Streaming Video over TFRC with Linear Throughput Equation

Agnieszka Chodorek and Robert R. Chodorek

***Abstract*—The TCP-Friendly Rate Control (TFRC) protocol manifests strong equality towards competing TCP or TCP-friendly flows. Although the RFC 3448 suggests that TFRC is suitable for multimedia, this equality is a great disadvantage in the case of transmitting multimedia over the TFRC.**

The TFRC emulates TCP-like congestion control using the TCP throughput equation. In the paper, we substitute the TCP throughput equation recommended for the TFRC with a linear throughput equation. Simulation results show that the proposed solution is more suitable for multimedia than the equation proposed in RFC 3448. Experiments were carried out using an event-driven ns-2 simulator, developed in U. C. Berkeley.

***Index Terms*—congestion control, multimedia, TCP-friendly protocol**

I. INTRODUCTION

THE phenomenon of the collapse of TCP transmissions which compete for bandwidth with multimedia over RTP/UDP or UDP, was the reason for the design of so-called TCP-friendly transport protocols. One of the best known, and the first standardized TCP-friendly protocol was the TCP-Friendly Rate Control (TFRC) [1], [2]. This multipurpose protocol was designed to carry different kinds of data, including real-time multimedia.

TCP-friendly transport protocols implement TCP-like congestion control and behave under congestion like TCP. Among others, they equally share the throughput of bottleneck links with TCP flows or other TCP-friendly flows. This feature is a great advantage in the case of bulk data transfer because it allows for the achievement of Quality of Service (QoS) appropriate for each transmission. In the case of real-time multimedia transmission, we can see the opposite tendency. If flow equality is contrary to real-time requirements, we observe degradation of the QoS of the multimedia transmission. The deeper the conflict between equality and real-time becomes, the larger degradation can be observed [3], [4].

The TFRC emulates TCP-like congestion control using the TCP throughput equation. The equation is used for the estimation of instantaneous throughput of TFRC under congestion. In the paper, we substitute the TCP throughput equation recommended for the TFRC a linear function of packet error rate. The aim of such substitution is to develop a transport protocol which is more suitable for multimedia than TFRC and more TCP-friendly than RTP.

The paper is organized as follows. Section 2 briefly describes the TFRC protocol. Section 3 proposes a linear function which will be used as a throughput equation for the TFRC. Section 4 describes simulation experiments. Section 5 presents the simulation results of TFRC and TCP transmissions in shared link. Section 6 summarizes our experiences.

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II. THE TFRC PROTOCOL

The TFRC protocol represents the modern approach to transport layer protocols, which treats the protocols as a set of building blocks – independent components from which transport protocols are assembled [5]. The TFRC is a congestion control building block designed to be reasonably fair when competing for bandwidth with TCP flows. As other control systems, the TFRC consists of:

- a controller which makes decisions about the value of the controlled quantity,
- a control device which adjusts the controlled quantity to the value given by the controller.

In the case of TFRC, the controller (the congestion control mechanism) evaluates the output throughput of flow using the so-called TCP throughput equation, which is, in fact, an analytical model of the TCP behaviour under congestion. The equation describes TCP throughput as a function of packet error rate. The TFRC uses Padhye's model of TCP throughput, described in [6], [7]. According to this model, the throughput of the TCP protocol (and, in result, the TFRC throughput) is equal to:

$$T(PER) = \frac{MSS}{RTT}\frac{C}{\sqrt{\frac{2}{3}PER}+12PER\sqrt{\frac{3}{8}PER}(1+32PER^2)}. \quad (1)$$

where PER denotes the packet error rate, T is a TCP throughput, and C is the scale coefficient.

The output throughput of TFRC is adjusted to the value given by the controller using the rate control mechanism. This mechanism modulates the TFRC sending rate in packets per second.

The authors of RFC 3448 recommend that the TFRC is suitable for applications such as telephony or streaming media. They suggest also that the TFRC could be used in a transport protocol such as Real-time Transport Protocol (RTP) [8], which is commonly used as a transport protocol for audio and video transmission.

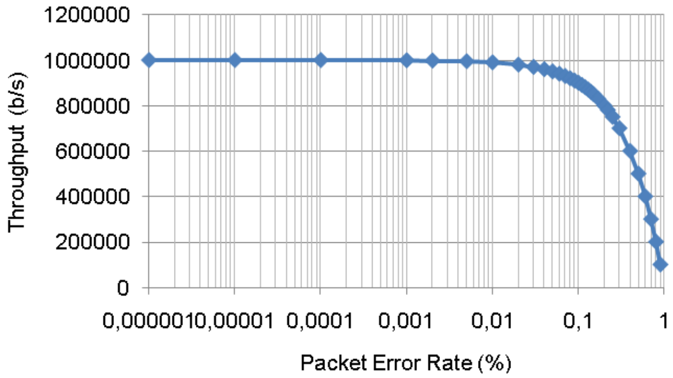

Fig. 1. Throughput of the RTP as a function of Packet Error Rate (PER).

