VIDEO TRANSPORT OVER AD-HOC NETWORKS USING MULTIPLE PATHS

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ABSTRACT

Enabling video transport over ad-hoc networks is more challenging than over other wireless networks because a connection path in an ad-hoc network is highly error-prone and a path can go down frequently. On the other hand, it is possible to establish multiple paths between a source and a destination, which provides an extra degree of freedom in designing video coding and transport schemes. In this paper, we review several video encoding and transport control techniques, all assuming that a routing protocol is able to set up and constantly update two paths each made of multiple links. The techniques that we have examined include i) layered coding and selective Automatic Repeat Request (ARQ), ii) reference picture selection, and iii) multiple description coding. Depending on the availability of a feedback channel, the delay constraint, and the error characteristics of the established paths, one technique is better suited than another. These techniques are also applicable to other networks such as the Internet where it is possible to set up multiple paths.

1. INTRODUCTION

An ad-hoc network is a collection of mobile nodes that will create the network "on the fly". The main differences between ad-hoc networks and conventional cellular technology are the lack of a centralized administration within ad-hoc networks and the independence from pre-existing infrastructure. Consequently, in an ad-hoc network, besides having quite high transmission bit error rates during fading periods, the network topology may change frequently and unpredictably, which makes video transmission over ad-hoc networks more challenging than over conventional wireless networks. On the other hand, since all nodes in an ad-hoc network can be connected dynamically in an arbitrary manner, it is usually possible to establish more than one path between a source and a destination given their mesh topology, and many ad-hoc routing protocols (e.g., ZRP [1]) essentially provide multiple paths between the source node and the destination node. A video coding and transmission scheme should take advantage of the availability of multiple paths for combating transmission errors.

The idea of utilizing path diversity in multimedia data transmission was proposed in [2, 3], which mainly considered image transmission. Recently, several error resilient video coding and transport control techniques have been proposed for video transmission using path diversity, especially in an ad-hoc network environment. In [4], a feedback-based reference picture selection scheme for video transmission over multiple paths was proposed. By selecting reference pictures according to the predicted status of the paths' condition and the correctly decoded pictures, which in turn depends on the feedback message, the scheme can achieve high error resilience at some cost in coding efficiency. Layered coding combined with a selective ARQ transport scheme was proposed in [5], in which base layer and enhancement layers are transmitted over different paths and only base layer is allowed to be retransmitted. This scheme can significantly reduce error propagation in the reconstructed frames at the cost of retransmission delay. Both of the above two schemes are applicable only when feedback channels are available in transmission.

If feedback is not available, multiple description coding (MDC) is a natural option for multiple path transmission. MDC refers to a coding method that generates two or more correlated bitstreams so that a high-quality reconstruction can be obtained from all the bit streams together, while a lower, but still acceptable, quality reconstruction is guaranteed if only one bit stream is received. A multiple description video coding technique, dubbed multiple description motion compensation (MDMC), was proposed in [6]. MDMC predicts current frame from two previously encoded frames and transmits different descriptions over different paths. By varying the coding parameters, it can achieve the desired trade-off between redundancy and distortion.

In this paper, the above three video encoding and transport control techniques are reviewed. Their pros and cons are studied. The paper is organized as follows. Details of these three schemes are given in section 2. In section 3, simulations are conducted to observe the performances of

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the three schemes. Their pros and cons are discussed in section 4.

2. THE THREE PROPOSED SCHEMES

In this section, we discuss the details of the three proposed schemes in [4, 5, 6]. To simplify the discussion, we assume two paths are used in the transmission. The three schemes can be extended to more than two paths with some minor modifications.

