MULTFRC-LERD: An Improved Rate Control Scheme for Video Streaming over Wireless

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Abstract. We propose the Loss Event Rate Discounting scheme to improve the performance of MULTFRC over wireless networks. In our MULTFRC-LERD scheme, each TFRC connection includes several loss discounting levels. When the wireless bandwidth is underutilized, we increase the discounting level of the TFRC connection at first, and when all the existing connections have reached the highest loss discounting level we open a new connection. The connection number and loss discounting level are determined by Inverse Increase Additive Decrease algorithm. Analytical and simulation results demonstrate that our scheme is a finer granularity rate control scheme for video streaming over wireless networks and can reduce the resource consumption significantly compared with MULTFRC. Moreover, LERD extends the range of applicability of the MULTFRC scheme.

1 Introduction

Over the past several years, the Internet has witnessed a tremendous growth in the use of audio and video streaming. Wide deployment of these applications without appropriate congestion control mechanisms may result in unfair bandwidth allocation or even congestion collapse. Because the congestion control scheme used by TCP halves the sending rate in response to a single loss event, it is unsuitable for the multimedia streaming applications. TCP-Friendly Rate Control (TFRC) [1], an equation-based congestion control scheme, was proposed to provide a relatively more stable sending rate for these applications.

TFRC was originally developed for media streaming over wired network. It assumed that most packet losses are due to congestion. While in a wireless environment, a significant fraction of packet losses may occur due to transmission errors. Treating wireless losses as congestive will cause TFRC reduce its sending rate unnecessarily and thus result in poor performance.

Chen and Zakhor proposed MULTFRC [2] to improve the throughput performance on the wireless link. MULTFRC allocates a certain number of TFRC connections for a given wireless streaming application to fully utilize the wireless bandwidth. Chen has shown that if the number of connections and packet

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size are chosen appropriately, MULTFRC can approach the optimal bandwidth utilization. The advantage of MULTFRC is that it does not need to modify the network infrastructure or protocols. However, the system resources it consumes are directly proportional to the number of TFRC connections. When the number of opened connections becomes too large, the end system, which is typically power-limited handheld equipment, can not afford such huge resource consumption. Additionally, adjusting the connection number can only achieve coarse granularity rate control, thus there is a quantization effect under the low error rate environment. Finally, the range of applicability of MULTFRC is limited.

We find that discounting the loss event rate can achieve the similar effect of opening multiple TFRC connections, and it has the potential to achieve finer granularity rate control. Furthermore, it makes MULTFRC applicable to a wider range. The cost of our scheme compared with MULTFRC is that it needs to make a small modification to the TFRC sender side code to provide the loss event rate discounting capability.

The rest of this paper is organized as follows. Section 2 reviews the related work on improving TFRC performance over wireless networks. In Section 3, we discuss the concept of Loss Event Rate Discounting (LERD) and our proposed MULTFRC-LERD scheme. Experimental results are given in Section 4. Finally, Section 5 concludes the paper and describes the future work.

2 Related Work

There have been a lot of efforts to improve the performance of TCP/TFRC over wireless networks.

Application layer solution: MULTFRC [2] can be considered as an application layer solution because it does not need to modify the network infrastructure or protocols. It improves the TFRC performance over wireless networks from the application level point of view.

Transport layer solution: In the transport layer, many efforts are devoted to differentiating the congestion losses from wireless losses. Cen et al. [3] proposed a hybrid end-to-end Loss Differentiation Algorithm (LDA), which combines three base LDAs: Biaz [4], Spike [5] and ZigZag [3]. Samaraweera [6] proposed an end-to-end noncongestion packet loss detection (NCPLD) algorithm for a TCP connection in a network with a wireless backbone link. Liu et al. [7] proposed an approach which integrates PLP and HMM. An HMM is trained over the observed RTTs to infer the cause of loss. Yang et al. [8] exploited the link layer information in wireless channels to discriminate between the wireless losses and congestion losses. Bae et al. [9] used ECN marking in conjunction with RED queue management scheme, and calculated the TCP-friendly rate based on ECN-marked packet probability instead of packet loss probability. Installing an agent at the edge of wired and wireless network is another method to discriminate the congestion losses from wireless losses [10].

3 Our MULTFRC-LERD Scheme

In this section, we first introduce the concept of Loss Event Rate Discounting (LERD), and then present the framework of MULTFRC-LERD system. Finally, we describe the IIAD control algorithm used in our system.

