ROBUST TRANSMISSION OF VIDEO DATA STREAM OVER WIRELESS NETWORK BASED ON HIERARCHICAL SYNCHRONIZATION

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ABSTRACT

In this paper, we propose an error-resilient transmission technique for the H.263 video data stream over wireless networks. The proposed algorithm employs bit rearrangement hierarchically, providing the robust and exact synchronization against the bit errors, without requiring extra redundant information. In addition, we propose the recovery algorithm for the lost or erroneous motion vectors. We implement the encoder and decoder, based on the H.263 standard, and evaluate the proposed algorithm through intensive computer simulation. The experimental results demonstrate that the proposed algorithm yields good image quality, in spite of the channel errors, and prevents the error propagation both in the spatial and the temporal domain efficiently.

1. INTRODUCTION

The video coding technique for error-prone channels should achieve robustness against the noise, as well as the high compression efficiency. To achieve a high compression, most video source coders employ the prediction, such as the motion compensation (MC), and the transform, such as the discrete cosine transform (DCT) [1, 2]. But these techniques cause the error propagation both in the spatial and the temporal domain. Moreover, these coding schemes adopt the variable length codes (VLC), such as the Huffman codes, making these techniques too sensitive to the bit errors. Thus, an error-resilient video coding technique is of importance to transmit the video signal over error-prone channels, such as wireless networks.

In several existing methods to protect the encoded video data stream against the transmission errors, forward error correction (FEC) and error concealment (EC) techniques are widely used [4–7]. However, the FEC technique does not only degrade the compression efficiency, but also fails catastrophically with increased bit error rate (BER) or longer bursts. On the other hand, the EC technique, which does not require the increase in the transmission bandwidth, provides a relatively poor performance, when information of adjacent blocks is not available.

The error localization technique is considered as another solution to the channel errors, which employs synchronization codes, intra blocks, or intra frames. This scheme is capable of preventing the error propagation in the temporal domain by intra-coding and in the spatial domain by synchronization codes. However, it has still the vulnerable nature and, thus, its applications are limited, due to the restriction in the bandwidth.

In this paper, we propose an error-resilient transmission technique for the H.263 [2] video data stream over wireless networks. The proposed algorithm employs the bit rearrangement technique of error-resilience entropy coding (EREC) [3] hierarchically, without requiring additional redundant information, providing the robust and exact synchronization against the bit errors. The proposed algorithm employs forward and backward rearrangement systematically in GOB, macroblock, block, and DCT coefficients levels. This scheme protects the forward rearranged data against the bit errors independently. Moreover, it can minimize the effects of errors, since the bit errors in another slot affect only high frequency DCT coefficients. Therefore, it confines the effect of error within certain level. In addition, we propose the recovery algorithm for the lost or erroneous motion vectors. In the conventional H.263, the motion vectors are inter-coded, for example, the differential pulse code modulation (DPCM). Thus, even an error in one motion vector can damage the successive motion vectors. However, the proposed algorithm recovers the corrupted motion vectors within one pixel error, since the differences of the motion vectors and DCT coefficients of the following macroblocks can be successfully decoded in our approach.

The paper is organized as follows. Section 2 de-

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scribes the hierarchical synchronization technique to provide more robust and exact synchronization than the conventional inserting sync-codes. Section 3 presents the recovery algorithm for the corrupted motion vectors. Section 4 examines the performance of the proposed algorithm through computer simulation and shows the superiority of the proposed algorithm. Section 5 presents the conclusion of this paper.

2. HIERARCHICAL SYNCHRONIZATION TECHNIQUE

Each frame in the H.263 video data stream can be discriminated by the picture-sync-code (PSC), and the group-of-blocks (GOBs) in each frame, consisting of several macroblocks, are synchronized to prevent the corruption of the consecutive VLCs, due to the bit errors. But the insertion of sync-codes is not so practical to real error-prone environments. Thus, another scheme, such as the error-resilience entropy coding, has been proposed [3]. The EREC technique is capable of synchronizing the succeeding VLCs or variable length blocks (VLBs), by packetizing all bits to the fixed length slots with least redundancy. Let N VLBs be synchronized by the EREC and let the bit errors occur in p slots due to noisy channels, then the EREC technique can protect the rest $(N-p)$ VLBs at most.

