# A Low Complexity Prioritized Bit-plane Coding for SNR Scalability in MPEG-21 Scalable Video Coding

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## ABSTRACT

In this paper, we propose a low complexity prioritized bit-plane coding scheme to improve the rate-distortion performance of cyclical block coding in MPEG-21 scalable video coding. Specifically, we use a block priority assignment algorithm to firstly transmit the symbols and the blocks with potentially better rate-distortion performance. Different blocks are allowed to be coded unequally in a coding cycle. To avoid transmitting priority overhead, the encoder and the decoder refer to the same context to assign priority. Furthermore, to reduce the complexity, the priority assignment is done by a look-up-table and the coding of each block is controlled by a simple threshold comparison mechanism. Experimental results show that our prioritized bit-plane coding scheme can offer up to 0.5dB PSNR improvement over the cyclical block coding described in the joint scalable verification model (JSVM).

**Keywords:** Scalable video coding, bit-plane coding, fine granularity scalability, MPEG-21.

## 1. INTRODUCTION

To support clients with diverse capabilities in complexity, bandwidth, power and display resolution, the MPEG committee is defining a novel scalable video coding (SVC) framework[3,4] that can simultaneously support spatial, temporal and SNR scalabilities under the constraints of low complexity and low delay. SVC is an extension of the newly adopted H.264/AVC video standard[6]. Specifically, for spatial scalability, the input video is first decimated into various spatial resolutions and each spatial resolution sequence is then coded in a separated layer using H.264/AVC. Within each spatial layer, the hierarchical bi-directional prediction scheme (derived from motion compensated temporal filtering) is applied in every group of pictures to provide temporal scalability. In addition, to remove the redundancy among different spatial layers so as to increase the coding efficiency, the prediction residues of lower spatial resolution layers are used to predict the ones of higher resolution layers. The residual frames after the inter-layer prediction are then transformed and successively quantized for SNR scalability.

In the working draft 1.0 (WD1.0) of SVC[3], each successively quantized refinement layer is coded by a subband coding scheme to provide fine granular SNR scalability. Fig. 1 illustrates how the coding is performed in a refinement layer. The coding process is partitioned into the significant and refinement passes. The significant pass first encodes the insignificant coefficients which show zero values in the subordinate layers. After that, the refinement pass refines the remaining significant coefficients ranging from -1 to +1. Particularly, during the significant pass, the significant transform blocks including at least one significant coefficient are coded prior to those insignificant blocks. Typically, the significant blocks have more non-zero coefficients than the insignificant ones. Non-zero coefficients generally offer better rate-distortion performance. Thus, the block type classification and reordering is to have more non-zero coefficients be transmitted first so as to improve the rate-distortion performance. In addition, to offer more uniform update over the entire frame, the coding of each type of blocks is performed in a subband-by-subband manner.

