Refined Error Concealment for Multiple State Video Coding over Ad Hoc Networks

Yiting Liao and Jerry D. Gibson
Department of Electrical and Computer Engineering
University of California, Santa Barbara
Email: {yiting, gibson}@ece.ucsb.edu

***Abstract*—Providing reliable end-to-end video communications over wireless ad-hoc networks is a challenging problem due to the highly dynamic topology of the ad-hoc networks and the unreliable wireless channels. Multiple description coding (MDC) with path diversity is often proposed to maintain connectivity but the challenge is to match the chosen MDC method with an effective error concealment scheme. The paper proposes refined error concealment (REC) methods on a macroblock (MB) basis for a popular MDC method called multiple state video coding (MSVC) to improve the transmitted video quality over the lossy networks. The performance of the MSVC method with refined error concealment (MSVC_REC) is evaluated over a two-hop two-path wireless ad-hoc network model. When compared to MSVC and single description coding (SDC), MSVC_REC is shown to provide better PSNR performance over the wireless ad-hoc network with both burst and random losses.**

I. INTRODUCTION

Wireless ad-hoc networks have a dynamically changing topology that can cause failures of links and nodes, thus resulting in path loss. Additionally, video communications over wireless ad-hoc networks can suffer from noise and fading effects in the channel. Therefore, it is important to provide error resilience for reliable video communications over such an error-prone network. One possible approach is multiple description video coding (MDVC), where the basic idea is to encode the video sequence into several descriptions for transmission over multiple paths. Each description can be independently decoded and combined with the other descriptions to provide an acceptable video quality. When more descriptions are received for reconstruction, higher video quality can be achieved. The main benefit of MDVC is that it can provide adequate video quality without retransmitting lost packets.

Many MDVC algorithms have been proposed [1] and they can be divided into three categories: subsampling algorithms in temporal [2], spatial [3] or frequency domain [4], multiple description quantization algorithms [5], and multiple description transform coding [6]. Reference [7] provides a good review for MDVC algorithms.

Since subsampling methods are easy to implement and compatible with different video standards, they have been the most commonly investigated MDVC algorithms. These methods generally work in spatial, temporal, or frequency domain to generate multiple descriptions, and any corresponding correlation is used to recover a lost description. One of the most popular MDVC methods is multiple state video coding (MSVC) [2], which temporally downsamples the video sequence and uses the correlation between adjacent frames in two descriptions to recover from frame loss. More details about MSVC are discussed in Section II.

In this paper, we propose refined error concealment methods for MSVC and study the performance for video communications over a two-hop two-path wireless ad-hoc network model. This wireless ad-hoc network model characterizes burst losses in the network by a path availability model and random losses in the channel by a physical layer model, and therefore, the transmitted video may experience both consecutive frame losses and random macroblock (MB) losses. The proposed refined error concealment methods for MSVC conceal the lost MB by exploring the information from both descriptions to provide better recovery. Simulation results show that MSVC with refined error concealment (MSVC_REC) can effectively improve the video quality over such lossy wireless ad-hoc networks.

The paper is organized as follows. In Section II, the system architecture of MSVC is introduced and the properties of the two-path two-hop ad-hoc network model are analyzed. In Section III, the refined intra and inter MB concealment methods for MSVC are discussed, respectively. Performance comparisons for single description coding (SDC), MSVC and MSVC_REC over the wireless ad-hoc networks are presented in Section IV. Conclusions are given in Section V.

II. BACKGROUND

A. Multiple State Video Coding (MSVC)

Figure 1 shows the system architecture of the multiple state video coding (MSVC) method proposed by Apostolopoulos in [2]. The encoder part creates the two descriptions of the video sequence, which are then transmitted over two paths through the wireless ad-hoc network.

