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A SIMULATION-BASED COMPARATIVE STUDY OF CONTROLLED DELAY (CODEL) WITH RANDOM EARLY DETECTION (RED) FOR NETWORK PERFORMANCE EVALUATION

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ABSTRACT: *The rising need to use the internet for time/delay-sensitive applications with different Quality of Service (QOS) requirements has made network management and control even more challenging. The current congestion avoidance and control mechanisms for Transport Control Protocol (TCP) are insufficient to offer good service in all circumstances. A few decades ago, the TCP successfully regulated Internet congestion control. However, it is already widely acknowledged that TCP has reached its limits and that new congestion control protocols will be required in the near future. This has prompted a significant amount of research on novel congestion control designs that will meet the demands of the future Internet. With widespread public attention and study, the full buffer problem has not gone away, but rather worsened. As a result, there has been a surge in interest in using Active Queue Management (AQM) in Internet routers to minimize queue latency. The effectiveness of a recently developed AQM, Controlled Delay (CoDel) algorithm, designed to work in today's network setups and can be deployed as a main part of the bufferbloat solution, is evaluated in this research study. CoDel's effectiveness is evaluated by running simulations in ns-3 and comparing its results to that of Random Early Detection (RED), another promising network queue management technique.*

KEYWORDS: AQM, Network Simulation; Traffic-Flow; Traffic-Congestion; Ns3, *Bufferbloat, CoDel, RED.*

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INTRODUCTION

The Internet has seen a massive transformation in the past few decades. High delays and jitter have been noticed {5} on the Internet, which are caused by enormous network buffers, often known as Bufferbloat. Transmission Control Protocol (TCP) communications that take a long time fill these buffers, causing all traversing packets to be delayed. Novel applications with essentially and sometimes orthogonal requirements have evolved. Some have a high bandwidth need, while others require low loss, low delay, or a mix of these characteristics. Meeting all of the needs of fresh applications is difficult and necessitates unique approaches. With the emergence of network-intensive internet applications, the desire for increased bandwidth has pushed router buffer management to the top of the priority list. Buffering is required for the network to function properly, absorbing bursts of traffic and ensuring that links are used to their full capacity. As a result, routers must be designed in such a way that they can survive enormous queues in their buffers to accommodate temporary congestion. Currently, congestion is detected by the Transport Control Protocol (TCP) only after a packet has been discarded. With the rise of high-speed networks, it's more vital than ever to have high throughput while keeping average queue sizes low. Bufferbloat is a phrase used to describe when computer network buffers (queues) underperform, causing extra slowness. Many Active Queue Management strategies (such as Drop-tail, RED, CODEL, PIE, PPV, and others) have been shown to decrease the consequences of bufferbloat.

TCP performance in RED of accurately sharing received packets has been shown to be influenced by management issues {3}. According to {14}, having bursts of packets flowing at full speed can cause TCP to slow down and fail to function effectively in the face of congestion. Furthermore, the lack of QoS data on AQM performance makes it difficult to prevent TCP failure or slowdown, which can be caused by a variety of performance characteristics in different network conditions {14}.

As a result, this research examined two methods: Random Early Detection (REM) and Controlled Delay (CoDel), which were chosen based on evidence found by academics in fair traffic circumstances.

We proposed a simulation-based comparison assessment of modern AQM approaches in this paper. Simulations are important in research and teaching because they allow us to investigate systems that are too complicated for mathematical study. On the other hand, it provides a simple approach to reproduce results, which is especially useful in dynamic network contexts where topology changes regularly. Simulation is useful for analyzing, testing, and comparing novel algorithms to current ones. Simulating the network also makes it easier to scale it up or down. We utilized ns-3 {2}, a discrete-event network simulator that was launched in 2008. This simulator provides a high level of realism, including kernel implementation and the ability to mix real application code with a virtual machine environment or test-bed {11}. Many studies have shown that protocol entities built in ns-3 are similar to real computers. However, in this work, simulation will be used to compare RED and CoDel.