III. Linear throughput equation

A typical feature of TCP-friendly protocols is an equality of competing TCP flows. This equality means that sometimes the TFRC is not able to meet the real-time requirements of multimedia transmission. It means that TCP is too aggressive (when compared with TFRC) to allow the TFRC to manage the real-time transmission of multimedia. As a result, the TFRC is not able to preserve QoS for multimedia traffic.

A protocol which is aggressive enough to force real-time transmission in the presence of TCP flows is the RTP – the transport protocol intended for the real-time multimedia transmission. However, the RTP protocol is not designed for TCP-friendliness and some researchers have reported that it can cause the degradation of TCP connections in a shared link.

Our proposition is a combination of two features: TCP-friendliness of the TFRC and good QoS of real-time multimedia transmission, presented by the RTP. We want to achieve this goal by applying elements of the real-time behavior of the RTP to the TFRC. As a result, the new TFRC should be more aggressive than the standard one and still able to co-operate with the TCP in a shared link.

Because the RTP implements neither congestion control, flow control, nor error control, theo traffic offered will be reduced only by packet losses (Fig. 1). As a result, in a network that is well-dimensioned for multimedia the analytical model of RTP throughput should depend only on the target bit rate of the carried multimedia stream and the packet error rate. Thus, the RTP throughput equation should be as follows:

$$T\,(PER) = \frac{S_p}{t_0} - \frac{S_l}{t_0}. \tag{2}$$

where PER denotes the packet error rate, T is the RTP throughput, S_p is the amount of information (in bits) sent in RTP packets (both in headers and payloads) during the time t_0, S_l is an amount of information carried in RTP packets which were lost or damaged during the time t_0, t_0 is the observation time.

Note that the above analytical model of RTP throughput describes both the transmission of streaming media over RTP/UDP and the transmission of streaming media over UDP. In the paper, we propose to substitute the TCP throughput equation (1) used by the TFRC with the linear throughput equation:

$$T\,(PER) = TBR\,(1 - PER) \tag{3}$$

where TBR is the target bit rate of multimedia stream.

Because

$$\frac{S_p}{t_0} = TBR \tag{4}$$

and

$$\frac{S_l}{S_p} = PER \tag{5}$$

The linear throughput equation describes, in fact, the RTP/UDP throughput as a function of packet error rate.

Because the proposed equation is based on the RTP model, we believe it is aggressive enough to preserve the real-time character of transmitted steaming media. However, it does not mean that TFRC will behave under congestion like the RTP if the linear throughput equation is used. The RTP protocol does not implement congestion control. It is not able to change the transmission rate due to congestion.

The TFRC with the linear throughput equation will still have congestion control, although the usage of this equation causes congestion control to be a "light" version. The sending rate is reduced only by packets which are lost due to congestion. It means that TFRC can not aggressively avoid congestion but it does not allow the congestion to grow.

IV. Simulation experiments

Simulation experiments were carried out using single-bottleneck topology (Fig. 2.). Senders S are connected to router R1 via 100 Mb/s links with 1 μs propagation delay. The same links are used to connect receivers R and router R2. Routers are connected via 4 Mb/s bottleneck link with 10 ms propagation delay.

Constant Bit Rate (CBR) video stream is transmitted between S and R end-systems and the target bit rate of the stream is equal to B. Because we assume that the network is well-dimensioned for multimedia, 0 Mb/s $\leq B \leq$ 4 Mb/s. Real-time CBR transmission is carried out using the TFRC and modified TFRC with linear throughput equation. For the sake of comparison, RTP/UDP protocols also are used. FTP over TCP transmissions are carried out between the pair of nodes S_i^{TCP} and R_i^{TCP}, i = 1,...,N. All transport protocols used in experiments have the same size of data packets – 1000 B (960 B of data + 40 B overheads).

During the experiments we investigated achieved the throughput (both for multimedia and bulk data transfer). Experiments were carried out using Berkeley's ns-2 simulator [8].

V. Simulation results

In the first experiment we changed the number of competing TCP flows N from 0 to 10. The target bit rate of CBR transmission was set to 1 Mb/s (1/4 of throughput of the bottleneck link). Results are shown in Fig. 3.