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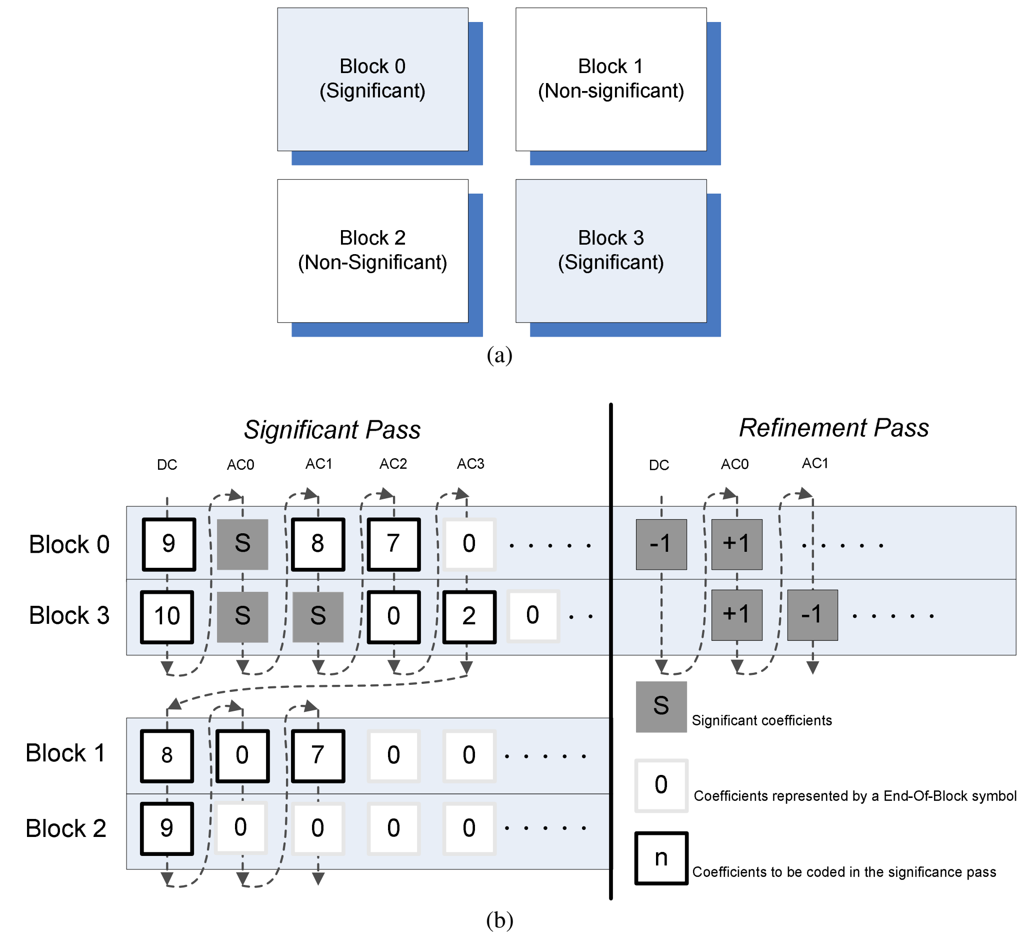


Figure 1: Subband coding scheme in the WD1.0 of SVC, (a) Significance status of 4x4 integer transform blocks in a refinement layer and (b) Subband coding order in a refinement layer.

However, subband-by-subband coding order could cause poor rate-distortion performance[2]. In each transform block, an End-Of-Block (EOB) symbol is coded after a significant coefficient to indicate the end of block coding. For example, in Fig. 1 (b), an EOB symbol is coded after the non-zero DC coefficient of Block 0 to indicate that there are still coefficients to be coded in the Block 0. But, the EOB symbol of Block 0 is meaningless to the following DC coefficient coding in the rest of blocks. Such an EOB symbol is coded as an overhead to the other blocks. As the number of blocks in a refinement layer increases, more EOB symbols are introduced between two consecutive subband coding. Such a syntax placement will cause poor rate-distortion performance.

To improve the rate-distortion performance, a cyclical block coding[1,5] scheme is proposed. Instead of coding the EOB symbol right after a significant coefficient, cyclical block coding[1,5] moves the EOB symbol to the beginning of next insignificant coefficient coding. Moreover, to maximize the efficiency of each coded EOB symbol, the coding of a block is continued until a significant coefficient is coded and recognized. Fig. 2 shows the content and the coefficient coding order within each coding cycle. Since every coding cycle in each block will include the coding of an EOB symbol, the significance indication bits and a non-zero quantization level, we define the notion of (EOB, Run, Level) symbol to represent those coefficients to be coded in a cycle. Fig. 3 illustrates the conceptual coding order of cyclical block coding[1,5] using (EOB, Run, Level) symbol. As shown (in Fig. 3), each transform block is equally coded with a (EOB, Run, Level) symbol in a coding cycle. Blocks with less non-zero coefficients are completed prior to the blocks having more non-zero coefficients. However, from the rate-distortion optimization perspective, blocks with more energy should be assigned with higher coding priority. Currently, cyclical block coding[1,5] does not offer a mechanism to distinguish the importance of different symbols and blocks.

