What is the normal time required to download the webpage on h1 from h2?

```
mininet> h2 wget h1
--2021-10-27 22:02:23--  http://10.0.0.1/
Connecting to 10.0.0.1:80... connected.
HTTP request sent, awaiting response... 200 OK
Length: 177669 (174K) [text/html]
Saving to: 'index.html'

     0K .......... .......... .......... .......... .......... 28%  180K 1s
    50K .......... .......... .......... .......... .......... 57%  173K 0s
   100K .......... .......... .......... .......... .......... 86%  168K 0s
   150K .......... .......... ...                              100%  183K=1.0s

2021-10-27 22:02:24 (175 KB/s) - 'index.html' saved [177669/177669]
```

The time taken is 1 second.

What was your initial expectation for the congestion window size over time?

The initial state of congestion control would be slow start, so cwnd should increase exponentially e.g. 1, 2, 4, 8.... Over time a long period of time cwnd is expected to average to a very high value since loss events would be uncommon in the controlled environment.

After starting iperf on h1, did you observe something interesting in the ping RTT?

```
64 bytes from 10.0.0.2: icmp_seq=155 ttl=64 time=790 ms
64 bytes from 10.0.0.2: icmp_seq=156 ttl=64 time=805 ms
64 bytes from 10.0.0.2: icmp_seq=157 ttl=64 time=806 ms
64 bytes from 10.0.0.2: icmp_seq=158 ttl=64 time=807 ms
64 bytes from 10.0.0.2: icmp_seq=159 ttl=64 time=838 ms
64 bytes from 10.0.0.2: icmp_seq=160 ttl=64 time=824 ms
64 bytes from 10.0.0.2: icmp_seq=161 ttl=64 time=843 ms
64 bytes from 10.0.0.2: icmp_seq=162 ttl=64 time=824 ms
64 bytes from 10.0.0.2: icmp_seq=163 ttl=64 time=611 ms
64 bytes from 10.0.0.2: icmp_seq=164 ttl=64 time=427 ms
64 bytes from 10.0.0.2: icmp_seq=165 ttl=64 time=422 ms
64 bytes from 10.0.0.2: icmp_seq=166 ttl=64 time=433 ms
64 bytes from 10.0.0.2: icmp_seq=167 ttl=64 time=460 ms
64 bytes from 10.0.0.2: icmp_seq=168 ttl=64 time=480 ms
64 bytes from 10.0.0.2: icmp_seq=169 ttl=64 time=472 ms
64 bytes from 10.0.0.2: icmp_seq=170 ttl=64 time=490 ms
64 bytes from 10.0.0.2: icmp_seq=171 ttl=64 time=486 ms
64 bytes from 10.0.0.2: icmp_seq=172 ttl=64 time=505 ms
64 bytes from 10.0.0.2: icmp_seq=173 ttl=64 time=508 ms
64 bytes from 10.0.0.2: icmp_seq=174 ttl=64 time=515 ms
64 bytes from 10.0.0.2: icmp_seq=175 ttl=64 time=539 ms
64 bytes from 10.0.0.2: icmp_seq=176 ttl=64 time=515 ms
64 bytes from 10.0.0.2: icmp_seq=177 ttl=64 time=542 ms
64 bytes from 10.0.0.2: icmp_seq=178 ttl=64 time=534 ms
64 bytes from 10.0.0.2: icmp_seq=179 ttl=64 time=547 ms
64 bytes from 10.0.0.2: icmp_seq=180 ttl=64 time=563 ms
64 bytes from 10.0.0.2: icmp_seq=181 ttl=64 time=580 ms
64 bytes from 10.0.0.2: icmp_seq=182 ttl=64 time=583 ms
64 bytes from 10.0.0.2: icmp_seq=183 ttl=64 time=578 ms
64 bytes from 10.0.0.2: icmp_seq=184 ttl=64 time=587 ms
64 bytes from 10.0.0.2: icmp_seq=185 ttl=64 time=602 ms
64 bytes from 10.0.0.2: icmp_seq=186 ttl=64 time=598 ms
64 bytes from 10.0.0.2: icmp_seq=187 ttl=64 time=610 ms
64 bytes from 10.0.0.2: icmp_seq=188 ttl=64 time=616 ms
64 bytes from 10.0.0.2: icmp_seq=189 ttl=64 time=620 ms
64 bytes from 10.0.0.2: icmp_seq=190 ttl=64 time=633 ms
64 bytes from 10.0.0.2: icmp_seq=191 ttl=64 time=642 ms
64 bytes from 10.0.0.2: icmp_seq=192 ttl=64 time=631 ms
64 bytes from 10.0.0.2: icmp_seq=193 ttl=64 time=640 ms
64 bytes from 10.0.0.2: icmp_seq=194 ttl=64 time=654 ms
64 bytes from 10.0.0.2: icmp_seq=195 ttl=64 time=650 ms
```

