Comparative Analysis of Variants of Token Bucket Traffic Meter Algorithms for QoS Router using UDP as Traffic Agent

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Abstract
Traffic meter algorithms serve as a means of examining traffic stream's conformance with service level agreement between customers (traffic sources) and Internet Service provider at the edge router of a differentiated service domain for proper quality of service admission control. This paper presented comparative analysis of variants of token bucket meter algorithms for QoS router using user datagram protocol as traffic agents and exponential ON/OFF as traffic generator. The research adopted simulation technique to carry out the design of network models or topologies using the same parameter setting to implement the algorithm of token bucket variants of traffic meter. The following metrics were used for the evaluation: throughput, fairness rate, loss rate and one-way packet delay. The evaluated results were ranked and further subjected to 2-way analysis of variance (ANOVA) model to indicate the significant differences among the traffic meter algorithms. Based on ranking system, TRTCM was ranked first in terms of throughput (with 67117) and fairness rate (with 0.2586) and TBM was ranked first in terms of loss rate (with 74.003) and one-way packet delay (with 0.09304). The 2-way ANOVA model showed the significant differences among the traffic meter algorithms considered for the simulation..

Keywords:
Comparative Analysis, Token Bucket Traffic Meter Algorithms, QoS Router, Traffic Agent

1. INTRODUCTION

The need to improve on the deployments of multimedia applications over the Transport Control Protocol/Internet protocol (TCP/IP) suite is of great important because it requires very high bandwidth, bursty data transmission and stringent delay constraints for quality of service (QoS) (Lochin & Anelli, 2009). The admission control mechanism or conditioner is introduced assurance (Oyetunji, Oladeji, & Emuoyinbofarhe, 2012; Pandit, 2006) The TCP/IP protocol suites define set of rules that communicating devices must follow to communicate with one another over the Internet (Ferouzan, 2013).

In attempt to work on the QoS of the conventional internet, IETF came up with two architectures: integrated services (IntServ) and differentiated services (DiffServ) architecture. The IntServ architecture is characterized by resource reservation for each session or flow by the router along the path of the traffic to the destination. Its problem is scalability when thousands of applications are requesting for reservation at the same time. This limitation of IntServ architecture brought about the development of DiffServ architecture which makes provision for traffic flows demanding same treatment from the network to be aggregated at the routers (Braden, Clark, & Shenker, 1994; Clark & Fang, 1998; Kurose & Ross, 2000).

DiffServ is based on a simple model which attempts to move complexity of the network to the edge router and keep the functionality of the core network as simple as possible (Blake et al., 1998). Core devices perform only the forwarding operation

at the boundary of the DiffServ network or domain to check whether a service request is to

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be granted or rejected (Georgoulas, 2007). The DiffServ model uses this mechanism at the network edge (edge routine) to measure, mark, shapen or police packets if necessary.

Before traffic flows enter the network core from different edge domains, they need to be marked either as in-profile or out-of-profile at their respective edge networks. Traffic meter algorithms measure the properties of the stream of packets that arrive to the router against a set traffic profile. It guides in regulating the injection of traffic to the network (Nordström, 2006). This paper considers comparative analysis of token bucket variants of traffic meters algorithms: token bucket meter (TBM), single rate three color meter (SRTCM) and two rate three color meter (TRTCM) algorithms using user datagram protocol as traffic agent because most multimedia applications are deployed on UDP.

2. TRAFFIC CLASIFICATION AND CONDITIONING

Traffic conditioning normally takes place at the boundary of a network. Differentiated services are then extended across a differentiated service domain (DSD) boundary by establishing a Service Level Agreement (SLA) which describes the type of service to be provided from a service provider to a customer between upstream network and downstream DSD. The SLA guides in specifying the traffic classification and re-marking rules, and it may also specify traffic profiles and action to traffic stream which can be in-profile (traffic stream that complies with SLA) or out-of-profile (traffic stream that do not comply with SLA). Traffic Conditioning Agreement (TCA) is derived from this Service Level Agreement. (Blake et al., 1998; Carlson et al., 1998; Oyetunji et al., 2012; Strauss, Kourie, & Olivier, 2005).

