PSNR Evaluation of Media Traffic over TFRC

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***Abstract*—Due to the remarkable increase in media traffic over the existing best-effort IP Internet, the Internet congestion state is expected to worsen. TCP-friendly rate control protocol TFRC is one of the most promising congestion control techniques developed so far. Those techniques have been thoroughly tested in terms of being TCP-friendly and fair. Yet, their impact on the visual quality of the media traffic traversing Internet is still questionable. This paper investigates, in a simulated environment, the effect of incorporating TFRC on the peak signal-to-noise ratio PSNR of the transmitted video over Internet. A number of arbitrary raw videos are encoded, converted into trace files via a known tool-set, and then pushed into a simulated network environment to run over TFRC protocol with coexisting TCP flows. This scenario was run for a variety of videos having different content types, frame lengths, and motion complexity scale. The output video files of the simulations are then examined in terms of PSNR. TFRC was shown to produce visually meaningful and acceptable output video files. Some variations in the PSNR values were recorded among the simulated videos. TFRC performance on slow motion videos was slightly better than on medium-motion that was better than that on high-motion videos.**

***Index Terms*—TFRC, PSNR, Congestion Control**

I. Introduction

THE amount of media traffic traversing the Internet has remarkably increased over the last decade. Applications pushing media traffic such as VoD, VoIP, and various video streaming websites have been lately invading the cyber space. The best-effort existing IP infrastructure was not primarily designed to suffice the Quality of Service QoS requirements of such traffic. Both of the current UDP and TCP have drawbacks when used as the transport protocol for media traffic. TCP seems to break the delay constraints due to its acknowledgments; meanwhile UDP shows aggressiveness in acquiring the available bandwidth to accomplish the streaming task leaving an unfair share for the co-existing TCP flows, and leading to a congestion condition.

During the unwanted periods of congestion; routers tend to discard legitimate packets traversing a certain bottleneck to be able to serve the aggressive media packets concurrently crossing. Efforts have been made by researchers to generally control the congestion through several congestion control protocols. Researches tried to find protocols that can balance between allowing for QoS achievement for the sake of media traffic and acting in a TCP-friendly manner at the same time. This was via building congestion control protocols that leave a fair share of bandwidth for the concurrent TCP flows traversing across the same bottleneck. Protocols designed for this purpose and have been tested regarding compatibility with the TCP-friendliness concept defined in [1].

TFRC presented in [2] was one of the congestion control protocols that managed to achieve smoothness in its rate of transmission variations in addition to fulfilling the TCP-friendliness condition. For this reason TFRC was the best current promising candidate for media streaming applications, where its smoothness helps in reducing the undesired jitter of the perceived video. TFRC has been extensively tested in terms of fairness, aggressiveness, and responsiveness as in [3] and in terms of user-perceived media quality on analytical basis in [4]. Yet, testing the produced media files running over TFRC in terms of PSNR and visual meaningfulness has not been extensively made.

This paper presents a simulated investigation for TRFC in terms of PSNR values for a number of video files running over it. The video files used varied in their content types, frame lengths, and motion complexity scales. Therefore, these files can be a good measure for the evaluation purpose.

The rest of this paper is organized as follows: Section II covers the TFRC literature and its modified versions made to tackle the media streaming task. Section III explains our simulation environment utilized; the tool-set used in simulations, the topology of the simulated network, and the characteristics of the running video clips. Section IV presents the simulations output results focusing on the PSNR values, and finally Section V concludes.

II. The TFRC Protocol

A. TCP Friendly Congestion Control

TCP friendly congestion control schemes lies into two main categories according to [1]: (i) single rate schemes and (ii) multi-rate schemes. Unicast applications tend to utilize the single rate protocols where all recipients receive data with the same rate. This feature limits the scalability of the protocol towards bandwidth variations in the path to some recipients. Multi-rate protocols are more flexible and enable the allocation of different rates for different recipients which makes it more appropriate for the multicast applications.

Each of those two top categories can be sub-divided into other two sub-categories as follows: (i) rate-based schemes and (ii) window-based schemes.

