1. a) Given the following traffic graph, draw the arrival curve and determine its bucket parameters $R$, $b$, and $r$

![Traffic Graph](image)

b) Assume the flow characterized by the token bucket at part (a) is allocated a rate of 2 Bps. What is the maximum delay experienced by the flow? What is the minimum buffer required such that to avoid overflow?

2. A source shapes its traffic to ensure that at most 600 Kb are transmitted in any 10 second period, and the maximum burst size is 200 Kb. Assume the pick rate ($R$) at which the source can transmit is 100 Kbps. For questions (a) and (b) assume a fluid flow system in which the traffic is sent bit-by-bit.

   (a) If the source uses a token bucket regulator to shape its flow, what are the values of the average rate $r$, and token depth $b$?

   (b) Assume the source traffic is served at a fixed rate $r_s = 50$ Kbps. What is the minimum size of the queue to prevent losses? What is the maximum time a bit can be delayed in the queue?

   (c) Assume now that the source sends packets of size 10 Kb, and that the source traffic is constrained by a token bucket with parameters ($R$, $r$, $b$) as computed at part (a). What is the departure time of the 1st, 20th, and 30th packet? (Assume that the source has always packets to send).

3. Consider the following 5 packets arriving at a router with an output link capacity of 1Mbps:

   - Packet 1 arrives at time 0 with size 3Kb from IT
   - Packet 2 arrives at time 0 with size 2Kb from Business
   - Packet 3 arrives at time 2 with size 4Kb from Business
   - Packet 4 arrives at time 2 with size 4Kb from IT
   - Packet 5 arrives at time 3 with size 3Kb from IT
Assume both IT and Business classes have a weight of 1.

(a) In what order are packets transmitted using the round-robin scheduling discipline?

(b) In what order are packets transmitted using FQ. Draw the fair queueing diagram like the one on Slide 21 of Lecture 15.

(c) Draw the corresponding virtual/clock time graph for part (b).

(d) Redo parts (a) and (b) if the Business class is twice as important as the IT class, i.e., the Business class has a weight of 2, while the IT class has still a weight of 1.

4. Consider five flows A, B, C, D and E with arrival rates of 1, 2, 3, 5 and 8Mbps, respectively, which traverse a link of capacity 15Mbps.

(a) Assume all flows have equal weights. Assuming that max-min fairness is applied, compute the fair share.

(b) Now assume that flows A, B, C, D and E have weights 5, 4, 3, 2 and 1, respectively. What is the fair share of each flow in this case.

(c) Repeat questions (a) and (b) if the link capacity is 20 Mbps.

5. In a fluid flow system (1 bit packets), consider the arrival traffic characterized by a token bucket with parameters $r$ (average rate) = 5 Mbps, $R$ (maximum rate) = 10 Mbps, and $b$ (token depth) = 100Kb. Assume the router can allocate only a 50Kb buffer for this flow,

a) What is the minimum rate $r_a$ that needs to be allocated by a router in order to guarantee that the packets will be transmitted without packet loss.

b) What is the maximum delay that the router for guarantee for the packets?

6.

a) Give an example of a real-time, non-robotic application that is intolerant/rate adaptive.

b) Explain why you might expect a loss-tolerant application to be at least somewhat rate adaptive.

c) Part (b) notwithstanding, give an example of a non-robotic application that might be considered tolerant/nonadaptive. Hint: Tolerating even small losses qualifies an application as loss tolerant; you will need to interpret rate adaptive as the ability to adjust to substantial bandwidth changes.