From the TCA we can further define the role of traffic classification. It identifies a subset of traffic that will receive a differentiated service such that the identified traffic stream will then be conditioned and/or mapped to one or more behaviour aggregates. Traffic conditioning performs metering, shaping, policing and marking or re-marking of traffic to ensure that traffic entering a domain conforms to the rules specified in the TCA as shown in Figure 1 (Miller, 2009). In the simplest model, each packet is either in-profile or out-of-profile based on the metering result at the arrival time of the packet. In-profile packets obtain better traffic conditioning and forwarding treatment than out-of-profile packets (Blake et al., 1998; Strauss et al, 2005).

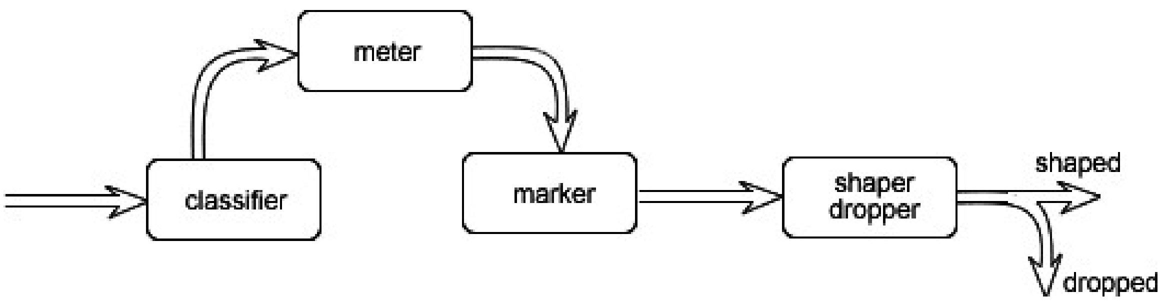

Figure 1: DiffServ traffic conditioner block in the edge router Source: (Andreozzi, 2000)

3. VARIANTS OF TOKEN BUCKET TRAFFIC METER ALGORITHMS

The variants of token bucket traffic meter algorithms considered in this paper are token bucket meter (TBM) algorithm, single rate three color meter (SRTCM) algorithm and two rate three color meter (TRTCM) algorithm.

Token Bucket Meter (TBM) Algorithm

TBM measures traffic stream based on two traffic conditioning parameters: Committed Information Rate (CIR) and Committed Burst Size (CBS) with 2 drop precedence (Complaint and Non-Compliant) (Freed, Amara, & Borella, 2006). The meter is identified in form of token bucket (C). The maximum size of C is CBS. Originally, the token bucket is full, i.e. $T_C(0) = CBS$, where T_C is the token count. If ($T_C < CBS$) then $T_C \leftarrow T_C + 1$ else T_C is not incremented.

The marker makes use of meter to determine the color of the newly arrived packets. Assume a packet of size B bytes arrives at time t. If $T_C(t) - B \geq 0$, then the packet is marked green and $T_C \leftarrow T_C - B$. Else the packet is marked red and T_C remain unchanged as shown in Figure 2 (Freed et al., 2006).

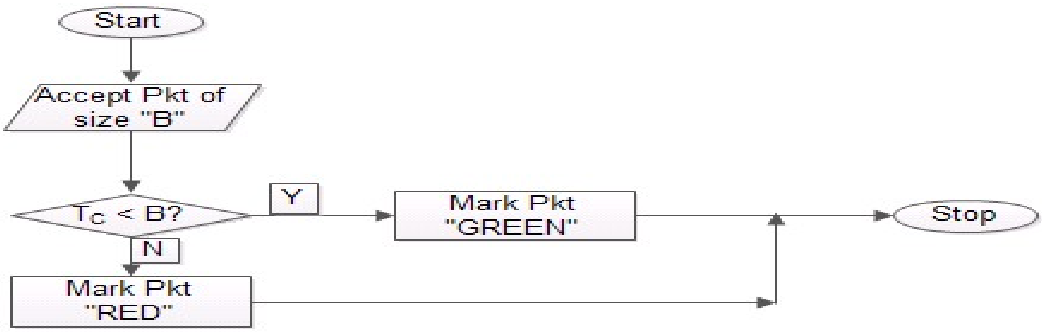

Figure 2: Flow Chart for TBM algorithms

Single Rate Three Color Meter (SRTCM) Algorithm

The SRTCM measures traffic stream based on three parameters: CIR, CBS and EBS coupled with three drop predecences (one for complaint packets and two for non-compliant packets) and passes the measurements to its marker (Freed et al., 2006). SRTCM uses single rate and it is identified in terms of two buckets: C and E. The capacity of C is CBS and that of E is EBS. Originally, both tokens are full, i.e. $T_C(0) = CBS$ and $T_E(0) = EBS$.

