# Lab Exercise 5: TCP Congestion Control and Fairness

**There are 7 labs during this course. For each student, the 5 best performing labs will contribute to your final lab mark.**

## Objectives:

- gain insights into the operation of TCP.
- study how competing flows share nework resources.
- get familiar with the ns-2 simulator

## Prerequisites and Links:

- Week 6 & 7 Lectures
- Relevant Parts of Chapter 3 of the textbook
- Introduction to ns-2 as part of Lab Exercise 4
- Basic understanding of Linux. A good resource is here (http://www.ee.surrey.ac.uk/Teaching/Unix/) but there are several other resources online:
- tpWindow.tcl (https://webcms3.cse.unsw.edu.au/COMP3331/18s2/resources/17314)
- Window.plot (https://webcms3.cse.unsw.edu.au/COMP3331/18s2/resources/17317)
- WindowTPut.plot (https://webcms3.cse.unsw.edu.au/COMP3331/18s2/resources/17318)
- tp_fainess.tcl (https://webcms3.cse.unsw.edu.au/COMP3331/18s2/resources/17319)
- fairness_pps.plot (https://webcms3.cse.unsw.edu.au/COMP3331/18s2/resources/17320)
- tp_TCPUDP.tcl (https://webcms3.cse.unsw.edu.au/COMP3331/18s2/resources/17322)
- TCPUDP_pps.plot (https://webcms3.cse.unsw.edu.au/COMP3331/18s2/resources/17323)

## Marks: **10 marks.**

- You need to submit a report for this lab. There is no demonstration.
- Please attend the lab in your allocated lab time slot.
- This lab comprises of a number of exercises. Pl note that not all the exercises for this lab are marked. However, you have to submit a report containing answers for all of the lab exercises.
- We expect the students to go through as much of the lab exercises as they can at home and come to the lab for clarifying any doubts in procedure/specifications.

## Deadline:

***Midnight Friday 14th Sep 2018*** .You can submit as many times as you wish before the deadline. A later submission will override the earlier submission, so make sure you submit the correct file. Do not leave until the last moment to submit, as there may be technical or communications error and you will not have time to rectify it.

## Late Submission Penalty:

Late penalty will be applied as follows:

- 1 day after deadline: 20% reduction
- 2 days after deadline: 40% reduction
- 3 days after deadline: 60% reduction
- 4 or more days late: NOT accepted

Note that the above penalty is applied to your final mark. For example, if you submit your lab work 2 days late and your score on the lab is 8, then your final mark will be 8 - 3.2 (40% penalty) = 4.8.

## Submission Instructions:

Submit a PDF document **Lab5.pdf** with answers to all questions for Exercises 1, 2 & 3. To include all supporting documents, create a tar archive of all files called **Lab5.tar.** Submit the archive using give. You can submit from a lab machine or ssh into the CSE login server.

## Original Work Only:

You are strongly encouraged to discuss the questions with other students in your lab. However, each student must submit his or her own work. You may need to refer to the material indicated above (particularly Tools of the Trade document) and also conduct your own research to answer the questions.

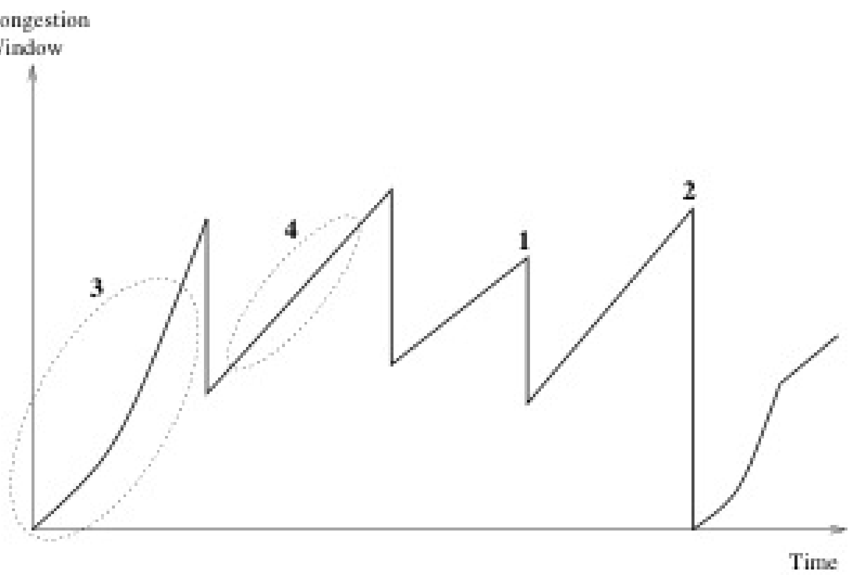
## Important Note:

