Layered Multicast: A Study of Loss Event Rate Estimation in a Low Level of Statistical Multiplexing

Osman Ghazali
Department of Computer Sciences
Universiti Utara Malaysia
06010 UUM Sintok, Kedah, Malaysia
osman@uum.edu.my

Suhaidi Hassan
Department of Computer Sciences
Universiti Utara Malaysia
06010 UUM Sintok, Kedah, Malaysia
suhaidi@uum.edu.my

***Abstract*—Layered multicast protocol (LMP) uses TCP-equation model to estimate TCP-compatible rate. One of the most important parameter of TCP-equation model is loss event rate. It is acquired by estimating the number of packets between two lost events, which is determined by packet-drop pattern at the bottleneck link. In a low level of statistical multiplexing environment packet-drop pattern at the bottleneck link is determined by the queuing management and the behaviours of competing data flows. Since TCP is the dominant protocol of the Internet, the performance of LMP is greatly affected by the behaviours of TCP flows. Since TCP is an aggressive and bursty protocol, competing with TCP results in volatile estimated loss event rate for LMP. Smoothing techniques for loss even rate have been proposed to reduce the volatility of loss event rate. This paper presents a comparative study of loss event rate smoothing techniques for layered multicast protocol. The study has been conducted in a low level statistical multiplexing environment.**

Index Terms - Congestion Control, Loss Rate, Layered Multicast, Transport Protocol

I. INTRODUCTION

Layered Multicast Protocol (LMP) is one of the solutions for data transmission of continuous multimedia applications over the Internet. It allows users with different network capacities to achieve different reception rates and enables users of different network bandwidth perceive different multimedia qualities.

TCP-equation model is the technique commonly used to control congestion in TCP-friendly rate-based layered multicast protocols. It has been adopted in many non-TCP protocols as it enables the protocols to control congestion and at the same time to be friendly towards TCP flows. In a high level of statistical multiplexing environment, TCP-equation model perform well. However, in a low level of statistical multiplexing environment, TCP-equation model perform poorly.

TCP Reno equation models the long-term behaviour of TCP Reno with the functions of packet size, loss event rate, round trip time and retransmission timeout [1]. Loss event rate, i.e. the inverse of loss interval size, is regarded as one of the most important parameters in TCP-equation model [2]. It has greater influence on the accuracy and stability of TCP-compatible rate estimation than the other parameters. However, in both high and low level of statistical multiplexing environments estimated loss event rates are volatile [3]. For the layered multicast communication, the volatility is exaggerated by the misleading loss event information, which is the result of the inability of the sender to assign session's sequence number to the packets. To address this problem, smoothing techniques for loss event rate are proposed. The techniques are of two-step lost interval filtering, packet reordering and conservative loss event rate.

This paper reports the implementation of loss event rate smoothing techniques in a LMP. In particular it reports the observation and comparative performance evaluation of the smoothing techniques under a low level of statistical multiplexing environment. The remainder of this paper is organised as follows. The next section gives a brief overview of the level of statistical multiplexing, Section III gives a brief overview of TCP-friendly equation model, Section IV gives an overview of loss event rate estimation, Section V describes smooth loss event rate estimation, Section VI describes the experimental settings, Section VII presents the result, and Section VIII concludes this paper.

II. LEVEL OF STATISTICAL MULTIPLEXING

The level of statistical multiplexing of a link refers to the number of traffics on the link. The number of traffics affects the behaviour of the link's traffics, in particular to what extent the behaviour of a single data flow affects the behaviours of other data flows.

In a high level of statistical multiplexing environment, there is large number of data flows on the link. The aggressiveness and volatility of a competing data flow can be absorbed by other flows. That is the aggressiveness and volatility of the data flow has no or little effect on the aggregate traffic behaviour. In this environment the collective behaviour of competing traffics determines the individual behaviour of a data flow. On the other hand, in a low level of statistical multiplexing environment, the number of data flows is small and not sufficient to absorb the aggressiveness and volatility of a single data flow. Therefore, the behaviour of a competing data flow will affects the performance of other data flows.

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TCP is the dominant protocol in the Internet and constitutes of 90% of the Internet traffics. It is a bursty and aggressive protocol. On the other hand LMP is a smooth and steady protocol that relies on equation models to determine its flow rate. In a low level of statistical multiplexing environment, non-aggressive protocols such as LMP could not compete fairly with TCP flows. That is the volatility of TCP flows results in the volatility of LMP flows and TCP aggressiveness starves LMP data flows. This is unfavourable for continuous multimedia applications, which favours smoother throughput.

