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The Relationship of TFRC Congestion Control to Video Rate Control Optimization

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***Abstract*-Rate control plays an important role in delivering video traffic over the Internet due to highly bursty nature of the video data and variability of the network bandwidth. The researchers in this area are either controlling the video rate coding or optimizing the congestion control to support the video traffic transmission. As a consequence of layering principle of the network architecture, the algorithm in each layer works independently. Thus, any optimization at video coding rate does not necessarily improve the video data transmission effectively. In this paper, we investigated the above-mentioned premise. We found that TFRC works independently from the video coding rate. Consequently, any effort to optimize the video traffic Internet transmission needs to consider employing rate control schemes both at video coding rate and congestion control algorithm.**

I. INTRODUCTION

Due to the surge of media traffic over the existing best-effort Internet, the network congestion condition is projected to worsen. Thus, delivering video traffic over the Internet needs to employ rate control scheme as a result of video playback timing constraint and variability rate in the network bandwidth.

There are two rate control schemes, currently being studied. One of them is on optimizing video coding rate at the application layer, thus it will not generate uncompromising bursty video traffic into the network interface. Another study is on regulating the network congestion through several congestion controls at the transport layer.

The Internet is built on the notion of protocol layering by breaking the complex task of network functions into self-regulating protocol layers. Each layer performs different operations with minimum interaction among them. In the context of this study the main layers involved are application layer and transport layer. The application layer performs video coding rate control. Meanwhile, the transport layer regulates transmission rate in the Internet.

Fig. 1 illustrates the relationship of the above-mentioned components. The sender and the receiver perform application layer tasks. The video coding rate is done at the sender. The processes (of the video coding rate) end at the network interface. Then the data will be sent to the receiver via the Internet. The Internet network is represented by the cloud in the Fig. 1. The Internet transmission rate for this study is regulated by TFRC transport protocol congestion control.

The layering principle has functioned well in the Internet in terms of scalability and functionality, at least for data applications. On the other hand, the layering makes it difficult to provide end-to-end performance guarantees. This is highly true in terms of fulfilling some of the application performance requirements, such as in the case of application that is sensitive to delays.

Thus, any optimization at video coding rate does not necessarily improve the video data transmission effectively. Most of the video coding rate adaptation studies are focusing on controlling traffic admission into the network interface. On the other hand, the studies on the transport protocol, such as TFRC, are regulating the transmission in the network, particularly in terms of controlling the congestion control. The TFRC will work independently from the algorithm at the application layer, it will solely be based on the content in the network interface buffer and current state of network congestion/losses.

This paper investigated the previously mentioned statement by looking deeply inside both the video rate adaptation and the transport layer protocol. For the video

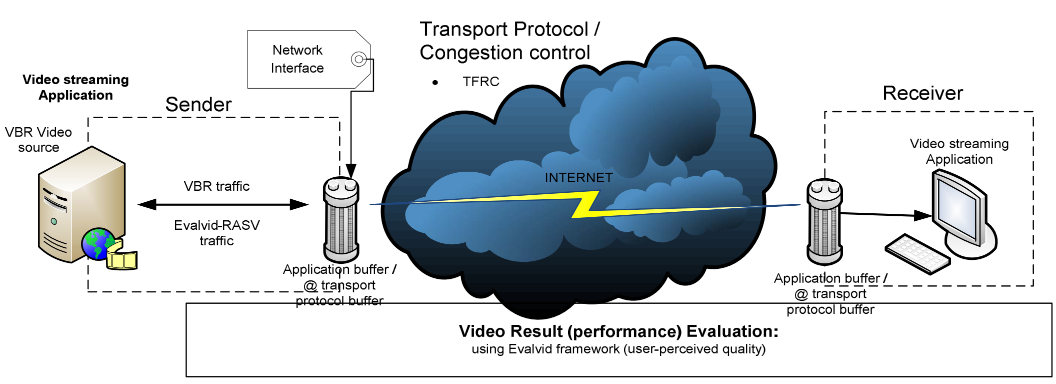

Figure 1. Video Transmission Architecture of the Evalvid-RASV

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rate adaptation, we used the Evalvid-RASV [1], a shaped VBR (SVBR) [2] rate adaptation for stored video system. Whereas, in the transport layer protocol, we examined the TFRC.

