4 Internetworking

4.1 W&P, P6.1

(a) 2 points. How many IP addresses need to be leased from an ISP to support a DHCP server (with L ports) that uses NAT to service N clients at the same time, if every client uses at most P ports?

(b) 2 points. If M unique clients request an IP address every day from the above mentioned DHCP server, what is the maximum lease time allowable to prevent new clients from being denied access assuming that requests are uniformly spaced throughout the day, and that the addressing scheme used supports a max of N clients at the same time?

4.2 Insufficient IP addresses (optional; 0 point)

(a) Consider a type D subnet (there are 256 IP addresses in a type D network, and one of these IP addresses is used for broadcasting). Assume that 15 IP addresses are assigned to servers, then how many hosts can this subnet support if there is no DHCP service nor NAT service?

(b) Assume that there is a DHCP server in the subnet, and that each host connects to the Internet 8 hours a day. How many hosts can this subnet support?

(c) Assume that the DHCP server also runs the NAT protocol, and can use up to 2000 TCP ports for each dynamic IP address. Also assume that each host needs 20 TCP connections. How many hosts can this subnet support?
5 Transport

5.1 W&P, P7.1

(a) 2 points. Suppose you and two friends named Alice and Bob share a 200 Kbps DSL connection to the Internet. You need to download a 100 MB file using FTP. Bob is also starting a 100 MB file transfer, while Alice is watching a 150 Kbps streaming video using UDP. You have the opportunity to unplug either Alice or Bob’s computer at the router, but you cannot unplug both. To minimize the transfer time of your file, whose computer should you unplug and why? Assume that the DSL connection is the only bottleneck link, and that your connection and Bob’s connection have a similar round trip time.

(b) 2 points. What if the rate of your DSL connection were 500 Kbps? Again, assuming that the DSL connection were the only bottleneck link, which computer should you unplug?

5.2 W&P, P7.2

As shown in Figure 8, station A has an unlimited amount of data to transfer to Station E. Station A uses a sliding window transport protocol with a fixed window size. Thus, station A begins a new packet transmission whenever the number of unacknowledged packets is less than $W$ and any previous packet being sent from A has finished transmitting.

The size of the packets is 10000 bits (neglect headers). So for example if $W > 2$, station A would start sending packet 1 at time $t = 0$, and then would send packet 2 as soon as packet 1 finished transmission, at time $t = 0.33$ ms. Assume that the speed of light is $3 \times 10^8$ meters/sec.

Figure 8: Transmitting data from stations A, B to E.

(a) 4 points. Suppose station B is silent, and that there is no congestion along the acknowledgement path from C to A. (The only delay acknowledgements face is the propagation delay to and from the satellite.) Plot the average throughput as a function of window size $W$. What is the minimum window size that A should choose to achieve a throughput of 30 Mbps? Call this value $W^*$. With this choice of window size, what is the average packet delay (time from leaving A to arriving at E)?

(b) 4 points. Suppose now that station B also has an unlimited amount of data to send to E, and that
station B and station A both use the window size $W^*$. What throughput would A and B get for their flows? How much average delay do packets of both flows incur?

(c) 4 points. What average throughput and delays would A and B get for their flows if A and B both used window size $0.5W^*$? What would be the average throughput and delay for each flow if A used a window size of $W^*$ and B used a window size of $0.5W^*$?

5.3 W&P, P7.3

As shown in Figure 9, flows 1 and 2 share a link with capacity $C = 120$ Kbps. There is no other bottleneck. The round trip time of flow 1 is 0.1 sec and that of flow 2 is 0.2 sec. Let $x_1$ and $x_2$ denote the rates obtained by the two flows, respectively. The hosts use AIMD to regulate their flows. That is, as long as $x_1 + x_2 < C$, the rates increase linearly over time: the window of a flow increases by one packet every round trip time. Rates are estimated as the window size divided by the round-trip time. Assume that as soon as $x_1 + x_2 > C$, the hosts divide their rates $x_1$ and $x_2$ by the factor $\alpha = 1.1$.

\[ T_1=0.1 \text{ sec} \quad \text{Link} \quad C=120 \text{ Kbps} \]

\[ T_2=0.2 \text{ sec} \]

Figure 9: Two flows sharing a link.

(a) 3 points. Draw the evolution of the vector $(x_1, x_2)$ over time.

(b) 3 points. What is the approximate limiting value for the vector?

5.4 W&P, P7.4

Consider a TCP connection between a client C and a server S.