Related Study

The authors of {1} investigated the performance of Drop-Tail queuing, Codel, Pie, and PPV in simulated rural broadband networks with limited capacity. They compared the new algorithms to Adaptive CODEL as a benchmark, and found that in order to attain a low queuing delay, the

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techniques increase packet loss. The performance of Drop-Tail queuing, Codel, Pie, and PPV in constant capacity networks was studied, and the results showed that PIE and CoDel perform better than the others in terms of packet loss rates influencing video quality.

According to {6}, some researchers recommend active queue management (AQM) as a solution to bufferbloat, while others recommend end-to-end low-priority congestion control (LPCC) strategies. For LPCC, CoDel is an example of AQM and LEDBAT. The methodologies of AQM and LPCC were merged in this paper. The problem was demonstrated in the real world for any tested combination of AQM rules and LPCC protocols in a series of experiments conducted on both controlled testbeds and the Internet.

According to {12}, routers that use Passive Queue Management (PQM) techniques only have control over queue occupancy, which increases queue latency. The authors tested CoDel's efficiency by simulating it in ns-2 and compared it to existing AQM techniques in a number of Internet configurations. The benefits and drawbacks of CoDel have been explored based on the simulation results.

Delays on the order of seconds have become widespread due to the installation of unreasonably-sized FIFO/Drop-Tail buffers at the edge of many networks, according to {9}. Despite being recently introduced and debated at the IRTF and the IETF, CoDel and PIE have not yet been extensively examined or compared, except through simulation. In this paper, the authors conducted an experimental evaluation utilizing real-world implementations in both wired and wireless test beds, and compared them to an older RED variant known as Adaptive RED.

According to {7}, PIE and CoDel performed on simulated rural broadband networks with low capacity. They examined the new algorithms against Adaptive RED and found that PIE and CoDel both increase packet loss in order to achieve a short queuing time. Loss-sensitive unreliable multimedia applications such as real-time and near-real-time video were investigated, and the results revealed that PIE outperforms CoDel in terms of packet loss rates affecting video quality, and that ARED's performance in constant capacity links is comparable to that of PIE and CoDel.

The Phenomenon of Bufferbloat

To handle bursts of packets on an entering connection and then play them out on an outgoing link, every piece of network equipment requires some level of buffering. Buffering allows packets waiting for transmission to be queued, decreasing data loss.

Bufferbloat is characterized as an excess of buffering in network equipment that is poorly managed, resulting in excessive latency and lower performance. Excessive packet buffering, in other words, causes significant end-to-end latency and throughput reduction. It's best described as the buffering of too many packets in transit between two network endpoints, which causes excessive delays and causes TCP's flow control algorithms to become confused. Bufferbloat causes queues to grow too lengthy before any packets are lost, causing packets to be dropped. Consider it a basic problem with an easy solution of making the buffers smaller, and it will only get more complicated. A precise remedy to bufferbloat necessitates a better knowledge of what's going on as well as software improvements across the net.

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Active Queue Management

Algorithms and approaches for controlling the quantity of data kept in network node buffers are referred to as AQM. AQM's primary premise is to drop packets in advance based on some gauge of local congestion or queue utilization. They can also be used to provide explicit congestion notification, for example, by marking packets rather than dropping them. When buffers fill up, they can not fulfill their job of managing bursts of packets, and TCP can't function correctly in the face of congestion unless it's told to slow down by packet drop.

To address the delay issue, active queue management strategies are also required. Buffers are required to handle traffic surges, hence bufferbloat cannot be remedied by reducing buffer sizes to extremely small numbers. AQMs are required in more than just Internet routers. They are required wherever there is a risk of a backlog forming, such as in our home routers, computers, and smartphones, where AQMs are now lacking. Because most deployed algorithms are RED {4} versions, they require tuning and are frequently left unconfigured, even on routers where they may be very useful. CoDel Controlling Queue Delay {10} has several implementation advantages over other AQMs and may solve the above-mentioned adaptive AQM difficulties. Almost the bulk of its work is done at the dequeue stage (when packets are transmitted). Although CoDel necessitates adding a timestamp to each packet as it is received, timing information is readily available from a CPU register in current CPUs, even if this cannot be done by network hardware.

