Interaction Studies of Some Recent AQMs with High Speed TCPs through Experimental Evaluation

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ABSTRACT
The two approaches of congestion control i.e. source based approach and router based approach have their own limitations. In source based approach, It is difficult to get correct location of congestion and without proper admission control; it would be difficult to effectively manage the congestion problem. So both approaches have to work in coordination for effectively control the congestion problem. In this context, an interaction study plays an important role to verify how an AQM implemented at router end works with TCP at source end. In this paper, the performance of some recent AQM approaches: CoDel and sfqCoDel have been analyzed, in presence of different high speed TCP variants at the source end. The main objective of this work is to obtain the interaction patterns of recently proposed AQMs with different high speed TCP variants like: HTCP, Compound and Cubic.Simulation results show that that if the objective is to achieve a better throughput and improved fairness simultaneously, sfqCoDel may be a good choice of AQM.

General Terms
Network Congestion Control Algorithms

Keywords
High Speed Networks, Congestion Control, Active Queue Management, Buffer-Bloat

1. INTRODUCTION
Network congestion control was considered as problem of distributed nature and requires a distributed solution in terms of TCP and AQM in high speed networks [1]. It was also observed that TCP congestion control at source end and AQM at router end cooperate closely to solve a global issue of network congestion. Different AQMs interact with TCPs in its own manner, thus performance of an AQM may be different in presence of various TCPs used at source end. It is not always feasible to convince the Internet service provider and router manufacturer to change the AQM and TCP after deployment. Thus one should know the fact in advance how effectively a particular AQM will perform with a high speed TCP working at source ends. There are few studies have been performed to evaluate the performance of new AQMs like CoDel[2] and sfqCoDel[3] for high speed environment as most of the evaluation was performed in traditional non high speed environment. Along with that, AQM evaluations have been performed eitherby considering TCP Reno, SACK or TCP Cubic in traditional non high speed networks.

In the present work the interaction patterns of some recently proposed AQMs like CoDel and sfqCoDel have been analyzed, with various TCPs like HTCP[4], COMPOUND[5] and CUBIC[6], designed for high speed wired network. The following issues related with TCP-AQM interaction have been considered:

- Whether the AQM algorithms designed by considering non high speed TCP variants working at source end, work well with the high speed TCP variants?
- How effectively a particular AQM will interact with a High speed TCP variant in terms of various performance parameters.

Solution to above mentioned issues may depend on the particular high speed TCP, particular AQM algorithm and particular network scenario used. Three well-known AQMs, three TCP variants and two congestion scenarios have been considered and simulations have been performed in all possible combinations. In every case four performance measures were observed: the average queue size, the throughput, the fairness and the packet loss ratio.

The paper is organized as follows: In Section 2 of this paper, a brief review of previous interaction studies of various Source based and Router based congestion control approaches (especially for high speed Internet) has been mentioned. In section 3, an experimental evaluation and analysis of, interaction behavior of various AQMs have been performed. Section 4 finally concludes the paper.

2. RELATED WORK
In computer network literature very few interaction works have been observed. Chydzinski A. et al. [7] has studied the performance of AQM algorithms in Internet routers in presence of new versions of the TCP congestion control mechanism. They compared the performance of droptail, adaptive RED [8], AVQ [9], PI [10] and REM [11] queueing in four TCP cases: classic New Reno, Sack, Fack and Cubic. Through simulation they found that, the application of Fack and Cubic versions of TCP have (with some exceptions) minor impact on the basic performance characteristics (throughput and delay) of the router’s queueing mechanism. However, application of Cubic TCP has often a positive impact on the stability of the router’s queue size. As for the interflow fairness for different TCPs, the results are not univocal – both fairness improvement and degradation can be observed depending on the network congestion level.

A. Esheteet. al. [12] have performed simulation to study the intra protocol fairness and TCP friendliness properties of high speed TCP variants: HSTCP, Compound, BIC and Cubic in presence of AQM approaches RED, FRED and CHOKe at router buffer. They observed poor fairness among high speed TCP variants in presence of these AQMs. They proposed a new AQM AFpFT which helps battle the TCP heterogeneity and enforce fairness among the various considered TCP variants.

