FLoadAutoRED: An Active Queue Management Scheme to Prevent Congestion in a Dynamically Varying Traffic in IP Networks

CHAPTER 7

EXPERIMENTS AND RESULTS

7.1 NETWORK TOPOLOGY

The simple network topology used for experimentation is shown in Figure 7.1.

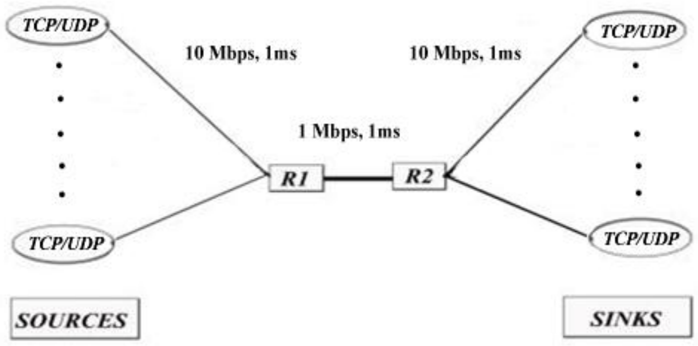

Figure 7.1 Simple Network Topology

7.2 PERFORMANCE METRICS

The following performance metrics are also considered for evaluation:

i) Throughput

ii) Queuing Delay

i. Throughput

It is the amount of data moved successfully from one node to another in a given time period. Throughput is used to describe the capability of a system to transfer data. It is also a measurement of the reliable data transfer rate, and it can also indicate the performance of the link, the routing systems and the host systems. It is defined as,

$$Throughput = \frac{TotalPacketsReceived}{SimulationTime} \times \frac{8}{1000}\ Mbps$$

ii. Queuing Delay

Queuing delay is the time the packet stays in the node. Queuing delay occurs when the queue service rate is not fast enough to serve all the incoming packets from different sources using this queue, therefore, the packets accumulate in the queue and wait for service.

$$Queueing\ Delay = ArrivalTimeatQueue - DepartureTimefromQueue\ ms$$

Following are the experiments conducted to evaluate the performance of the proposed algorithm.

i) Robustness with respect to Buffer size
ii) Robustness with respect to Number of TCP Connections
iii) Robustness with respect to Link Capacity (Bandwidth)
iv) Robustness with respect to UDP Rate changes
v) Robustness with respect to Pareto Flow
vi) Robustness with respect to Dynamic Load

7.3 EXPERIMENT I - ROBUSTNESS WITH RESPECT TO BUFFER SIZE

The experiment is conducted to study the effect of buffer size on the performance metrics of the proposed AQM scheme. Buffer size is very important and a critical component in a network topology.

7.3.1 Parameter Settings

In this section, to simulate the FLoadAutoRED algorithm a single link of capacity 1Mbps is considered as in Figure 7.1 that drops packet according to the AQM algorithm. The parameter for the experiment is tabulated in Table 7.1a. The parameter for the various AQMs is listed in Table 7.1b for all the experiments. The congestion link is in between the two routers R1 and R2. In the simulation setup 150 TCP flows are considered in the network and the physical queue size is varied from 60 to 350 packets. The maximum threshold max_{th} is set to be twice minimum threshold min_{th}. The parameters of the AQMs are set as recommended in [2], [18], [28], [34].

Table 7.1a Parameter Setting of FLoadAutoRED

Type of Sources	Link Capacity	Link Delay	Packet Size	max_p	γ	Delta	δ	SimulationTime
TCP (FTP)	1Mbps	1ms	1 Kbytes	0.02	0.2	11.25	0.06	100 secs

Table 7.1b Parameter setting of AQMs

RED	REM	AVQ	AutoRED	CHOKe
w_q = 0.002 max_p =0.02	α = 0.10 γ = 0.001 ϕ = 1.001	α = 0.15 γ = 1	max_p =0.02	w_q = 0.002 max_p =0.02

7.3.2 Performance Evaluation

The performance of the algorithm are evaluated based on the metrics and the results are shown in the Figures 7.2 to 7.7.

