

# CS 252: Lab 4

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## Exercise 2

1. For the given data link, the maximum throughput the ftp flow can achieve is 7739.2 Kbps for Flow 1 and 342.326 Kbps for Flow 2. (Total is 8081.526 Kbps)
2. Considering RTT as (approx) 20 ms (Twice of delay), theoretically window size which achieved 7739.2 Kbps as throughput is 19348 bytes.
3. Experimentally, minimum window size at which this throughput was obtained is 19300 bytes.
4. The maximum achieved throughput is slightly less than the raw data rate of the link ( $7739.2 < 8192$ ) as can be expected, considering the delay incurred and queuing.
5. For delay = 5 ms, Maximum throughput is (7762.56 Kbps, 343.362 Kbps) at minimum window size of 10800 bytes.  
For delay = 10 ms, Maximum throughput is (7739.2 Kbps, 342.326 Kbps) at minimum window size of 19300 bytes.  
For delay = 20 ms, Maximum throughput is (7692.48 Kbps, 340.248 Kbps) at minimum window size of 37600 bytes.  
Maximum throughput is reduces slightly as we increase the delay (as expected), and the minimum window size increases almost proportionally as we increase the delay. (Theoretical window size also increases almost proportionally as it is dependent on delay)

### Exercise 3

1. For `CBRdataRate = "448Kbps"`, observed Throughput is 461.296 Kbps.  
For `CBRdataRate = "896Kbps"`, observed Throughput is 921.748 Kbps.  
For `CBRdataRate = "1344Kbps"`, observed Throughput is 1382.2 Kbps.
2. Maximum throughput achieved is 7768.12 Kbps achieved at minimum `CBRdataRate` of 7560 Kbps.
3. The maximum achieved throughput is less than the raw data rate of the link ( $7768.12 < 8192$ ) as can be expected, considering the delay incurred and queuing.

## Appendix

```
(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$ ./waf --run lab4FTPonly
Waf: Entering directory `~/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
[2735/2795] Compiling scratch/lab4FTPonly.cc
[2755/2795] Linking build/scratch/lab4FTPonly
Waf: Leaving directory `~/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
Build commands will be stored in build/compile_commands.json
'build' finished successfully (2.775s)

senderWindowSize: 10700
Delay: 5ms

===== Flow monitor statistics =====

Flow ID: 1
Src Addr: 10.1.1.1 ----- Dst Addr: 10.1.1.2

Tx Bytes      4962828
Tx Packets    8442
Rx Bytes      4956360
Rx Packet     8431
Input Load    7754.69 Kbps
Observed Throughput 7745.07 Kbps
Mean delay    0.00589622
Mean jitter   0.000591057
Flow ID: 2
Src Addr: 10.1.1.2 ----- Dst Addr: 10.1.1.1

Tx Bytes      219236
Tx Packets    4216
Rx Bytes      219028
Rx Packet     4212
Input Load    342.937 Kbps
Observed Throughput 342.59 Kbps
Mean delay    0.005054
Mean jitter   9.49893e-10

(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$
```

Figure 1: TCP: Delay 2ms, Window Size 10700 bytes

```
(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$ ./waf --run lab4FTPonly
Waf: Entering directory `~/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
[2734/2795] Compiling scratch/lab4FTPonly.cc
[2755/2795] Linking build/scratch/lab4FTPonly
Waf: Leaving directory `~/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
Build commands will be stored in build/compile_commands.json
'build' finished successfully (2.667s)

senderWindowSize: 10800
Delay: 5ms

===== Flow monitor statistics =====

Flow ID: 1
Src Addr: 10.1.1.1 ----- Dst Addr: 10.1.1.2

Tx Bytes      4974000
Tx Packets    8461
Rx Bytes      4967532
Rx Packet     8450
Input Load    7773.07 Kbps
Observed Throughput 7762.56 Kbps
Mean delay    0.00646203
Mean jitter   0.000591057
Flow ID: 2
Src Addr: 10.1.1.2 ----- Dst Addr: 10.1.1.1

Tx Bytes      219704
Tx Packets    4225
Rx Bytes      219496
Rx Packet     4221
Input Load    343.711 Kbps
Observed Throughput 343.362 Kbps
Mean delay    0.005054
Mean jitter   9.47867e-10

(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$
```

