Datagram Congestion Control

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1 Overview

1.1 Description

DCCP is an emerging protocol that aims to provide improved congestion control alongside the TCP protocol. While its development has gone through many phases, it is still not yet deemed ready for industry adoption.

In this report we will investigate the characteristics of DCCP and evaluate its effectiveness in comparison to the TCP and UDP protocols. It must be noted that this may not accurately reflect the final, intended operation of the DCCP protocol. This report derives value from the fact that the protocol was tested on Linux (Ubuntu) machines whose kernel support the DCCP protocol in its current state.

1.2 Goal

The goal of this report is to investigate the operation of the DCCP protocol and the congestion control that is afforded by its use. For this reason, we evaluated DCCP's operational behavior when run concurrently with both the TCP and UDP protocols. The three major areas of investigation are as follows:

- Contention of bandwidth between the TCP and DCCP protocols
- Whether UDP suppresses the complete bandwidth of TCP and DCCP
- Whether TCP or DCCP contends more effectively against UDP

In answering the above, the outcome of this investigation is to evaluate the effectiveness of DCCP as currently available through selected Ubuntu distributions.

2 Implementation

The three protocols were implemented in Python. A server and client python program was written for each of respective protocols. Simulating transmission of data over the protocols therefore involved running a separate process for each server on a node. Furthermore, single or multiple clients corresponding to these servers may be run on the same or different nodes.

2.1 Features Included

The clients can successfully connect to their respective servers, and send messages. These messages consisted of packets of pre-determined size so as to maximize bandwidth usage of the protocol or client. In the case of DCCP, multiple clients were required to make use of a greater amount of bandwidth, due to a variety of complications. See §7 for more.

2.2 Features Not Included

The client implementations of the protocols do not allow multiple clients to be launched through one execution of the program. Thus, a user may have to run the program multiple times in terminal, or otherwise seek to make use of a bash script for doing so. This feature was not strictly required for the investigation, however.

2.3 Extra Features Included

The server programs provide a real-time graph of data received through its protocol. This feature was found *not* to impact the data collection significantly. For instance, saving the data instead of plotting it in real time-yielded similar bandwidth read-outs from the servers, indicating that the act of plotting did not affected the bandwidth throughput.

The form of data collection measured the actual data sizes of the packets received by the servers. Consider that another metric would be to count the number of packets received by the server, and consequently multiply it by the pre-determined packet sizes in order to determine bandwidth usage. This latter metric was found to be a bit wanting, as it does not exhibit cases where a number of packets may be received by the adaptor, but for various reason would not be passed up the protocol stack to the Python program. See §7 for more.

2.4 Algorithms and Data Structures

To ensure thread-safe operations, the use of the Python GIL (Global Interpreter Lock) was employed. This granted us the ability to use thread-safe data structures containing the number of bytes received in a certain time period.

Real-time graphing was enabled by appending the most current bandwidth sampling in a time interval (typically 1 second) to a list of the 100 most recently sampled data points. The oldest data point in this list was consequently popped off.

Critically, these operations takes place in a designated thread. A `BandwidthMonitor` class was created for the purpose of sampling the bandwidth usage in a time interval. The interval is determined by the time taken between calling the class's `initiate` and `terminate` methods. A lock of the bandwidth count is obtained once during each call, and the bandwidth determined is returned by the `terminate` method.

3 Protocol Details

An outline of each of the protocols are given below, and the features provided by each.

TCP TCP is a *connection-oriented* protocol that ensures reliable delivery of data over a network through bit streams. Key features that TCP provides are ordered data transfer, retransmission of lost packets, error-checking, flow control, and congestion control. These features allow TCP to be considered "reliable".

Most of the features mentioned make use of the fact that TCP implements a sliding window for sending and receiving data. Congestion control is afforded by four algorithms, namely, slow-start, congestion avoidance, fast retransmit, and fast recovery.

UDP UDP is a *connectionless-oriented* protocol that does not rely on handshaking like TCP. It is considered “unreliable” as it does not guarantee delivery of UDP datagrams (or messages) that are sent to a host. Furthermore, UDP does not implement any error-checking algorithms.

UDP is preferable to TCP in cases where waiting for packets is less desirable than dropping a few packets. UDP inherently provides shorter latencies, and thus has application in VoIP and online games.

DCCP DCCP is a *message-oriented* protocol, and provides a reliable connection between hosts. The distinguishing feature of DCCP is that it it implements congestion control mechanisms at the transport layer, rather than assuming such control at the application layer.

This form of congestion control is considered TCP-friendly, meaning that it contends fairly in terms of bandwidth with programs making use of the TCP protocol. However, in an application like VoIP, it is desirable to send new data rather than resend old data. Timing constraints are placed on data in the DCCP protocol, allowing it to discard data that is considered “too old” to be considered useful.