Lin Xue et al.[13] presented an experimental evaluation of the effect of various queue management schemes on high speed TCP variants in realistic10Gbps network environment. They evaluated queue management schemes such as Drop-tail, RED, CHOKe, and SFB for popular high speed TCP variants such as TCP-RENO, HSTCP, and CUBIC over CRON [14], a real 10Gbps high speed network testbed. Performance results are presented for several important metrics of interests such as link utilization, fairness, delay, packet drop rate, and computational complexity. Their work support further research on the designand deployment issues of queue management schemes for highspeed networks.

N. Kuhn et al. [15] have performed simulations to compare RED's gentle_ mode to CoDel in terms of their ability to reduce the latency for various TCP variants: New Reno, Vegas, Compound and Cubic. They found that CoDel reduces the latency by 87%, but RED still manages to reduce it by 75%. However, the use of CoDel results in a transmission time 42% longer thanwhen using RED. They observed that RED could be considered as a good candidate to tackle Bufferbloat[16]. Rao V. et al. [17] has performed a comprehensive analysis of sfqCoDel for Active Queue Management. They compared sfqCoDel with CoDel in presence of two TCP variants TCP-SACK and Cubic, and found that sfqCoDel is much better than CoDel in certain areas where CoDel fails to perform well.

Present work extends the above contributions further by analyzing the interaction studies between high speed TCP variants with most recent AQM solutions like CoDel and sfqCoDel.

3. EXPERIMENTAL EVALUATION

In this section, the interaction pattern of RED, CoDel, and sfqCoDel with various high speed TCPs have been evaluated carefully. Various experiments have been conducted to simulate various scenarios in high speed networks.

3.1 Simulation Setup

The network simulator ns-2.35[18] is used to conduct a comparative analysis among RED, sfqCoDel and CoDel AQM mechanisms. A single duplex bottleneck topology is used for all simulations shown in Figure 1. The bottleneck bandwidth is set to 622Mbps and bottleneck round trip delay set to 48ms. Non bottleneck bandwidth of 1Gbps with round trip delay set to 1ms. Bottleneck buffer size is set to 8xBDP (bandwidth-delay product).

Three different variants of high speed TCPs: HTCP, COMPOUND and CUBIC are considered to be implemented at source end. Based on recommended values [2], the values of interval and target queue delay for CoDel are set to 100ms and 5ms respectively.Simulation have been performed by considering that all TCPs are having equal QoS requirements in terms of throughputand delay.

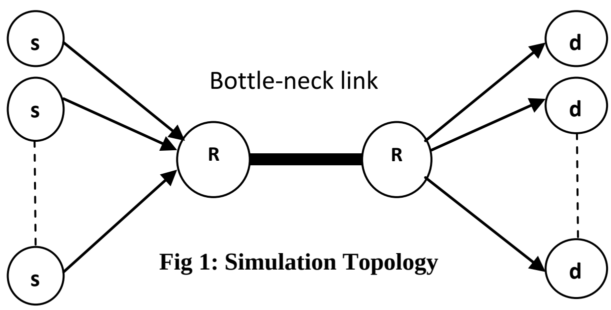

Fig 1: Simulation Topology

3.2 Simulation Scenarios

There are different possible simulations scenarios by considering different combinations of high speed TCP variants and AQM variants. Various experiments have been performed by considering following simulation scenarios:

3.2.1 All flows are using same high-speed TCP variant for each AQM

Under this scenario three traffic flows are assumed each using same high speed TCP variant at the source end. Simulation is performed for each TCP variant by considering different AQM variants one by one.

3.2.2 All flows are using different high-speed TCP variant for each AQM

In this scenario three traffic flows are assumed to be using three different variants of high speed TCP. Simulation is performed by considering each AQM variants one by one. The main objective of this scenario is to study the inter-protocol-fairness capability of different AQM.

