | -1.7 | -2.4 | -0.5 | -1.4 | -2.8 |
| Class C | -0.1 | -1.1 | -1.7 | -0.2 | -1.7 | -2.2 |
| Class D | -0.2 | -1.0 | -1.3 | -0.1 | -2.1 | -2.2 |
| Class E | -0.1 | -3.3 | -2.7 | -0.2 | -7.8 | -5.8 |
| All | -0.1 | -1.5 | -2.0 | -0.3 | -2.8 | -3.2 |
| Enc Time[%] | 111% | | | 108% | | |
| Dec Time[%] | 94% | | | 93% | | |
|  |  |  |  |  |  |  |
|  |  | Random access |  |  | Random access LoCo |  |
| Y BD-rate | U BD-rate | V BD-rate | Y BD-rate | U BD-rate | V BD-rate |
| Class A | -0.3 | 0.9 | -2.0 | -0.7 | -0.5 | -2.2 |
| Class B | 0.0 | -1.1 | -2.7 | -0.6 | 0.1 | -0.5 |
| Class C | -0.2 | -0.8 | -1.4 | -0.5 | -0.1 | -0.4 |
| Class D | 0.0 | -0.7 | -1.2 | -0.5 | -0.3 | -0.2 |
| Class E |  |  |  |  |  |  |
| All | -0.1 | -0.6 | -1.9 | -0.6 | -0.1 | -0.6 |
| Enc Time[%] | 130% | | | 129% | | |
| Dec Time[%] | 95% | | | 97% | | |
|  |  |  |  |  |  |  |
|  | Low delay | | | Low delay LoCo | | |
|  | Y BD-rate | U BD-rate | V BD-rate | Y BD-rate | U BD-rate | V BD-rate |
| Class A |  |  |  |  |  |  |
| Class B | 0.0 | -0.2 | -3.5 | -1.1 | 0.2 | 0.8 |
| Class C | -0.3 | -1.0 | -2.6 | -1.0 | 0.0 | 0.4 |
| Class D | -0.3 | -0.6 | -1.7 | -1.1 | 0.3 | -0.4 |
| Class E | 0.0 | -4.1 | -2.5 | -0.4 | -2.1 | -1.1 |
| All | -0.2 | -1.2 | -2.6 | -0.9 | -0.3 | 0.1 |
| Enc Time[%] | 126% | | | 123% | | |
| Dec Time[%] | 98% | | | 100% | | |

**Table 4 Comparison results (TMuC-0.9 RQT w/ inter-frame speedup and QuadtreeTUMaxDepthInter = 2 & QuadtreeTUMaxDepthIntra = 1 vs. TMuC-0.7 two-level method)**

# Conclusions

The results reveal that the current residual quad-tree segmentation and signaling needs further improvement given both the complexity and coding efficiency performances tested and verified. It is recommended to set up an ad-hoc group to investigate this issue, and come up with a better TU tree representation method which would simplify both the HEVC encoder and decoder design.

# References

1. T. Wiegand, etal. **“BoG report: residual quadtree structure”** JCTVC-C319, 3rd. JCT-VC Meeting, Guangzhou, CN, October 2010.
2. JCT-VC, “**Common test conditions and software reference configurations**”, JCTVC-C500, 3rd. JCT-VC Meeting, Guangzhou, CN, October 2010.