(a) 3 points. Sketch a diagram of the window size of the server S as a function of time.

(b) 2 points. Using the diagram, argue that the time to transmit $N$ packets from S to C is approximately equal to $a + bN$ for large $N$.

(c) 3 points. Explain the key factors that determine the value of $b$ in that expression for an Internet connection.

5.5 Window size control (exercise)

Assume that a host A in Los Angeles sends packets, each of 1KByte, to a host B in San Francisco, through a connection of 100Mbps capacity. Also assume that the round-trip time of each packet is a constant of 130ms (no jitter).

(a) 3 points. If A uses the window flow control mechanism with a constant window size $W$, then what is the average bit rate of the connection as a function of $W$? What happens as $W$ increases to infinity?

(b) 2 points. Now consider the case where $W$ fluctuates, at a much slower timescale than the round-trip time (this is not true in the TCP protocol) as in Figure 10. What is the average rate of the connection assuming $W_{\text{max}}$ is “not too big”?
5.6 TCP with AIMD (exercise), adapted from P5.3

Flows 1 and 2 share a link (the only bottleneck link) with capacity $C = 20$Mbps as in Figure 11. The round-trip time of flow 1 is $\tau_1 = 0.1s$ while that of flow 2 is $\tau_2 = 0.2s$ (assume that there is no jitter). Let $x_1$ and $x_2$ denote the throughput of flows 1 and 2 respectively. The hosts use AIMD to regulate their flows:

- When $x_1 + x_2 \leq C$, the throughput $x_1$ and $x_2$ increase linearly over time: the window of a flow increases by one packet every round-trip time. Assume that the packet size is 1.5KBytes.
- When $x_1 + x_2 > C$, the hosts divide their window size by the factor $\alpha = 1.1$. Assume that flow 1 and 2 decrease their window sizes at most once every 0.2ms.

Throughput is estimated as the window size divided by the round-trip time.

(a) **5 points.** Assume that at time $t = 0$, the window size of both flows is 1. Draw the evolution of the vector $(x_1, x_2)$ over time. [Hint: use matlab.]

(b) **3 points.** What is the approximate limiting behavior for the vector? You will notice that the end-point of the vector moves on a line that go through the origin as time evolves, and you are required to give the slope of this line.

(c) **4 points.** Repeat (a) and (b) for $\alpha = 1.2, 1.3, 1.4, 1.5$. Can you find out how the slope depends on $\alpha$?

5.7 TCP Vegas (exercise)

Consider the case where A sends packets of 1KB to B via a 1Mbps link with 20KB buffer as in Figure 12. The propagation delay (round-trip time with the buffer being empty) is assumed to be 20ms. Assume
that A uses TCP Vegas as the transmission control protocol, i.e., it keeps track of the minimum round-trip time $\tau_{\text{min}}$ and the current round-trip time $\tau$, and updates the window size $W$ according to

$$W \left\{ \begin{array}{ll}
W + 1 & \text{if } \frac{W}{\tau_{\text{min}}} - \frac{W}{\tau} < \frac{\alpha}{\tau_{\text{min}}} \\
W - 1 & \text{if } \frac{W}{\tau_{\text{min}}} - \frac{W}{\tau} > \frac{\beta}{\tau_{\text{min}}} \\
W & \text{otherwise}
\end{array} \right. $$

where $\alpha, \beta$ are TCP parameters. The parameters are chosen $\alpha < \beta$ to introduce hysteresis, which can reduce the fluctuation in window size $W$.

Now we try to analyze the steady-state of this scenario. We start with making the following simplifications: at steady state, one has

$$\frac{W}{\tau_{\text{min}}} - \frac{W}{\tau} = \frac{(\alpha + \beta)/2}{\tau_{\text{min}}}.$$

Assume $\alpha = 2.8$ and $\beta = 3.2$.

(a) 3 points. If $\tau_{\text{min}}$ observed by A is equal to the round-trip time without queueing delay, which is 20ms, then what is the window size $W$ at steady state? How many packets are there in the buffer?

(b) 3 points. If $\tau_{\text{min}}$ observed by A is equal to the round-trip time without queueing delay, plus $\tau_e = 10\text{ms}$, i.e., 30ms, then what is the window size $W$ at steady state? How many packets are there in the buffer?

(c) 4 points. At what value of $\tau_e$ will the buffer be full? Let $\tau_{\text{e}}^*$ denote this value. What happens if $\tau_e > \tau_{\text{e}}^*$?