3.3 Performance Metrics

The major performance parameters considered for analysis are listed below:

- Throughput,
- Average queue size at the congested router,
- Packet drop rate and
- Inter-protocol-fairness
- Intra-protocol-fairness.

3.4 Result and Analysis

In this section first the result and analysis of some recently proposed AQMs in presence of each scenario have been explained as follows:

3.4.1 All flows are using same high-speed TCP variant for each AQM

The AQM-TCP interaction capability of three different AQMs RED, CoDel, and sfqCoDel with three different TCPs: Cubic, HTCP and Compound TCP have been compared. Three pairs of high speed TCP flows have been compared each using same TCP variant and sharing the common medium. Three different set of simulations have been performed, one for each TCP variant: HTCP, Cubic and Compound, by considering three different AQMs: RED, CoDel and sfqCoDel at bottleneck router one by one. A comparison is performed by considering each performance metric as follows:

3.4.1.1 Average Queue Length

Figure 2 exhibits the average queue length of router buffer in presence of three different AQMs interacting with high speed TCP variant: HTCP.Following observations can be found from figure 2:

- RED exhibits largest queue length while interacting with HTCP.
- sfqCoDel performs best in terms of queue length in presence of HTCP.
- CoDel is better than RED in terms of queue length management.

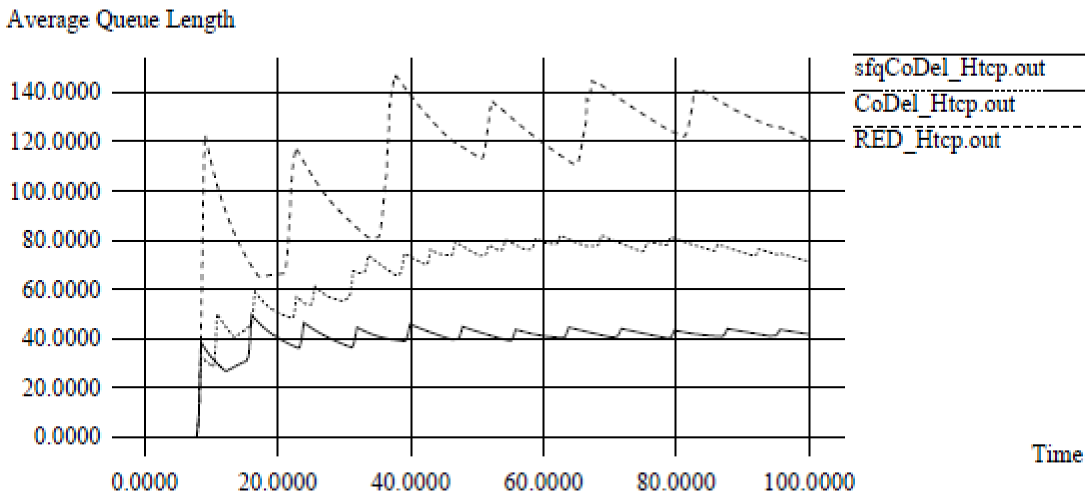

Fig 2: Average queue length of HTCP flows in presence of different AQM

Figure 3exhibits the average queue length of router buffer in presence of three different AQMs interacting with high speed TCP variant: Compound TCP.Following observations can be found from figure 3:

- sfqCoDel performs best in terms of queue length in presence of Compound TCP.
- CoDel and RED are equally good in terms of queue length management.

