Reliable scalable video streaming using layer weight switching-based unequal Luby transform

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A layer weight switching-based unequal Luby transform (LWS-ULT) method is proposed to minimise video distortion over packet-lossy networks. The proposed ULT method divides all quality layers into more important set (MIS) and less important set to provide unequal packet protection property in LT codes based on error propagation effects. The number of quality layer in MIS is adjusted in accordance with channel status. At high packet loss rate, lower number of quality layer is assigned into MIS for more protection of quality layer with larger error propagation weight. On the other hand, higher number of quality layer is included in MIS for improving video quality by expanding the range of protection at low packet loss rate. Simulation results demonstrate that the proposed LWS-ULT method gives robust performance and significantly improved video quality (0.9–1.2 dB in Y-PSNR), compared with the conventional ULT schemes.

Introduction: In extensive multimedia communication environments, robust multimedia streaming over unreliable networks has been an active and challenging area of research [1, 2]. To provide variable services with the combined scalability such as temporal, spatial, and quality scalability, an international video coding standard named the scalable video coding extension of H.264/AVC (H.264/SVC) has been developed [1]. Although the scalable bitstream can be effectively adapted to variable network conditions and devices, the error resilient transmission of compressed video based on hierarchical prediction structure is still a big technical challenging issue [2–4].

This Letter proposes a novel layer weight switching-based unequal Luby transform (LWS-ULT) method that improves the video quality delivered over packet erasure channels. A well-known previous ULT method [4] (R-ULT) manages FEC rate adaptively by the importance of sets (more important set [MIS] and less important set [LIS]). However, the management of FEC rate could increase the video quality degradation because of the over and under FEC packet assignment for MIS and LIS in accordance with time-varying channel environments. The proposed LWS-ULT method assigns the appropriate number of FEC packets based on both channel status and error propagation effects. At high packet loss rate, the proposed method reduces the number of quality layer of a group of pictures (GOP) in MIS for protecting more localised MIS in limited channel resources. Otherwise, the number of quality layer in MIS is increased for improving video quality at lower packet loss rate condition.

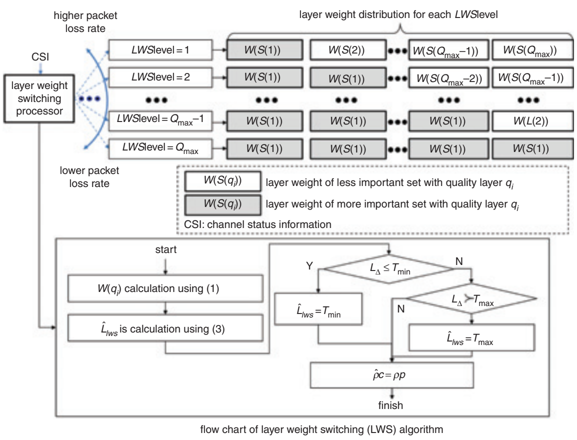

Fig. 1 *Schematic illustration (upper part) and block diagram of the proposed LWS method*

LWS method: The proposed LWS-ULT method is consists of two processes; (i) layer weight switching process: LWS and (ii) LWS-based unequal Luby transform process: LWS-ULT. First, the upper part of Fig. 1 explains the LWS mechanism with the schematic illustration. Based on channel status, LWS processor determines how many number of quality layers are assigned in MIS using the level of LWS which is denoted as L_{lws}. At higher packet loss rate, L_{lws} is switched into lower value and the number of quality layers in MIS is decreased for more protection of localised quality layers in MIS with limited channel resources. In case of lower packet loss rate, L_{lws} is switched into higher value and the number of quality layers in MIS are increased for improving the packet recovery rate by expanding the range of quality layers.

The flow chart of the LWS method is shown in lower part of Fig. 1. Based on the characteristics of the SVC structure [1], the layer information for each packet is included in the header of the network abstraction layer unit. The layer information includes the temporal layer index (t_i) and the quality layer index (q_i), and it is used to quantify the error propagation effect from packet losses. Due to the dependent relationship between the quality layers, the error propagation effect from a lower quality layer is much larger than that from a higher quality layer for reconstructed video quality.