The Evalvid-RASV implemented SVBR and Evalvid [3] environment for a stored video transmission system. SVBR is a preventive traffic control which allows VBR coded video traffic direct into the network but will regulate unpredictable large bursty traffic by utilizing leaky bucket algorithm.

Then again, Evalvid is a user-perceived tool-set for video performance evaluation. Therefore, the video transmission researchers are able to evaluate their network designs or setups in terms of user perceived video quality. Then the study by Ke et. al in [4] has integrated Evalvid with NS2. It enables researchers and practitioners in general to simulate and analyze the performance of real video streams with consideration for video semantics under a vast range of network scenarios. After that, Lie and Klaue in [2] have implemented Evalvid-RA, which integrated SVBR and Evalvid in NS simulation environment.

We analyzed on how the TFRC will react to the adaptive rate VBR (Evalvid-RASV) and with an open-loop VBR (non-adaptive rate VBR). We also support the finding by adding a performance increment in the TFRC by enabling ECN/RED capability. We found that TFRC works in the same manner both with Evalvid-RASV environment and on open-loop VBR. This finding demonstrates the fact that improving video coding rate will not necessarily improve the video data transmission effectively. In addition, we found that the overall performance directly related the performance of the TFRC.

The remainder of this paper is organized as follows. In the next section, we provide a brief background on the related studies on this issue. In Section III we will explain on how the experiments were done. Then in the section follows, the results of the experiments will be discussed. Finally, we conclude the paper in Section V.

II. RELATED WORKS

As a consequence of explosive growth of media traffic traversing the Internet in recent years, many optimization studies are being done. These are due to the fact that media traffic data will produce irregular data to the network, which is not designed to suffice the requirements of such traffic natively. Thus it will probably congest the network and in the worst case scenario, it may lead to congestion-collapsed network.

There are two rate control for video transmission schemes; involving controlling the video rate coding and regulating the transport protocol. In the first scheme, the video data source is regulated so that in the network interface there will be fewer burst. In the second scheme, the network congestion is regulated, which can determine a suitable network speed rate.

A. VBR Rate control studies

As stated in the previous section, the need for the video rate control is clear. However, producing an efficient video rate control is still a challenging task. Nevertheless, there are many studies are done on various dynamic-network scenarios.

Hamdi *et al*. in [2] have introduced a novel concept of the SVBR. SVBR is a preventive traffic control which allows VBR coding video traffic direct into the network but at the same time it will regulate unpredictable large bursty traffic by utilizing a leaky bucket algorithm. The leaky bucket used by them can be considered as an imaginary buffer, thus no extra delay is introduced.

Another work is published in [5]. The rate control is regulated by adjusting the frame size output by a scalar from a rate-distortion curve. However, they used synthetic traffic, which hinders them from assess the result by using user-perceived video performance evaluation.

Various ways of implementing video rate control have been proposed in [6]. Among other are on how bits are allocated to the frames that are nearer to their reference frame, which is I-frame; the usage of target buffer level as a function of the frame position in the GOP, so that it will be achieved gracefully at the end of a GOP; and the use of q quantization value of an I-frame which is decided based on its spatial complexity.

B. TFRC Controls for Video Transmission Studies

The study by M. A. Talaat, *et al.* [7] found that TFRC had shown to produce acceptable quality for the video transmission. They claim that they found the performance of TFRC in terms of quality degrades slightly (by inspecting PSNR value gained) with the increase in the motion complexity of the transmitted videos. We are in an opinion that the finding is a typical result of the video transmission studies.

There were various attempts toward optimizing the performance of TFRC for video data transmission. One of the attempts is to use variable packet size streams [8]. The author enhanced the TFRC by modifying the concept of TCP-friendliness. Previously, these kinds of flows are penalized because it imitates TCP's behavior by giving less throughput to the flows that use small packets. By modifying the concept of TCP-friendliness, his TFRC performs better than the original TFRC for the media data transmission.

The other attempt was to utilize the unused gap in the TFRC rate. TFRC works smoother in comparison to aggressive TCP rate, whereas TFRC rate is based on the TCP equation model. Thus TFRC will use smaller available bandwidth in comparison to TCP. Therefore, the study in [9] computes the rate gap between TFRC and the ideal TCP rate, then utilized them in the TFRC rate calculation.

