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Understanding the Impact of TFRC Feedbacks Frequency over Long Delay Links

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***Abstract*—TFRC is a transport protocol specifically designed to carry multimedia streams. TFRC does not enable a reliable and in order data delivery services. However TFRC implements a congestion control algorithm which is friendly with TCP. This congestion control relies in a feedback mechanism allowing receivers to communicate to the senders an experienced drop rate. Although the current TFRC RFC states that there is little gain from sending a large number of feedback messages per RTT, recent studies have shown that in long-delay contexts, such as satellite-based networks, the performance of TFRC can be improved by increasing the feedback frequency. Nevertheless, currently it is not clear how and why this increase may improve the performance of TFRC. Therefore, in this paper, we aim at understanding the impact that multiple feedback per RTT may have (i) on the key parameters of TFRC (RTT and error rate) and (ii) on the network parameters (reactiveness, fairness and link utilization). We also provide a detailed description of the micro-mechanisms at the origin of the improvements of the TFRC behavior when multiple feedback per RTT are delivered, and determine the context where such feedback frequencies should be applied.**

I. INTRODUCTION

TCP-Friendly Rate Control (TFRC) [1] is a protocol which provides a congestion control compatible with TCP without reordering and reliability services. Currently, TFRC is one of the most promising approach for the transfer of multimedia flow in shared networks such as Internet.

In order to adapt the rate of TFRC to the network conditions, receivers estimate a drop rate p, which is sent to the senders (the TFRC feedbacks). In the sender side, at every received feedback, TFRC updates its rate according to (1) :

$$X = \frac{s}{R\sqrt{\frac{2bp}{3}} + t_{RTO}\left(3\sqrt{\frac{3bp}{8}}\right)p(1+32p^2)} \tag{1}$$

Where :

- X is the TCP's average transmit rate in bytes per second;
- s is the segment size in bytes (excluding IP and transport protocol headers);
- R is the round-trip time in seconds;
- t_{RTO} is the TCP retransmission timeout value in seconds;
- b is the maximum number of packets acknowledged by a single TCP acknowledgment (set to one following the current RFC).

Several studies have shown that TFRC offers good responsiveness and higher TCP-friendliness level compared to others TCP-friendly schemes in a wide range of wired-network topologies [2]. As a consequence, many efforts have been made to optimize [3], [4] and to adapt TFRC to network dynamics introduced by wireless networks (such as in the context of vertical handovers [5], [6]).

In parallel, the use of satellite in IP networks, as a mean to transfer multimedia streams to fixed or mobile terrestrial nodes, motivates the analyze of TFRC in a satellite context. Thus, in a previous contribution [7] we have reported in a preliminary study that in long delay link, the goodput of TFRC can be improved by increasing the numbers of feedbacks per RTT. Thus, following empirical measurements, we advise to send at least one feedback every 100ms when RTT reaches one second delay.

Therefore, in this paper, we aim at providing a detailed study of the impact of the feedback frequency on the TFRC key parameters, like the experienced RTT and the estimated drop rate. Later, we focus on the impact of multiple feedback per RTT on the reactiveness and the fairness. The main goal of this study is to determine the context where the increase of the feedback frequency may improve the behavior of TFRC.

Well understand the whole behavior of TFRC in presence of multiple feedbacks per RTT would allow us to better tune TFRC stack and avoid unnecessary overhead. Indeed, increasing the amount of feedback messages might impact on the return link capacity of satellite link (quite low in general). Thus, a particular attention must be taken to minimize this value.

II. TOPOLOGY

In order to investigate the impact of the feedback frequency on the TFRC behavior, we drive a set of simulations with the ns-2.33 network simulator and using the default TFRC parameters, only varying the feedback frequency. The topology used is shown in Figure 1.

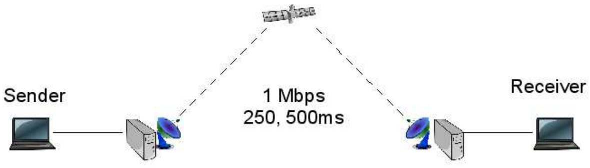


Fig. 1. Topology

In our simulations, we send two, three and four TFRC flows sharing a bottleneck with a maximum capacity of 1Mbps. The propagation delay of the bottleneck link is fixed to 250ms to simulate LEO satellite links and 500ms to simulate GEO satellite links. Those propagation delay values are identical for both forward and reverse paths. Finally, TFRC is configured to send one, two, three, four, five and ten feedback messages per RTT.

