Problem Set #3

Due Friday, November 13th (23:55pm)

Problem 1 (10pts)

Consider a network with MPLS enabled routers as shown in Figure 1 below. We would like to perform traffic engineering using MPLS so that traffic from R1 to R6 will be routed as R1->R3->R5->R6->A and traffic from R2 to R6 will be routed as R2->R3->R4->C.

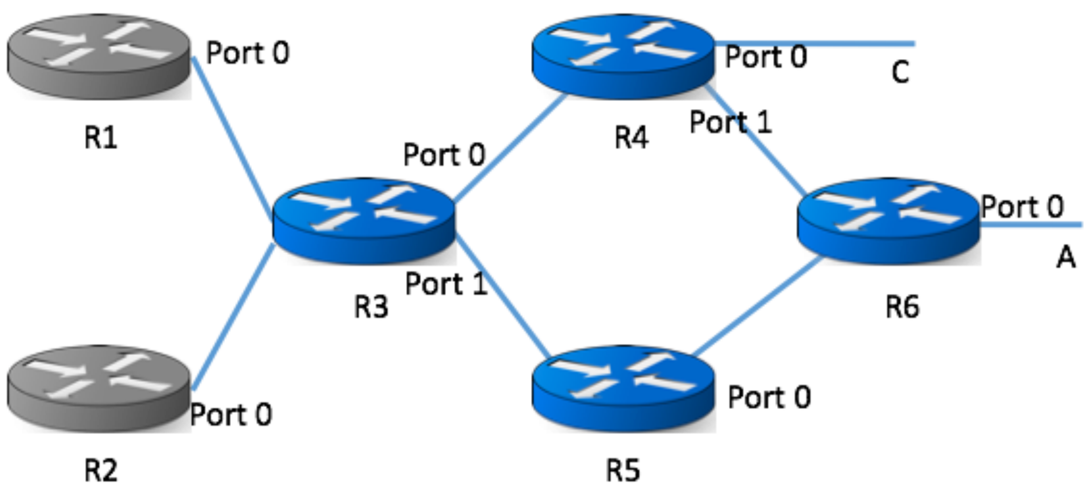

Figure 1. MPLS enabled network for Problem 1

Please fill in the following tables of MPLS entries for each router.

R1			
In label	Out label	Dst	Out interface
-	1	A	0

R2			
In Label	Out Label	Dst	Out interface

-	2	C	0

R3			
In label	Out label	Dst	Out interface
1	4	A	1
2	3	C	0

R4			
In label	Out label	Dst	Out interface
3	-	C	0
6?	5	A	1

R5			
In label	Out label	Dst	Out interface
4	5	A	0

R6			
In label	Out label	Dst	Out interface
5	-	A	0

I have indicated '6?' on the in label on R4 because I have assigned it an unused label number, 6. I've done so because the R3 table doesn't contain a corresponding out label for R4 that indicates the new destination, R6. Reusing 3 wouldn't work since this would be the only thing matched and the packet would be sent straight to C since that label matches.

Problem 2 (20pts)