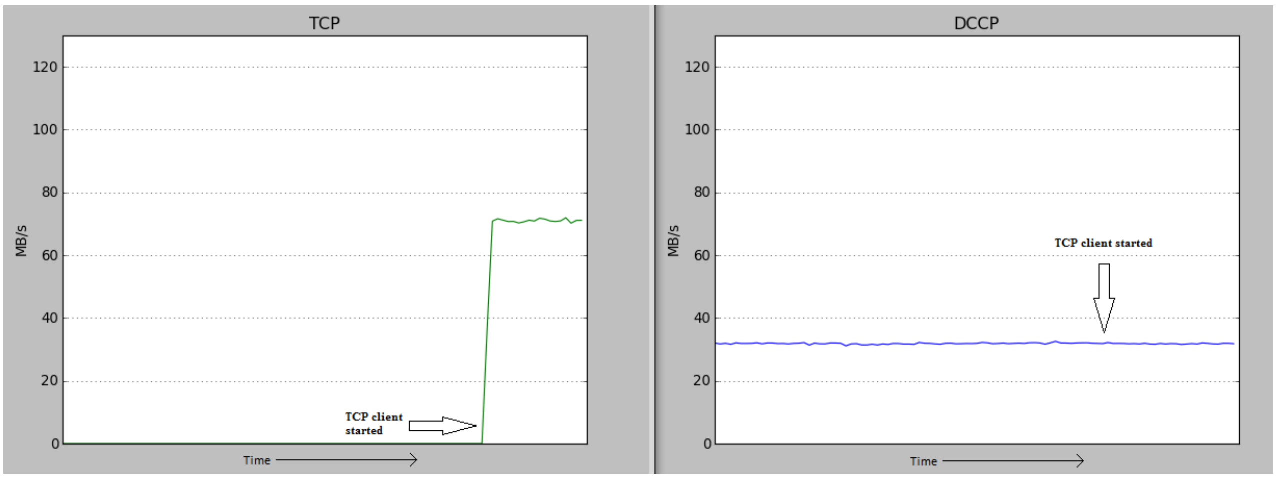
DCCP makes use of congestion control algorithms which have a corresponding identifier. These CCID modules are implemented by the kernel of the operating system.

4 Methodology and Experiments

The investigation was carried out by considering DCCP’s interaction with TCP and UDP in turn, while keeping the goals mentioned of §1.2 in mind.

4.1 TCP and DCCP Contention

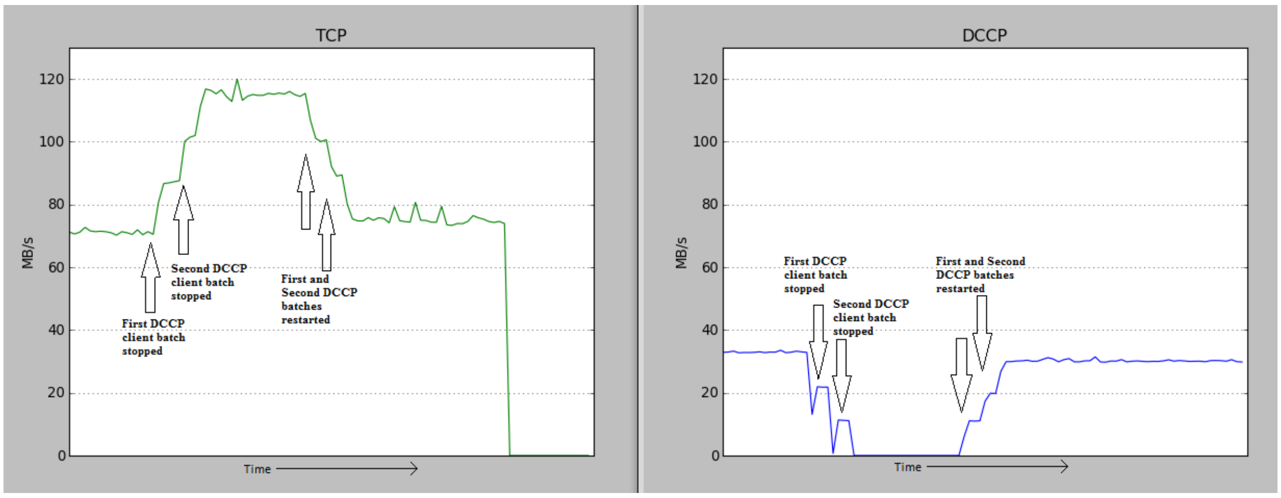
Consider the following graphs, which give a clear indication of bandwidth fluctuation when running TCP and DCCP concurrently:



First, a DCCP connection was made (corresponding to the blue line in the graph). This connection consisted of three hosts running multiple DCCP clients each, with each DCCP client sending to a single host running the DCCP server.

