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Research Article

Comparative Analysis of Controlled Delay (CoDel) with Deficit Round Robin (DRR) to Overcome Bufferbloat Problem in Wired Network

Hashim Ali[†*] Samiullah Khan[†] and Muhammad Quaid[†]

[†]Department of Computer Science, Institute of Business and Management Sciences (IBMS), The University of Agriculture Peshawar Pakistan

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Abstract

Bufferbloat is a problem in a packet-switched network which can happen due to increase in buffer size usage with increase in internet traffic. This creates high latency in network which ultimately degrades network performance. The active queue management (AQM) is considered to be solution for bufferbloat problem. The usage of larger size buffer in networks increases the queuing delay. This delay becomes more severe when the buffer remains full persistently behave as bad queue. The transport layer protocol misinterprets this large delay with congestion in networks which degrade their sending rate. This research study focuses on evaluation of CoDel performance for solving bufferbloat problem in wired networks. CoDel was compared with DRR in bandwidth and maximum transmission unit (MTU) simulation scenarios using network simulator-2 (ns-2).The range of packet delay and dropped rate parameters are used to analysis the Codel in above mentioned scenarios for its strength and weakness. The results revealed that CoDel has efficiently overcome bufferbloat problem as compare to DRR by having less packet delay.

Keywords: *Bufferbloat, active queue management, Controlled Delay, Deficit Round Robin, network simulator-2*

1. Introduction

Bufferbloat is an important problem in a packet-switched network where overloaded buffering of packets inside the network causes high latency and jitter, resulted in to diminishes the overall network throughput. The bufferbloat is the existence of overloaded buffers inside the network. Large buffers have been placed in throughout the Internet. This oversized buffers confused fundamental congestion avoidance algorithms of transport layer protocols in Internet. In other words, the time consuming delays from bufferbloat problem are frequently attributed inaccurately to network congestion (Gettys and Nichols, 2011).

The active queue management (AQM) is considered to be solution for persistently full buffers for two decades but has not been usually deployed. This is due to difficulties in active queue management (AQM) implementation and universal confusion regarding internet packet loss and queue dynamics (Nichols and Jacobson, 2012).

1.1 Buffer bloat

To recognize the problem with buffering, there is a need to study why buffering is being done in the first place. Generally at least one packet buffering is essential to successfully transmit traffic from the LAN interface to the WAN interface. If at least one packet is not buffered, than it is not possible to receive or route any packets. But nearly all routers will buffer far more than just one packet and the basis for this is throughput. Incoming traffic does not always arrived at a fixed rate. The router buffered the extra packets to maintain fixed outgoing traffic with motivation of maximum network resources utilization. The large buffers may get better throughput but also increase latency. This helped bulk flows to have improved performance with downloading or uploading but interactive flows suffers such as gaming and VoIP traffic due to increase in latency. On other hand, the increase in latency affect throughput if it is demanding to download and upload at the same time; the ACK traffic for the upload will get trapped in the bufferbloat caused by the download, and the ACK traffic for the download will get trapped in the bufferbloat caused by the upload, causing everything to slow down.

This problem can be solved by reducing the size of the queue in the router, as often it is especially oversized, but away from a certain point, making the queue smaller will start to hurt throughput, forcing it to make a trade-off between latency and throughput. The answer lies in more highly developed queue management, but it would like to queue packet as much as required to sustain throughput.

*Corresponding author: **Hashim Ali**

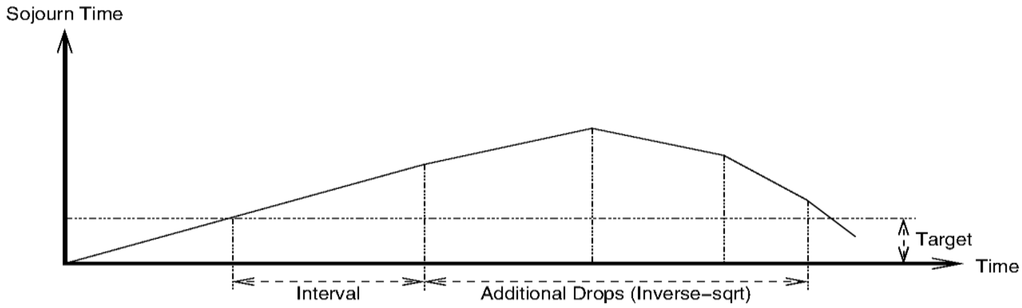

Figure 1.2 Controlled Delay (CoDel)

The latest and best in this field is the CoDel (controlled delay) queue management algorithm, which endeavor to do reasonable behavior with very little tuning.