2.1. Feedback Based Reference Picture Selection

One of the main challenges in video coding for ad-hoc networks is how to limit the extent of error propagation caused by one bad path. Feedback based reference picture selection (RPS) scheme in [4] can achieve both high error propagation resilience and high coding efficiency by choosing reference frames based on the feedback message and path status prediction. In the RPS scheme, even frames are sent on one path and odd frames are sent on the second path. If any packet in a frame is detected as lost, the receiver sends a negative feedback (NACK) for that frame. Otherwise, it sends a positive feedback (ACK). In the encoder, if an ACK is received for frame n, the path on which frame n was transmitted is marked as a "good" path , otherwise, the path is marked as a "bad" path. The encoder always selects the nearest possibly correctly decoded frame as the reference picture, which is either a frame sent on a "good" path which has not been acknowledged yet, or a frame with a positive acknowledgement. Such a scheme offers a good trade-off between coding efficiency and error resilience. When both paths are good, it uses the immediate neighboring frame as the reference, thereby achieving the highest possible prediction gain and consequently coding efficiency. On the other hand, when one path is bad, the encoder avoids using any frames that are affected by path errors, thereby minimizing the error propagation period. Figure 1 is an example of the proposed reference selection scheme. Here we assume Round Trip Time (RTT) is less than 3 coded frames intervals. When NACK (1) is received at the time for coding frame 4, the encoder knows that frames 2 and 3 cannot be decoded correctly. Therefore, frame 0 is chosen as reference for frame 4. Furthermore, path 2 is set to "bad" status. When encoding frame 6, because path 2 is still in the "bad" status the encoder uses frame 4 instead of frame 5 as reference frame. On the other hand, when ACK (7) is received, path 2 is changed to "good" status, so frame 9 is chosen as the reference of frame 10.

The efficiency of feedback-based RPS depends on the delay involved in receiving the feedback information. The shorter the delay is, the more quickly the encoder can response to the changing characteristics of the channels and

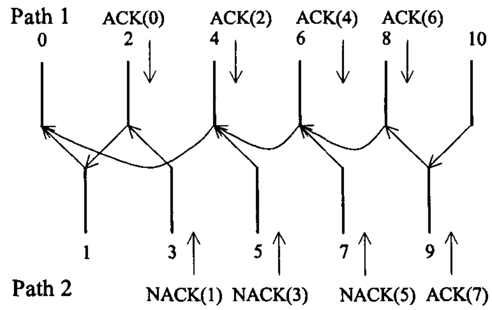

Fig. 1. Illustration of the RPS scheme. The arrow associated with each frame indicates the reference used to code that frame.

use less distant frames as reference pictures, the more quickly the decoder can stop the error propagation. Note that the delay in receiving the feedback information does not cause extra decoding delay. Therefore, this feedback-based approach is a viable options even for interactive applications. In the RPS scheme, additional buffers are needed both in the encoder and decoder.

2.2. Layered Coding and Selective Automatic Repeat Request

The above reference picture selection technique dose not introduce any decoding delay. If some delay is allowed, a layered video coding along with selective ARQ [5] can be used. In this scheme, a video stream is layer coded. The packets of base layer and those of enhancement layer are transmitted separately on two disjoint paths. The receiver will send ARQ requests to the sender if a base layer packet is lost. The base layer packet is retransmitted on the path of the enhancement layer and the enhancement packet scheduled to be transmitted at that time instance is discarded. In such a case, the next enhancement layer is predicted only from its base layer. Figure 2 shows an example of the proposed scheme. The scheme essentially is an unequal protection technique. Its error resilient performance does not depend on the RTT but the decoding and display delay is determined by RTT (the additional delay caused by retransmission is 1.5D if D is the RTT). Additional buffers are also needed in this scheme.

2.3. Multiple Description Motion Compensation

Unlike the above two techniques, multiple description motion compensation (MDMC) codec [6] is a multiple description coding scheme which does not require a feedback channel. MDMC is built on top of the highly successful block-

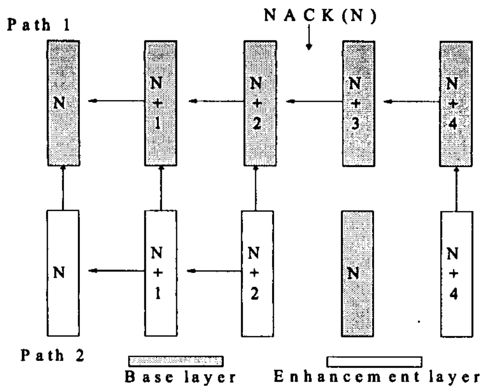

Fig. 2. Illustration of the layered coding and base layer ARQ scheme.