Figure 2: TCP: Delay 2ms, Window Size 10800 bytes

```
(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$ ./waf --run lab4FTPOnly
Waf: Entering directory `~/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
[2734/2795] Compiling scratch/lab4FTPOnly.cc
[2755/2795] Linking build/scratch/lab4FTPOnly
Waf: Leaving directory `~/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
Build commands will be stored in build/compile_commands.json
'build' finished successfully (2.664s)

senderWindowSize: 10900
Delay: 5ms

===== Flow monitor statistics =====

Flow ID: 1
Src Addr: 10.1.1.1 ----- Dst Addr: 10.1.1.2

Tx Bytes          4974000
Tx Packets        8461
Rx Bytes          4967532
Rx Packet         8450
Input Load        7773.07 Kbps
Observed Throughput 7762.56 Kbps
Mean delay        0.00646203
Mean jitter        0.000591057
Flow ID: 2
Src Addr: 10.1.1.2 ----- Dst Addr: 10.1.1.1

Tx Bytes          219704
Tx Packets        4225
Rx Bytes          219496
Rx Packet         4221
Input Load        343.711 Kbps
Observed Throughput 343.362 Kbps
Mean delay        0.005054
Mean jitter        9.47867e-10

(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$
```

Figure 3: TCP: Delay 2ms, Window Size 10900 bytes

```
(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$ ./waf --run lab4FTPOnly
Waf: Entering directory `~/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
[2734/2795] Compiling scratch/lab4FTPOnly.cc
[2755/2795] Linking build/scratch/lab4FTPOnly
Waf: Leaving directory `~/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
Build commands will be stored in build/compile_commands.json
'build' finished successfully (2.654s)

senderWindowSize: 19200
Delay: 10ms

===== Flow monitor statistics =====

Flow ID: 1
Src Addr: 10.1.1.1 ----- Dst Addr: 10.1.1.2

Tx Bytes          4822884
Tx Packets        8204
Rx Bytes          4812888
Rx Packet         8187
Input Load        7537.39 Kbps
Observed Throughput 7520.02 Kbps
Mean delay        0.0109266
Mean jitter        0.000592241
Flow ID: 2
Src Addr: 10.1.1.2 ----- Dst Addr: 10.1.1.1

Tx Bytes          212892
Tx Packets        4094
Rx Bytes          212424
Rx Packet         4085
Input Load        333.349 Kbps
Observed Throughput 332.654 Kbps
Mean delay        0.010054
Mean jitter        9.79432e-10

(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$
```

Figure 4: TCP: Delay 10ms, Window Size 19200 bytes

```
(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$ ./waf --run lab4FTPNly
Waf: Entering directory `/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
[2734/2795] Compiling scratch/lab4FTPNly.cc
[2755/2795] Linking build/scratch/lab4FTPNly
Waf: Leaving directory `/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
Build commands will be stored in build/compile_commands.json
'build' finished successfully (2.653s)

senderWindowSize: 19300
Delay: 10ms

===== Flow monitor statistics =====

Flow ID: 1
Src Addr: 10.1.1.1 ----- Dst Addr: 10.1.1.2

Tx Bytes          4963416
Tx Packets         8443
Rx Bytes          4952832
Rx Packet          8425
Input Load        7756.62 Kbps
Observed Throughput 7739.2 Kbps
Mean delay        0.0109339
Mean jitter       0.000592247
Flow ID: 2
Src Addr: 10.1.1.2 ----- Dst Addr: 10.1.1.1

Tx Bytes          219080
Tx Packets         4213
Rx Bytes          218612
Rx Packet          4204
Input Load        343.02 Kbps
Observed Throughput 342.326 Kbps
Mean delay        0.010054
Mean jitter       9.51701e-10

(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$
```

Figure 5: TCP: Delay 10ms, Window Size 19300 bytes

```
(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$ ./waf --run lab4FTPNly
Waf: Entering directory `/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
[2737/2795] Compiling scratch/lab4FTPNly.cc
[2755/2795] Linking build/scratch/lab4FTPNly
Waf: Leaving directory `/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
Build commands will be stored in build/compile_commands.json
'build' finished successfully (2.651s)

senderWindowSize: 19400
Delay: 10ms

===== Flow monitor statistics =====

Flow ID: 1
Src Addr: 10.1.1.1 ----- Dst Addr: 10.1.1.2

Tx Bytes          4963416
Tx Packets         8443
Rx Bytes          4952832
Rx Packet          8425
Input Load        7756.62 Kbps
Observed Throughput 7739.2 Kbps
Mean delay        0.0109339
Mean jitter       0.000592247
Flow ID: 2
Src Addr: 10.1.1.2 ----- Dst Addr: 10.1.1.1

Tx Bytes          219080
Tx Packets         4213
Rx Bytes          218612
Rx Packet          4204
Input Load        343.02 Kbps
Observed Throughput 342.326 Kbps
Mean delay        0.010054
Mean jitter       9.51701e-10

(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$
```

