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Performance Comparison of RED and REM in Active Network-based Congestion Control Protocol

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Abstract

We review in this paper the active networks based congestion control TCP (Transmission Control Protocol) for unicast flows and active queue management policies. The objective of the work is to evaluate the impact of different queue management policies on the performance of the Active Networks Congestion Control TCP (ACC TCP).

We integrate, run, and test the novel active queue management algorithm called REM (Random Early Marking) over the active networks based congestion controlled network. The integration of REM on ACC TCP network simulator as has been performed in this work, as well as the comparison of the effect of Random Early Detect (RED) and REM queuing policy on the network with and without enabling the active networks congestion control protocol. It can be concluded that the implementation of the active networks paradigm into congestion control, enhanced by the application of REM queuing policy improves the performance of the network in terms of low buffer occupancy and stability compared with the one using RED.

INTRODUCTION

The Internet performance perceived by the users depends largely on the performance of TCP, due to the fact that TCP is the most widely used transport layer protocol in the Internet. Although the performance dynamics of TCP over traditional networks are relatively well understood, the research community is only beginning to explore the TCP performance implications for the emerging and future networking environments [10]. Active Networks Congestion Control (ACC TCP) [6] is an example of a proposal to enhance TCP, which implements the active networks paradigm into congestion control mechanisms. Active networks facilitate the deployment of new network protocols and allow application developers to define custom protocols, without having to wait for a standardization stage [18].

In this paper we conduct performance evaluation of the integration of two novel approaches, a) to network architecture called active networks and b) the buffer queue management algorithm called Random Early Marking [1]. Both approaches consider the problem domain of congestion control for TCP. Congestion has become a major problem in the Internet due to the increase in the number of users and applications. The result of congestion is excessive packet drop and delay in the network. During congestion, the network throughput may drop to zero and the path delay may become very high. A congestion control scheme helps the network to recover from the congestion state. A variety of new schemes based on active networks have been proposed in the literature to overcome the problem of congestion such as Application Specific Congestion Control (ASCC) [3], Active Reliable Multicast (ARM) [15], Active Error Recovery/Nominee Congestion Avoidance algorithm (AER/NCA) [13], and Active Layered Multicast Adaptation (ALMA) protocol [21].

The objective of the work is to assess the performance of the ACC TCP proposed by Faber [6] in relation to the addition of REM as a queuing policy. The methodology used in this work consists of modeling and designing several experiments based on simulation scenarios in order to study the impact of some network parameters on the data transport. The experimental design is implemented using the ns-2.1k5 network simulator of the Virtual Internet Testbed (VINT) project of the Lawrence Berkeley National Laboratory [7] and the ACC TCP ns extension [6]. We have also integrated the ACC TCP with REM [1]. The scenarios to evaluate the traffic flow behavior of TCP and active networks based TCP have been simulated and analyzed.

The remainder of this paper is organized as follows: we describe the background and related work including the description of active networks and ACC TCP, as well as active queue management algorithms such as RED and REM. We discuss the experimental design and simulation
2 BACKGROUND AND RELATED WORK

The following sections discuss active networks, congestion control, and approaches to perform congestion control using active networks as well as active queue management policies. Even though the two approaches to enhance the performance of the networks use the term 'active', they do not use it with the same meaning. RED or REM are required beyond the ACC TCP despite the fact that the active router shorten the time for congestion relief, because routers need a buffer scheduling policy to handle the packet. We are using the novel approaches in order to achieve better network performance.

2.1 Active Networks

Active networks (AN) allow programs to be injected into the networks in the data packets being sent [18]. Active networks have been an ideal candidate for enhancing the existing networks by enabling the amelioration of new service requirements quickly and efficiently [17]. Active networks allow intermediate routers to perform computations up to the application layer. Router and switches within the network can perform computations on user data flowing through them.