ping with iperf

```
64 bytes from 10.0.0.2: icmp_seq=60 ttl=64 time=36.8 ms
64 bytes from 10.0.0.2: icmp_seq=61 ttl=64 time=43.8 ms
64 bytes from 10.0.0.2: icmp_seq=62 ttl=64 time=34.6 ms
64 bytes from 10.0.0.2: icmp_seq=63 ttl=64 time=41.4 ms
64 bytes from 10.0.0.2: icmp_seq=64 ttl=64 time=33.1 ms
64 bytes from 10.0.0.2: icmp_seq=65 ttl=64 time=35.9 ms
64 bytes from 10.0.0.2: icmp_seq=66 ttl=64 time=31.8 ms
64 bytes from 10.0.0.2: icmp_seq=67 ttl=64 time=33.0 ms
64 bytes from 10.0.0.2: icmp_seq=68 ttl=64 time=42.3 ms
64 bytes from 10.0.0.2: icmp_seq=69 ttl=64 time=39.6 ms
64 bytes from 10.0.0.2: icmp_seq=70 ttl=64 time=37.2 ms
64 bytes from 10.0.0.2: icmp_seq=71 ttl=64 time=31.2 ms
64 bytes from 10.0.0.2: icmp_seq=72 ttl=64 time=40.2 ms
64 bytes from 10.0.0.2: icmp_seq=73 ttl=64 time=33.3 ms
64 bytes from 10.0.0.2: icmp_seq=74 ttl=64 time=31.4 ms
64 bytes from 10.0.0.2: icmp_seq=75 ttl=64 time=36.2 ms
64 bytes from 10.0.0.2: icmp_seq=76 ttl=64 time=30.8 ms
64 bytes from 10.0.0.2: icmp_seq=77 ttl=64 time=32.2 ms
64 bytes from 10.0.0.2: icmp_seq=78 ttl=64 time=30.9 ms
64 bytes from 10.0.0.2: icmp_seq=79 ttl=64 time=39.0 ms
64 bytes from 10.0.0.2: icmp_seq=80 ttl=64 time=36.6 ms
64 bytes from 10.0.0.2: icmp_seq=81 ttl=64 time=39.5 ms
64 bytes from 10.0.0.2: icmp_seq=82 ttl=64 time=32.2 ms
64 bytes from 10.0.0.2: icmp_seq=83 ttl=64 time=32.5 ms
64 bytes from 10.0.0.2: icmp_seq=84 ttl=64 time=32.5 ms
64 bytes from 10.0.0.2: icmp_seq=85 ttl=64 time=31.9 ms
64 bytes from 10.0.0.2: icmp_seq=86 ttl=64 time=33.3 ms
64 bytes from 10.0.0.2: icmp_seq=87 ttl=64 time=33.7 ms
64 bytes from 10.0.0.2: icmp_seq=88 ttl=64 time=32.4 ms
64 bytes from 10.0.0.2: icmp_seq=89 ttl=64 time=32.4 ms
64 bytes from 10.0.0.2: icmp_seq=90 ttl=64 time=40.1 ms
64 bytes from 10.0.0.2: icmp_seq=91 ttl=64 time=37.0 ms
64 bytes from 10.0.0.2: icmp_seq=92 ttl=64 time=33.9 ms
64 bytes from 10.0.0.2: icmp_seq=93 ttl=64 time=33.0 ms
64 bytes from 10.0.0.2: icmp_seq=94 ttl=64 time=42.8 ms
64 bytes from 10.0.0.2: icmp_seq=95 ttl=64 time=39.9 ms
64 bytes from 10.0.0.2: icmp_seq=96 ttl=64 time=52.4 ms
64 bytes from 10.0.0.2: icmp_seq=97 ttl=64 time=47.7 ms
64 bytes from 10.0.0.2: icmp_seq=98 ttl=64 time=48.2 ms
64 bytes from 10.0.0.2: icmp_seq=99 ttl=64 time=39.9 ms
64 bytes from 10.0.0.2: icmp_seq=100 ttl=64 time=32.5 ms
```