CoDel promised for fair sharing of recourses among all the flows over Internet. This will help to avoid a situation in which a few flows dominated on all network recourses. Unfortunately CoDel is in early stage of its development which needs further research to find out any inefficiency in fair sharing of recourses (Mithrandi, 2013).

1.2 Active Queue Management (AQM)

AQM algorithms have been widely considered in the recent years to monitor queue sizes and limited congestion in routers. AQM mechanisms were designed with motivation to stay away from congestion by proactively informing the TCP sender about congestion such as dropping or marking a packet. Random Early Detection (RED) is the most widely deployed AQM mechanism in the routers, though it has been shown that the effectiveness of RED basically depends on properly setting at parameters such as minimum and maximum threshold. RED achieves better performance and low latency by well managing a router buffer (Floyd and Jacobson, 1993).

In recent time, a new AQM mechanism called Controlled Delay (CoDel) has been proposed to overcome the shortcomings of PQM (passive queue mechanism) and RED. Unlike RED, CoDel is parameter less AQM Mechanism that adopts itself to the dynamic link characteristics and can be deployed easily. In addition, unlike RED that use average queue size as a predictor of congestion, CoDel uses packet sojourn time to predict congestion in links (Nicholas and Jacobson, 2012).

1.3 Controlled Delay (CoDel)

Controlled delay is a scheduling algorithm for the network scheduler. It is adopted to overcome bufferbloat in network links (such as routers) by setting limits on the delay that a packet experienced while passing through the buffer. CoDel aims at improving the performance of the Random Early Detection (RED) algorithm by showing some primary misconceptions in the algorithm which is easier to manage without need of manual configuration. The CoDel is to manage queue length, sustaining satisfactory queuing to keep link busy by avoiding building up the queue beyond threshold. This is done by like better dropping packets that remain in the queue for too long.

As soon as each new packet appears, it is marked with its arrival time. Soon after when a packet turn to be dequeued, CoDel calculates its sojourn time (the current time minus the arrival time). If the sojourn time for packets being dequeued increases the target time for a time period of at least interval, a packet will be dropped in order to signal the source endpoint to decreases its send rate. If the sojourn time increases than the target time, extra packet drop will take place on a schedule calculated from an inverse-square-root control law until either (1) the queue becomes empty (2) a packet is encountered with a sojourn time that is less than the target time. This target time, is usually set to about five milliseconds, and the interval is in general set to about 100 milliseconds. This approach has established to be quite effective in a large variety of situations (Raghuvanshi*et al*., 2013).

The above diagram show that time rises from left to right, and the curve gives the sojourn time of the packet at the head of the CoDel queue as a function of time. The sojourn time increases extensively above the target, requiring CoDel to respond so as to bring the sojourn back below target at the right-hand end of the diagram.

While distinguished earlier, CoDel reacts by dropping or ECN-marking packets, and the second and consequent vertical dot-dashed lines correspond to single dropped (or ECN-marked) packets. This way that still during the time that the sojourn time is larger than the target time, the majority packets are being transmitted rather than being dropped. The cause for this is that it can receive on the order of 100 milliseconds for the detail of the packet drop to accomplish the traffic source. CoDel mechanism design therefore must allocate for this delay, which it does by scheduling packet-drops at an interval that is adequately large to allow the traffic source time to react. If the sojourn time leftovers above the target for an extended time period, CoDel drops at gradually decreasing intervals of time until an appropriate estimate of the round-trip time is observed and the flow is brought under control.

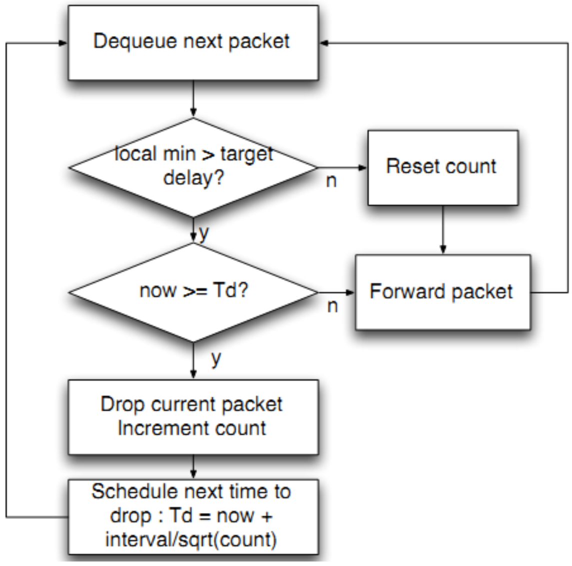

Figure 1.3: Simplified CoDel algorithm flowchart (Sharma, 2014)

But one drawback of CoDel is that it organizes only a single queue. As a result, packets from low-bandwidth sessions (such as VOIP sessions) can be delayed by packets from high-bandwidth upload sessions (McKenney and Taht, 2013).