III. IMPACT OF FEEDBACK FREQUENCY ON TFRC PARAMETERS

In order to observe the benefits or drawbacks of increasing the feedback frequency on TFRC, next subsections present a detailed view of two parameters that drive the overall TFRC behavior (see Eq. 1): the computed loss rate p, and the experienced RTT. Note also that in this study, simulation results with one feedback per RTT are used as reference as this frequency corresponds to the value set by default in the standard TFRC implementation.

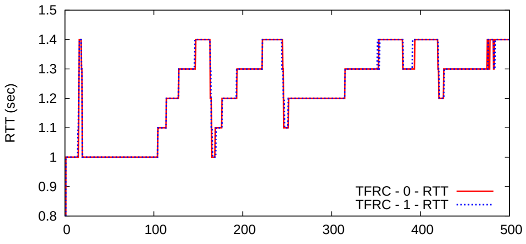
A. Impact on the computed loss rate

After every simulation done, we compute the cumulative average of the reported loss rate p by the receiver of each connection. In Table I, we present the average value of p as a function of the reference value (*i.e.* one feedback per RTT). Thus, values bigger than one reveal a higher computed drop rate and respectively, values smaller than one reveal a lower computed drop rate.

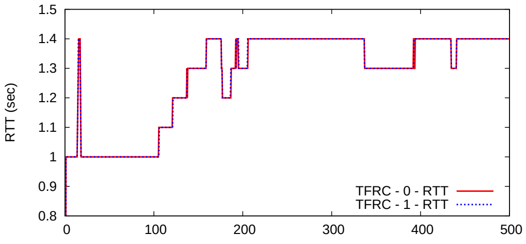
No. flows	RTT (ms)	Feedback per RTT (p_N/p_1)				
		2	3	4	5	10
2	500	0.88	0.98	0.89	0.94	0.90
2	1000	**1.06**	**1.14**	0.99	0.89	0.92
3	500	0.84	0.95	0.86	0.91	0.89
3	1000	0.92	0.94	0.90	0.95	1.00
4	500	**1.04**	0.98	**1.01**	0.92	0.93
4	1000	**1.00**	**1.06**	0.97	**1.11**	**1.00**

TABLE I
AVERAGE LOSS RATE

From Table I it can be observed that in most cases, feedback frequencies higher than one per RTT lead to a lower computed drop rate. However, the computed drop rate does not follow a uniform behavior. Indeed, the feedback frequency cannot be related to the value of p, since those values seem to follow random distribution. Therefore, the feedback frequency has not much impact on the computed loss rate from a macroscopic point of view.



(a) 1 feedback/RTT



(b) 4 feedback/RTT

Fig. 2. Experienced RTT

B. Impact on the computed RTT

In order to explain the impact of the feedback frequency on the experienced RTT, we present in this section the evolution of the computed RTT during the simulation with a 500ms link delay, two competing flows and one feedback per RTT (Figure 2(a)) and four feedbacks per RTT (Figure 2(b)). We have chosen those feedback frequencies since they represent the general behavior of the computed RTT in all our simulations.

Since after the Slow-Start, TFRC suffers from link under-utilization and slow convergence [8], during the first hundred seconds, TFRC experiences an RTT similar to the link propagation delay. However, after second 100, when TFRC enters in a steady state, it can be observed that the increase of the feedbacks frequency leads to a higher experienced RTT.

When TFRC sends only one feedback per RTT (Figure 2(a)), at second 165, the experienced RTT decreases to 1 second. In addition, around seconds 250 and 310, the senders estimate an RTT equal to 1.2 second.

Increasing the feedback frequency increases the experienced RTT. Indeed, when TFRC sends up to four feedbacks per RTT (Figure 2(b)), the experienced RTT is most of the time equal or higher than 1.3 second. Only at second 180 and during for few seconds, the experienced RTT falls down to 1.2 second. Sending more than 4 feedbacks per RTT does not introduce significantly variations to the experienced RTT showed in Figure 2(b).

Since in our simulations we did not introduce reverse traffic, occupancy link introduced by 4 feedback per RTT in the reverse path remains negligible. Thus, the higher experienced RTT means higher link utilization in the forward path.

IV. UNDERSTANDING THE IMPACT FREQUENCY ON TFRC

We have seen that when the feedback frequency increases, the rate of the senders tends to decrease while the experienced

RTT seems to increase. At first glance, this phenomenon seem to violate the next basic rule : the decrease of the rate of the senders should decrease the congestion in networks. Therefore the experienced RTT should also decrease.

