DSRED: Improving Performance of Active Queue Management over Heterogeneous Networks

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Abstract- Studies have shown that IETF recommended active queue management scheme (RED) suffers from low throughput, large delay/jitter, and inducing instability in networks. To improve the throughput and delay of RED gateways, Double Slope RED (DSRED) was proposed and was shown to outperform RED in a homogeneous TCP/IP network. The objective of this paper is to evaluate DSRED in a *heterogeneous network* environment. Simulation results have shown that, in a heterogeneous network, *DSRED results in better performance than RED* in terms of throughput and queuing delay.

1 Introduction

Active queue management has been recommended by IETF RFC 2309 for use in the routers of Next Generation Internet in order to improve the performance of networks. Random Early Detection (RED) [1] was proposed to solve the global synchronization problem in TCP/IP based networks. RED uses a *single linear drop function* to calculate the drop probability of a packet, and uses four parameters and average queue size to regulate its performance.

Studies have shown that RED has problems such as low throughput [2], unfairness to connections [3] and traffic types [4], large delay/jitter [5], inducing traffic instability [6], and parameter sensitivity [7].

In [8], we proposed a new active queue management scheme called Double Slope Random Early Detection (DSRED), and showed that DSRED outperformed RED in terms of throughput and queuing delay in a *homogeneous TCP/IP environment.* Since the next generation network will be heterogeneous, consisting of different type of networks, it is crucial to verify the performance and robustness of DSRED in a heterogeneous network environment. The *objective* of this paper is to demonstrate that our proposed DSRED scheme improves the *throughput and delay* of RED in a heterogeneous network environment such as TCP/IP over ATM.

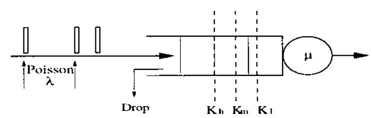

Figure 1: Model for DSRED buffer at gateway.

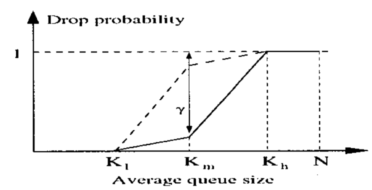

Figure 2: Drop function of DSRED.

The rest of the paper is organized as follows. In Section 2, we briefly describe the *Double Slope Random Early Detection* (DSRED) scheme. Section 3 gives simulation results and discussion, followed by conclusions in Section 4.

2 Double Slope Random Early Detection (DSRED) Scheme

In this section, we briefly describe the Double Slope Random Early Detection (DSRED) scheme proposed in [8].

2.1 *Principle of DSRED*

As shown in Figures 1 and 2, DSRED divides the gateway buffer segment between K_l and K_h into two subsegments separated by K_m. The overall drop function from K_l to K_h are described by two linear segments with slopes α and β respectively. The slopes for these two linear segments are adjusted by the mode selector γ. Here, K_m is set to $0.5(K_l + K_h)$. The drop function, $p_d(avg)$, of DSRED can be expressed as:

$$p_d(avg) = \begin{cases} 0 & avg < K_l \\ \alpha(avg - K_l) & K_l \le avg < K_m \\ 1 - \gamma + \beta(avg - K_m) & K_m \le avg < K_h \\ 1 & K_h \le avg \le N \end{cases} \quad (1)$$

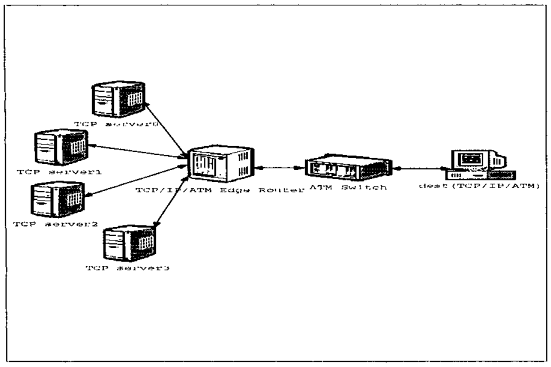

Figure 3: Network configuration for simulation.

where, α, β and avg are given by: $\alpha = \frac{2(1-\gamma)}{K_h - K_l}$, $\beta = \frac{2\gamma}{K_h - K_l}$,and $avg = (1-w)avg + wq$. The above equations governing packet dropping in DSRED translate to the following rules:

- When the average queue length, avg, is less than K_l, no packet is dropped;
- When the average queue length, avg, is between K_l and K_m, packets are dropped according to the drop function with slope α;
- When the average queue length, avg, is between K_m and K_h, packets are dropped according to the drop function with slope β;
- When the average queue length, avg, exceeds K_h, packets are dropped with a probability of one.