1.4 The Controlled Delay (CoDel) mechanism

The CoDel mechanism implements in two phases. The first phase is that when the packet is enqueued and second when the packet is dequeued. The current queue size is checked when the packet arrives. The packet is enqueued if the current queue size below than queue limit and the timestamp is added in the header. This timestamp show enqueue time. When the packet is dequeued the timestamp is extracted from the header. The packet sojourn time is obtained from the current time minus arrival time. The CoDel algorithm remains either in the dropping state or not in the dropping state.

If the packet sojourn time increases than target for a specified interval of time, the packet will be dropped in order to signal source end point to decrease its sending rate. The packets are proactively dropped while dequeuing rather than during enqueuing. The time duration between the two proactive packet drops are calculated by the following equation: next drop time + = interval /√ count. The count indicates the total number of packets dropped since the dropping state is entered. If the packet sojourn time decreases than target the CoDel algorithm leaves the dropping state. The two well-known CoDel parameters to be set to realize optimal results: target and interval. These parameters are fixed and their values are obtained based on the observations from several experiments. The target time is usually set to about five milliseconds, and the interval is in general set to about 100 milliseconds (Matilda *et al.*, 2013).

1.5 Deficit Round Robin (DRR)

The DRR is a scheduling discipline technique for the network scheduler. DRR is a modified weighted round robin which can manage variable size packet exclusive of calculating their mean size. An upper limit packet is subtracted from the packet length, and packets that go above that number are held back until the next visit of the scheduler.

The basic round robin servicing of queues can be done in constant time. The most important problem which is that fair when all flow get same packet size but unfair when different flows with different packet sizes. This problem can be avoided with deficit round robin while still requiring constant time. The stochastic fair queuing is use in DRR which allocate flows to queues.

The queues can managed by round robin servicing with a quantum of service allocated to each queue. The difference from basic round robin is that when a packet size was too large that queue cannot send it in the previous round, the remainder from previous quantum is added to the quantum for next round. It kept track off queues that were shortchanged in a round are rewarded in the next round (Shreedhar and Varghese, 1996).

The diagram 1.4 shows that initially all the deficit counter variables are initialized to zero. The round robin pointer points to the top of the active list. When the first queue is serviced the Q value of 500 is added to deficient counter value. The remainder after servicing the queue is left in DC variable.

The diagram1.5 has shown that after transmitting a packet size of 200, the queue had 300 bytes of quantum left. It could not use at the current round since the next packet in the queue is 750 bytes. Therefore the amount of 300 will carry out over the next round when it can send packet of size totaling 300 (Deficit from previous round) + 500 (quantum).

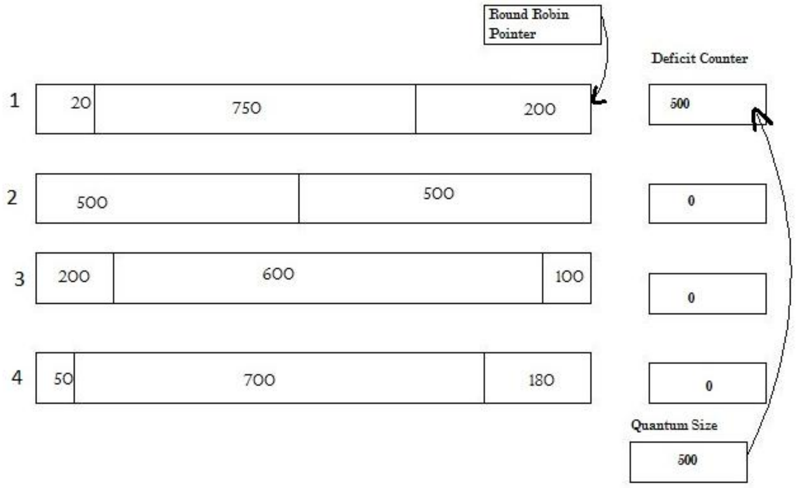

Figure 1.4 Deficit Round-Robins (1) (Shreedhar and Varghese, 1996)