based motion compensated prediction (MCP) framework. Compared with traditional MCP, MDMC uses a linear superposition of two predictions from two previously coded frames. In the MDMC encoder, the central prediction is obtained by [1]

$$\hat{\psi}(n) = h_1 \tilde{\psi}_e(n-1) + (1-h_1)\tilde{\psi}_e(n-2), \quad (1)$$

where $\tilde{\psi}_e(n-1)$ and $\tilde{\psi}_e(n-2)$ are motion compensated predicted signals constructed from two previously encoded frames $\psi_e(n-1)$ and $\psi_e(n-2)$ respectively. The central prediction error $e_0(n) = \psi(n) - \hat{\psi}(n)$ is quantized by quantizer $Q_0(\cdot)$ to $\tilde{e_0}(n)$. The quantized prediction errors and motion vectors for even frames are sent on one path, and those for odd frames are sent on the other path. In the decoder, if frame $n-1$ is received, frame n is reconstructed using

$$\psi_d(n) = h_1 \tilde{\psi}_d(n-1) + (1-h_1)\tilde{\psi}_d(n-2) + \tilde{e}_0(n). \quad (2)$$

If frame $n-2$ is damaged but frame $n-2$ is received , the decoder only use reconstructed frame $n-2$ for prediction, i.e. $\hat{\psi}_d(n) = \tilde{\psi}_d(n-2)$. To circumvent the mismatch between the predicted frames used in the encoder and the decoder, the signal $e_1(n) = \tilde{\psi}_e(n-2) - h_1\tilde{\psi}_e(n-1) - (1-h_1)\tilde{\psi}_e(n-2) - \tilde{e}_0(n)$ is quantized by another quantizer $Q_1(\cdot)$, which is typically coarser than $Q_0(\cdot)$, and the output $\tilde{e}_1(n)$ is sent along with other information of frame n. Now when frame $n-1$ is damaged but frame $n-2$ is received, the side decoder reconstructs the frame n using

$$\psi_d(n) = \tilde{\psi}_d(n-2) + \tilde{e}_0(n) + \tilde{e}_1(n). \quad (3)$$

In addition, the lost frame $\psi(n-1)$ is estimated based on $\tilde{e}_0(n)$ and reconstructed even frames, using

$$\tilde{\psi}_d(n-1) = \left(\psi_d(n) - (1-h_1)\tilde{\psi}_d(n-2) - \tilde{e}_0(n)\right)/h_1. \quad (4)$$

[1] The original MDMC codec in [6] was developed for an ideal MD channel, in which a description is either completely received or lost. We modified its implementing for application in a lossy packet networks.

The MDMC codec can offer trade-offs between redundancy and distortion over a wide range by adjusting the predictor coefficient h_1 and the parameter for quantizer $Q_1(\cdot)$. These coding parameters can be varied based on the desired redundancy-distortion trade-off, which in turn depends on network error characteristics. There is only one additional buffers needed in MDMC compared with the conventional codec that uses only one previous frame for MCP.

3. PERFORMANCE OF THE THREE SCHEMES

To evaluate the performance of the three techniques, the QCIF sequence "Foreman" (frame 1 to 200, QCIF) are encoded at 10 fps. We assume the allocated bandwidth on each path for source coding is 57kbps. TMN8.0 [7] rate control method is used in RPS and ARQ but the frame layer rate control is disabled. In both cases, the feedback time is assumed to be less than 300ms. In MDMC, h_1 is set as 0.9, and quantization parameter (QP0,QP1) is fixed at (8,15), which can satisfy the same bandwidth requirement. Note that for MDMC method, its optimal coding parameters h_1 and QP1 are determined by the characteristics of the source and the channels. It is likely that some other choice of the coding parameters may yield better results for MDMC. In all methods, 5% macroblock level intra refreshments are used. One group of blocks (GOB) is packetized into each packet. In layered coding+ARQ transmission, the base layers are transmitted on the better channel if the two channels have different error characteristics.