3 Simulation Results

Simulations were carried out with the OPNET5.1. This section describes the simulation configuration and results.

3.1 *Simulation Configuration*

The simulation configuration is shown in Figure 3. To provide a fair comparison with RED, we use a similar network topology and configuration as in [1]. The ATM link provides a subnet connection between the TCP servers and destination. Four ftp sources send packets to the same destination via a TCP/IP/ATM edge gateway. To make the comparison more general, we investigated the performance of DSRED and RED with different traffic contracts at the edge router. Parameters for the simulation configuration were as follows. *TCP server0 to Edge Router:* Propagation delay $1ms$, link rate $100Mbps$. *TCP server1 to Edge Router:* Propagation delay $3ms$, link rate $100Mbps$. *TCP server2 to Edge Router:* propagation delay $5ms$, link rate $100Mbps$. *TCP server3 to Edge Router:* propagation delay $7ms$, link rate $100Mbps$. *Dest to Edge Router:* Propagation delay $5ms$, bottleneck link at OC1 rate. The sum of the link rates from the four TCP servers to the edge router was $400Mbps$, which was much higher than the bottleneck link rate. The above values were chosen to induce congestion in the router. *Edge Router Buffer Size:* 200 packets as in [1]. $K_l = 6$, $K_h = 20$: The values were chosen such that $K_h \geq 3K_l$ as suggested in [1, 9].$w = 0.07$. $Max_{drop} = 0.1$, and $\gamma = 0.96$. The selection of Max_{drop} is based on the suggestion given in [9].

3.2 *Performance Criteria*

We used the following performance criteria to compare the performance of DSRED and original RED.

- *Normalized throughput at edge router:* defined during a time period by $\frac{\text{total packets received at destination}}{\text{total packets sent by servers}}$;
- *Edge router queuing delay:* queuing delay experienced by a queued packet at the edge router;
- *Edge router queue size:* queue size of the buffer at the edge router;
- *Packet drop at edge router:* the number of packets dropped per-second at the edge router.

3.3 *Results*

For TCP/IP over ATM, the ATM network is viewed as a subnet of TCP/IP, i.e., the end users (TCP server and destination) run applications over the TCP/IP protocol. TCP/IP and ATM are different network protocols; TCP/IP provides no quality of service guarantee, while ATM provides quality of service guarantees. Therefore, traffic mapping is needed to run TCP/IP over ATM. The traffic mapping is done at the *edge router* at the edge of the TCP/IP and ATM networks. RFC 2381 [10] recommends mapping of best effort service to nrt-VBR and UBR. We have therefore compared the normalized throughput, edge router queue size, queuing delay and packet drop performance for DSRED and RED using the nrt-VBR and UBR traffic contracts at the TCP/IP/ATM edge router.

3.3.1 *nrt-VBR Traffic Contract at Edge Router*

Figures 4 to 8 show the normalized throughput, instantaneous queue size, average packet drop, and average queuing delay for DSRED and RED under nrt-VBR traffic contract at the TCP/IP/ATM edge router.

At the start of transmission, TCP goes through a slow start phase when the router is not congested (0 to 60 seconds), and the normalized throughput is almost equal to one for both DSRED and RED during this time period as seen from Figures 4 and 5. As the TCP traffic rate increases, the router queue quickly builds up and reaches its peak value at around 60 seconds as shown in Figure 6 which depicts the queue sizes for DSRED and RED. The congestion of the router results in a higher packet drop rate at around 50 seconds as shown in Figure 7. This, in turn, results in a rapid decrease in the normalized throughput for both DSRED and RED after 80 seconds as shown in Figures 4 and 5.

DSRED and RED use the average queue length as the control variable to perform packet drop. Because the average queue length calculation works like a low pass filter, the change of average queue length always falls behind the change of instantaneous queue size. This results in a time delay between the packet drop and the change of instantaneous queue as can be seen from Figures 6 and 7 where the instantaneous queue size and packet drop rate reach their peaks at 50 and 90 seconds respectively.

Our proposed DSRED uses a two-segment linear drop functions with two distinct slopes instead of one as used in original RED. Therefore, DSRED will provide congestion signals to TCP servers more effectively than RED. In turn, the gateway queue will be maintained at a lower level, and the packet drop rate will be lower as can be seen in Figures 6 and 7.