If ($T_C < CBS$) then $T_C \leftarrow T_C + 1$ else

If ($T_E < EBS$) then $T_E \leftarrow T_E + 1$ else

Neither T_C nor T_E are incremented

When a packet of size B arriving at time t, the following happens:

If $T_C(t) - B \geq 0$, the packet is marked green and then $T_C \leftarrow T_C - B$

If $T_E(t) - B \geq 0$, the packet is marked yellow and then $T_E \leftarrow T_C + 1$

If neither of the previous cases is valid, the packet is marked red. T_C and T_E remain unchanged as shown in Figure 3

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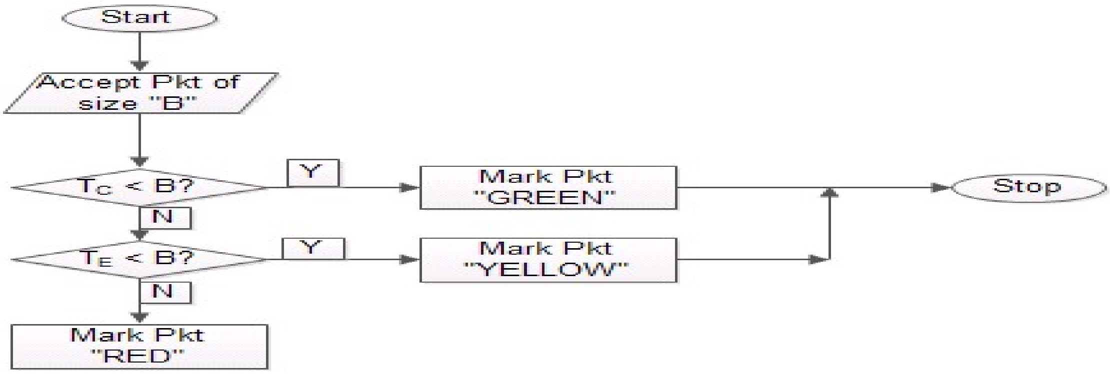

Figure 3: Flow Chart for SRTCM algorithms

Two Rate Three Color Meter (TRTCM) Algorithm

The TRTCM measures traffic stream based on four traffic conditioning parameters: Committed Information Rate (CIR), Peak Information Rate (PIR) and two burst sizes namely Committed Burst Size (CBS) and Peak Burst Size (PBS) with 3 drop precedence (one complaint and two non-compliant packets). TRTCM uses two rates (CIR and PIR) and it is also identified in terms of two buckets: C and P. The capacity of C is CBS and that of P is PBS. For clearity sake, its algorithm is discussed in (Heinanen & Guérin, 1999). Originally, both token buckets are full, i.e. $T_c(0)$ = CBS and $T_p(0)$ = PBS.

- If ($T_c < CBS$) then $T_c \leftarrow T_c + 1$ else
- If ($T_P < PBS$) then $T_P \leftarrow T_P + 1$ else neither T_c nor T_P are incremented

When a packet of size B arrives at time t, the following happen:

- If $\mathbf{T_c(t) - B \geq 0}$, the packet is marked as green and $\mathbf{T_C} \leftarrow \mathbf{T_C} - B$
- If $\mathbf{T_c(t) - B < 0}$ and $\mathbf{T_p(t) - B \geq 0}$, the packet is marked yellow and $\mathbf{T_P} \leftarrow \mathbf{T_P} + 1$

If neither of the previous cases is valid, the packet is marked red. T_C and T_P remain unchanged as shown in Figure 4 (Freed et al., 2006).