3.1 LERD: Loss Event Rate Discounting

We use the following simple TFRC model to explain the concept of LERD:

$$T = \frac{c \cdot S}{rtt \cdot \sqrt{p}} , \tag{1}$$

where p denotes the Loss Event Rate, T represents the transmit rate, S is the packet size, rtt is the end-to-end round trip time, and c is a constant factor. This simple model has captured all the essential factors and can explain the LERD scheme more clearly.

When the wireless link is underutilized, the total throughput of multiple TFRC connections is multiplying the throughput of one TFRC connection by the number of connections m. Thus the throughput of MULTFRC can be expressed as:

$$T_m = m \cdot \frac{c \cdot S}{rtt \cdot \sqrt{p}} . \tag{2}$$

By equation analysis and simulation validation, we find that the similar effect of multiple simultaneous TFRC connections can be achieved by discounting the loss event rate p, i.e. ,

$$p_d = d \cdot p , \tag{3}$$

where d is the discounting factor, and it can take any value between 0 and 1. In the case of original TFRC, the discounting factor d is equal to 1. The smaller discounting factor corresponds to the more aggressive TFRC-LERD connection. Replacing the loss event rate p in Equation 1 by p_d, we get the throughput of one TFRC-LERD connection:

$$T_d = \frac{c \cdot S}{rtt \cdot \sqrt{p_d}} . \tag{4}$$

Comparing Equation 2 with Equation 4, we can see that MULTFRC and LERD try to improve the throughput by adjusting different parameters. MULTFRC uses the number of connections m to tune the throughput, and our LERD scheme uses the discounting factor d to adjust the sending rate. The discounting factor d can take any value between 0 and 1.0, however, the number of connections m in MULTFRC scheme can only take the positive integers, e.g., 1, 2, 3,$\cdots$, therefore LERD has the potential to achieve finer granularity rate control than MULTFRC.

3.2 MULTFRC-LERD

The framework of MULTFRC-LERD system is illustrated in Fig. 1. In our system, each TFRC connection is divided into L loss discounting levels. Each level is characterized by a discounting factor $d_i (1 \leq i \leq L, 1 = d_1 > d_2 > \cdots > d_L > 0)$. The lowest level is assigned $d_1 = 1$, which means no discounting at all. For each TFRC connection C_k we maintain a variable d_{c_k} in its sender side to keep its current loss discounting factor. When TFRC sender receives the loss event rate p from the receiver, we discount it by its current discounting factor, i.e., $p_d = p \cdot d_{c_k}$, and use the discounted loss event rate to compute the sending rate. The number of connections and their respective discounting factors are controlled by the Connection Manager.

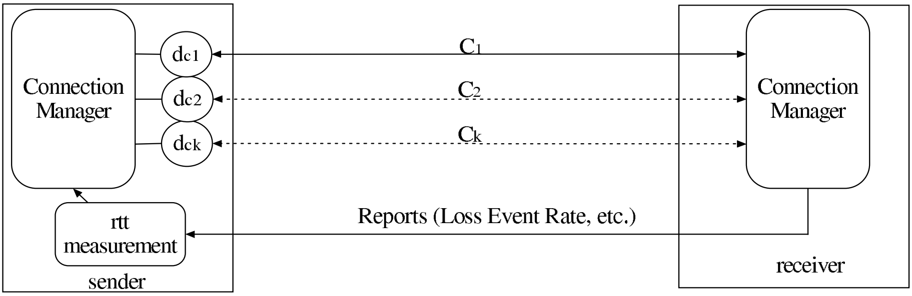


Fig. 1. The framework of MULTFRC-LERD system

The control algorithm employed in our Connection Manager is the Inverse Increase Additive Decrease (IIAD) algorithm similar to that used in MULTFRC. But the adjusting granularity in our algorithm is one discounting level rather than one connection as in MULTFRC. Our IIAD algorithm is described as follows (*threshold*, *alpha* and *beta* are predetermined constants.):

```
Measure average_rtt over a specified period.
if (average_rtt < threshold) {
  discount_level = discount_level + alpha / discount_level;
}
else {
  discount_level = discount_level - beta;
}
```

When we need to increase the discounting level, which is indicated by the IIAD algorithm, we increase the discounting level of the last opened connection. If the last opened connection has reached the highest discounting level, we open a new TFRC connection. Similarly, when we need to decrease the discounting level, we decrease the discounting level of the last opened connection. If the last opened connection has reached its lowest discounting level, we close this connection.