![Figure 1. Active networks and queue management architecture](image)

Many prototypes of applications and Execution Environment (EE) such as ANTS [20], CANES [4], and Switchware [11] have been introduced by various research centers around the globe. All of these EEs are expected to accommodate the main purpose of AN which is to allow the user to inject customized programs into the network. In order to standardize the active networks deployment, the Active Networks Encapsulation Protocol (ANEP) has been introduced to provide interoperability between layers for AN [5]. It specifies a mechanism for encapsulating active networks frames for transmission over different media.

AN architecture consists of Node Operating Systems (NODES) and execution environments in which the active applications run. In addition a congestion control scheme such as buffer management and scheduling also exists in the router. Figure 1 shows the architecture of active networks and queue management mechanism.

2.2 Congestion Control

Congestion control is an application that can benefit from a combination of end system and network processing, such as feedback congestion control using active networks as the use of better queue management in the active node. Several mechanisms can be placed in the network for example to discard packets in the switches/routers. The application deals with how to adapt to the congestion, whereas the network knows the location and timing in which adaptation is needed. In the case of congestion control, the AN approach can be used to provide information about the time and place where the congestion occurs. The use of this information in a timely manner will enhance the performance of the network.

2.3 Active Congestion Control TCP (ACC TCP)

The work of Faber [5] applies the active network technology to feedback congestion control specifically TCP. Active Congestion Control (ACC) exploits state and programmability to reduce the delay when congestion is signaled to the sending systems. ACC packets contain 4 to 8 bytes characterization of the state of the endpoint congestion feedback. When congestion occurs at a router, particularly when a packet is dropped, the route determines the congestion window size, deletes packet from the sender that violate the new window value (that would not be sent with this new window size), and informs the sender of the new window size.

Under ACC TCP, active routers generate a congestion signal, in the form of a TCP acknowledgement for the TCP source. This will shorten the time required for congestion notification to reach the sender. The TCP acknowledgments (congestion signal) advertise a TCP window size of the current window size. When congestion is experienced by the system, the ACC TCP notifies the end system and then filters one window of traffic. Thus, ACC uses active network technology to reduce the control delay exhibited by feedback congestion control system by means of generating ACC packets and starting traffic modification from the congested route. Each packet contains a program or data for a router that enables it to react to network congestion, hence avoiding the delay in communicating congestion information to endpoints.

2.4 Active Queue Management (AQM)

A queue management algorithm traditionally manages the length of packet queue in the router by dropping packets only when the buffer overflows such as in the droptail technique. In addition to the traditional queuing algorithm, several active queue policies such as RED and REM have been introduced, in which the congestion problem is addressed in a proactive manner. The main purpose of AQM is to provide congestion information to
sources to set their rates. RED controls its average queue size to manage its transmission rate. RED randomly drops packets prior to the period of congestion and informs the routers to reduce their transmission rate. RED algorithm learns on sources of congestion by probabilistically marking and dropping packets. RED performance could be enhanced by sensitive parameter setting and desynchronization, which prevent bursty loss and buffer overflows [9]. RED promotes fairness by dropping random packet before the queue becomes full. RED algorithm has been widely implemented in commercially available routers due to its capacity in avoiding the global synchronization problem in which drop tail tends to drop packets simultaneously, causing low throughput and high delay jitter [12].

REM is a new active queue management scheme that has the features to match user rate to network capacity while keeping buffers, in addition to sum prices which is the end-to-end marking (or dropping) probability observed by a user [1]. It depends largely on the sum of link prices. REM attempts to achieve high utilization as well as negligible loss and delay. Unlike RED, which measures congestion by the average queue size, REM measures congestion in price. Neither queue management policies needs per flow information. As the number of sources increase, the queue and loss are increased in RED, whereas in REM the increase is negligible.

RED and REM are primarily different in their way of detecting and measuring the network congestion. Note that marking in RED means a slow down request to anticipate congestion sooner in the path to destination, whereas in REM, marking allows a source to estimate the aggregate drop rate on its path. The REM-based network has been designed to ensure fairness and stabilize the network because constant bandwidth probing is not necessary in REM.