Figure 6: TCP: Delay 10ms, Window Size 19400 bytes

```
(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$ ./waf --run lab4FTPonly
Waf: Entering directory `/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
[2735/2795] Compiling scratch/lab4FTPonly.cc
[2755/2795] Linking build/scratch/lab4FTPonly
Waf: Leaving directory `/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
Build commands will be stored in build/compile_commands.json
'build' finished successfully (2.730s)

senderWindowSize: 37500
Delay: 20ms

===== Flow monitor statistics =====

Flow ID: 1
Src Addr: 10.1.1.1 ----- Dst Addr: 10.1.1.2

Tx Bytes          4880508
Tx Packets        8302
Rx Bytes          4859928
Rx Packet         8267
Input Load        7625.92 Kbps
Observed Throughput 7593.75 Kbps
Mean delay        0.0210502
Mean jitter       0.000594647
Flow ID: 2
Src Addr: 10.1.1.2 ----- Dst Addr: 10.1.1.1

Tx Bytes          214972
Tx Packets        4134
Rx Bytes          214088
Rx Packet         4117
Input Load        337.252 Kbps
Observed Throughput 335.865 Kbps
Mean delay        0.020054
Mean jitter       9.71817e-10

(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$
```

Figure 7: TCP: Delay 20ms, Window Size 37500 bytes

```
(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$ ./waf --run lab4FTPonly
Waf: Entering directory `/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
[2735/2795] Compiling scratch/lab4FTPonly.cc
[2755/2795] Linking build/scratch/lab4FTPonly
Waf: Leaving directory `/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
Build commands will be stored in build/compile_commands.json
'build' finished successfully (2.762s)

senderWindowSize: 37600
Delay: 20ms

===== Flow monitor statistics =====

Flow ID: 1
Src Addr: 10.1.1.1 ----- Dst Addr: 10.1.1.2

Tx Bytes          4943424
Tx Packets        8409
Rx Bytes          4922844
Rx Packet         8374
Input Load        7725.56 Kbps
Observed Throughput 7692.48 Kbps
Mean delay        0.0211184
Mean jitter       0.00059465
Flow ID: 2
Src Addr: 10.1.1.2 ----- Dst Addr: 10.1.1.1

Tx Bytes          217728
Tx Packets        4187
Rx Bytes          216844
Rx Packet         4170
Input Load        341.635 Kbps
Observed Throughput 340.248 Kbps
Mean delay        0.020054
Mean jitter       9.59463e-10

(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$
```

Figure 8: TCP: Delay 20ms, Window Size 37600 bytes

```

(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$ ./waf --run lab4FTPOnly
Waf: Entering directory `/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
[2737/2795] Compiling scratch/lab4FTPOnly.cc
[2755/2795] Linking build/scratch/lab4FTPOnly
Waf: Leaving directory `/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
Build commands will be stored in build/compile_commands.json
'build' finished successfully (2.844s)

senderWindowSize: 37700
Delay: 20ms

===== Flow monitor statistics =====

Flow ID: 1
Src Addr: 10.1.1.1 ----- Dst Addr: 10.1.1.2

Tx Bytes          4943424
Tx Packets        8409
Rx Bytes          4922844
Rx Packet         8374
Input Load        7725.56 Kbps
Observed Throughput 7692.48 Kbps
Mean delay        0.0211184
Mean jitter       0.00059465
Flow ID: 2
Src Addr: 10.1.1.2 ----- Dst Addr: 10.1.1.1

Tx Bytes          217728
Tx Packets        4187
Rx Bytes          216844
Rx Packet         4170
Input Load        341.635 Kbps
Observed Throughput 340.248 Kbps
Mean delay        0.020054
Mean jitter       9.59463e-10
(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$

```

Figure 9: TCP: Delay 20ms, Window Size 37700 bytes

```

(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$ ./waf --run lab4CBROnly
Waf: Entering directory `/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
[2742/2795] Compiling scratch/lab4CBROnly.cc
[2755/2795] Linking build/scratch/lab4CBROnly
Waf: Leaving directory `/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
Build commands will be stored in build/compile_commands.json
'build' finished successfully (2.727s)

CBRdataRate: 448Kbps

===== Flow monitor statistics =====

Flow ID: 1
Src Addr: 10.1.1.1 ----- Dst Addr: 10.1.1.2

Tx Bytes          294840
Tx Packets        546
Rx Bytes          294300
Rx Packet         545
Input Load        462.272 Kbps
Observed Throughput 461.296 Kbps
Mean delay        0.010542
Mean jitter       0
(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$