In this paper, we apply the MSVC method using the H.264 coder [8]. The video sequence is temporally downsampled into two sub-sequences and encoded as two descriptions (shown in Fig. 1) using the H.264 encoder. The two descriptions are then transmitted over the ad-hoc network using path diversity. When

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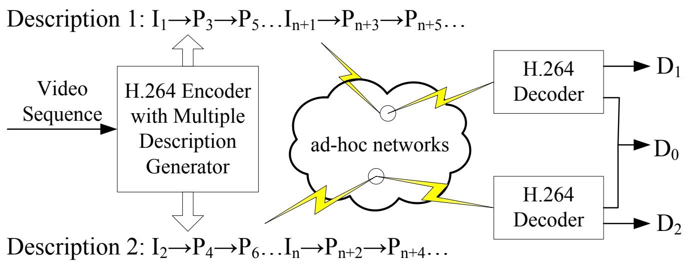


Fig. 1. MSVC system architecture

both descriptions are successfully received at the decoder, they can be decoded and interleaved for display. If one description suffers severe losses, the other description can still be decoded independently and used to conceal the lost description. Due to the decreased correlation between adjacent frames, the total bitrate is increased by MSVC for equivalent error-free performance.

B. Two-hop Two-path Ad-hoc Network Model

Because of the dynamic topology of wireless ad-hoc networks, the paths in the network may fail and cause burst losses. Also, there are random bit errors due to noise and fading in the physical channel. A two-hop two-path ad-hoc network model in [9], which consists of a path availability model [10] and a physical layer model [11], is used to capture the packet loss features of wireless ad-hoc networks.

1) Path Availability Model [10]: The path availability model characterizes the burst losses in the network caused by route changes, node mobility, *etc*. The model assumes that there are N+2 nodes in the area as shown in Fig. 2. Two nodes represent the sender and receiver nodes while the other N nodes, which move randomly in the area, can serve as the router nodes. In this model, a two-hop scenario is used, i.e. a path between the sender and receiver nodes is set up when one of the N nodes can serve as the router node. The path may become unavailable due to node movement and route switching delay. The average path unavailability time depends on many factors such as number of nodes in the network, distance between sender and receiver nodes, node velocity, and transmission range. According to [9], we know that the path down time is on the order of seconds, which may cause long burst packet losses. We will see later that MSVC is an effective method to combat burst losses in the network.

2) Physical Channel Model: When the path is set up for transmission, we need to consider bit errors due to the noise and fading in the physical channel, and the Gilbert Elliot model [11] is used to simulate this random loss. In this model, the channel transits between the good state (low bit error rate) and the bad state (high bit error rate) with certain transition rates. Any bit error in a packet will cause packet loss. Therefore, the packet loss rate is higher for a larger payload size.

III. MSVC WITH REFINED ERROR CONCEALMENT

When video is transmitted over wireless networks, a typical maximum transfer unit (MTU) size is around 100 bytes [12], which means each frame consists of more than one packet. Therefore, a packet loss only causes some MB losses in a frame. In [2], it is assumed that every packet loss leads to one entire frame loss and the state recovery methods introduced are on a frame basis. In this paper, we propose the refined error concealment methods on a MB basis to enhance the reconstructed video quality for MSVC. We refer to the approach as multiple state video coding with refined error concealment (MSVC_REC).

In general, the existing error concealment methods exploit the correlation between a lost macroblock and its adjacent MBs in the spatial or temporal domain. In H.264, some non-normative error concealment methods are introduced to conceal the lost MBs. The lost MB in an intra frame is concealed by weighted pixel interpolation while the lost MB in an inter frame is recovered by motion-compensated concealment using the estimated motion vectors.

A. Refined Intra MB concealment for MSVC

In H.264, the lost MB in an intra frame is concealed spatially based on weighted pixel interpolation. Each pixel in the lost MB is estimated from the weighted sum of the boundary pixels in the adjacent MBs. If two or more correctly received neighboring MBs are available, only they are used for concealment. Otherwise, concealed MBs are also used for the interpolation. The lost MB in an intra frame is only concealed spatially in order to stop the error propagation from the previous group of picture (GOP). For MSVC, each description has an intra frame in every GOP and the two intra frames are consecutive as shown in Fig. 1. Therefore, we can apply both temporal and spatial concealment for the lost MB in the two consecutive intra frames.

