Analysis of Congestion Control Techniques for Time-Critical Applications

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Abstract

Social media video applications, such as TikTok, require smooth and uninterrupted data transmission. These applications are time-sensitive and could not tolerate long delays in transmission caused by data transmission protocols. For example, the congestion control and reliability check protocols, TCP and UDP, are used in today's Internet. TCP is a reliable transport layer protocol with congestion control mechanism which delivers the data in an ordered manner and retransmits the data in case of errors. TCP needs improvement when used for applications in which reliability could be compromised for high performance. UDP is suitable for time-sensitive applications, but it has no mechanism to keep a smooth transmission in case of congestion. Datagram congestion control protocol (DCCP) has been developed to overcome the weaknesses of TCP and UDP with more control on the congestion and the timely delivery of data. It delivers the data in time and also has congestion control mechanism. This paper compares the performance of advanced congestion control techniques of DCCP, such as CCID 2 and CCID 3, over different networks through simulations. The proposed simulation networks are configured with a high speed bandwidth and random link failures. The results show that CCID 2 (TCP-like) is better in dealing with network congestion in a 5-node scenario. Whereas, on a 20-node scenario and a link failure scenario, CCID 3 (TFRC) outperforms CCID 2 and TCP.

Keywords—TCP, UDP, DCCP, Congestion, Reliability.

1 Introduction

The research on various real time applications, particularly smartphone applications for streaming media, and web based games, question the reliability of the existing protocols such as TCP. Generally, Internet utilize TCP and UDP for sending and receiving data for these applications [1][2]. TCP guarantees an ordered data delivery and reliability. It means when a data unit is lost, it has an effect on the processing of new and existing data in the queue (for example, the data present in the receiver buffer) due to the duplicate re-transmission of the data. It also leads to the possibility of the network congestion.

Normally at that point, TCP sender lowers its data transmission which is not suitable for smartphone applications for streaming media. Thus, TCP needs improvements for streaming media application. Alternatively, if UDP is used for these applications, it becomes challenging to recuperate from congested network because of the design of the protocol.

Therefore IETF has introduced a new transport layer protocol, named DCCP, which provides a reliable and advanced congestion control mechanism. It is suitable for time-critical and real-time applications. DCCP provides the options of using more than one congestion control algorithms which are differentiated by congestion control identifiers. Currently, two CCIDs are operational with DCCP. First is CCID 2 (TCP-like Congestion Control) and second is CCID 3 TFRC (TCP-friendly Rate Control) [3][4][5][6]. CCID 2 is based on a window stream control and is reasonable for bursty constant applications which essentially need to move a large information in a short period. Therefore, it is useful for online games and packed encoded recordings. CCID 3 is suitable for real-time applications where smooth changes in data rate are expected, such as web based communication [7][8][9]. The experimental work on the behavior of TCP and DCCP shows that CCID 3 is suitable for those application that need smooth data rate [10]. Another study [11] on MPEG4 video over a congested network by using TCP, UDP, CCID 2 and CCID 3 shows that the variants of DCCP deliver improved quality

ISSN: 2523-0379 (Online), ISSN: 1605-8607 (Print)

of service. The parameters include data transmission rate and the number of losses. However, the jitter in the transmission is efficiently handled by the UDP. Authors in [12] presented the performance of CCID 2 relative to the congestion variants of TCP, that are NewReno, BIC and CUBIC. CCID 2, when combined with NewReno, increases the quality of service. Whereas, combination of BIC and CUBIC with CCID 2 lowers the quality of service when RTT is more than 25 ms. The work on Mobile adhoc networks [13] for the implementation of DCCP shows that end-to-end delay of TFRC is less than that of UDP and TCP. The end-to-end delay of UDP increases with the increase in the number of nodes. The monitoring of jitter value in the given scenario also recommends TFRC for the mobile adhoc networks. The researchers in [14] evaluated the congestion control techniques of DCCP in terms of power usage. The study concludes that the DCCP is suitable for multimedia applications. The researcher also find the need for the improvements in the existing transport protocols for efficient transmission using multi-homing by CMT-SCTP protocol [15][16][17]. However, no such suitable extensions for DCCP have been hitherto found.

