Group-of-pictures-based unequal error protection for scalable video coding extension of H.264/AVC

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Abstract. We address the problem of unequal error protection (UEP) for SNR enhancement layer network abstraction layer (NAL) units of scalable video coding extension of H.264/AVC standard over wireless packet-erasure channel. We develop a UEP scheme by jointly selecting SNR NAL units and allocating unequal amounts of protection to selected NAL units for every group of pictures in the sequence. A simple heuristic algorithm is proposed to quickly derive the protection pattern. Experimental results demonstrate the proposed UEP scheme provides significant error resilience. © 2009 Society of Photo-Optical Instrumentation Engineers. [DOI: 10.1117/1.3152774]

Subject terms: H.264/AVC; scalable video coding; equal error protection (EEP); unequal error protection (UEP).

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1 Introduction

Scalable video coding (SVC) combined with unequal error protection (UEP) is promising to deliver video robustly. SVC extension of the H.264/AVC standard has achieved significant improvement in coding efficiency when providing spatial, temporal, and SNR scalability in a single bitstream relative to the scalable profiles of prior video coding standards. Medium-granular SNR scalability (MGS) provides network abstraction layer (NAL) unit-based SNR scalability.

A UEP scheme for bitstream transmission over the packet erasure channel roughly comprises the source selection stage and channel rate allocation stage. Which part of the encoded bitstream is decided for transmission in the source stage according to the source rate and channel rate allocation stage to maximize overall distortion reduction at decoder. A traditional one-dimensional UEP scheme jointly considering source selection and channel rate allocation on image or video bitstream is investigated in which channel rate assignment algorithm, but Refs. 6–8 are only for

Now, the objective of the optimization is to find the proper channel rate allocation matrix $K$.
Fig. 2 PSNR comparison of the UEP scheme against EEP scheme for MGS enhancement NAL units.

\[ K = \begin{bmatrix}
K(0,0) & \cdots & K(0,F-1) \\
\vdots & \ddots & \vdots \\
K(G-1,0) & \cdots & K(G-1,F-1)
\end{bmatrix}, \]

\[-1 \leq K(i,j) \leq N-1. \quad (3)\]

Here, channel rate allocation \( K(i,j) = -1 \) means the corresponding MGS NAL unit is not to transmit. Thus, \(-1 \leq K(i,j) \leq N-1\) integrates the source selection stage and channel rate allocation stage. Constraint 1 is

\[ \sum_{i=0}^{G-1} \sum_{j=0}^{F-1} h(i,j) \leq L, \quad (4) \]

which restricts the total amount of source bits and channel bits not to exceed the transmission block target rate. \( h(i,j) \) is calculated as

\[ h(i,j) = \begin{cases} 
\frac{B(i,j)}{N-K(i,j)} & 0 \leq K(i,j) \leq N-1 \\
0 & K(i,j) = -1.
\end{cases} \quad (5) \]

\( B(i,j) \) is the number of source data bytes in MGS NAL unit \((i,j)\). The constraint 2 is

\[ K(i,j) \geq K(i,j+1), \quad i = 0, \ldots, G-1, \quad j = 0, \ldots, F-2, \quad (6) \]

because a higher layer MGS NAL unit will be useless if the lower one is not available. Now the optimization problem is then expressed as

\[ \max D_{\text{reduction}}(K) \]

s.t. \((4),(6)\). \quad (7)

We introduce \( GF(N+1) \) binary variables \( Q(i,j,q) \) \(i=0,\ldots,G-1, j=0,\ldots,F-1, q=0,\ldots,N\) to reformulate the primal problem (7) inspired by Ref. 10. Let \( N+1 \) binary variables represent \( K(i,j) \) for frame \( i \) and SNR layer \( j \). Set the \( q \)’th binary variable as 1 and other binary variables as 0 to represent channel rate allocation \( K(i,j) = q-1 \). Thus

\[ P(i,j,q) = \sum_{m=0}^{q-1} P(m,N), \quad (q = 0, \ldots, N). \quad (8) \]

Let \( b(i,j,q) = [\Delta D(i,j)] [P(i,j,q)] \), \( b(i,j,q) = 0 \) for \( q = 0 \).

\[ h(i,j,q) = \begin{cases} 
\frac{B(i,j)}{N-q+1} & 1 \leq q \leq N \\
0 & q = 0
\end{cases} \quad (9) \]

Hence, \( b(i,j,q) \) and \( h(i,j,q) \) are increasing with \( q \) for given \( i,j \) and they could be seemed as the profit and weight of item \( q \) on table \( i,j \) respectively. \( L \) is regarded as weight capacity of knapsack. Then the problem is to select one and only one item from each table in order to maximize overall profit with the constraint (6) and without exceeding the knapsack’s weight capacity. This is like a multiple-choice knapsack problem (MCKP), which is well known to be nondeterministic polynomial-time (NP) hard. We construct a heuristic solution as follows:

**Table 1 DMOS comparison of the UEP scheme against EEP scheme at PLR=30%**

<table>
<thead>
<tr>
<th>Sequence</th>
<th>L</th>
<th>EEP</th>
<th>Proposed</th>
<th>UEP all</th>
<th>Sequence</th>
<th>L</th>
<th>EEP</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harbour</td>
<td>1100</td>
<td>39.82</td>
<td>36.25</td>
<td>37.58</td>
<td>Harbour</td>
<td>600</td>
<td>40.11</td>
<td>36.72</td>
</tr>
<tr>
<td>Mobile</td>
<td>1200</td>
<td>40.42</td>
<td>36.09</td>
<td>38.91</td>
<td>Mobile</td>
<td>800</td>
<td>41.59</td>
<td>38.78</td>
</tr>
<tr>
<td>Foreman</td>
<td>600</td>
<td>39.13</td>
<td>30.74</td>
<td>34.02</td>
<td>Foreman</td>
<td>200</td>
<td>39.98</td>
<td>33.79</td>
</tr>
<tr>
<td>Crew</td>
<td>1000</td>
<td>40.15</td>
<td>31.88</td>
<td>36.54</td>
<td>Crew</td>
<td>500</td>
<td>40.51</td>
<td>36.15</td>
</tr>
</tbody>
</table>
Step 1: Sort all items except items with $q=0$ by their profit density $b_{i,j,q}/h_{i,j}$ in decreasing order. Denote it as list1. Every element list1[x] contains the item index (i,j,q), profit b and weight h, b and h represent the corresponding $b_{i,j,q}$ and $h_{i,j}$, respectively.

Set $K(i,j)=1$, $\forall i,j$, Set $C=0$; For ($t=0$; $t<F$; $t++$)

Set $x=0$;

While (list1[x].j $= f$ & & C+list1[x].h == L & & x $< G-F-N$)

If (K(list1[x].i, list1[x].j) == -1 & & list1[x].j == 0) $||$ list1[x].j $> 0$ & & list1[x].q == K(list1[x].i, list1[x].j−1+1))

$K$(list1[x].i, list1[x].j) = list1[x].q−1;

C = C+list1[x].h;

End If

x++; End While

End For

Step 2: Sort $\lambda_j=(b_{i,j,K(i,j)+2}−b_{i,j,K(i,j)+1})/(h_{i,j,K(i,j)+2}−h_{i,j,K(i,j)+1})$, $\forall i,j$ in decreasing order. Denote it as list2. Every element list2[y] contains the item index (i,j).

Set found=0; Set y=0;

While (C+h*list2[y].i, list2[y].j, K(list2[y].i, list2[y].j)+2)−h*list2[y].i, list2[y].j, K(list2[y].i, list2[y].j)+1) == L & & y < G−F−N

If (list2[y].j == 0) $||$ list2[y].j $> 0$ & & K(list2[y].i, list2[y].j+1) == K(list2[y].i, list2[y].j)

$K$(list2[y].i, list2[y].j) = K(list2[y].i, list2[y].j); $C$ = C+h*list2[y].i, list2[y].j, K(list2[y].i, list2[y].j)+1;

End If

y++; End While

If (found == 1) goto Step 2; else End.

The complexity of algorithm mainly comes from sorting algorithm, which is $O(\text{GFN} \log(\text{GFN}))$.

3 Experimental Results

We encode with $G=16$ and $F=3$ MGS enhancement layers. One-hundred different runs of the experiments were conducted to transmit video sequences with different packet-loss patterns. For the two-state Markov channel, the average burst length is 9.57. We set $N=100$. “Foreman 200” means the result for sequence foreman and $L=200$.

The heuristic channel rate allocation algorithm runs very fast and on average produces results within 0.1 s on a PC with 2.0-GHz CPU. We compare the UEP scheme with EEP scheme in which the elements of $K$ have the same value under different average packet loss rate (PLR) and the results are depicted in Fig. 2. Figure 2(a) shows the result of EEP without any MGS enhancement NAL unit transmission when source rate to transmit exceeds transmission block rate target. It can be seen that proposed UEP scheme shows graceful degradation and an improvement of at least 2.5 dB in quality is achieved when compared with equal error protection (EEP). Figure 2(b) shows the performance of proposed UEP and EEP when source rate to transmission is less than transmission block target rate. At most, 3-dB gains are achieved for proposed UEP over EEP. If all MGS enhancement NAL units have to be included in the transmission block (as in Refs. 6 and 7) then the Eq. (7) changes slightly by setting $0 \leq K(i,j) \leq N−1$. It can be solved by starting from $K(i,j)=0$ and applying step 2 in proposed heuristic solution. Curves “UEP-all” in Fig. 2(b) show it is inferior to the proposed UEP scheme especially at high packet loss rate.

We take a subjective test of some results according to the double-stimulus continuous quality-scale method suggested by ITU-R BT.500-11. The mean opinion scores are rescaled to a range of 0–100. Difference mean opinion scores (DMOS) are calculated as the difference between the original video and the test video. Table 1 shows the DMOS of UEP and EEP at PLR=30%. It can be seen that subjective rating of the proposed method is better than the others.

4 Conclusions

We propose a UEP scheme by jointly selecting source packets and allocating unequal amounts of protection to MGS enhancement NAL units for every GOP. A heuristic algorithm is proposed to quickly get the solution. As illustrated by our simulation results, the proposed UEP scheme provides significant error resilience.

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References