The provided scripts (for ns-2 and gnuplot) have been tested on CSE Linux machines. They may not work on your personal machine even if you have installed ns-2 and gnuplot. As such, we suggest that you work on a CSE machine to complete these lab exercises. You can do so by going to a lab in person or via connecting to CSE through ssh. Pl note that in order to see the graphs produced by various scripts, you must be logged in CSE systems using vlab.

## Revision of TCP Congestion Control (NO SUBMISSION REQUIRED)

The following question is included so that you can revise the TCP congestion control algorithm. It is recommended that students have a short discussion with their tutors at the start of the lab to go over this question and TCP congestion control in general. Students are strongly encouraged to participate and ask questions. You are not required to submit the answer for this question in your lab report. I suggest that you use the first 15-20 minutes of the lab to go over this.

The graph in the figure below shows how the congestion window of a TCP Reno connection changes over time. It is drawn roughly to scale. Certain parts of the graph that are of extra interest have been marked with numbers. With the help of the graph, answer the following questions:



Question 1. Name the loss events that occur at 1 and 2. Explain why the congestion window is changed differently in those two cases.

Question 2. What phase of the TCP congestion control algorithm coincides with the circled segment marked by 3 ?

Question 3. What phase of the TCP congestion control algorithm coincides with the circled segment marked by 4 ?

Question 4: Why is the congestion window increased more rapidly at 3 than at 4?

Question 5: Can you precisely explain what happens to the window after 2 ?

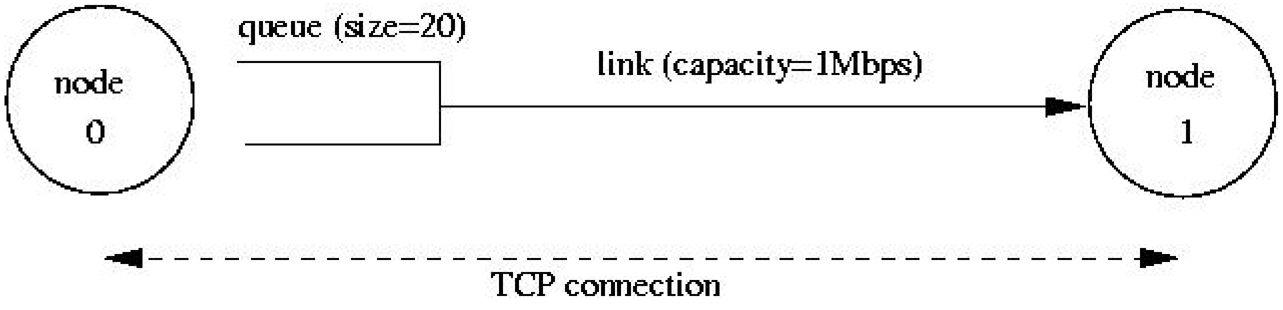
## Exercise 1: Understanding TCP Congestion Control using ns-2

We have studied the TCP congestion control algorithm in detail in the lecture (and Section 3.6 of the text). You may wish to review this before continuing with this exercise. Recall that, each TCP sender limits the rate at which it sends traffic as a function of perceived network congestion. We studied three variants of the congestion control algorithm: TCP Tahoe, TCP Reno and TCP new Reno.

We will first consider TCP Tahoe (this is the default version of TCP in ns-2). Recall that TCP Tahoe uses two mechanisms:

- A varying congestion window, which determines how many packets can be sent before the acknowledgment for the first packet arrives.
- A slow-start mechanism, which allows the congestion window to increase exponentially in the initial phase, before it stabilises when it reaches threshold value. A TCP sender re-enters the slow-start state whenever it detects congestion in the network.

