1. Scheduling and QoS

<table>
<thead>
<tr>
<th>Packet #</th>
<th>Size</th>
<th>Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>90</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>80</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>120</td>
<td>3</td>
</tr>
</tbody>
</table>

Suppose a router has three input flows and one output. It receives the packets listed in the table above all at about the same time, in the order listed, during a period in which the output port is busy but all queues are otherwise empty. Give the order in which the packets are transmitted for

*Note: Resolve ties in the order of flow 1, flow 2, and flow 3*

a. Fair Queueing.

Sequence: 3, 1, 4, 2

b. Weighted fair queuing with flow 1 having twice as much share as flow 2, and flow 3 having three times as much share as flow 2.

Sequence: 4, 1, 2, 3
2. Token Bucket Filter

Assume that a host is sending a router packets that it would like the router to forward. The router has implemented traffic policing using a token bucket filter as shown in the lecture slides. The token bucket has a fill rate of “r” bits per second (bps) and has a depth of “b” bits.

For simplicity assume that data can be sent as individual bits rather than packets. Assume the average rate at which the host sends the router data follows the figure below and that the token bucket is initially full when time is 0. 

*Show your work for all parts of this problem.*

For the following parts, assume \( r = 1500 \text{ bps} \) and \( b = 500 \text{ bits} \)

a. What happens when the bucket is full and the fill rate is faster than the drain rate?

- The bucket “overflows”
- No more can be stored in the bucket when its depth is reached

b. How many bits worth of tokens are in the bucket when the time equals 2 seconds?
• For the first second, the bucket is already full and the bucket is filling faster than it is draining, so there is no change to the number of bits worth of tokens in the bucket
• For the time between 1 and 2, the drain rate is 500 bps more than the fill rate. Since this occurs for 1 second, 500*1 = 500 bits are consumed from the bucket, so the bucket is now empty: 0 bits

  c. How many bits worth of tokens are in the bucket when the time equals 5 seconds?

• Whatever happened before doesn’t matter in the case because from 4 to 5, the fill rate was 500 bps more than the drain rate, so the bucket must now be full again

  d. Is any loss of the host’s sent bits? If so, at what time did the loss begin?

• From a previous part, we know the bucket is empty at 2 seconds
• From 2 to 3 seconds the drain rate is equal to the fill rate, so there would be no change to the number of tokens in the bucket
• From 3 to 4 seconds, the drain rate is again 500 bps more than the fill rate. In this case, because the bucket is empty, there will now be loss starting at 3 seconds
• As a sidenote, about 2 out of every 3 bits will still get through during the time between 3 to 4 seconds because the fill rate to drain rate ratio is 2/3
3. Network Address Translation

Assume that the router multiplexes the public address using ports starting from 2000 and then incrementing by one. The router’s public ip address is 200.1.1.201 as shown in the figure above.

a. What would be the entries in the NAT Translation Table at the end of the following events assuming the table has been partially filled due to previous traffic. Fill in the entries in the table below; you may or may not need all the rows.
   i. 10.3.2.12:6000 sends a message to 74.12.39.33:80
   ii. 10.3.2.13:1234 sends a message to 79.204.197.200:80
   iii. 10.3.2.11:5000 sends a message to 190.36.204.45:80
   iv. 10.3.2.12:1500 sends a message to 79.197.206.200:80

b. What does the router do differently to a packet coming in from the Internet destined to the local network versus a packet coming from the local network destined to somewhere on the internet?

- From the internet to the local network the destination ip address and port numbers are changed before forwarding
- From the local network to the internet the source ip address and port numbers are changed before forwarding
### NAT Translation Table

<table>
<thead>
<tr>
<th>WAN Side Address</th>
<th>LAN Side Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>200.1.1.201:2000</td>
<td>10.3.2.11:6000</td>
</tr>
<tr>
<td>200.1.1.201:2001</td>
<td>10.3.2.13:1234</td>
</tr>
<tr>
<td>200.1.1.201:2002</td>
<td>10.3.2.11:5000</td>
</tr>
<tr>
<td>200.1.1.201:2003</td>
<td>10.3.2.12:6000</td>
</tr>
<tr>
<td>200.1.1.201:2004</td>
<td>10.3.2.12:1500</td>
</tr>
</tbody>
</table>

### 4. TCP Behavior
Assume the following questions are related to TCP connections implementing the TCP Reno flavor of TCP including slow start, congestion avoidance, fast retransmit, and fast recovery.

- **a.** When is slow start used by TCP?
  - At the beginning of a TCP connection
  - After a timeout occurs

- **b.** When does the Additive Increase part of congestion avoidance take place?
  - After the slow start threshold (ssthresh) has been set and the current congestion window meets or exceeds that threshold
  - This occurs after a fast retransmit and fast recovery as well as after slow start meets the ssthresh assuming ssthresh has already been set
c. What do fast retransmit and fast recovery do for TCP? When does it come into play?

- When there is a loss of a packet in sequence, packets with higher sequence numbers that get through would cause duplicate ACKs to be sent and after 3 have been received, fast retransmit and fast recovery take place
- Happens after a loss and the congestion window is then halved and TCP enters into congestion avoidance

d. What happens after a timeout occurs?

- TCP enters into slow start again because there could have been a significant loss since fast retransmit and fast recovery weren’t able to take care of the loss before the timeout of the packet occurs

5. TCP Slow Start Extension
   a. When does TCP leave the slow start phase?

- After a loss occurs
- b. How much larger is the send window after 1 RTT in slow start?

- The send window doubles
- This window at most the advertised window of the receiver which is also no greater than the receiver’s window size
- c. How do you calculate the effective throughput of a transfer?

- Can be thought of as the utilization of the link
- For a given amount of time it would be the amount of data sent over that time versus how much data could have been sent based on the bandwidth of the link