Some of the rate-based schemes apply the additive increase multiplicative decrease AIMD approach embedded in TCP. Other rate-based just tune their sending rate in accordance with a TCP model. In both cases the reliability feature of TCP is absent. Example protocols that lie in this category are RAP [5], LDA+ [6], and TFRC.

TCP itself is a window-based protocol, yet some problems should be considered when applying this mechanism on multicast connections. Multicast TCP MTCP [7] is an example protocol of this multicast category that managed to deal with these problems.

B. TFRC Protocol

TFRC is the evolution of TFRCP [8]. It was mainly written for unicast communications but it can be adapted for multicast. Its sending rate is tuned according to the TCP complex equation (1).

$$T = \min\left(\frac{W_m S}{RTT}, \frac{S}{RTT\sqrt{\frac{2bP}{3}} + RTO\min\left(1,3\sqrt{\frac{3bp}{8}}\right)P\left(1+32p^2\right)}\right) . \quad (1)$$

Where the parameters are as follows:

- *T*: TCP throughput
- *RTT*: Round-trip time
- *RTO*: Retransmission time-out value
- *S*: Segment size
- *P*: Rate of packet loss
- *b*: Number of packets acknowledged by each ACK
- W_m : Maximum congestion window size *cwnd.*

TFRC uses its sophisticated mechanisms to gather the equation parameters. The average loss interval is the chosen method to fulfill the requirements of the loss rate estimation. The loss rate is measured via loss intervals through tracking the number of packets between consecutive loss events. The average of a specified number of loss intervals is calculated using decaying weights so that old loss intervals contribution in this average is less. The loss rate is considered as the inverse of the average loss interval size.

Some additional mechanisms are adopted to prevent TFRC from responding aggressively to single loss events, and to guarantee that the sending rate adapts quickly to the long intervals that are loss-free. *RTT* is measured by sending feedback time stamps to sender.

TFRC goes through a slow-start phase directly after starting just like TCP in order to increase its rate to reach a fair share of the bandwidth. The slow-start phase is ended by reporting a loss event. TFRC receiver updates the equation parameters and feeds them back to sender to adjust its rate every round-trip time. TFRC adopts additional delay-based congestion avoidance by adjusting the inter-packet gap which would be applied in some environments that do not support the TCP complex equation.

TFRC main advantage is its stable and smooth sending rate variations. This feature greatly fits in the media application transmission besides being responsive to the co-existing traffic in a TCP-friendly manner.

C. TFRC Enhancement Attempts

Several attempts were made to enhance the performance of TFRC in order to more suit the media traffic requirements such as discussed in the following lines:

In [9] authors observed some performance degradation for TFRC over wireless networks, and hence they tried to customize it through a more advanced equation. This equation was reached via modeling wireless TCP rather than wired TCP. Applying this equation led to a remarkable throughput increase with about 30% over wireless networks with loss of 10% while maintaining the TFRC main features of TCP-friendliness and smoothness.

In [10] an attempt was made to enhance TFRC performance over mobile and pervasive networks that focused on overcoming data losses due to the frequent loss of connectivity. The method used was applying a mechanism that resembles Freeze–TCP when a disconnection incident is expected. Additionally, a probing mechanism to enable speedy adaptation to new network conditions was proposed.

Another enhancement was made in [11] where authors tackled the problem of keeping fairness and smoothness of TFRC media streams when existing among other streams. They proposed MulTFRC that was successful in keeping low delay values to satisfy the media QoS requirements.

In [12] the enhancement was that authors computed the rate gap between the ideal TCP throughput and the smoothed TFRC throughput replacing it. Any rate gain from this gap was opportunistically exploited via video encoding. A frame complexity measure is specified to determine the additional rate to be used from this rate gap, and then the target rate for the encoder and the final sending rate are then negotiated through the same frame complexity.

In [13] authors suggested incorporating the selective retransmission concept into TFRC. Retransmission of lost packets is done selectively when no congestion case is present. Selective retransmission was shown to have a significant positive effect on the streamed media quality over TFRC.