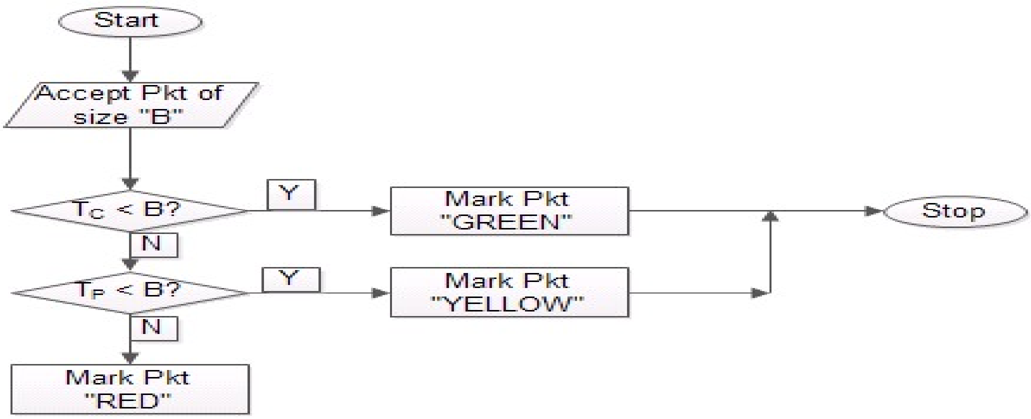

Figure 4: Flow Chart for TRTCM algorithms

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3. METHODOLOGY

This research adopts simulation approach to carry out design and simulation of network topology to implement token buckets variants of traffic meter algorithms in order to create platform for absolute comparison among the meter algorithms on UDP as traffic agents using exponential ON/OFF as traffic generator as shown in Figure 5. The topology was simulated using a software simulator called network simulator-2 (ns-2).

The data generated from the simulation experiments were traced into files, analyzed and evaluated based on the following network performance metrics: throughput, fairness rate, loss rate and one-way packet delay to showcase the strengths and weaknesses of the meter algorithms. The results of the evaluation based on the performance metrics were further analyzed using two-way analysis of variance to show the significance differences among the studied meter algorithms.

4. EXPERIMENTAL SETUP

Since multimedia applications are expected to be routed through a core router, the research used user datagram protocol (UDP) as traffic agents that requires no acknowledgement. Each source is conditioned differently with its own parameter settings. Exponential ON/OFF was used to generate traffic from the eight sources as shown in Figure 2. Buffer size is assumed to be finite and the server is the bottlenecked core router with a deterministic capacity (bandwidth).

5. SIMULATION TOPOLOGY

The network topology design shown in Figure 5 represents the network models used for this research to implement the algorithms of the variants of token bucket traffic meters (token bucket meter (TBM), single rate three color meter (SRTCM) and two rate three color meter (TRTCM)). In the network topology, the same parameter settings were used to create platform for comparison among the traffic meter algorithms. The packet sizes for the simulated experiments were varied using 500bytes, 1000bytes and 2000bytes for the first, second and third scenarios respectively for each traffic meter algorithm to run the simulation three times.

The network topologies were designed to consist of 21 nodes (eight nodes are for sources, three nodes are for edge routers, two nodes are core routers and the remaining eight nodes are for destinations). The node-to-node network links from sources to destinations were configured with bandwidth of 10Mbps and link delays of 5ms except from the core router C2 to edge router E3 which was configured as 5Mbps of bandwidth and 5ms of link delay. The core to core router configuration was set to 5Mbps intentionally to study the effect of congestions at the core routers. The sources (S_1, S_2, S_3, S_4) generated traffic streams with Exponential ON/OFF using UDP as traffic agent and send them to ingress edge router (E1).

Likewise, the sources (S_5, S_6, S_7, S_8) also generated traffic streams via the same medium using UDP as traffic agent and send them to edge router (E2). At the ingress routers (E1 and E2), the incoming traffic streams are admitted, classified and conditioned with traffic conditioning functions such as metering, marking and policing using associated differentiated services code point (DSCP) to carry out traffic profiles enforcement before sending them to the core router for forwarding. Each meter algorithm measured the traffic stream to ensure whether the traffic stream is in-profile or out-of-profile for proper traffic admission control. The core router buffers the packets into respective queues using priority scheduling discipline to forward them to respective destinations (D_1, D_2, D_3, D_4, D_5, D_6, D_7 and D_8) through the egress router (E3). The transmission mode used between sources and destinations were full duplex transmission

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modes while simplex transmission mode was used between edge router and core router and also between core router and core router.