III. TCP Equation Model

Since TCP is the most dominant traffic in the Internet, it is suggested that other protocols have to be friendly towards TCP [4]. Equation-based LMPs employ TCP-equation model as the technique to control congestion, and to be friendly towards TCP flows. A number of TCP-friendly equations that model long-term TCP throughput have been proposed, one of the most popular models is the TCP Reno equation model proposed by [2]. Using the model, equation-based LMPs can estimate TCP-compatible rate, and adjust their sending or reception rates according on the estimated TCP-compatible rates.

TCP Reno equation models TCP Reno behaviour with the functions of packet size, loss event rate, round trip time and retransmission timeout. The values of these parameters are estimated using the information from the received packets. Among the parameters, loss event rate and round trip time are the most difficult to estimate, while retransmission timeout can be estimated using round trip time.

IV. Loss Event Rate Estimation

loss event rate is suggested as the better representation of general TCP behaviour [2]. It is the inverse of the size of a loss interval, and the size of a loss interval is the number of received and lost packets within a loss interval. A loss interval begins with a loss event and ends with another loss event. A loss interval may contain one or more packet loss occurrences during one round trip time. A lost packet is considered a part of an existing loss interval if it occurs within a round trip time since the last loss event. Otherwise, the packet becomes the first packet of a new loss event.

A. Problems of Loss Event Rate Estimation

In a low level statistical multiplexing environment, the packet drop pattern of a LMP data flow is subjected to any behaviour of the competing data flows. An observation of loss event patterns of a layered multicast protocol shows oscillatory loss intervals are estimated at receivers [3]. Though average loss interval algorithm [2] is used to mitigate the effect of the oscillatory loss intervals, the small size of loss history windows limits the effectiveness of this technique. Moreover, TCP burstiness and aggressiveness add to the volatility of LMP data flows.

In a LMP session, data packets are distributed across multicast layers where each layer can be seen as a single layered multicast. Therefore, it is not possible to assign the session's sequence numbers to the packets. Consequently, the packets can only be assigned layers' sequence numbers. However, the assigned layers' sequence numbers mislead receivers regarding the packet loss events and the size of lost intervals. As a result, loss event rates are wrongly estimated at receivers.

B. Average Loss Interval

Average loss interval algorithm is recommended as the best weighted average for loss event rate estimation [2]. This method uses dynamic history windows and exponential weighted moving average. The average loss interval size is computed as the weighted average of the last *k* loss intervals as follows:

$$l_{avg}(n) = \frac{\sum_{i=0}^{k-1} w_i l_{n-1}}{\sum_{i=0}^{k-1} w_i} \quad (1)$$

and for weights w_i:

$$w_i = \begin{cases} 1 & \text{for} \quad 1 < i < n/2, \\ 1 - \dfrac{i - n/2}{n/2 + 1} & \text{for} \quad n/2 < i < n. \end{cases} \quad (2)$$

The smoothness and stability of ALI depends on loss history size that the higher loss history size is the smoother and more stable ALI is. However, large loss history window size reduces the protocol responsiveness towards bandwidth changes, which is very problematic in controlling network congestion. The recommended windows size is between 8 and 32.

V. Smooth Loss Event Rate Estimation

Smooth loss event rate estimation address oscillatory loss event rate using smoothing technique, namely two-step loss interval filtering [5], packet reordering [6] and conservative loss event rate.

A. Two-Step Loss Interval Filtering

Packet drop patterns at the bottleneck link and the misleading packet sequence numbers result in fluctuation of observed loss interval sizes at layered multicast receivers. Some of loss interval sizes are too high or low that are not representing the actual network condition. These unrepresentative loss intervals are temporary and not sustainable, that in long term they will not form a new loss interval trend. On the other hand, the change of loss interval that is a result of the change of the available bandwidth in the network is sustainable and will form a new loss interval trend in long term.

With the assumption that unrepresentative loss interval changes are temporary and occasionally occurred, the two-step loss interval filtering technique identifies and discards the extreme temporary change of observed loss interval size and only considers sustainable observed loss interval for inclusion in the loss windows history. The technique consists of a

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preliminary test and two filtering steps. The preliminary test examines the newly observed loss interval and assigns its status, the first filtering step tests whether the change in the observed loss interval is a formation of a new loss interval trend, and the third step confirms the formation of the new loss interval trend.