2 Overview

This section gives a brief theoretical background of the protocols studied in this research.

2.1 TCP

TCP enables two systems to set up a connection and begin correspondence through streams of information. TCP consists of a set of IP headers and port number that identifies the TCP communication.
Using TCP, Congestion occurs because of the transmission of large amount of data. During congestion, large amount of data is at high risk of to be lost. The delay in data transmission and the overflow are also common consequences of congestion. To overcome the network congestion, four algorithms are used by TCP that include fast retransmit, slow start, fast recovery and congestion avoidance.

Fast Recovery:
Fast Recovery algorithm has been used widely over the Internet. After the initial congestion is detected, the client retransmits few of the packets in order to reduce the congestion. In this algorithm, the retransmit delay is not calculated and is based upon the ratio of the amount of lost data to the overall amount of data in an interval of time.

Slow Start:
This algorithm balances the transmission rate of the connection on the basis of parameters such as congestion window size. Slow start occurs automatically every time a packet arrives. This indicates that a TCP connection is automatically slow starting, unless the user changes the TCP packet header with this option.

Fast Retransmission:
Quick retransmit is an upgrade to TCP that decreases the time a sender holds up before retransmitting a lost section. A TCP sender normally utilizes a straightforward clock to perceive the lost fragments.

2.2 DCCP

The Datagram Congestion Control Protocol (DCCP) is a transport layer protocol based on UDP. Additionally, it is capable of providing reliable connection and congestion control mechanism and feature negotiation. It overcomes the selective functionality problem in TCP and UDP protocols. The main motivation to design this protocol is to support timeliness in data transmission and provide reliable data transfer with congestion control. The core features of DCCP are the following:

- It provides unreliable flow.
- It is reliable for connection initiation and connection termination.
- It has feature negotiation ability.
- It offers ECN-aware feature.
- It contains advanced congestion handling.
- It can also find the Path Maximum Transmission Unit (PMTU).

DCCP is equipped with options to transmit data with TCP congestion mechanism as well as some advanced congestion control techniques. congestion control is mechanism for choosing between several congestion control algorithms in DCCP. It can mainly use two algorithms that are CCID 2 and CCID 3.

2.3 CCID 2

CCID 2 is a TCP-Like congestion control mechanism which is based on AIMD strategy. CCID 2 takes the benefit of available bandwidth which can adopt to the changes of congestion window like TCP. CCID 2 has the following features:

1) The sender defines the initial window size and continues to transmit as long as the data is available and window space is free.

2) One acknowledgement per two packets is used, however, it can also be configured to other settings.
3) Drop packets and ECN are used to predict congestion.
4) In case of congestion, the algorithm reduces the window size.
5) Selective acknowledgement is used like in other protocols such as SCTP [18][19].

2.4 CCID 3

DCCP can be configured to CCID 3 mechanism. It uses TFRC in order to reduce the network congestion. The sender maintains the sending rate by observing the lost event sent by the receiver and goes through a constant sending rate for a specific duration. one feature of CCID 3 is the use of ECN (Explicit Congestion Notification) which helps in providing end-to-end congestion notification through adjusting ECN in the IP header. TFRC is an advanced congestion handling technique which maintains a specific transmission rate by calculating the throughput value. Generally, TFRCs congestion control mechanism has the following features:

- In case of data loss, the receiver notifies to the receiver.
- The sender, with the help of the receiver's feedback messages, tries to maintain RTT.
- The sender calculates the expected transmission rate by using the parameters of RTT and the number of losses [3].

