EE 5150 Communication Networks
Quiz 1, Jan-May 2022

Total time **75 minutes**. *Total points* **30**. *You must* **justify** *your steps to get full points.*

You must follow the instructions below.

You will have **additional 15 minutes** to scan your answer sheets and upload them on the submission portal in moodle (PDF/JPG/JPEG/PNG/GIF format). Thus, by the end of **one and a half hour** you should finish submitting your answers. Though moodle will allow you to submit late (up to half an hour), all delays will be recorded by moodle and your marks may be deducted accordingly.

If you are unable to upload your answer sheets within one and half hour because of some moodle issues, please email your scanned answer sheets to the TAs immediately.

You can consult your class notes and text books, but your are NOT allowed to use the internet. Also, you must NOT discuss with anybody else.

ATTENTION: the questions you need to answer

Add the last two digits of your IIT Madras roll number and multiply that sum by 2. The final answer you obtain is your **KEY**.

Based on your **KEY** you have to answer a set of questions chosen randomly for you. The following table matches the **last digit of your KEY** with the set of questions you need to answer. Answer only that set of questions. **No marks will be awarded for answering other questions.**

Last digit of your **KEY**	Answer question numbers
0	1, 4, 5
1	2, 3, 5
2	2, 4, 5
3	1, 3, 5
4	1, 4, 5
5	2, 3, 5
6	1, 3, 5
7	2, 4, 5
8	2, 3, 5
9	1, 4, 5

Questions

1. (15 points) In Figure 1, a network is shown. This has two paths, path J and path L, from node S to node D. Each link on path J has a delay of 2 ms when it is in "good" state and 5 ms when it is in "bad" state. On the other hand, each link on path L has a delay of 1 ms when it is in "good" state and 3 ms when it is in "bad" state.

   Any link on path J is in good state with probability 0.8, independent of any other link. However, on path L, all links are simultaneously in good state with probability 0.8 or simultaneously in bad state with probability 0.2.

   Clearly, the end to end delays on path L and J are random. There can be many metrics for choosing the best path.

   Let X be the end to end delay (in ms) on a path.

   (a) Which path would have the smallest $\mathbb{E}[X]$?

   (b) Which path would have the smallest $\mathbb{E}[X] + 5(\mathbb{E}[X^2] - (\mathbb{E}[X])^2)$?

   (c) Which path would have the smallest $\mathbb{E}[X] + 1000\,\mathbb{P}(X \geq 2\mathbb{E}[X])$?

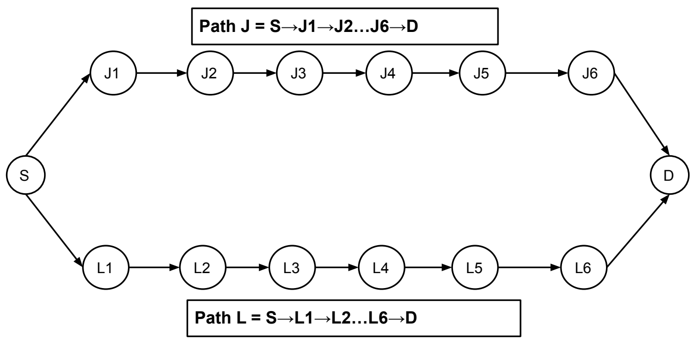

Figure 1: Illustration of the two paths (L and J) from S to D.

2. (15 points) In Figure 1, a network is shown. This has two paths, path J and path L, from node S to node D. Each link on path J has a delay of 1 ms when it is in "good" state and 4 ms when it is in "bad" state. On the other hand, each link on path L has a delay of 0.5 ms when it is in "good" state and 2 ms when it is in "bad" state.

   Any link on path J is in good state with probability 0.8, independent of any other link. However, on path L, all links are simultaneously in good state with probability 0.9 or simultaneously in bad state with probability 0.1.

   Clearly, the end to end delays on path L and J are random. There can be many metrics for measuring the quality of a path. In this problem, we explore a few.

   Let X be the end to end delay (in ms) on a path.

   (a) Which path would have the smallest $\mathbb{E}[X]$?

   (b) Which path would have the smallest $\mathbb{E}[X] + 5(\mathbb{E}[X^2] - (\mathbb{E}[X])^2)$?

   (c) Which path would have the smallest $\mathbb{E}[X] + 1000\,\mathbb{P}(X \geq 2\mathbb{E}[X])$?

3. (10 points) Recall TCP Reno and its (approximate) differential equation based analysis. Note that, in the congestion avoidance (CA) phase, on reception of dupACK, the congestion window W is halved, and on the reception of W ACKs, the congestion window is increased to $W + 1$.

   Consider the following variation of TCP Reno. On reception of dupACK during the CA phase, the congestion window W is reduced **to** $\sqrt{W}$. On reception of an ACK during the phase, the congestion window W is increased **to** $W + 1$.

   (a) Following the approach taken in the analysis of TCP Reno, derive the differential equation for the evolution of the congestion window.

   (b) Find the average throughput. You may assume the probability of dupACK/loss, q, to be close to zero.

4. (10 points) Recall TCP Reno and its (approximate) differential equation based analysis. Note that, in the congestion avoidance (CA) phase, on reception of dupACK, the congestion window W is halved, and on the reception of W ACKs, the congestion window is increased to $W + 1$.

   Consider a variation of TCP Reno, where on reception of dupACK during the CA phase, the congestion window W is reduced **by** $\sqrt{W} + 1$. On reception of $\sqrt{W}$ ACK during the phase, the congestion window W is increased **to** $W + 1$.

   (a) Following the approach taken in the analysis of TCP Reno, derive the differential equation for the evolution of the congestion window.

   (b) Find the average throughput. You may assume the probability of dupACK/loss, q, to be close to zero.

5. (5 points) Summarize the roles played by the application, transport and network layers in loading a webpage on your browser.