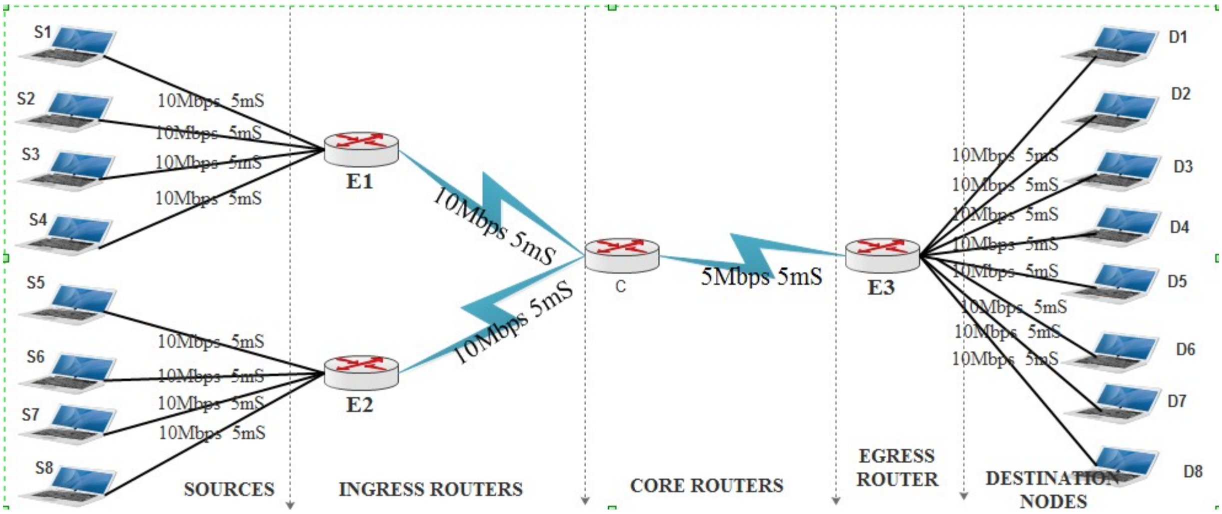

Figure 5: Network topology

6. RESULTS

The simulations were carried out for 80 seconds and the data generated were traced into an output file for performance metrics analyses. The analyses of the results were based on the following metrics: throughput, fairness rate, loss rate and one-way packet delay. The analyzed results were further subjected to ranking and two-way ANOVA model using two factors: **traffic meter type** (TRTCM, SRTCM and TBM) and **packet sizes** (500B, 1000B and 2000B). Two hypotheses were setup: Null hypothesis (shows no significance difference) and alternative hypothesis (shows significance differences among the traffic meters). α is taken to be 0.05 and the calculated P-value is compared with α to know if there is any significant difference or not. If P-value $< \alpha$, there is significant difference else there is no significant difference.

6.1 Analysis Based on Throughput

The higher the throughput value, the better the performance of the meter algorithm. Throughput is taken as the work done or total number of packets that gets to the destination. Comparing TRTCM, SRTCM and TBM in terms of throughput, Table 1 shows the throughput values of token bucket variants of traffic meter algorithms: TRTCM, SRTCM and TBM algorithms for 80 seconds simulation time interval each. The result gotten for each traffic meter in Table 1 was showcased graphically with bar chart in Figure 6. Figure 7 showed the 2-way ANOVA analyses with p-value of 0.000 which makes the null hypothesis to be rejected for alternative hypothesis. It shows that there is significant difference among the traffic meters. From the analyses, TRTCM algorithm was ranked first, followed by SRTCM and then TBM. Applications that require high throughput value on UDP traffic agent could make use of TRTCM algorithm.