Layer weight in a quality layer q_i is defined as $W(q_i)$ and calculated simply as

$$W(q_i) = (Q_{\max} - q_i) \cdot \alpha \tag{1}$$

where α is the scaling factor of $W(q_i)$. The updated moving average of the current packet loss rate ($\hat{\rho}_{\mathrm{c}}$) is computed as follows:

$$\hat{\rho}_{\mathrm{c}} = \gamma \cdot \rho_{\mathrm{c}} + (1-\gamma) \cdot \rho_{\mathrm{p}} \tag{2}$$

where ρ_{c} and ρ_{p} are the current packet loss rate and previous moving average of packet loss rate, respectively. In (2), γ is a constant for moving average calculation. Based on (2), the level of LWS ($\hat{L}_{\mathrm{lws}}$) is calculated as

$$\begin{aligned} L_{\Delta} &= \hat{\rho}_{\mathrm{c}} - \rho_{\mathrm{p}} \\ \hat{L}_{\mathrm{lws}} &= L_{\mathrm{lws}} + L_{\Delta} \end{aligned} \tag{3}$$

If $\hat{\rho}_{\mathrm{c}}$ is smaller than ρ_{p}, $\hat{L}_{\mathrm{lws}}$ is decreased by the amount of L_{Δ}. It means that the number quality layers in MIS is decreased and more protection is allocated in the small size of MIS. On the other hand, If $\hat{\rho}_{\mathrm{c}}$ is larger than ρ_{p}, $\hat{L}_{\mathrm{lws}}$ is increased by the amount of L_{Δ}. It can achieve higher video quality by increasing the number of quality layer in MIS.

Finally, $\hat{L}_{\mathrm{lws}}$ is compared with two threshold values, $T_{\min}$ and $T_{\max}$. If $\hat{L}_{\mathrm{lws}}$ is less than $T_{\min}$, $T_{\min}$ is assigned into $\hat{L}_{\mathrm{lws}}$. If $\hat{\rho}_{\mathrm{c}}$ exceeds $T_{\max}$, the $T_{\max}$ is set as $\hat{L}_{\mathrm{lws}}$. Layer weights of the following quality layers are sequentially shifted from that of previous quality layer as shown in Fig. 1.

Proposed LWS-ULT method: Under various network conditions, the LT codes are a class of packet level FEC technique and suitable for the data recovery in the packet erasure channel [3, 4]. Robust soliton distribution (RSD) ($\mu(d)$) [4] has been widely used in LT encoding for selecting the degree d and it is introduced as follows:

$$\mu(d) = \frac{\phi(d) + \tau(d)}{Z} \tag{4}$$

$$Z = \sum_{d=1}^{I} \phi(d) + \tau(d) \tag{5}$$

where $\phi(d)$ represents the ideal soliton distribution. $\tau(d)$ is a new function for the RSD and K is the number of input symbols. The d input symbols selected from (4) are utilised to get an output symbol by XOR operation. Fig. 2 shows a bipartite encoding graph to generate output symbols. Packets in each quality layer are used as input symbol for generating output symbol in LT codes.

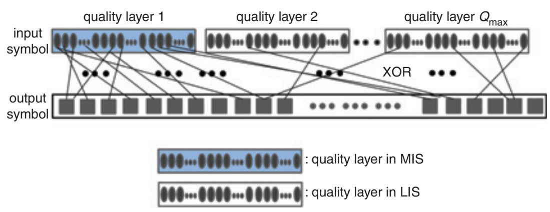

Fig. 2 *Bipartite encoding graph of the proposed ULT method*

We define $P_s(q_i)$ as the probability that an output symbol is connected to a particular input symbol in $S(q_i)$ for $q_i = 1, 2, \ldots, Q_{\max}$. As mentioned in [4], it is ensured that if the probability of selecting any input symbol from $S(q_i)$ is greater than that of choosing the input symbol in $S(q_j)$, the average packet recovery rate from packet loss for the input symbols in quality layer $S(q_i)$ is smaller than that of input symbols in quality layer $S(q_j)$. Based on $W(q_i)$ in (1), $P_s(q_i)$ is induced as

$$P_s(q_i) = \frac{W(q_i)}{\sum_{q_i=1}^{Q_{\max}} W(q_i)} \quad (6)$$

On the basis of (6), the encoding procedure of the LWS-ULT is as follows.

(1) LWS process is performed based on the flow chart in Fig. 1.
(2) Select randomly a value for degree d_i, $d_i \in \{1, 2, \ldots, I\}$ and $d_i \in \{1, 2, \ldots, O\}$. I and O are the number of input symbols and the number of output symbols, respectively
(3) Calculate $P_s(q_i)$ for each quality layer q_i.
(4) Select one of predefined quality layers, $\hat{q}_i$ using $P_s(q_i)$ and uniformly choose an input symbol in the selected quality layer $(\hat{q}_i)$.
(5) Set an output symbol by XOR operation of the selected input symbols.
(6) Repeat steps (1)–(5) until all of output symbols are determined.