3 Simulation Environment

NS-2.35 is used to configure and simulate the proposed scenarios. Two scenarios are proposed, as shown in Figure 1 and Figure 2, to evaluate the performance of TCP and DCCP variants (CCID 2, CCID 3). To analyze the performance, throughput is used as a criterion and it is calculated in Mbps. Throughput is defined as the total number of successfully received packets at the receiver in one second. In the proposed scenarios, the simulation parameter queue type is droptail, and the queue size is 20 packets. The overall simulation running time is 100 seconds. Three different scenarios are proposed to evaluate the congestion control techniques, i.e. TCP, CCID 2 (TCP-Like) and CCID 3 (TFRC).

In scenario–1, there are 20 nodes in the topology consisting of three senders (S1, S2 and S3), and three receivers (R1, R2 and R3). Scenario–2 consists of five nodes in the proposed topology: two senders (S1 and S2), and one receiver (R1) as shown in Fig 2a. In the same 5-nodes topology, link failure is also added as shown in Fig 2b.

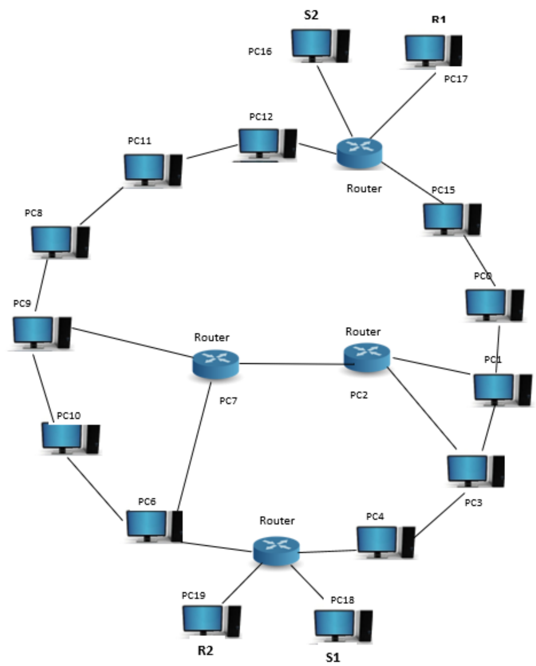


Fig. 1: Scenario 1: 20 node topology

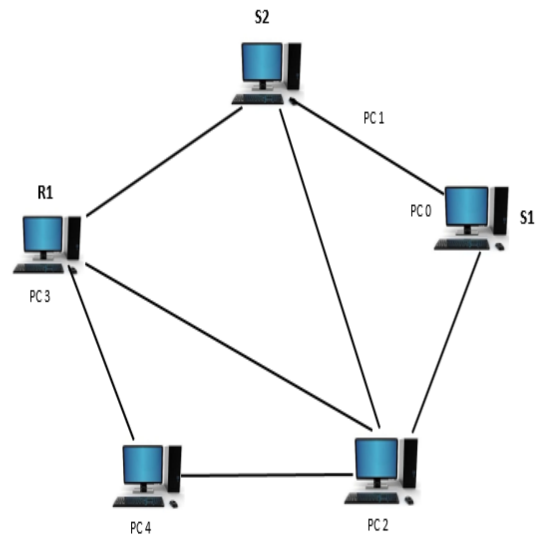
4 Simulation Results

In this section, we will analyze the outcomes achieved from our simulations in different scenarios. We compared TCP with CCID 2 (TCPLike) and CCID 3 (TFRC) in terms of throughput. We increased delay from 10 ms to 500 ms for all scenarios and varied bandwidth from 10 Mbps to 100 Mbps. In the second simulation, we set a delay of 10 ms, 30 ms, 90 ms and varied bandwidth from 10 Mbps to 100 Mbps.