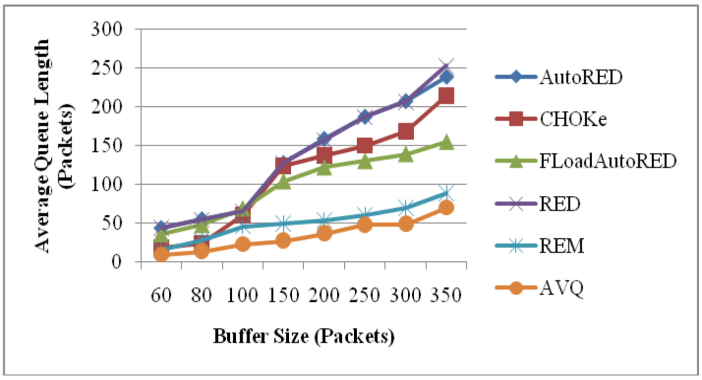

Figure 7.2 Comparison of Average Queue Length of AQM Schemes

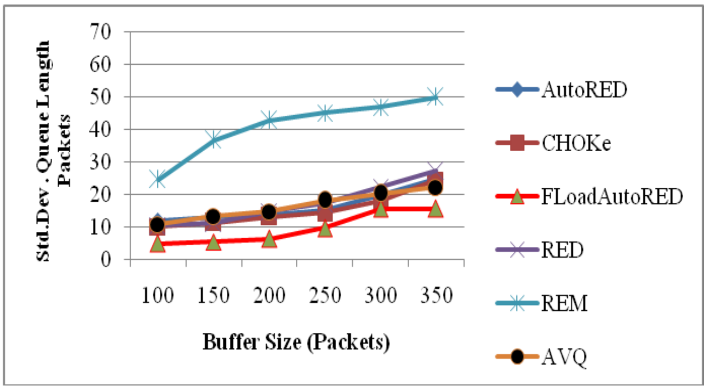

Figure 7.3 Comparison of Std. Dev. Average Queue Length of AQM Schemes

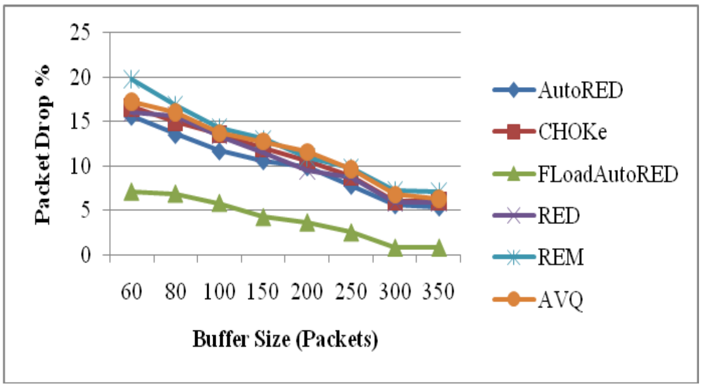

Figure 7.4 Comparison of Packet Drop Rate of AQM Schemes

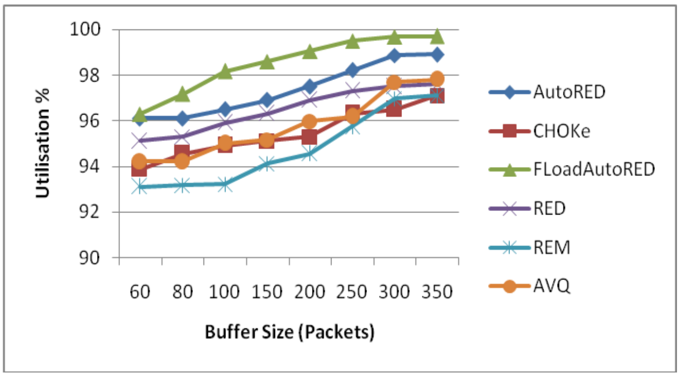

Figure 7.5 Comparison of Utilisation of AQM Schemes

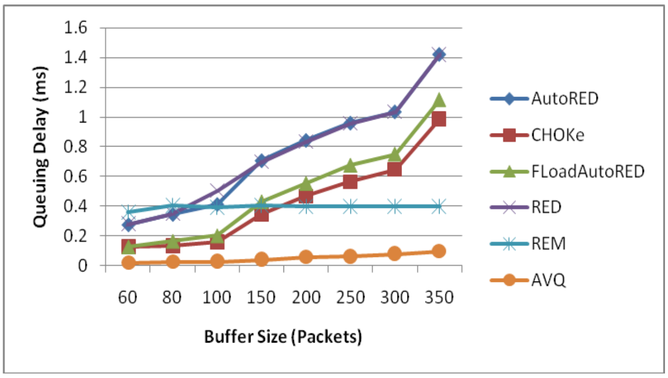

Figure 7.6 Comparison of Queuing Delay of AQM Schemes

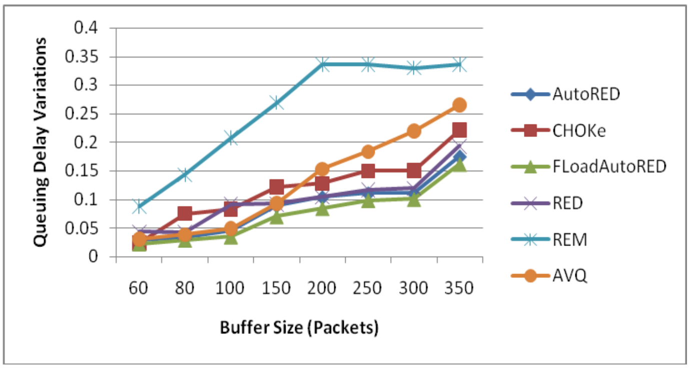

Figure 7.7 Comparison of Queuing Delay Variations of AQM Schemes

7.3.3 Conclusion

Comparison of the performance indices are shown in terms of average queue length, standard deviation of queue length, link utilization and packet loss ratio when the buffer size has different values. From Figure 7.2, the average queue length of AutoRED increases steeply as the buffer size increases. The average queue length of CHOKe and RED is at a higher level with increasing buffer size. This results in full buffer size for a long time, which in turn, increases the average queue length and packet loss as in Figure 7.4. The average queue length of REM and AVQ is kept always at a lower level irrespective of the buffer size. The consequence is the poor utilisation of REM and AVQ in transient shown in Figure 7.5. FLoadAutoRED achieves a smaller variation in average queue length for different buffer sizes. The standard deviation of queue length is lower for FloadAutoRED as shown in Figure 7.3. Figure 7.5 shows that the performance of link utilization and packet losses are degraded when buffer size is small. However, rate-based AQM achieve a smaller average queue length with an acceptable queuing delay and variations compared to queue-based AQMs as in Figure 7.6 and Figure 7.7.

7.4 EXPERIMENT II - ROBUSTNESS WITH RESPECT TO NUMBER OF TCP CONNECTIONS

In a real environment, the number of TCP connections is diffcult to estimate. Hence, the second experiment is conducted to evaluate the proposed algorithm with respect to varying TCP connections.

7.4.1 Parameter Settings

In this section, to simulate the FLoadAutoRED algorithm a single link of capacity 1Mbps as in Figure 7.1 used that drops packet according to the AQM algorithm as the parameter set in Table 7.2. The congestion link is in between the two routers R1 and R2. The link is shared by n TCP flows with a physical buffer size of 300 packets. The TCP flows are derived from FTP sessions. In the simulation setup, the TCP flows are varied from 30 connections to 1000 connections.

Table 7.2 Parameter Setting of FLoadAutoRED

Type of Sources	Link Capacity	Link Delay	Packet Size	max_p	γ	Delta	δ	Simulation Time
TCP (FTP)	1Mbps	1ms	1 Kbytes	0.02	0.2	11.25	0.06	100 secs

7.4.2 Performance Evaluation

The performance of the algorithm are evaluated based on the metrics and the results are shown in the Figures 7.8 to 7.13.

