Multipath Transmission with Forward Error Correction Mechanism for Delay-sensitive Video Communications

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Abstract

The Concurrent Multipath Transmit with Forward Error Correction (CMT-FEC) mechanism uses multiple paths for data transfer and employs Forward Error Correction (FEC) to adapt to changing conditions in the wireless network. The CMT-FEC mechanism cannot be used in delay-sensitive video communications when the FEC block length is longer than the end-to-end delay because this will lead to the video frame not being playable on-time at the receiver end. This paper proposes the Delay-sensitive Multipath FEC (DM-FEC) mechanism using a mathematical analytical model to determine the appropriate transmission rate, FEC block length, and FEC redundancy on each path in a multipath environment. The DM-FEC mechanism does not cause the video frame to be unplayable or impede the timely recovery of video information.

Keywords: Multipath Transmission, Forward Error Correction, Delay-sensitive.

I. Introduction

Wireless networks have seen tremendous growth in recent years. The high bandwidth consumption properties of video communications necessitate stringent requirements with respect to delay, bandwidth availability, and packet loss. The current Internet was originally designed for data transmission and not for video communications, and thus it can be used to provide only best-efforts services. The current situation makes the deployment of video communications over the Internet an unprecedented challenge. Moreover, wireless networks are more prone to being congested due to wireless channel interference or low channel strength, leading to bit errors in the packet. Once wireless losses occur during transmission, the error propagates because of dependencies among the compressed video stream. As a result, the reconstructed video quality deteriorates severely. Therefore, it is important to devise new ways to protect compressed video streams from channel errors.

Forward Error Correction (FEC) has been a commonly used mechanism which offers such protection. The FEC mechanism improves the reliability of transmission by adding extra redundancy packets [1]. The principle of the FEC mechanism is that \(k\) source packets with \(h\) redundant packets become a block with \(n\) packets. When a receiver receives \(k\) or more packets, the decoder recovers the missing or error packets from the redundant packets [2]. Multipath transmission can reduce the variability in packet loss which enhances the recovery performance of the FEC mechanism [3]. To enhance the transmission performance, we proposed Concurrent Multipath Transmit with Forward Error Correction (CMT-FEC) mechanisms in [4], [5], and [6] which use multiple paths to exploit multiple paths effectively. Multipath transmission is a transmission mechanism by which the sender relays packets via more than one path at the same time and the receiver receives packets from either a single path or from multiple paths. The important benefit resulting from the use of multipath transmission is that, because the packet loss patterns for different paths are independent and packet losses do not occur simultaneously, burst packet losses do not occur. Reducing burst packet losses is very important for video communications because it is easier to recover the video content from several isolated losses [7]. Multipath transmission has more available bandwidth which can be used for transmitting video communications.

Previous studies have not considered packet loss types that cause congestion and wireless packet losses, and FEC redundancy increased as the average packet loss rate increased. Indiscriminately increasing FEC redundancy would result in the self-induced congestion effect impeding the timely recovery of video information because of packet losses and longer end-to-end delay. Moreover, previous studies have not selected the most appropriate transmission rate on each path. Congestion packet losses become critical when the available bandwidth is insufficient on some paths. Furthermore, previous studies haven’t selected the most appropriate FEC block length. The video frame not being playable on-time at the receiver side becomes critical when the end-to-end delay is longer. Accordingly, a Delay-sensitive Multipath Transmission with FEC (DM-FEC) mechanism is proposed to resolve the above-mentioned problems. We
propose a mathematical analytical model, with which we can find the appropriate transmission rate, FEC block length and FEC redundancy on each path in a multipath environment. The DM-FEC mechanism has better performance in terms of increased Decodable Frame Rate (DFR) and Peak Signal-to-Noise Ratio (PSNR), compared to conventional multipath FEC mechanisms.

The remainder of this paper is organized as follows. Section II presents related background and FEC mechanisms in a multipath environment. The DM-FEC mechanism and mathematical analytical model are introduced in Section III. Section IV discusses the experimental setting and analyzes the simulation results. Finally, the paper is summarized in Section V.

II. Background and Related Works

A. FEC Mechanism

An (n, k) block erasure code converts k source packets into a group of n coded packets, such that any k of the n encoded packets can be used for reconstructing the original source packets as shows in Figure 1. The remaining (n – k, h), packets are referred to as parity packets. The FEC mechanism codes are able to correct both errors and erasures in a block of n packets. The recovery rate of the FEC mechanism can thus be attained by calculating the probability that more than k packets out of n are successfully received, given the degree of redundancy h. Depending on the selection of h, the recovery performance model of the FEC mechanism can achieve the desired quality of service for robust video communications.

