50.012 Networks (2023 Term 6)

Homework 2

Hand-out: 16 Feb

Due: 7 Mar 23:59

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1. (2019 midterm exam question) Consider data communication over a link of RTT 100ms and transmission bandwidth 1Gbit/s. Assume 1G=10^9. Consider a pipelined transport protocol that uses ACKs to decide if packets were received successfully. Answer the following three questions:

1.1 After the protocol has sent a packet, what is the minimum amount of time needed for the protocol to infer that the packet was lost?

1.2 If the protocol uses a window size of 6 packets (each of size 1000 bytes), what is the maximum achievable data throughput?

1.3 To fully use the transmission bandwidth, estimate the minimum window size (in bytes) needed.

(1.1) minimum amt of time: 100 ms

(1.2) Throughput = $\frac{1000 \text{ byte} \times 6 \times 8 \text{ bit/byte}}{0.1 s} = 4.8 \times 10^5$ bit/s

(1.3) window size = 10^9 bit $\times$ 0.1 s $\times \frac{1}{8}$ byte/bit $= 1.25 \times 10^7$ byte

2. Consider the three 16-bit words (shown in binary) below.

01101001 11110110

11100011 00011100

1 01001101 00010010

10101010 10101010

1 11110111 10111100 } wrap around

What is the Internet checksum value for these three16-bit words?

11110111 10111101

Take 1's complement, checksum is :

0000100001000010

3. (textbook chapter 3, problem P44): Consider sending a large file from a host to another over a TCP connection that has no loss.

3.1 Suppose TCP uses AIMD for its congestion control without slow start. Assuming cwnd increases by 1 MSS every time a batch of ACKs is received and assuming approximately constant round-trip times, how long does it take for cwnd increase from 6 MSS to 12 MSS (assuming no loss events)?

3.2 Again, assume in the first RTT 6 MSS was sent, what is the average throughout (in terms of MSS and RTT) for this connection up through time = 6 RTT?

(3.1) from 6 MSS to 12 MSS, 6 RTT is needed.

(3.2) $\frac{(6+7+8+9+10+11+12)\,MSS}{6\,RTT} = 8.5\ MSS/RTT$

4. (textbook Chapter 3, problem 45 and 53) Recall the macroscopic description of TCP throughput. In the period of time from when the connection's rate varies from W/(2 · RTT) to W/RTT, only one packet is lost (at the very end of the period). W is measured in terms of the number of segments.

4.1 Show that the loss rate (fraction of packets lost) is equal to

$$L = \text{loss rate} = \frac{1}{\frac{3}{8}W^2 + \frac{3}{4}W}$$

4.2 Use the result above to show that if a connection has loss rate L, then its average rate is approximately given by

$$\approx \frac{1.22 \cdot MSS}{RTT\sqrt{L}}$$

4.3 Let's assume 1500-byte packets and a 100 ms round-trip time. If TCP needed to support a 1Gbps connection, what would the tolerable loss rate be? How about 100Gbps?

(4.1) $\frac{W}{2} + (\frac{W}{2}+1) + \cdots + W = \sum_{n=0}^{W/2}(\frac{W}{2}+n) = (\frac{W}{2}+1)\frac{W}{2} + \sum_{n=0}^{W/2} n$

$= (\frac{W}{2}+1)\frac{W}{2} + \frac{W/2\,(W/2+1)}{2} = \frac{W^2}{4} + \frac{W}{2} + \frac{W^2}{8} + \frac{W}{4} = \frac{3}{8}W^2 + \frac{3}{4}W$

since only 1 packet is lost, so loss rate $= \frac{1}{\frac{3}{8}W^2+\frac{3}{4}W}$

(4.2) in 4.1, $L = \frac{1}{\frac{3}{8}W^2+\frac{3}{4}W} \approx \frac{1}{\frac{3}{8}W^2} = \frac{8}{3W^2}$