In [14] authors claimed that TFRC does not perform satisfactorily on multi-hop ad-hoc wireless networks. They saw that TFRC sending rate can be deceived by MAC layer contention effects such as retransmission and exponential back-off. Hence, they proposed enhancing TFRC by introducing RE-TFRC. RE-TFRC used measurements of the current round-trip time and a model of wireless delay to prevent TFRC from overloading the MAC layer while keeping its TCP-friendliness feature.

In [15] a performance analysis of a QoS-aware congestion control mechanism named guaranteed TFRC (gTFRC) was presented. gTFRC was embedded into the enhancement transport protocol (ETP) that enables protocol mechanisms to be dynamically controlled. gTFRC managed to reach a minimum guaranteed transfer rate for any given round-trip values and any network provisioning conditions as well

In [16] an extension for TFRC was suggested in order to support variable packet size streams. Variable packet size is already utilized over Internet in both video and VoIP transmission. This enhancement of TFRC was made through a modified concept of TCP-friendliness and was validated to perform better than the original TFRC with the packets of variable sizes.

All of the above enhancement attempts focused on achieving a better quality of data transmitted over TFRC while maintaining the its main advantageous characteristics of being TCP- friendly and fair in acquiring a bandwidth share.

III. Simulation Environment

This section describes our simulation environment used to perform the PSNR evaluation of the media traffic over TFRC. The main three components of these simulations are the tool-set used, the topology of the simulated network created using ns-2.28 [17], and finally the group of video files arbitrarily chosen for this purpose.

A. EvalVid Tool-set and Evalvid-RA

In [18] Chih-heng Ke et al. proposed a novel and complete tool-set for evaluating the quality of video MPEG video transmissions delivery over simulated networks environment. This tool-set is based on the EvalVid framework [19]. They managed to let ns-2 as a general network simulator replace the EvalVid simple error simulation model through extending its connecting interfaces. This allowed researchers and practitioners in general to simulate and analyze the performance of real video streams with consideration for the video semantics under a vast range of network scenarios.

The tool-set valuable feature is that it allows for the examination of the relationship between two well-known objective metrics for QoS assessment of video quality of delivery: the PSNR and the fraction of decodable frames.

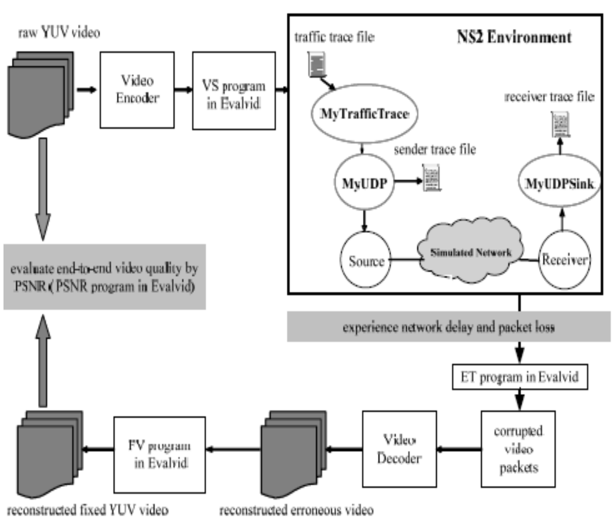

Fig. 1. EvalVid Tool-set

As shown in Fig. 1 the concept of this tool-set is built upon creating trace files from an encoded raw video. These files are text files and are fed into the simulation environment to be used as traffic generators based on the encoded video parameters. The output of the simulation process can be decoded then to produce the output video file of the simulation. The quality of both of this output file and the original video file can then be compared to obtain a representative PSNR value for the media quality of the produced video from simulation.

EvalVid-RA proposed. in [20] is an extension of EvalVid tool-set that supports the rate adaptive media content as well as the TFRC protocol in the simulation environment, thus it was chosen to be used in this work.

B. Simulation Network Topology

Our simulation topology used in this paper is the same simple topology used in [20].