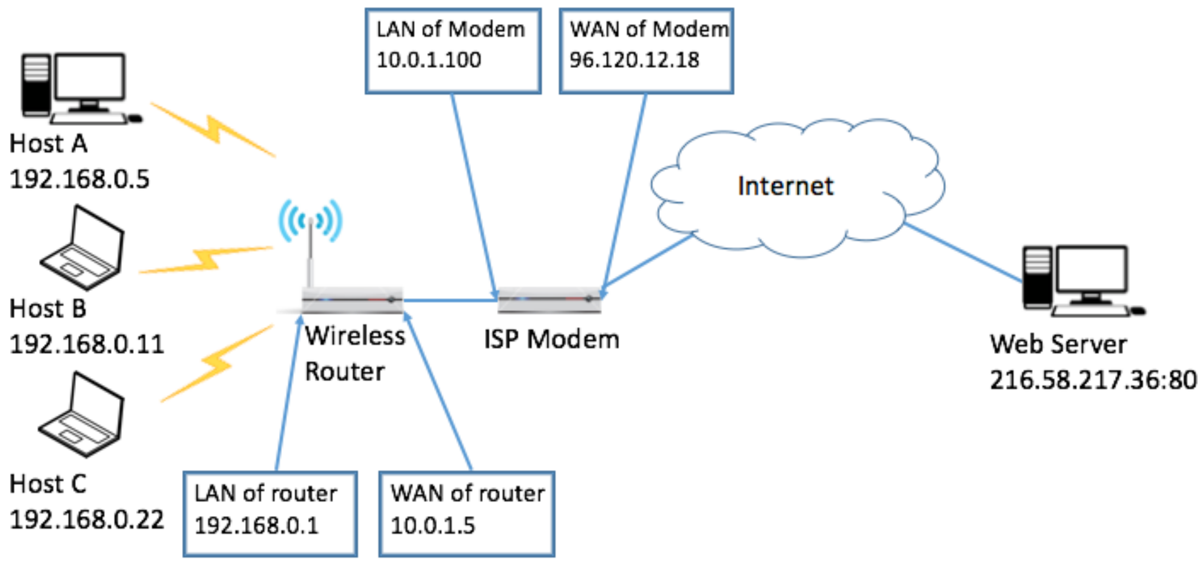

Figure 2. Network setup for Problem 2.

The Figure 2. above is a typical home network setup. An ISP Modem provides internet service; a wireless router is connected to the ISP Modem via Ethernet. Hosts A, B and C are connected to the wireless router to access the Internet.

(a) In order for the hosts A, B, and C to access the Web Server, Network Address Translation (NAT) with random port mapping needs to be enabled for both the Wireless Router and the ISP Modem. Assume Hosts will pick a random port number between 8000 and 9000, the Wireless Router can choose a random port number between 2000 and 2500, and the ISP Modem can choose a random port number between 3000 and 4000. Please fill in the NAT table for the Wireless Router and the ISP Modem below.

NAT Table of Wireless Router	
LAN side	WAN side
192.168.0.5:8000	10.0.1.5:2000
192.168.0.11:8080	10.0.1.5:2020
192.168.0.22:8888	10.0.1.5:2222

NAT Table of ISP Modem	
LAN side	WAN side
10.0.1.5:2000	96.120.12.18:3000
10.0.1.5:2020	96.120.12.18:3030
10.0.1.5:2222	96.120.12.18:3333

(b) Now we look into the details about how packets are exchanged between Host B and Web Server. Assume Host B sends a HTTP request packet to Web Server. And Web Server then sends HTTP content back to Host B. Please fill in the tables below to show how the packet's IP header changed along the route. (Please formulate your answer based on your answers for (a).)

HTTP request Before entering Router	
Src IP	192.168.0.11
Src Port	8080
Dst IP	216.58.217.36
Dst Port	80

HTTP request After exiting Router	
Src IP	10.0.1.5
Src Port	2020
Dst IP	216.58.217.36
Dst Port	80

HTTP request After exiting Modem	
Src IP	96.120.12.18
Src Port	3030
Dst IP	216.58.217.36
Dst Port	80

HTTP response Before entering Modem	
Src IP	216.58.217.36
Src Port	80
Dst IP	96.120.12.18
Dst Port	3030

HTTP response After exiting Modem	
Src IP	216.58.217.36

Src Port	80
Dst IP	10.0.1.5
Dst Port	2020

HTTP response After exiting Router	
Src IP	216.58.217.36
Src Port	80
Dst IP	192.168.0.11
Dst Port	8080

(c) Suppose now Host A also runs a webserver on port 8888, it is attached to a domain name http://www.mylocalhomeserver.com, explain **what NAT entries** should be added so that people from the internet can access this web server via URL. You can assume that the above domain name is registered properly.

The router would need an additional row detailing Host A's ip and the port 8888 and then mapping that to the WAN IP and a random port number (between 3000 and 4000).

