# Assignment 2
## CSC467/567 Spring 2017

71 points in total. Submission deadline: Feb 22, **2017 on conneX.**

The following scenario is the basis for Questions **1 to 4**: A router multiplexes four traffic flows on to a given link. These flows are individually queued as shown below. Flow A is a constant bit rate service, Flow B is a variable bit rate service and Flows C and D are best effort services.
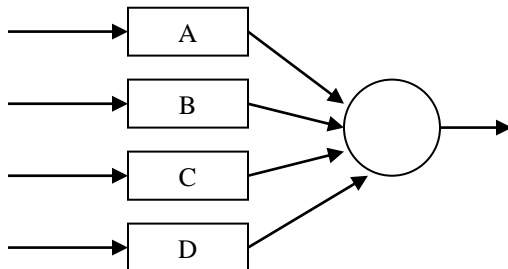


## Question 1 [3] (on-off model)

This question relates to understanding of average rate, peak rate and link rate of a source. Link rate is the maximum rate of a physical connection between the nodes. However, a source may send the data at a "peak rate" which usually is different from the link rate. Flow B sends the traffic using an on-off traffic model with an 'on' duration of 5 sec and 'off' duration of 15 secs. The source sends data at half the link rate (also known as the peak rate) when "on". What is the average data rate of this source? How many packets are sent by this source when it is on (called burst), assuming an average packet size of 2000 bits? Assume that the link bandwidth is 1.5Mbit/sec.
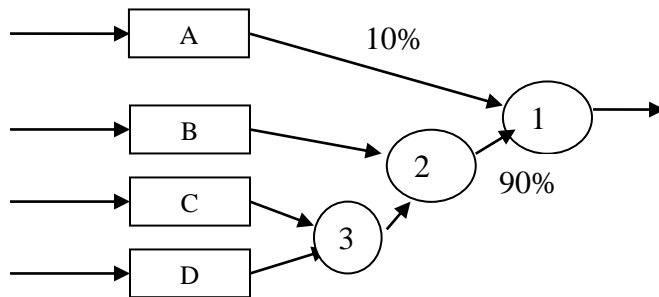
## Question 2 [26] (Scheduling)

Consider the four flows A, B, C, and D at the above queuing point. Each of the flows gets their own separate queue (per-flow queuing) as shown in the above figure. Assume that all packets are of equal length (assume unit length). We want to give a weight of 1 to connection A, 2 to B, 3 to C and 4 to D. Assume that there is always a packet waiting in the queue for each of the flows to be transmitted.
   a) Determine a frame (or cycle) for a WRR service schedule, explaining the reasons why you chose such a service cycle. [4]
   b) What is the ideal bandwidth (long term) each flow gets as per this WRR scheme? Assume a link bandwidth of 1.5Mbit/sec. [2]
   c) What is the bandwidth (long term) each flow gets as per this WRR scheme if you consider only 4 cycles? Is it close to ideal? [2]

d) Based on virtual finishing times of WFQ scheduler, determine the sequence of packets transmitted by the scheduler. Consider up to 40 such packet transmissions and verify that the packets are transmitted as per the weight allocation of the flows. [5]

e) What is the bandwidth each flow gets as per the above WFQ scheme? [2]

f) Comparing the service orders of the packets of the flows for both schedulers (WRR and WFQ), what can you infer on burst and delay behavior of the two systems? [2]

g) Would it be possible to make your WRR schedule to mimic WFQ service order? If so how? [2]

h) Repeat part (c) with variable packet size. Assume A sends 50-byte packets on the average, B sends 100-byte packets, C and D both send 500-byte packets. [5]

i) What is the bandwidth each flow gets as per the above WFQ scheme? [2]

## Question 3 [10] (Hierarchical Scheduling)

Let us divide the traffic as follows: Real-time (Flow A), Guaranteed (Flow B) and Best-effort (Flows C&D). The scheduler in the above question uses a HRR scheme and divides the link bandwidth as follows: Level 1 scheduler: 10% to Real-time and 90% to both Guaranteed and Best Effort traffic. The second level divides the allocated bandwidth as 20% to Flow B and the remaining to the third level. The third level scheduler divides the allocated bandwidth as 1/3 to Flow C and the remaining to flow D. Determine a schedule based on the HRR scheme discussed. Assume all packets are of constant length.



## Question 4 [5] (Scheduling SCFQ)

Packets of length 10 and 15 arrive at connections A and B at a scheduler serving a link of unit rate at time 0. Packets of length 5 and 10 arrive at connection A at times 9 and 17. What are the finish numbers under Self Clocked Fair Queueing (SCFQ) assuming the flows have equal weights?

## Question 5 [3]

Consider two connections with loads 0.2 and 0.4 that have mean waiting times of 0.3 and 0.4s at an FCFS scheduler. If a new scheduler gives the first connection a mean delay

of 0.1, what must be the mean delay of the other connection increase to? (Hint: use the conservation theorem)

## Question 6 [8]

A link of 100Mb/s is shared by 6 flows (f1 to f6) at a router. The maximum rate at which these flows wish to send data are as follows: f1=1Mb/s; f2=2Mb/s; f3=10Mb/s; f4=20Mb/s; f5=100Mb/s; f6=100Mb/s. Compute the rate allocated to each of these flows using max-min allocation. Assuming a WFQ scheduler serves these flows, what will be the weights set to these flows in order to achieve the max-min bandwidth?

## Question 7 [6]

Max-Min allocation algorithm we discussed in the class (Slide 24 of Queuing and Scheduling slides) uses the concept of equal fair-share where the bandwidth is equally divided among the flows. Extend this algorithm to include the concept of weighted fair share where the bandwidth allocated is in proportion to weights of the flows. Use this algorithm to compute the bandwidth allocation for Question 6 when the weights of the flows are w1=10; w2=10; w3=20; w4=20; w5=40; w6=100.

## Question 8 [10]

This question relates to delays experienced by flows in the network. Consider two flows Class 1 (high priority) and Class 2 (low priority) multiplexed (queued) at a router's outgoing link (1Mbps). Please refer to the slides 40 of Queueing and Scheduling. Assume Class 1 sends 500 bytes packets and Class 2 sends 1000 bytes packets. **Assume $S_i^2=2/\mu_i^2$.**

   a) What is the packet service time ($=1/\mu_1$=time to transmit a packet) for Class 1?
   b) What is the packet service time ($=1/\mu_2$=time to transmit a packet) for Class 2?
   c) Given Class 1 packet arrival rate = 25 packets/sec and Class 2 packet arrival rate = 50 packets/sec, what are the expected waiting times for each class? What are the expected number of customers (apply Little's law) in each queue? What is the total utilization of the queue?
   d) Given Class 1 packet arrival rate = 50 packets/sec and Class 2 packet arrival rate = 50 packets /sec, what are the expected waiting times for each class? What are the expected number of customers (apply Little's law) in each queue? What is the total utilization of the queue?
   e) Given Class 1 packet arrival rate = 100 packets/sec and Class 2 packet arrival rate = 50 packets /sec, what are the expected waiting times for each class? What are the expected number of customers (apply Little's law) in each queue? What is the total utilization of the queue?
   f) Analyze the data from parts (c), (d) and (e), i.e., given a change in class 1 load (traffic), how much % increase in delay is experienced by class 2 traffic?

**Little's Law:** $E\{n\} = \lambda. E\{w\}$. i.e., average (expected) number of customers in a queue = average arrival rate to the queue × average (expected) waiting time of the queue.