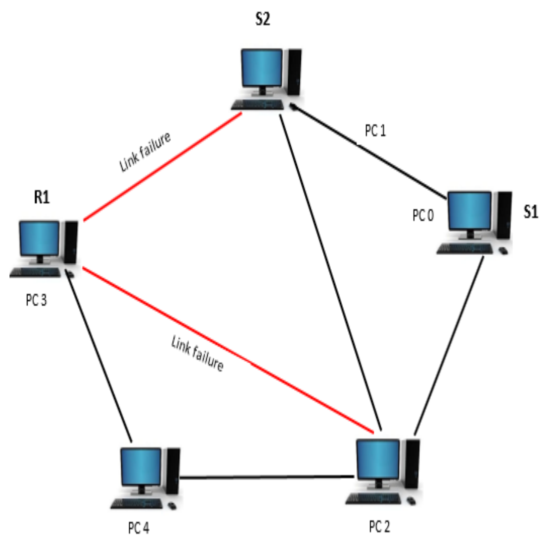
4.1 Experiment 1: 20-Nodes Scenario

The experimental graphs of 20-node scenario are shown in Fig 3. The horizontal axis shows delay or bandwidth, and the vertical axis represents throughput in kbps.

Figure 3 shows that at low delay, throughput of CCID 2 (TCP-like) is greater than CCID 3 (TFRC). However, as delay increases, TFRC's throughput is higher than TCP-like and TCP. Similarly, Figure 3c shows that the bandwidth increases from 10 Mbps to 100 Mbps at 10ms delay. It can be observed that at 50 Mbps and 80 Mbps bandwidth, TFRC's throughput decrease abruptly. Hence, it is concluded that throughput of TCP-like and TCP is less than that of TFRC as shown in Figure 3. Our results show that in 20-nodes



((a)) 5 nodes



((b)) 5 nodes with link failure

Fig. 2: Scenario 2: 5 nodes

scenario, TFRC's performance is better than TCP-like and TCP.

4.2 Experiment 2: 5-Nodes Scenario

The experimental results in terms of throughput of DCCP variants (CCID 2 and CCID 3) and TCP are shown in Figure 4. The throughput of DCCP variants is higher, as TCP re-transmits the loss packet and reduces the congestion window to one-half of the current value after occurrence of packet loss. On the other hand, less number of lost packets are not re-transmitted by CCID 2 and CCID 3 congestion control mechanisms. Hence CCID 2 and CCID 3 achieve higher throughput comapred to TCP.
It is also noticed that the performance of CCID 2 is better than CCID 3, as the congestion control mechanisms acts differently in congestion scenario. CCID 3 uses TFRC mechanism in which sender maintain its sending rate by the information advertised by the receiver. CCID 2 uses TCP based congestion mechanism in which it simply reduces the congestion window.

4.3 Experiment 3: 5 Nodes with Added Link Failure

In this experiment, the link failure is added in terms of packet loss in the 5-nodes scenario. The packet loss is randomly assigned to two links. The packet loss is random, for example, in case of 10% packet loss, the simulator randomly discards 10% of the data on the given link by assuming that the link is in failure state. In the topology, the link failure is applied on two links: one between R1 and S2, and second between R1 and PC2. The evaluation results of link failure scenario, while changing bandwidth and delay, are presented in Figure 5.
In link failure situation, it is concluded that TFRCs performance is better than TCP-Like and TCP. It is because in TFRC mechanism, as packets are dropped, the sender regulates its transmission rate according to its receiver rate.

5 Conclusion

DCCP is a relatively new protocol and is still under research with the perspectives of high rate data transfer, efficient congestion control and bandwidth usage. Due to these appealing features, it is very promising for applications such as online games, video streaming, uploading large amounts of data, and selecting the best links among multiple links. A number of scenarios are developed in this paper to configure DCCP and TCP. Most of the developed scenarios are multipath scenarios. DCCP attains high QoS parameters compared to TCP in the specified scenarios. It is concluded that TFRC performs better than TCP and TCP-like in link failure and 20-nodes scenario. The analysis also shows that the performance of TCP-like congestion mechanism in terms of throughput is greater as compared to TCP and TFRC in 5-nodes scenario. Since the reliability and re-transmission of loss packets in TCP is not suited for today's real-time applications, therefore, DCCP (CCID 2 and CCID 3) could be preferable to TCP in all scenarios.

