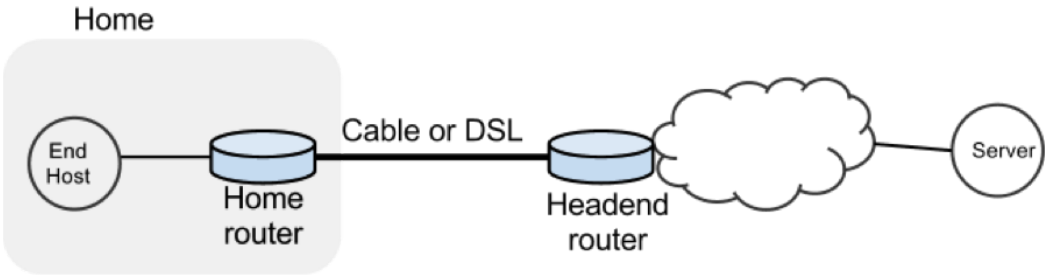
Bufferbloat on Network Emulator (Mininet)

Assignment Due: April, 11th 2021 11:59 PM (Pacific Time)

This document contains all the instructions necessary for completing the assignment, including setting up the simulation environment. Some sections may be unnecessary depending on students' experience. Yet, it is highly recommended that the document is read in full before attempting anything. This minimizes the chances for missing hints that may be helpful while finding the solutions.

Bufferbloat

In this exercise we will study the dynamics of TCP in home networks. Take a look at the figure below which shows a "typical" home network with a Home Router connected to an end host. The Home Router is connected via Cable or DSL to a Headend router at the Internet access provider's office. We are going to study what happens when we download data from a remote server to the End Host in this home network.



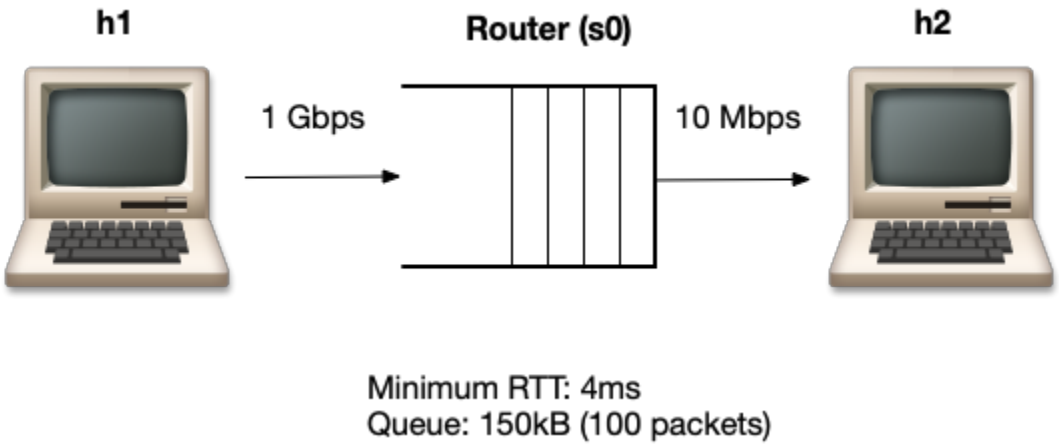
In a real network it's hard to measure cwnd (because it's private to the server) and the buffer occupancy (because it's private to the router). To ease our measurement, we are going to emulate the network in Mininet.

Goals

- Learn the dynamics of TCP sawtooth and router buffer occupancy in a network.
- Learn why large router buffers can lead to poor performance which is often called "**bufferbloat**."
- Learn how to use Mininet to create network topologies, run traffic generators, collect statistics and plot them.
- Learn how to package your experiments so it's easy for others to run your code.

Tasks

Within Mininet, create the following topology. Here h1 is a remote server (ie google.com) on the Internet that has a fast connection (1Gb/s) to your home router with a slow uplink connection (10Mb/s). The round-trip propagation delay, or the minimum RTT between h1 and h2 is 4ms. The router buffer size can hold 100 full sized ethernet frames (about 150kB with an MTU of 1500 bytes).



Then do the following:

- Start a long lived TCP flow sending data from h1 to h2. Use iperf.
- Send pings from h1 to h2 10 times a second and record the RTTs.
- Plot the time series of the following:
    - The long lived TCP flow's cwnd
    - The RTT reported by ping
    - Queue size at the bottleneck
- Spawn a webserver on h1. Periodically download the index.html web page (three times every five seconds) from h1 and measure how long it takes to fetch it (on average). The starter code has some hints on how to do this. Make sure that the webpage download data is going in the same direction as the long-lived flow.
- The long lived flow, ping train, and web server downloads should all be happening simultaneously.

Repeat the above experiment and replot all three graphs with a smaller router buffer size (Q=20 packets).

Setting up the Emulation Environment

Mininet is a network emulator that creates a virtual network on your computer that communicates actual packets between virtually independent nodes. This allows researchers to test different scenarios without having access to a large (possibly expensive) network.

You can check the Mininet web page (http://mininet.org) and follow the instructions to install it on your own environment if requirements are satisfied. However there is an easier method. Below we describe how to setup a VM that would have all the necessary modules installed for this class. You can even use it for the second assignment of this class, and maybe even for your final project.

Setting up a VM

In order to give you a more comprehensive "Computer Networks Researcher" VM (because you are one), we will describe setting up a VM with some useful networking research tools installed.