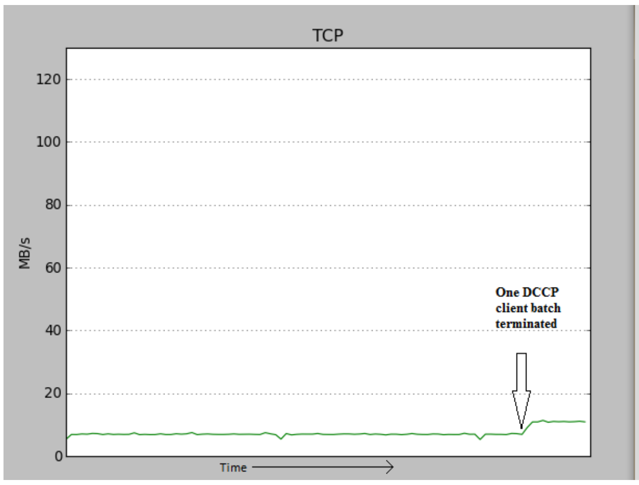
After an initial 100 data points were sampled, a TCP client was launched from another host, along with a corresponding TCP server running on the same host as the DCCP server. The new TCP connection did not affect the DCCP connection in any noticeable way. This is likely due to the fact that the DCCP connections were not making use of the full bandwidth available. However, note that the TCP connection is running at a lower throughput than the approximate 117 MB/s of which it can utilize in the absence of DCCP.

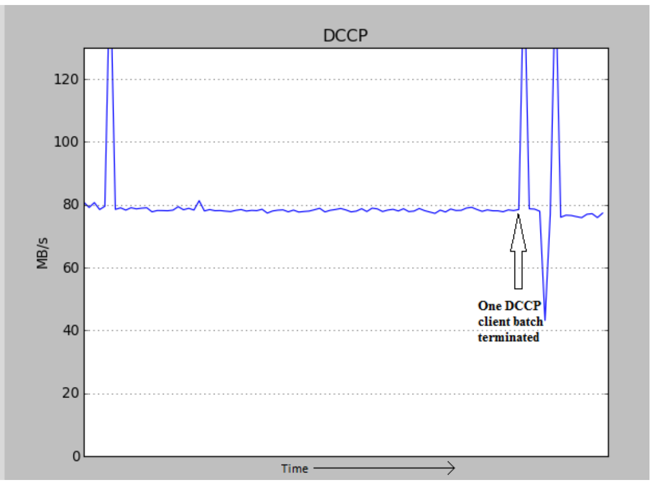
Next, a series of DCCP clients were terminated. The effect of this action on TCP was a sudden rise in throughput for TCP:



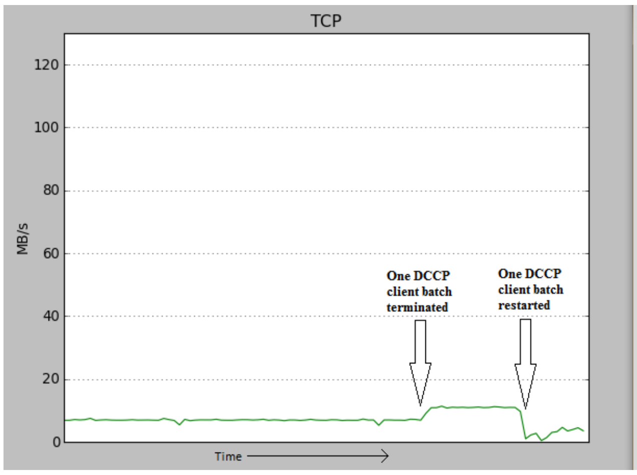
The DCCP clients were subsequently restarted, which again resulted in a reduced throughput of TCP, as indicated above.

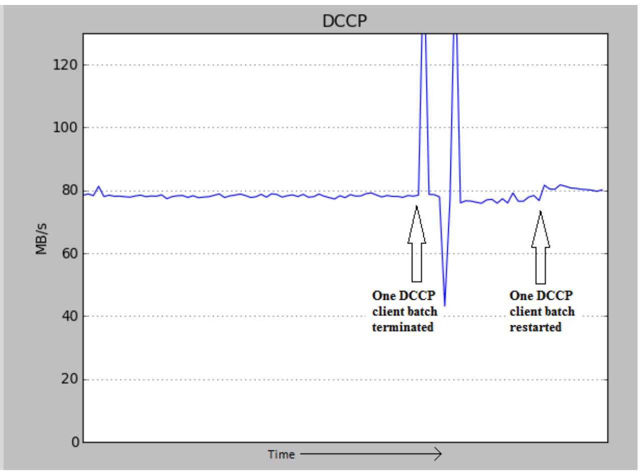
Following this, the behaviour of TCP and DCCP is analyzed when the initial DCCP bandwidth is *higher* than that of TCP. Two DCCP client batches were required to achieve this simulation. The throughput of the protocols are displayed below:





The above results indicate that TCP does not suppress DCCP's bandwidth when it is in effect. Instead, TCP operates at a lower potential throughput in DCCP's presence. After terminating one of the DCCP client batches, TCP's throughput increased. Restarting the same DCCP batch yielded the following graphs:





It is evident that DCCP's congestion control is in effect, as it allows TCP to make use of a significant amount of bandwidth, and does not suppress it outright. This contrasts greatly with UDP's effect as will be seen in §4.2.