After analyzing our simulation results, we find out that higher feedback frequency only improve the accuracy of the estimated RTT. Consequently, the accuracy of the estimated p increases and TFRC flows are able to grab the network resources with a minimum needed sending rate. In next paragraphs we will clarify this phenomenon.

Suppose that due to a congestion, a TFRC flow loses two packets (as described in Figure 3). Let us consider for this case two scenarios : (i) a feedback frequency #1 which computes the RTT #1 (in dashed lines) and (ii) another feedback frequency #2 (in plain lines) which results in the computation of a slightly lower (but more accurate) RTT #2. In this context, the way the number of loss events is computed is different. Indeed, in the first case both losses belong to the same loss event while in the second case, TFRC will see two losses events. As a consequence, TFRC will react differently.

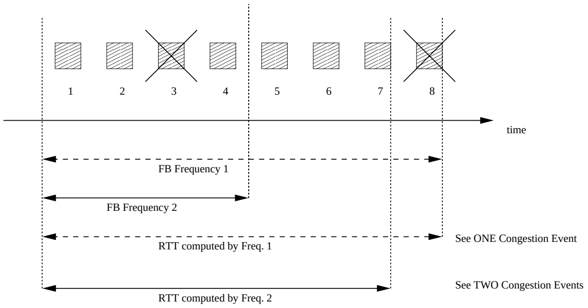
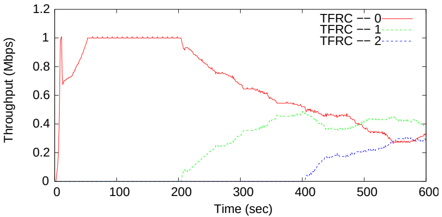


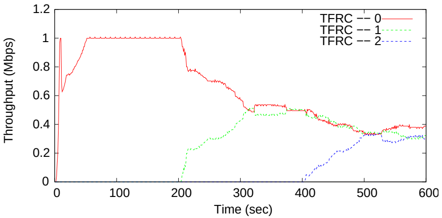
Fig. 3. Example of the impact of frequency feedback on losses

We could think that in this example, finally, the accuracy of the RTT value is counterproductive for the source as with a wrong RTT the receiver would estimate one Congestion Event only. Obviously, we will get the reverse case if the RTT given by samples from the frequency #2 is larger, but still accurate, than the RTT estimated by the frequency #1. As a conclusion, whenever the RTT increases or decreases conjointly with the distribution of the loss events, higher feedback frequency per RTT can result in a better adapted behavior of TFRC to the network conditions.

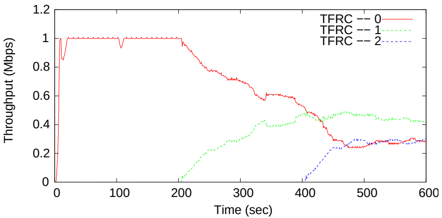
A more accurate view of the network state is suitable in high dynamic networks with long delay. Indeed, a more accurate perception of the congestion parameters leads to a faster adaptation of TFRC to network conditions. Since in real conditions, network are mostly dynamic environments, the benefits of higher feedback frequencies will remain more visible that in simulations environments [7]. In non-dynamic networks (e.g. networks where the assigned bandwidth to a flow remains almost constant), the benefits of increasing the feedback frequency remain limited even in presence of long propagation delay. This phenomenon is produced by the Congestion Avoidance mechanisms implemented in TFRC which introduce very slow oscillation of the rate after reacting to losses events, and when no more losses are detected (the steady state of TFRC).



(a) 1 feedback/RTT



(b) Multiple feedbacks



(c) Multiple feedbacks

Fig. 4. Active flows arriving with a 200s

Finally, we note that an increase of the TFRC feedback has limited benefices. Indeed, decreasing the inter-arrival time of feedback packets by only a few milliseconds does not introduce significantly variations in the behavior of TFRC.

V. IMPACT OF THE FEEDBACK FREQUENCY ON THE NETWORK

In this new section we aim at knowing if such benefits can have an impact on macroscopic networks parameters, like the responsiveness of TFRC and the fairness.

Thus, we have simulated 3 flows sharing a bottleneck, coming in to the network with an inter-arrival time of 200ms. In this case, we used a 250ms propagation link delay (RTT $\approx$ 500ms). Figures 4(a), 4(b) and 4(c) show graphically the evolution of the rate seen by the receivers for simulations with 1, 4 and 5 feedback/RTT respectively. Functions were plotted by calculating the goodput in a one second interval.

A. Reactiveness and Convergence

In the first case, with a frequency of one feedback per RTT, it can be observed from Figure 4(a) that every time a new flow enters the network, it needs almost 200 seconds to converge and enter in a steady state phase.