Controlling Queue Delay and Random Early Detection

According to {8}, the core idea is to keep queue length under control by keeping enough queueing to keep the outgoing connection active while avoiding building up the queue beyond that point. Controlling Delay (CoDel) is a novel Active Queue Management (AQM) approach for dealing with the Internet's Bufferbloat problem. There has been a lot of talk recently about Internet delays that can last several seconds or even minutes. Delay-sensitive services like VoIP/Skype are hampered by these delays. Large buffers in Internet routers, which will be filled up by long-lasting TCP connections, such as downloads, are part of the problem. The CoDel algorithm [CoDel] was released into the public domain in May 2012, and the authors have provided an open source implementation.

It is designed to overcome bufferbloat in network links (such as routers) by setting limits on the delay network packets suffer due to passing through the buffer being managed by CoDel. CoDel tries to improve the RED algorithm's overall performance by correcting some underlying misconceptions about the method. The following are some of CoDel's most important characteristics:

i. It is parameter-free, requiring no knobs or handles for operators, users, or implementers to change.

ii. It differentiates between good and bad queues, keeping delays minimal while allowing for traffic spikes.

iii. It manages delays while being unaffected by round-trip delays, link rates, or traffic volumes. As each packet is received and queued, CoDel adds a timestamp to it. The time spent in the line is calculated when the packet reaches the front of the queue. The technique sets a timer to remove a packet at dequeue if the time spent by a packet within

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the queue exceeds a predetermined threshold. When the queuing delay inside a time interval exceeds the threshold value and the queue contains at least one MTU's worth of bytes, the queue is dropped.

CoDel, in comparison to RED, keeps the packet delay closer to the goal value over the whole bandwidth range (from 0.064kbps to 1Mbps). Because the measured link utilizations are consistently near 100% of link bandwidth, this appears to result in a decent queue. The CoDel method is depicted in Figure 1 in a simplified manner, as described in {13}.

Performance Metrics

The following criteria can be used to assess the performance of the Controlled Delay active queue management system for the Internet:

i. **Average time from start to finish**: It is the average time it takes for a packet to go from source to destination. All conceivable delays caused by queuing at the interface queue, propagation and transfer times, and retransmission delays are included in this statistic. In our simulation findings, Delay represents the queue delay.

ii. **Rate of Packet Loss**: The packet loss rate refers to the number of packets lost due to router buffer overflow and congestion notifications (in AQM approaches), as well as data lost by the source or intermediary nodes throughout the simulation period.

iii. **Throughput**: The average data rate of a source delivering packets and received by the receiver is known as throughput.