Simulation results: To evaluate the performance of the proposed LWS-ULT method, the 'Foreman' and 'City' video sequences are pre-encoded using JSVM version 9.8 [5]. The scalable video is coded with one spatial layer CIF (30 fps), four quality layers ($Q_{\max} = 4$) and five temporal layers with the GOP size of 16. The values of two parameters α in (1) and γ in (2) are set as 1.2 and 0.8. $T_{\max}$ and $T_{\min}$ are set as 1 and $Q_{\max}$, respectively. The simulations are performed using NS-3 Network Simulator [6] and the transmission unit is 150 bytes.

To show the effectiveness of the proposed approach, packet recovery ratio for each layer l ($R_p(l)$) is simply defined as the ratio of the number of decoded packets of layer l to the number of all packets in layer l at each step of decoding procedure and $R_p(l)$ for a specific iteration is given as

$$R_p(l) = \frac{\text{the number of decoded packets of layer } l}{\text{total number of packets in layer } l} \quad (7)$$

Fig. 3 shows $R_p(l)$ curves for all iterations. Fig. 3*a* shows the $R_p(l)$ of equal LT without considering MIS. Most of the time, equal packet recovery rate is achieved for all quality layers. On the other hand, the $R_p(l)$ of the proposed ULT method is shown in Fig. 3*b*. It is observed that the variations of $R_p(l)$ for more important quality layers stand above the curves corresponding to those for less important quality layers. It is induced that the more important layers have more chance to be delivered safely and recovered at the destination side.

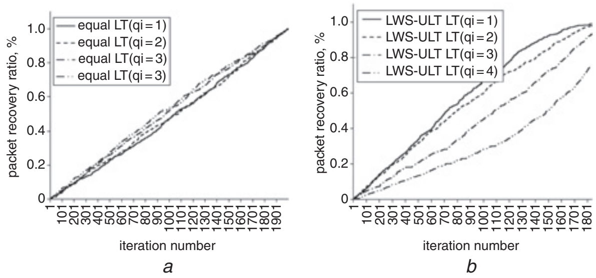

Fig. 3 *Variation of $R_p(l)$ for all iteration in accordance with $W(q_i)$*
a $W(q_i) = \{1, 1, 1, 1\}$
b $W(q_i) = \{4, 3, 2, 1\}$

Figs. 4*a* and *b* show the PSNR comparison of the proposed LWS-ULT method with Equal LT and R-ULT methods for different low and high packet loss rates (5% and 15%). It is observed that the proposed method provides higher PSNR values by 0.9 dB and 1.2 dB in Y-PSNR for different packet loss rates. These PSNR gains are from the effective reduction of error propagation by including the layer importance-based FEC adjustment considering network conditions.

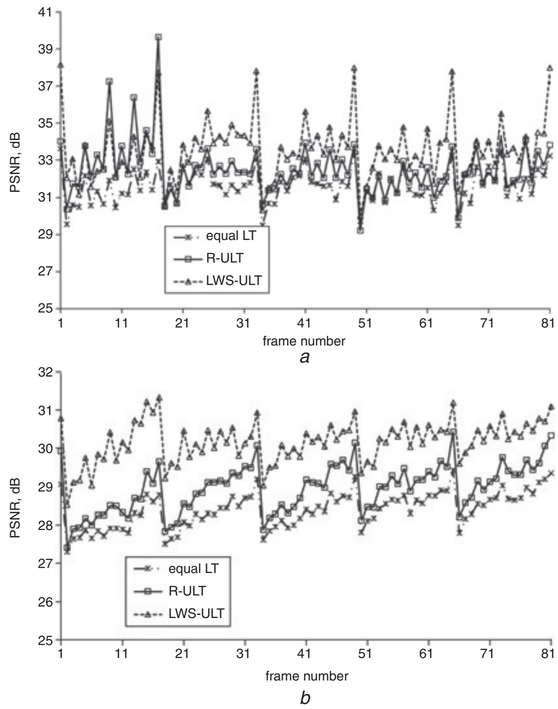

Fig. 4 *PSNR comparison of the proposed LWS-ULT with equal LT and R-ULT for different packet loss rates and video sequences*
a Equal LT (31.61 dB), R-ULT (32.51 dB), and LWS-ULT (33.59 dB) for packet loss rate of 5% in 'Foreman'
b Equal LT (28.38 dB), R-ULT (28.95 dB), and LWS-ULT (30.12 dB) for packet loss rate of 15% in 'City'

Conclusion: This Letter proposes the LWS-ULT method for scalable video streaming over packet-lossy networks. First, the appropriate level of LWS is determined in accordance with the network status. Then, the proposed LWS-ULT method provides unequal packet recovery property in LT codes based on error propagation effects and the level of LWS. Simulation results demonstrate the proposed method achieves higher PSNR values (0.9 to 1.2 dB) than conventional FEC methods under various network conditions.

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One or more of the Figures in this Letter are available in colour online.

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