DSRED forces the TCP servers to back off more effectively than when RED is used. This results in a lower packet drop in DSRED which, in turn, results in a higher throughput. As shown in Figure 7 where the peak value of packet drop for RED is around 5.2 packet/second which is almost twice the value for DSRED. Therefore, the normalized throughput of DSRED rapidly increases and remains at a high level (around 0.9) for the rest of simulation period as shown in Figure 4. Although the normalized throughput for RED also increases rapidly, its high packet drop rate results in the normalized throughput always being lower (around 0.6) than that of DSRED as seen in Figure 5.

It is seen from Figure 6 that DSRED maintains the gateway queue at a lower level than RED. DSRED queue has a smaller queuing delay (0.35 sec) than RED (0.55 sec) as is evident from Figure 8.

3.3.2 *UBR Traffic Contract at Edge Router*

Figures 9 to 13 show the normalized throughput, instantaneous queue size, average packet drop, and average queuing delay for DSRED and RED under UBR traffic contract at edge router. It is seen that, as in the case of nrt-VBR traffic contract described in Section 3.3.1, DSRED has better performance than RED also in the case of UBR traffic contract. We therefore, conclude that *our proposed DSRED outperforms RED in term of normalized throughput queuing delay, and packet loss in a heterogeneous networks environment.*

For ease of comparison between the performance of DSRED and RED, the results discussed in Sections 3.3.1 and 3.3.2 for DSRED and RED over a heterogeneous network have been summarized in Table 1, where NTP, AQD,

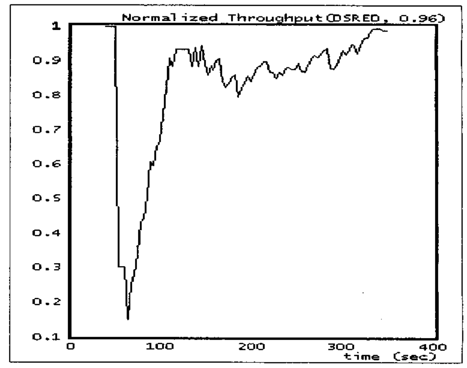

Figure 4: Normalized throughput for DSRED with nrt-VBR traffic contract at edge router.

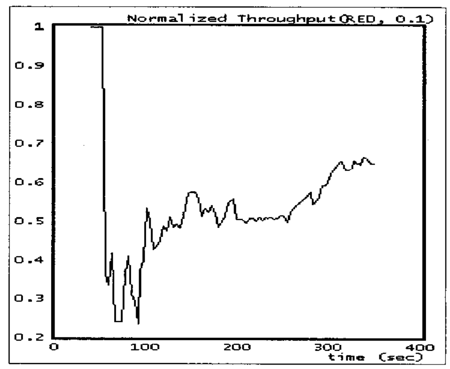

Figure 5: Normalized throughput for RED with nrt-VBR traffic contract at edge router.

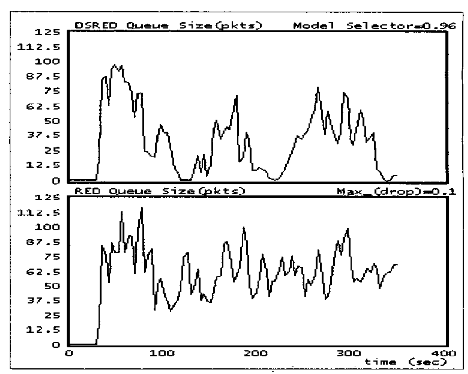

Figure 6: Instantaneous Queue size for DSRED and RED with nrt-VBR traffic contract at edge router.

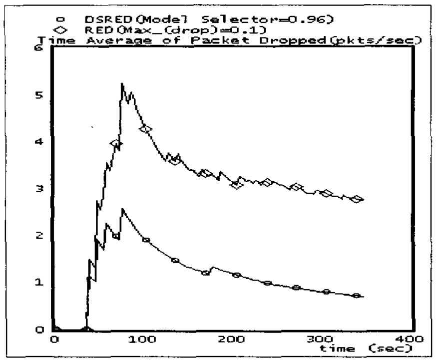

Figure 7: Time average of packet drop for DSRED and RED with nrt-VBR traffic contract at edge router .

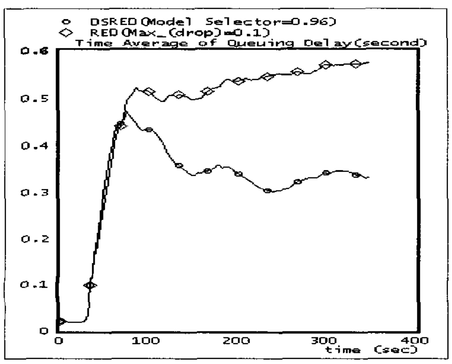

Figure 8: Time average of queuing delay for DSRED and RED for nrt-VBR traffic contract at edge router.

