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Layered Multiple Description Coding For Robust Video Transmission Over Wireless Ad-Hoc Networks

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***Abstract*—** This paper presents a video transmission system using layered multiple description (coding (MDC) and multi-path transport for reliable video communications in wireless ad-hoc networks. The proposed MDC extends a quality-scalable H.264/AVC video coding algorithm to generate two independent descriptions. The two descriptions are transmitted over different paths to a receiver in order to alleviate the effect of unstable channel conditions of wireless ad-hoc networks. If one description is lost due to transmission erros, then the correctly received description is used to estimate the lost information of the corrupted description. The proposed MD coder maintains an adequate video quality as long as both description are not simultaneously lost. Simulation results show that the proposed MD coding combined with multi-path transport system is largely immune to packet losses, and therefore, can be a promising solution for robust video communications over wireless ad-hoc networks.

***Keywords*—** Multiple description coding, wireless video streaming, rate control.

I. Introduction

VIDEO streaming over wireless ad-hoc networks offers various possibilities for new applications, such as highway automation, broadband wireless Internet access, and search-and-rescue missions. However, video streaming over wireless ad-hoc networks has many technical challenges. Since ad-hoc networks are deployed instantly in situations where infrastructure is unavailable, the network topology is frequently changing due to node mobility and links are continuously established and broken. Therefore, the availability and quality of a link fluctuates and transmission error is more frequent than that in single-hop wireless networks.

The H.264/AVC video coding standard [1] provides a high coding efficiency and has a high degree of flexibility for operation in a variety of network conditions since many restrictions concerning the data structure (e.g., picture ordering, slice structure, and macroblock ordering) are removed. Flexible macroblock ordering (FMO), one of the new error-resiliency features provided in H.264/AVC, specifies a pattern that assigns the macroblocks in a picture to one of the slice groups. Each slice group is independently coded and transmitted. Recently, a simple two-layer scalable coder based on H.264/AVC has been proposed that allows H.264/AVC to achieve a quality scalable coding by exploiting the flexible macroblock ordering [2].

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Multiple description coding (MDC) has emerged as a promising technique to enhance the error resilience of a video transport system [3]. An MD coder generates two or more independently decodable and equally important descriptions (or bitstreams) so that each description alone provides low but acceptable quality and multiple descriptions lead to higher quality. This MD coding approach is especially effective in wireless ad-hoc networks where the error rate is high and the network conditions change frequently due to potential node mobility. The benefits of using MDC in video streaming can be further amplified when MDC is combined with multi-path transport [4], [5]. In these approaches, each description is explicitly transmitted over an independent path to a receiver. In wireless ad-hoc networks, multiple paths can be supported by practical multi-path routing protocols such as DSR and TORA [6].

In this paper, we propose a video transmission system using H.264/AVC-based MD coding and multi-path transport. The proposed MD coder divides a sequence of video frames into two regions according to motion activity and encodes the blocks belonging to the more important region into two independent descriptions. The two descriptions are transmitted over different paths to a receiver in order to alleviate the effect of unstable channel conditions of wireless ad-hoc networks. If the two descriptions are received error-free, then a high quality video is reconstructed. If one description is lost, then the other description can still be decoded to produce a basic video quality, and furthermore, the correctly received description is used to estimate the lost information of the corrupted description.

The rest of the paper is organized as follows. In Section II, we introduce the proposed multiple description video coding algorithm combined with multi-path transport and decoder-side error concealment. The simulation results are given in Section III and Section IV concludes the paper.

II. Proposed Scalable Multiple Description Video Coding

We propose a multiple description video coding method that extends the quality-scalable H.264/AVC video coding algorithm proposed in [2]. The proposed method achieves quality scalable coding by exploiting the block ordering scalability of H.264/AVC and improves the error resiliency of H.264/AVC in wireless ad-hoc networks by coding the video into multiple independently decodable descriptions. In addition, an error

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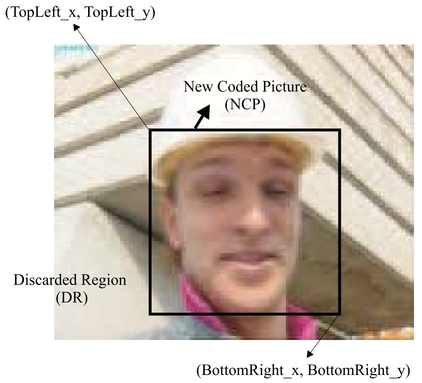


Fig. 1 Division of the original picture into a rectangular New Coded Picture (NCP) region and a Discarded Region (DR)

concealment algorithm is employed at the decoder to estimate the lost description based on the information contained in the correctly received description.