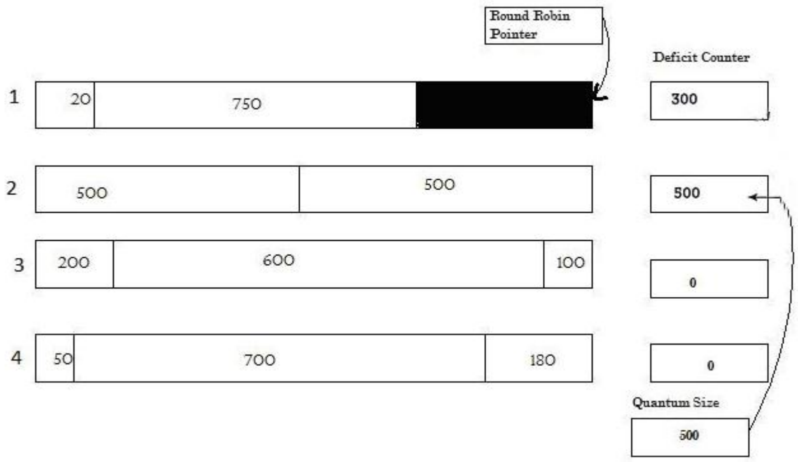

Figure 1.5 Deficit Round-Robins (Shreedhar and Varghese, 1996)

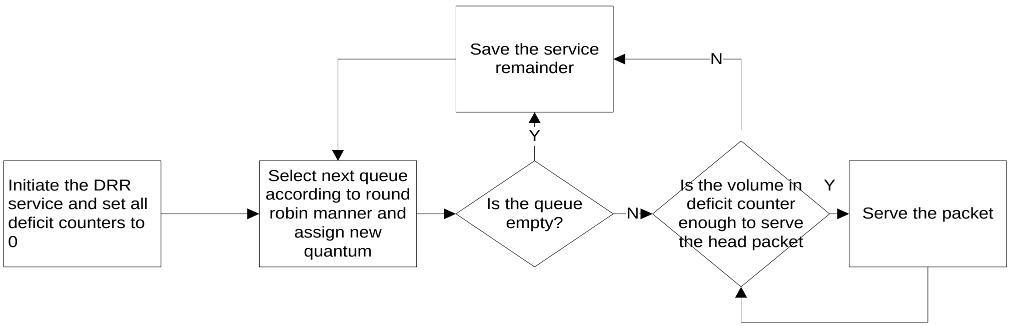

Figure 1.6: Flow diagram of DRR mechanism (Liu *et al.*, 2010)

1.6 Deficit Round Robin (DRR) Scheduling Mechanism

The DRR scheduling mechanism manages the traffic flows in a round robin manner. But DRR provide deficit counters for individual traffic flows unlike other round robin variants. In each round a volume of service equal to its quantum size is supplied to active flow. The left volume of service is accumulated in a deficit counter for the subsequently round. The deficit counter of a traffic flow is equal to the sum of its quantum size and the volume of its left over service from the previous round. An active flow have the packets that can be supply in each round is decide by the value of its deficit counter. The DRR mechanism manages the next active flow in two conditions. When the current queue is empty or there is insufficient service volume left to handle traffic of the current flow. There is a fixed quantum assigned to each flow due to avoid misbehavior in traffic flow. The DRR can also remove the problem of unfairness caused by the variable packet size of different flows. The important advantage of DRR is that no user can dominate on network. In DRR the service provided to each flow only depends on its fixed quantum and any misbehavior traffic flow cannot dominated the left over service of the other flow (Liu *et al*., 2010).

1.7 Problem Statement

CoDel is an emerging active queue management technique, proposed to control bufferbloat in wired networks. CoDel is still immature to be standardized by IETF (Internet Engineering Task Force), so there is a research need to extensively analyze the performance of CoDel in wired network. This study helped researchers to find out shortcoming of CoDel and in its further improvement.

2. Related Work

Huang *et al*. (2013) stated that traditional active queue management mechanisms were not suitable when there were huge user request and dynamic change of networks. It was suggested an API (Adaptive Proportional Integral) active queue management. API acquired the current queue size by real-time monitoring router buffer queue, Based on the current queue size with the target queue size deviation. It dynamically adjusts the relevant parameters in PI algorithm and the dropped rate probability. The simulation results in ns-2 reported that API has a better response speed and a smaller jitter size than PI algorithm. It was reported that API achieved better stability in the dynamic change of network.