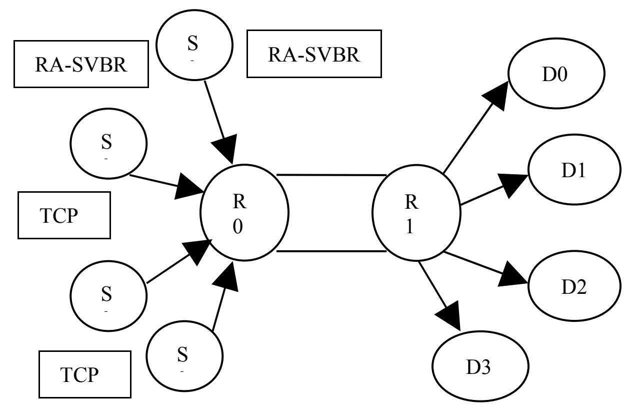

Fig. 2. Simulation Topology

As shown in Fig. 2, it is a simple dumbbell topology and composed of four traffic sources and four traffic destinations. We used ns-2.28 as our network simulator for this work to build this topology.

Both *S0* and *S1* are fed with the simulated video trace files while *S2* and *S3* generate TCP traffic. The video traffic is *shaped variable bit-rate traffic rate adaptive* (RA-SVBR), and the bottleneck between the routers *R0* and *R1* is 40Mbit/s link with propagation delay of 10ms. The access network capacities were set to 32Mbit/s with 5ms delay producing a one-way propagation delay of 20ms. The fair share after starting all sources was over 625Kbit/s and both *R0* and *R1* routers used ordinary random early detection (RED).

C. The Video Clips Used in Simulations

Thirty five video clips used in our simulations as shown in Table 1. They are provided for research purposes by Arizona State University research group in [21]. They were meant to vary in size, length, content type, and motion complexity scale. Their frames sizes were either CIF 352x288 or QCIF 176x144. Their number of frames ranged from 90 to 2101 frames and their content type covered the categories of news, sports, monitoring hall videos, and others. Their motion complexity scale specified ranged from low-motion to medium-motion and high-motion. We have chosen to perform the evaluation on some videos in both their CIF and QCIF sizes.

This group of clips is believed to be an expressive sample of clips normally streamed over Internet. Clips were used in YUV format where they are firstly encoded using ffmpeg.exe and then passed by the mp4.exe as components of the used tool-set. The resulting text files are then fed into the ns-2 simulation file where the output is concatenated through et_ra.exe tool and then decoded via ffmpeg.exe. The output decoded file quality is the compared to the original file quality using the psnr.exe program as demonstrated in Fig. 1.

$$PSNR\,(dB) = 20\log_{10}\frac{V_{peak}}{MSE}$$
(2)

$V_{peak} = 2^k - 1$, k is the number of bits per pixel, and MSE is the mean square error of the luminance component.

The final output of the tool-set is a text file that contains a table of two columns where the PSNR value of each compared video frame calculated according to equation (2).is recorded corresponding to this frame number. We utilized the mean PSNR value for each simulated video file for our evaluation.

#	Video Name	Size of Frames	No. of Frames	Motion Complexity
1	Akiyo	352x144	300	Low
2		176x144		
3	Bridge-close	352x144	2001	Low
4		176x144		
5	Bridge-far	352x144	2101	Low
6		176x144		
7	Bus	352x144	150	High
8	Carphone	176x144	382	Medium
9	Claire	176x144	494	Low
10	Coastguard	352x144	300	High
11	Container	352x144	300	Low
12		176x144		
13	Football	352x144	130	High
14		176x144		
15	Foreman	352x144	300	High
16		176x144		
17	Grandma	176x144	870	Low
18	Hall	352x144	300	Low
19		176x144		
20	Highway	352x144	2000	High
21	Miss-America	176x144	150	Low
22	Mobile	352x288	300	Medium
23		176x144		
24	Mom-daughter	352x144	300	Low
25		176x144		
26	News	352x144	300	Low
27		176x144		
28	Paris	352x144	1065	Medium
29	Salesman	176x144	449	Low
30	Silent	352x144	300	Low
31		176x144		
32	Stefan	352x144	90	High
33	Suzie	176x144	150	Medium
34	Tempete	352x144	260	Low
35	Waterfall	352x144	260	Low