Table 1: Throughput analyses for the traffic meters

SCENERIOS	**Traffic Meters**		
	TRTCM-UDP	**SRTCM-UDP**	**TBM-UDP**
1st (500 Bytes)	100432	100285	100009
2nd (1000 Bytes)	50458	50252	50024
3rd (2000 Bytes)	50462	50311	50019
Avg. Throughput	**67117**	**66949**	**66684**
Rank	**1st**	**2nd**	**3rd**

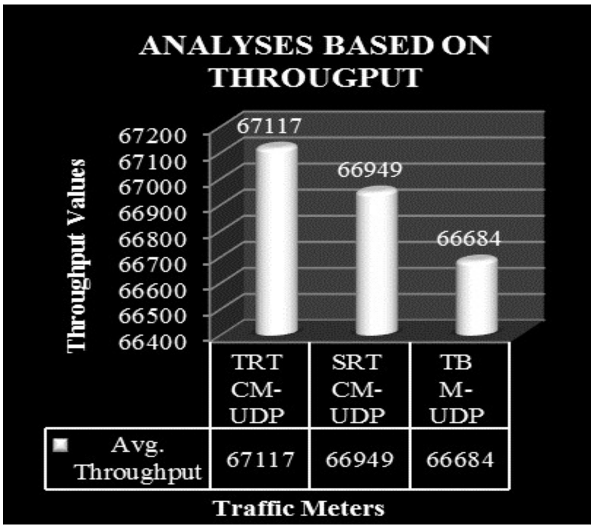

Figure 6: Throughput analyses for the traffic meters

a. **UNIVARIATE ANALYSIS OF VARIANCE**

Traffic Agent=UDP

Between-Subjects Factors[a]

		Value Label	N
Traffic Meter Type	1	TRTCM	3
	2	SRTCM	3
	3	TBM	3
Packet Size			3
500			3
			3
1000			
2000			

Test of Between-Subjects Effects[b]

Dependent Variable: Throughput

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Traffic Meter Type	286403.556	2	143201.778	374.112	0.000
Packet Size	4.998E9	2	2.499E9	6.528E6	0.000
Error	1531.111	4	382.778		
Corrected Total	4.998E9	8			

Homogeneous Subsets

Throughput

Duncan

Traffic Meter Type	N	Subset 1	Subset 2	Subset 3
TBM	3	6.67E4		
SRTCM	3		6.69E4	
TRTCM	3			6.71E4
Sig.		1.000	1.000	1.000

Figure 7: ANOVA analyses for throughput using UDP as traffic agent

6.2 Analysis Based on Fairness Rate

6.3

The higher the fairness rate value, the better the performance of the traffic meter. Fairness rate is evaluated based on Jain fairness index (Jain, 1990) which states that

$$\text{Jain index } (I_{Jain}) = \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n\sum_{i=1}^{n} x_i^2}$$

Where n is the number of active queues and x_i is the number of packets that were transmitted in queue i. Comparing TRTCM, SRTCM and TBM in terms of fairness rate, Table 2 shows that TRTCM algorithm was ranked first, followed by SRTCM and then TBM. The result gotten for each traffic meter in Table 2 was represented graphically with bar chart in Figure 8. Figure 9 showed the 2-way ANOVA analyses with p-value of 0.000 which makes the null hypothesis to be rejected for alternative hypothesis. It shows that there is significant difference among the traffic meters. Applications that require high fairness rate value on UDP traffic agent could make use of TRTCM algorithm

Table 2: Fairness rate analyses for the traffic meters

SCENERIOS	**Traffic Meters**		
	TRTCM-UDP	**SRTCM-UDP**	**TBM-UDP**
1st (500Bytes)	0.2494	0.1267	0.12531
2nd (1000Bytes)	0.2621	0.1285	0.12579
3rd (2000Bytes)	0.2643	0.1285	0.12573
Avg. Fairness	**0.2586**	**0.1279**	**0.1256**
Rank	**1st**	**2nd**	**3rd**

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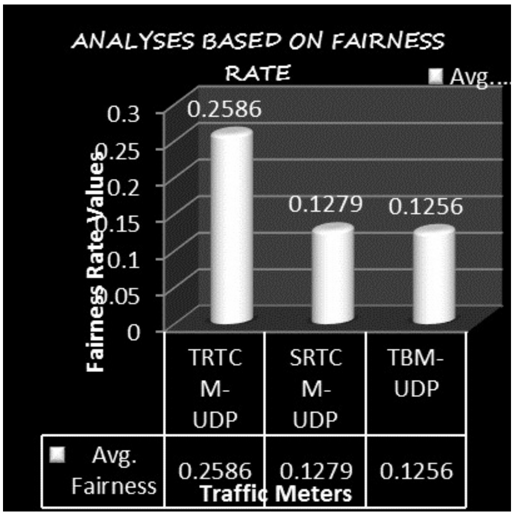

