Instructions

1. The university has important rules for exams. Please carefully read the instructions below. Failure to comply with any of the instructions below may result in our being unable to accept or grade your exam or initiating disciplinary actions
2. The exam must be taken completely alone. Showing it or discussing it with anybody is forbidden, including (but not limited to) the other students in the course in current or previous years. It is also forbidden to use any solutions to similar problems from previous years as reference material.
3. Given your final grade depends on your rank in the class, you don't want to penalize yourself discussing your solutions with the other students.
4. You may use any publicly available material you want, including books, the internet, etc. (You are NOT allowed to submit questions to internet discussion groups, though!).
5. If you find a solution to a test problem in a book or online, cite it in your submission and do not copy it as-is, but make changes that demonstrate you understand what you are writing. Otherwise, we may not accept it.
6. You must submit your exam electronically only in .pdf format via Blackboard no later than **3:59 pm May 1, 2020**. Files submitted after this time will be discarded.
7. Show your work. You need to demonstrate your understanding by showing the detail of your work.
8. Consent: By submitting this exam I declare I am aware of the Kent State Administrative Policy Regarding Student misconduct and I acknowledge that any academic misconduct on this exam will lead to a grade "F" for the course and that the misconduct will be reported to the Center for Student Conduct.

1. We want to compare the performance of a switch (L2) versus a router (L3) in terms of the average packet delay. In both, we use the same hardware that consists of a processor that runs at 1 Gbps (2^{30} bps). The switch accepts 1 KB ($2^{10}B$) fixed size packets. The router accepts variable size packets with an average 1 KB. In both scenarios, packets arrive at a rate $\lambda = 64$ packets/s.

   (a) What is the service rate (μ), in terms of packets/s, at each port for the switch and the router? 4 pts

   (b) What is the traffic intensity (service utilization, ρ) at each port for the switch and the router? 4 pts

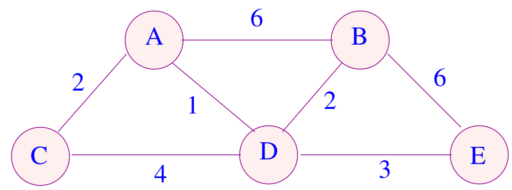
   (c) What is the average queuing delay for the switching port? 4 pts

   (d) What is the average queuing delay for the router port? 4 pts

   (e) Which one is faster and by how much? 4 pts

Note that: The delay in a buffer with variable size packets is, $D = \frac{1}{\mu - \lambda}$
The delay in a buffer with fixed size packets, $D = \frac{2-\rho}{2\mu(1-\rho)}$
where $\rho = \lambda/\mu$.

2. Consider the following network of 5 routers, with edge weights labeled.



(a) Use Link State routing algorithm to derive the routing table for node A. Show the step-by-step operation.

i. Draw the spanning tree. 7 pts

ii. What happens where there is a tie in choosing the next hops between to or more nodes? 3 pts

(b) Now consider a Bellman-Ford-based distance-vector protocol. Assume that the protocol has converged, and then router E fails. 10 pts

i. Will the protocol converge? If yes, show the sequence of updates that result (after each update, show the next hop and cost for E as seen by each of the remaining routers. If not, explain why not.

3. An Internet Service Provider (ISP) deploys a leaky bucket followed by a token bucket to regulate the traffic and control the data rate with the following parameters.

Leaky bucket departure rate:	2 packet per second.
Leaky bucket size:	5, initially empty.
Token bucket size:	20, initially full. Each token is good for one packet (1 KB = $2^{13} bps$)
Token arrival rate:	1 every 4 seconds. 1 at time 4, 8, 12, etc.

(a) Determine the content of the buckets and the number of packets dropped by each bucket for the following time interval. Note: operations are performed at the end of each cycle (i.e., if the leaky bucket is full, 2 packets arrive, and two packets depart, ther is no overflow). 10 pts

Time(t)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Packet arrival	6	0	3	5		1	1	8		3	2	6			4	8
Leaky bucket length																
Token bucket length																
# of packets dropped from leaky bucket																
# of packets dropped from token bucket																

(b) What is the effective rate (Packets/sec) of the leaky bucket for this packet stream? 5 pts

(c) What is the effective rate (Packets/sec) of the entire system? 5 pts

4. Suppose you are using TCP over a 1-Gbps (2^{30} bps) link with a latency 100 ms to transfer a 10 MB (10×2^{20}B) file. The TCP receiving window is 1 MB. If TCP sends 1 KB (2^{10} B) packets (assuming no congestion):
   - How many RTTs does it take until Slow Start opens the send window to 1 MB? 5 pts
   - How many RTTs does it take to send the file? 5 pts
   - Given the receiving window is 1 MB, and the Slow Start starts with 1 KB, what is the effective throughput (bps)? 5 pts
   - How many RTTs does it take to send the file if TCP runs into a congestion when the window size is 8KB? 5 pts

5. TCP has a 32-bit sequence number field and 16-bit advertised window field. Assume that RTT is 512 (2^9) ms, transmission speed is 1 Gbps (2^{30} bps) and each segment transmitted is 1B byte. Note that Since not two identical sequence numbers can be unacknowledged in the pipe, half of the sequence numbers can used (2^{31}).

   (a) How long does it take for the sequence numbers to warp around? 5 pts

   (b) Now, instead of sending 1 B segment, let's send a 16 B segment. How long does it take for the sequence numbers to warp around? 5 pts

   (c) What is the drawback in using large segments? 5 pts

   (d) What is the maximum achievable throughput? 5 pts