The provided script, tpWindow.tcl (https://webcms3.cse.unsw.edu.au/COMP3331/18s2/resources/17314) implements a simple network that is illustrated in the figure below.



Node 0 and Node 1 are connected via a link of capacity 1 Mbps. Data traffic will only flow in the forward direction, i.e. from Node 0 to Node 1. Observe that packets from node 0 are enqueued in a buffer that can hold 20 packets. All packets are of equal size and are equal to the MSS.

The provided script accepts two command line arguments:

- the maximum value of the congestion window at start-up in number of packets (of size MSS).
- The one-way propagation delay of the link

You can run the script as follows:

```
$ns tpWindow.tcl <max_cwnd> <link_delay>
```

**NOTE:** The NAM visualiser is disabled in the script. If you want to display the NAM window (graphical interface), then uncomment the fifth line of the 'finish' procedure (i.e. remove the "#"):

```
proc finish {} {
     global ns file1 file2
     $ns flush-trace
     close $file1
     close $file2
     #exec nam out.nam &
     exit 0
}
```

We strongly recommend that you read through the script file to understand the simulation setting. The simulation is run for 60 seconds. The MSS for TCP segments is 500 bytes. Node 0 is configured as a FTP sender which transmits a packet every 0.01 second. Node 1 is a receiver (TCP sink). It does not transmit data and only acknowledges the TCP segments received from Node 0.

The script will run the simulation and generate two trace files: (i) *Window.tr,* which keeps track of the size of the congestion window and (ii) *WindowMon.tr* , which shows several parameters of the TCP flow.

The *Window.tr* file has two columns:

```
time congestion_window_size
```

A new entry is created in this file every 0.02 seconds of simulation time and records the size of the congestion window at that time.

The *WindowMon.tr* file has six columns:

```
time number_of_packets_dropped drop_rate throughput queue_size avg_tput
```

A new entry is created in this file every second of simulation time. The *number_of_packets_dropped* , *drop_rate* and *throughput* represents the corresponding measured values over each second. The *queue_size* indicates the size of the queue at each second, whereas *avg_tput* is the average throughput measured since the start of the simulation.

Question 1: Run the script with the max initial window size set to 150 packets and the delay set to 100ms (be sure to type "ms" after 100). In other words, type the following:

```
$ns tpWindow.tcl 150 100ms
```

In order to plot the size of the TCP window and the number of queued packets, we use the provided gnuplot script Window.plot (https://webcms3.cse.unsw.edu.au/COMP3331/18s2/resources/17317) as follows:

```
$gnuplot Window.plot
```

What is the maximum size of the congestion window that the TCP flow reaches in this case? What does the TCP flow do when the congestion window reaches this value? Why? What happens next? Include the graph in your submission report.

Question 2: From the simulation script we used, we know that the payload of the packet is 500 Bytes. Keep in mind that the size of the IP and TCP headers is 20 Bytes, each. Neglect any other headers. What is the average throughput of TCP in this case? (both in number of packets per second and bps)

You can plot the throughput using the provided gnuplot script WindowTPut.plot (https://webcms3.cse.unsw.edu.au/COMP3331/18s2/resources/17318) as follows:

```
$gnuplot WindowTPut.plot
```

This will create a graph that plots the instantaneous and average throughput in packets/sec. Include the graph in your submission report.

Question 3: Rerun the above script, each time with different values for the max congestion window size but the same RTT (i.e. 100ms). How does TCP respond to the variation of this parameter? Find the value of the maximum congestion window at which TCP stops oscillating (i.e., does not move up and down again) to reach a stable behaviour. What is the average throughput (in packets and bps) at this point? How does the actual average throughput compare to the link capacity (1Mbps)?

**TCP Tahoe vs TCP Reno**

Recall that, so far we have observed the behaviour of TCP Tahoe. Let us now observe the difference with TCP Reno. As you may recall, in TCP Reno, the sender will cut the window size to 1/2 its current size if it receives three duplicate ACKs. The default version of TCP in ns-2 is TCP Tahoe. To change to TCP Reno, modify the Window.tcl OTcl script. Look for the following line:

```
set tcp0 [new Agent/TCP]
```

and replace it with:

```
set tcp0 [new Agent/TCP/Reno]
```

Question 4: Repeat the steps outlined in Question 1 and 2 (NOT Question 3) but for TCP Reno. Compare the graphs for the two implementations and explain the differences. (Hint: compare the number of times the congestion window goes back to zero in each case). How does the average throughput differ in both implementations?