Another approach is to create parallel transmissions for one media application transmission. The work by Damjanovic and Welzl [10] extends the derivation underlying the TFRC equation, resulting in a tunable version called 'MulTFRC,'. Their algorithm is capable of computing the appropriate *n* flow of TCP-friendly data rate that matches the throughput of *n* TCP flows. Their simulations and real-world test demonstrate that MulTFRC performs significantly better than its competitors, potentially making it applicable in a broader range of settings than what TFRC is normally associated with.

C. Integrated Schemes Studies

One of the studies which employ rate control at both schemes is as reported in [11]. Among the challenges in integrating the schemes are rate matching between the two schemes, to ensure TCP-friendliness, users demand for a high-quality media, and smooth media output under the varying network conditions. Thus, in their study they have introduced a rate smoothing control mechanism to meet the rate matching with the controlled transmission buffering delay. They also developed an adaptive rate control for the I-frame which is designed to reduce the frame skipping.

The other study is done by Lie and Klaue in [12]. They adjusted the video coding rate base on the feedback from TFRC and a proprietary congestion control system namely P-AQM. The video coding rate here is based on Hamdi et al. SVBR concept [2].

III. THE EXPERIMENTS

We have run the experiments by simulation with a large number of video frames. As a comparison, we run as well a set of experiments using "non-adaptive" VBR (open-loop) with the smallest Q (the highest quality). All the experiments are conducted in ns2 simulation.

In setting the simulation experiments, we attempt to closely match the real Internet environment wherever possible. Most of the topologies, setting and parameters used in these studies have been based on various works of others, in particular video transmission research.

For the experiments, a well known dumb-bell topology is extended into the Evalvid-RASV as depicted in Fig. 2. Since

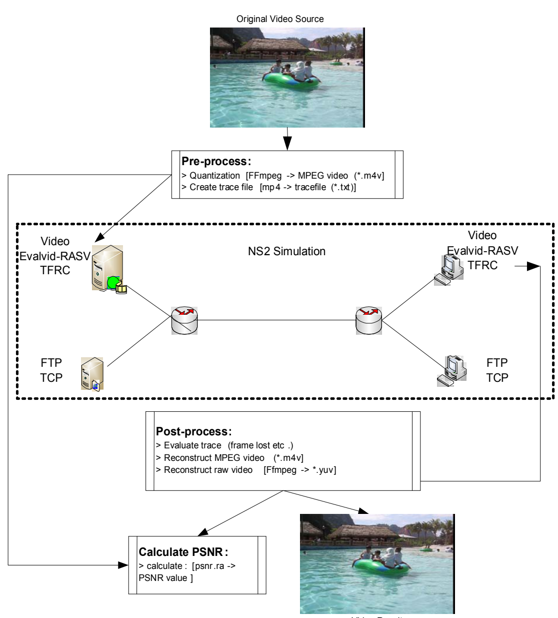

Figure 2. Simulation Setup

we are interested to examine the relationship between the application algorithm and the transport layer, this topology is considered sufficient. The FTP node does not play significant role in view of the fact that the bottleneck bandwidth is relatively big. Yet, we still let it there, thus the simulation topology is not too simple and at the same time it can be a flexibility for us to test with other settings.

For propagation delays at both end links, we used 2 ms and at the bottleneck link used 50 ms one-way delay. Thus, end-to-end round trip propagation delay was 108 ms. This value is closely representative of typical WAN delays on the Internet, which is 105 ms [13]. For bandwidth speed at the receiver link, we used 340 Kbps to represent the lowest broadband home Internet access speed in Malaysia. In the bottleneck link, we used 1.5 Mbps as the bandwidth speed. This bandwidth is sufficiently provisioned so that congestion only occurs at the video application link.

In the first set of simulation experiments, we run open loop video rate coding with quantization value two. These experiments will generate a large volume of video data into the network interface. Then we evaluated on how the TFRC reacted to that data. On the second set of the experiments, we run our own video rate control, namely Evalvid-RASV. This coding will generate moderate data into the network interface.