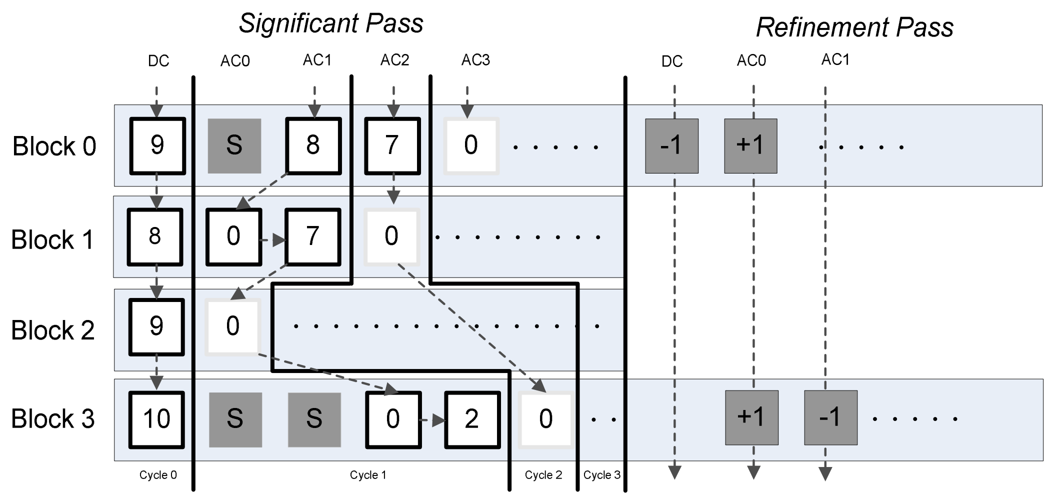


Figure 2: Cyclical block coding scheme.

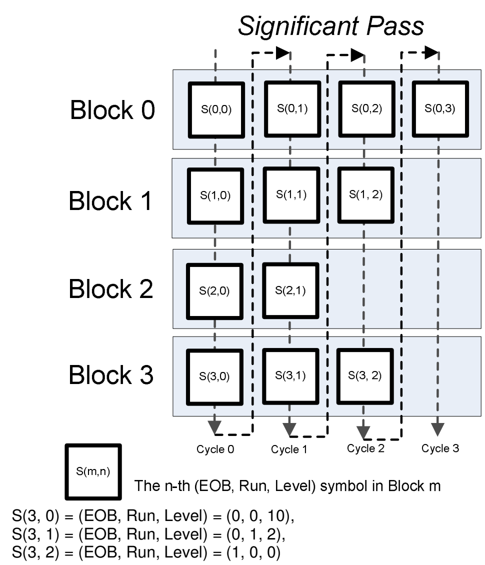


Figure 3: Conceptual coding order of cyclical block coding.

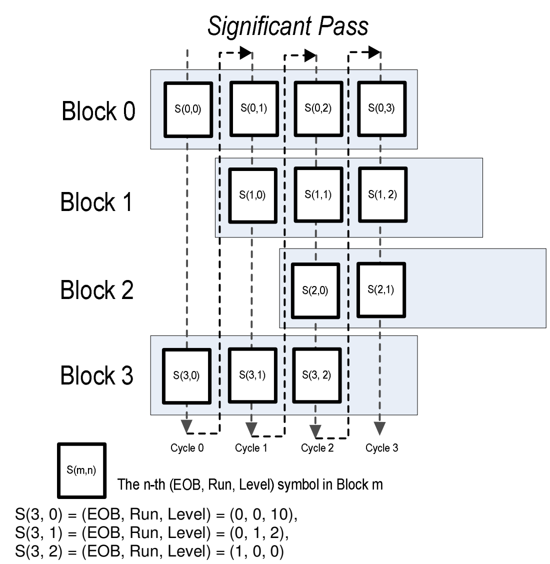


Figure 4: Conceptual coding order of prioritized cyclical block coding.

