CS353 Spring 2016
Homework 1
Due: March 10th at 10am

Name: ______________________________

USC-ID: ______________________________

Grade Table (for staff use only)

Question	Points	Score
1	15	
2	13	
3	12	
4	8	
5	6	
6	11	
7	10	
8	10	
Total:	85	

Instructions

- Submit this homework on BlackBoard in pdf format
- To submit, you can print out this document, write your answers on it, scan it and upload it. Or you can also use a pdf markup program to insert your answers into this document in the provided spaces, Or create a separate solution pdf (without the questions), each answer neatly labeled, and upload only solutions.
- If you need more space for work attach sheets at the end of the homework when you submit
- If you have questions, please ask on Piazza
- Question 8 is a bonus question and requires you to make measurements using networking tools
- Some potentially useful information:
  1 Byte = 8 bits, 1 Mbps = $10^6 \frac{\text{bits}}{\text{sec}}$, 1 Gbps = $10^9 \frac{\text{bits}}{\text{sec}}$, 1 millisecond (or msec) = 10^{-3} sec, 1 microsecond (or μsec) = 10^{-6} sec, 1 nanosecond (or nsec) = 10^{-9}. Assume speed of light is 2.0 x 10^8 m/s (speed in optical fibre)
- **READ THIS:** In this homework there are several questions that go beyond what we covered in class. When you start reading the question and it doesnot sound familiar, just work through the problem step-by-step and the answers should come out. Some of the problems involve some basic algebra and probability. They are mainly intuitive, but if you are having trouble with these concepts please attend office hours.

1. **Miscellaneous Short Questions**

(a) (2 points) Which (if any) of these Internet design principles would be violated by giving some packets priority over others when forwarding (e.g., flow A's packets might be sent before flow B's, if they both have packets in the buffer)? Mark as many as apply.

○ Layering: it is about modularity and encapsulation, hence not violated

○ End-to-End principle: about end points knowing application and high level requirements

hence not violated

○ Fate Sharing: is about packets getting dropped if router fails, hence not violated

○ None of the above: this is the correct choice

(b) (2 points) Consider a link with bandwidth B (in Mbits/second) and propagation delay L (in seconds). The source is sending an extremely large packet (assume infinitely large for the purposes of the question), and has just finished sending bit x on the wire; what bit y did the receiver just receive (don't worry about errors of plus/minus one)? Express your answer in terms of x, B, and L. Pay attention to units.

Solution: this is related to bandwidth delay product.

$x - B * L * 10^6$ if $x > B * L * 10^6$ (bandwidth delay product)

else

0

Basically, $B * L * 10^6$ is the number of bits that can be sent on the link in the times between the bit y was sent and when bit x was sent

(c) (2 points) How long does it take a 10Gbps link to transmit a 1500byte packet?

solution: $(1500 * 8)/(10 * 10^9) = 1.2$ μ seconds

(d) (2 points) Host S1 sends a packet to Host D (which has a single IP address), and when it passes through router X, it is then sent to router Y (i.e., Y is the next hop on X's path to D). Immediately thereafter, without any changes in the routing tables, Host S2 sends a packet to Host D and when it passes through router X it is then sent to router Z. What can we **definitely** conclude about the routing state?

Solution : The routing state is not destination-based.

(e) (1 point) Which of these were not one of the goals (according to David Clark) for the Internet design? Mark all that apply.