REM was introduced by Low et al. [16] who view feedback congestion control system as a duality model; the interaction between the end system and the network. In order to see the impact of queue management models, we will take into account an example in which a set of S sources share a network of links L. Upon a transmission with rate χ(s,t) which is a function of period t, each source s attains a utility U(s). A congestion measure p(s,t) is updated at every link, and each source updates its rate χ(s) according to the sum of p(s,t). The following vector forms represent the relationship:

\[ x(s+1) = F(x(s), p(s), p(s+1)) \]

The function F models the source algorithm such as TCP Reno [8], whereas the function G models queue management. Each TCP/AQM scheme that attempts to optimize the network usage can be characterized by the function of (F, G, U) to describe the source rates, congestion measure, and the utility function. Table 1 shows RED and REM from the angle of duality model. Further discussion on the derivation and explanation of this comparison can be found in [16].

<table>
<thead>
<tr>
<th>Function G</th>
<th>RED</th>
<th>REM</th>
</tr>
</thead>
<tbody>
<tr>
<td>p(s+1) = F(x(s) p(s), p(s+1))</td>
<td>x(s) = G(p(s))</td>
<td>x(s) = G(p(s))</td>
</tr>
</tbody>
</table>

Table 1. The comparison of RED and REM

In Table 1, p(s): congestion measure at the link; p(s+1): p(s) (aggregate source rate at bottleneck link); G: queue length; d is a constant > 0; and s is a constant.

REM proved to be capable of detecting network congestion more accurately than RED in [16] and therefore maintains smaller queue occupancy at the gateway. Consequently, REM is believed to provide a more robust and a better end-to-end performance. The comparison of RED and REM on TCP Reno performed in [2] has shown that REM’s key feature is lower buffer occupancy at steady state while achieving high utilization at the same time as the number of connection changes.

2.5 Simulation Tool and REM Active Implementation

The ns simulation tool is used in the simulation study [7]. ns is at present the most widely used simulator for network simulation. The REM algorithm has been integrated part of the queuing policy in the active congestion control TCP ns extension of Faber [6]. Therefore in addition to drop tail active and RED active flows, we have REM active flows that can be run to benefit from the existence of both the active networks and REM. We have implemented this by creating a Queue/REM/Active mechanism by modifying the tel and c code available from ns 2.16s with active networks extension and REM C codes of Low et al. [1].

3 EXPERIMENT DESIGN & SIMULATION

3.1 Description of Experiments

This section describes the network configuration and parameters to evaluate the active queue management on active networks-based TCP. There are two parts in the simulation. The first part is to perform microscopic analysis of the queue length on a simple topology, which consists of 4 TCP Tahoe or ACC TCP flows. A similar simple topology using 40 TCP or ACC TCP flows is also used to evaluate the impact of varying the starting time of the flows.

The second part of the experiment is the comparison of the active networks and non-active networks based systems on a more complex topology. This was achieved by using a stable network topology and then imposing bursty cross traffic to the network. The simulation experiments are run for each running policy, i.e. RED and REM, in order to do performance comparison using different performance metrics. Within each scenario, simulation were run for 1) constant number of sources and varying the length of delay at the congested link 2) constant length of delay for the congested link and varying the number of sources, and 3) constant number of sources and delay of the congested
link but varying the maximum buffer size. The objective of the experiments are 1) to observe the behavior of the ACC TCP relative to TCP under different circumstances in terms of the active queue management used in the node (RED and REM), 2) to analyze the results of the set of experiments when running ACC TCP and REM.

Simulation is performed in a stable network environment in which FTP applications are attached to the TCP sources and flow towards the TCP sinks. Subsequently, constant bit rate cross traffic sources are added to the network to evaluate the impact of bursty cross traffic to the throughput of the network. The simulation experiments performed in this study use the network configuration shown in Figure 3.