B. Packet Reordering

Packet loss is detected when the sequence numbers of the received packets are out of order. In layered multicast communication, however, the sequence numbers are unsynchronized across layers where packets are assigned layer's sequence number. Since a layered multicast session consists of many layers, this poses a problem of accurate loss interval size estimation for layered multicast session. To address this problem session's packet reordering based on the sender's packet timestamp was proposed [6].

To determine the sending time of lost packets we can compare the sequence number and sender timestamp of the packets of from same layer that arrived at the receiver. For a loss event with single packet loss, the sending time of the lost packet can be inferred using the equation depicted in (3).

$$ts\_loss = \frac{ts\_pre\_loss + ts\_af\_loss}{2} \quad (3)$$

Where *ts_loss* is the estimated sending time of the loss packet, *ts_pre_loss* is the sending time of the packet before the loss packet, and *ts_af_loss* is the sending time of the packet after the loss packet.

For a loss event with more than one packet loss, the sending time of the lost packets can be inferred using the equation (4) and (5).

$$sending\_gap = \frac{ts\_af\_loss - ts\_pre\_loss}{pkt\_losses + 1} \quad (4)$$

Where *sending_gap* is the waiting period between two consecutive packets of the same layers, *ts_af_loss* is the timestamp of the immediate packet after the loss packet, and *ts_pre_loss* is the timestamp of the immediate preceding packet of loss packet

$$loss\_ts_i = ts\_bf\_loss + (i * sending\_gap) \quad (5)$$

Having known the sending time of all packets, including loss packets, accurate packets sequence can be obtained by reordering received packets based on their sending time. Therefore, accurate loss interval size can be estimated.

C. Conservative Loss Event Rate

The recommended ALI's loss window histories are between 8 and 32 windows. Using 32 windows will result in smooth and steady loss event rate but slow response to the changes of available bandwidth. However, 8 windows are not enough to smooth loss event rate. To solve this problem we suggest being conservative. That TCP-compatible rate is set to the minimum of short-term ALI and long-term ALI.

Short-term ALI is estimated using Two-Step Loss Interval Filtering and 8 windows. Meanwhile, long-term ALI is estimated unfiltered loss interval samples and 32 windows. Long-term ALI uses unfiltered loss interval samples as they represent the actual network condition. It can absorb the extreme loss interval size as it uses a large window history. The conservative loss event rate algorithm is follows:

```
IF long-term-loss-event-rate < short-term- loss-event-rate
    Use long-term- loss-event-rate
ELSE
    Use short-term- loss-event-rate
ENDIF
```

VI. EXPERIMENTS

To study the loss interval filtering technique, we implement the technique in a TCP-Friendly Layered Multicast Protocol (TFLMP) [7] using NS-2. The experiments are set with the objectives to study the stability and precision of loss rate and TCP-compatible.

A. Performance Metrics

To evaluate the precision of loss rate and TCP-compatible rate estimation we use fixed sending and reception rate, and we compare the loss rate and the estimated TCP-compatible rate with the fair bandwidth share per-flow, i.e. 300 Kbps per flow. Coefficient of variation (CoV) and variability measurement as in [8] are used to evaluate the stability of loss rate and TCP-compatible rate estimation. The calculation of CoV and variability are performed per-flow basis, the per-flow results are averaged for all simulations.

B. Simulation Setting

Four different TFLMP implementations are used in this study. The first TFLMP is the TFLMP with no filtering technique. The second TFLMP is the TFLMP with Two-Step Loss Interval Filtering. The third TFLMP is the TFLMP with Two-Step Loss Interval Filtering and packet reordering. Finally, the fourth TFLMP is the TFLMP with all filtering techniques. They are named TFLMP-1, TFLMP-2, TFLMP-3, and TFLMP-4 respectively.

Our assumption in this study is that loss rate at receivers are independent of the sender's rate [9], where it is determined by the behaviour of competing flows and the queuing management at the bottleneck link. Based on the assumption, we set fixed sending and reception rate at 300 Kbps for all TFLMP implementations. The sending rate is distributed across 3 layers. The rate for each layer is set to rate multiplier 1.3, and the cumulative rate of all layers is 300 Kbps. This serves our need very well since all TFLMPs under study used the same sending and reception rate. All TFLMP implementations except TFLMP-4 use short-term loss event rate.