B. Conventional Multipath Forward Error Correction Mechanisms

One of the conventional multipath FEC mechanisms employs a path-independent multipath transmission mechanism [5] [6]. This mechanism sends source data along different paths and then the FEC encoder encodes the redundancy for each path. Because the loss patterns of the various paths are different and independent, different paths have a different number of redundancies. The path-dependent multipath transmission mechanism can reduce the packet losses in each individual path. Another conventional multipath FEC mechanism employs a path-independent multipath transmission mechanism [4] [8] [9]. The sender of this mechanism encodes the redundancy and sends all data over multiple paths. The path-independent multipath transmission mechanism can reduce the packet losses on all multiple paths because the receiver is able to observe the average losses on multiple paths. Previous studies which haven’t considered the longer length of the FEC block lead to the end-to-end delay becoming longer. The longest end-to-end delay leads to the video frame becoming unplayable on-time on the receiver side. The DM-FEC mechanism uses a mathematical analytical model to find the most appropriate transmission rate, FEC block length and FEC redundancy on each path in a multipath environment to solve this problem.

III. Delay-sensitive Multipath Transmission with Forward Error Correction (DM-FEC) Mechanism

A. Available Bandwidth Measurement

We also use the Packet Gap Model (PGM) to measure the available bandwidth [10] in this paper. The PGM exploits the information in the time gap between the arrivals of two successive probes at the receiver. A probe pair is sent with a time gap \( \Delta_{in} \); it reaches the receiver with a time gap \( \Delta_{out} \). Assuming a signal bottleneck and that the queue does not become empty between the departure of the first probe in the pair and the arrival of the second probe, then \( \Delta_{out} \) is the time taken by the bottleneck to transmit the second probe in the pair and the cross traffic that arrived during \( \Delta_{in} \). The available bandwidth, ABW, can be calculated as equation (1).

\[
ABW = C \times \left( 1 - \frac{\Delta_{in} - \Delta_{out}}{\Delta_{in}} \right)
\]  

(1)

B. Transmission Rate, FEC Block Length, and FEC Redundancy

The multipath transmission environment is shown in Figure 2 [5]. To avoid congestion packet losses on each
path, the transmission source data packets and FEC redundant packets cannot exceed the available bandwidth on each path. The FEC redundancy increases to protect the source packets when the source data packets over the path have a higher packet loss rate. Hence, in the first step of the DM-FEC mechanism, the selection of the path with the smallest average packet loss rate is a top priority in order to reduce FEC redundancy. Accordingly, the DM-FEC mechanism not only doesn’t cause congestion losses but can also select the appropriate FEC redundancy on each path. Assume video communication requires a requested bandwidth RBW bps. The transmission ratio of source data packets on each path \( p \) is \( M_p \). Hence, the transmission rate of source data packets on each path \( p \) can be calculated according to equation (2).

\[
M_p \times RBW, \quad (2)
\]

where the sum of all \( M_p \) is 1. When the available network bandwidth on each path \( p \) is ABW\(_p\) bps, we can calculate the congestion packet loss rate on each path \( p \), \( C_p \), from the various values of \( M_p \) according to equation (3).

\[
C_p = \frac{M_p \times RBW \times \left(1 + \frac{h}{k}\right) - ABW_p}{M_p \times RBW \times \left(1 + \frac{h}{k}\right)} \quad (3)
\]

The FEC block length cannot lead to an unacceptable end-to-end delay on the receiver side. Hence, the packet end-to-end delay needs to be lower than the delay constraint value, DC. The packet end-to-end delay in one FEC block length can be calculated according to equation (4).

\[
Delay_{FEC} = n \times \frac{packet\ size}{\sum_{p=1}^{M_p} M_p \times RBW} \quad (4)
\]

A longer FEC block length, \( n \), will lead to a longer end-to-end delay, \( Delay_{FEC} \). Delay\(_{FEC}\) needs to be smaller than DC. Hence, the length of the FEC block is selected to make Delay\(_{FEC}\) smaller than DC. Furthermore, an unsuccessfully recovered rate after the FEC recovery mechanism, \( UR_p \), for each path’s average packet loss rate, \( loss_p \), can be calculated according to equation (5).

\[
UR_p = \sum_{h=0}^{h} C_p^h \times loss_p^{h-1} \times (1 - loss_p) \quad (5)
\]

The effective packet loss rate after the FEC decoding process, \( R_{effective,p} \), can be estimated according to equation (6).

\[
R_{effective,p} = UR_p \times \frac{\sum_{i=0}^{M_p - 1} C_p^i \times loss_p^{i-1} \times (1 - loss_p)}{k + h} \quad (6)
\]

The successful transmission rate needs to be subtracted from the effective packet loss rate after the FEC decoding process and congestion losses data packets from the transmission rate of source data packets on each path. Hence, the appropriate transmission ratio of \( M_p \) and FEC redundancy on each path are found to rely on the calculation of the maximum successful transmission rate, \( S_{DM-FEC} \), according to equation (7).

\[
S_{DM-FEC} = \sum_{p=1}^{M_p} M_p \times (1 - R_{effective,p}) \times (1 - C_p) \quad (7)
\]

The DM-FEC mechanism uses a numerical analysis method to find the parameters \( S_p \), \( h \), \( k \) in order to obtain the maximum successful transmission rate. Once the parameters \( S_p \), \( h \), \( k \) of maximum successful transmission rate are decided, the sender transmitted data packets employ these parameters.