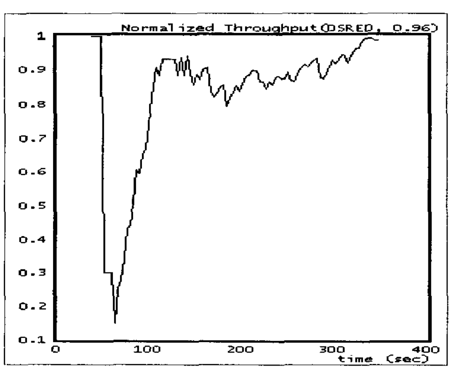

Figure 9: Normalized throughput for DSRED with UBR traffic contract at edge router.

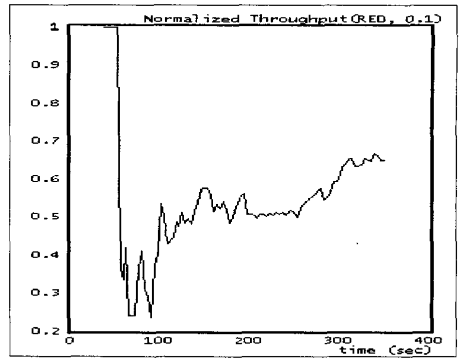

Figure 10: Normalized throughput for RED with UBR traffic contract at edge router.

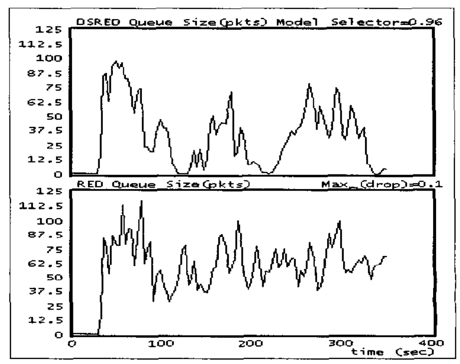

Figure 11: Queue size for DSRED and RED with UBR traffic contract at edge router .

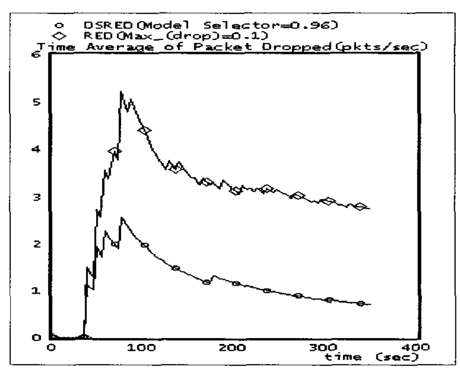

Figure 12: Time average of packet drop for DSRED and RED with UBR traffic contract at edge router.

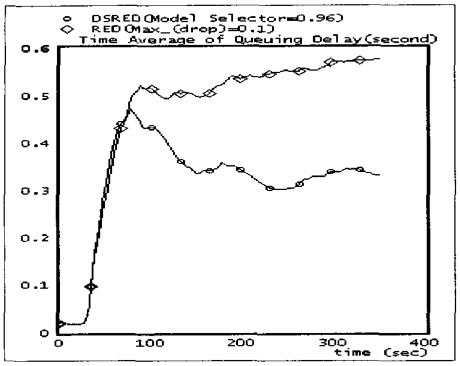

Figure 13: Time average of queuing delay for DSRED and RED for UBR traffic contract at edge router.

Table 1: Simulated Edge Router Performance for DSRED($\gamma = 0.96$) and RED($Max_{drop} = 0.1$) with Traffic Contract nrt-VBR and UBR.

	DSRED		RED	
Criteria	nrtVBR	UBR	nrtVBR	UBR
NTP	0.98	0.98	0.66	0.66
AQD(s)	0.3	0.3	0.55	0.55
PQS (Pkt)	100	100	118	118
APD (Pkt/s)	0.8	0.8	3.0	3.0

PQS and APD represent normalized throughput, average queuing delay, peak queue size, and average packet drop respectively.

4 Conclusion

In this paper, we have evaluated the performance of our proposed DSRED active queue management scheme under a heterogeneous network environment. TCP/IP over ATM, using nrt-VBR and UBR traffic contracts at the edge router, have been used for the study. Results show that *DSRED has a much higher normalized throughput, lower average queuing delay, queue size, and packet drop probability* than RED under same network configuration.

It is also found that our DSRED is robust for different traffic contracts at the edge router, i.e, exhibits similar performance for different traffic contract. DSRED will therefore be very suitable for the next generation network which are expected to be a heterogeneous network consisting of different network technologies.

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