A brief description for each of the videos content is presented in the following lines:

1. Akiyo: a news reporter talking
2. Bridge-close: a close scene of Charles bridge
3. Bridge-far: a far view of a Charles bridge
4. Bus: a moving bus
5. Carphone: a person talking inside a car
6. Claire: a talking person
7. Coastguard: panning of a coastguard ship moving
8. Container: a container ship moving slowly
9. Football: a high-motion football game
10. Foreman: a foreman talking
11. Grandma: an old woman talking
12. Hall: a hallway
13. Highway: a scene from a fast car on a highway
14. Miss America: a woman talking to camera
15. Mobile: panning of moving toys
16. Mother-daughter: Mom and daughter speaking to camera
17. News: two news reports talking
18. Paris: two people talking with high-motion gestures
19. Salesman: a salesman talking in his office
20. Silent: a person demonstrating sign language
21. Stefan: a tennis player
22. Suzie: a woman talking in the phone
23. Tempete: a moving camera
24. Waterfall: a waterfall natural scene

IV. SIMULATIONS RESULTS

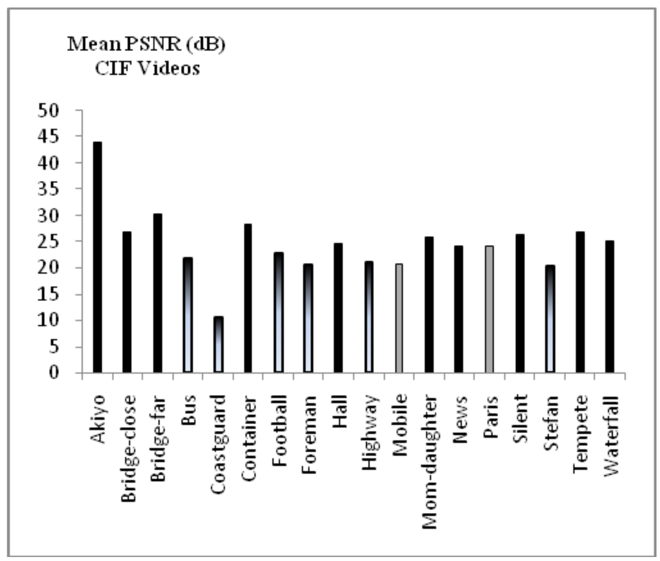

Fig. 3 Mean PSNR Values for CIF Videos

The first finding of this evaluation process was that the PSNR values of the output files all lie in the acceptable range. This means that TFRC is a suitable candidate for running the media traffic from both points of views of TCP-friendliness and media quality maintenance. The output files were visually meaningful. They had a degraded quality with respect to the original video files, but all the files were considered to be visually acceptable by human eye as well as PSNR values.

The mean PSNR values shown in both Fig. 3 and Fig. 4 are the results of comparing the output video files of simulation over TFRC protocol and the original video files. Those PSNR values were calculated using the psnr.exe program as a part of the EvalVid tool-set. The program compares each output video file to the original file on frame-by-frame basis. It produces a text file that contains a PSNR value for each of the video frames. The mean of those PSNR values were compared.

Results show that the mean PSNR values of the low-motion videos such as Akiyo, Container, and Grandma are higher than those of the medium-motion scale which are in turn higher than the high-motion videos mean PSNR values. This shows that the performance of the TFRC protocol streaming gets better when the motion complexity is lower.

To illustrate this finding, in Fig. 3 and Fig. 4 the PSNR values of the low-motion videos were made in solid black color, the PSNR values of the medium motion videos were made in solid grey while those of the high-motion were made in gradient.