ping without iperf

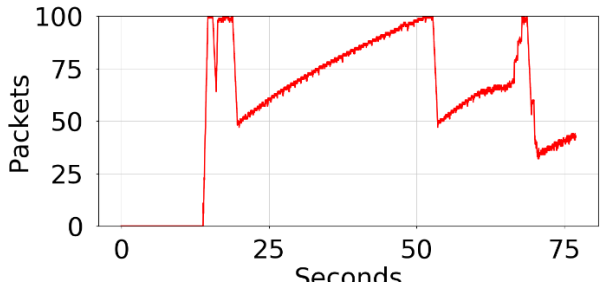
As evident, running iperf causes a substantial increase in the RTT value for ping.

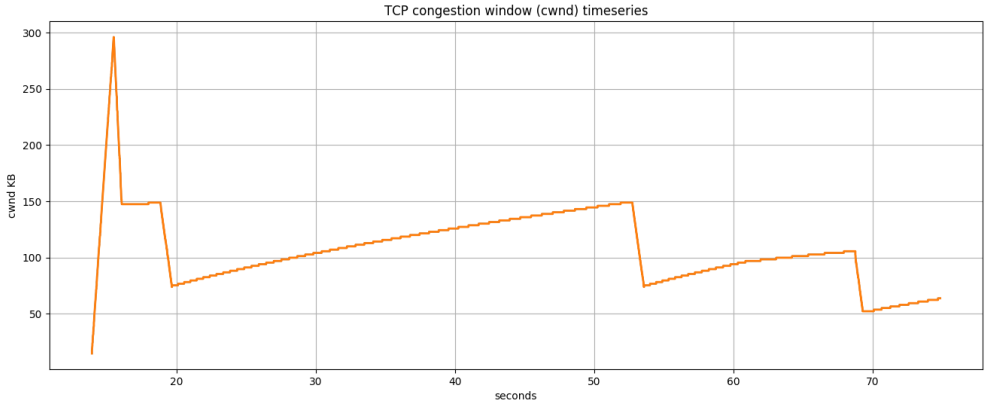
After starting iperf on h1, why does the web page take so much longer to download?

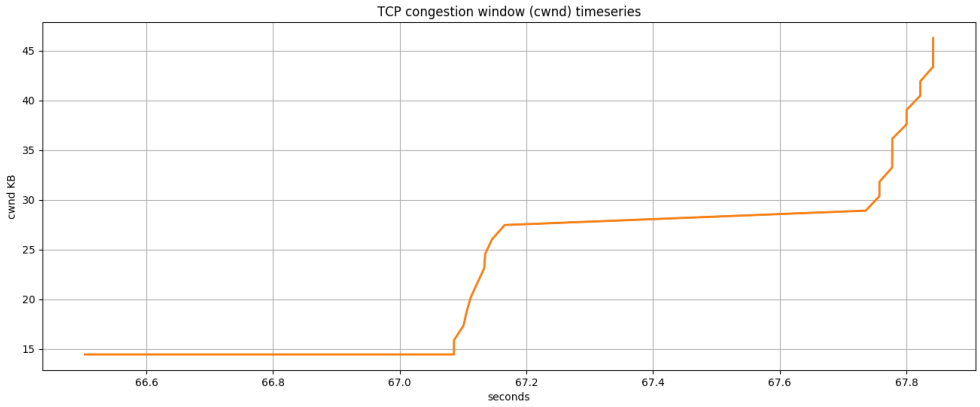
```
^Cmininet> h2 wget h1
--2021-10-27 21:44:12--  http://10.0.0.1/
Connecting to 10.0.0.1:80... connected.
HTTP request sent, awaiting response... 200 OK
Length: 177669 (174K) [text/html]
Saving to: 'index.html.1'

     0K .......... .......... .......... .......... .......... 28% 32.7K 4s
    50K .......... .......... .......... .......... .......... 57% 38.1K 2s
   100K .......... .......... .......... .......... .......... 86% 83.1K 1s
   150K .......... .......... ...                              100%  328K=3.5s

2021-10-27 21:44:17 (49.4 KB/s) - 'index.html.1' saved [177669/177669]
```

The webpage takes longer to download since the available bandwidth is mostly used up by iperf, hence increasing the time required to download the file.