4 Simulation Results

In this section, we implement the loss event rate discounting functionality and compare the performance of MULTFRC and MULTFRC-LERD.

4.1 Simulation Setup

We use ns-2 to study the performance of MULTFRC-LERD. The network topology used in the simulation is shown in Fig. 2, which is the same as that used in MULTFRC. The transmission error in the wireless link is simulated by the exponential error model, and the packet error rate varies from 0.01 to 0.16. The last hop wireless link is the bottleneck of the path from sender to receiver. The parameters used are shown in the figure. In this simulation, the values of *threshold*, *alpha* and *beta* are $1.2 \cdot rtt_{min}$, 1, and 1, respectively. We employ a simple three-level discounting scheme, and the corresponding discounting factors are 1.0, 0.5 and 0.2. It is possible to use more refined discounting levels. Here we just want to demonstrate the effectiveness of LERD.

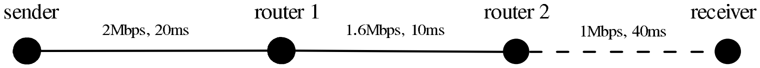


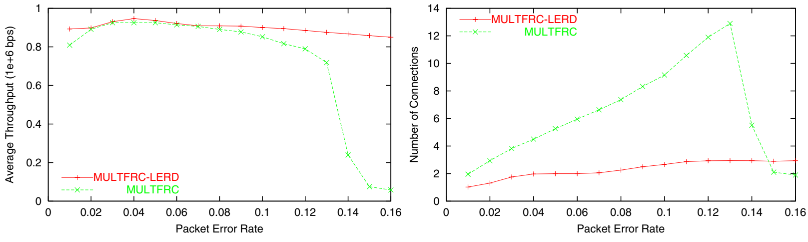
Fig. 2. Wireless last hop topology

4.2 Performance of MULTFRC-LERD

We simulate MULTFRC-LERD and MULTFRC for 9000 seconds with the packet error rate varying from 0.01 to 0.16. The performance comparison is given in Fig. 3.

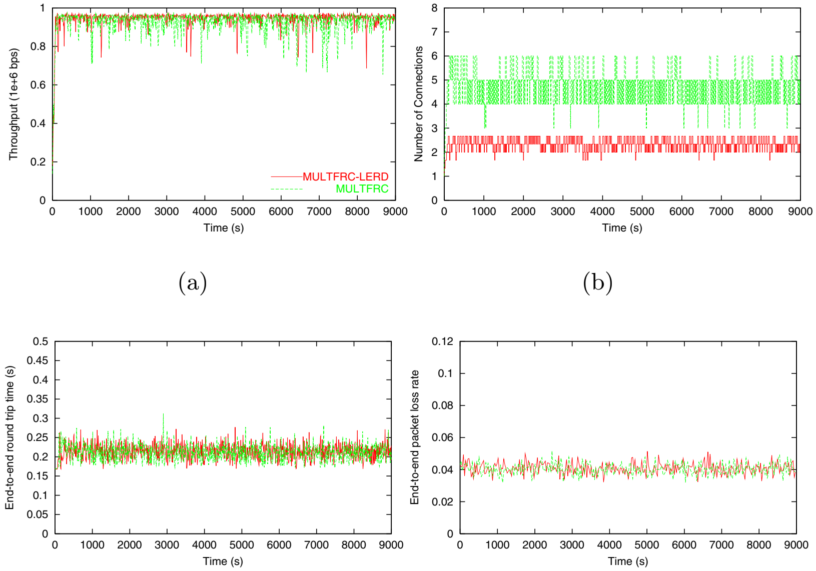
Fig. 3(a) shows the average throughput of our MULTFRC-LERD scheme and MULTFRC. Notice that when the packet error rate is low our scheme outperforms MULTFRC, because the connection number can only achieve coarse granularity rate control and there is a quantization effect when the number of connections is small, which is also pointed out in [2]. The throughput improvement of our scheme is achieved by its finer granularity rate control. We find that these two schemes have comparable performance when the wireless packet error rate is between 0.02 and 0.08. But when the error rate exceeds 0.08, the performance of MULTFRC degrades. It is because the original TFRC cannot work well under such high packet error rate environment, where the high loss event rate prevents TFRC from increasing its sending rate. However, LERD scheme mitigates the negative impact of high wireless error rate by discounting the loss event rate and is still able to approach the optimal bandwidth utilization even when the error rate is very high.