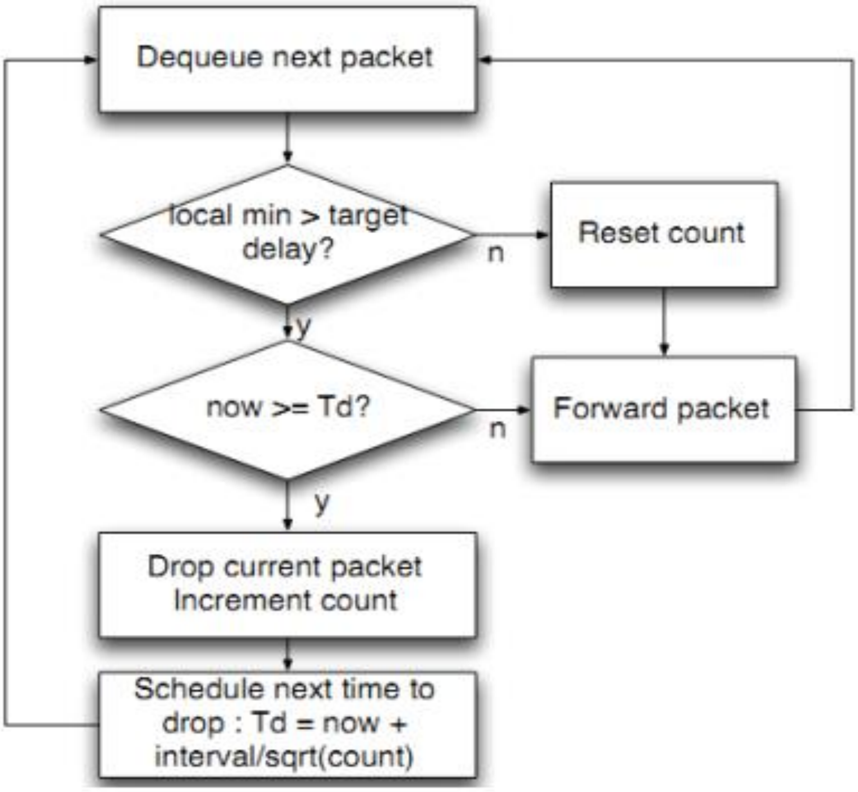

Figure 1: Simplified CoDel algorithm flowchart

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Simulation Setting and Environment

Network Simulator 3 was used to run simulations and assess the proposal's performance. NS-3 is a discrete event simulator for networking research that supports simulation of both wired and wireless transport protocols. Figure 2 shows the basic structure of an NS-3 topology, which is made up of nodes connected by links. A network element such as a host, switch, or router is represented by a node. The physical and MAC layers of a connection between two nodes are represented by a link. Source and sink agents are attached to individual nodes and create traffic. The link is in charge of buffering and buffer management.

Data is transmitted from one wireless node to another wireless node in this example (A and D). In the simulation, the wireless nodes are immobile. To test the veracity of the technique in discourse, all simulations in the thesis are run many times across multiple circumstances. The purpose of the simulations in this part is to compare the CoDel algorithm's performance against that of other queue management techniques; RED. End-to-end average The major criterion for comparison is the time spent queuing. More particularly, latency under load is measured using CoDel and RED's respective queuing systems. Only the throughput and packet loss ratio are taken into account. In the simulations, there is a hint of possible enhanced packet delivery or bandwidth utilization. The test cases were run with the ns-3 RED AQM module in place of CoDel for comparison. The most recent ns-3 RED settings and code, which examines the initial link bandwidth and delay to change its settings, were utilized.

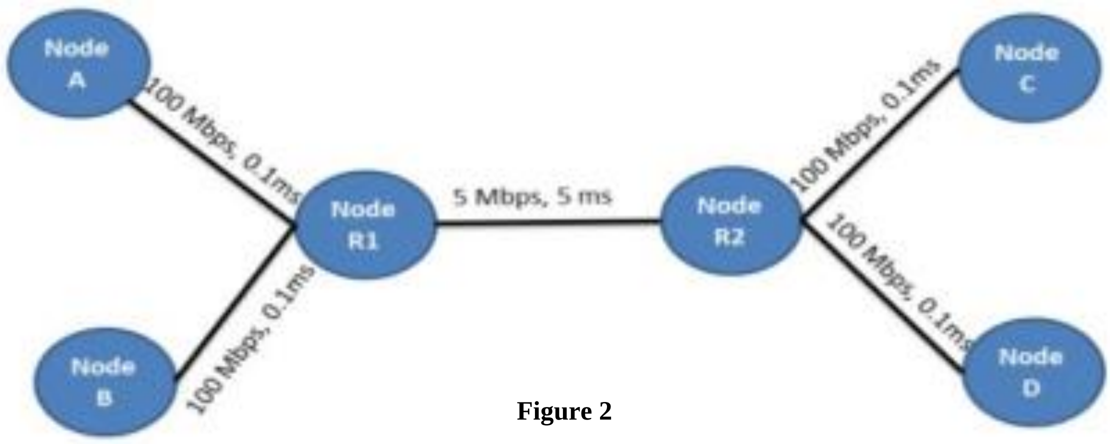

Figure 2

The parameters that were utilized in the simulation are mentioned below, along with their values.