In this paper, we propose a prioritized significance pass coding scheme to improve the rate-distortion performance of cyclical block coding[1,5]. Specifically, our coding scheme uses a block priority assignment algorithm to firstly transmit the (EOB, Run, Level) symbols with potentially better rate-distortion performance. Fig. 4 shows the conceptual coding order of our scheme. As shown, our priority assignment may unequally code each block in a coding cycle. Particularly, to avoid transmitting the priority information (overhead), the encoder and the decoder refer to the same context for priority assignment. Furthermore, to reduce the complexity, the priority assignment is done by a table look-up operation and the coding of each block is controlled by a simple threshold comparison mechanism. Experimental results show that our prioritized significance pass coding scheme has a consistent improvement at all bit rate ranges as compared to the cyclical block coding[1,5] and the subband coding[3,4]. Specifically, up to 0.5dB improvement is observed. The rest of this paper is organized as following: Section 2 elaborates the detail of our block priority assignment scheme. Then, Section 3 gives the coding flow of our prioritized significance pass coding. And, Section 4 shows the experimental results using the Joint Scalable Video Model 1.0[5] (JSVM1.0) of SVC. Lastly, Section 5 gives our conclusions for this work.

## 2. STOCHASTIC BLOCK PRIORITY ASSIGHMENT

The block priority assignment is to have the (EOB, Run, Level) symbols with potentially better rate-distortion performance be coded first. However, the actual rate-distortion performance of each (EOB, Run, Level) symbol is only available at the encoder. Thus, in this paper, we establish the priorities of different blocks by estimation. Moreover, to avoid transmitting the priority overhead for each block, the encoder and the decoder refer to the same significance status context for priority estimation. The priority for each block is thus known to both sides based on the previously transmitted information.

### 2.1 Energy density index

For estimating the priority of a block, the encoder and the decoder refer to the significance status for calculating an energy density index as defined below:

$$Energy\ Density\ Index\ (block\ k) \triangleq \frac{N}{Z} = \frac{Number\ of\ \ Signficaitnt\ Coefficients\ (in\ block\ k)}{1 + Zigzag\ \ Index\ of\ \ Last\ Significant\ Coefficient\ (in\ block\ k)}, \tag{1}$$

where $Zigzag\ Index\ of\ \ Last\ Significant\ Coefficient$ ranges from 0 to 16 with 0 denoting DC coefficient index and 15 representing the highest AC coefficient index.

To demonstrate how to calculate the energy density index for a block, we use the Block 3 in Fig. 2 and Fig. 3 for illustration. For instance, before coding the S(3, 0) symbol in Fig. 3, which corresponds to the DC coefficient of Block 3 in Fig. 2, we learn that both $Number\ of\ \ Signficaitnt\ Coefficients$ and $Zigzag\ Index\ of\ \ Last\ Significant\ Coefficient$ have the values of 2. Thus, by Eq. (1), the energy density index for the Block 3 is 2/3. Similarly, after coding the S(3, 0) symbol, the $Number\ of\ Signficaitnt\ Coefficients$ increases to 3 and $Zigzag\ Index\ of\ Last\ Significant\ Coefficient$ remains unchanged. Thus, the energy density index for the Block 3 becomes 3/3 after coding the S(3, 0) symbol. Following the same principle, one can derive the energy density indices for all the other blocks in each coding cycle.

The energy density index characterizes the energy distribution in a block. Higher energy density index implies that the next significant coefficient in a block could be coded and recognized with shorter run. In other words, the next (EOB, Run, Level) symbol could have better rate-distortion performance and should be assigned with a higher coding priority. Although the energy density index can not accurately tell the rate-distortion performance of each (EOB, Run, Level) symbol, it can effectively rate the relative rate-distortion performance of different symbols.