**Note:** Remember to include all graphs in your report.

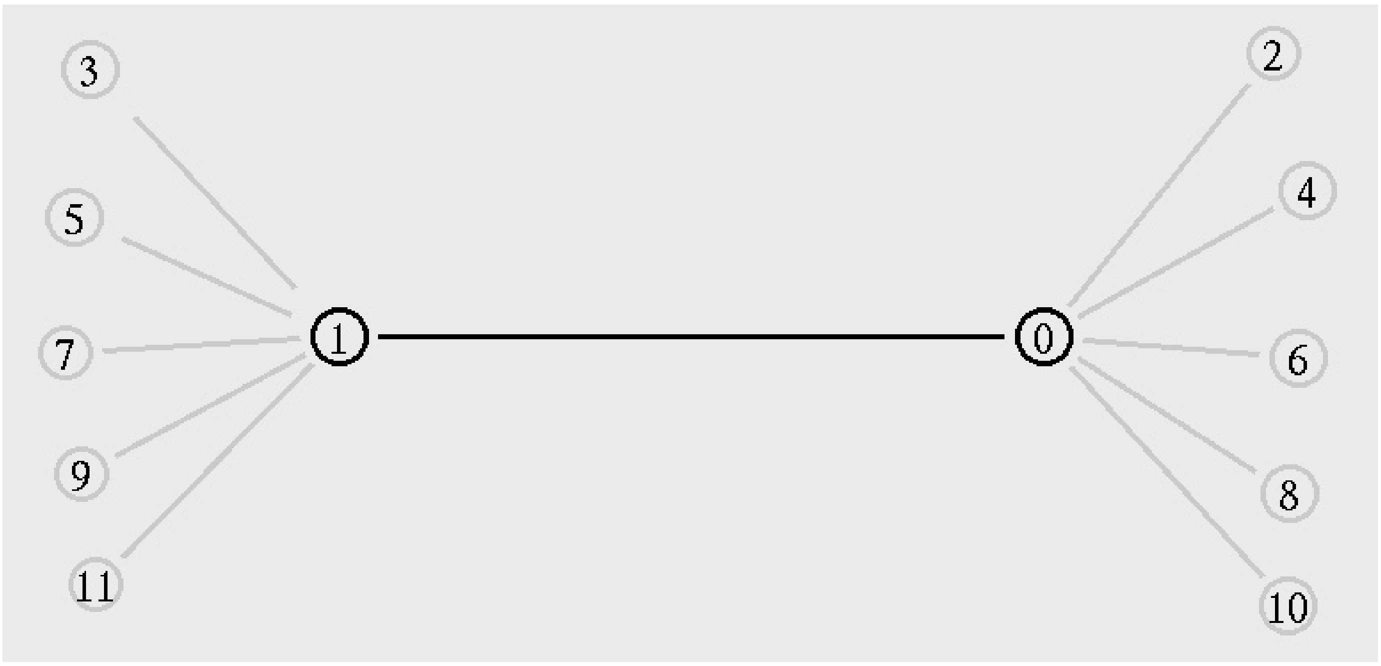
## Exercise 2: Flow Fairness with TCP

In this exercise, we will study how competing TCP flows with similar characteristics behave when they share a single bottleneck link.

The provided script, tp_fairness.tcl (https://webcms3.cse.unsw.edu.au/COMP3331/18s2/resources/17319) generates 5 source-destination pairs which all share a common network link. Each source uses a single TCP flow which transfers FTP traffic to the respective destination. The flows are created one after the other at 5-second intervals (i.e., flow *i+1* starts 5 seconds after flow *i* for *i* in *[1,4]* ). You can invoke the script as follows

```
$ns tp_fairness.tcl
```

The figure below shows the resulting topology; there are 5 sources (2,4,6,8,10), 5 destinations (3,5,7,9,11), and each source is sending a large file to a single destination. Node 2 is sending a file to Node 3, Node 4 is sending a file to Node 5, and so on.