• The simulation software utilized was Network Simulator 3 (NS-3).

• The algorithms that are being compared are CoDel and RED.

• File transfer application used Linux TCP suite

• Single bottleneck topology with two-way traffic

• The target delay was set to 6ms throughout the simulation.

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SIMULATION RESULTS AND DISCUSSION

Results

The simulation results were analyzed by Microsoft Excel 2010. During simulation, the bottleneck bandwidth varied from 64 kbps to 1 Mbps. The outcomes for bottleneck packet loss at the bottleneck, queuing delay, and bottleneck throughput are shown in figures 3 through 5.

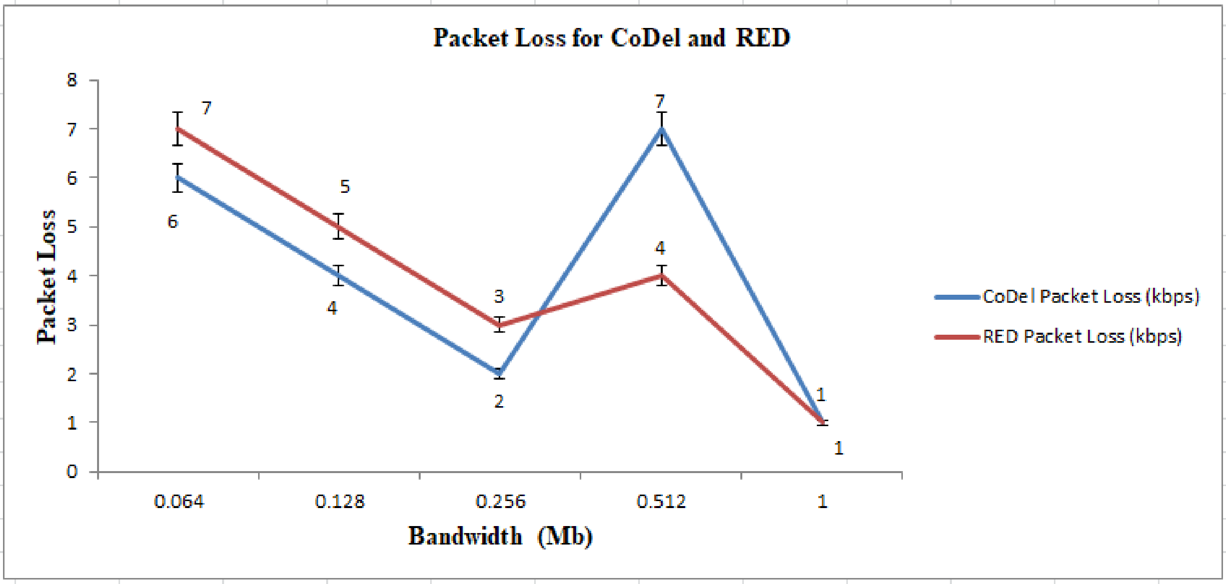

Figure 3 Packet Loss for both CoDel and RED

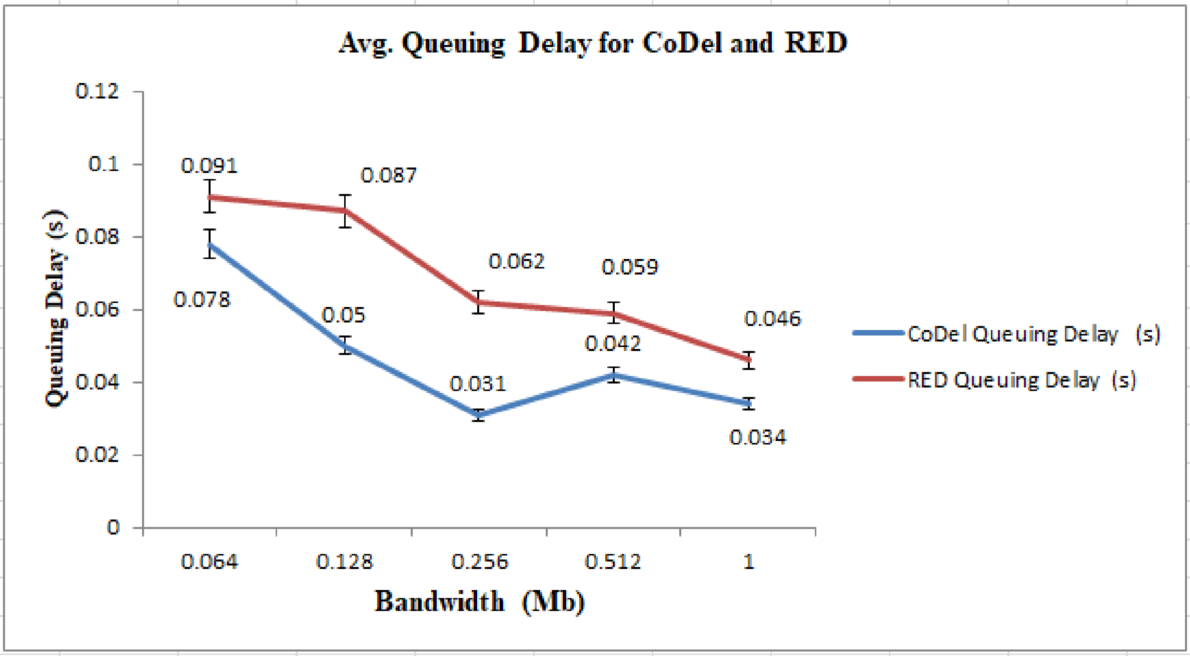

Figure 4: Avg. Queuing Delay for both CoDel and RED

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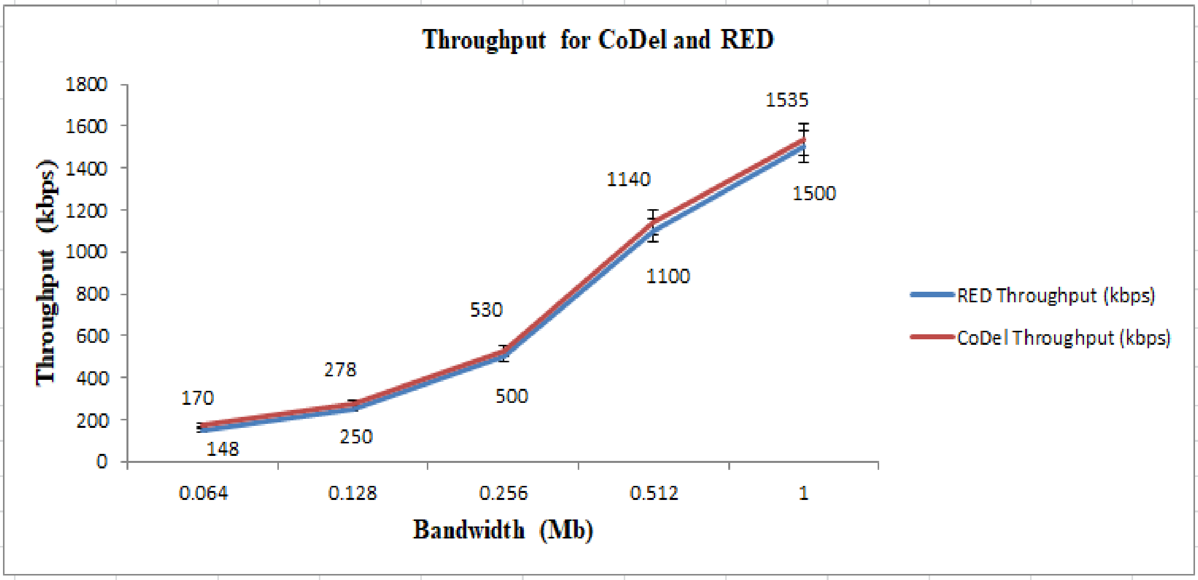