Table 1. Luminance Priority Table

| | | N (Number of Significant Coefficients) | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| Z (1+ Zigzag Index of Last Significant Coefficient) | 0 | 1 | | | | | | | | | | | | | | | | |
| | 1 | | 136 | | | | | | | | | | | | | | | |
| | 2 | | 65 | 135 | | | | | | | | | | | | | | |
| | 3 | | 41 | 86 | 134 | | | | | | | | | | | | | |
| | 4 | | 29 | 64 | 97 | 133 | | | | | | | | | | | | |
| | 5 | | 22 | 49 | 76 | 103 | 132 | | | | | | | | | | | |
| | 6 | | 17 | 40 | 63 | 85 | 107 | 131 | | | | | | | | | | |
| | 7 | | 14 | 33 | 52 | 72 | 91 | 110 | 130 | | | | | | | | | |
| | 8 | | 11 | 28 | 45 | 62 | 79 | 96 | 113 | 129 | | | | | | | | |
| | 9 | | 9 | 24 | 39 | 54 | 69 | 84 | 99 | 114 | 128 | | | | | | | |
| | 10 | | 8 | 21 | 34 | 48 | 61 | 75 | 89 | 102 | 115 | 127 | | | | | | |
| | 11 | | 7 | 18 | 31 | 43 | 55 | 68 | 80 | 92 | 105 | 116 | 126 | | | | | |
| | 12 | | 6 | 16 | 27 | 38 | 50 | 60 | 73 | 83 | 95 | 106 | 117 | 125 | | | | |
| | 13 | | 5 | 15 | 25 | 35 | 46 | 56 | 67 | 77 | 88 | 98 | 108 | 118 | 124 | | | |
| | 14 | | 4 | 13 | 23 | 32 | 42 | 51 | 59 | 71 | 81 | 90 | 100 | 109 | 119 | 123 | | |
| | 15 | | 3 | 12 | 20 | 30 | 37 | 47 | 57 | 66 | 74 | 82 | 93 | 101 | 111 | 120 | 122 | |
| | 16 | | 2 | 10 | 19 | 26 | 36 | 44 | 53 | 58 | 70 | 78 | 87 | 94 | 104 | 112 | 121 | 0 |

### 2.2 Table look-up

According to Eq. (1), the energy density index is a real number and its calculation involves floating point division arithmetic. To reduce the complexity for calculating energy density index, we use a table look-up operation to replace the floating point division.

For a 4x4 integer transform block, we find that the possible combination of *Number of Signficaitnt Coefficients* and *Zigzag Index of Last Significant Coefficient* is finite. Thus, we can calculate the energy density index for each combination in advance. In addition, given the energy density index of each combination, we can further perform the sorting and construct a table to record the priority for each combination. Particularly, during the sorting, if there are two combinations having the same energy density index, the one having smaller *Zigzag Index of Last Significant Coefficient* will be assigned with higher priority. This is to assign (EOB, Run, Level) symbol located at the lower frequency bands with higher coding priority. Table 1 lists our luminance priority table in terms of $N$ ( *Number of Signficaitnt Coefficients* ) and $Z$ (1+ *Zigzag Index of Last Significant Coefficient* ). Higher value means higher coding priority and zero priority value, i.e., ($N$=16, $Z$=16), denotes the case of having no coefficients to be coded in the significant pass. In addition, both $N$ and $Z$ factors of a block are set to zero if there is no significant coefficient. One can follow the same principle to construct the priority tables for the chrominance components.

## 3 PRIORITIZED SIGNIFICANT PASS CODING FLOW

Given the priority of each block, Fig. 5 shows our improved significance pass coding flow. In brief, our significant pass coding mainly includes 3 steps which are (1) Initialization, (2) Priority threshold setting, and (3) Coding.