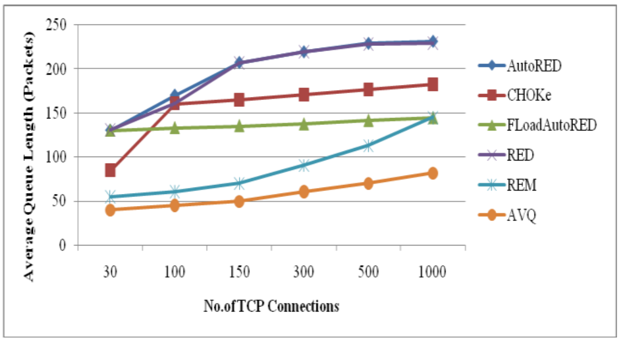

Figure 7.8 Comparison of Average Queue Length of AQM Schemes

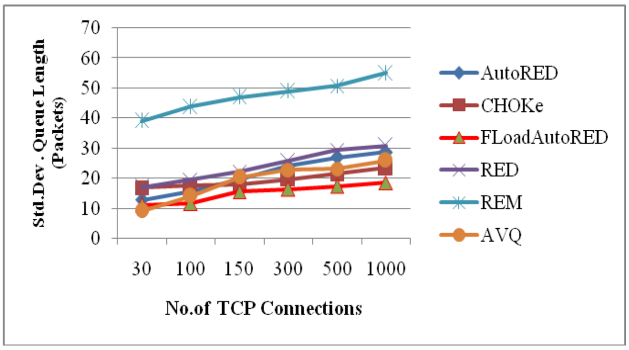

Figure 7.9 Comparison of Std. Dev. Average Queue Length of AQM Schemes

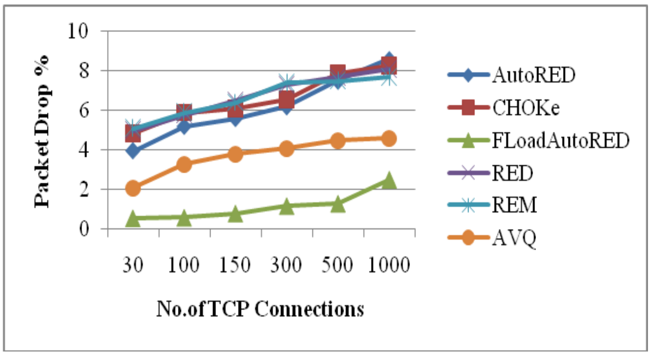

Figure 7.10 Comparison of Packet Drop Rate of AQM Schemes

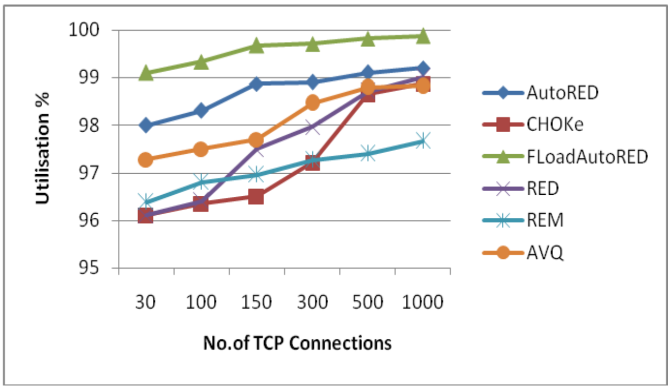

Figure 7.11 Comparison of Utilisation of AQM Schemes

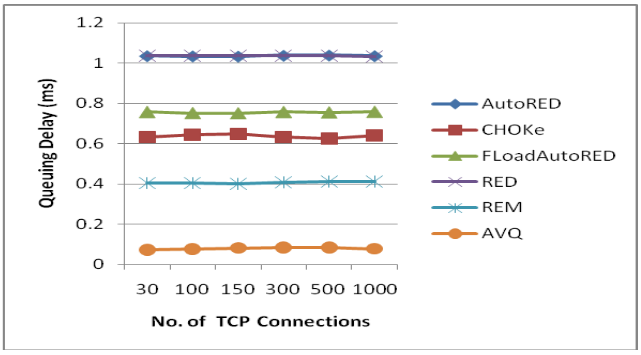

Figure 7.12 Comparison of Queuing Delay of AQM Schemes

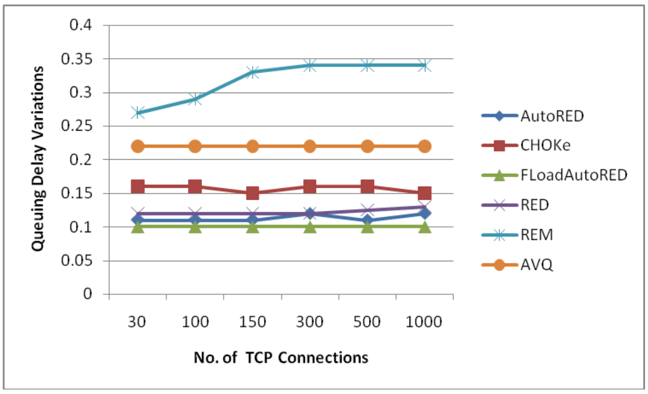

Figure 7.13 Comparison of Queuing Delay Variations of AQM Schemes

7.4.3 Conclusion

In a real environment of IP networks, the number of connection varies. Therefore, a robust algorithm should be unaware of variations in the value of the number of connections. The simulation with the number of FTP connections ranging from 30 to 1000 is executed. As shown in Figure 7.8, the average queue length of queue-based AQM schemes is sensitive to changes in the value of the number of FTP connections. However, the average queue length of rate-based AQM schemes like AVQ does not vary much regardless of the value of FTP connections. In the case of AutoRED and REM, the average queue length varies heavily with FTP connections. As the number of FTP flow increases, the loss rate of queue-based AQM schemes becomes substantially higher than those of the rate based AQM schemes as observed in the Figure 7.10. The average queue length is almost stable regardless of the varying of FTP connections in FLoadAutoRED. The early controlling of queue in FLoadAutoRED is done by introducing the packet arrival rate which is reflected in the standard deviation of queue length that is relatively small compared to those of other AQM schemes. The link utilization of the queue based AQM schemes is satisfactory as shown in Figure 7.11. These simulation results shown in Figure 7.9 -7.13 validate the effectiveness of the early queue control in FLoadAutoRED AQM scheme, which leads to low queuing delay jitter, high utilization and a small loss rate for a wide range of the traffic load.

7.5 EXPERIMENT III - ROBUSTNESS WITH RESPECT TO LINK CAPACITY (BANDWIDTH) CHANGES

Next the experiments are conducted to evaluate the robustness with respect to link capacity or bandwidth change.

7.5.1 Parameter Settings

In this section, to simulate the FLoadAutoRED algorithm a single link of capacity is considered as a variable that drops packet according to the AQM algorithm according to the parameters set as in Table 7.3. The congestion link is in between the two routers R1 and R2. All links have a small propagation delay of 1ms. The TCP flows are derived from FTP sessions. The link capacity varies from 0.5Mbps to 50 Mbps.

Table 7.3 Parameter Setting of FLoadAutoRED

Type of Sources	**Link Capacity**	**Link Delay**	**Packet Size**	**max_p**	γ	**Delta**	δ	**Simulation Time**
TCP (FTP)	1Mbps	1ms	1 Kbytes	0.02	0.2	11.25	0.06	100 secs

7.5.2 Performance Evaluation

The performance of the algorithm are again evaluated based on the metrics and the results are shown in the Figures 7.14 to 7.19.

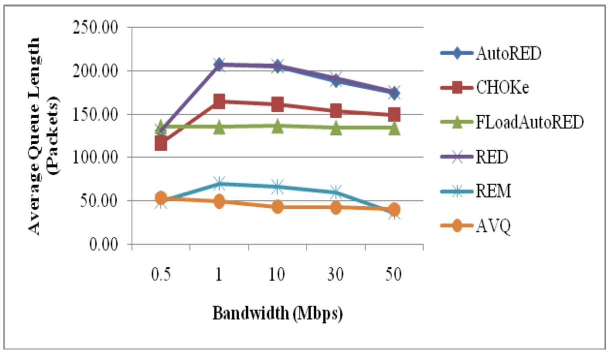

Figure 7.14 Comparison of Average Queue Length of AQM Schemes

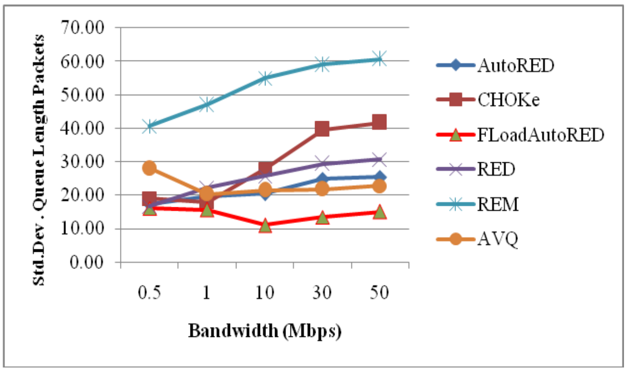

Figure 7.15 Comparison of Std. Dev. Average Queue Length of AQM Schemes

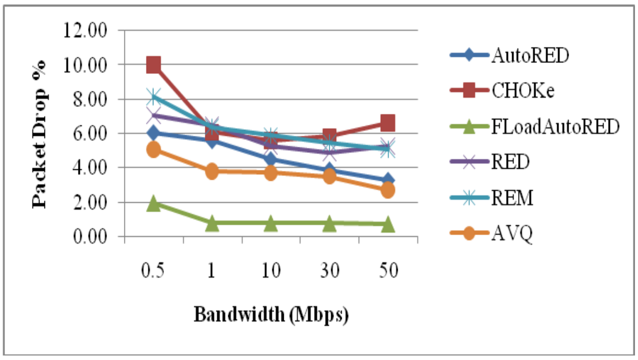

Figure 7.16 Comparison of Packet Drop Rate of AQM Schemes

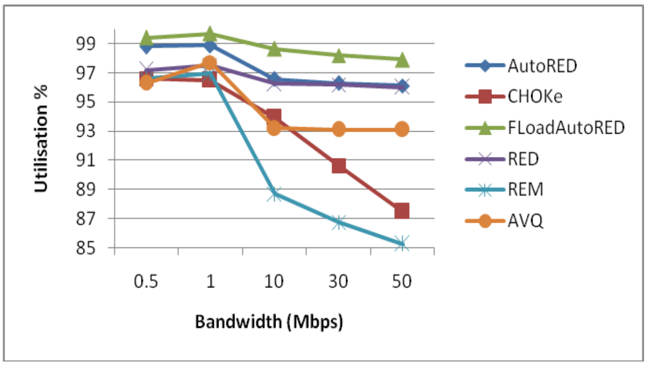

Figure 7.17 Comparison of Utilisation of AQM Schemes

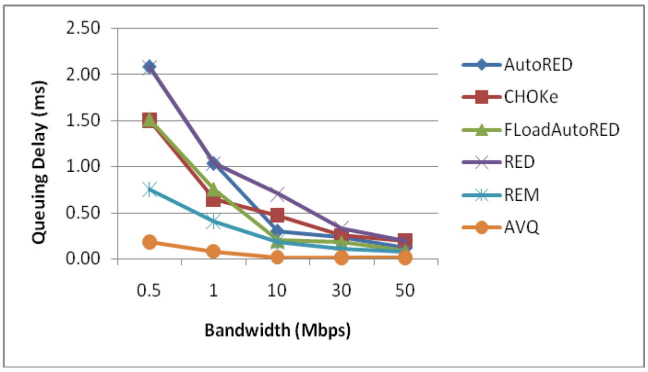

Figure 7.18 Comparison of Queuing Delay of AQM Schemes

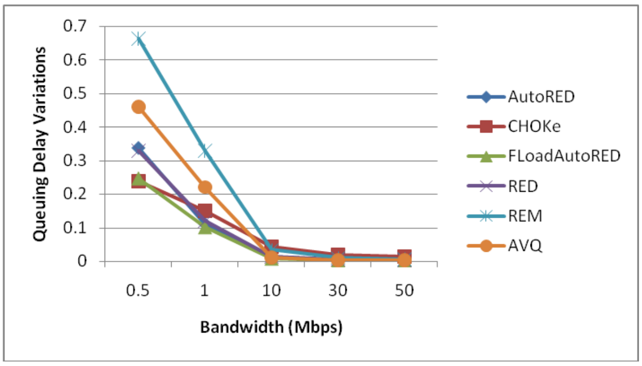

Figure 7.19 Comparison of Queuing Delay Variations of AQM Schemes

7.5.3 Conclusion

To study the effect of bottleneck link capacity C, simulation is performed with different link capacity in the range of 0.5–50 Mb/s. Figures 7.14 to 7.19 shows the comparison of the performance metrics of the various AQM schemes in relation to changes in the value of C. As shown in Figure 7.17, the AQM performance deteriorates significantly, i.e. the link utilization decrease for all the AQM schemes when link capacity increases. The average queue length and instability decreases for very high link capacity as in shown in Figures 7.14 and 7.15. Because high bandwidth will result in large congestion window and small packet loss probability, the stability is difficult to preserve.