Similarly, the proposed algorithm provides error-resilience capability to the compressed stream, by hierarchical synchronization based on the H.263 bitstream structure. Firstly, the GOB layers are synchronized with the information of total used bits (the fixed length frame header information and the variable length video data) in a frame, which can be achieved just by applying the EREC in the GOB level. Secondly, the bit rearrangement is repeated in the macroblock layers ,based on the GOB sync-position. And then the coded blocks in each macroblock are rearranged within the average macroblock size using the coded block pattern (CBP) information. Since the macroblock is composed of the header (the CBP information and the motion vectors) and the coded block data, the hierarchical structure of bit rearrangement, shown in Fig. 1, makes each macroblock to protect the header information more efficiently, and provides faster synchronization in the block layer, alleviating also the degradation in video quality. Finally, the synchronization technique is applied to the DCT coefficients layer.

The proposed algorithm requires no redundant information, such as the average macroblock size or the average block size in each macroblock. That is, the given bitrate is maintained, in spite of providing much more robustness to the transmission errors. And this

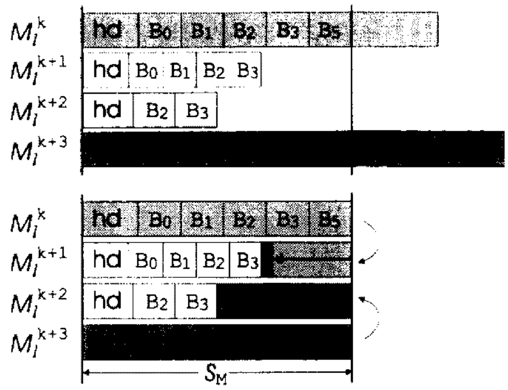

Figure 1: The structure of bit rearrangement in macroblock and block levels

technique employs the forward and backward bit arrangement. More specifically, the VLBs in each layer, whose length is less or equal to the average size, are rearranged in forward direction and the others in backward direction, which allows each VLB to be independent of each other against the bit errors.

Let s_M, T and N be the average macroblock size, the number of bits in a frame and the number of macroblocks, respectively, and let M_i and s_B^i be the i-th macroblock and the average block size of i-th macroblock, then the encoding procedure is summarized as follows:

1. Calculate $s_M = \lceil \frac{T}{N} \rceil$
2. Calculate $s_B^i = \frac{s_M}{(\# \text{ of blocks})}$, based on the CBP in each macroblock.
3. Classify all macroblocks into set $A = \{M_i : \mathit{length} \le s_M\}$ and set A^c.
4. For $M_i \in A$, rearrange the DCT coefficients by s_B^i and synchronize each block.
5. For $M_i \in A^c$, classify the coded blocks of M_i by s_B^i, similar to the step 3. Rearrange the DCT coefficients bits within s_B^i and synchronize each block. And for the blocks, whose length is larger than s_B^i, rearrange the remaining bits of the blocks sequentially at the tail of M_i.
6. Repeat the step 4 and 5 until all bits in the GOB level are completely rearranged.

Assuming that the picture-sync-code is transmitted with reliability, the total bits used in each frame can be obtained from $S_k = F_k - F_{k-1}$, where S_k and F_k are the total used bits of k-th frame and the position of k-th picture-sync-code, respectively. So, the sync-positions can be derived easily from total used bits of the frame. Similarly, the decoding procedure is described as follows:

1. Calculate $T_k = F_{k+1} - F_k$ and derive s_M. And then calculate the synchronization position of the GOBs and MBs.

2. For the macroblock M_i, whose length is less or equal to s_M, decode its header information and find synchronization position, based on the CBPs. And then decode the bitstream of each block, and repeat it until the decoding of the GOB layer bitstream is completed.

3. For the macroblock $M_j (j \neq i)$, search the dependent set of each macroblock, based on the decoded M_i, then continue to decode M_j.

4. For the erroneous macroblock M_k, try to decode B_l^k.

5. For the macroblock whose motion vectors are erroneous or lost, recover the motion vectors as shall be described later.

By rearranging the VLBs to the fixed length slots, the VLBs, whose length is longer than the average size, are spreaded to other slots (rearranged in backward direction) and apt to be corrupted by errors with high probability. In most cases, However, since only the high frequency DCT coefficients are included in the backward rearranged bits, the degradation in the video quality can be minimized.

