# ECE/CSC 570 – Section 3, Computer Networks, Homework #1
# (Total 91 points + up to 30 extra points, Due on Sept. 11, 2019)

*You are strongly recommended to read Chapter 1 of our references (Tanenbaum and/or Kurose & Ross, either of them is ok) and revisit lecture notes and the Class Exercises. Then, solve the following problems. Some of them are taken from these references but retyped here for your convenience (just in case you don't have the books).*

Throughout the course, we assume $1k = 10^3$, $1M = 10^6$, so on. DO NOT assume $1k = 2^{10}$, etc.

Submission Instruction:

- On-campus students: submit your hard copy in class by the beginning of the class. No need to type your solution. *No online submission allowed.*
- EOL (DE) students: visit wolfware Moodle course website, and look for "HW1 online submission link for DE/EOL students". The HW for EOL students will be due by around midnight on the day it's due (11:45PM EST, Sept. 11th for HW#1 for instance). Note that it's Eastern Time (so if you are in CA you must submit HW by 8:45PM on the day it's due), and we have set it up in a way that after this time you won't be able to submit your HW. Typically, scanned pdf file or any other electronic file should be ok. Make sure it's clearly legible; pictures or multiple files are not acceptable. If you (EOL students) have any trouble in submitting HW, please let the TA know.

**Problems:**

1. **(6 points)** Which of the OSI layers or sub-layers (if appropriate) handle each of the following:
   (a) Providing reliable, connection-oriented path between source and destination.
   (b) Determining alternate route for packets when the original route gets congested (e.g., routers on that path are dead).
   (c) Determining which user 'owns' the wireless channel to the access point in 802.11b.

2. **(10 points)**: A factor in the delay of a store-and-forward packet-switching system is how long it takes to store and forward a packet through a switch/router. If switching time is $50\mu$sec, is this likely to be a major factor in the response of a client-server system where the client is at NCSU and the server is in San Francisco (SF), CA?

   Assume the propagation speed in copper and fiber to be 2/3 the speed of light in vacuum, i.e., $v = \frac{2}{3} \cdot c = 2 \times 10^8$ m/s, and the distance between NCSU and SF along the route is about 5000km. Assume that there are about 15 routers/switches (the store-and-forward devices) along the route between NCSU and SF.

3. **(10 points)** Compare the delay in sending an $x$-bit message over a $k$-hop path in a circuit-switched network and in a lightly loaded (no queueing delay) packet-switched network. Ignore

the processing delays. The circuit setup time is $s$ sec, the propagation delay is $d$ sec per hop, the packet size is $p$ bits, and the data rate is $b$ bps. For the sake of simplicity, assume that $x/p$ is an positive integer and there is no header added to each packet.

Under what conditions does the packet-switched network have a lower delay (lower end-to-end latency)?

4. **(15 points)** Consider the example in "Packet vs. Circuit Switching' slide with the following variation. Each user, when active, needs 300Kbps bandwidth. There are total 50 such users wanting to get connected, where each user will be active with probability 0.2, all going through a link of 6Mbps.

   (a) (5 points) Under circuit switching, up to how many users can be supported on this link?

   (b) (10 points) Under packet switching, write down the probability that there are $k$ active users out of 50, $k = 0, 1, \ldots, 50$. What is the average number of active users? What is the probability that the link is actually overloaded, when the link can not support the bandwidth requirement of all active users? (Just clearly write down your expression. You don't need to compute the number.)

5. **(20 points)**: Consider sending a file of 16Mbits from Host A to Host B. There are three links and two store-and-forward routers (or switches) between A and B. (See Lecture note "Class Exercise 1: Delay Calculation" for instance.) Assume that processing delay is zero, and no link is congested (that is, no queueing delays), and the one-way propagation delay of each link is 10ms. Host A divides this file into smaller units with $S$ bits each and adds 20 bytes (=160 bits) of fixed-length header to each. This way, each packet will now be $L = 160 + S$ bits long. Each link has a transmission rate of $R$ =2Mbps. Again, for simplicity, assume that $16Mbits/S$ is always an integer, regardless of your choice of $S$ here.

   - (10 points) Express the total end-to-end delay $T$ of moving this file from A to B in terms of $S$ (the size of data portion of each packet). Call it $T = g(S)$, a function of $S$, and discuss how this would change if $S$ gets very small or very large.
   - (10 points) Then, find the value of $S^*$ (in bits) that minimizes $g(S)$. Does this optimal $S^*$ depend on the link speed $R$? (In other words, would $S^*$ change if we upgrade $R$ to $R = 200$Mbps (100 times faster)?