In the quality-scalable H.264/AVC video coding algorithm [2], the blocks containing a large amount of motion constitute the base layer of the coded sequence and provides a basic video quality. The blocks with low motion are considered to be less important and coded for enhancement. In each frame, only the blocks belonging to the base layer are coded and the enhancement layer blocks are substituted with the collocated blocks of the previous reference frame. Therefore, the moving parts of the sequence are coded using a higher number of frames and less moving or static parts are coded with a lower frame rate.

The proposed MD coding method extends the quality-scalable H.264/AVC algorithm to generate multiple independent descriptions for the blocks in the base layer. The detailed coding operation of the proposed method consists of the following steps. In the first step, motion vectors of the macroblocks (MBs) are estimated and the resulting information is used to determine the position and size of the coded region. The position and size of the New Coded Picture (NCP) region is defined by two points (`TopLeft_x, TopLeft_y`) and (`BottomRight_x, BottomRight_y`) as shown in Figure 1. First, the values (`TopLeft_x, TopLeft_y`) and (`BottomRight_x, BottomRight_y`) of the rectangle are initialized to zero. Then, the maximum of the two motion components of each MB (MV_x, MV_y) is compared to the motion activity threshold V_{th}. If

$$\max(MV_x, MV_y) \geq V_{th}, \tag{1}$$

then the values of the two corners are adjusted to include the current MB into the NCP region. Otherwise, the rectangle remains unchanged. Macroblocks are processed in the raster scan order and the two slices are determined at the end.

To increase error resilience of the quality-scalable H.264/AVC video coding algorithm, we encode the MBs in the NCP region using MDSQ [8] and generate two descriptions. In MDSQ, two quantizers whose decision regions are offset by one-half of a quantization interval from each other are used. Figure 2 shows an example of the decision regions of

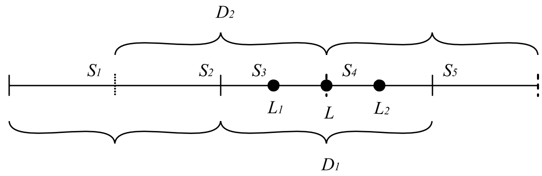


Fig. 2 The decision regions of the two coarse quantizers and the central quantizer defined in MSDQ [7]

the two coarse quantizers and the central quantizer defined in MDSQ. Let D_1 and D_2 be the two descriptions that have been generated by two coarse quantizers. When both descriptions are received, we can decide whether L_1 or L_2 is the correct reconstruction level. On the other hand, when only one of the descriptions is correctly received, we cannot decide the actual (fine) quantization interval. For example, when only D_1 is available, the reconstruction level is decided to be the midpoint L of the quantization interval $[S_2, S_5]$ (Figure 2) and this coarse quantization makes the single-description reconstruction quality low.

In order to improve the video quality in the presence of lost description(s), we employ an error concealment algorithm that exploits the spatio-temporal smoothness property in video signals as in [7]. When one of the descriptions is lost during transmission, only one description that contains the coarsely quantized MBs is available at the decoder. To enhance the single-description reconstruction quality at the decoder, we refine the coarsely quantized coefficients with a technique that finds the optimal coefficient adjustments by exploiting the smoothness property of video signals [7]. In this approach, our objective is to find the best reconstruction level for each coefficient so as to minimize a pre-defined spatio-temporal smoothness measure. The adjustment of the coefficient, δ, should be restricted to $\delta < \Delta$ (Figure 2), where

$$\Delta = \frac{S_5 - S_2}{2} = S_5 - L = L - S_2 \tag{2}$$

The refinement process for an $N \times N$ block can be represented in matrix form as

$$\mathbf{f} = \mathbf{T}(\hat{\mathbf{a}} + \mathbf{\Lambda}) \tag{3}$$

where $\vec{f}$ is a vector composed of the original sample values, $\vec{\hat{a}}$ and $\vec{\Lambda}$ are vectors containing the transform coefficients from the received description and the coefficient adjustments, respectively. $\vec{T} = [t_0, t_1, \cdots, t_{N^2-1}]^T$ and t_k is the k^{th} transform basis vector. All vectors are arranged in a row-major order. The optimal solution for Equation (3) with respect to $\vec{\Lambda}$ is given by

$$\mathbf{\Lambda_o} = \mathbf{f_p} - \mathbf{T}\hat{\mathbf{a}}, \tag{4}$$

where $\vec{f_p}$ is the temporal prediction for an $N \times N$ block.