The script produces one output file per flow; farinessMon *i* .tr for each *i* in *[1,5]* . Each of these files contains three columns:

time | number of packets delivered so far | throughput (packets per second)

You can plot the throughput as a function of time using the provided gnuplot script, fairness_pps.plot (https://webcms3.cse.unsw.edu.au/COMP3331/18s2/resources/17320) , as follows:

```
$gnuplot fairness_pps.plot
```

**NOTE:** The NAM visualiser is disabled in the script. If you want to display the NAM window (graphical interface), modify tp_fairness.tcl and uncomment the fifth line of the 'finish' procedure:

```
proc finish {} {
    global ns file1 file2
    $ns flush-trace
    close $file1
    close $file2
    #exec nam out.nam &
    exit 0
}
```

Run the above script and plot the throughput as a function of time graph and answer the following questions:

Question 1: Does each flow get an equal share of the capacity of the common link (i.e., is TCP fair) ? Explain which observations lead you to this conclusion.

Question 2. What happens to the throughput of the pre-existing TCP flows when a new flow is created? Explain the mechanisms of TCP which contribute to this behaviour. Argue about whether you consider this behaviour to be fair or unfair.

**Note:** Remember to include all graphs in your report.

## Exercise 3: TCP competing with UDP

In this exercise, we will observe how a TCP flow reacts when it has to share a bottleneck link that is also used by a UDP flow.

The provided script, tp_TCPUDP.tcl (https://webcms3.cse.unsw.edu.au/COMP3331/18s2/resources/17322) , takes a link capacity value as a command line argument. It creates a link with the given capacity and creates two flows which traverse that link, one UDP flow and one TCP flow. A traffic generator creates new data for each of these flows at a rate of 4Mbps. You can execute the simulation as follows,

```
$ns tp_TCPUDP <link_capacity>
```

After the simulation completes, you can plot the throughput using the provided gnuplot script, TCPUDP_pps.plot (https://webcms3.cse.unsw.edu.au/COMP3331/18s2/resources/17323) , as follows,

```
$gnuplot TCPUDP_pps.plot
```

Question 1: How do you expect the TCP flow and the UDP flow to behave if the capacity of the link is 5 Mbps ?

Now, you can use the simulation to test your hypothesis. Run the above script as follows,

```
$ns tp_TCPUDP.tcl 5Mb
```

The script will open the NAM window. Play the simulation. You can speed up the simulation by increasing the step size in the right corner. You will observe packets with two different colours depicting the UDP and TCP flow. Can you guess which colour represents the UDP flow and the TCP flow respectively ?

You may disable the NAM visualiser by commenting the "exec nam out.nam &' line in the 'finish' procedure.

Plot the throughput of the two flows using the above script (TCPUDP_pps.plot) and answer the following questions:

Question 2: Why does one flow achieve higher throughput than the other? Try to explain what mechanisms force the two flows to stabilise to the observed throughput.

Question 3: List the advantages and the disadvantages of using UDP instead of TCP for a file transfer, when our connection has to compete with other flows for the same link. What would happen if everybody started using UDP instead of TCP for that same reason?

**Note:** Remember to include all graphs in your report.

Resource created 4 months ago (Monday 16 July 2018, 02:50:39 PM), last modified 2 months ago (Wednesday 12 September 2018, 05:17:55 PM).

## Comments

(/COMP3331/18s2/forums/search?forum_choice=resource/17353) (/COMP3331/18s2/forums/resource/17353)

Add a comment

Kavitha Narayanan (/users/z5190588) 2 months ago (Thu Sep 13 2018 12:38:03 GMT+1000 (澳大利亚东部标准时间)), last modified 2 months ago (Thu Sep 13 2018 12:40:59 GMT+1000 (澳大利亚东部标准时间))

## Exercise 2: Flow Fairness with TCP:

**For this question, should we assume same RTT/MSS for each pair of TCP connections?Also is the link capacity necessary to calculate fairness?or can we just consider the throughput numbers in the trace file of each connection enough to answer the question?(and when the question says plot the graph,it basically means run the script for gnuplot and copy the graph to the report? or we have to plot it by ourselves with the throughput numbers**

Reply

Nadeem Ahmed (/users/z3003139) 2 months ago (Thu Sep 13 2018 15:31:22 GMT+1000 (澳大利亚东部标准时间))

You can make any reasonable assumption for any missing data. You can answer based on the throughput graph only. And yes plotting means to simply run the given script and capture the screenshot for inclusion in the report.