A dumbbell topology as depicted in Figure 1 is used. The network bandwidth is shared between 1 TFLMP and 4 TCP connections. This represents a low level of statistical multiplexing environment, which environment TCP-equation model performs poorly [8]. The bottleneck link between router R_1 and R_2 is configured to have a propagation delay of 20 ms and a bandwidth of 1.5 Mbps (fair bandwidth share of 300

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Kbps for each flow). All access links have a delay of 6 ms, and are sufficiently provisioned to ensure that packet drops due to congestion only occur at the bottleneck link.

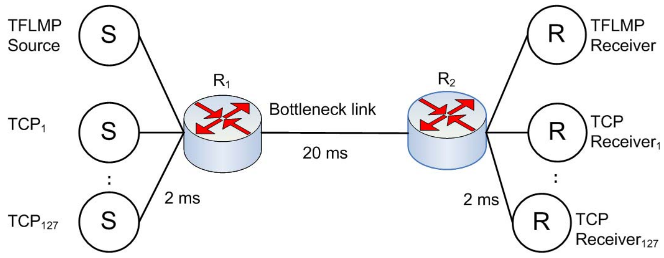

Figure 1. Simulation Topology

We use DVMRP [10] routing protocol at all routers. DropTail and RED queuing managements with buffer size of two bandwidth delay products are used in the experiments. Constant bit rate (CBR) is used as TFLMP data source, and we set the packet size of all flows to 1000 bytes. For the TCP flows we use New TCP Reno, and to avoid the influence of the maximum window, we set max-window to 4000 packets. The summary of simulation scenario is in Table I.

TABLE I. SIMULATION SCENARIO

Bottleneck link's bandwidth	1.5 Mbps
Access link's bandwidth	10 Mbps
TFLMP session	1
TCP session	4
Fair bandwidth share	300Kbps
Packet size	1000 bytes
Queuing management	DropTail, RED

We start the multicast source at time zero and its sinks at 3 seconds later. In order to avoid synchronisations, all TCP sessions start at between 3 and 4 seconds using random number generator (RNG seeds). Each TFLMP implementations is run 20 times for duration 500 seconds.

VII. RESULTS

Our analysis is based on the trace data from the simulations. We ignore the data for the first 100 seconds of the simulations, and measure mean, CoV and variability of the estimated loss event rate and TCP-compatible rate for the 101^{st} second to the 499^{th} second of the simulation. Results are averaged for all 20 simulation runs.

Table II shows the result of average estimated loss event rate under DropTail gateway. TFLMP-1 estimates the lowest loss event rate but with the highest CoV and variability. On the other hand, TFLMP-4 estimates the highest loss event rate with the lowest CoV and variability. It is also shown in the table CoV and variability decrease with the additional smoothing techniques in TFLMP. This indicates the techniques significantly reduce loss event rate volatility and increase loss event rate stability. This is illustrated in Figure 2 that the estimated loss event rate of TFLMP-4 is smoother and more stable than the estimated loss event rate of TFLMP-1. However, as shown in the average loss event rate column of Table II the smoothing techniques increase the average estimated loss event rates. This will result in lower estimated TCP-compatible rate.

TABLE II. MEAN, COEFFICIENT OF VARIATION AND VARIABILITY OF LOSS EVENT RATE UNDER DROPTAIL GATEWAY

Filtering Technique	Average Loss Event Rate	CoV (%)	Variability (%)
TFLMP-1	0.0352	31.91	13.00
TFLMP-2	0.0445	31.33	6.07
TFLMP-3	0.0448	28.16	5.95
TFLMP-4	0.0472	24.55	3.79