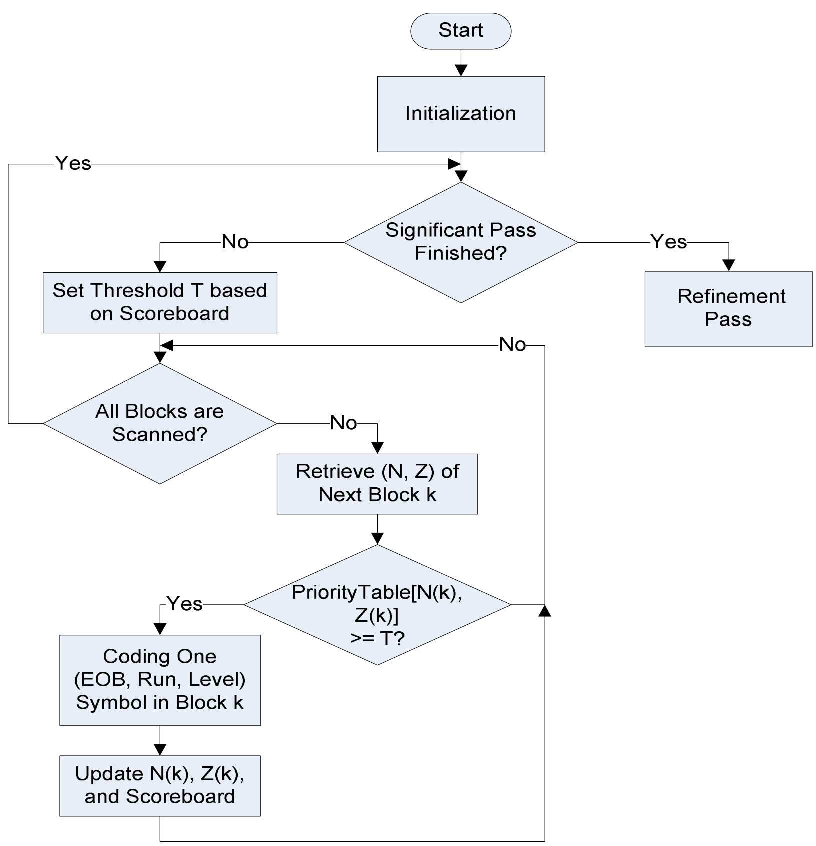


Figure 5: Proposed significant pass coding flow.

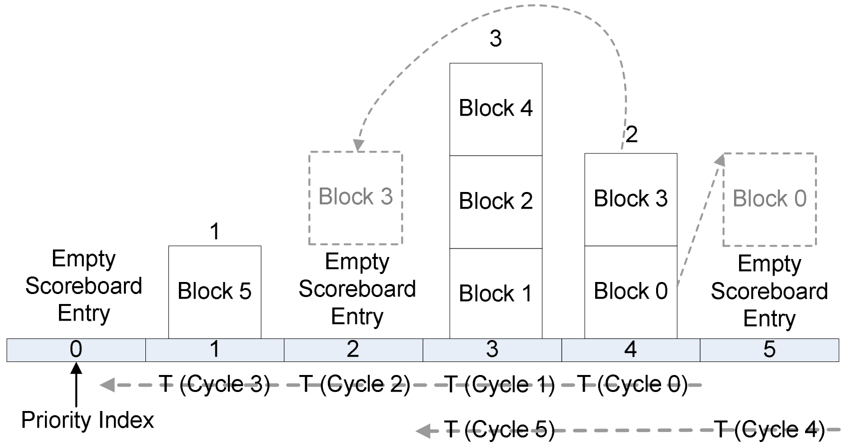


Figure 6: Priority scoreboard searching and threshold determination process.

### 3.1 Initialization

During the initialization, we calculate the ($N$, $Z$) parameters for each block and allocate a register to record the values. In addition, we create a priority scoreboard to maintain the priority distribution of transform blocks. The dimension of the priority scoreboard is determined by the number of possible priority values. For instance, in Table 1, there are totally 137 possible priority values for the luminance blocks. Thus, the luminance priority scoreboard has 137 entries. The $n$-th entry records the number of blocks having priority value of $n$.