Solution: Privacy

(f) (1 point) Write the following address in dot-quad notation:

11010011101010011011111100011101

solution: 211.169.191.29

(g) (1 point) If the above address was in the original IP addressing scheme, what is its network address (expressed in dot-quad)?

solution: 211.0.0.0/8 or just 211 is fine too

(h) (1 point) If the above address was in the classful IP addressing scheme, what is its network address (expressed in dot-quad)?

solution: 211.169.191.0/24

(i) (1 point) If the above address was a /15 in the CIDR addressing scheme, what is its network address (expressed in dot-quad)?

solution: 211.168.0.0/15

(j) (1 point) Write the following address in binary: 67.114.184.23

solution: 01000011 01110010 10111000 00010111

(k) (1 point) Write the following prefix in binary: 222.10.0.0/19

solution: 11011110 00001010 000

2. **Maximizing Utility for Video Streaming**

In theoretical discussions of network design, one often assumes that the goal is to maximize the total utility (or happiness) of network users. In this problem we compare the total utility produced by the two design choices for networks: (i) on-demand (packet switching) or (ii) reservations (circuit switching). We assume that there are N users (each wanting to send a single flow) over a link of bandwidth B (measured in Mbits/second).

In this first problem in utility maximization, we consider streaming video. We assume that each user wants to stream videos of CS353, which we assume last forever. The happiness of an individual user i is denoted by U_i and is a function of the bandwidth b_i (measured in Mbits/second) their flow receives from the network. We assume that $U_i(b_i) = (b_i)^r$ for some power r, with $r > 0$. The total utility is $U_T = \sum_i U_i$. In the questions below, express your answers in terms of r, B, and N where relevant.

(a) (4 points) Under on-demand (packet switching), all flows share the bandwidth equally: $b_i = B/N$. What is the total utility U_T under this design?

solution: $U_i = (\frac{B}{N})^r$

$U_T = N * (\frac{B}{N})^r = B^r N^{1-r}$

(b) (4 points) Under reservations, one flow gets the entire network bandwidth B, and the others all get zero. What is the total utility U_T under this design? solution: B^r

(c) (1 point) For what values of r does on-demand provide a higher total utility? $0 < r < 1$

(d) (2 points) For what values of r does reservations provide a higher total utility? $r > 1$

(e) (2 points) For what values of r do they provide the same utility? $r = 1$

3. **Performance Comparison of Various Designs**

Consider a series of N links connecting a source with its destination. Each link has bandwidth B (in Mbits/sec) and propagation delay (or latency) L (in seconds). We are going to compare three technologies (and ignoring processing time for all packets).

- On-demand packet switching: there are two possible forwarding designs here
  - Store and Forward: packets are not forwarded on the next link until the last bit of the packet has arrived off the previous link.
  - Cut-Through: a packet can start being forwarded on the next link as soon as its first bit has arrived from the previous link.
- Reservations: there is only one design here
  - The reservation request is handled in a store-and-forward manner at each hop (because the reservation request must be inspected before forwarding the packet). The reservation acceptance is forwarded in a cut-through manner, and the data transmission is handled in a cut-through manner. The sizes of the reservation request and acceptance packets are R, and the reservation acceptance packet is sent from the destination as soon as the last bit of the reservation request arrives there.

Design #1: Using on-demand packet-switching, with Store and Forward.

(a) (2 points) How long does it take for a packet of length P (expressed in Mbits) to reach the destination (i.e., when does the last bit of the packet arrive)? Express your answer in terms of N, B, L, and P.

Solution: $N(L + \frac{P}{B})$ For each link, there is a P/B transmission delay and L propagation delay

(b) (2 points) How long does it take for a file of size kP (which is sent as k packets of size P) to reach the destination (i.e., when does the last bit of the last packet arrive)? Express your answer in terms of k, N, B, L, and P.

Solution: $(K + N - 1)\frac{P}{B} + NL$ The first packet would be sent as in the previous part, and then there will be an additional k-1 packets worth of transmission delay.

Design #2: Using on-demand packet-switching, with Cut-Through forwarding?

(c) (2 points) How long does it take for a packet of length P to reach the destination (i.e., when does the last bit of the packet arrive)? Express your answer in terms of N, B, L, and P.

Solution: $\frac{P}{B} + NL$ All the transmission delays except one will overlap with the propagation delay of the adjacent link, since packets can start being sent as soon as they arrive, so we do not count them in our calculation.