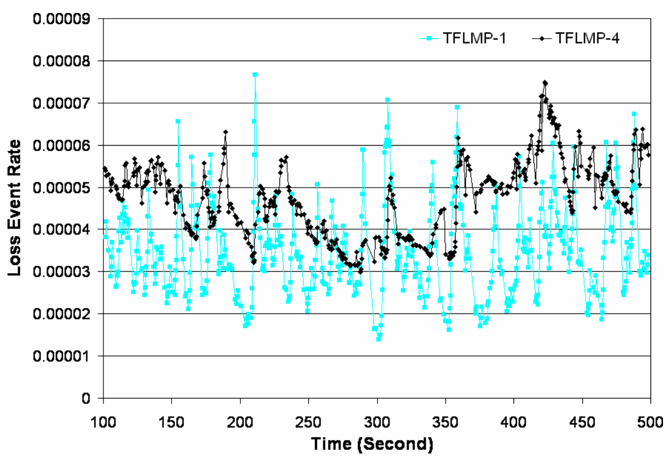

Figure 2. An Instance of Estimated Loss Event Rate under DropTail Gateway

Table III shows the result of the average estimated TCP-compatible rate under DropTail gateway. TFLMP-1 estimates the highest TCP-compatible rate with the highest CoV and variability. On the other hand, TFLMP-4 estimates the lowest TCP-compatible rate with the lowest CoV and variability. The difference between the two average TCP-compatible rates is 41 Kbps. This can be attributed to the higher loss event rate estimation by the TFLMP with smoothing techniques. Figure 3 illustrates an instance of estimated TCP-compatible rates of TFLMP-1 and TFLMP-4 simulations (one simulation run). It can be observed that the estimated TCP-compatible rates of TFLMP-4 are slightly lower than the estimated TCP-compatible rates of TFLMP-1, but the estimated TCP-compatible rates of TFLMP-4 are more stable than the estimated TCP-compatible rates of TFLMP-1.

The CoV column of Table III shows CoV decreases with additional smoothing techniques in TFLMP. This indicates the stability of estimated TCP-compatible rate increases with additional smoothing techniques in TFLMP. However, as shown in the CoV column, the CoV of TFLMP-2 is higher than the CoV of TFLMP-1. We further investigate by calculating the variation of TCP-compatible rates for both TFLMP-1 and TFLMP-2, and find out the TCP-compatible

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rate variation of TFLMP-1 is slightly higher than TFLMP-2. Their variations are 50 Kbps and 46 Kbps respectively.

TABLE III. MEAN, COEFFICIENT OF VARIATION AND VARIABILITY OF ESTIMATED TCP-COMPATIBLE RATE UNDER DROPTAIL GATEWAY

Filtering Technique	Average TCP-Compatible Rate (T)	T Ratio to Theoretical Fair Bandwidth Share (%)	CoV (%)	Variability (%)
TFLMP-1	226 Kbps	75.18	22.36	15.80
TFLMP-3	195 Kbps	65.14	23.31	11.84
TFLMP-2	193 Kbps	64.37	21.92	11.64
TFLMP-4	185 Kbps	61.62	19.79	11.16

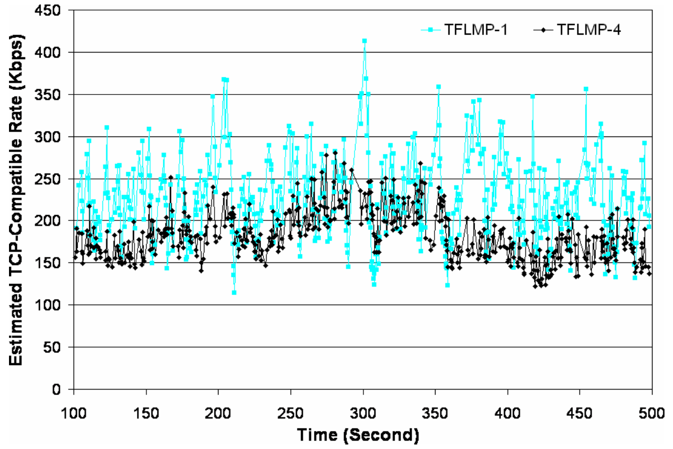

Figure 3. An Instance of Estimated TCP-Compatible Rate under DropTail Gateway

The CoV of estimated loss event rate as shown in Table II are higher than the CoV of estimated TCP-compatible as shown in Table III. TCP-compatible rate is determined by the function of packet size, loss event rate, round trip time and retransmission timeout. As CoV measures dispersion or deviation from the mean, the effect of loss event rate variation is absorbed by the other parameters of TCP-equation model.