3.2 Topologies

The first topology to analyze the queue length for each queue management is shown on a single link network with 4 sources in Figure 2. They are all greedy sources in the form of FTP (File Transfer Protocol) applications. This FTP connection is a long-lived data transfer, which takes place during the entire simulation time. The size of each TCP packet is 1 Kbyte. All traffic in these experiments is unidirectional. All incoming links to router 1 have 16 Mbps capacity and a delay of 30ms. The bandwidth of the bottleneck link is 10 Mbps and the delay is 150 ms. All outgoing links to the sinks have 16 Mbps bandwidth and 50 ms delay. The purpose of the parameter choice is to create a realistic simple model in which the queue occupancy can be evaluated distinctively.

The second topology (Figure 3) shows the simulation performed on the N sources configuration consisting of N identical TCP Tahoe sources. N TCP sources and N TCP sinks are connected to the three intermediate routers. The link between router R1 and R2 is the uncongested link with variable delay. A set of UDP cross traffic sources is attached to the second router during the second stage of each experiment in this part. The simulation parameters can be seen in Table 2. The specific numbers for various variables applied in the simulation were chosen in aiming to induce congestion to the network. The delay at the congested link between R1 and R2 is varied between 50 to 250 ms to acquire variable bandwidth-delay product links. The buffer size was also varied to see how tight buffering policy affects the dropping of packets in the network. The cross traffic is bursty UDP flows which are not responsive to congestion. The bandwidths of the links are 10 Mbps and the link delays are 10 ms, except for the link between R2 and R3, which is 1.5 Mbps.

In these simulation experiments, RED parameters were set to the following values: RED buffer's maximum threshold value is 80, minimum threshold value is 20, maximum probability value is 0.1, and $w_0 = 0.002$. In the case where REM queue management was used, the following parameters were set according to REM parameter's value as follows, $\delta=0.02$, $\beta=0.03$, $N_0=50$, $\gamma=0.01$, and $\alpha=0.1$. These values are commonly used REM and RED parameter settings in

The investigation of the RED Active and REM Active parameter tuning is beyond the scope of this investigation although some literature indicated that the RED and REM parameter sensitivity lead to different networks behavior such as [14] and [19].

4. RESULTS AND EVALUATION

4.1 Performance Metrics

The performance metrics of the experiments reported in this work consist of throughput, average queue length, and Packet Retransmission Ratio (PRR). It is desirable to observe performance at both intermediate nodes and end systems. The throughput has been obtained from accumulating the bytes received by each sink endpoint during the simulation time. Retransmitted packets are not taken into consideration in calculating the throughput. These metrics were chosen to represent the behavior of the systems during the transmission phase, the processing in the intermediate nodes, and the situation at the receiving ends.

![Figure 2. Topology 1](image)

![Figure 3. Topology 2](image)

<table>
<thead>
<tr>
<th>Simulation Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sources</td>
<td>10, 20, 30, 40</td>
</tr>
<tr>
<td>Sources - Router 1 and 3</td>
<td>10 Mbps, 10 ms delay</td>
</tr>
<tr>
<td>(Unconnected link)</td>
<td></td>
</tr>
<tr>
<td>Router 1 - Router 2 link</td>
<td>1 Gbps, 10 ms delay</td>
</tr>
<tr>
<td>Cross Traffic</td>
<td>10 Mbps exponential on-off sources</td>
</tr>
<tr>
<td>Cross Traffic - Router 2</td>
<td>200 Mbps, 2.5 ms burst, 2.5 ms delay</td>
</tr>
<tr>
<td>Cross Traffic - Router 3</td>
<td>23 and 30</td>
</tr>
</tbody>
</table>
4.2 Microscopic Behavior of the Queue Length

4.2.1 Basic Queue Length

Figure 4 shows the result of the basic queue length analysis, using RED and REM queueing management on TCP and ACC TCP. For each graph, the x-axis shows the simulation time in seconds. The y-axis shows the number of packets in the queue. The graphs show the queue length during the first 5 seconds of the simulation. The differences in the peak of the queue length built up during the simulation when using RED and REM active can be identified in Figure 4a and 4b. The queue length of RED active builds up more slowly than that of RED. Figure 4c and 4d show the differences of the packet queue length when REM is implemented. REM active packet queue length is relatively low. These graphs show the microscopic behavior of the queue occupancy at the beginning of the simulation and indicate that although the difference is marginal, the queue of REM active is lower than that of RED.