### 3.2 Priority threshold setting

After the initialization, the priority scoreboard is examined to determine the priority threshold which is further used for block coding control. Specifically, in each coding cycle, a block with priority greater than (or equal to) a threshold $T$ is allowed for coding one (EOB, Run, Level) symbol. Oppositely, we disable the coding of a block if its priority is lower than $T$. To have higher priority blocks be coded with more (EOB, Run, Level) symbols, we set the threshold $T$ by searching through the scoreboard from the highest priority index toward the lowest priority one. During the search, the threshold $T$ is set to the index of first non-zero entry. Fig. 6 depicts an example of the priority threshold determination. As shown, the first non-zero entry from the highest priority index (5) is 4. Thus, $T$ of Cycle 0 is set to 4. After a coding cycle, we repeat the process by searching the scoreboard from the current threshold $T$ (i.e., 4 in the example of Fig. 6). For instance, after Cycle 0, the threshold $T$ of Cycle 1 is set to 3. Once the scoreboard is completely searched, we restart the process by searching from the highest priority index. Such cyclical searching process is continued until the significant pass is completed. Particularly, after a coding cycle, priority scoreboard may be dynamically updated to consider the change of block priority. Our threshold determination is also dynamically adjusted. As shown, at the end of Cycle 3, the Block 0 which is of highest priority has been coded with 4 symbols while the lowest priority Block 5 only has one coded symbol. Note that our prioritized bit-plane coding can converge to cyclical block coding[1,5] by setting $T$ to 1 in each coding cycle.

### 3.3 Coding

After the priority threshold $T$ is set, the coding process is performed by comparing the priority of each block with the threshold. Only the blocks with priority greater than (or equal to) $T$ are allowed for coding one (EOB, Run, Level) symbol. After coding one symbol in a block, the associated ($N$, $Z$) parameters and the priority scoreboard will be updated accordingly.

## 4 EXPERIMENTS

For the experiments, we implement our prioritized significance pass coding by modifying the JSVM 1.0[5]. To show the performance improvement, we use the subband coding in WD1.0[3,4] and the cyclical block coding[1] in JSVM 1.0[5] as

Table 2. Encoder Parameters

| Sequence | Football | Football | Mobile | Mobile | Crew | Crew |
|---|---|---|---|---|---|---|
| Resolution | CIF | QCIF | CIF | QCIF | CIF | QCIF |
| Frame Rate | 30 | 15 | 30 | 15 | 30 | 15 |
| GOP Size | 16 | 8 | 16 | 8 | 16 | 8 |
| With Update Step | Yes | No | Yes | No | Yes | No |
| Base-Layer Qp | 41.3 | 35.1 | 38 | 36.7 | 36 | 33.7 |
| MPEG-4 AVC Compatible Base-ayer | | | Yes | | | |
| Number of Spatial Layers | | | 1 | | | |
| Number of FGS layers | | | 2 | | | |

baseline. Specifically, for each algorithm, the associated encoder follows the configuration in Table 2 to produce a scalable bit-stream. After that, the corresponding decoder truncates the pre-encoded scalable bit-stream at multiple bit rates and measures the PSNR of decoded video respectively. To simply address the performance at the refinement layers (i.e., FGS layers), we use only one spatial layer in all the testing conditions.

Fig. 7 shows the results of PSNR comparison. First, we observe that different algorithms show similar or same PSNR performance at the end of a FGS layer. This is because different algorithms only differ in coefficient coding order. The number of coefficients to be coded in a FGS layer is fixed. Thus, after coding an entire FGS layer, all the algorithms show the same or similar PSNR results. In addition, the proposed prioritized bit-plane coding shows a consistent improvement over the cyclical block coding[1,5] and the subband coding[3,4]. Particularly, there is a ~0.5dB improvement at the bit rates that are close to the end of the second FGS layer. The improvement in the first FGS layer is less significant because there are less (EOB, Run, Level) symbols for optimization. One should note that current JSVM implementation produces each FGS layer by using a fixed quantization parameter difference. The first FGS layer typically has fewer coefficients and narrower bit rate scalable range than the second FGS layer.

## 5 SUMMARY AND CONCLUSION

In this paper, we propose a low complexity prioritized bit-plane coding scheme to improve the rate-distortion performance of cyclical block coding[1,5]. Instead of coding each block equally in a coding cycle, our scheme allows different blocks be coded unequally for improving the rate-distortion performance. Specifically, we first assign each block a coding priority by referring to the significance status of the transform coefficients. Then, according to the block priority distribution, a low complexity and threshold based coding control mechanism is used to have different blocks be coded in a sorted manner. Experimental results show that such a change to the cyclical block coding[1,5] can have up to 0.5dB PSNR improvement. In addition, by optimizing the priority assignment scheme and the coding control mechanism, further improvement is expected.