Increasing the feedback frequency to four per RTT (second case) improves significantly the responsiveness of TFRC. Indeed, at second 200, flow labeled “TFRC–0” quickly yield 0.2 Mbps to flow labeled “TFRC–1”. Thus, new incoming flows need around 100ms to converge, which represent only 50% of the total time needed by the first case. In this second case, flows converged to a point very close to the fairness point.

When TFRC is configured to deliver up to 5 feedbacks per RTT (third case), it can be observed that at second 340, flows far from the fairness point after one of them detect losses events. When a third flow comes into the network, a faster convergence between last two flows can be observed. However, the “TFRC–1” flow, which has been less penalized by losses events remains far of the fairness line.

Results from the third case are useful to illustrate that higher feedback frequencies can improve the convergence speed of flows. Moreover, the resulting fairness level will depend on how lost packets were distributed between flows.

Another parameter which is important to explorer is the link utilization. After calculating the average link utilization of the bottleneck, we have found that in general, the available bandwidth is well filled when multiple feedback per RTT are delivered. Indeed, in our simulation, the bottleneck utilization ranges from 97% for the worst case to 98% for the best case.

VI. Experiments with real implementation

For the sake of completeness, additionally, we present some results of TFRC on an emulated satellite network. We have used the same implementation as in [7] where the number of feedbacks sent during an RTT, N_{Fb}, is periodically calculated as :

$$N_{Fb} = \max(int(\frac{RTT}{RTT_{ref}}), 1) \tag{2}$$

where RTT is the current estimated RTT and RTT_{ref}, the targeted interval between two feedback messages.

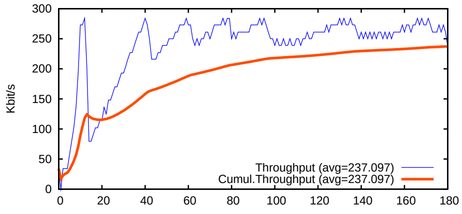
Note that to obtain the standard TFRC behavior, in Equation 2, $RTT_{ref} = RTT$. To analyze the behavior of TFRC in presence of multiple feedbacks in a single RTT we used $RTT_{ref} = 100ms$.

We emulate a satellite network by using the Linux Netem emulator in a PC configured as a router. This replaces the satellite link shown in Figure 1. The results presented here are for the GEO satellite configuration, with a 1000ms RTT and a 1Mbps capacity for both uplink and downlink. No packet loss rate was introduced.

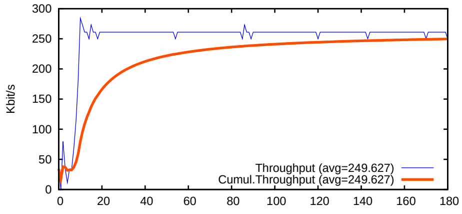
Figure 5 show the resulting throughput obtained by one TFRC flow, with one feedback per RTT shown in 5(a) and the dynamic feedback computation scheme shown in 5(b). We can clearly see in these figures the benefit of using the multiple feedbacks scheme on the instantaneous throughput obtained by TFRC.

VII. Conclusion

In this article we show that increasing the numbers of feedback per RTT may improve the perception of the congestion level parameters at the sender. The key at the origin of such improvement is an accurate value of the experienced RTT by the senders. Since a more accurate RTT value implicitly improves the drop rate seen by the receivers, this result in faster adaptation (high responsiveness) of TFRC to the network congestion levels.



(a) 1 feedback/RTT



(b) Multiple feedbacks

Fig. 5. Throughput obtained by one TFRC flow

Our analysis have also shown that the improvements carried in by the increase of the feedback frequency may have important effects on long-delay dynamic networks. Indeed, in short-delay networks, one feedback per RTT is enough to get an accurate RTT value. Also, in non-dynamic networks, the congestion avoidance mechanisms of TFRC which seek to avoid oscillations and losses events, limit the benefits of having a more accurate RTT value.

However, in long-delay dynamic networks, like satellite-based networks, increasing the feedback frequency leads to improvement of the fairness and the reactivity.

Following our simulation and emulation results, we find that in a context where the base RTT values are between 500ms and 1000ms, increasing feedback from one to 4 or 5 feedbacks per RTT (*i.e.* around one feedback every 200ms) improves the performance of TFRC. Also that higher frequency of feedback does not provide further performance improvements.

We hope this study will help TFRC users to better understand the impact of the feedback frequency and to the deployment of TFRC over long-delay links.

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