4.2.2 Implication of Different Sources' Starting Time

In this section we show the results of the dynamics of the queue length of RED and REM active queue management using ACC TCP. The topology is similar to Figure 2. However, the scenario is slightly different. We simulated the case explained in [2] and compared the achieved results for RED and REM queue management mechanisms on ACC TCP. We ran the simulation for 200 seconds. At 0 second, 10 sources are active and at each subsequent 50 seconds interval, 10 more flows are activated until the total number of sources is equal to 40 at 200 seconds. The results shown in REM active schemes are relatively robust for varying traffic load. REM feature of low buffer occupancy at steady state while achieving high utilization at the same time as the number of connection changes can be seen here.

Figure 5 shows the differences between RED and REM when the ACC TCP is implemented and clearly demonstrate their characteristics. The queue built up when we used REM did not increase with the increase in the number of sources. The behavior of REM when the system entered and left congestion can be observed in this graph in which the source starting times have been staggered.

Using REM active, as the average load on the network exceeds the bottleneck link capacity, the buffer requirement does not increase correspondingly. In the experiment with REM on ACC, the routers allocate high rates to sources when the network is lightly loaded. The sources may dump bursty packets into the network. This leads to a linear increase in maximum queue lengths. Figure 5b shows that REM active is more stable than the RED active queueing management, as the load of the network increased.

4.3 Stable Network

The following sections discuss simulation variables and their effects on congestion control mechanism. These results are obtained when the simulation is conducted using the second topology.

4.3.1 Varying the Delay of the Uncongested Link

The following subsection depicts the throughput, average queue length, and packet retransmission ratio for simulation in which the delay of the uncongested link between R1 and R2 is varied to generate different bandwidth-delay product network conditions (Figure 6). For throughput results we plot the average throughput obtained by each of the queue management algorithms deployed. The simulation was run 10 times and the results were averaged.

Figure 6a shows that the throughput of active networks based flows using REM is relatively stable when the delay of the uncongested link is increased. It is obvious that REM is better compared with RED in both active and non-active networks based simulation. REM can improve the throughput up to 19% (when the variable delay is 150 ms). REM and RED act proactively upon detecting incipient congestion. The previous result in [16] shows that the throughput share under REM is independent of the propagation delay.
Figure 4. Comparison of packet queue length vs time for different buffer queue management

Figure 5. Simulation of packet queue affected by different sources’ starting time (queue length vs time) increase. The REM active average queue length obviously higher compared with RED active in all cases.

4.3.3 Varying Number of Maximum Buffer Size

The maximum buffer size of router 2 in the Topology has been changed from 25 to 30 packets to show the effect of the increase on buffer size. Figure 8 shows the throughput of 8 experiments using 25 and 30 packets.

4.4 Bursty Network

The following subsections discuss the results of the simulation parameters variation and the effects of congestion control mechanism in the case where UDP cross traffic is added to the network using the second topology.

4.4.1 Varying the Delay of the Uncongested Link

Figure 9a shows that when the delay of the uncongested link is set to 250 ms, all active based congestion control schemes perform better than the non-active ones. It can be seen in Figure 9b that the average queue lengths of different queue mechanisms show an increasing trend. The buffer occupancy of REM active is consistently the lowest among all queuing mechanisms. Figure 9c shows a slight reduction in the packet retransmission ratio for variable delay up to 200 ms and then a slight increase when the variable delay is increased to 250 ms. In all cases REM performs better than RED. All ACC TCP react better than TCP to bursty cross traffic. It can be seen that all queuing mechanisms with ACC have higher throughput especially in high bandwidth delay product area. ACC does not only
depending on router communication, which yields to better performance. Table 3 shows the comparison of REM active with RED active throughout, in which REM active performed up to 6.49% better than the RED active, as well as enjoying lower packet loss and lower packets transmitted.