The smoothing techniques reduce the variability of the estimated TC-compatible rates, but not as much as they reduce the variability of estimated loss event rate. The loss event rate variability of TFLMP-2, TFLMP-3 and TFLMP-4 as shown in Table II are lower than the TCP-compatible rate variability as shown in Table III. It is also shown in Figure 2 and Figure 3, where the estimated loss event rate of TFLMP-4 in Figure 2 is smoother and more stable than the estimated loss event rate of TFLMP-4 in Figure 3. The proposed smoothing techniques are to smooth out estimated loss event rate and the result shows significant reduction in loss event rate variability. However they could not reduce the variability of estimated TCP-compatible as much as the estimated loss event rate because other parameters such as round trip time and retransmission timeout also contribute to estimated TCP-compatible rate volatility. Moreover, under low level statistical multiplexing environment round trip time and retransmission timeout are very volatile.

Table IV shows the result of estimated loss event rate under RED gateway, and Figure 4 illustrates an instance of estimated loss event rate under RED gateway. Generally the simulation result under RED gateway shows similar trend with the simulation result under DropTail gateway. TFLMP-1 estimates the lowest loss event rate but with the highest CoV and variability. On the other hand, TFLMP-4 estimates the highest loss event rate with the lowest CoV and variability. The smoothing techniques reduce loss event rate volatility as shown in CoV and variability columns. However, the smoothing techniques the estimated loss event rate as shown in average loss event rate column.

TABLE IV. MEAN, COEFFICIENT OF VARIATION AND VARIABILITY OF LOSS EVENT RATE UNDER DROPTAIL GATEWAY

Filtering Technique	Average Loss Event Rate	CoV (%)	Variability (%)
TFLMP-1	0.0343	32.98	12.85
TFLMP-2	0.0403	28.47	6.05
TFLMP-3	0.0405	27.78	6.13
TFLMP-4	0.0429	23.99	3.99

All TFLMP implementations under RED gateway show lower estimated loss event rate compare to the estimated loss event rate under DropTail gateway. This can be attributed to random packet drop implemented in the RED gateway. With random packet drop, bursty traffics such as TCP more likely to be dropped. This forces TCP flows to back-off and provides more bandwidth for TFLMP.

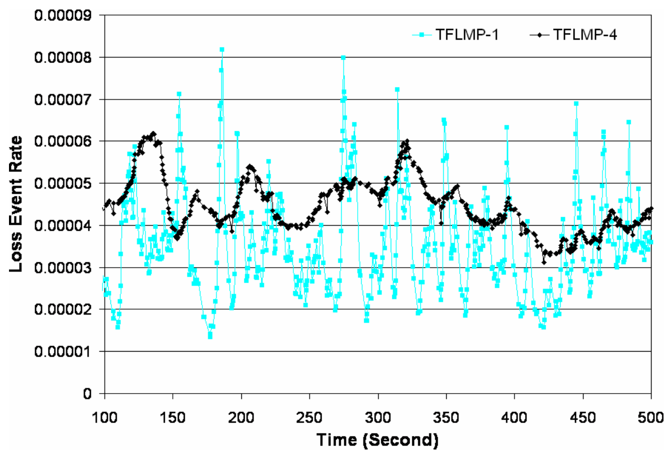

Figure 4. An Instance of Estimated Loss Event Rate under RED Gateway

Table V shows the result of TCP-compatible rate estimation under RED gateway, and Figure 5 illustrates an instance of estimated TCP-compatible rate under RED gateway. The result also shows similar trend with the simulation under DropTail gateway. The TFLMP with no smoothing technique estimates the highest TCP-compatible rate with the highest CoV and variability, while the TFLMP with all smoothing techniques estimates the lowest TCP-compatible rate with the lowest CoV and variability. The difference between the highest and the lowest is 37 Kbps.

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Similar to the result under DropTail gateway, the result under RED gateway also shows that the smoothing techniques reduce the TCP-compatible rate variation as shown in CoV and variability columns.

The average TCP-compatible rates of all TFLMP implementations are between 248 Kbps and 211 Kbps, or between 82.51% and 70.45% of theoretical fair bandwidth share. These rates are higher than the TCP-compatible rates estimated under DropTail gateway. This is attributed to DropTail queuing policy which results to high packet drop for TFLMP data flows and high queuing delay variation.

However, these rates are still quite low compare to the theoretical fair bandwidth share. This is expected as in low level of statistical multiplexing environment the number of traffic is not sufficient to absorb the volatility of other flows. In this study TFLMP competes with TCP. Since TCP is an aggressive and bursty protocol, TFLMP cannot compete fairly with TCP.