Figure 8: Fairness rate analyses for the traffic meters

a. UNIVARIATE ANALYSIS OF VARIANCE

Traffic Agent=UDP

Between-Subjects Factorsa

		Value Label	N
Traffic Meter Type	1	TRTCM	3
	2	SRTCM	3
	3	TBM	3
Packet Size	500		3
	1000		3
	2000		3

Test of Between-Subjects Effectsb

Dependent Variable: **Fairness Rate**

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Traffic Meter Type	347.757	2	173.878	942.015	0.000
Packet Size	0.578	2	0.289	1.566	0.315
Error	0.738	4	0.185		
Corrected Total	349.073	8			

Homogeneous Subsets

Fairness rate

Duncan

Traffic Meter Type	N	Subset 1	Subset 2
TBM	3	0.12560	
SRTCM	3	0.12792	
TRTCM	3		0.25861
Sig.		0.545	1.000

Figure 9: ANOVA analyses for fairness rate using UDP as traffic agent

6.4 Analysis Based on Loss Rate

The lower the loss rate value, the better the performance of the traffic meter algorithm. Loss rate is evaluated based on the formula stated below

$$\textbf{Loss Rate} = \frac{(\text{Packet enqued} - \text{packet received})}{\text{packet enqued}} * 100$$

Where **packet enqued** are the packets that are queued up at the ingress routers and **packet received** is the total packet that got to the destination.

Comparing TRTCM, SRTCM and TBM in terms of loss rate, Table 3 shows that TBM algorithm was ranked first, followed by SRTCM and then TRTCM. The result gotten for each traffic meter in Table 3 was represented graphically with bar chart in Figure 10. Figure 11 showed the 2-way ANOVA analyses with p-value of 0.002 which makes the null hypothesis to be rejected for alternative hypothesis. It shows that there is significant difference among the traffic meters. Applications that require low loss rate value on UDP traffic agent could make use of TBM algorithm.

Table 3: Loss rate analyses for the traffic meters

SCENERIO	**TRAFFIC METERS** TRTCM-UDP	SRTCM-UDP	TBM-UDP
1st (500Bytes)	74.61	73.84	73.93
2nd (1000Bytes)	74.7	74.27	74.05
3rd (2000Bytes)	74.7	74.19	74.03
Avg. Loss Rate	**74.67**	**74.1**	**74.003**
Ranks	**3rd**	**2nd**	**1st**

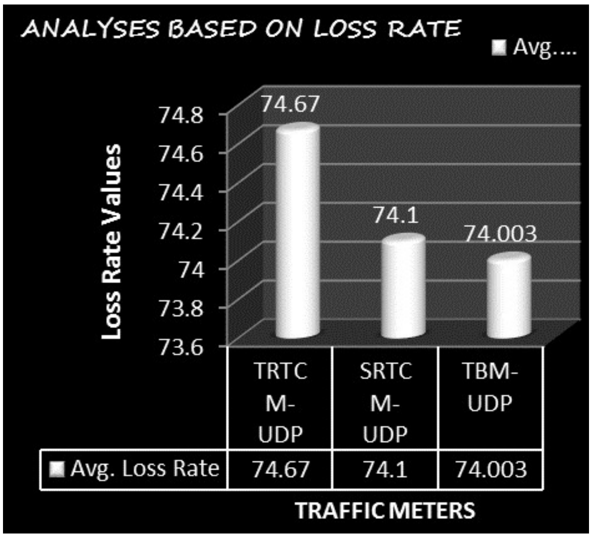

Figure 10: Loss rate analyses for the traffic meters

a. UNIVARIATE ANALYSIS OF VARIANCE

Traffic Agent=**UDP**

Between-Subjects Factorsa

	Value Label	
Traffic Meter Type 1	TRTCM	3
2	SRTCM	3
3	TBM	3
Packet Size 500		3
1000		3
2000		3