The process to conceal lost MBs in the two consecutive intra frames is shown in Fig. 3. The lost MB in the intra frame is concealed by either copying the MB from the corresponding position in the other intra frame or applying weighted pixel interpolation. If both intra frames have some lost MBs in the same position, these lost MBs are concealed by weighted pixel interpolation. Otherwise, we copy the MB in the corresponding position in the other intra frame and calculate the side match distortion [13] from the correctly received neighbour MBs. If the side match distortion is smaller than the pre-defined

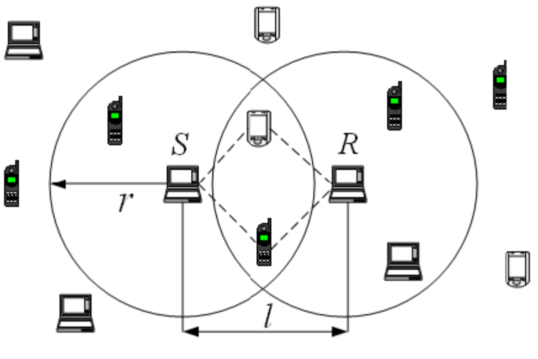


Fig. 2. Two-hop ad-hoc network, S: Sender, R: Receiver [9]

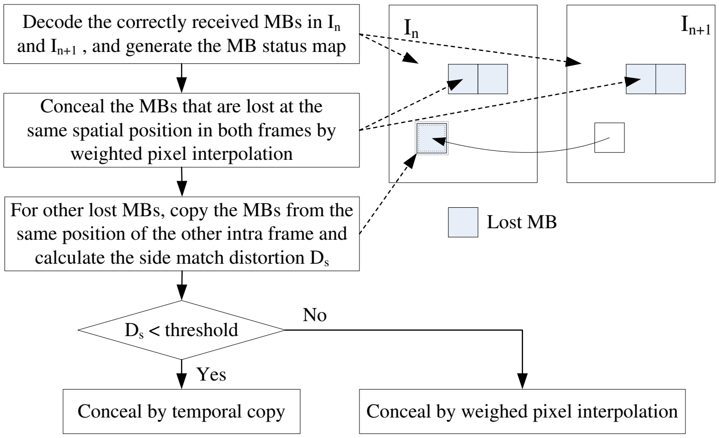


Fig. 3. Error concealment in intra frame for MSVC

threshold, the temporal copy concealment is applied to conceal the lost MB. If not, the weighted pixel interpolation is used to conceal the lost MB.

B. Refined Inter MB concealment for MSVC

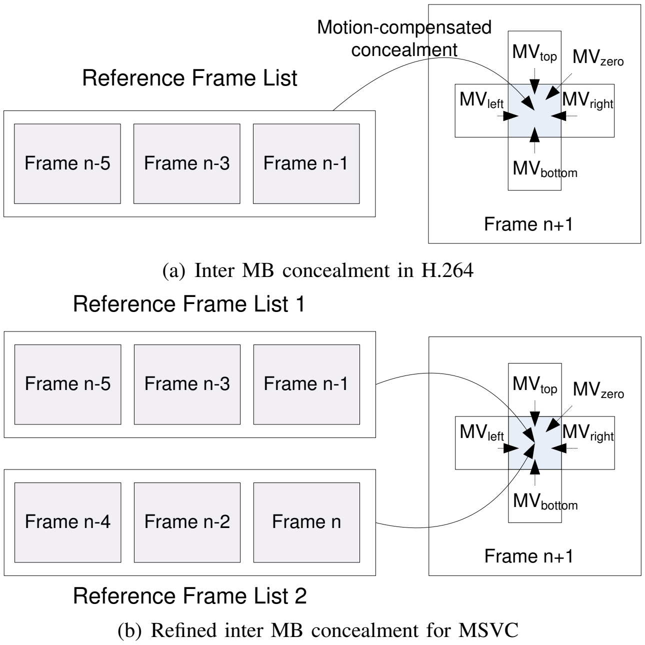
In [13], the lost inter MB is concealed by estimating the lost motion vector from the neighbour MBs and applying motion-compensated prediction. When an inter MB is lost, the motion vector of the missing MB is predicted from one of the neighbour MBs or zero motion vector as shown in Fig. 4(a). The motion vector that has the minimum side match distortion is used for motion-compensated concealment. The reference frames used to conceal the lost MB are the same as the reference frames for correctly received MBs.

For MSVC, we can explore the information from both descriptions to enhance the inter error concealment, that is, we use two reference frame lists from each description respectively for the motion-compensated concealment. The reference list that results in better side match distortion is used as the reference to recover the lost MBs. As shown in Fig. 4(b), we add reference frame list 2 from the other description. Since the estimated motion vector is corresponding to the reference frames in list 1, we need to scale it accordingly when reference frame list 2 is used. The same motion-compensated concealment is applied for reference frame list 2. Finally, we choose the estimated motion vector and reference list that minimizes the side match distortion to conceal the lost inter MB.