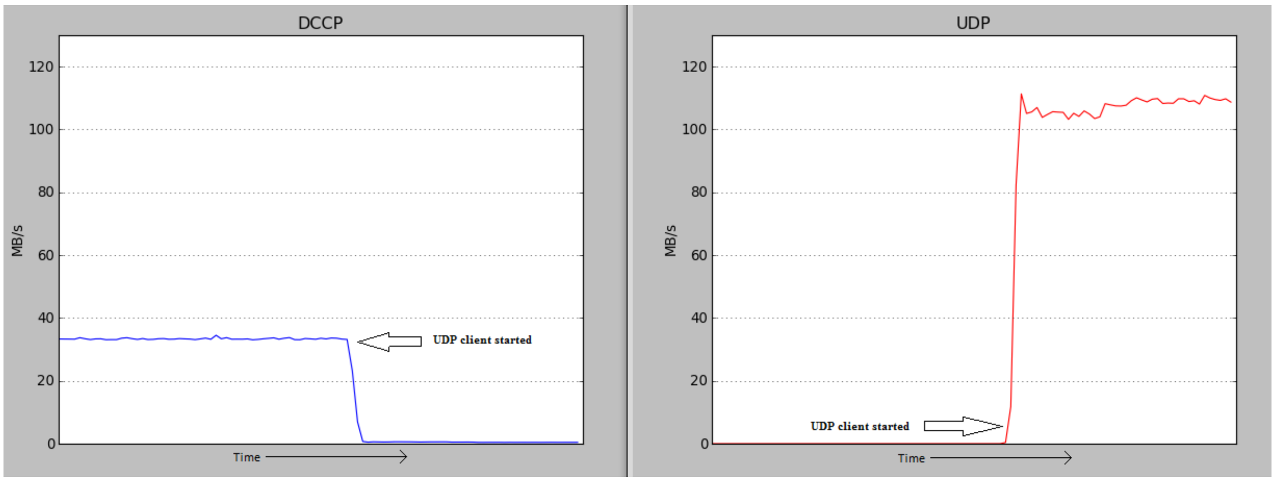
Note also that the sum of the bandwidths used by TCCP and DCCP make use of the full spectrum of bandwidth available, but in a controlled manner.

The bandwidth spikes are considered “anomalies”, and are discussed in greater detail in §7.

4.2 DCCP, TCP, and UDP Bandwidth Usage

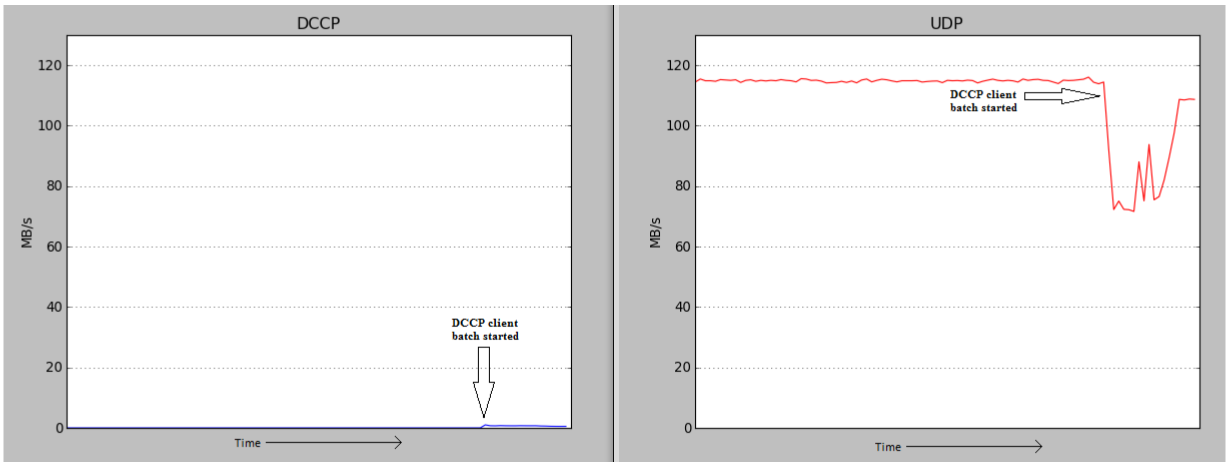
4.2.1 DCCP and UDP

Consider the test set-up of DCCP as above, contending for bandwidth against the UDP protocol:



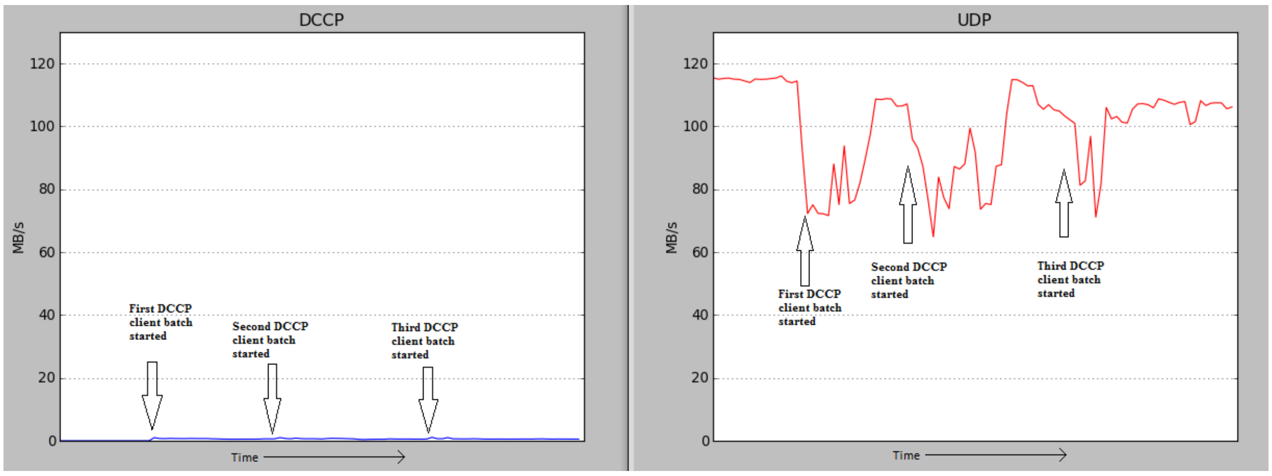
As indicated above, a UDP client was launched from a separate host, with the UDP server running on the same host as the DCCP server. DCCP bandwidth is immediately suppressed down to a minute amount of about 0.5 MB/s.

The following scenario depicts the behavior of UDP initially running in the absence of DCCP traffic. Note the stability of UDP bandwidth (i.e. no fluctuations), prior to enabling DCCP traffic.



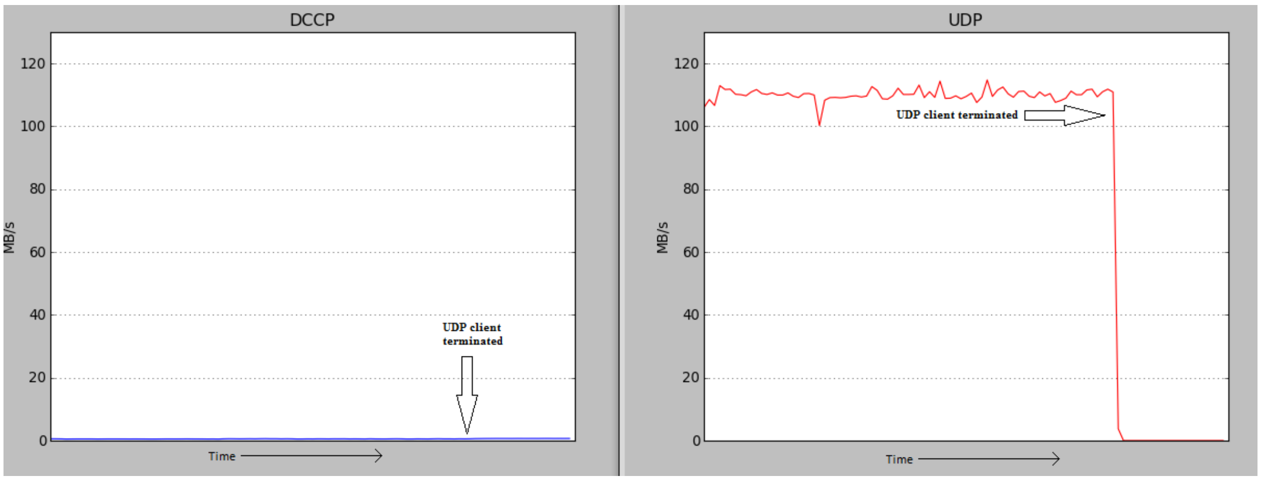
After initiating DCCP traffic, UDP traffic fluctuates greatly. However, it restricts DCCP traffic to a very small amount.