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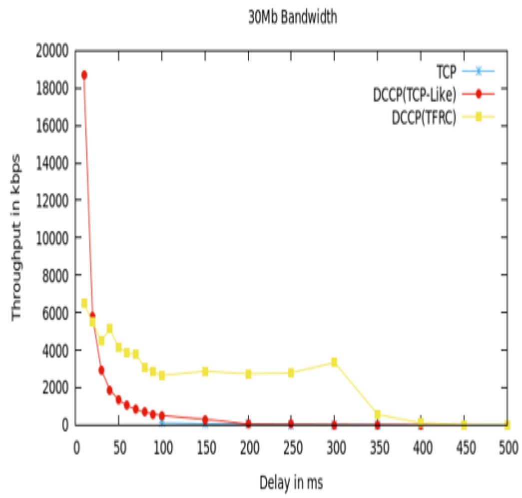
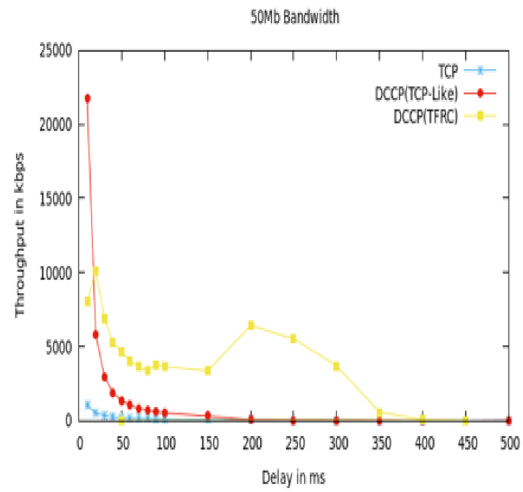
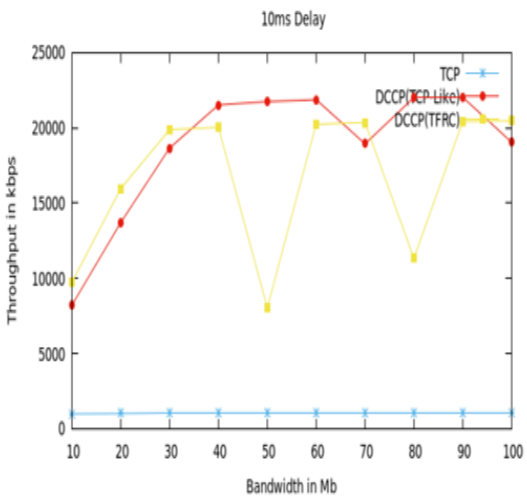


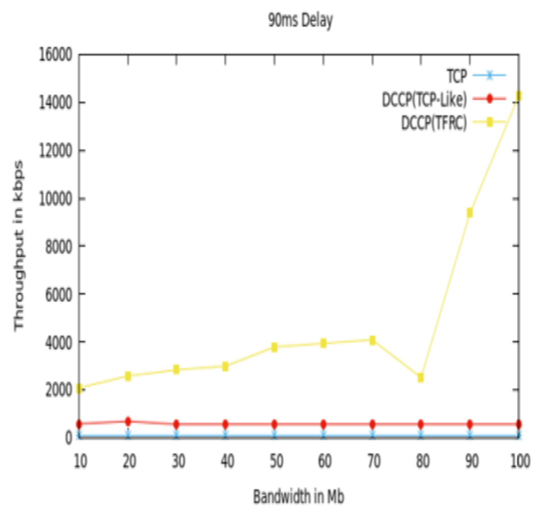
((a)) 10 ms to 500 ms Delay and 30Mbps



((b)) 10 ms to 500 ms Delay and 50Mbps



((c)) 10 to 100 Mbps bandwidth and 10ms delay



((d)) 10 to 100 Mbps bandwidth and 90ms delay

Fig. 3: Throughput (Experiment 1)