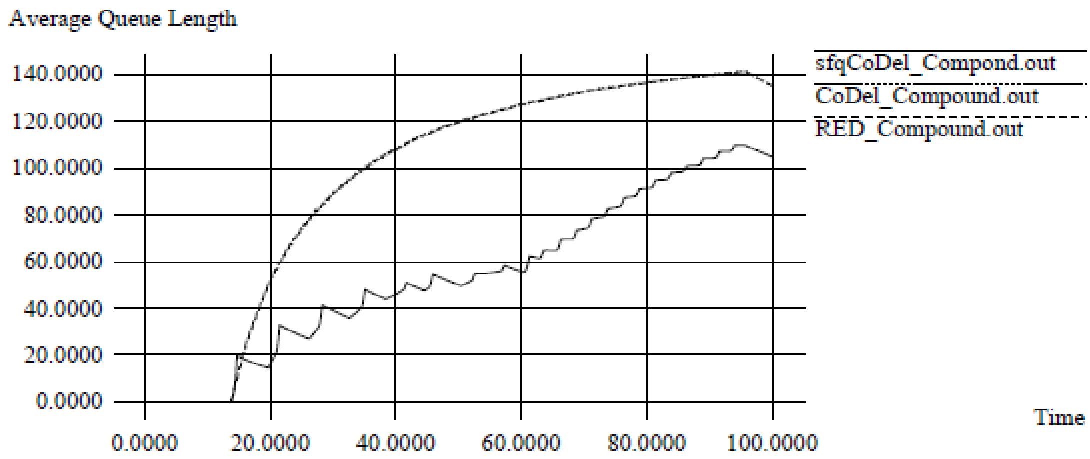

Fig 3: Average queue length of Compound TCP flows in presence of different AQM

Figure 4exhibits the average queue lengths of router buffer in presence of three different AQMs interacting with high speed TCP variant: Cubic TCP.

Following observations can be found from figure 4:

- RED exhibits largest queue length while interacting with Cubic TCP but still it becomes stable after 60 seconds of simulation.
- sfqCoDel performs best in terms of queue length in presence of Cubic TCP.

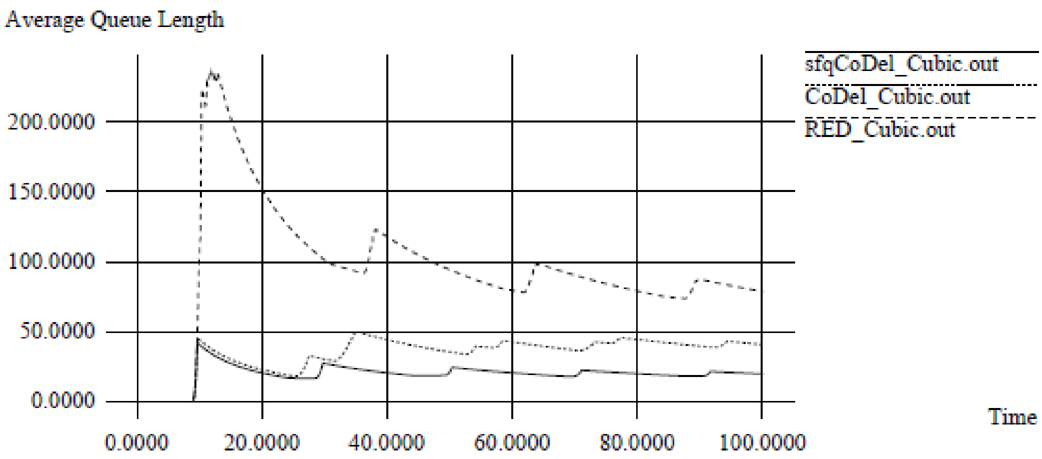

Fig 4: Average queue length of Cubic TCP flows in presence of different AQM

Thus it can be concluded that sfqCoDel performs better in terms of queue length management while interacting with different TCP variants.

3.4.1.2 Throughput

Figure.5 represents the throughput characteristics of three different AQMs in presence of TCP variant: HTCP at source end. RED gives worst performance in terms of throughput while interacting with HTCP as it exhibits an oscillatory behavior. CoDel is better than RED as it provide higher throughput as compared with RED.