(d) (2 points) How long does it take for a file of size kP (which is sent as k packets of size P) to reach the destination (i.e., when does the last bit of the last packet arrive)? Express your answer in terms of k, N, B, L, and P. Solution: $\frac{kP}{B} + NL$

Design #3: Using Reservations

(e) (2 points) How long does it take for a packet of length P to reach the destination (i.e., when does the last bit of the packet arrive)? Express your answer in terms of R, N, B, L, and P.

Solution: Since the request is handled as store-and-forward and the reservation and data are forwarded in a cut-through manner,

Setup time: $N(\frac{R}{B} + L) + (\frac{R}{B} + NL)$

Data sending time: $NL + \frac{P}{B}$

Thus, Total time: $3NL + (N+1)\frac{R}{B} + \frac{P}{B}$

(f) (2 points) How long does it take for a file of size kP to reach the destination (i.e., when does the last bit of the file arrive)? Express your answer in terms of R, k, N, B, L, and P.

Solution: $3NL + (N+1)\frac{R}{B} + \frac{kP}{B}$

4. **Putting in Numbers**

Consider a series of 3 links which use store-and-forward, with each link having a bandwidth of 100Mbps and a propagation delay of 1msec. At time $t = 0$ packet P1 is sent, and at time $t = 3msec$ packet P2 is sent.

(a) (4 points) If packet P1 contains 100kbits and packet P2 contains 200kbits, when will the last bit of packet P2 arrive?

Solution: 12 msec. The transmission delay of P1 will be 1 msec and that of P2 will be 2 msec. The last bit of P1 will arrive at the end of each link at times t = 2, 4 and 6. The first bit of P2 will arrive at the end of each link at times t = 4, 7 and 10. The last bit of P2 will arrive at the end of each link at times t = 6, 9 and 12.

(b) (4 points) If packet P1 contains 200kbits and packet P2 contains 100kbits, when will the last bit of packet P2 arrive?

Solution: 10 msec. The transmission delay of P1 will be 2 msec and that of P2 will be 1 msec. The last bit of P1 will arrive at the end of each link at times t = 3, 6 and 9. The first bit of P2 will arrive at the end of each link at times t = 4, 6 and 8. However, at time t = 8 the destination is still receiving P1, and will be until time t = 9, so P2 has to wait. Thus the first bit of P2 is not actually received until time t = 9, and so the last bit will not be received until time t = 10.

5. **Dealing with Errors**

Consider a series of N links, with a source A on one end sending to a destination B on the other end. Each link randomly drops each packet with probability p. We want to compare two different designs that attempt to recover from these errors.

Design #1: On each hop, each packet is resent up to k times (as needed).

(a) (3 points) What is the probability that a packet sent by A will be delivered to B? Express your answer in terms of N, p, and k.

Solution: $(1-p^k)^N$ The probability of failure of a given link is p, so the probability of it failing every retransmission is p^k. The probability of the packet getting through the link at least once in k retransmissions is then $(1-p^k)$. Then there are N links each with this probability of success, so the probability of all of them succeeding is $(1-p^k)^N$

Also accept, if the student interpreted the question as k+1 transmissions total. In this case, replace the k term in the solution with k + 1.

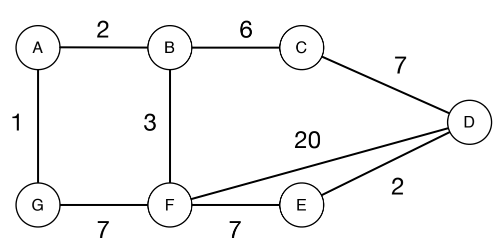
Design #2: The packet is resent from A up to k times (as needed), with no per-link retransmissions.

(b) (3 points) What is the probability that a packet sent by A will be delivered to B. Express your answer in terms of N, p, and k.