Numerically, the PSNR values of the low-motion CIF videos are all above 24, the values for the medium-motion files lies in the range 20~24, meanwhile the values of all the high-motion goes from 20 to down. The same observation existed on the QCIF files where the low-motion videos PSNR values are all above 30 while the high-motion videos PSNR values are all below 20 keeping the medium-motion videos PSNR values in between.

We recall that the videos used for these simulations represent an expressing sample for the streamed video clips on the net either in real-time or on demand. This makes our simulation results very helpful for measuring the performance of the TFRC and enables the simulations results to resemble those of the real-world.

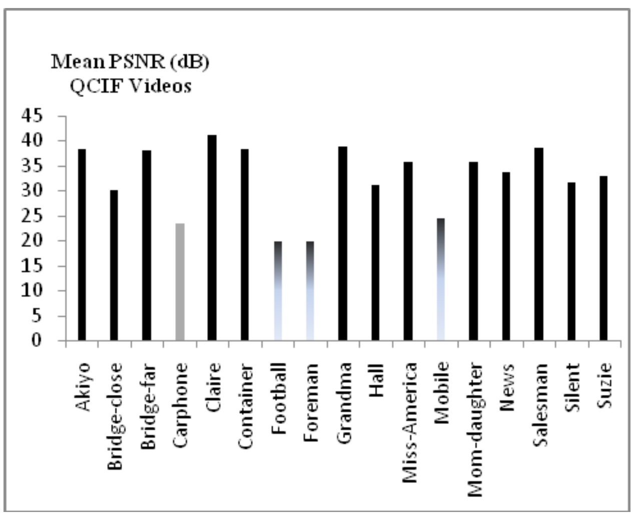

Fig. 4 Mean PSNR Values for QCIF Videos

The significance of the results in Fig. 3 and Fig. 4, appears, in our point of view, when we compare the mean PSNR values of the CIF or the QCIF files relative to each other taking into account the motion scale of each compared video.

These simulations made all files of the same frame size pass by the same encoding and simulation circumstances so that the only factor that will let their mean PSNR values differ would be their differences in content and motion scale.

V. Conclusion

The problem of Internet congestion control has been handled by researchers over the last decade. It was observed that the quantity of media traffic traversing the Internet has tremendously increased due to the increase in the number of emerging applications running such traffic which led to worsening the case of congestion.

Several congestion control protocols have been developed to face the problem and also have been tested from the TCP-friendliness point of view and achieved promising performance in many cases, but the media traffic currently booming over Internet imposed some additional criteria on the congestion control protocols other than just being TCP-friendly and fair in bandwidth acquiring. These criteria focused on delivering the media traffic with an acceptable quality leading to a visually meaningful and acceptable traffic.

TFRC according to the researches is a good candidate protocol for this target. It can balance between accomplishing the TCP-friendliness task and allowing for some QoS constraints to be met. A number of research work targeted the evaluation of TFRC in terms of TCP-friendliness and fairness and many tests were done for this purpose either in the simulated environments or in the real-world. TFRC has not been thoroughly tested so far regarding the quality of the media traffic running over it.

This work evaluated the quality of an expressive sample group of videos when transmitted over TFRC. This evaluation utilized the simulation environment and was made in terms of the visual usefulness of the received video files. It was also made in terms of the mean PSNR values in dB of the output files of the simulation process when compared to the originally transmitted files over TFRC. Simulations used TFRC as the transport protocol for the media files and meant to compare the quality of the video files after being transmitted over TFRC with their quality before transmission.

TFRC was shown to produce acceptable quality for the received video files. This emphasizes the fact that TFRC is still the candidate for the congestion control problem solving. It was also shown through the simulations results that the performance of TFRC in terms of quality degrades slightly with the increase in the motion complexity of the transmitted videos. The received low-motion videos managed to have better mean PSNR values than others of medium-motion, also medium-motion videos managed to act better than high-motion videos regarding the same mean PSNR concern. It can be said that the PSNR value was inversely proportional to the motion scale of videos.

We believe that our work here can be helpful for researchers handling the congestion control problem and researchers trying to enhance the performance of TFRC in order to increase its capabilities of being the congestion control problem solution.

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