Test of Between-Subjects Effectsb

Dependent Variable:**loss rate**

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Traffic Meter Type	0.779	2	0.389	39.684	0.002
Packet Size	0.079	2	0.040	4.027	0.110
Error	0.039	4	0.010		
Corrected Total	0.897	8			

Homogeneous Subsets

Loss Rate Percentage **Duncan**

Traffic Meter Type	N	Subset 1	Subset 2
TBM	3	7.4003E1	
SRTCM	3	7.4100E1	
TRTCM	3		7.4670E1
Sig.		0.298	1.000

Figure 11: ANOVA analyses for loss rate using UDP as traffic agent

6.5 Analysis Based on One-way Packet Delay

The lower the one-way packet delay value, the better the performance of the traffic meter algorithm. One-way packet delay was calculated by subtracting packets arrival time (a(n)) from departure time (d(n)) as stated in (Mezger & Petr, 1995):

$$\text{Packet delay} \rightarrow d(n) - a(n)$$

Comparing TRTCM, SRTCM and TBM in terms of one-way packet delay, Table 4 shows that TBM algorithm was ranked first, followed by SRTCM and then TRTCM. The results gotten for each traffic meter in Table 3 were represented graphically with bar chart in Figure 12. Figure 13 showed the 2-way ANOVA analyses with p-value of 0.006 which makes the null hypothesis to be rejected for alternative hypothesis. It shows that there is significant difference among the traffic meters. Applications that require low loss rate value on UDP traffic agent could make use of TBM algorithm

Table 4: One-way packet delay analyses for the traffic meters

SCENERIOS	TRAFFIC METERS		
	TRTCM-UDP	**SRTCM-UDP**	**TBM-UDP**
1st (500Bytes)	0.4419	0.2978	0.06564
2nd (1000Bytes)	0.86667	0.58865	0.10664
3rd (2000Bytes)	0.86717	0.58663	0.10685
Avg.One-way packet delay	**0.7253**	**0.491**	**0.093**
Ranks	**3rd**	**2nd**	**1st**

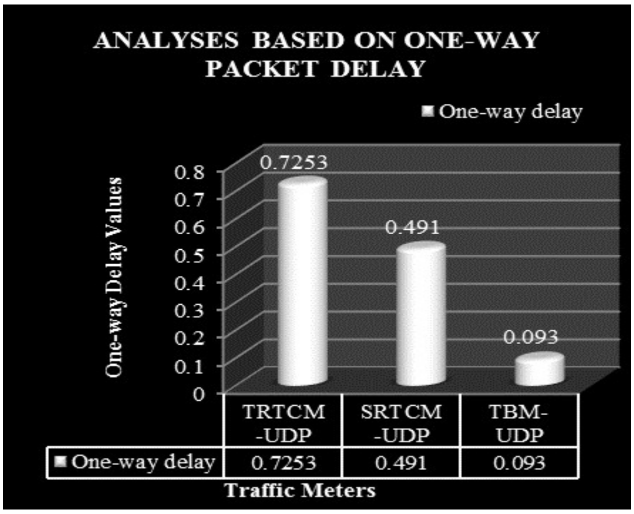

Figure 12: One-way packet delay analyses for the traffic meter algorithms

7. Conclusion

Looking at the four performance metrics that were used to evaluate the token bucket variants of traffic meter algorithms using UDP as traffic agent, TRTCM algorithm was ranked first for both throughput and fairness rate while TBM algorithm was ranked first for both loss rate and one-way packet delay. Applications that require high throughput and fairness rate could make use of TRTCM algorithm while the ones that require low loss rate and low one-way packet delay can make use of TBM algorithm for quality of service admission control in the internet as shown in Table 5

Table 5: Ranking system analyses for meter algorithms using UDP as traffic agent

TRAFFIC METER	PERFORMANCE METRICS USING UDP							
	ONE-WAY PKT DELAY	Rank	FAIRNESS RATE	Rank	THROUGHPUT	Rank	LOSS RATE	Rank
$TRTCM_{AVG}$	0.7253	3RD	**0.259**	**1ST**	**67117**	**1ST**	74.67	2ND
$SRTCM_{AVG}$	0.491	**2ND**	0.1279	2ND	66949	2ND	74.1	3RD
TBM_{AVG}	**0.093**	**1ST**	**0.126**	3RD	66684	3RD	**74**	**1ST**

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