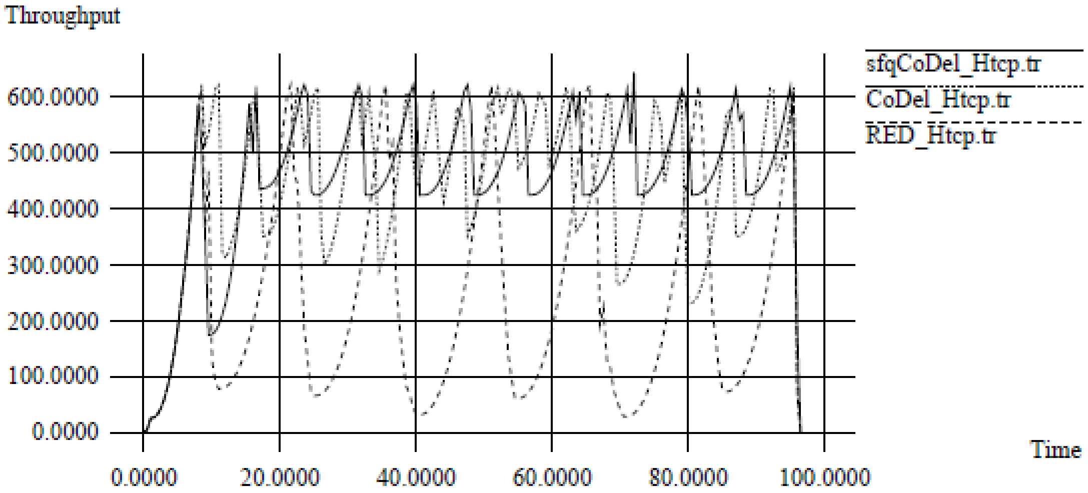

Fig 5: Total Throughput of HTCP flows under different AQMs

Figure 6 represents the throughput characteristics of three different AQMs in presence of TCP variant: Compound TCP at source end. From this figures it is clear that CoDel and RED are equally able to provide a higher and constant throughput to source ends. While sfqCoDel exhibits poor throughput performance with Compound TCP.

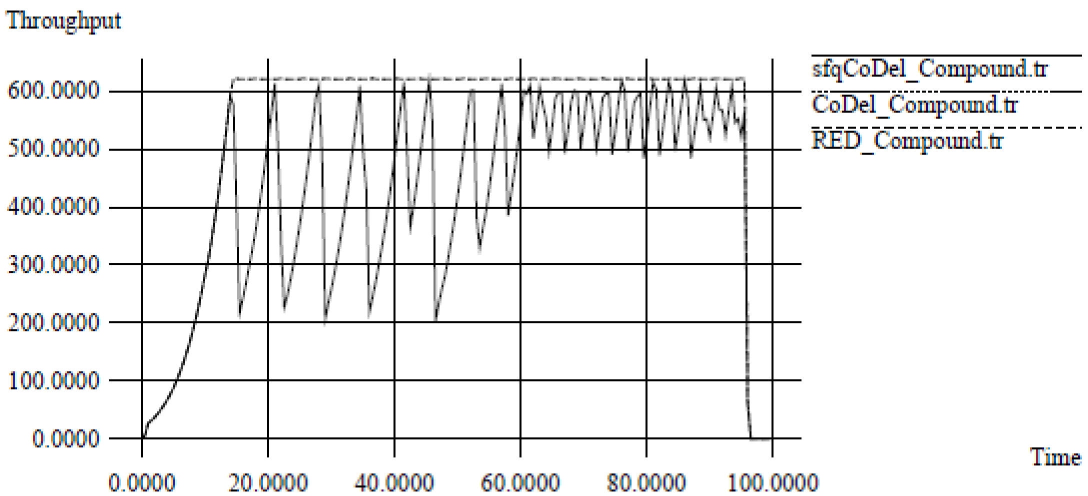

Fig 6: Total Throughput of Compound TCP flows under different AQMs

Figure 7 shows the throughput characteristics off three different AQMs in presence of TCP variant: Cubic TCP at source end. From this figures it is clear that CoDel able to provide a higher throughput to source ends. While sfqCoDel exhibits lower throughput performance as compare to CoDel, while interacting with Cubic TCP. RED exhibits a poor performance in terms of throughput with Cubic TCP.