TABLE V. MEAN, COEFFICIENT OF VARIATION AND VARIABILITY OF ESTIMATED TCP-COMPATIBLE RATE UNDER DROPTAIL GATEWAY

Filtering Technique	Average TCP-Compatible Rate (T)	T Ratio to Theoretical Fair Bandwidth Share (%)	CoV (%)	Variability (%)
TFLMP-1	248 Kbps	82.51	23.35	16.76
TFLMP-3	222 Kbps	74.03	21.64	13.45
TFLMP-2	221 Kbps	73.66	21.53	13.39
TFLMP-4	211 Kbps	70.45	19.57	13.01

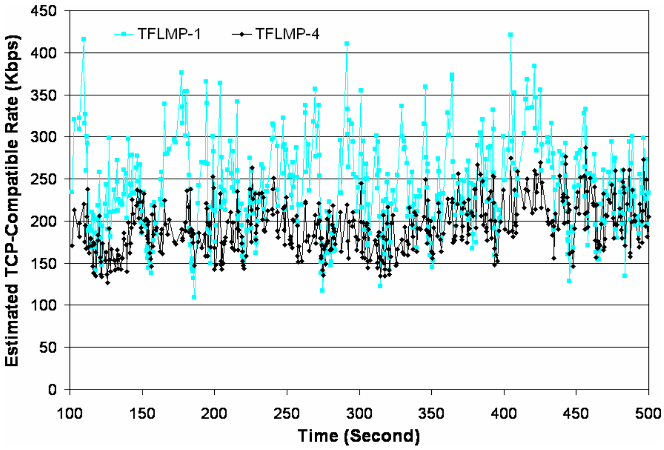

Figure 5. An Instance of Estimated TCP-Compatible Rate under RED Gateway

VIII. CONCLUSION

Under both DropTail and RED gateway the smoothing techniques namely two-step filtering, packet reordering and conservative loss event rate reduce the volatility of estimated loss event rate and TCP-compatible rate and result in smoother estimated loss event rate and TCP-compatible rate. Combinations of the three smoothing techniques significantly reduce CoV and variability of the estimated loss event rate and TCP-compatible rate, where TFLMP-4 estimates loss event rate and TCP-compatible rate with the lowest CoV and variability. However, the smoothing techniques also reduce the estimated loss interval size and loss event rate. This results in lower estimated TCP-compatible rate in the TFLMP with smoothing techniques.

REFERENCES

[1] J. D. Padhye, V. Firoiu, D. F. Towsley, and J. F. Kurose, "Modelling TCP Throughput: A Simple Model and its Empirical Validation," in the Proceedings of ACM Special Interest Group on Data Communications (SIGCOMM 1998), Vancouver, 1998.

[2] S. Floyd, M. Handley, J. Padhye, and J. Widmer, "Equation-Based Congestion Control for Unicast Applications," in the Proceedings of ACM Special Interest Group on Data Communications (SIGCOMM 2000), Stockholm, Sweden, 2000.

[3] O. Ghazali and S. Hassan, "Loss Interval Distributions of a TCP-Friendly Layered Multicast Protocol," Forthcoming, 2005.

[4] M. Handley, S. Floyd, J. Pahdye, and J. Widmer, "TCP Friendly Rate Control (TFRC): Protocol Specification," IETF, RFC 3448, 2003.

[5] O. Ghazali and S. Hassan, "Low Variance Loss Event Rate Estimation for Layered Multicast Protocol," Forthcoming, 2005.

[6] O. Ghazali and S. Hassan, "Smooth Loss Event Rate Estimation for Layered Multicast Protocol," Forthcoming, 2005.

[7] O. Ghazali and S. Hassan, "Implementation of a TCP-Friendly Layered Multicast Protocol on NS-2 Simulator," in the Proceedings of NS-2 Workshop, Serdang, Malaysia, 2004.

[8] J. Widmer, "Equation-Based Congestion Control," Master Thesis, Department of Mathematics and Computer Science. Germany: University of Mannheim, 2000.

[9] J. Widmer, R. Denda, and M. Mauve, "A Survey of TCP-Friendly Congestion Control," *IEEE Network*, vol. 15, pp. 28-37, 2001.

[10] D. Waitzman, C. Partridge, and S. Deering, "Distance Vector Multicast Routing Protocol," IETF, RFC 1075, 1988.

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