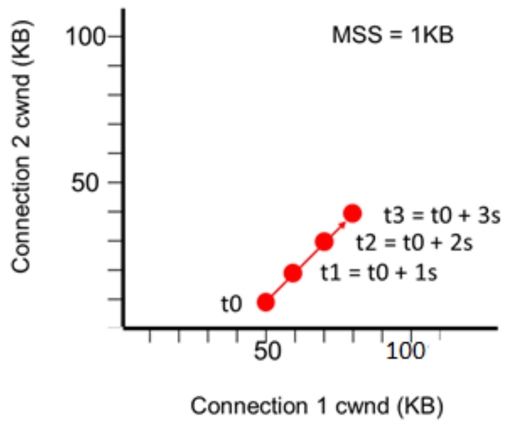
$\sqrt{L} = \sqrt{\frac{8}{3}}\frac{1}{W}$, $W = \sqrt{\frac{8}{3}}\cdot\frac{1}{\sqrt{L}}$

$\frac{3}{4}\cdot\sqrt{\frac{8}{3}}\cdot\frac{1}{\sqrt{L}}\cdot\frac{MSS}{RTT} \approx \frac{1.22\,MSS}{RTT\cdot\sqrt{L}}$

(4.3) 1 Gbps connection: $L = \left(\frac{1.22\times 1500\times 8\text{ bit}}{0.1s\times 10^9\text{ bit/s}}\right)^2 = 2.14\times 10^{-8}$

100 Gbps connection: $L = \left(\frac{1.22\times 1500\times 8\text{ bit}}{0.1s\times 100\times 10^9\text{ bit/s}}\right)^2 = 2.14\times 10^{-12}$

5. (2020 midterm exam question) Consider two TCP Reno connections that share one link. The figure bellow shows the evolution of the size of their respective congestion window (cwnd) over time. As shown, at time t0, connection 1's cwnd = 50KB and connection 2's cwnd=10KB. At time t1=t0+1s, connection 1's cwnd = 60KB and connection 2's cwnd=20KB. At time t2=t0+2s, connection 1's cwnd = 70KB and connection 2's cwnd=30KB. At time t3=t0+3s, connection 1's cwnd = 80KB and connection 2's cwnd=40KB. Assume the maximum segment size (MSS) for both connections is 1KB and both connections have constant round-trip time (RTT). We further assume that when the sum of the cwnd of the two connections reaches 120KB, both connections experience a packet loss event as indicated by triple duplicate ACKs. We also assume these are the only moments that the two connections experience packet losses.



5.1 From time t0 to t3, the two connections are in which state of the TCP congestion control? After the packet loss event at t3, what will be the cwnd size of connection 1 and connection 2 respectively?

5.2 What is the RTT for the two connections respectively? What is the respective average throughput of these two connections from t0 to t3?

5.3 Assume the two connections run for a long time. What will these two connections' respective average throughput converge to?

5.4 Assume now connection 1's RTT reduces by 50% and connection 2's RTT remains unchanged. After a long time, what will these two connections' respective average throughput converge to?

(5.1) "congestion avoidance", after t3:

cwnd of connection 1: $\frac{80kB}{2} + 3 = 43kB$

connection 2: $\frac{40kB}{2} + 3 = 23kB$

(5.2) Both connection 1 and 2's cwnd increased 10 kB in 1s.

The MSS is 1kB, so $RTT = \frac{1}{10} = 0.1$ (s)

Average throughput: connection 1: $\frac{(50+51+\cdots+80)}{3.1} = \frac{2015kB}{3.1s} = 5.2Mbps$

connection 2: $\frac{(10+\cdots+40)}{3.1} = \frac{775kB}{3.1s} = 2Mbps$

(5.3) both: $\text{Avg thru put} = \frac{3}{4} \times \frac{60 \times 10^3 \text{ byte} \times 8 \text{ bit/byte}}{0.1s}$

$= 3.6 \times 10^6 bps = 3.6 Mbps$

(5.4) total window size = 120 $\quad 120/3 = 40$

for connection 1, cwnd fluctuate 40 kB ~ 80 kB

for connection 2, cwnd fluctuate 20 kB ~ 40 kB

connection 1: $\frac{3}{4} \times \frac{80 \times 10^3 \text{ Byte} \times 8 \text{ bit/Byte}}{0.05 s} = 9.6 Mbps$

connection 2: $\frac{3}{4} \times \frac{40 \times 10^3 \text{ Byte} \times 8 \text{ bit/Byte}}{0.1s} = 2.4 Mbps$