Figure 5: Throughput for both CoDel and RED

Low packet drop rate, minimum queuing latency and high throughput are all desirable qualities of an optimal AQM mechanism. CoDel satisfies all of the desirable features, as seen in the graphs above. When bandwidth is limited, the delay caused by bursts of packets is predicted to be greater, resulting in higher queue occupancy. When bandwidth is increased, the latency caused by bursts of packets should be reduced, and queue occupancy should be reduced as well.

DISCUSSION

In CoDel and RED, Figure 3 depicts the variation in bottleneck bandwidth and the resulting Packet losses. CoDel has a lesser drop rate of all the simulated AQMs except at 0.512Mbps. This is due to the fact that it strives to keep the line small and the queuing delay below a predetermined threshold (6ms). As a result, it drops as many packets as it requires. When congestion arises at the rate set during configuration, RED begins dropping packets.

Before the buffer is filled, packets in RED are dropped at random, and the probability of a drop increases as the average queue size grows. Looking at Figures 3 and 4, it can be deduced that as the queue size reduces in RED (i.e. the delay reduces), the packet drops descent as well. It employs early packet dropping to reduce congestion, reduce queuing delays, and prevent buffer overflows.

The queuing time is depicted in Figure 4 as the bottleneck bandwidths change. The bottleneck variation as changed from 64 kbps to 1 mbps, and the testing yielded positive findings, as expected: when transmitting a packet from one end to the other, CoDel had the shorter latency when compared to RED. Packets cannot reach their destination quicker than the time it takes

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to send them at the bottleneck rate. In the presence of a bandwidth bottleneck, a packet must incur at least a minimal delay.

When a packet stays in the queue for more than 6 milliseconds, CoDel drops it, preventing the buffer from being congested. In RED, however, packets are discarded at random before the buffer is full, and the probability of a drop increases as the average queue size grows and vice versa. RED governs the macroscopic behavior of the queue length (looking at the average fixed in the specified parameters). As a result, in the case of RED, as the bottleneck grows, there is a considerable fluctuation in end-to-end latency.

Figure 5 depicts how CoDel's performance varies in response to bottleneck variations in terms of throughput. Because the overall question is how well CoDel handles the internet latency, throughput and packet loss ratio are only addressed in this study as an indication of possible better packet delivery or bandwidth utilization by CoDel in the simulations. The average data rate of a source sending packets and the receiver receiving them is known as throughput. In terms of throughput, CoDel performed better when compared to RED. A source cannot send a packet faster than the receiver's line's bottleneck bandwidth. The lesser the packet loss, the greater the throughput.

CONCLUSIONS AND FUTURE WORK

The goal of this research is to find out how effective CoDel is under different network congestion situations. CoDel's performance is compared to that of RED. CoDel is an AQM technique for congested queues that is very broad, efficient, and parameterless. It is a crucial tool for dealing with bufferbloat. It achieves a low end-to-end delay and better throughput compared to RED. This suggests that the performance of CoDel can be tweaked for specific networking applications. The CoDel technique bridges the gap between optimal TCP behavior and bufferbloat resolution.

More research could provide more information on performance in a wider range of scenarios, as well as on CoDel's performance in comparison to other active queue management systems. Future research could also focus on updating CoDel to make it more effective for multiple queues in addressing the bufferbloat problem.

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