Solution: $1-(1-(1-p)^N)^k$ The probability that a packet does not get dropped on a given link is (1 - p), so the probability that packet gets through all N links without bring dropped is $(1-p)^N$. This means the probability it does get dropped is the complement of this, which is $1-(1-p)^N$. The probability that it gets dropped on all k retransmissions is the probability it gets dropped on one raised to the k power,$(1-(1-p)^N)^k$. So finally, the probability that it makes it through at least once in k retransmissions is $1-(1-(1-p)^N)^k$

Also accept, if the student interpreted the question as k+1 transmissions total. In this case, replace the k term in the solution with k + 1.

6. **Distance Vector**



Consider the network graph in the diagram, with the specified link weights. Assume that a distance-vector routing algorithm is run on this network, and that algorithm uses poison reverse.

(a) (3 points) After the routing algorithm has converged, what path does a packet take from G to D? Specify all the hops along the path (e.g., G-X-Y-Z-...-D).

Solution: G-A-B-F-E-D

(b) (3 points) What distance toward D does router G advertise to router F?

solution: 15

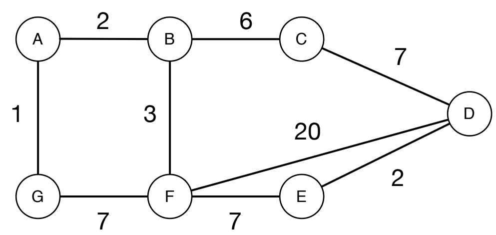
(c) (3 points) Assume that the link between E and F goes down. Before any routing messages are sent (but E and F recompute their shortest available paths based on what they have previously been told by their neighbors), when a packet with destination D arrives at F, to which router does it send it?

Solution: D

(d) (2 points) Assume that the link between E and F stays down, and that the algorithm has had a chance to reconverge. When a packet with destination D arrives at F, to which neighboring router does it send it?

Solution: B

7. **Link State**



Assume that the network is now running a link-state algorithm. Assume that the routing protocol has converged, but then the link between D and E goes down (and both D and E know about the outage).

(a) (5 points) Once the update about this outage travels to C and F, but nowhere else, what happens to a packet sent from G towards D? Specify the first six hops along the path (e.g., G-X-Y-Z-...).

Solution: GABFBF

(b) (5 points) Now assume that the update about the outage has spread throughout the network and all routes have been recomputed. Specify the path for a packet sent from G towards D (e.g., G-X-Y-Z-...).

Solution: GABCD

8. **Bonus Fun!**

The `ping` program determines the round-trip-time (RTT) to any host in the Internet. Using a computer on campus (either your laptop connected to USC network or aludra) ping the following hosts five times each to calculate an "average RTT" :

- `umass.edu` (Amherst, MA)
- `ucsd.edu` (San Diego, CA)
- `utexas.edu` (San Antonio, TX)
- `columbia.edu` (New York, NY)
- `www.ed.ac.uk` (Edinburgh, Scotland)
- `www.tsinghua.edu.cn` (Beijing, China)
- `hi.is` (Reykjavik, Iceland)
- `aalto.fi` (Helsinki, Finland)

For each of these cities find the physical distance from USC (You can look these up here: http://www.geobytes.com/citydistancetool.htm), and then compute the estimated time T for a packet to reach that location.

(a) (8 points) Plot a graph where the x axis represents the distance to each city, and the y axis represents the ratio between the RTT as measured by the `ping` program and the shortest possible time 2T to reach that city and return. You may disregard transmission delays as ping packets are quite small. Explain what you see in the plot in a few sentences.

solution: Please work out...

The ideal ratio should be 1. It is unlikely to achieve it, and there should overall be a slight decreasing trend because other delays are more impactful when the travel time (propagation delay) is smaller. Also, slightly suboptimal paths will not negatively affect the RTT as much. Note: The data points often may not reflect any trend :(so credit was given regardless of what was written here.

(b) (2 points) Use the "traceroute" tool to observe the path from your laptop/host to three of the destinations above. Paste the output below. What part of the path is same? What part of the path different?

solution: I noticed akamai as a hop. give full points if tracroute output is given.