We also developed scripts and coding to produce some beneficial data for easier analysis. Among the output produced are the status of queue at the receiving router when each packet is sent, the accumulated number of packet drops, the number of packets generated by video coding, the number of packets at the network interface (specifically at TFRC buffer) and the transmission rate.

In order to show that the overall performance will increase if the transport protocol performance increases as well, we setup the application of ECN/RED in the network experiments. We used RED router and enable the ECN capability. This solution has been documented in detail and lengthy in RFC 3168, "The Addition of Explicit Congestion Notification (ECN) to IP" [14]. It has been accepted as a standard by IETF. The idea is to detect the incipient of congestion before the queue overflows, and provide an indication of this congestion to the TCP end nodes. Thus, it can reduce unnecessary queuing delay for all traffic sharing that queue.

Early solution is to use active queue management mechanisms to detect the incipient of congestion. We can refer the solution in RFC 2309, "Recommendations on Queue Management and Congestion Avoidance in the Internet" [15] By using active queue management, TCP does not have to rely on buffer overflow as the only indication of congestion. ECN/RED is using explicit feedback from the network and we can expect performance improvement with explicit participation of the network [16].

In order to implement ECN/RED, we increased the router buffer size. ECN/RED is more effective if the router buffer size is bigger. We used the following parameter for Queue/RED; thresh_ = 5, maxthresh_ = 15 and q_weight = 0.002.

IV. The Results and Discussions

Normally, when there is a big volume of data at the network interface, the transport protocol transmission rate will increase accordingly. Nevertheless, we want to attract the attention that the transport protocol will work independent than the video coding rate. We want to highlight again that Evalvid-RASV video coding rate will produce moderate data into the network interface, whereas VBR-Q2 coding rate will produce very huge data into the network interface. Thus, we can observe either TFRC will respond in another way with the different amount of the data in the network interface.

The chart in Fig. 3 indicates that the Evalvid-RASV algorithm is working efficiently. The router queue fullness (marked by R2 Queue) is around 14 packets (the maximum packet size). Although some drops occurred (which means Evalvid-RASV has introduced more than the queue limit), the number is small. Only 35 packets are dropped in comparison to more than 9000 packets transmitted successfully. Furthermore, the algorithm is working at the Group of Picture (GoP) granularity. This means that each control is done on group of video frames and not on every packet.

The drops occurred as a result of the low bandwidth speed at the receiver link. As mentioned previously, we used the low bandwidth speed as a reason to represent the lowest broadband home Internet access speed in Malaysia. Thus, the overflow queue occurred at the receiving router resulting in packet drop.

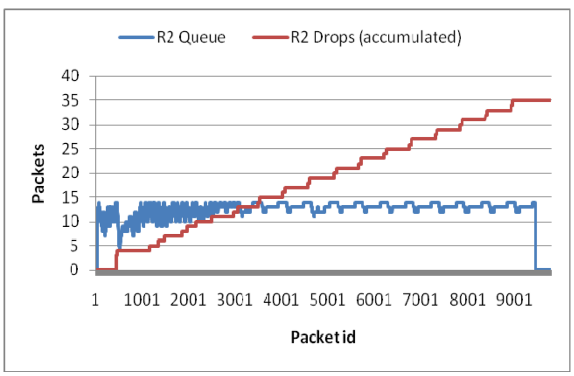

Figure 3. Evalvid-RASV, Router Queue and Accumulated Drops

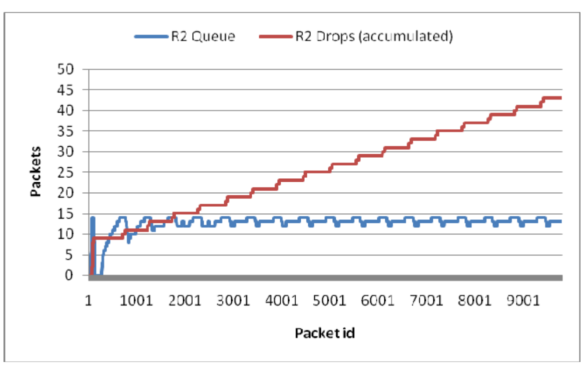

Figure 4. VBR-Q2, Router Queue and Accumulated Drops

The plot in Fig. 4 shows similar number of packets from open loop video rate coding with quantization value two. Although the drops are higher, but it is still considerably low in comparison to the number of packets transmitted. The router queue size was around 14 packets. It shows that the router queue is used almost to the optimum level. However, we want to highlight that the overall number of packets to be transmitted with VBR-Q2 video coding are more than 103,000 (compared to only less than 10,000 packets with Evalvid-RASV). The total drops are almost 400 packets.