Malangadan*et al*. (2013) a non-linear, time delayed, fluid model for Compound TCP (C-TCP) which is broadly implemented in the current internet. The model was combined with a Drop-Tail queue policy which was deployed in router. It was considered that a topology where two different sets of Compound flows, each keeping up by separate edge routers, combine at a common core network router. The unambiguous analytical conditions were obtained for the small and the intermediate router buffer management, under which synchronization would occur between the two competing sets of TCP flows. The conditions were made unambiguous in terms of a coupling strength, which depends on Compound parameters and on network parameters like the feedback delay, link capacity and router buffer sizes. Variations in the coupling strength can lead to the appearance of deterministic, nonlinear, oscillations in the form of limit cycles in the queue size. It was noticed that with Drop-Tail, small buffers were found to be preferable over intermediate buffers because it can guarantee low latency and stable queues in high speed networks.

Raghuvanshi*et al*. (2013) nowadays internet has become extremely a large source of information. There had been a remarkable increase in the diversity of Internet applications, with each application demanding an unambiguous presentation criterion to be fulfilled. Passive queue mechanisms (PQM) have been used by routers which cause global synchronization. Therefore, interest had been increasing in exploring Active Queue Management (AQM) in Internet routers in order to reduce latency and jitter that gather the demands of time sensitive applications. The mainly focus on analyzing the efficiency of a recently proposed AQM mechanism called Controlled Delay (CoDel). The advantages and shortcomings of CoDel in terms of blockage link utilization, mean queue length and packet drop rate. The performance of CoDel was compared with random early detection (RED). It was observed that CoDel was independent of queue size, queue size averages, queue size thresholds, rate measurements, and link utilization. It achieves high link utilization and reduces the queue occupancy.

Chen *et al*. (2012) Active Queue Management (AQM) endeavors to make available high link utilization and low queuing delay in networks. But it was difficult to adapted AQM parameters in response to dynamic network scenarios with changeable roundtrip time, link capacity and traffic load. It was recommended that statistical adapting random early detection (SA-RED) algorithms to dynamically tune RED parameters based on the standard deviation of instantaneous queue size. The suggested mechanism and resultant algorithms can be easily implemented. It can avoid the problem of measuring network parameters, such as the number of TCP flows and round trip time. Moreover, AQM were efficient by maintaining low queuing delay and achieving high link utilization.

Patil and Raina (2012) noticed that Implementing queue control mechanism policy and buffer management mechanism, nonlinear fluid models of TCP Reno with Drop-Tail. Further it analyzed that in a transitional buffer rule, the system loses stability as link capacity or the feedback delay increases. A simple model with small buffer was implemented for bursty traffic which showed the loss of local stability. It was suggested that some strategy, for a threshold-based queue policy to guarantee stability of the queues and low-latency in the network. Packet-level simulations provide to substantiate the analysis and the proposed guidelines.

Ramakrishna *et al*. (2012) the users of internet increased rapidly through last decade. It was difficult task to manage network traffic. It has important to achieve better throughput in internet. Congestion was one of significant issue in internet. To avoid congestion and reduce packet loss a number of queue management algorithms were designed. Active queue management was one of the best techniques which achieve better control over congestion. A new load based active queue management was compared with RED. It was suggested that new load based (AQM) was better in performance in terms of queuing delay and queue size stability.