6. **(30 points)**: In the lecture slides ("Class Exercise 3: Asymmetric Setting), suppose that we put another router R2 in the middle of R-B link, thus forming two routers in the middle (R1, R2), with three links from the sender A to the receiver B. The newly added link R2–B is identical to the original A–R link (now called A–R1 link), with the same link speed of 10Mbps and propagation delay of 10ms. Instead, the middle link R1–R2 is slow, running at 1Mbps, with propagation delay of 90ms.

   The sender A has 3 packets to transmit to B, each of which is 50kbits. Assume that the queues at each of the routers R1 and R2 are all empty initially and ignore any processing delay at R1 and R2.

   (a) (5 points) Assume that A starts transmitting 3 packets back-to-back at $t = 0$, when does the first packet arrive to B?

(b) (15 points) When does the last (3-rd) packet arrive to B (i.e., the total end-to-end delay to transmit all 3 packets back to back to the destination B)? Compute the total queueing delay (sum of queueing delays over the path from A to B) for each of the three packets. What is the average queueing delay (out of 3 packets)?

*You need to show clearly all your steps. Simply writing down numbers or only your final answers will get zero credit.*

(c) (10 points) Suppose now that the sender A decides to transmit 3 packets not back-to-back, but with some 'spacing' in the middle. In other words, A starts transmitting packet 1 at $t = 0$, and once A is done transmitting packet 1, A goes idle, waiting for $s$ seconds, and then starts transmitting packet 2 at $t = \tau + s$, where $\tau$ is the transmission delay of one packet over the link A–R1. Similarly, there is $s$-seconds spacing between packet 2 and packet 3. What is the minimum value of $s$ such that none of the packets will suffer any queueing delay in the middle? Do you think the sender A in reality can find such spacing so that packets won't have to wait in the queue? Here assume there is no other protocol running between A and B (i.e., take the scenario 'as is', or assume UDP is running end-to-end). Carefully write down your logics.

7. **(Extra credits up to 30 points)**: The *traceroute* (or *tracert*) program allows you to send packets to intermediate routers along your path to the destination and see those intermediate nodes as well as the round-trip-time delay to each of these nodes. Try using *traceroute* or *tracert* to see how long it takes from your location to several well-known locations.

It would be the best to use universities since the location of their servers is known very accurately. For example, *berkeley.edu* is in Berkeley, California, *columbia.edu* is in New York, *purdue.edu* is in West Lafayette, Indiana, *vu.nl* is in Amsterdam, the Netherlands, *www.usyd.edu.au* is in Sydney, Australia, and *www.uct.ac.za* is in Cape Town, South Africa. If desired, you may want to try any other known servers (e.g., company headquarters or government sites, e.g., *francetelecom.com*, *nytimes.com*, *www.chinadaily.com.cn*), as long as the location of the servers are clearly known or can be identified.

For each of this traceroute executions, you will see the IP addresses of all the intermediate routers along the path. You will also see the end-to-end delay not only to these servers, but also to all intermediate nodes. Make sure to include screenshots of your experiments, with your choices of destination servers (and locations if the name of the server doesn't say much about the location), along with the discussion in your own words.

While all the explanation so far would have worked out nicely in an ideal world using your vanilla traceroute in unix/linux/mac or tracert in Windows, in reality, you will probably find that it's not the case if you try within a domain surrounded by a firewall (NCSU!). Many routers in the middle are also likely to be configured to block all such traceroute/ping commands running on ICMP protocols. Don't give up yet. There are several traceroute applications that bypass such hurdle. For example, search on the Web for traceroute bypassing firewall or something like this, and you will run into several ways to do so, e.g., `https://community.spiceworks.com/tools/traceroute/`. I'm not suggesting that you should use this particular application. You can try this or anything else of your choice. Just make sure you never provide your unity ID or any info that may reveal your real identity in installing/using the application.

**(Up to 10 points:)** Briefly explain in your own words how traceroute works and why the standard version (e.g., tracert in windows) often doesn't work.

**(Up to 20 points:)** Assuming you now have a working traceroute application, do the following:

(a) (5 points) Choose one destination server, find the physical location of the intermediate nodes by their IP's. From these data, plot the average one-way end-to-end delay over the Internet as a function of the distance (approx.) from your location to each of the intermediate nodes (routers). (Use "driving direction" on maps.google.com to estimate the physical distance.)

(b) (5 points) With your data collected in (a), compute the propagation delay (approximate) between routers. (Assume that the speed of propagation is $2 \times 10^8$m/s.) How much delay is then from non-propagation delay (i.e., transmission delay + queueing delay + processing delay) over each link?

(c) (5 points) Repeat this experiment from your PC with wired Ethernet connection and your laptop (if possible) with wireless connection and compare. Are the routers and delay different (even if you do experiment with wireless 'right after' from your wired PC to the same destination)?

(d) (5 points) Repeat this experiment in different time of day (say, try around 10AM and 10PM to the same destination). Are the routes (the sequence of IP addresses of routers along the path to the destination from your computer) the same?