7.6 EXPERIMENT IV - ROBUSTNESS WITH RESPECT TO UDP RATE CHANGES

The next experiment conducted is to evaluate the algorithm's performance based on the varying UDP rate.

7.6.1 Parameter Settings

In this section, to simulate the FLoadAutoRED algorithm a single link of capacity 1Mbps is considered. The packet drops according to the AQM algorithm as the parameters set in Table 7.4. The congestion link is in between the two routers R1 and R2. The link is shared by 'n' TCP flows and 'n' UDP flows. In the simulation 32 TCP flows and 1 UDP flow with constant bit rate varies from 0.02Mbps to 1 Mbps in the simple network.

Table 7.4 Parameter Setting of FLoadAutoRED

Type of Sources	**Buffer Size**	**Link Capacity**	**Link Delay**	**Packet Size**	**max_p**	γ	**Delta**	δ	**Simulation Time**
TCP (FTP)	300 Packets	1Mbps	1ms	1 Kbytes	0.02	0.2	11.25	0.06	100secs

7.6.2 Performance Evaluation

The performance metrics evaluated and considered are shown in Figures 7.20 to 7.25.

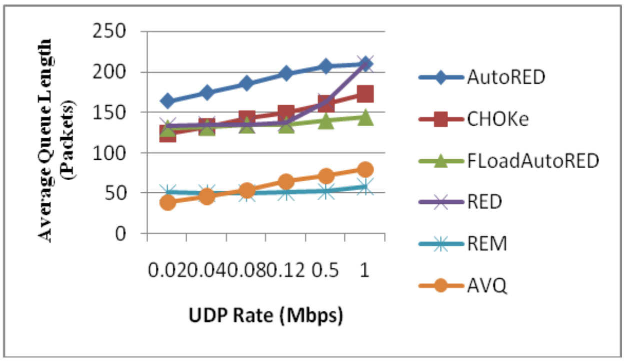

Figure 7.20 Comparison of Average Queue Length of AQM Schemes

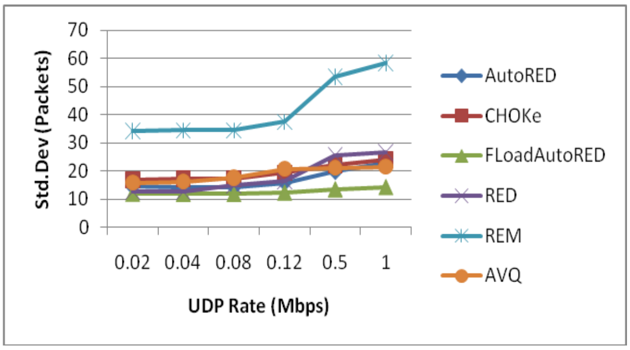

Figure 7.21 Comparison of Std. Dev Average Queue Length of AQM Schemes

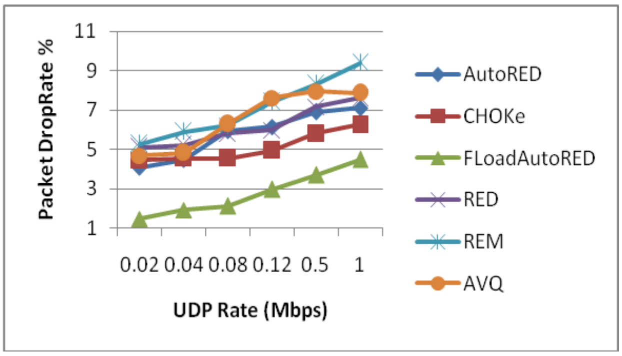

Figure 7.22 Comparison of Packet Drop Rate of AQM Schemes

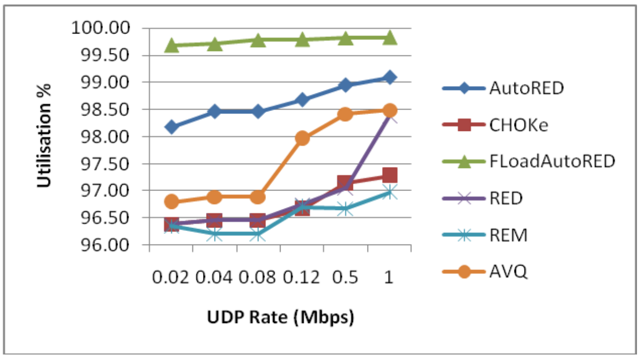

Figure 7.23 Comparison of Utilisation of AQM Schemes

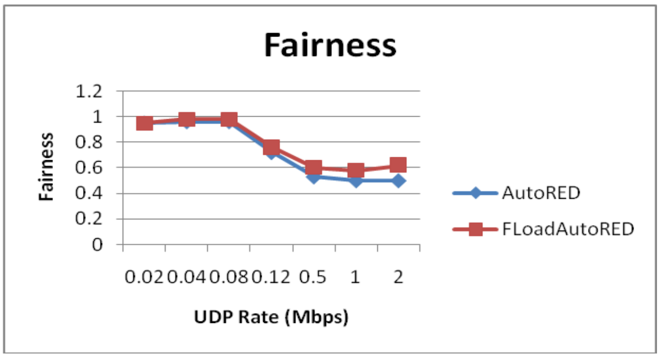

Figure 7.24 Comparison of Fairness of AQM Schemes

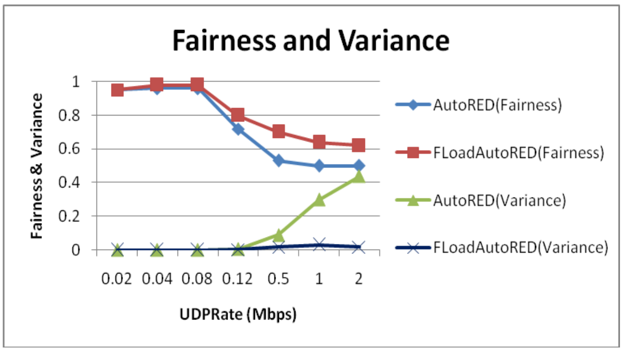

Figure 7.25 Comparison of Fairness and Variance of AQM Schemes

7.6.3 Conclusion

In the section, portion of UDP traffic load is increased, i.e. from 0.02Mbps to 50 Mbps, for observing the effect of UDP traffic. Figures 7.20 to 7.21 show the average queue length and standard deviation of queue length of FLoadAutoRED. They are little affected by the introduction of the UDP flows. However as the UDP rate increases to a higher level, the AQM schemes do not tolerate resulting in a higher packet loss. The AQM RED projects packet loss performance as in Figure 7.22 which is very terrible even though its link utilization is high. The average queue length is maintained at a lower level even with increasing UDP rate in REM and AVQ. There is a large overshoot of the queue dynamic in REM compared to other AQM schemes. The entire TCP throughput is affected by UDP traffic. For all AQM schemes, the TCP throughput is reduced when UDP traffic is increased. In spite of the existence of UDP flows, FLoadAutoRED outperforms the other schemes for link utilization of TCP traffic as in Table 7.23. The fairness of the proposed AQM is higher as the UDP rate increase which is observed in Table 7.24 and Table 7.25.

7.7 EXPERIMENT V - ROBUSTNESS WITH RESPECT TO PARETO FLOW

The next set of experiments is conducted to study the robustness of the algorithm with respect to the increasing and decreasing Pareto flow.

7.7.1 Parameter Settings

In this section, the FLoadAutoRED algorithm is simulated with a single link of capacity 1Mbps. The packet drops according to the AQM algorithm as the parameters set in Table 7.5. The congestion link is in between the two routers R1 and R2. In a realistic traffic scenario, simulation is performed with the short-lived web flows. The web-like mice traffic is generated using on/off traffic, whose burst time and idle time are taken from the Pareto distribution. In this experiment, a workload of sources is changed by increasing the number of connections by100 for every 100 s by increasing the load. In load decreasing scenario, 1000 connections are started initially and dropped by100 for every 100s.