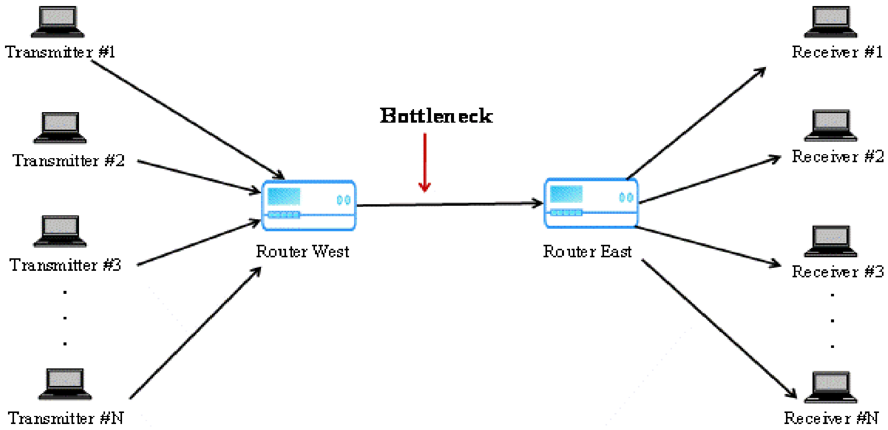

Figure 3.1 Screen Snapshot of the Dumb Bell topology

3. Research Methodology

Bufferbloat is a problem which exists when excess buffering inside the network causes high latency and jitter and reduces the network throughput. The proposed solutions for above problem CoDel (Controlled Delay) algorithms were designed. For this purpose, different research papers were studied in order to find limitation in the mentioned problem. According to the problem come to know, that above solution is still under developmental stages which have limitation and drawbacks. The realistic internet environment in network simulator-2 (NS-2) were established where the bandwidth of network changes constantly. CoDel was compared with well-known queuing mechanism i.e. Deficit Round Robin (DRR). The simulation environment for bufferbloat problem was designed in which implement and simulate CoDel solution for bufferbloat problem in ns2. The results have been collected and analyzed using Microsoft Excel which was reported in thesis.

3.1 Research Simulation and Analysis Tools

A variety of simulation tools are presented in network for research purpose. Network simulator (NS-2) was used due to high popularity among the researchers and its open source availability. The Microsoft Excel was also used for plotting of graphs and charts.

3.2 Parameters

The parameters used for the effectiveness measurement of CoDel in overcoming bufferbloat problem are briefly defined below.

3.2.1 Packet Queuing Delay

This parameter is used to find the time consumed by a packet while passing through a buffer. The unit used for packet queuing delay will be millisecond.
Packet Queueing Delay ($Delay_{pq}$) = T2 - T1

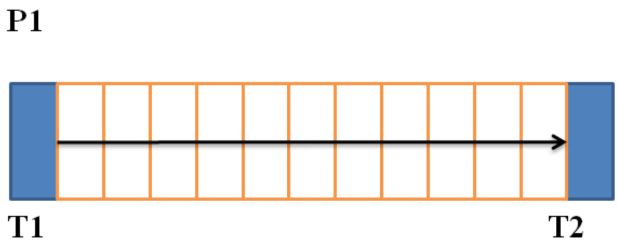

Figure 3.2: Packet delay measuring in buffer

3.2.2 Dropped Rate

The quantity of packets dropped per second is measured using dropped rate parameter. Here the number of packets per second will be used as a unit for measurement.

3.3 Dumbbell Topology

Dumbbell topology is used in this study. In this topology single bottleneck link is used between source and destination nodes. A simple topology is designed in which TCP flows share a bottleneck router with AQM schemes. This dumbbell topology considers a single bottleneck link traversed by multiple TCP flows.

4.Result and Discussion

The role of active queue management needs to be redefining due to advancement in technology. The buffers are used to absorb the extra packet bursts that occur naturally at intermediate nodes due to mismatches in traffic arrival and departure. The buffer has to drop some packet at specific point to control congestion causes due to traffic sources. This required lot of configuration tweaking by maintains many parameters which degrade AQM performances. CoDel claims to be parameter less AQM which handle good and bad queue differently. The theme of CoDel is to maintain minimum delay at any cost so that traffic sources are not misguided in calculating the network congestion. This study have simulated and compared the CoDel with DRR using variety of simulation scenarios as discussed in next section.

Table 4.1 Simulation Environment

Parameter	Value
Simulator	Ns2
Algorithms	CoDel, DRR
Topology	Dumb bell topology with two way traffic
Traffic Type	Constant Bit Rate(CBR), File Transfer Protocol (FTP)

4.1 Simulation Scenarios

According to the role of AQM techniques and utilization of buffer in today internet, the simulation scenarios were configured using network simulator-2 (NS-2). These simulation scenarios are different bandwidth and maximum transmission unit.