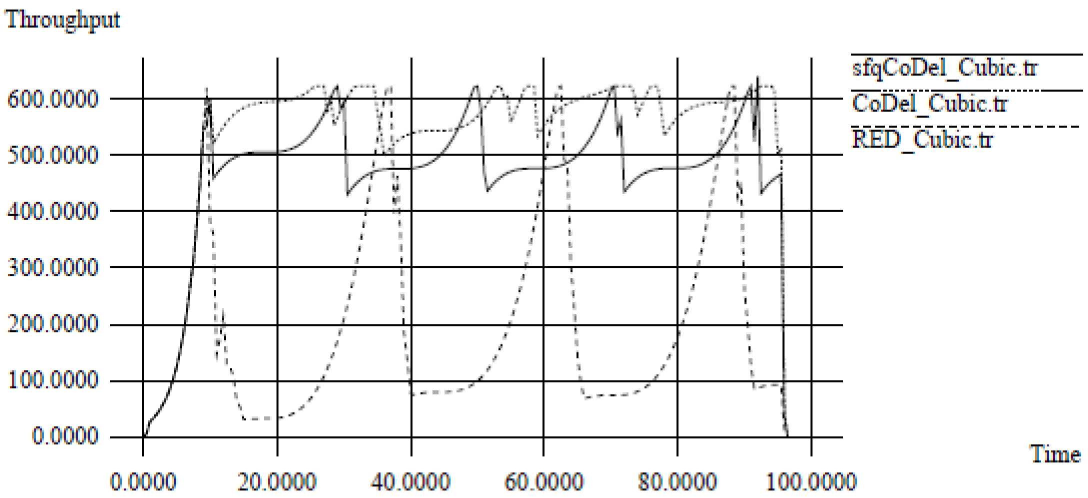

Fig 7:Total Throughput of Cubic TCP flows under different AQMs

Table 1 and Figure.8 further summarize the throughput performance of three different AQMs while interacting with three different TCPs.

Thus it can be concluded that in terms of throughput CoDel is able to provide better performance as compared to other AQMs while interacting with different TCP variants.

Table 1.Total throughput of TCPs using different AQM

	High speed TCP		
AQM	**CUBIC**	**HTCP**	**COMPOUND**
RED	222.941	267.52	560.511
CoDel	545.43	450.827	560.511
sfqCoDel	472.625	458.605	441.94

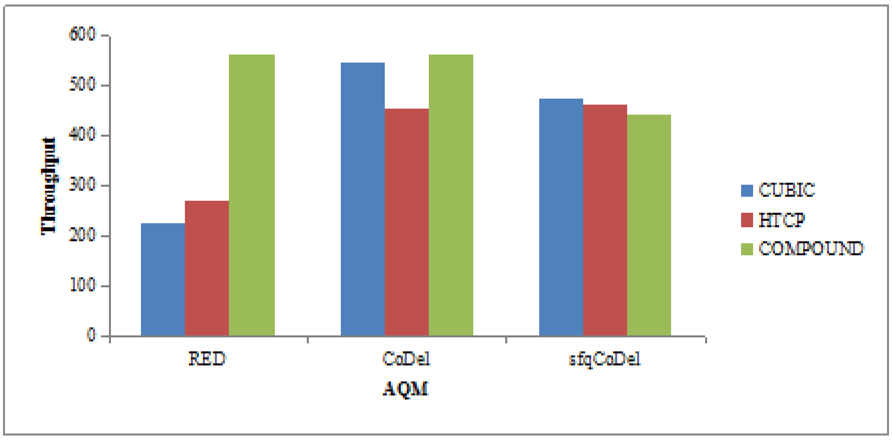

Fig 8: Total Throughput of TCPs using different AQM

3.4.1.3 Fairness

Table 2 and figure 9 summarize the performance of RED, CoDel and sfqCoDel in terms of fairness performance criterion. It can be observed from table2, RED and sfqCoDel all are capable to achieve nearly equal fairness for three different TCPs. On the other hand CoDel suffers from unfairness while interacting with HTCP.