Reply

Kavitha Narayanan (/users/z5190588) 2 months ago (Thu Sep 13 2018 17:38:15 GMT+1000 (澳大利亚东部标准时间))

Ok sir, Thank you for the clarification!

Reply

Rafael Barreto Sotomayor (/users/z5192279) 2 months ago (Wed Sep 12 2018 18:07:18 GMT+1000 (澳大利亚东部标准时间))

Hi all - Do we need to submit all the files generated by the ns-2 simulations as a Lab5.tar? Or is it sufficient to just put all the graphs generated in the report and submit just a Lab5.pdf?

Reply

Ali Dorri (/users/z5095883) 2 months ago (Wed Sep 12 2018 18:19:23 GMT+1000 (澳大利亚东部标准时间))

Just the graphs should be enough.

Reply

Rafael Barreto Sotomayor (/users/z5192279) 2 months ago (Thu Sep 13 2018 09:25:15 GMT+1000 (澳大利亚东部标准时间))

Hi Ali - the graphs are already in the report, do we still need to include them separately?

Reply

Ali Dorri (/users/z5095883) 2 months ago (Thu Sep 13 2018 10:34:43 GMT+1000 (澳大利亚东部标准时间))

No, if they are included in the report it should be enough

Reply

Raghav Singh (/users/z5190887) 2 months ago (Wed Sep 12 2018 17:13:58 GMT+1000 (澳大利亚东部标准时间))

Hi! You have written "ns tp_TCPUDP 5Mb" for testing. It should be "ns tp_TCPUDP.tcl 5Mb" I know this is a small thing but I thought I'll let you know anyway. Sorry!

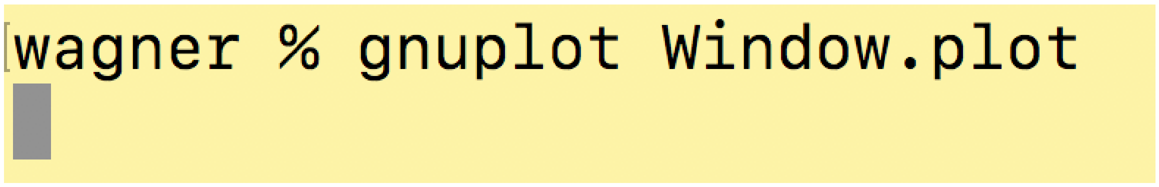
Reply

Nadeem Ahmed (/users/z3003139) 2 months ago (Wed Sep 12 2018 17:18:35 GMT+1000 (澳大利亚东部标准时间))

Thanks for pointing that out. Correction has been applied.

Reply

Jialun Li (/users/z5172023) 2 months ago (Wed Sep 12 2018 14:12:39 GMT+1000 (澳大利亚东部标准时间))



```
wagner % gnuplot Window.plot
```

When I was trying to run this command "$gnuplot Window.plot" (from my computer ssh), it get stuck like this. Then I press <return> it just quits without creating any graph.png.

Reply

Thomas George (/users/z5112681) 2 months ago (Wed Sep 12 2018 17:01:05 GMT+1000 (澳大利亚东部标准时间))

same

Reply

Mingda Liu (/users/z5019749) 2 months ago (Wed Sep 12 2018 16:34:01 GMT+1000 (澳大利亚东部标准时间))

Same here!

Reply

Nadeem Ahmed (/users/z3003139) 2 months ago (Wed Sep 12 2018 16:56:36 GMT+1000 (澳大利亚东部标准时间)), last modified 2 months ago (Wed Sep 12 2018 17:09:01 GMT+1000 (澳大利亚东部标准时间))

You cannot see the graph over ssh. Use vlab.

https://taggi.cse.unsw.edu.au/FAQ/VLAB_-_The_technical_details/

Reply

Abanob Tawfik (/users/z5075490) 2 months ago (Tue Sep 11 2018 14:47:29 GMT+1000 (澳大利亚东部标准时间))

for part 1 question 4, when i performed the exercise using TCP reno, i got this weird bump at the start that i cant seem to understand. the window size increases to 100 and there seems to be a timeout, as there is a drop, however there is a brief period of transmission circled in my picture, and then the window size goes to 0, however the slow start threshold is now 25, in the lecture it said the window drops by half in an event of triple dupack/timeout. the little bump also didnt have the same behaviour as fast re-transmit. is this just an anomoly or is there more to it?