Table 7.5 Parameter Setting of FLoadAutoRED

Type of Sources	Pareto
Buffer Size	200 Packets
Link Capacity	1Mbps
Link Delay	1ms
Packet Size	1 Kbytes
max_p	0.02
γ	0.2
Delta	11.25
δ	0.06
Burst Rate	64kbps
Burst-time	1s
Idle time	1s
Shape	1.5
max_{th}	150 Packets
min_{th}	75 Packets

7.7.2 Performance Evaluation

The queue length is considered to express the response performance of the AQMs in Figures 7.26 to 7.30 and Figures 7.31 to 7.35 for increasing pareto and decreasing pareto respectively.

7.7.2.1Increasing Pareto

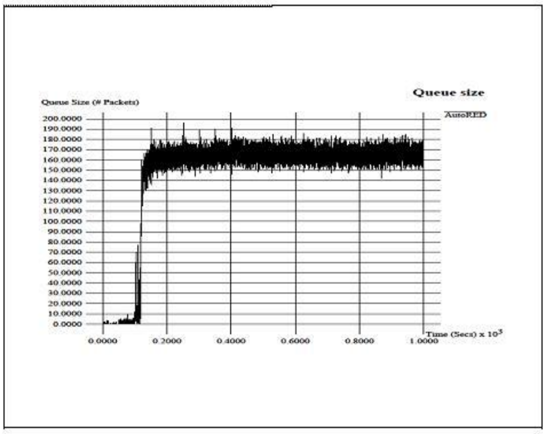

Figure 7.26 Response Performance of AutoRED

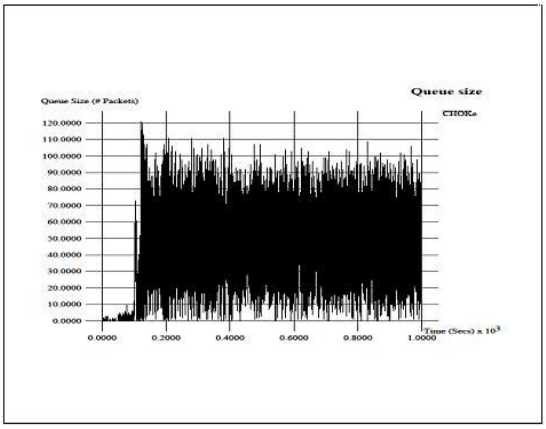

Figure 7.27 Response Performance of CHOKe

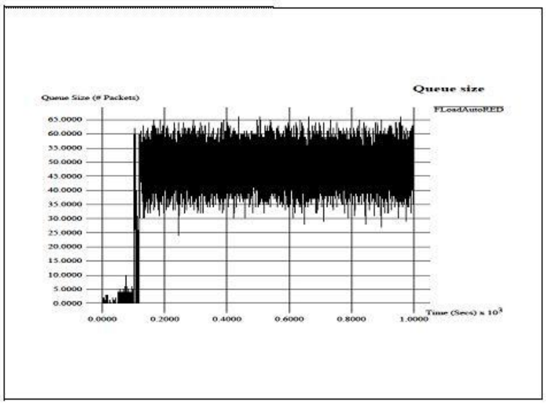

Figure 7.28 Response Performance of FLoadAutoRED

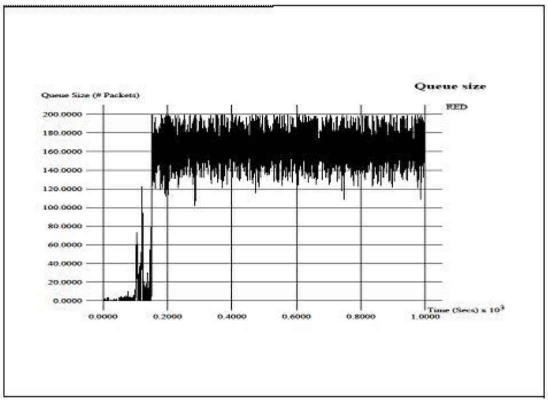

Figure 7.29 Response Performance of RED

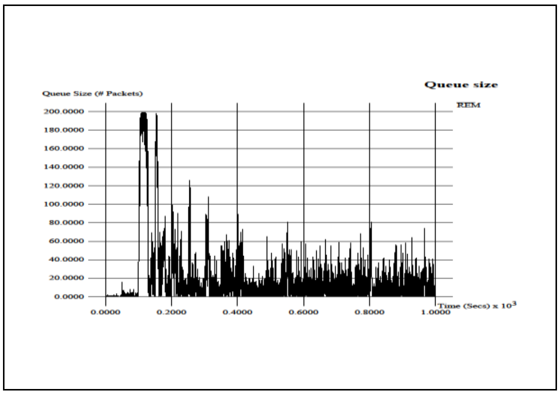

Figure 7.30 Response Performance of REM

7.7.2.2 Decreasing Pareto

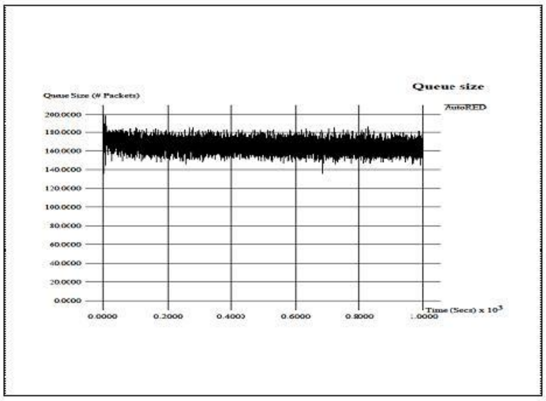

Figure 7.31 Response Performance of AutoRED

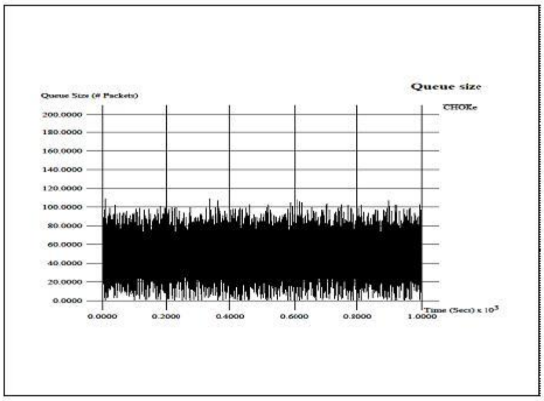

Figure 7.32 Response Performance of CHOKe

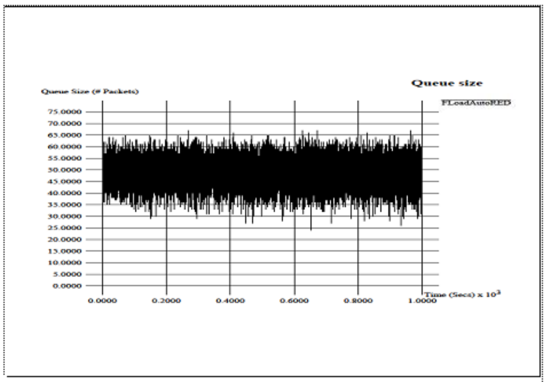

Figure 7.33 Response Performance of FLoadAutoRED

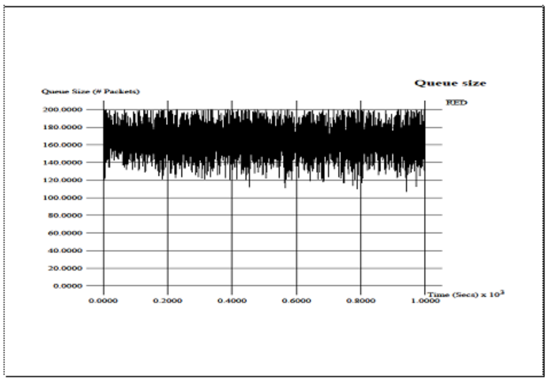

Figure 7.34 Response Performance of RED

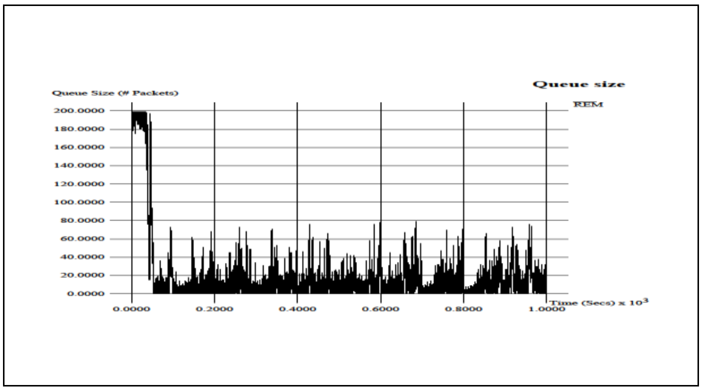

Figure 7.35 Response Performance of REM

7.7.3 Conclusion

The queue evolution using different AQM algorithms are depicted in Figures 7.26 to 7.35. As shown in Figure 7.28, the queue size is more stable in FLoadAutoRED than that of other AQM schemes under either increasing or decreasing load conditions. The congestion notification may be delayed under heavy traffic scenario, which results in increasing queuing size and delay remarkably as shown in queue based AQMs. FLoadAutoRED projects a lower queue size compared to other AQM schemes. The queue stability in FLoadAutoRED is better compared to other AQMs. This signifies that the queuing delay for FLoadAutoRED is small.