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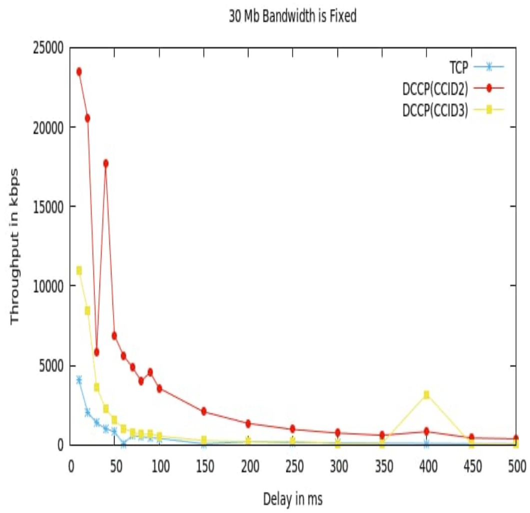
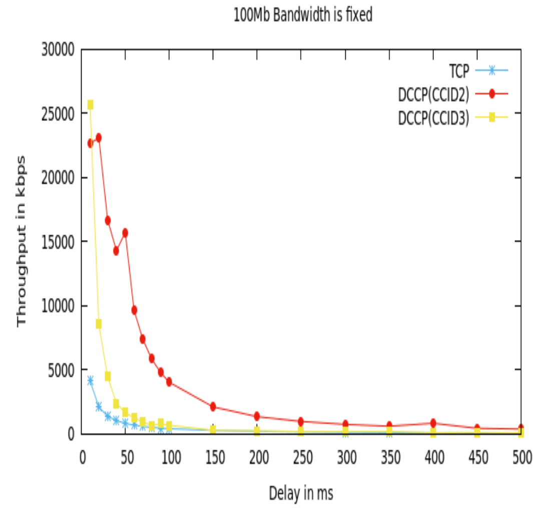
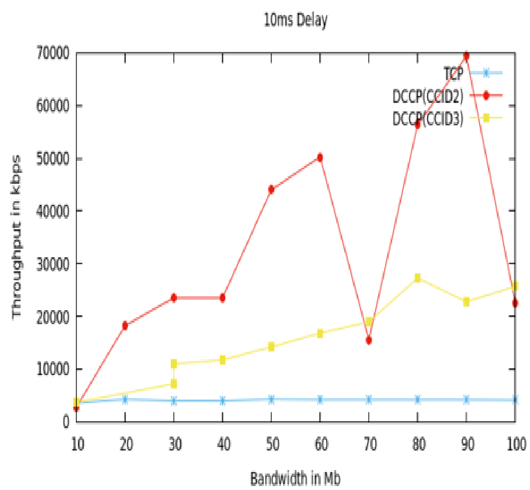


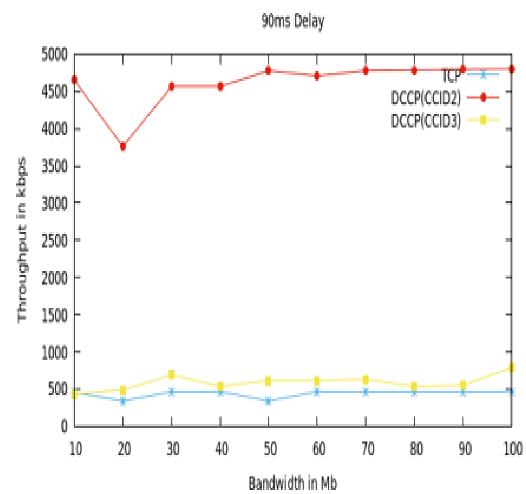
((a)) 10 ms to 500 ms delay and 30 Mbps bandwidth



((b)) 10 ms to 500 ms delay and 100 Mbps bandwidth



((c)) 10 Mbps to 100 Mbps bandwidth and 10ms Delay



((d)) 10 Mbps to 100 Mbps bandwidth and 90ms Delay

Fig. 4: Throughput (Experiment 2)