3. RECOVERY OF THE LOST OR ERRONEOUS MOTION VECTORS

In the conventional H.263, the motion vectors are inter-coded. Let MV_i be the motion vector associated with i-th macroblock, the motion vectors of each macroblock in the GOB are arranged as $MV_0, MV_1, \cdots, MV_m$. The motion vector of the first macroblock is intra-coded, and the others are inter-coded such that $MV_{d_k} = MV_k - MV_{k-1}$. Therefore, the corruption of a motion vector results in failing to decode the motion vectors of the consecutive macroblocks. For example, if the motion vector of the i-th macroblock is erroneous, then the next motion vector is reconstructed erroneously such that $MV_{i+1} = MV_{d_{i+1}} + MV_i$, even if the difference $MV_{d_{i+1}}$ can be decoded correctly by our approach.

In the proposed algorithm, the motion vectors and some block data, associated with macroblocks succeeding the macroblock whose motion vectors are corrupted, can be decoded correctly with synchronization technique. These information can be used to recover the corrupted motion vector and correct the consecutive motion vectors. That is, the corrupted motion vector MV_i is recovered by selecting the possible motion vector, minimizing the sum of $\mathcal{F}\{\mathcal{D}(M_j)\} (i < j \leq i_{max})$, each of which is the sum of differences between the boundary pixel value of the j-th decoded macroblock $\mathcal{D}(M_j)$ and that of the boundary image, given by

$$
\begin{aligned}
(m_x, m_y) &= \arg \min_{(m_x, m_y) \in \mathcal{M}} \sum_{k \in G'_l} \mathcal{F}\{\mathcal{D}(M_k)\} \qquad (1) \\
\mathcal{F}\{\mathcal{D}(M_k)\} &= d_U + d_R + d_l \\
d_U &= \sum_{x \in M_k} |M_k(x, y_{min}) - M_k(x, y_{min} - 1)| \\
d_R &= \sum_{y \in M_k} |M_k(x_{max}, y) - M_k(x_{max} + 1, y)| \\
d_L &= \sum_{x \in M_k} |M_k(x, y_{max}) - M_k(x, y_{max} + 1)|
\end{aligned}
$$

where $\mathcal{M}$ is the set of possible motion vectors, or $\mathcal{M} = \{(m_x, m_y) : -16.5 \leq m_x, m_y < 16\}$, which is of half-pixel accuracy, and G'_l is the set of macroblocks affected by the erroneous motion vector.

If the MV_i is erroneous, then the possible motion vector $\hat{MV}_i$ and $MV_{d_j} (i < j \leq k)$ yields the MV_k, given by

$$MV_k = \hat{MV}_i + MV_{d_{i+1}} + \cdots + MV_{d_k} \qquad (2)$$

For the given motion vector $\hat{MV}_i$, the variation in the distortion is increased by accumulation of the erroneous motion vectors. Therefore, the corrupted motion vectors can be recovered with more accuracy, even if perfect recovery cannot be guaranteed, as the set G'_l is increased.

4. SIMULATION RESULTS

The proposed algorithm is evaluated on the real video sequences, "Foreman" and "Carphone" sequences. The test sequences are in the standard QCIF (176 × 144) format and the frame rate is 8.33 frames/sec. All sequences are encoded with the quantization step size 10 at variable bit rate (VBR). It is assumed that the wireless channel is a time-selective Rayleigh-fading channel, where the carrier frequency is 2GHz. For instance, the relative velocity between the mobile and the base station 60 km/h causes 111Hz in Doppler shift. And we adopt the DQPSK (differential quadrature phase shift keying) modulation scheme, which encodes two bits into one symbol and transmits the phase increment between two successive symbols. Since the detection of

(a) H.263, 23.40dB (b) Proposed, 29.44dB

Figure 2: "Foreman" 4-th frame, BER = 10^{-3}

(a) H.263, 27.69dB (b) Proposed , 30.68dB

Figure 3: "Carphone" 54-th frame, BER = 10^{-3}

DQPSK depends only on the phase difference, the amplitude distortion mainly caused by fading has little influence on the operation of DQPSK. Thus, it is believed that the DQPSK is robust to fading and doesn't cause relatively long bursty errors.