Simulation results show that CBR video transmissions will preserve their real-time character if a modified TFRC with a linear equation is used in the transport layer. Streaming video

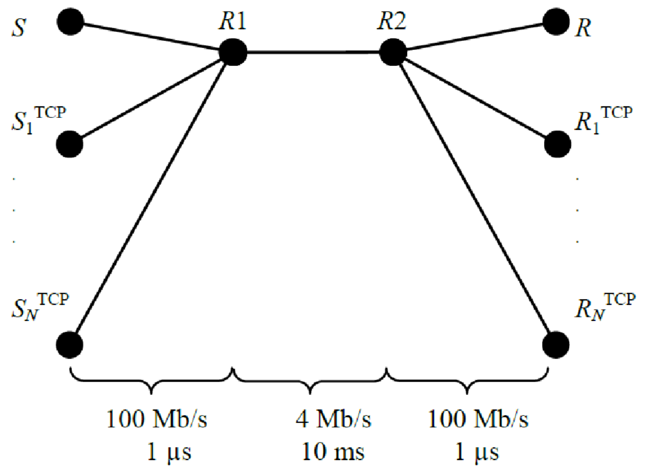

Fig. 2. Topology of simulated network.

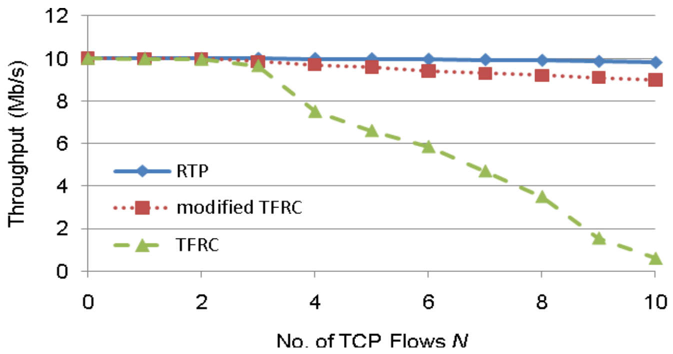

Fig. 3. Throughput of CBR the transmission as a function of N.

over classic TFRC (with TCP throughput equation) causes strong degradation of a CBR connection in the case of larger values of N.

The usage of the proposed solution instead of classic TFRC allows one to achieve throughput of the CBR stream comparable to the throughput of CBR over RTP. Moreover, the parameters of TCP transmissions are approximately the same as those observed when classic TFRC is used. It means that the linear equation avoids the collapse of the TCP connections and allows the TCP to utilize available bandwidth (bandwidth of the bottleneck link reduced by target bit rate of multimedia stream).

In the second experiment we changed the throughput of the CBR transmission B from 0.5 Mb/s to 4 Mb/s (throughput of the bottleneck link). The number of competing TCP flows was set to 1. Results of experiments are shown in Fig. 4.

As we can see in Fig. 4, TFRC with the linear equation allows one to transmit real-time multimedia even if the target bit rate of the CBR stream is close to the throughput of bottleneck link. Both RTP and classic TFRC were able to carry out real-time transmission up to about a half of the throughput of the bottleneck link (at least in this experiment). In the case of both modified TFRC and classic TFRC, concurrent TCP streams were able to utilize all remaining bandwidth of the bottleneck link.

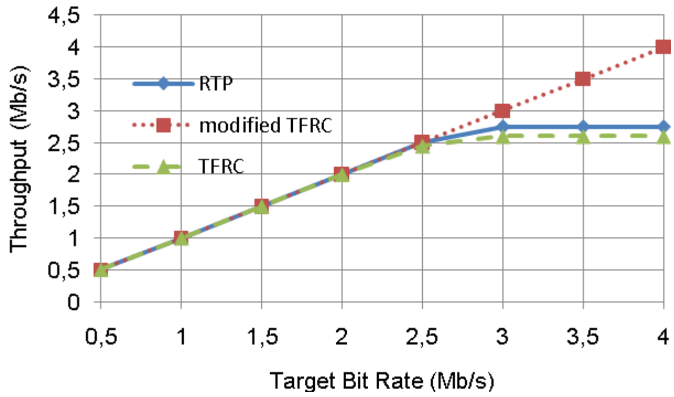

Fig. 4. Throughput of CBR transmission as a function of B.

VI. Conclusion

Although the authors of TFRC suggest that the protocol is suitable for multimedia transmission, it is not aggressive enough to meet the QoS requirements of carried streaming media when it competes for bandwidth with the TCP. In the paper we propose to substitute the original TFRC throughput equation with a linear throughput equation. This substitution makes the TFRC more aggressive, which allows the protocol to preserve the real-time character of the transmitted flow no worse than the RTP or the UDP protocol. Moreover, in situations when the usage of the RTP causes the collapse of TCP transmission (or, at least, worsening of the QoS of one or more TCP flows), the proposed solution is “friendly” enough for competing TCP flows to equally share the remaining bandwidth. Such results allow us to believe that the proposed linear equation is more suitable for multimedia transmission than the equation originally included in the RFC 3448.

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