Likewise the modem would need an additional row. This would map the ip and port that the router presents to the modem's wan ip and a random port between 2000 and 2500.

For both random ports the check that would need to be made is that these mappings are unused currently.

This will allow the initial request to the server. From here the new connections would create additional sockets. For each of these the same process will need to be done to support the connection.

When connections get closed the entries should be removed from each NAT table in order to preserve space.

(d) The wireless link at the last mile is very error prone and you would like to improve the performance. What would you do in this case?

Given ownership of this connection I would explore possibility of wired connections. Outside of this trying to detect and correct errors as quickly as possible would be key. Retransmission after first duplicate ACK would be a possibility. Another is to try redundant transmission in hope that at least one will get through. Neither is ideal though because it will decrease throughput on the network.

Problem 3 (10pts)

Suppose a router has three input flows and one output flow. It receives the packets listed in the Table 1. below, 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, assuming:

The queues would look like this at the beginning

	Next out		
Flow 1	200	200	
Flow 2	160	200	160
Flow 3	210	120	90

(a) Fair queuing

Round 1:

(flow 1) F_i = A_i + P_i = 200
(flow 2) F_i = A_i + P_i = 160
(flow 3) F_i = A_i + P_i = 210

Flow 2 would be chosen since it is the lowest value. A_i is equal for all of these problems and will be represented as 0 henceforth. F_(i-1) has been omitted as for the first round there is no previous finish time.

Round 2:

(flow 1) F_i = A_i + P_i = 200
(flow 2) F_i = F_(i-1) + P_i = 360
(flow 3) F_i = A_i + P_i = 210

Round 3:

(flow 1) F_i = F_(i-1) + P_i = 400
(flow 2) F_i = F_(i-1) + P_i = 360
(flow 3) F_i = A_i + P_i = 210

Round 4:

(flow 1) F_i = F_(i-1) + P_i = 400
(flow 2) F_i = F_(i-1) + P_i = 360
(flow 3) F_i = F_(i-1) + P_i = 330

Round 5:

(flow 1) F_i = F_(i-1) + P_i = 400
(flow 2) F_i = F_(i-1) + P_i = 360
(flow 3) F_i = F_(i-1) + P_i = 420

Round 6:

(flow 1) F_i = F_(i-1) + P_i = 400
(flow 2) F_i = F_(i-1) + P_i = 520
(flow 3) F_i = F_(i-1) + P_i = 420

Round 7:

(flow 1) empty
(flow 2) F_i = F_(i-1) + P_i = 520
(flow 3) F_i = F_(i-1) + P_i = 420

Round 8:

(flow 1) empty
(flow 2) F_i = F_(i-1) + P_i = 520
(flow 3) empty

From this we can see the packet order would be:

3, 1, 6, 7, 4, 2, 8

(b) Weighted fair queuing with flow 2 having twice as much share as flow 1, and flow 3 having 1.5 times as much share as flow 1. Note that ties are to be solved in the order of flow1, flow2 and flow3.

The change here is how much bandwidth each flow receives. flow 1 has 1/6, flow 2 has 1/3, and flow 3 has 1/2. The rounds are again as follows:

Round 1:

(flow 1) (5/6) F_i = 166.67
(flow 2) (2/3) F_i = 106.67
(flow 3) (1/2) F_i = 105

Round 2:

(flow 1) (5/6) F_i = 166.67
(flow 2) (2/3) F_i = 106.67
(flow 3) (1/2) F_i = 165

Round 3:

(flow 1) (5/6) F_i = 166.67
(flow 2) (2/3) F_i = 240
(flow 3) (1/2) F_i = 165

Round 4:

(flow 1) (5/6) F_i = 166.67
(flow 2) (2/3) F_i = 240
(flow 3) (1/2) F_i = 210

Round 5:

(flow 1) (5/6) F_i = 333.33
(flow 2) (2/3) F_i = 240
(flow 3) (1/2) F_i = 210

Round 6:

(flow 1) (5/6) F_i = 333.33
(flow 2) (2/3) F_i = 240
(flow 3) (1/2) F_i = empty

Round 7:

(flow 1) (5/6) F_i = 333.33
(flow 2) (2/3) F_i = 346.67
(flow 3) (1/2) F_i = empty

Round 8:

(flow 1) (5/6) F_i = empty
(flow 2) (2/3) F_i = 346.67
(flow 3) (1/2) F_i = empty

Packet order is as follows:

6, 3, 7, 1, 8, 4, 2, 5

Packet	Size	Flow
1	200	1
2	200	1
3	160	2
4	200	2
5	160	2
6	210	3
7	120	3
8	90	3

Table 1.

Problem 4 (15pts)

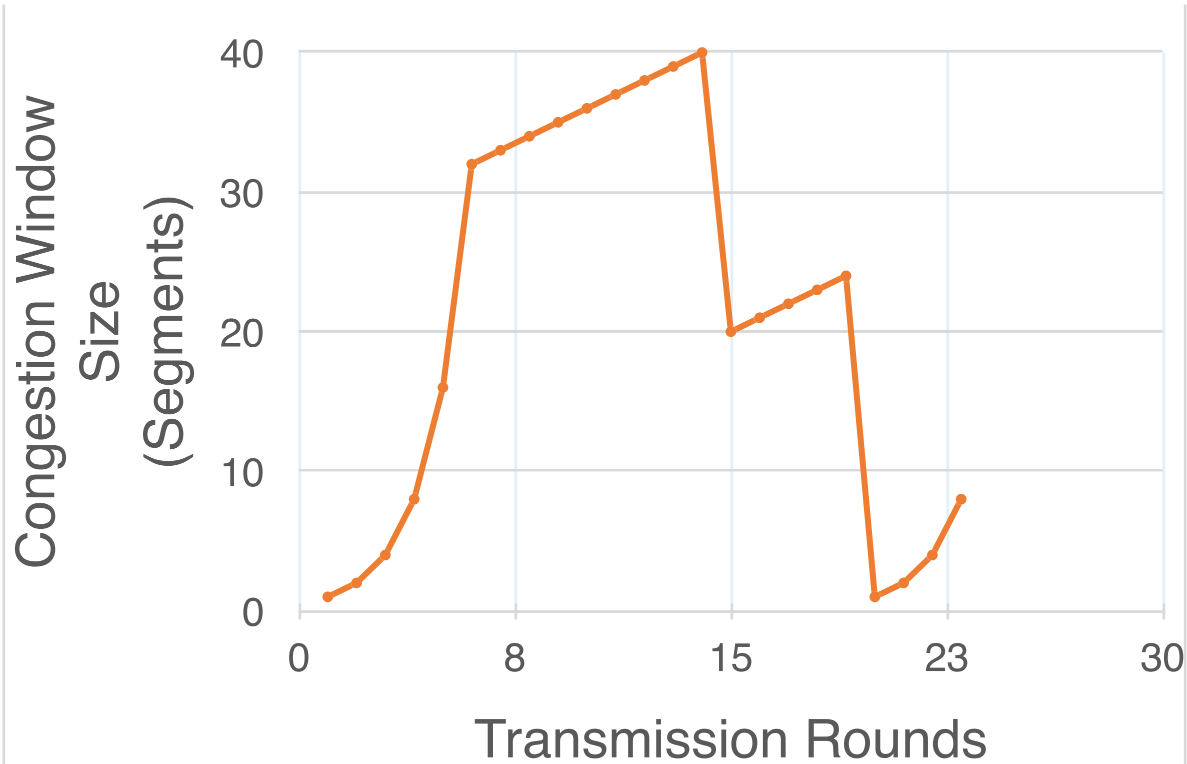

Figure 3. Congestion Window Size

Assuming TCP Reno is the protocol experiencing the behavior shown above, answer the following questions:

(a) Identify the RTT rounds when TCP runs Slow Start (e.g., from the 1th round to which round?)

  a. Slow start is used from rounds 1 to 6 and again from 20 to 23.