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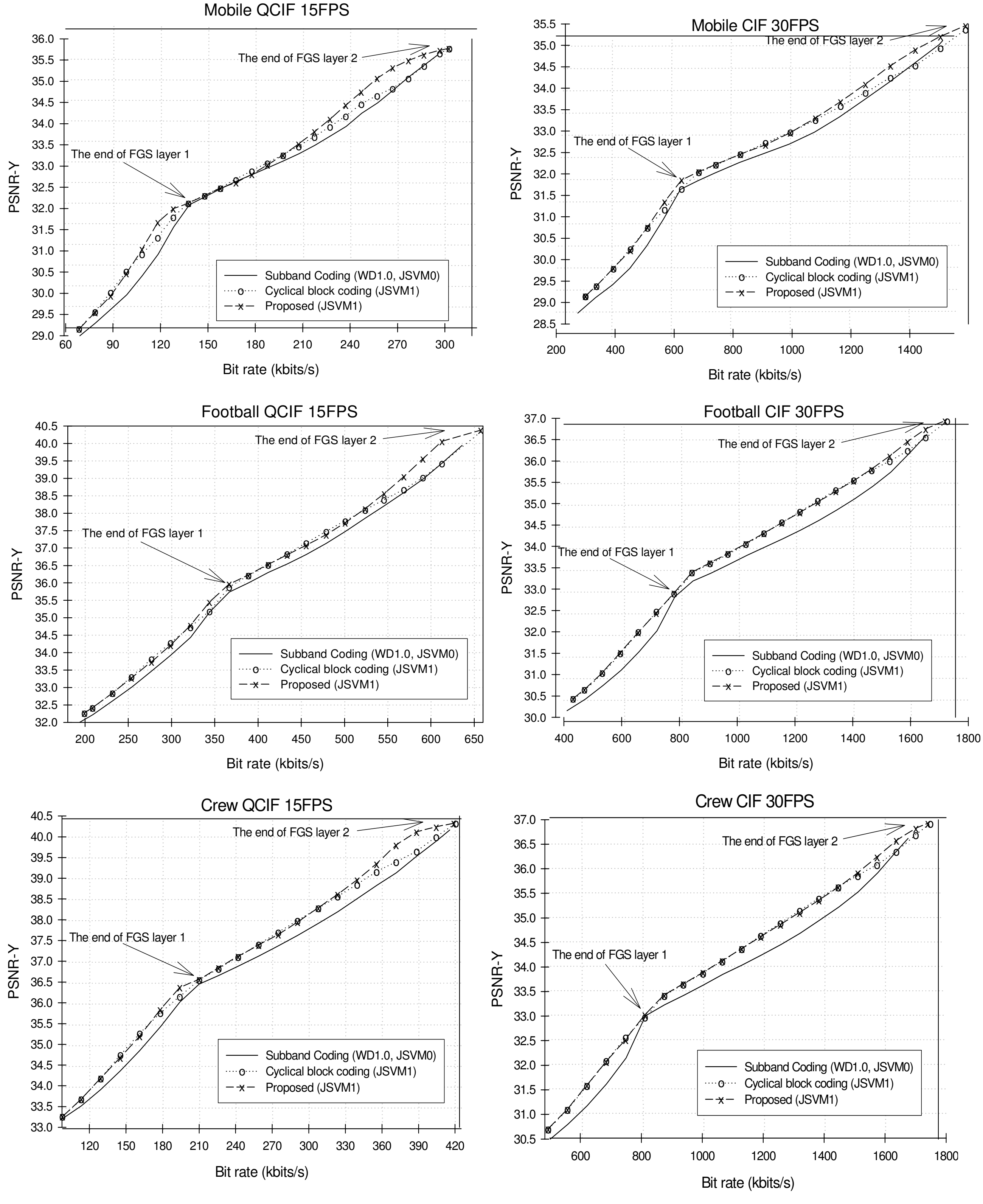


Figure 7: PSNR comparison.