4.4.2 Varying Number of Sources

Figure 10a shows that throughput for all active and non-active network-based flows are decreasing from 3.8 Kbps when 10 sources are activated, to 1 Kbps when 50 sources are enabled at the same time. Most of the schemes show that the throughput at the uncongested link decreases proportionally to the number of connections using the link. The reason is that with a larger number of connections, it takes a larger number of packet drops to sufficiently signal the host to back off its sending rate. Figure 10b shows that REM average queue length for 150ms delay of the uncongested link delay is higher than that of RED.

In general for multiple sources and queuing techniques at the router with basic TCP, the graphs show a similar trend to the results performed by ACC TCP. However in most cases, networks that employ active networks and active queue management such as REM show better performance. Overall the results show that using active congestion control and active queue management will not always improve the performance of the system in every case.

5 CONCLUSION

This paper presents the performance evaluation of the active network-based congestion control protocol (ACC TCP). In essence, this paper embraces two visions in networking, namely active networks and active queue management. The impact of different active queue management, i.e. RED and REM, has been evaluated to see their effect on the network topologies with and without using the active networks approach.

We have compared the performance of RED, RED active, REM, and REM active with a standard parameter setting of RED and REM. Performance metrics are throughput, queue length, and packet retransmission ratio. Microscopic behavior analysis of RED active and REM active show that REM is better in terms of its stability on steady state condition, in which the average queue occupancy is lower.

In general this work has shown that REM active schemes can improve the performance of the network up to 6.49% compared with RED active. This is mainly due to the fact that REM leads to few buffer occupancy in the steady state.

In this case REM active enables more packets sent compared with RED active. The throughput, average queue length, and packet retransmission ratio comparison certainly shows that the performance of REM as well as the performance of RED on ACC TCP is susceptible to traffic variability in terms of network parameters and topology. This work has shown that augmenting an existing feedback system with active networks-based algorithm and employing RED and REM queuing mechanism is beneficial to the overall performance of the network, although the improvement is somewhat marginal.

One of the goals of deploying active networks-based congestion control protocol is to ensure that the mechanism to overcome the congestion can be performed closer to the source of the congestion itself instead of having to wait until the end system reacts to it. Within the context of active networks and congestion control, the motivation behind this work is to gain better understanding of the impact of active networks to unicast traffic management. The results show that when both ACC TCP and AQM approach are implemented, the performance results will not always be superior. Further work to investigate the behavior of each parameter tuning in RED and REM should be performed to evaluate the scheme more thoroughly in active networks based congestion control protocol. Open research issues such as complexity of RED and REM parameter setting, the nature of short and long-lived traffic (web-like TCP traffic), how to co-operate the mechanism in the active queue management and active networks arose from our investigation.

Figure 6. Average throughput, queue length, and PRR with different queuing management (varying number of delay)
Figure 7. Average throughput and queue length with different queuing management (varying number of sources)

Figure 8. The comparison of throughput performance with different queuing management.

Table 3. Comparison of RED and REM Throughput on ACC TCP for Figure 9a

<table>
<thead>
<tr>
<th>Variable Delay</th>
<th>RED Active</th>
<th>REM Active</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>4.19</td>
<td>4.19</td>
<td>0%</td>
</tr>
<tr>
<td>100</td>
<td>4.16</td>
<td>4.29</td>
<td>0.99%</td>
</tr>
<tr>
<td>150</td>
<td>4.18</td>
<td>4.28</td>
<td>0.3%</td>
</tr>
<tr>
<td>200</td>
<td>4.10</td>
<td>4.25</td>
<td>1.7%</td>
</tr>
<tr>
<td>250</td>
<td>4.14</td>
<td>4.12</td>
<td>2%</td>
</tr>
</tbody>
</table>

Figure 9. Average throughput, queue length, and PRR with different queuing management (varying number of delay with UDP cross traffic)

Figure 10. Average throughput, queue length, and PRR with different queuing management (varying number of sources with UDP cross traffic)

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