4.2 Bandwidth Scenario

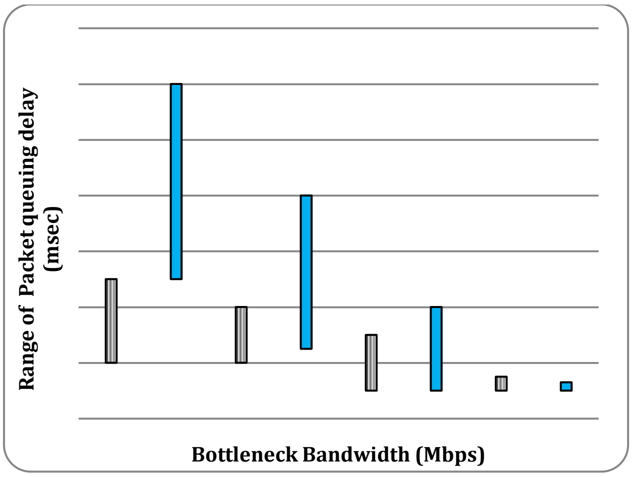

Figure 4.1: Range of packet delay in bandwidth scenario

In Fig. 4.1, The CoDel range of packet delay was compared with DRR using bandwidth scenario such as 2, 4, 10 and 100 Mbps. In each sub scenario (2, 4 and 10 Mbps), the CoDel has comparatively less packet delay range. The CoDel minimum range of packet delay are from 0.01 to 0.03 (ms) at 10 Mbps while at most range of packet delay from 0.02 to 0.05 (ms) at 2 Mbps. The DRR minimum range of packet delay are from 0.01 to 0.04 (ms) at 10 Mbps while at most range of packet delay from 0.05 to 0.12 (ms) at 2 Mbps. The CoDel is used to manage the length of a queue so that it does not run complete, it adding the maximum delay under load. Such management also allows TCP to do its job of sharing links well without which it cannot function as intended.

DRR has fewer packet delay range in 100 Mbps sub scenario as compare to CoDel. The internet has been saved from damage by a constant increase in link rates and by usage pattern. This large increase in bandwidth is not a true solution for existent problem. The CoDel has better performance by having less in the range of packet delay as compare to DRR.

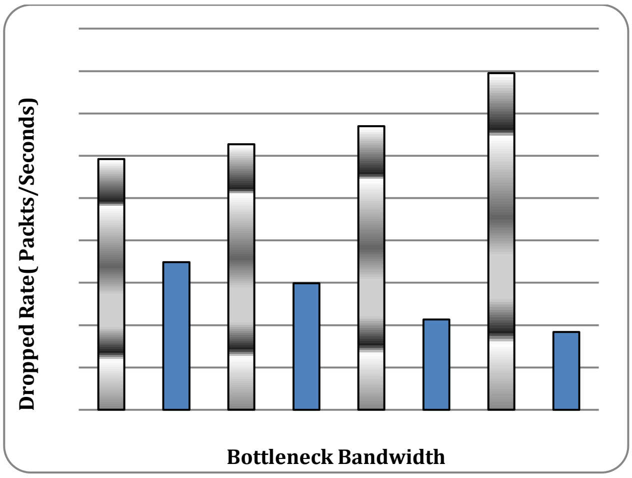

Figure 4.2: Packets dropped rate in bandwidth scenario

In Fig. 4.2, The CoDel packet dropped rate was compared with DRR using bandwidth scenarios of 2, 4, 10 and 100 Mbps. In each sub scenario, the packet dropped rate of DRR is low as compared to CoDel. The CoDel's dropped rate is minimum up to12 packets/seconds in 2 Mbps bottleneck bandwidth scenario while maximum packet dropped rate is observed having 16 packets/seconds in 100 Mbps bottleneck scenario. The DRR dropped rate is minimum up to 4 packets/seconds in 100 Mbps bottleneck bandwidth scenario while maximum packet dropped rate is observed having 7 packets/seconds in 2 Mbps bottleneck scenario CoDel is a drop strategy which is adaptive to the dynamic internet traffic.

Maximum Transmission Unit (MTU)