Table 2.Fairness among TCPs using different AQM

	High speed TCP		
AQM	**CUBIC**	**HTCP**	**COMPOUND**
RED	0.9998	0.9993	0.9999
CoDel	0.9977	0.9787	0.9999
sfqCoDel	0.9999	1	0.99955

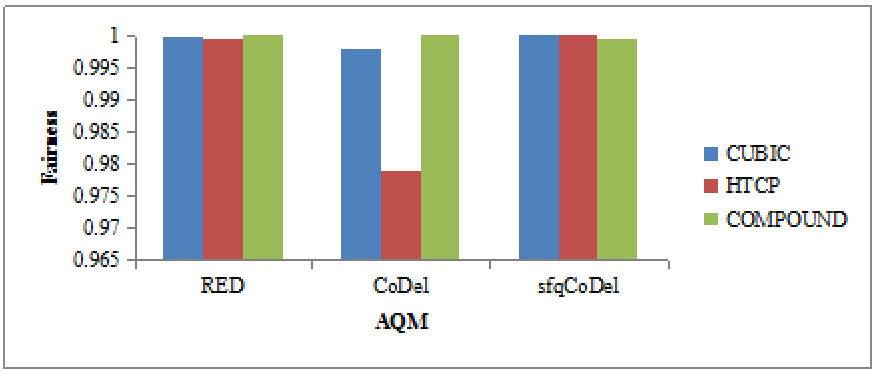

Fig 9: Fairness for different AQMs in presence of different TCPs

3.4.1.4 Packet Loss Rate

Table 3 and figure 10 shows the performance parameter packet loss rate for different combinations of AQMs and high speed TCPs.

Following observations have been found:

- RED is suffering from a higher loss rate for all TCPs except Compound TCP.
- CoDel is better than sfqCoDel in terms of packet loss rate as for all TCPs CoDel packet loss rate is lower than sfqCoDel packet loss rate.
- sfqCoDel is better than RED but still suffers from a larger packet loss rate for all TCPs.

Thus it can be concluded that sfqCoDel may be a good choice of AQM if the objective is to minimize packet loss rate.

Table 3.Packet loss percentage of TCPs using different AQM

	High speed TCP		
AQM	**CUBIC**	**HTCP**	**COMPOUND**
RED	8.45	4.697	0
CoDel	0.00052	0.0016	0
sfqCoDel	0.00135	0.0034	0.0034

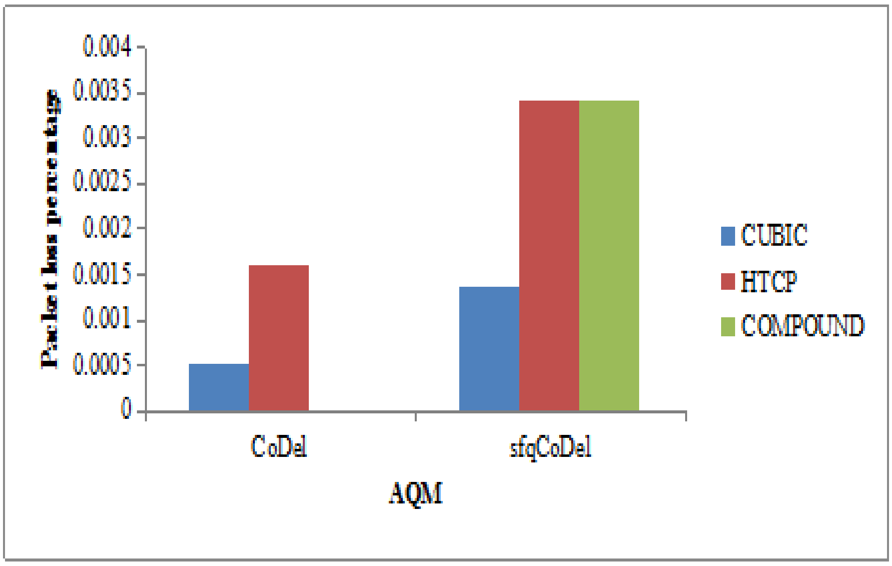

Fig 10: Packet loss percentage of TCPs using different AQM

3.4.1.5 Average Queuing Delay

It can be inferred from table 4 and figure 11 that CoDel and sfqCoDel all are equally capable to minimize the queuing delay in presence of large buffer at router queue.