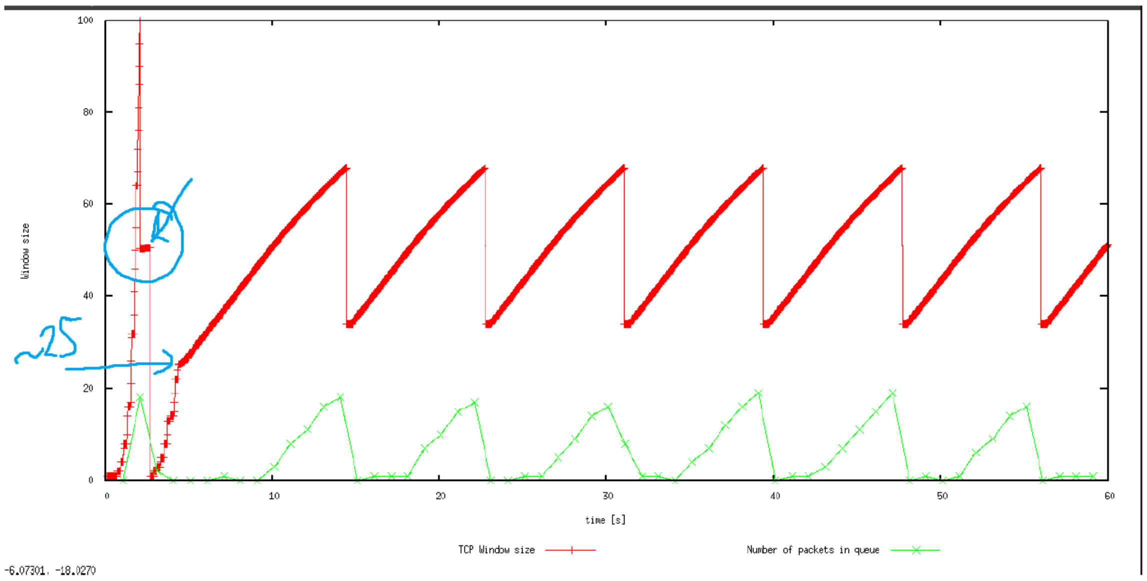


*Figure 9 plot of the TCP Reno window size and queued packets*

Reply

Nadeem Ahmed (/users/z3003139) 2 months ago (Tue Sep 11 2018 17:54:52 GMT+1000 (澳大利亚东部标准时间))

The circled point is due to 3DUPAcks. The SSthrehold has fallen down to 50 and retransmission has been done but the losses seems to be in consecutive segments (not an isolated loss that can be recovered by a single retransmission) resulting in a timeout. Cwnd is now reduced to 1 and SSthrehold to half of previous value (50/2=25).

Reply

Liyee Zhen (/users/z5133975) 2 months ago (Mon Sep 10 2018 17:04:01 GMT+1000 (澳大利亚东部标准时间))

How do we see the graph after running gnuplot? The process stays running without an output when the command is ran on ssh.....

Reply

Michael Theos (/users/z3419746) 2 months ago (Fri Sep 14 2018 12:50:11 GMT+1000 (澳大利亚东部标准时间))

If you copy the lines from the TCPUDP plot file that redirects output to a png file into the other 2 plot files, you can make them all save to a file

Reply

Nadeem Ahmed (/users/z3003139) 2 months ago (Mon Sep 10 2018 19:11:52 GMT+1000 (澳大利亚东部标准时间)), last modified 2 months ago (Wed Sep 12 2018 17:07:44 GMT+1000 (澳大利亚东部标准时间))

Read the script. Its writing to a .png file. Locate this file.