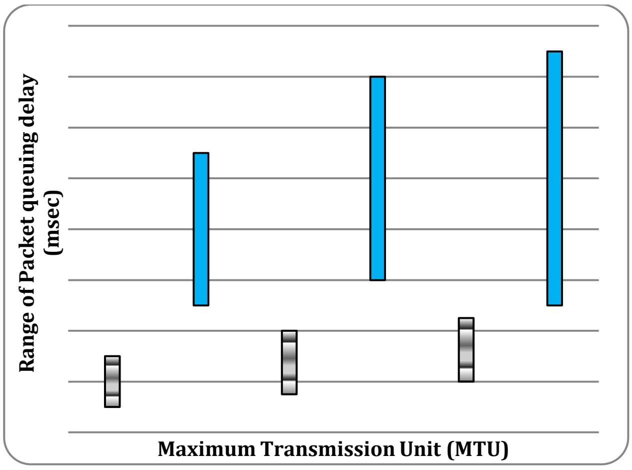

Figure 4.3: Range of packet delay in MTU variation scenario

In Fig. 4.3, CoDel range of packet delay was compared with DRR using maximum transmission unit of 500, 1000, and 1500 MTU. In each sub scenario, the Codel has good result by having less in range of packet delay as compared to DRR. The CoDel has minimum range of packet delay from 0.01(ms) to 0.03(ms) at 500 MTU while at most range of packet delay is from 0.02 to 0.05 milliseconds at 1500 MTU. The DRR has minimum range of packet delay from 0.05 to 0.11ms at 500 MTU while at most range of packet delay is from 0.05 to 0.15 milliseconds at 1500 MTU.

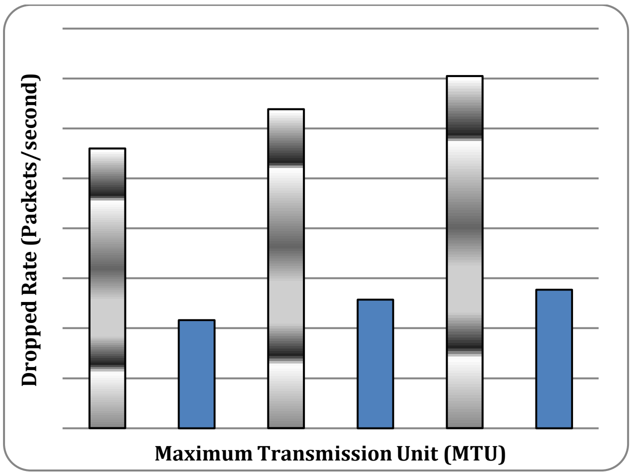

Figure 4.4: Packets dropped rate in MTU variation scenario

In Fig. 4.4, The CoDel packet dropped rate was compared with DRR using maximum transmission unit of 500, 1000 and 1500 MTU. In each sub scenario, the DRR has less in packet dropped rate as compared to CoDel. The CoDel's dropped rate is minimum up to 11 packets/seconds in 500 MTU scenario while maximum packet dropped rate is observed having 14 packets/seconds in 1500 MTU. The DRR dropped rate is decreased up to 4 packets/seconds at 500 MTU scenarios while most packet dropped rate is observed having 6 packets/seconds in 1500 MTU scenario.

4.4 Discussion

One of the important features of effective AQM is to keep delay low as much as possible. In the light of this statement, the CoDel has comparatively low delay in all scenarios such as link bandwidth and maximum transmission unit. In addition to this, CoDel has low variation in delay range in each sub scenario as compare to DRR due to adaptive nature of CoDel to the dynamic traffic sources. This further proves the effectiveness of CoDel adaptable in buffer management used in our dynamic world of internet. CoDel is a drop strategy so it drops the packet and prevents the congestion of the buffer. It does not allow a packet to remain in the queue for more than 5ms. The DRR has less in range of packet dropped rate as compared to CoDel. This is because the CoDel tries to keep the queuing delay less than a target delay. When the queuing time becomes above than the target time it drop the packets until the flow become under control. The DRR begins dropping packets when congestion occurs at a rate which was selected during configuration. Packet drops are low in the case of DRR as it delivers the packet even in the face of causing a lot of delay.

Conclusion and Future Directions

Due to a growth in the variety of Internet applications, the bufferbloat problems have become increasingly noticeable. As a result, there has been an active interest towards deploying the efficient AQM mechanisms in the Internet. Although a lot of AQM mechanisms have been developed over last two decades, but it has failed to implementation due to difficulties and universal misunderstanding about internet packet loss and queue dynamics. In recent time, The CoDel a parameter less AQM mechanism has been proposed to remove the problem of bufferbloat. To find the efficiency of CoDel it has been compared with DRR in different link bandwidth and maximum transmission unit. The range of packet delay and dropped rate parameters are used to find it strengthens and weakness. CoDel has better performance by having comparatively small in range of packet delay in scenarios such as bandwidth and maximum transmission unit. The only limitation of CoDel discovered in this research work is comparatively high packet dropped rate which can be improved during future research work.

Future Directions

- CoDel should be evaluated for wireless and hybrid network scenarios.
- CoDel performance should be analyzed using interactive real time communications.
- CoDel should be evaluated using various sizes of buffers.

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