The blocks in the discarded region are not coded and replaced with the collocating blocks of the previous reference frame. The two descriptions generated by the proposed MD coding method are transmitted over different paths to a receiver to increase the capacity and reliability of data transmissions.

Since the probability of all paths being down is relatively small because of the statistical independence of the packet loss events over different paths in the multi-path transport system, the probability of losing both descriptions is relatively small. The proposed MD coder is quality-scalable because the MBs in the more important slice (in the NCP region) are coded with a higher frame rate for base quality, while the less important MBs (in the discarded region) are coded with a lower frame rate for enhancement. The motion activity threshold value V_{th} controls the base layer quality and the coding bit rate. The proposed method is also error-resilient because it generates two independently decodable descriptions for the MBs belonging to the more important region, transmits them over different paths to a receiver, and therefore, maintains satisfactory video quality most of the time by exploiting inter-description redundancy.

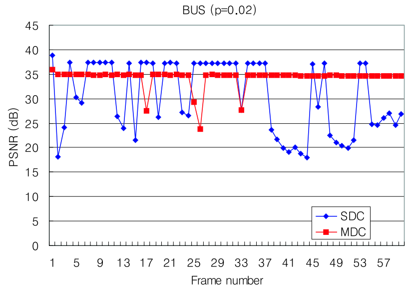
III. Performance Evaluation

A number of experiments were performed to examine the effectiveness of the proposed MD coding with multi-path transport versus the layered single description (SD) coding [2] with single-path transport in error-prone networks. We used the CIF (352×388 pixels/frame for luminance and 176×144 pixels/frame for chrominance components) sequence Bus encoded at 30 frames/s in the experiments. The SD coding and the proposed MD coding algorithms were individually implemented on top of the H.264/AVC JM 10.1 reference software.

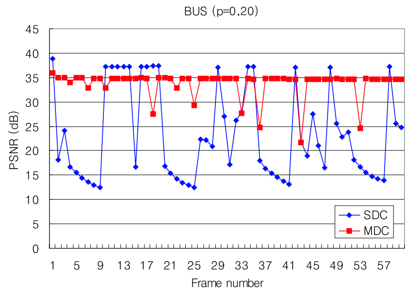
For the SD coder, the input video frames are divided into two regions according to the motion activity and the MBs belonging to the NCP region are coded into one description and transmitted over a single path. The encoding bit rate is set to 1.5 Mb/s. In the proposed system, the input video frames are divided into two regions according to motion activity and the MBs in the NCP region are encoded using MDSQ to generate two descriptions. For an intra MB, the transform coefficients are first quantized using the default quantizer, and then, two descriptions are generated by looking up the index assignment table proposed in [8]. For an inter MB, motion-compensation is performed based on the reconstruction generated using two descriptions, and the transform coefficients of the residual signal are coded into two descriptions using the same method as in intra MBs. For independent decoding of each description, the header and motion information of all MBs in a frame are duplicated in both descriptions. The combined bit rates for the two descriptions is set to 1.5 Mb/s. For the proposed multi-path transport system, we assume that two independent paths are already set up in advance.

Error concealment is performed at the decoder when packets are lost. In the SD coder, the lost frame is copied from the previous frame. In the proposed MD coder, if one of the descriptions is lost during transmission, then the MBs in the NCP region of the lost description are refined using the error concealment method introduced in Section II. If both descriptions are lost, then the lost frame is copied from the previous frame.

We compare the performance of the SD coder with single-path transport and the proposed MD coder with multi-path transport under various network conditions. Specifically, we examine the effects of packet loss rates and burst lengths for the two schemes. For the multi-path transport system, we assume that the two paths used are disjoint to each other. We can obtain two disjoint paths by using various heuristic algorithms as in [10].