7.8 EXPERIMENT VI - ROBUSTNESS WITH RESPECT TO DYNAMIC LOAD

The next experiment is conducted and evaluated by varying the load dynamically as follows:

i) Increasing and Decreasing Load

ii) Increasing Load

iii) Decreasing Load

7.8.1 a) Parameter Settings - Robustness with respect to Increasing and Decreasing Load

In this section, FLoadAutoRED algorithm is simulated with a single link of capacity 1Mbps as set up in Figure 7.1 that drops packet according to the AQM algorithm as the parameters set in Table 7.6. The congestion link is in between the two routers R1 and R2. The link is shared by ‘n’ TCP flows with the physical buffer size of 300 packets.

The network is simulated for a dynamic traffic scenario. Initially at t = 0s, 200 TCP connections are established, another 200 TCP connections are additionally established at t = 100 s. At t = 200 s, 200 connections are dropped abruptly and following it another 400 connections are immediately established. At t = 300 s, the 400 connections are terminated. All the traffic are terminated at t = 350 s.

Table 7.6 Parameter Setting of FLoadAutoRED

Type of Sources	Link Capacity	Link Delay	Packet Size	max_p	γ	Delta	δ	SimulationTime
TCP (FTP)	1Mbps	1ms	1 Kbytes	0.02	0.2	11.25	0.06	350secs

b) Performance Evaluation

The queue length of the AQMs is evaluated and observed as in Figures 7.36 to 7.40.

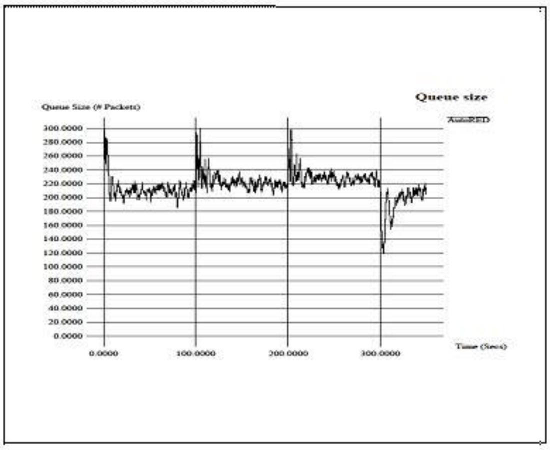

Figure 7.36 AutoRED - Queue Length Vs Time

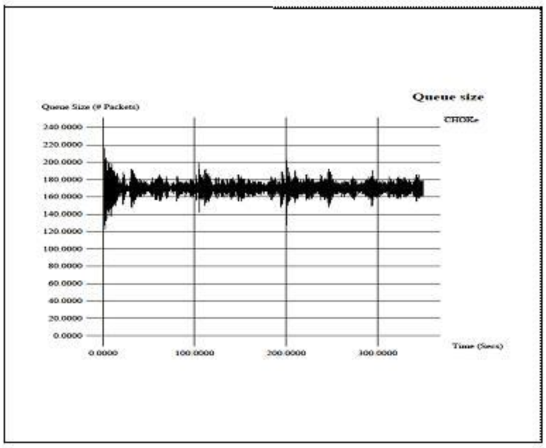

Figure 7.37 CHOKe - Queue Length Vs Time

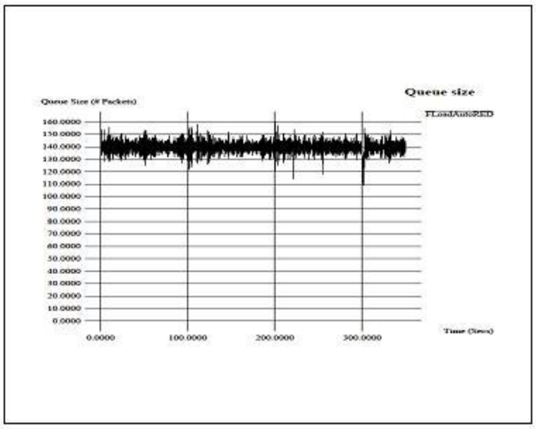

Figure 7.38 FLoadAutoRED - Queue Length Vs Time

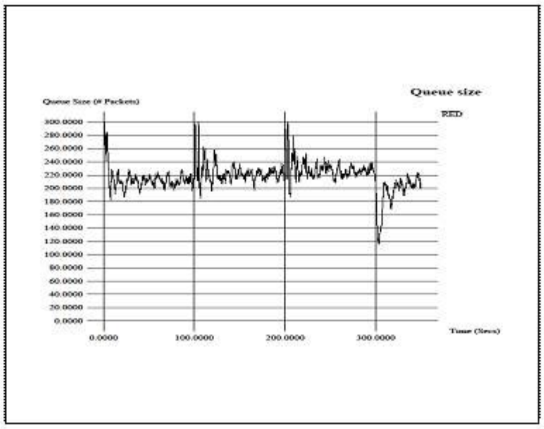

Figure 7.39 RED - Queue Length Vs Time

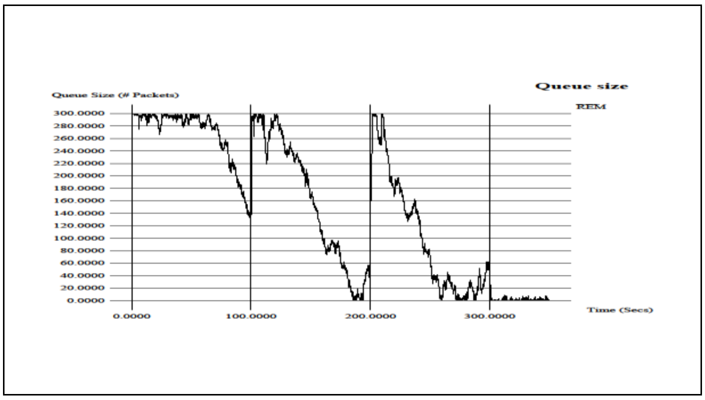

Figure 7.40 REM - Queue Length Vs Time

7.8.2 a) Parameter Settings - Robustness with respect to Increasing Load

In this section, FLoadAutoRED algorithm is simulated with a single link of capacity 1Mbps is set up as in Figure 7.1 that drops packet according to the AQM algorithm as parameters set in Table 7.6. The congestion link is in between the two routers R1 and R2 with the physical buffer size of 300 packets.

The network is simulated for a dynamic traffic scenario. Initially at t = 0 s, 200 TCP connections are established, another 200 TCP connections are additionally established at t = 50 s. Every 50 s, 200 connections are additionally established till 200 s. At t = 300 s, all the connections are terminated.

b) Performance Evaluation

The queue length of the AQMs is evaluated and observed as in Figures 7.41 to 7.45.

