1. Suppose you are designing a bus-based switch with 16 ports and 1 Gb/s links. Assume your circuit
technology allows you a clock rate of \( (400/n) \) MHz where \( n \) is the number of loads on each bus line.
Assuming a conventional, single-level bus, how many bus lines are needed to provide the bandwidth
to accommodate 100% loading on all links? (You may neglect added bandwidth needed for internal
control information.)

How many pins are required to connect each IPP and OPP to the bus?

Suppose you change to a subdivided bus with knockout concentrators at the output? How many pins
are needed to connect each IPP in this case? How many pins for each OPP, assuming that there are no
active components between IPPs and OPPs? If you can insert buffers between IPPs and OPPs, how
would your answer change (explain how you would use the buffers)?

Suppose you change the design to use a ring, instead of a bus. How many pins are required per IPP
and OPP in this case?

2. In the RARD queueing model, as presented in the class notes, the transition probabilities leaving state
\( B \) imply a particular mechanism for discarding cells that arrive when the queue is full. Specifically,
if a cell arrives when the queue is full, and the first cell in the queue does not leave during that time
step, then the arriving cell is discarded.

In some queue implementations an arriving cell is discarded if the queue is full when the cell arrives,
regardless of whether another cell can leave during that time step. How do the transition probabilities
change to model a queue implementation that works this way? Derive equations for the steady-state
probabilities \( \pi(0), \ldots, \pi(B) \) in terms of \( \lambda, \mu \) and \( B \) for this variant of the model.

Give expressions for the average queue length and for the cell loss probability.

Make a plot of cell discard probability as a function of input load for a queue with a capacity of 5
cells, using your modified queueing model (fix \( \mu = 0.5 \) for this). On the same plot, show the cell
discard probability for the original RARD queueing model for a queue with a capacity of 5 cells and
for a queue with a capacity of 6 cells. How important is the difference between these two queueing
models? Consider both short queues and long queues when answering this.

3. Consider a four port bus-based switch in which the traffic distribution from inputs to outputs is
distributed randomly, but unevenly as follows.

Input 0 sends 70% of its arriving traffic to output 1, 10% to output 2 and 20% to output 3.
Input 1 sends 25% of its arriving traffic to output 0, 40% to output 2 and 35% to output 3.
Input 2 sends 40% of its arriving traffic to output 0, 20% to output 1 and 40% to output 3.
Input 3 sends 60% of its arriving traffic to output 0, 25% to output 1 and 15% to output 2.

What is the probability that in any given cell cycle, output 0 receives no cells, one cell, two cells,
three cells or four cells? Assume that all inputs receive cells on their input links with probability \( p \)
and that the outputs for all cells are independent.
What is the average number of cells received by output 0 each cell cycle?
What is the average queue length for output 0, assuming that it has a queue with a capacity of 5 cells?
What is the cell discard probability?

4. Consider an output queue for a 600 Mb/s link in a bus-based switch, and assume that the data flowing through the queue originates from a set of WWW servers. Assume that each file transfer is 200 Kbytes and that one file is sent on each virtual circuit every 8 seconds (on average). To give the users good interactive response, we want it to take at most one second from the time the user clicks on an item until it is completely transferred to the user’s computer. Assume that the user’s computer contributes 30 ms of delay when sending the request, another 30 ms when receiving the response and that the server contributes 100 ms of delay in responding to the request. Also, assume that the one way propagation delay through the network is 40 ms.

What rate, should each file be sent at to meet the objective of a one second response time? What is the average rate at which data is sent on each virtual circuit.

How many virtual circuits of this type can share a link, if we want to limit the congestion probability to .01? What is the average link utilization in this case? What is the virtual cell loss under these conditions?

How many virtual circuits can share the link with congestion probability .01 if each file is sent at 50 Mb/s instead of the rate you calculated? How many if each file is sent at 200 Mb/s? What is the average link utilization and virtual cell loss in each of these cases?

Which choice of rates gives the best performance from the user’s standpoint? From the standpoint of the network service provider? Which, in your opinion, is the best choice overall? Why?

5. Consider a 150 Mb/s link that is experiencing an extended overload period caused by 40 virtual circuits, each sending 5 Kbyte packets continuously at 30 Mb/s. Approximately what fraction of the cells sent on this virtual circuit are lost due to overflow of the queue at the sending end of the link?

Assuming the queue controller does not implement early packet discard, or any similar method of preserving packet integrity, approximately what fraction of the packets sent are corrupted (that is, have at least one of their cells lost)?

Suppose the queue controller does implement early packet discard and that the buffer is large enough to ensure that it never overflows and never becomes empty during the overload period. What fraction of the packets are lost in this case? Approximately what fraction of the time is the buffer below the threshold?

Suppose we were to add another virtual circuit sending 5 Kbyte packets at 1 Mb/s. Approximately what fraction of packets sent by this new virtual circuit will be lost?

6. Consider an output queue in an ATM switch that uses Early Packet Discard (without hysteresis), to maintain packet integrity. Based on the worst-case analysis, how large a buffer is needed if we want to maintain 100% goodput for offered loads up to five times the link rate. Assume that the virtual circuit peak rate is 20 Mb/s, that the link rate is 600 Mb/s and the packet length is 6,000 bytes. Repeat the analysis for a link rate of 2.4 Gb/s.

Answer all the questions above again, using the even-offset analysis. Repeat again, assuming the buffer controller uses EPD with hysteresis.

7. Consider the network shown below
Assume that the network implements ABR flow control and that there are ABR virtual circuits joining A and A', B and B', C and C', D and D'. Assume all links are operating at 150 Mb/s, that the output buffer at switch X on the link to Y has sufficient capacity to hold 1 Mbit and the delays experienced by cells are as indicated indicated by the labels in the figure. Also, assume that at time 0, A and D are sending data at 80 Mb/s and 30 Mb/s respectively. Now suppose that after 10 ms, B starts sending a burst at 100 Mb/s and C starts sending at 60 Mb/s. At what time does the buffer become full?

Assuming the ABR controller attempts to allocate the bandwidth fairly among the competing sources and that 90% of the link bandwidth is allocated during an overload period, how much bandwidth will each of the four sources be assigned by the controller, assuming that none is given more than it wants? (A wants 80, B wants 100, C wants 60 and D wants 30.)

At what time do A, B, C and D change their rates? (Assume that resource management cells must propagate to the receivers before being sent back to the senders.)

At what time does the rate into the buffer drop below the link rate?

Approximately how much data is lost during the period of time when the buffer is full?

Repeat the analysis, assuming that switch X places the allocated rate information directly into the “returning” resource management cells.

8. Consider a virtual circuit that is being monitored by a Usage Parameter Control mechanism with two buckets, one for limiting the peak rate, the other for limiting the average rate. Each time a cell is sent on the virtual circuit, one token is consumed from each of the two token buckets. If either of them does not have a token available, the cell is discarded. Assume that the peak rate bucket can hold one token and that a new token is generated every 20 microseconds. Assume that the average rate bucket has a capacity of 120,000 tokens and a new token is generated every 250 microseconds. If both buckets are full initially, for how long can the user send data at a rate of 10 Mb/s before the average rate reservoir is empty? What is the most bursty repeated pattern of data transmissions that could be sent over this virtual circuit without causing any cells to be lost?