Extending this idea, consider the following graphs, which indicate the fluctuation of DCCP and UDP bandwidth upon successive addition of DCCP clients. In particular, it is notable that DCCP does not gain any additional bandwidth by enabling more clients.



While dips in UDP traffic are evident, DCCP's bandwidth remains the same as the above scenario, at approximately 0.5 MB/s. However,UDP fluctuates much more in DCCP's presence as opposed to in its absence.

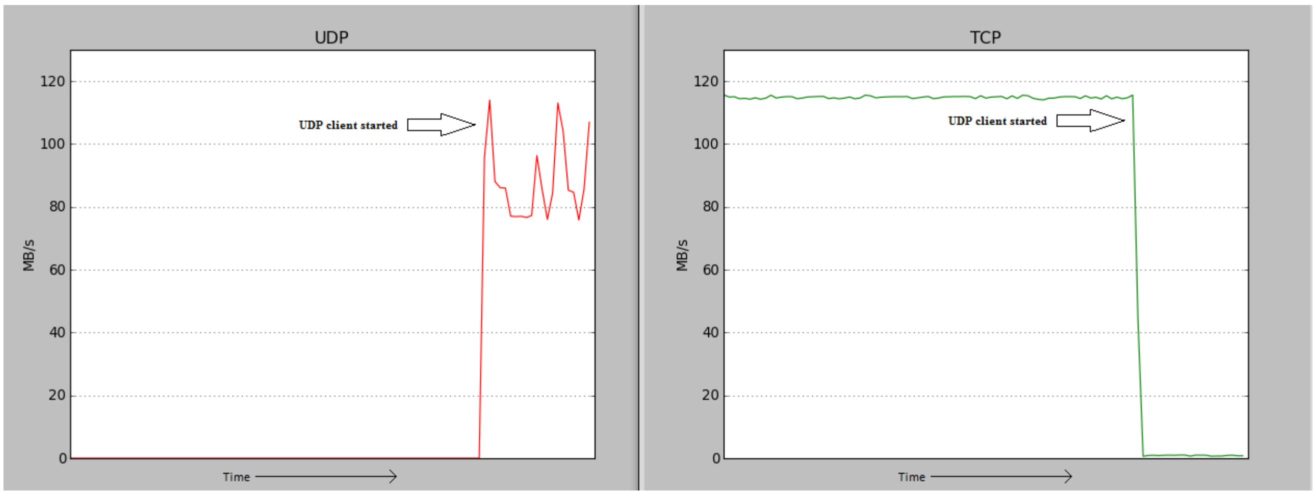
Interestingly, it was discovered that in the event that the UDP traffic is terminated while DCCP transmission (however small) is active, DCCP will *not* proceed to make use of the bandwidth that has become available:



It will be seen that this contrasts with TCP's behavior when UDP transmission is active. Thus, while DCCP has some effect on the stability of UDP, it cannot compete fairly for bandwidth.

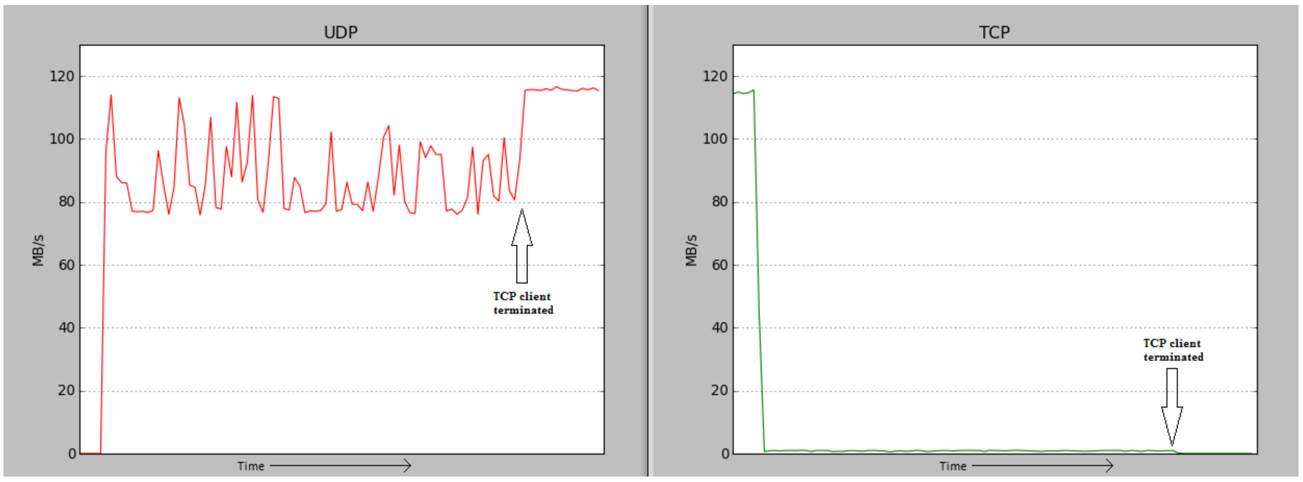
4.2.2 TCP and UDP

The scenario above is repeated with TCP replacing DCCP. In the same vein, consider the bandwidth utilization of the TCP and UDP protocols in the graph below:

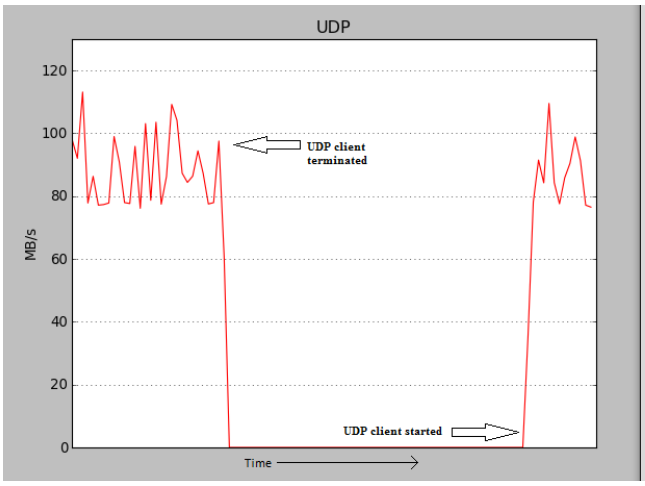


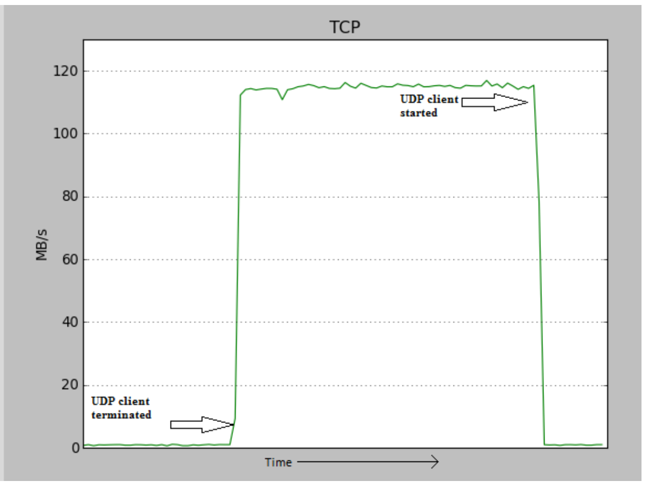
As indicated, TCP bandwidth takes a sharp dive as soon as the UDP client starts sending data.

In the following graphs, two notable points are raised. First, UDP bandwidth fluctuates greatly while the TCP protocol is active. Second, UDP bandwidth stabilizes as soon as the TCP bandwidth is eliminated:



However, unlike DCCP, TCP is able to make use of the available bandwidth when UDP is terminated:

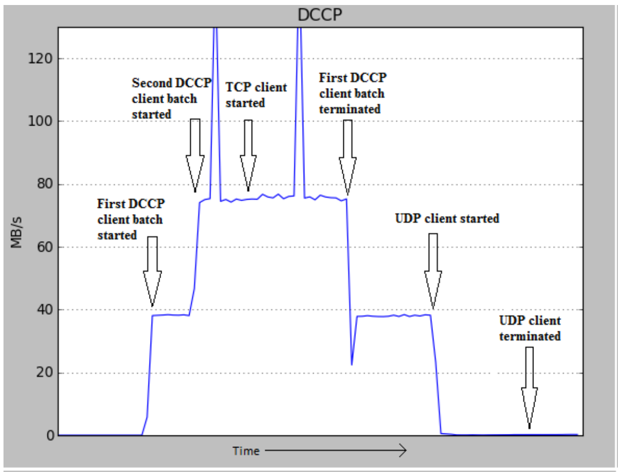


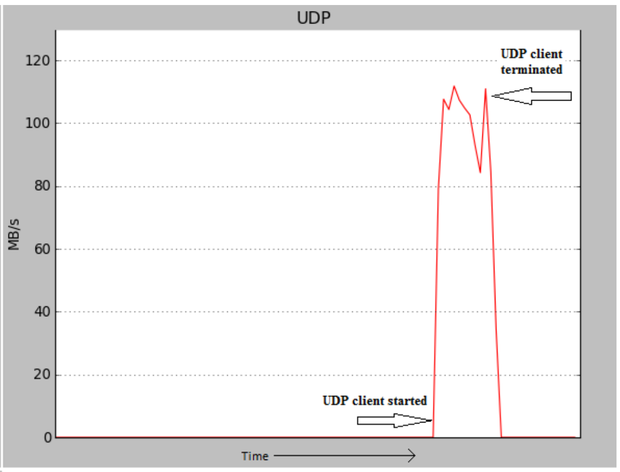


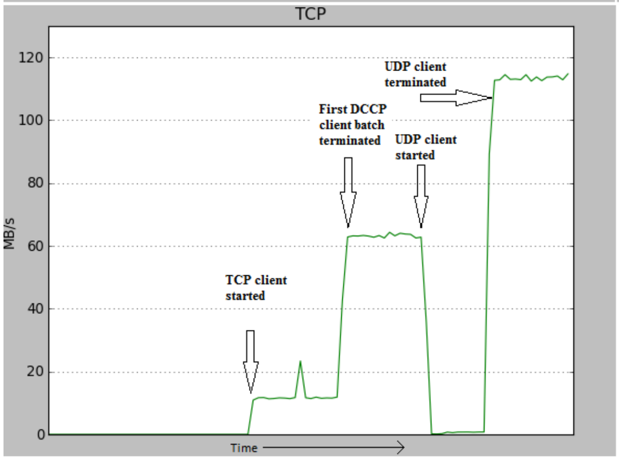
5 Extra Tests and Considerations

This report would not be complete without an evaluation of all three protocols running concurrently. However, it was necessary to establish each pairing separately, so that the behaviour from all three protocols can be analyzed with these results in perspective. Consider the following three graphs which summarize the following sequence of events:

1. One DCCP client batch is started, followed by a second batch
2. A TCP client is started
3. One DCCP client batch is terminated
4. A UDP client is started
5. The UDP client is terminated







The following behaviour is notable, and confirms the results found in the previous sections.

- When DCCP consumes the majority of the bandwidth initially, the initialized TCP client can still operate at with a reasonable amount of bandwidth available.
- When one of the DCCP client batches is terminated, TCP's bandwidth raises actively.
- The immediate presence of UDP traffic suppresses both that of TCP and DCCP's bandwidth.
- After the UDP client is terminated, TCP is able to make use of the available bandwidth, while DCCP is not.

6 Results

Having considered all of the above cases, the results can now be delivered conclusively.

Firstly, in §4.1 it was confirmed that DCCP tolerates TCP traffic to a much better extent than UDP. If TCP initially has a greater amount of incoming traffic, DCCP throttles itself accordingly. If DCCP initially has a greater amount of incoming traffic, TCP is still able to operate at a reasonable level.

Secondly, in §4.2, it was established that UDP indeed suppresses TCP and DCCP traffic. However, it does not completely and utterly do so, as TCP and DCCP can operate at a very ineffective level of about 0.5 MB/s.

Finally, it was interesting to note that while neither TCP or DCCP can hinder a large amount of incoming UDP traffic, only TCP can "recover" *after* the UDP traffic stops. DCCP traffic, on the other hand, remains at the very low rate that UDP suppressed it to.

The reason behind this latter point is not absolutely clear. One speculated reason is that the congestion control behind DCCP throttles DCCP traffic only in relation to TCP traffic, and not UDP. Thus, where DCCP can effectively maintain a reasonable bandwidth while only TCP is running, it has no safeguards once there is UDP traffic incoming. Once this UDP traffic is eliminated, DCCP does not detect that it has stopped, and maintains a low throughput.

7 Problems and Interesting Findings

7.1 Establishing a DCCP connection

One of the problems we[1] experienced was DCCP's inability to establish a connection without user intervention.

In order to establish a DCCP connection from a client to a server on different computers, it was first necessary to attempt a connection both ways. That is, one would need to initialize clients on both computers, each attempting to connect to the other. This connection need not succeed, but is necessary in order to prompt the kernel to use DCCP. These clients, their role being fulfilled, are discarded. Only then can a client-server connection from one computer to the other succeed.

7.2 Error 11

There were some initial difficulties in sending data over a DCCP connection. We initially simply sent our data using `socket.send()` on the client side, believing that as with TCP and UDP, this would be sufficient. This would result in `socket error 11, resource currently unavailable` being thrown, implying that if congestion is high, the congestion control protocol can decide not to send the data.

[1]The authors are fully aware that the use of personal pronouns are employed in this section. This is because "we" performed and encountered these actions. This is assumed to be an appropriate tone, and should not be considered "colloquial".

The `send` statement was thus placed within a try-except block a long with a sleep statement. The sleep statement would pace the client and prevent congestion, while the try-except block would ensure that the client continued to to send data after the “resource unavailable” exception occurred.

All that remained was to fine-tune the amount of time that the client would sleep for. Smaller times resulted in higher throughput and larger times resulted in lower throughput. It was hoped that there would be an ideal duration of time that would prevent the congestion control protocol from blocking the client, but ultimately the sleep interval was kept small to keep throughput high.

8 Conclusion