(b) Identify the RTT rounds when TCP runs Congestion Avoidance

14 and 19

(c) After the 14th RTT round, is segment loss detected by a triple duplicate ACK or by a timeout and why?

Round 14 is a loss due to triple duplicate ACK. A timeout would signal a need to restart and because of this a slow start would be initiated. This is not the behavior exhibited at the 15th round. Here we see a fast recovery consistent with detection of a triple duplicate ACK.

(d) During which RTT round the 170th segment is sent?

1 + 2 + 4 + 8 + 16 + 32 + 33 + 34 + 35 + 36 = 201 which would include the 170th segment and is the first time that segment is included. This is the 10th segment.

(e) Assuming a packet loss is detected after the 23th RTT round by the receipt of triple duplicate ACKs, what will be the value of the congestion window?

The value of the window will be 4. Triple duplicate ACK causes a fast retransmit which results in a multiplicative decrease but not a reset.

Problem 5 (15pts)

Figure 4. below shows how 2 disconnected LAN are connected by IP tunnel (the dash line). For each interface the IP and MAC addresses are shown in the figure. (HW1-HW14 are used to represent hardware addresses)

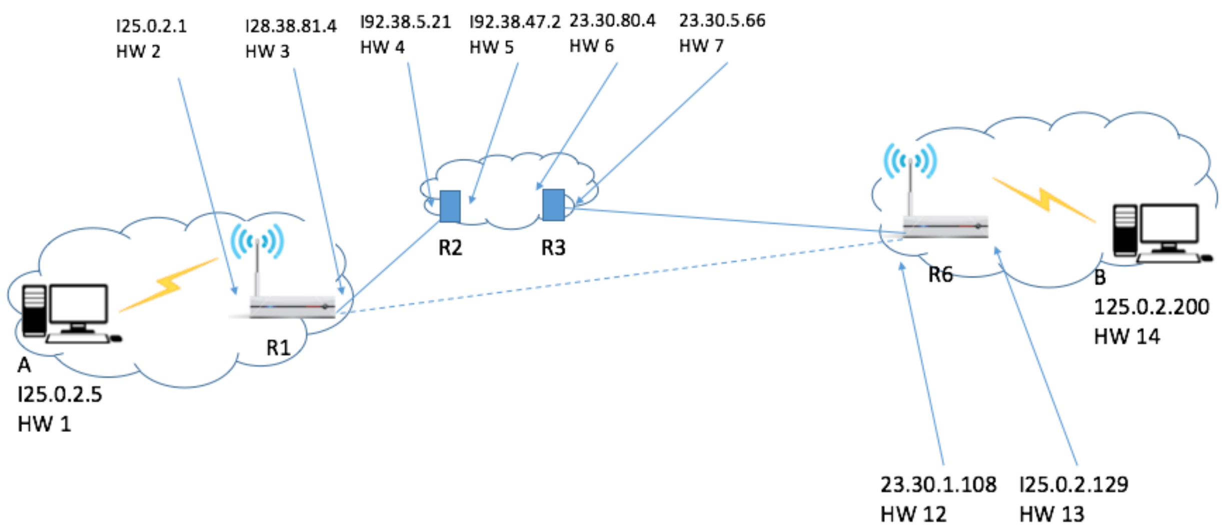

Figure 4. Network setup for Problem 5

Now Host B sends a packet to Host A. Please show how the packet travels along the route, please describe header information along the route.