In other words it can be said that these three AQMs are able to cope with the problem of bufferbloat. RED is not able to solve bufferbloat issue while interacting with Cubic and HTCP.Thus conclusion is that CoDel and sfqCoDel are good choice of AQM in terms of bufferbloat solution.

Table 4.Average queuing Delay of TCPs using different AQM

	High speed TCP		
AQM	**CUBIC**	**HTCP**	**COMPOUND**
RED	0.0602	0.05487	0.05218
CoDel	0.0507	0.05145	0.05218
sfqCoDel	0.0504	0.05087	0.05205

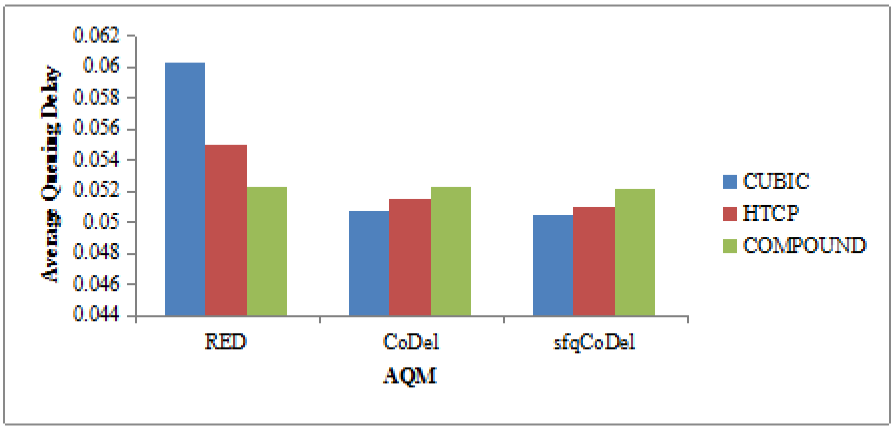

Fig 11: Average queuing Delay of TCPs using different AQM

3.4.2 All flows are using different high-speed TCP variant for each AQM

In this simulation scenario three TCP flows have been considered: HTCP, Compound TCP and Cubic TCP, all sharing a common bottleneck link. The major objective of this scenario is to check the inter-protocol fairness capability of different AQMs. Three differentsimulations have been performed by applying different variations of AQM one by one. Results of these simulations are summarized in table 5.

Table 5.Fairness and Throughput performance of TCPs using different AQMs

	Inter protocol Fairness	Total Throughput
RED	0.666	276.62
CoDel	0.853	526.99
sfqCoDel	0.997	554.44

From above table following observations can be inferred:

- RED is a poor choice of AQM as it is not able to maintain inter protocol fairness along with that it leads to poor total throughput.
- CoDel is an improvement over RED as it is able to provide slightly better fairness and a larger throughput than RED.
- sfqCoDel is better than CoDel as it provide a very good inter protocol fairness along with that a better throughput than CoDel.

4. CONCLUSION

TCP and AQM both play an important role for solving congestion in high speed networks. An interaction study has been performed for TCP-AQM interaction by considering three high speed TCP variants and three AQMs: RED, CoDel and sfqCoDel. Simulation results prove that if the objective is to achieve a better throughput and improved fairness simultaneously, sfqCoDel may be a good choice of AQM.Such interaction study plays an important role to verify how an AQM implemented at router end works with a specific TCP at source end.These results can be purposefully utilized in working out design and development of Congestion Control Approaches for high speed wired networks.

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