(a)

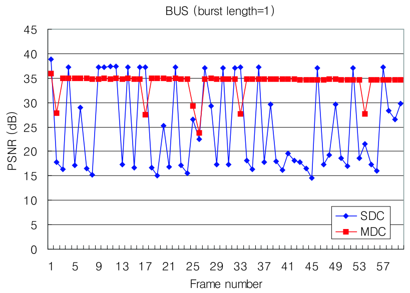


(b)

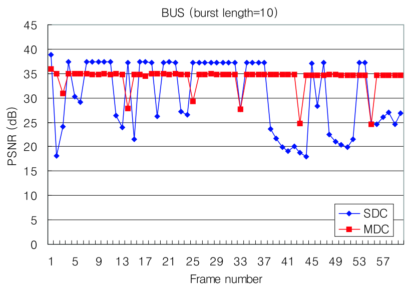
Fig. 3 Performance comparison between the SD coding with single-path transport and the proposed MD coding with multi-path transport (a) at 2% mean packet loss rate, and (b) at 20% mean packet loss rate

1) *Effect of packet loss rates:*
   Figures 3 (a) and (b) illustrate the PSNR values of the two schemes at different mean packet loss rates. The burst length was set to 5 for these experiments. The results show that the SD coding with single-path transport is very vulnerable to losses and the effect of loss propagates to future frames. However, the proposed MD coding with multi-path transport recovers fast from packet losses and maintains a reasonable video quality as long as both descriptions are not lost simultaneously.
2) *Effect of error burst lengths*: Figures 4 (a) and (b) compare the performance of the two systems at different burst lengths when the average packet loss rate was set to 10%. We observe that the reconstructed video quality of the single-path transport system fluctuates abruptly, especially when the burst length is short. On the other hand, the simulation results show that the proposed MD coding with multi-path transport is not sensitive to burst lengths.

Figure 5 compare the two schemes when the average packet loss rate and burst length are varied. When there is no loss, the performance of the proposed MD coding is lower than

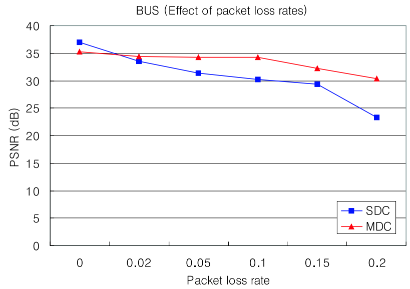


(a)

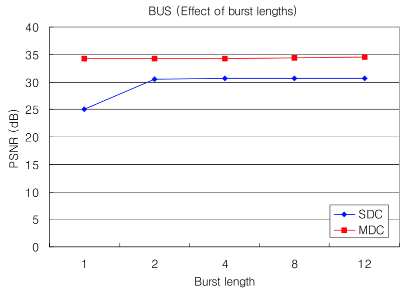


(b)

Fig. 4 Performance comparison between the SD coding with single-path transport and the proposed MD coding with multi-path transport (a) when burst length = 1, and (b) when burst length = 10



(a)



(b)

Fig. 5 Performance comparison between the SD coding with single-path transport and the proposed MD coding with multi-path transport (a) at different packet loss rates, and (b) with different burst lengths

that of the SD coding because of the redundancy introduced in generating multiple descriptions. However, as the packet loss rate increases the proposed MD coding with multi-path transport outperforms the SD coding with single-path transport because the proposed scheme is largely immune to packet losses and burst lengths as long as both descriptions are not lost simultaneously.

IV. Conclusion

This paper presents a video transmission system using H.264/AVC-based MD coding and multi-path transport for reliable video communications in wireless ad-hoc networks. The proposed method divides the input video frames into two regions according to motion activity and encodes the MBs belonging to the more important region into two independently decodable descriptions. Each description is transmitted over an independent path to a receiver. If both descriptions are received without errors, then a high quality video is produced. If one description is lost, then the other correctly received description can still be decoded and can be used to estimate the information contained in the lost description. Simulation results show that the proposed MD coding is largely immune to packet losses because the reconstructed video quality is maintained as long as both streams are not simultaneously lost. As a results, the proposed video transmission system consisting of H.264/AVC-based scalable multiple description coding, multi-path transport, and decoder-side error concealment enables reliable video delivery over wireless ad-hoc networks.

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