Fig. 2 shows the 4-*th* frame of the reconstructed "Foreman" sequence with bit error rate (BER) 10^{-3}. Fig. 2 (a) is obtained by the conventional H.263 with the simplest EC, in which the corrupted blocks are replaced by the blocks at the same location in the previous frame, and (b) by the proposed algorithm. Since there exist many motions in "Foreman" sequence, the conventional method yields the severe degradation in quality. On the other hand, the proposed algorithm is shown to provide better performance objectively and to make the damaged area to be subjectively less visible, although it causes some blocking artifacts in the boundary area, where the size of the used bits is much larger than the average macroblock size. As mentioned previously, notice that the high frequency DCT coefficients can be more vulnerable to the bit errors.

Fig. 3 shows the 58-*th* frame of the "Carphone" sequence with BER 10^{-3}. Since there exists relatively small motion in "Carphone" sequence, the damaged area, due to the channel errors, is not visible subjectively. However, the proposed algorithm is superior to the conventional H.263 by about 3dB.

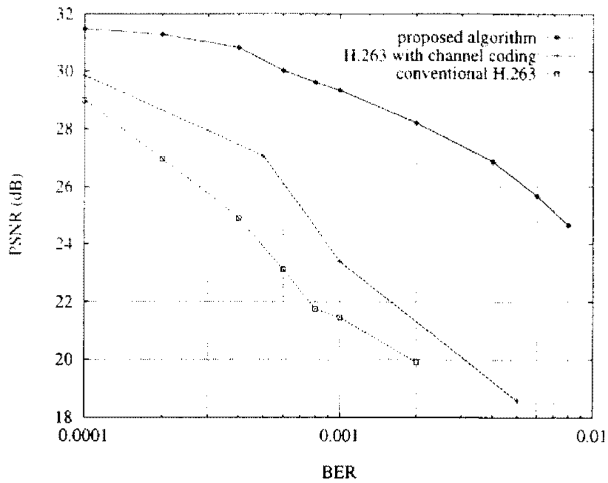

Figure 4: The PSNR performance by varying the BER ("Foreman" sequence)

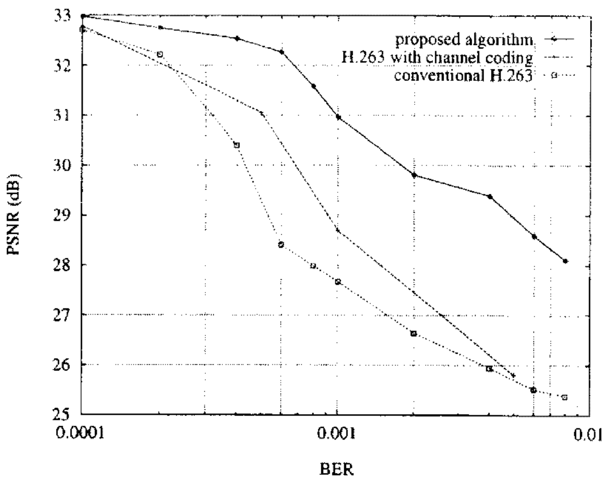

Figure 5: The PSNR performance by varying the BER ("Carphone" sequence)

Figs. 4 and 5 show the PSNR performance at various bit error rates. In the comparison, we consider the conventional H.263, the conventional H.263 with channel coding, and the proposed algorithm, where the channel coding is provided by the convolutional code with rate $R = 2/3$ [6]. These results show that the proposed algorithm can provide much better performance than the conventional methods.

5. CONCLUSION

In this paper, we proposed an error-resilient transmission technique for the H.263 video data stream over wireless networks. The proposed algorithm employed the bit rearrangement hierarchically, so that it provides the robust and exact synchronization against the transmission errors, without requiring extra redundant information. Moreover, the proposed algorithm provides more efficient protection to the relatively important information by hierarchical structure of bit rearrangement. In addition, the recovery algorithm for the lost or erroneous motion vectors was also proposed. The proposed algorithm was implemented, based on the H.263 standard, and evaluated through intensive computer simulation. The experimental results demonstrated that the proposed algorithm yields good image quality subjectively and objectively, in spite of transmission errors, and prevents the error propagation both in the spatial and the temporal domain efficiently.

6. REFERENCES

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