IV. Experimental Results

The experimental topology is shown in Figure 2. The video server side transmits video streams over the Internet, and the video receiver side is equipped with two wireless cards to connect two access points concurrently. The simulations are performed using the “Foreman” video trace from the TKN video trace library [11] [12]. The request bandwidth of “Foreman” streaming is 800 Kbps. The FEC mechanism encoding and decoding functions are implemented using the RS code. We use the NIST Net [13] to set the available bandwidth of path 1 as 600 kbps and that of path 2 as 350 kbps. We compare the conventional multipath method with the DM-FEC transmission mechanism in terms of DFR and PSNR value. Table 1 shows a comparison of the transmission DFR between the conventional multipath and DM-FEC transmission mechanisms. Table 2 shows a comparison of the PSNR value between the conventional multipath and DM-FEC transmission mechanisms.

Both path-dependent and path-independent multipath transmission mechanisms cause very critical congestion loss problems in path 2. Hence, the DFR is less than in the CMT-FEC and DM-FEC mechanisms. Moreover, the CMT-FEC mechanism cannot select the appropriate FEC block length to constrain the value of the delay. Hence, the DFR is less than in the DM-FEC mechanisms. The DM-FEC mechanism can dynamically adjust the transmission rate, FEC block length and FEC redundancy on each path. Hence, the DM-FEC mechanism not only doesn’t cause congestion loss problems but also FEC redundancy is less than in the path-dependent and path-independent multi-path transmission mechanisms. Furthermore, the DM-FEC
mechanism does not make the video frame unplayable on the receiver side. Therefore, the DM-FEC mechanism performs better than the conventional multi-path transmission mechanism in terms of DFR in Table 1 and PSNR in Table 2. Moreover, FEC redundancy in the conventional multipath transmission mechanism is based on the average packet loss rate on each path. However, the DM-FEC mechanism first selects the minimum average loss rate path for transmitted data. Hence, the average packet loss rate is less than the average packet loss rate on each path. Hence, FEC redundancy for the DM-FEC mechanism is still less than for conventional multipath transmission mechanisms.

Table 1: Variation in decodable frame rate with average packet loss rate

<table>
<thead>
<tr>
<th>DFR (%)</th>
<th>Path 1</th>
<th>Path 1</th>
<th>Path 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4%</td>
<td>5%</td>
<td>7%</td>
</tr>
<tr>
<td>Path 2</td>
<td>= 2%</td>
<td>= 3%</td>
<td>= 5%</td>
</tr>
<tr>
<td></td>
<td>63%</td>
<td>57%</td>
<td>51%</td>
</tr>
<tr>
<td></td>
<td>70%</td>
<td>65%</td>
<td>61%</td>
</tr>
<tr>
<td>Path 1</td>
<td>90%</td>
<td>88%</td>
<td>85%</td>
</tr>
<tr>
<td>Path 2</td>
<td>98%</td>
<td>97%</td>
<td>95%</td>
</tr>
</tbody>
</table>

Table 2: Variation in Peak Signal to Noise Ratio with average packet loss rate

<table>
<thead>
<tr>
<th>PSNR (db)</th>
<th>Path 1</th>
<th>Path 1</th>
<th>Path 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4%</td>
<td>5%</td>
<td>7%</td>
</tr>
<tr>
<td></td>
<td>= 2%</td>
<td>= 3%</td>
<td>= 5%</td>
</tr>
<tr>
<td>Path 2</td>
<td>17.3</td>
<td>15.3</td>
<td>13.1</td>
</tr>
<tr>
<td></td>
<td>19.1</td>
<td>17.5</td>
<td>15.8</td>
</tr>
<tr>
<td>Path 1</td>
<td>31.5</td>
<td>30.1</td>
<td>29.7</td>
</tr>
<tr>
<td>Path 2</td>
<td>32.7</td>
<td>32.1</td>
<td>31.3</td>
</tr>
</tbody>
</table>

V. Conclusions

Multipath transmission has been used in wireless networks. An important benefit resulting from the use of a multipath transmission is that it makes more bandwidth available, which can be used for transmitting video communications. This paper proposed a DM-FEC mechanism to resolve the abovementioned problems. The DM-FEC mechanism uses a mathematical analytical model to determine the appropriate transmission rate, FEC block length, and FEC redundancy on each path in a multipath environment. Hence, the DM-FEC mechanism doesn’t cause the self-induced congestion effect to impede the timely recovery of video information. Moreover, the DM-FEC mechanism yields a better video communications in term of DFR and PSNR value than the conventional multipath transmission mechanisms.

REFERENCES