Experiment 1 (qlen 100)

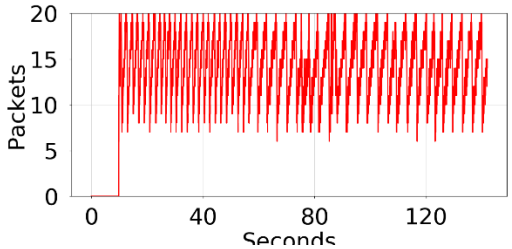


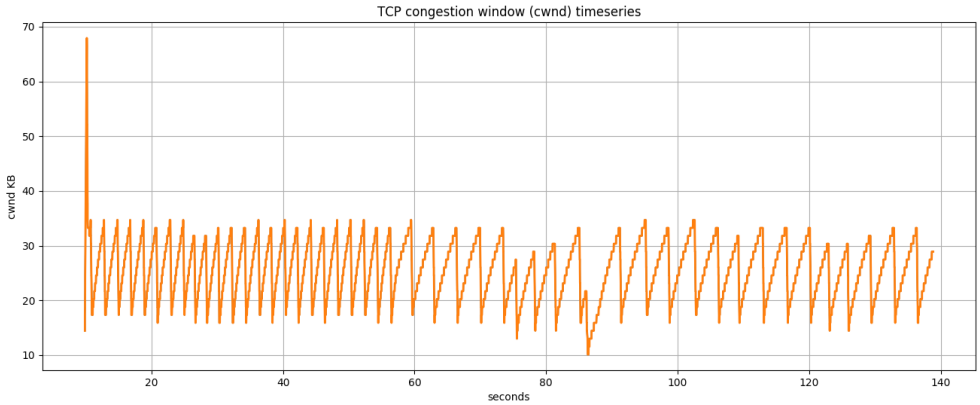


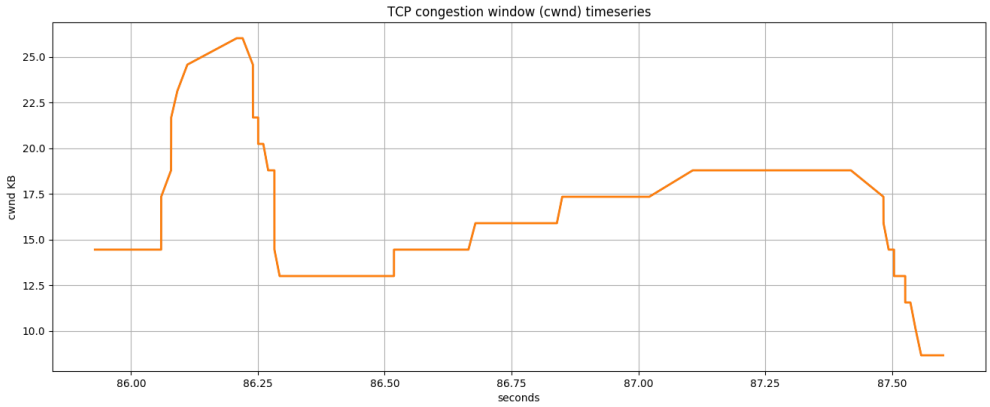


It takes a long time to fill the buffer as there is more space to be filled. wget has very low bandwidth since cwnd changes very little over a long time.

Experiment 2 (qlen 20)







Filling the buffer is much faster. cwnd decreases much more frequently than in 100 packets case, which leads to an increase in TCP fairness which allows wget to perform much better (we can see that in the 100-packet case there is a long time where wget cwnd is stagnant meaning bandwidth is very low). Maximum cwnd achieved is also much lower in this case.