IV. PERFORMANCE COMPARISON

A. Simulation Settings

In the simulation, we compare MSVC_REC to SDC and MSVC. Two QCIF (176×144) video sequences, Foreman and Coastguard, with 120 frames are encoded for SDC, MSVC, and MSVC_REC using baseline profile in JM13.2 [14] with RTP packet size 100 bytes. The GOP for each description is 40 and the total bitrate is set to be 150 kbps. Random intra refresh, which randomly encodes some MBs in intra mode, is introduced to enhance the error robustness of SDC. For MSVC, the state recovery method is applied on a frame basis, which means the lost frame is estimated by performing a motion-compensated interpolation from the correctly received frames in the other description. The refined error concealment methods proposed in Section III are implemented for MSVC_REC.



(a) Inter MB concealment in H.264

(b) Refined inter MB concealment for MSVC

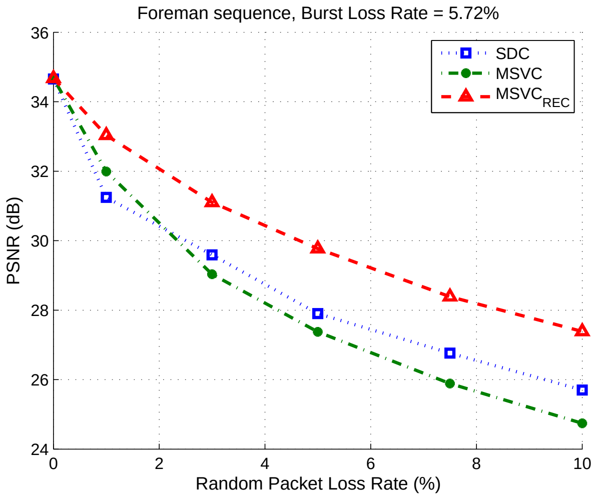
Fig. 4. Inter MB concealment methods

The two-hop two-path ad-hoc network model introduced in Section II-B is used to generate the error pattern. The plotted PSNR is averaged over 300 realizations for each error pattern. We investigate the effect of both burst losses due to path unavailability and random loss caused by bit errors in physical channel.

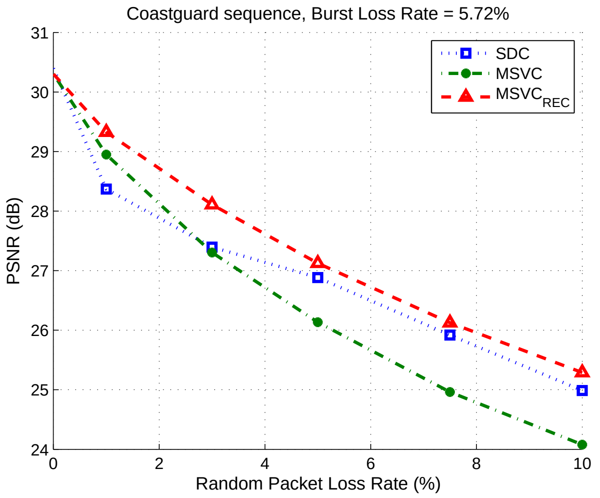
B. Simulation Results

In Fig. 5, the burst loss rate in the ad-hoc networks is fixed at 5.72% and the PSNR performance under different random loss rates is shown. Fig. 5(a) shows that, for the Foreman sequence, MSVC achieves a higher PSNR than SDC when the random loss rate is 1% and has a lower PSNR than SDC as the random loss rate increases. One reason is that SDC uses random intra refresh to enhance its error robust to random packet loss. In addition, the correlation between adjacent frames within a description for MSVC is lower than SDC, so the motion-compensated concealment for the original MSVC does not conceal the random lost MBs as well as SDC. In Fig. 5(a), we also see that the MSVC_REC method we propose outperforms MSVC in the range of 1.05 dB-2.64 dB and has a higher PSNR at around 1.8 dB than SDC. This is because with the refined error concealment methods, MSVC_REC better exploits the correctly received information from both descriptions to conceal the random lost MBs and thus alleviates error propagation.