The fact that we want to stress here is that TFRC works independently from what has been generated by the video coding engine. In the former case (with Evalvid-RASV), the packets queue at the network interface are small. This is due to the dynamic video coding based on Evalvid-RASV algorithm. In contrast, the latter case shows the number of packets queue at the network interface are huge as a consequence of the highest quantization parameter used. Ironically, TFRC seems to work independently regardless of how much data is in the network interface, as stated in RFC 5348 [17]. The TFRC increases the sending rate in each round-trip time until a loss occurs. When losses occur, the sending rate will decrease. Every changes in the sending rate are based on network status and not on what are available at the network interface.

Fig. 5 and Fig. 6 illustrate this relationship clearer. The "Data/s" expresses the TFRC transmission rate in Kbyte per second. The "TFRC Buffer" represents the current status of the number of packets in the TFRC buffer. It can be an indication of the video coding rate (by looking at the balance in TFRC buffer while TFRC is sending the data). Finally, "R2 Queue" and "R2 Drop" represent quantity of packets in router 2 and the number of packet drops respectively.

It is clear from Fig. 6 that while TFRC buffer goes up to nearly 100,000 packets, the data transmission rates remain at around 40000 to 50000 Kbyte per second. In Fig. 5, when number of packets in TFRC buffer is around 20, the transmission rate is also around 40000 to 50000 Kbyte per second. It does not matter of the different scale used in Fig. 5 and Fig. 6, because our interest is on the relationship between number of packets in the TFRC buffer. As explained previously, the total number of packets produced by VBR-Q2 video coding are more than 103,000. Thus, in conclusion TFRC has worked independently regardless of what has been generated by the video coding engine.

In terms of user-perceived video quality, Evalvid-RASV obtained Peak Signal Noise Ratio (PSNR) value around 29.17, whereas VBR Q=2 resulted in PSNR value equal to 26.06. Although the difference is significant, it is still not big enough. We reckon that the small difference occurred as a result of TFRC not utilized the rate control at the application layer.