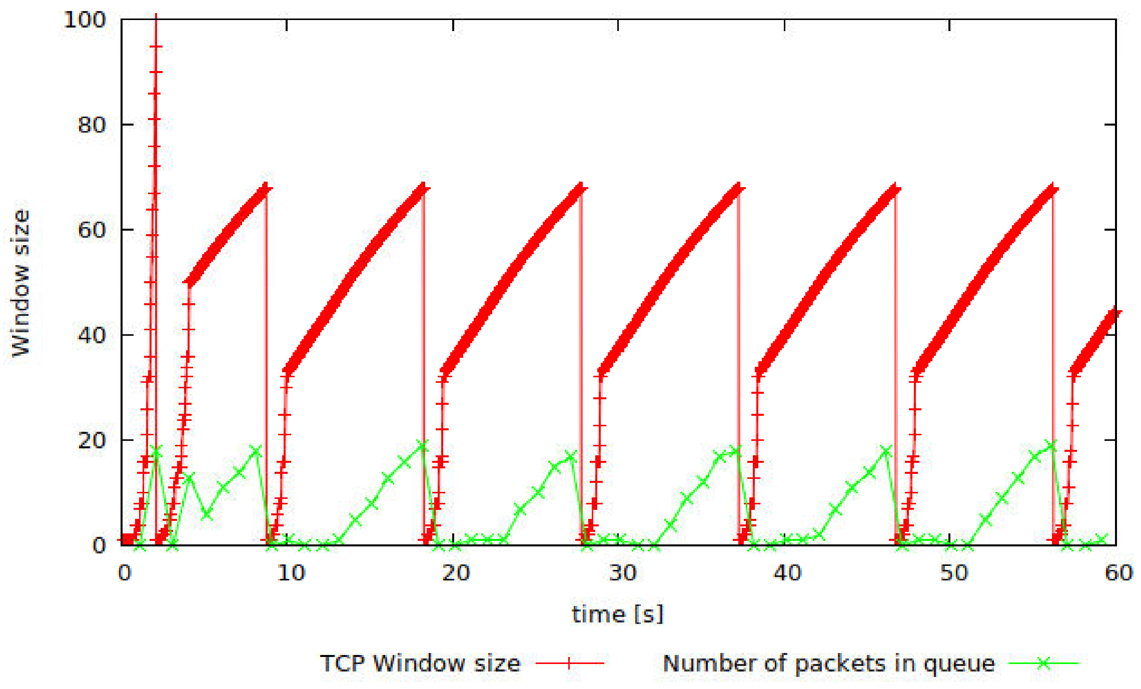
In case the script is not writing the graph to a png file, you need to run the command when using vLab so that you can see the graphical output in a new window.

https://taggi.cse.unsw.edu.au/FAQ/VLAB_-_The_technical_details/

Reply

Joshua Hing (/users/z5117173) 2 months ago (Sat Sep 08 2018 08:16:06 GMT+1000 (澳大利亚东部标准时间))

For TCP Tahoe, cwnd = 1 for both triple dup ACK and timeout. With that in mind, how can you determine what event caused the first cwnd drop?



Reply

Nadeem Ahmed (/users/z3003139) 2 months ago (Sat Sep 08 2018 11:40:20 GMT+1000 (澳大利亚东部标准时间))

You can't tell. Same is the case for all subsequent reductions to 1 cwnd for TCP Tahoe. Simply refer to this as a congestion event (either timeout or 3Dup ACKs).

Reply

Teng Long (/users/z5180585) 2 months ago (Fri Sep 14 2018 14:52:53 GMT+1000 (澳大利亚东部标准时间)), last modified 2 months ago (Fri Sep 14 2018 14:53:10 GMT+1000 (澳大利亚东部标准时间))

Does that means for the first slow start the congestion could either be caused by timeout or 3 ACK, and for the following congestion avoidance phases, the congestion should be caused by time out since the CWND is smaller than 100 where no packets will be dropped.

Reply

Nadeem Ahmed (/users/z3003139) 2 months ago (Fri Sep 14 2018 15:20:06 GMT+1000 (澳大利亚东部标准时间))

Packets drops are related to the queue length (shown in green). It touches 20 and then falls back due to reduction of the Cwnd. A single drop would be corrected by 3DUP Ack while more drops would result in Time out. For TCP Tahoe, as the reaction for both events is the same (reduce Cwnd to 1), you have to dig in the trace file to see what was the actual cause.

For this task, you don't need to actually find this out. Simply mention that a congestion event has happened.

Reply