Similar results can be seen for the Coastguard sequence in

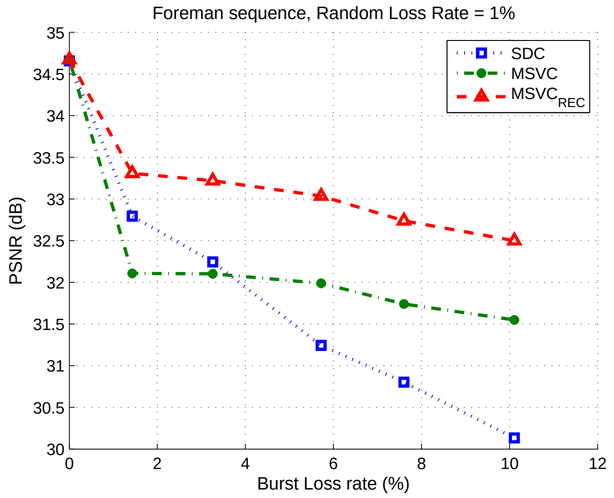


(a) Foreman sequence

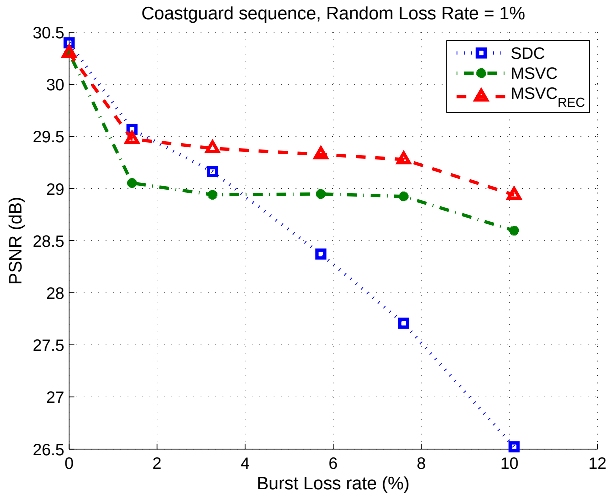


(b) Coastguard sequence

Fig. 5. PSNR performance in terms of random packet loss rate



(a) Foreman sequence



(b) Coastguard sequence

Fig. 6. PSNR performance in terms of burst loss rate

Fig. 5(b). The performance improvement for MSVC_REC is within the range of 0.4 dB-1.2 dB when compared to MSVC, and between 0.2 dB-1.0 dB when compared to SDC. Note that Coastguard sequence has higher motion than Foreman sequence and the temporal copy method may not perform well for high motion MBs.

Figure 6 investigates the PSNR performance for SDC, MSVC, and MSVC_REC under different burst loss rates. The random loss rate in the physical channel is fixed at 1% and the burst loss rate varies when the number of nodes in the ad-hoc network changes. We notice that performance of SDC drops greatly as the burst loss rate increases, which means SDC is vulnerable to long burst losses. On the other hand, PSNR of both MSVC and MSVC_REC drop slowly when the burst loss rate increases. We know that even if one description for MSVC is totally lost, the other description can still be correctly decoded and used to recover the lost description. The results shown in Fig. 6 prove that MSVC and MSVC_REC are more effective to combat burst losses than SDC. Also, MSVC_REC has higher PSNR than MSVC at about 1 dB for the Foreman sequence, and at about 0.4 dB for Coastguard sequence.

In Fig. 5 and Fig. 6, we see that MSVC_REC has better performance than SDC and MSVC under different combinations of burst loss rates and random loss rates. The performance gain for MSVC_REC compared to MSVC increases when random loss rate increases and a better gain is achieved for MSVC_REC compared to SDC when burst loss rate increases.

V. CONCLUSIONS

In this paper, we have proposed refined error concealment methods for MSVC based on H.264 to improve the error resilience for video communications over wireless ad-hoc networks. The refined intra MB concealment provides better concealment for the MBs in intra frames by using the temporal correlation between adjacent intra frames in two descriptions.

The refined inter MB concealment achieves improvement from the additional reference list used for motion-compensated concealment. Compared to SDC and the original MSVC, the MSVC_REC method is shown to obtain performance gains over the wireless ad-hoc networks for a wide range of different burst loss rates and random loss rates.

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