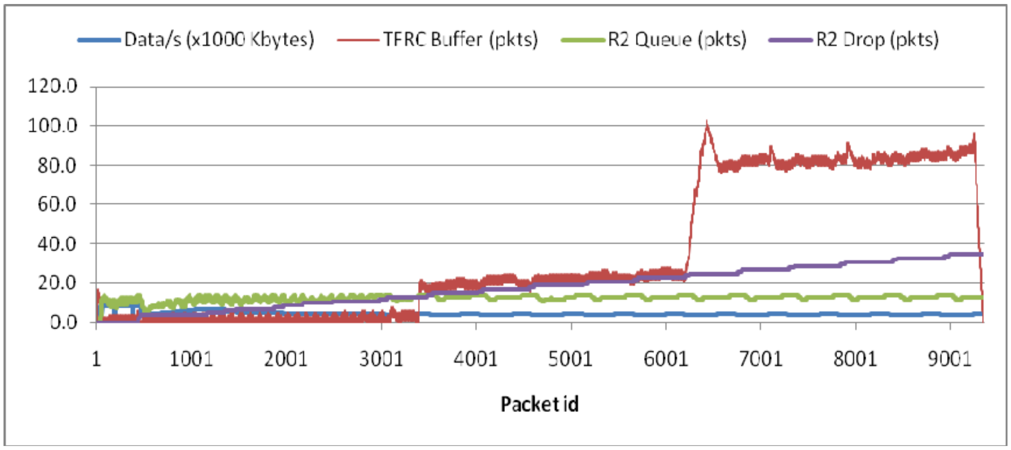

Figure 5. The Video Coding Rate and TFRC Rate in Evalvid-RASV

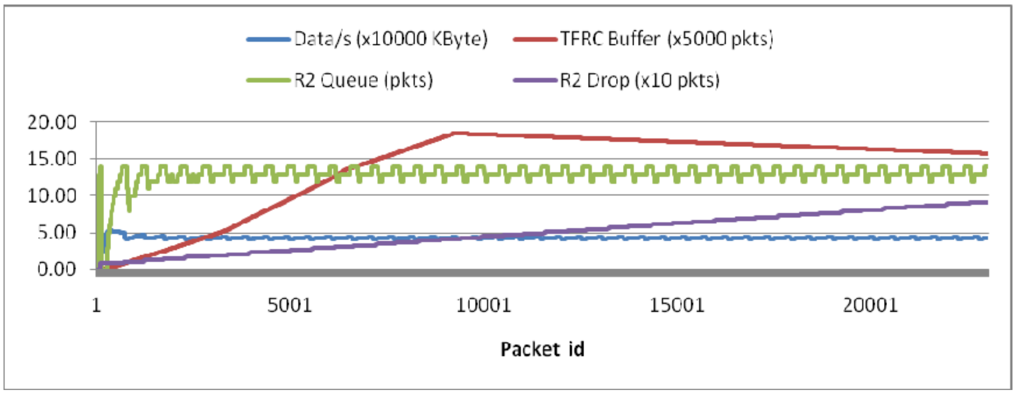

Figure 6. The Video Coding Rate and TFRC Rate in VBR-Q2

After we applied ECN to the Evalvid-RASV, number of drop frames reduced. The average PSNR value gained increased to 32.22. We plotted the PSNR values gained in Fig. 7 in comparison to the application of ECN and vice versa. It shows that Evalvid-RASV with ECN/RED at TFRC produced better PSNR values, which indicates that it resulted in better user-perceived video quality. We believed, it is an indication of the overall performance increment when we improve the transport layer performance.

V. CONCLUSION

We have shown that any optimization on the video coding rate does not automatically enhance the overall video data transmission. This is due to the layering principle separation of the computer network architecture. The improvement of the video coding rate will generate data into the network interface. Then the transport layer protocol transmission will pick up the data for the transmission. As such, improving the algorithm at the application layer will not necessarily improving the overall video data transmission.

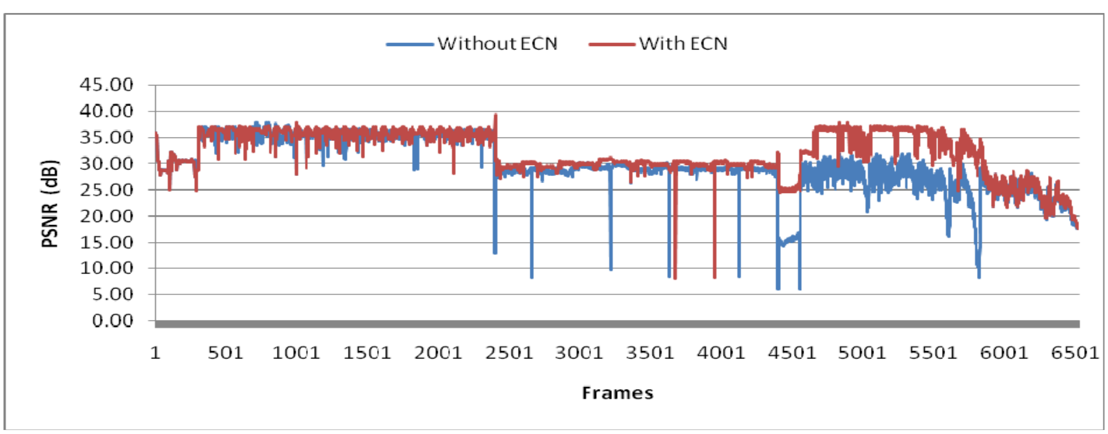

Figure 7. PSNR Values for Evalvid-RASV with and without ECN

We also exhibited that quantity of data at the network interface does not affect the TFRC. We have also demonstrated that improving the TFRC performance, the overall performance will increase as well. Hence, we somewhat concluded that any effort to effectively optimize the video traffic Internet transmission needs to consider employing rate control schemes both at the video coding rate and the congestion control algorithm.

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