# *Problem Set 1*

Due date: **Wednesday, Feb 18, 11:59pm**

Submission: In pdf format via the submission form on the class website.

This problem set is worth 100 points.

You may use software such as Mathematica for problems 2, 3, and 4.

Some problems ask you to choose examples or parameter value. In these cases, it is not okay to choose any example or value – rather, finding a suitable choice is part of the requirements.

## 1. Traceroute & Propagation Delay (20 points)

Use traceroute to get an estimate of the round-trip end-to-end delay from your home to gback.cs.vt.edu. Do a back-of-the-envelope calculation to find out what percentage of the overall delay can be attributed to propagation delay. Use a street atlas such as Google Maps to estimate distances. Make simplifying assumptions as you deem them necessary.

## 2. Simple Bandwidth/Delay Calculations (20 points)

*[These are derived from problems 14-17 in the book]*

Suppose two hosts, A and B, are separated by 10,000 kilometers and are connected by a direct link of $R$ = 1 Mbps. Suppose the propagation speed over the link is $2.5 * 10^8$ meters/sec.

a) Calculate the bandwidth-delay product, $R * t_{prop}$.
b) Consider sending a file of 400,000 bits from Host A to Host B. Suppose the file is sent continuously as one big message. What is the maximum number of bits that will be in the link at any given time?
c) Provide an interpretation of the bandwidth-delay product.
d) What is the width (in meters) of a bit in the link? What is the width in feet?
e) Derive a general expression for the width of a bit in terms of the propagation speed $s$, the transmission rate $R$, and the length of the link $m$.
f) Suppose we can modify $R$. For what value of $R$ is the width of a bit as long as the length of the link?
g) Repeat a) with $R$ = 1 Gbps.
h) Repeat b) with $R$ = 1 Gbps.
i) Repeat d) with $R$ = 1 Gbps.

j) Assume $R$ = 1Mbps. How long does it take to send the file from part b)?

k) Now suppose the file is broken up into 20 packets with each packet containing 20,000 bits. Suppose that each packet is acknowledged by the receiver and the transmission time of an acknowledgment packet is negligible. Finally, assume that the sender cannot send a packet until the preceding one is acknowledged. How long does it take to send the file?

l) What is the overhead of packetization and acknowledgement in part k), expressed in percent of bandwidth?

## 3. Statistical Multiplexing (25 points)

*[This is a variation of problem 8c/d in the book]*

Refer to slide 21 in lecture 2 for an illustration. Suppose 40 users (not 35 as shown on that slide!) are sharing an outgoing link that statistically multiplexes the packets they are sending. Each user transmits only 10% of the time.

a) Find the probability that exactly $n$ of these users are transmitting simultaneously.

b) Find the probability that $n$ or more users are transmitting simultaneously. Compute the value for $n=11$. Give your result with an accuracy of 4 decimal digits after the period.

c) Solve the general case: Suppose that a link has a capacity $R$ and that each user transmits at a rate that is a fraction $f$ of the link capacity. Given $N$ users that share this link, what is the probability that more than $1/f$ users are transmitting simultaneously? (In the example given above, $f=0.1$ and $R$=1*Mbps,* and $N=40$.) Plot your result over an interesting range.

**Hint:** Use the binomial distribution to model part a). You may use the central limit theorem to approximate parts b) & c), although this is not required; in particular if you use such software as Mathematica, which allows exact computation. If you approximate, recall that the mean $\mu$ of a binomial distribution with $n$ trials is $\mu = np$ and its standard deviation $\sigma$ is given as $\sigma = \sqrt{np(1-p)}$.

Consider doing part c) before part b).

## 4. Message vs. Packet Switching (20 points)

*[This is an extension of problem 22 in the book.]*

As we discussed in lecture, splitting a message into smaller packets can reduce the transmission delay when that message is sent across multiple links in a network that uses store and forward. However, the applet we looked at omits one pesky detail: if messages are split into packets, each packet needs to have a header that contains the information necessary to reassemble the message.

This header needs to be transmitted, which adds transmission delay. In this problem, you're asked to examine the relationship between message size, packet size, and header size.

Consider sending a large file of $F$ bits from host A to host B. There are two links (and one switch) between A and B. The links are uncongested, so there is no queuing delay. Host A splits the file into segments of $S$ bits each and adds 160 bits of header to each segment, forming packets of length $L = 160 + S$ bits. Each link has a transmission rate of $R$ bps. Disregard propagation and processing delay.

a) Pick a value for $F$ and $R$ and plot the end-to-end delay involved in transmitting the file as a function of $S$.

b) Find the value of $S_{min}$ that minimizes the delay of moving the file from Host A to Host B.

c) Does $S_{min}$ depend on the bandwidth $R$ in your answer to b)? Give the formal reason and intuition as to why $S_{min}$ does (or does not) depend on the link bandwidth $R$!

Note: You pick values for $F$ and $R$ **only** for subpart a) for the purposes of plotting. You **must** solve parts b) and c) for the general case, that is, by treating $F$ and $R$ as variables. Also, note that c) asks for formal reason **and** intuition as to the dependency of $S_{min}$ on $R$!

## 5. Internet Trivia & Terms (15pts)

Use appropriate resources to answer the following questions. Cite your sources.

a) What is Internet2?

b) What is the National Lambda Rail (NLR)?

c) What is "dark fiber"?

d) What is a "co-location facility"?

e) What is a "peering conflict"?

f) What is "network neutrality"?