We also simulate two other options for video transmission over the two-path environment: video redundancy coding (VRC) [8] and alternative GOB (Alt-GOB) transmission. VRC is a error resilient video coding technique which generates several independent bit streams by using independent prediction loops. In the special case of two descriptions, an even frame is predicted from the previous even frame, and an odd frame from the previous odd frame. The information of even frames is sent on one path and that of odd frames on the other path. In VRC the 2-5 mode is used when the two channel packet loss rates are (3%,3%) and the 2-3 mode is used for the loss rates of (10%,10%) and (5%,10%), based on the recommendation given in [8].In Alt-GOB transmission, even GOBs and odd GOBs are sent to two paths alternatively. In the decoder, the missing GOBs are concealed using the motion information from above GOBs.

To simulate video transmission over ad-hoc networks, a multi-hop channel model [4] was used to generate bursty packet loss patterns. WE assume that multiple paths can typically be set up for two end users and each path consists of multiple links. A three-state Markov model was used for each link with the three states representing the "good", "bad" and "down" status of the link, respectively. The "down"

Table 1. Average PSNR of Decoded Images in Our Simulations

packetloss rate	(3%,3%)	(10%,10%)	(5%,10%)
RPS	31.3	27.5	28.8
layer coding+ARQ	31.1	29.4	30.6
MDMC	31.3	26.8	27.9
VRC	30.1	24.8	25.3
Alt-GOB	27.73	23.26	24.20

Table 2. Comparison of the Three Schemes

	RPS	layered+ARQ	MDMC
feedback needed	Yes	Yes	No
decoding delay	No	$\geq$ 1.5RTT	No
redundancy controlled by	error rates	error rates	encoding parameters
additional buffers	$\geq$RTT*fps	$\geq$1.5RTT*fps	1

state means the link is totally unavailable (loss rate is 1). The "good" state has a relatively lower packet loss rate than the "bad" state. The packet losses are assumed to consist of packets lost due to link failures or FEC failures. In our simulation, two paths were set up for each connection, and each path was continuously updated as follows: After every two seconds, four links were chosen randomly from a link pool to construct a new path. Each link had its own state transition parameters and packet loss rates. A video packet can go through a path correctly only when it goes through every link successfully. For each pair of specified average loss rates, ten packet loss traces were generated according to the above multi-hop channel model. The average PSNRs of decoded video sequences are given in Table 1. From this table, we can see i)The three proposed schemes all outperform VRC and Alt-GOB; ii)layered coding+ARQ has highest decoding quality when packet loss rate is high, especially for unbalanced channels; iii) for channels with low error rate, MDMC and RPS outperforms layered coding+ARQ.

4. COMPARISON OF THE THREE SCHEMES

The above three schemes have their respective pros and cons. Depending on the availability of a feedback channel, the delay constraint, and the error characteristics of the established paths, one technique may be better suited than another.

Layered coding along with selective ARQ is suitable when feedback channels are available and the latency caused is tolerable in the application. The redundancy of this scheme comes from the scalable coding and the retransmission. It is difficult to control the amount of the redundancy introduced, so it has the lowest quality when packet loss rate is low. However, when the packet loss rate is high, this method provides better video quality than the other two proposed scheme, at the cost of extra delay. If the RTT is equal to d frame intervals, then the additional delay is at least $1.5d$. Also, additional buffers are required at both the encoder and decoder to store up to $1.5d$ previous frames.

RPS is applicable when feedback channels are available. The redundancy depends on the packet loss rate and the RTT. When the paths are error free, RPS has the highest encoding efficiency. Compared with ARQ, there is no decoding delay incurred but additional buffers are still needed.

MDMC, unlike the other two, does not need feedback, nor does it incur additional delay. It is easier to control the redundancy in MDMC by changing the predictors and the side quantizer.The redundancy can be achieved in a wider range than the above two schemes. Since MDMC needs no feedback information, so it does not require on-line encoding. For video streaming applications, the video can be pre-encoded. The challenge with MDMC is how to adapt the coding parameters based on the error characteristics of the paths so that the added redundancy is appropriate.

5. REFERENCES

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