Fig. 3(b) illustrates that MULTFRC-LERD uses much fewer connections than MULTFRC. When the packet error rate exceeds 0.13, the connection number of MULTFRC drops sharply, because under such high error rate the MULTFRC scheme is not effective any more, its connection number cannot reach the optimal value and the performance degrades significantly.



(a) (b)

Fig. 3. MULTFRC-LERD and MULTFRC under different packet error rate environment (from 0.01 to 0.16): (a) average throughput. (b) average number of connections opened



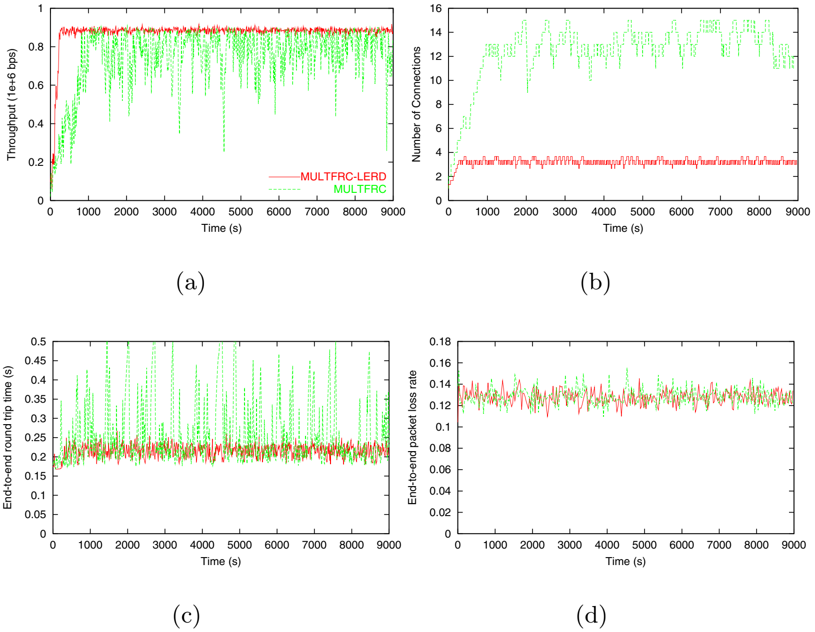
(a) (b)

(c) (d)

Fig. 4. The performance comparison of MULTFRC-LERD and MULTFRC when the wireless packet error rate is 4%: (a) throughput, (b) number of connections opened, (c) end-to-end round trip time, (d) end-to-end packet loss rate

In the following, we analyze two typical scenarios: the medium error rate environment (PER=0.04) and the environment with very high error rate (PER=0.12).

Fig. 4 demonstrates that the performance of our MULTFRC-LERD scheme is comparable to MULTFRC under the error rate of 0.04, but the number of connections opened by MULTFRC-LERD is much smaller. Note that in Fig. 4(b),



(a) (b)

(c) (d)

Fig. 5. The performance comparison of MULTFRC-LERD and MULTFRC when the wireless packet error rate is 12%: (a) throughput, (b) number of connections opened, (c) end-to-end round trip time, (d) end-to-end packet loss rate

we also display the discounting levels of MULTFRC-LERD. Because the optimal point of MULTFRC resides between 4 and 5, MULTFRC frequently adds and drops connection to maintain a balance. However, in our scheme most adjustment is accomplished by changing the discounting factor. We argue that it is favorable because the cost of opening and dropping a connection is much higher than setting the discounting factor to a new value.

Fig. 5 illustrates that the performance of MULTFRC-LERD is much better than MULTFRC when the error rate is as high as 0.12. Under such environment, the original TFRC does not function properly any more. The end-to-end round trip time varies greatly, the connection number changes irregularly, which in turn results in highly varying throughput. However, our scheme is quite stable under this abnormally high error rate environment because LERD enhances the capability of TFRC to deal with high error rate.

5 Conclusion and Future Work

In this paper, we have proposed the Loss Event Rate Discounting scheme to improve the performance of MULTFRC system. We tested our scheme extensively under different error rate environments. Our results demonstrate that the advantages of our MULTFRC-LERD scheme over MULTFRC are three-folded:

Firstly, it reduces the resource consumption. The resource consumed by MULTFRC is reduced by 50 to 80 percent. Secondly, it can achieve finer granularity rate control. Our scheme mitigates the quantization effect of MULTFRC and improves its throughput under the low error rate environment. Finally, our scheme works well under very high error environments where MULTFRC does not function properly any more. In future work, we will investigate the more refined discounting levels and discounting factors, and how they affect the performance of MULTFRC-LERD.

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