- Visit http://mininet.org/download/ and download Mininet VM (mininet-2.3.0-210211-ubuntu-16.04.7-server-amd64-ovf.zip)
- Note that we are downloading Ubuntu 16.04.7 (not the most recent one)
- VM is about 1 GB, so it might take a moment to download
- Follow VM Setup Notes (http://mininet.org/vm-setup-notes/) to import the downloaded VM with default settings
- Before starting the VM, Settings > Network > Adapter 1 then select "Bridged Adapter". This will allow you to ssh into the VM once you turn it on.
- If you encounter a "Kernel driver not installed" error, you can follow the steps at https://medium.com/@Aenon/mac-virtualbox-kernel-driver-error-df39e7e10cd8 to solve it
- Both the username and password for the VM are `mininet`.
- Once you logged into the VM run `ifconfig` to figure out the IP address of your VM. It should look like the following:

```
mininet@mininet-vm:~$ ifconfig
eth0      Link encap:Ethernet  HWaddr 08:00:27:12:21:f8
          inet addr:192.168.1.181  Bcast:192.168.1.255  Mask:255.255.255.0
          UP BROADCAST RUNNING MULTICAST  MTU:1500  Metric:1
          RX packets:151 errors:0 dropped:0 overruns:0 frame:0
          TX packets:143 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:24084 (24.0 KB)  TX bytes:13772 (13.7 KB)

lo        Link encap:Local Loopback
          inet addr:127.0.0.1  Mask:255.0.0.0
          UP LOOPBACK RUNNING  MTU:65536  Metric:1
          RX packets:0 errors:0 dropped:0 overruns:0 frame:0
          TX packets:0 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1
          RX bytes:0 (0.0 B)  TX bytes:0 (0.0 B)
```

- In our case the address of the VM is 192.168.1.181, so we will run `ssh -L 8000:localhost:8000 mininet@192.168.1.181` when logging into it from our terminal.
- There is a step in Mininet Walkthrough where Wireshark is tested. If it doesn't work for you don't worry, we will not use Wireshark for our assignments.
- Since the Linux (and Python) versions of the VM are a little bit old we will need to upgrade some modules for our assignments. Run the following commands:
  - `pip install --upgrade pip==9.0.1`
  - `pip install termcolor --user`
  - `pip install matplotlib --user`
  - `sudo apt-get install curl`
- Now the VM is ready for running assignment programs.

Framework code

To help you get started, we provide a basic skeleton code. Once you have your VM instance running, run a Mininet sanity check (sudo mn --test pingall) and then continue with this assignment. Your instance should have Mininet and most tools pre-installed.

Clone the starter code for this project:

```
git clone https://github.com/brucespang/cs244-bufferbloat.git

cd cs244-bufferbloat
```

Look for TODOs in the starter code. The following are important files you will find in the repository. Ignore other files.

File	Purpose
bufferbloat.py	Creates the topology, measures cwnd, queue sizes and RTTs and spawns a webserver.
plot_queue.py	Plots the queue occupancy at the bottleneck router
plot_ping.py	Parses and plots the RTT reported by ping
plot_tcpprobe.py	Plots the cwnd time-series for a flow specified by its destination port
run.sh	Runs the experiment and generates all graphs in one go.

Note: We recommend you using a version control system to track changes to your assignment and back it up regularly on the "cloud." Both Github and Bitbucket host private git repositories for free. Do NOT use a public repo; you will run the risk of violating the Honor Code. This applies for all the assignments; feel free to use a public repo for the final project.

Submission/Deliverables

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Please upload all of the following to gradescope:

- **Final Code**: Remember one of the goals of this assignment is for you to build a system that is easy to rerun to reproduce results. Therefore, your final code MUST be runnable as a single shell command ("`sudo ./run.sh`"). We will test your code in the same setup.
- **README**: A file named `README` file with instructions to reproduce the results as well as the answers to the below questions. Please identify your answers with the question number, and please keep your answers brief. Please list installation instructions for any dependencies required to run your code.
- **Plots**: There should be 6 plots in total, 3 each for router buffer sizes 100 and 20 packets. They MUST have the following names and be present in your submission folder
    - `bb-q100/cwnd-iperf.png, bb-q100/q.png, bb-q100/rtt.png.`
    - `bb-q20/cwnd-iperf.png, bb-q20/q.png, bb-q20/rtt.png.`

Questions

Include your answers to the following questions in your README file. Remember to keep answers brief.

1. Why do you see a difference in webpage fetch times with short and large router buffers?
2. Bufferbloat can occur in other places such as your network interface card (NIC). Check the output of `ifconfig eth0` on your VirtualBox VM. What is the (maximum) transmit queue length on the network interface reported by ifconfig? For this queue size, if you assume the queue drains at 100Mb/s, what is the maximum time a packet might wait in the queue before it leaves the NIC?
3. How does the RTT reported by ping vary with the queue size? Describe the relation between the two.
4. Identify and describe two ways to mitigate the bufferbloat problem.
5. Describe how and why your results change when you re-run the emulation.

Notes

- When running the curl command to fetch a web page, please fetch webserver_ip_address/http/index.html.

Grading

Total: 10 pts

- 3 points: Producing working code that generates the graphs
- 5 points: Answering the questions
- 1 point: Producing correct graphs
- 1 point: Design and code quality

Mininet tutorial

The "Introduction to Mininet" tutorial on github has a number of examples to help you with common tasks you will encounter in this assignment: creating topologies, spawning programs (ping, iperf, etc.) and collecting output.

https://github.com/mininet/mininet/wiki/Introduction-to-Mininet

Useful Hints

To look at your output, `run.sh` script starts a web server in the `cs244-bufferbloat` directory using the command below. Then you can point a web browser to `<vm-ip>:8000` and browse your results.

```
python -m SimpleHTTPServer.
```

If your Mininet script does not exit cleanly due to an error (or if you pressed Control-C), you may want to issue a clean command `sudo mn -c` before you start Mininet again. Take a look at the `run.sh` script to see how it does that.