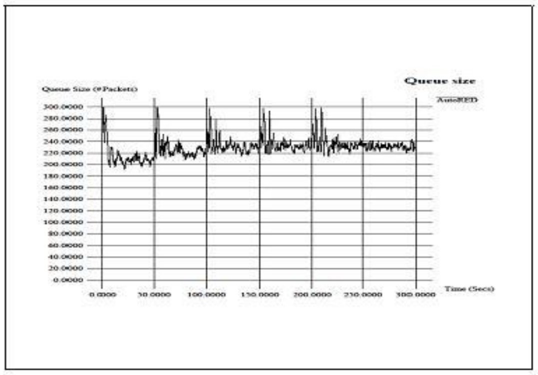

Figure 7.41 AutoRED - Queue Length Vs Time

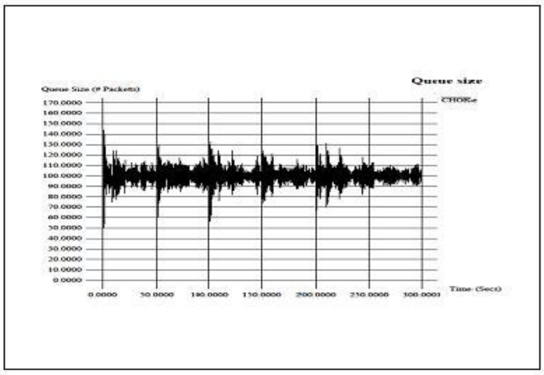

Figure 7.42 CHOKe - Queue Length Vs Time

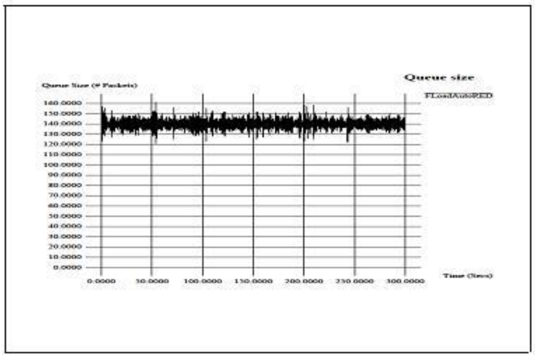

Figure 7.43 FLoadAutoRED - Queue Length Vs Time

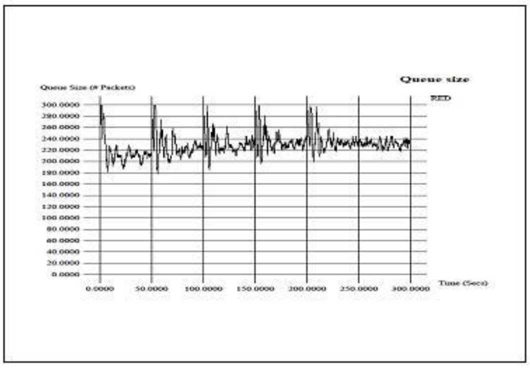

Figure 7.44 RED - Queue Length Vs Time

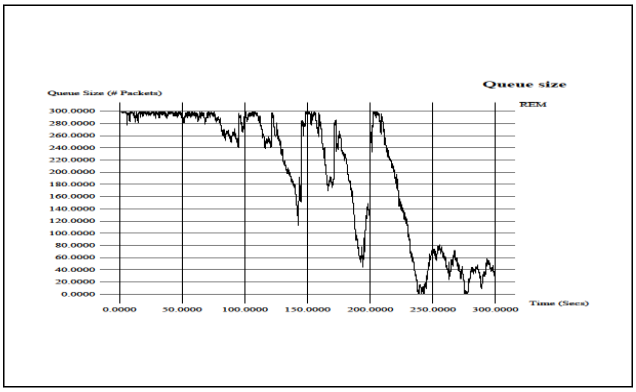

Figure 7.45 REM - Queue Length Vs Time

7.8.3 a) Parameter Settings - Robustness with respect to Decreasing Load

In this section, FLoadAutoRED algorithm is simulated with a single link of capacity 1Mbps as shown in Figure 7.1**.** The packet drops is according to the AQM algorithm with the parameters set as in Table 7.6. The congestion link is in between the two routers R1 and R2. The link is shared by n TCP flows with the physical buffer size of 300 packets.

A simulation is conducted using a dynamic traffic scenario. Initially at t = 0 s, 1000 TCP connections are established, another 200 TCP connections are terminated at t = 50 s. Every 50s, 200 connections are terminated till 200 s. At t = 300 s, all the connections are terminated.

b) Performance Evaluation

The queue length of the AQMs is evaluated and observed as in Figures 7.46 to 7.50.

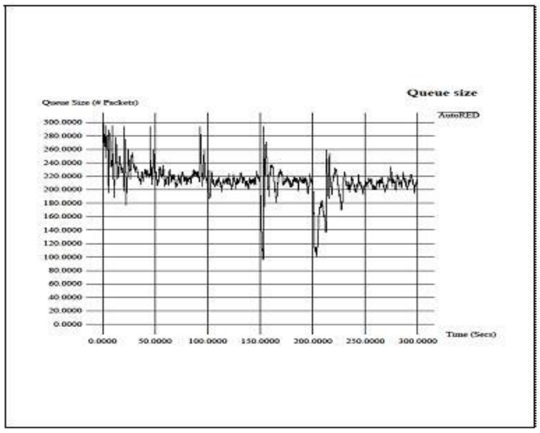

Figure 7.46 AutoRED - Queue Length Vs Time

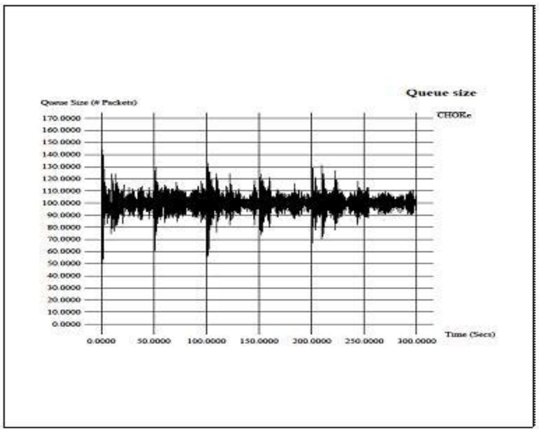

Figure 7.47 CHOKe- Queue Length Vs Time

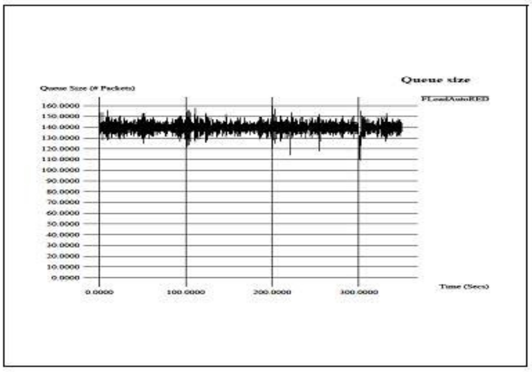

Figure 7.48 FLoadAutoRED - Queue Length Vs Time

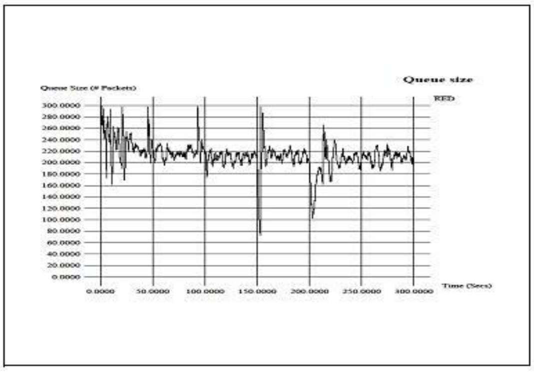

Figure 7.49 RED - Queue Length Vs Time

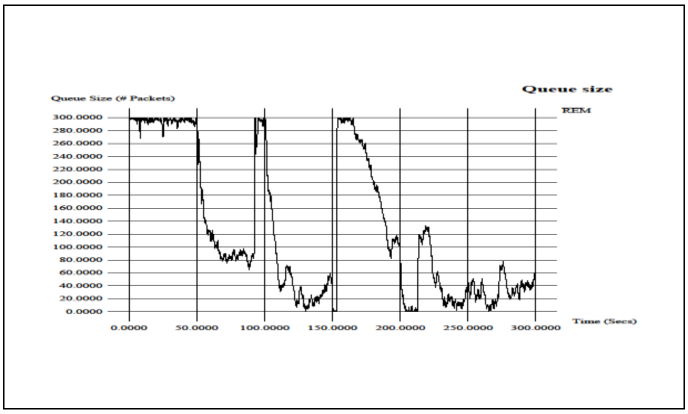

Figure 7.50 REM - Queue Length Vs Time

7.8.4 Conclusion

The simulation results show that FLoadAutoRED responses fast and maintain a small queuing delay jitter in dynamic traffic scenario. However, REM oscillates remarkably under heavy load conditions and decreases the utilization under light load, which leads to larger queuing delay and larger jitter. To compare the responsive performance of queue-based AQMs the queue evolution of RED, REM and AutoRED under dynamic traffic scenario are also depicted in Figures 7.36 to 7.50. The simulation results validate the following argument: there exists lag domino effect in queue-based AQMs, which leads to sluggish response and degenerated performance.