```

Figure 10: UDP: CBRdataRate 448 Kbps



```
(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$ ./waf --run lab4CBRonly
Waf: Entering directory `/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
[2743/2795] Compiling scratch/lab4CBRonly.cc
[2755/2795] Linking build/scratch/lab4CBRonly
Waf: Leaving directory `/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
Build commands will be stored in build/compile_commands.json
'build' finished successfully (2.729s)

CBRdataRate: 896Kbps

===== Flow monitor statistics =====

Flow ID: 1
Src Addr: 10.1.1.1 ----- Dst Addr: 10.1.1.2

Tx Bytes          590220
Tx Packets        1093
Rx Bytes          589140
Rx Packet         1091
Input Load        923.697 Kbps
Observed Throughput 921.748 Kbps
Mean delay        0.010542
Mean jitter        0

(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$
```

Figure 11: UDP: CBRdataRate 896 Kbps

```
(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$ ./waf --run lab4CBRonly
Waf: Entering directory `/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
[2743/2795] Compiling scratch/lab4CBRonly.cc
[2755/2795] Linking build/scratch/lab4CBRonly
Waf: Leaving directory `/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
Build commands will be stored in build/compile_commands.json
'build' finished successfully (2.661s)

CBRdataRate: 1344Kbps

===== Flow monitor statistics =====

Flow ID: 1
Src Addr: 10.1.1.1 ----- Dst Addr: 10.1.1.2

Tx Bytes          885600
Tx Packets        1640
Rx Bytes          883980
Rx Packet         1637
Input Load        1385.12 Kbps
Observed Throughput 1382.2 Kbps
Mean delay        0.010542
Mean jitter        0

(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$
```

Figure 12: UDP: CBRdataRate 1344 Kbps

```
(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$ ./waf --run lab4CBRonly
Waf: Entering directory `/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
[2743/2795] Compiling scratch/lab4CBRonly.cc
[2755/2795] Linking build/scratch/lab4CBRonly
Waf: Leaving directory `/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
Build commands will be stored in build/compile_commands.json
'build' finished successfully (2.734s)

CBRdataRate: 7550Kbps

===== Flow monitor statistics =====

Flow ID: 1
Src Addr: 10.1.1.1 ----- Dst Addr: 10.1.1.2

Tx Bytes          4976640
Tx Packets        9216
Rx Bytes          4965840
Rx Packet         9196
Input Load        7777.11 Kbps
Observed Throughput 7760.71 Kbps
Mean delay        0.010542
Mean jitter        0

(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$
```

Figure 13: UDP: CBRdataRate 7550 Kbps

```

(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$ ./waf --run lab4CBROnly
Waf: Entering directory `/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
[2743/2795] Compiling scratch/lab4CBROnly.cc
[2755/2795] Linking build/scratch/lab4CBROnly
Waf: Leaving directory `/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
Build commands will be stored in build/compile_commands.json
'build' finished successfully (2.666s)

CBRdataRate: 7560Kbps

===== Flow monitor statistics =====

Flow ID: 1
Src Addr: 10.1.1.1 ----- Dst Addr: 10.1.1.2

Tx Bytes          4983120
Tx Packets        9228
Rx Bytes          4970700
Rx Packet         9205
Input Load        7787.42 Kbps
Observed Throughput 7768.12 Kbps
Mean delay        0.011467
Mean jitter        2.01e-07

(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$

```

Figure 14: UDP: CBRdataRate 7560 Kbps

```

(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$ ./waf --run lab4CBROnly
Waf: Entering directory `/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
[2743/2795] Compiling scratch/lab4CBROnly.cc
[2755/2795] Linking build/scratch/lab4CBROnly
Waf: Leaving directory `/home/devansh/tarballs/ns-allinone-3.30/ns-3.30/build'
Build commands will be stored in build/compile_commands.json
'build' finished successfully (2.697s)

CBRdataRate: 7570Kbps

===== Flow monitor statistics =====

Flow ID: 1
Src Addr: 10.1.1.1 ----- Dst Addr: 10.1.1.2

Tx Bytes          4989600
Tx Packets        9240
Rx Bytes          4970700
Rx Packet         9205
Input Load        7797.71 Kbps
Observed Throughput 7768.12 Kbps
Mean delay        0.0147574
Mean jitter        9.16e-07

(3.8.6) devansh@dj:~/tarballs/ns-allinone-3.30/ns-3.30$

```

Figure 15: UDP: CBRdataRate 7570Kbps