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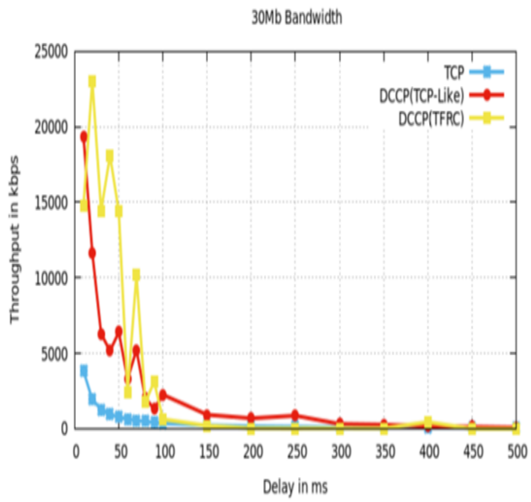
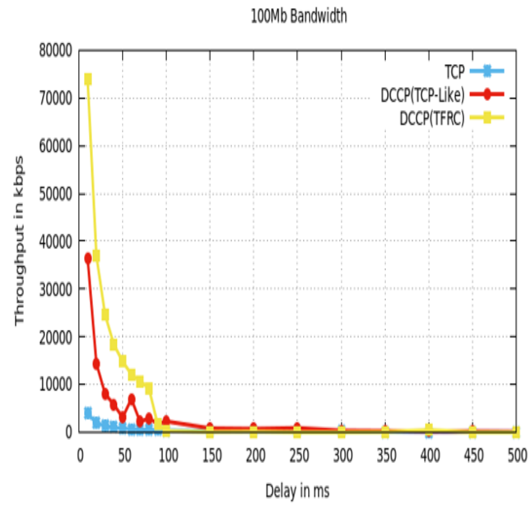
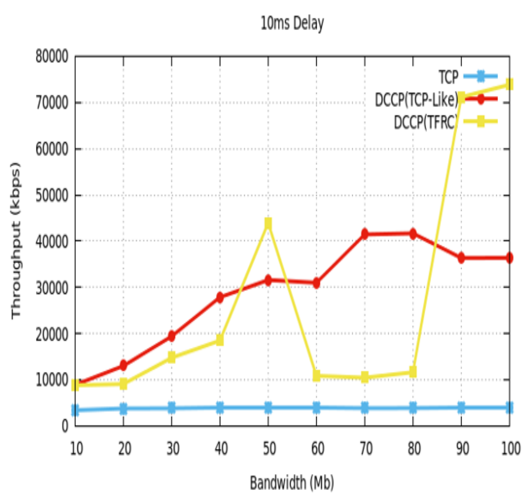


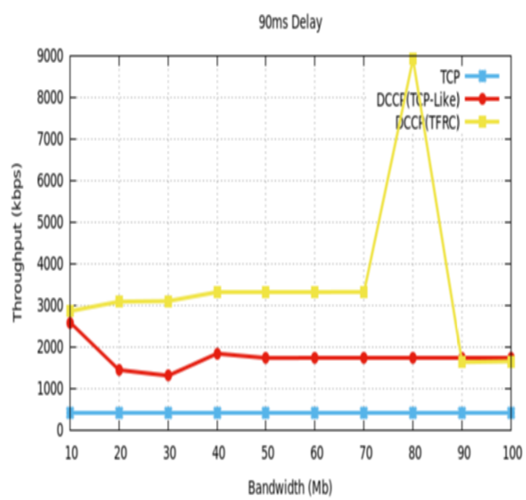
((a)) 10ms to 500ms Delay and 30Mb Bandwidth



((b)) 10ms to 500ms Delay and 100Mb Bandwidth



((c)) 10Mb to 500Mb Bandwidth and 10ms Delay



((d)) 10Mb to 500Mb Bandwidth and 90ms Delay

Fig. 5: Throughput (Experiment 3)