7.9 CONCLUSION

The AQMs AutoREDwithRED and FLoadAutoRED are compared with varying number for TCP connections and UDP rates.

7.9.1 Robustness with respect to Connections

Table 7.7 Comparison of Utilisation

Type of Traffic	No. of Connections	Utiilisation (%)		
		AutoREDwithRED	FLoadAutoRED	Improvement over AutoREDwithRED (%)
Small Traffic	30	98	99.1	1.1
	100	98.3	99.33	1.03
	150	98.87	99.68	0.81
Medium Traffic	300	98.9	99.71	0.81
	500	99.1	99.82	0.72
Large Traffic	1000	99.2	99.88	0.68

It is obvious from the Table 7.7 that the utilization of FLoadAutoRED is greater than AutoRED with an improvement ranging from 0.68% to 1.1%. To find the mean difference in the utilization between AutoRED and FLoadAutoRED student's t-test is computed. The same computed for the other performance metrics also. The t value 3.72 for the mean difference in the utilisation between the AutoRED and FLoadAutoRED is significant ($p < 0.004$).

It is evident from the Table 7.8 that the standard deviation of average queue size of FloadAutoRED is less than AutoRED with an improvement between 12.99% and 35.20%. The t value 7.547 for the mean difference in the standard deviation of average queue size between AutoRED and FLoadAutoRED is significant ($p < 0.001$).

Table 7.8 Comparison of Std. Dev Avg. Q. Size

Type of Traffic	No. of Connections	Std. Dev. Avg. Q Size (Packets)		
		AutoREDwithRED	FLoadAutoRED	Improvement over AutoREDwithRED (%)
Small Traffic	30	12.7	11.05	12.99
	100	15.6	7.6	25.64
	150	18.67	5.53	21.05
Medium Traffic	300	17.07	5.3	32.28
	500	17.9	5.43	35.20
Large Traffic	1000	17.79	4.5	35.74

Table 7.9 Comparison of Average Queue Size

Type of Traffic	No. of Connections	Avg Queue Size (Packets)	
		AutoREDwithRED	FLoadAutoRED
Small Traffic	30	130.4	130.33
	100	170.3	133.3
	150	207.6	135.6
Medium Traffic	300	219.7	137.55
	500	229.4	141.65
Large Traffic	1000	231.7	144.73

The average queue size is at a moderate value for the proposed AQM FLoadAutoRED compared to other AQM as shown in Table 7.9. The other AQMs either have a lower or larger queue size.

It is clear from the Table 7.10 that the packet drop rate of FLoadAutoRED is less than AutoREDwithRED with an improvement between 3.38% and 6.1%.The t value 6.769 for the mean difference in the packet drop rate between AutoREDwithRED and FLoadAutoRED is significant ($p < 0.001$).

Table 7.10 Comparison of Packet Drop Rate

Type of Traffic	No. of Connections	Packet Drop Rate (%)		
		AutoREDwithRED	FLoadAutoRED	Improvement over AutoREDwithRED (%)
Small Traffic	30	3.95	0.57	3.38
	100	5.2	0.6	4.6
	150	5.6	0.81	4.79
Medium Traffic	300	6.2	1.18	5.02
	500	7.5	1.3	6.2
Large Traffic	1000	8.6	2.5	6.1

It is clear from the Table 7.11 that the queuing delay of FLoadAutoRED is less than AutoREDwith with an improvement ranging from 26.8% to 27.3%. The t value 200.1 for the mean difference in the queuing delay between AutoRED and FLoadAutoRED is significant ($p < 0.001$).

Table 7.11 Comparison of Queuing Delay

Type of Traffic	No. of Connections	Queuing Delay (ms)		
		AutoREDwithRED	FLoadAutoRED	Improvement over AutoREDwithRED (%)
Small Traffic	30	1.036	0.757	26.9
	100	1.035	0.752	27.3
	150	1.034	0.751	27.3
Medium Traffic	300	1.038	0.757	27
	500	1.039	0.755	27.3
Large Traffic	1000	1.036	0.758	26.8

7.9.2 Robustness with respect to UDP Rate

It is clear from the Table 7.12 that the utilization of FLoadAutoRED is greater than AutoREDwithRED with an improvement of 0.74% to 1.51%. The t value 8.073 for the mean difference in the utilization between AutoREDwithRED and FLoadAutoRED is significant ($p < 0.001$). It is also evident from the Table 7.13 that the standard deviation of average queue size of FLoadAutoRED is less than AutoRED with an improvement ranging from 16.7% to 37.4%. The t value 2.758 for the mean difference in the standard deviation of average queue size between AutoRED and FLoadAutoRED is significant ($p < 0.002$).

The average queue size is maintained at a moderate value for the proposed AQM FLoadAutoRED compared to other AQM for the varying UDP rate as shown in Table 7.14. The other AQMs maintain a lower or larger queue size.

Table 7.12 Comparison of Utilisation

UDP Rate (Mbps)	Utiilisation (%)		
	AutoREDwithRED	FLoadAutoRED	Improvement over AutoREDwithRED (%)
0.02	98.18	99.68	1.51
0.04	98.46	99.71	1.24
0.08	98.46	99.78	1.32
0.12	98.68	99.79	1.11
0.5	98.95	99.82	0.87
1	99.09	99.83	0.74

Table 7.13 Comparison of Std. Dev Avg. Q. Size

UDP Rate (Mbps)	Avg. Q Size Std.Dev. (# Packets)		
	AutoREDwithRED	FLoadAutoRED	Improvement over AutoREDwithRED (%)
0.02	14.3	11.8	17.4
0.04	14.05	11.7	16.7
0.08	14.05	11.7	16.7
0.12	15.7	12.2	22.2
0.5	19.7	13.4	31.9
1	22.7	14.2	37.4

Table 7.14 Comparison of Average Queue Size

UDP Rate (Mbps)	Avg Queue Size (# Packets)	
	AutoREDwithRED	FLoadAutoRED
0.02	163.6	130.8
0.04	174	131.8
0.08	185.7	134.8
0.12	198.1	135.1
0.5	206.8	139.8
1	209.6	144.1

Table 7.15 proves that the packet drop rate of FLoadAutoRED is less than AutoRED with an improvement from 2.55% to 3.82%. The t value 4.307 for the mean difference in the packet drop rate between AutoRED and FLoadAutoRED is significant ($p < 0.002$).

Table 7.15 Comparison of Packet Drop Rate

UDP Rate (Mbps)	Packet Drop Rate (%)		
	AutoREDwithRED	FLoadAutoRED	Improvement over AutoREDwithRED (%)
0.02	4.08	1.47	2.61
0.04	4.47	1.92	2.55
0.08	5.95	2.12	3.82
0.12	6.14	2.97	3.17
0.5	6.9	3.7	3.20
1	7.1	4.5	2.60

The fairness of FLoadAutoRED is greater than AutoRED as shown in the Table 7.16. It has an improvement in the range 2% to 24%. The t value 2.10 for the mean difference in the fairness between AutoRED and FLoadAutoRED is significant ($p < 0.05$)

Table 7.16 Comparison of Fairness

UDP Rate (Mbps)	Fairness		
	AutoREDwithRED	FLoadAutoRED	Improvement over AutoREDwithRED (%)
0.02	0.95	0.95	0
0.04	0.96	0.98	2
0.08	0.96	0.98	2
0.12	0.72	0.8	10
0.5	0.53	0.7	24
1	0.5	0.64	21

This section explained elaborately all the experiments conducted and the performance of FLoadAutoRED in comparison with AutoREDwithRED to check the feasibility of the approach. It is observed that the proposed FLoadAutoRED outperforms the popular AQMs in terms of the various performance metrics like utilization, queue length, queue stability, fairness and queuing delay. Various experiments are conducted to verify the deviation in results. The next section summarises the result along with the future scope.