First, host B (HB) will create the packet. The source ip will be 125.0.2.200 and the destination ip will be 125.0.2.5, smac = HW14, dmac = HW13.
When R6 receives the packet it will encapsulate it within another packet where the exterior packet will have the info sIP = 23.30.1.108, dIP = 128.28.81.4, smac = HW12, dmac = HW7.
Next at R3 the outer packet is received and changed to sIP = 23.30.1.108, dIP = 128.38.81.4, smac = HW6, dmac = HW5.
Next at R2 the outer packet is received and changed to sIP = 23.30.1.108, dIP = 128.38.81.4, smac = HW4, dmac = HW3.
Now at R1 the packet is received and the outer packet is stripped away. The initial packet is again available. It's info will now be changed to sIP = 125.0.2.200, dIP = 125.0.2.5, smac = HW2, dmac = HW1/

Problem 6 (20pts)

Derive the expected throughput of the following TCP congestion control algorithm: The additive increment factor is **α**. Multiplicative decrease factor **β**, which means after loss, the window size will change from **W** to **(1-β)W**. Please order the throughput for each flow. AIMD(a,b) means the cwnd increases a per each round trip time and the cwnd sets to (1-b)W from W when the loss happens.

Throughput = $\frac{\#\text{packets}}{\text{time}}$

Packets:

$$\frac{1}{p} = A = \frac{1}{2}\left(W\beta \frac{W\beta}{\alpha}\right) + \left(W(1-\beta)\frac{W\beta}{\alpha}\right) = \frac{W^2(2-\beta)\beta}{2\alpha}$$

Time:

$$T = \frac{W\beta}{\alpha} RTT$$

$$W = \frac{\sqrt{2\alpha}}{\sqrt{\beta(2-\beta)p}}$$

$$\text{Throughput} = \frac{\left(\frac{W^2\beta(2-\beta)}{2\alpha}\right)}{\left(\frac{W\beta}{\alpha} RTT\right)} = \frac{W^2\beta(2-\beta)}{2W\beta\, RTT} = \frac{W(2-\beta)}{2RTT}$$

$$\text{Thr}\left(\frac{W\beta}{\alpha} RTT\right) = \frac{W^2\beta(2-\beta)}{2\alpha}$$

$$\text{Thr}\,(2W\beta\, RTT) = W^2\beta(2-\beta)$$

$$\text{Thr}\,(2RTT) = W(2-\beta)$$

$$\text{thr} = \frac{W(2-\beta)}{2RTT}$$

$$= \frac{\frac{\sqrt{2\alpha}}{\sqrt{\beta(2-\beta)p}}(2-\beta)}{2RTT}$$

$$= \frac{\sqrt{2\alpha}\sqrt{2-\beta}}{2\sqrt{\beta p}\, RTT} = \frac{\sqrt{\alpha}\sqrt{2-\beta}}{\sqrt{2\beta p}\, RTT}$$

✓

M↓
```python
def aimd(alpha, beta, RTT, p):
    return ((alpha * (2 - beta)) ** (1/2)) / ((2*beta*p)**(1/2) * RTT)
```

M↓
```python
flow1 = aimd(1, .5, 10**(-2), 10**(-6))
flow2 = aimd(2, .2, .1, 10**(-8))
flow3 = aimd(5, .8, .3, 10**(-9))
flow4 = aimd(8, .4, 1, 10**(-4))
flow5 = aimd(6, .5, .1, 10**(-10))
```

M↓
```python
print(flow1, flow2, flow3, flow4, flow5)
```

```
122474.48713915888 299999.99999999994 204124.1452319315 399.99999999999994 2999999.9999999995
```

M↓
```python
flow5 > flow2
```

```
True
```

M↓
```python
flow2 > flow3
```

```
True
```

M↓
```python
flow3 > flow1
```

```
True
```

M↓
```python
flow1 > flow4
```

```
True
```

Flow1: AIMD(a=1,b=0.5), RTT=10ms, loss rate = 10^{-6}
Flow2: AIMD(a=2,b=0.2), RTT=100ms, loss rate = 10^{-8}
Flow3: AIMD(a=5,b=0.8), RTT=300ms, loss rate = 10^{-9}
Flow4: AIMD(a=8,b=0.4), RTT=1000ms, loss rate = 10^{-4}
Flow5: AIMD(a=6,b=0.5), RTT=100ms, loss rate = 10^{-10}

From this I know the order is: **flow5 > flow2 > flow3 > flow1 > flow4**

Problem 7 (10pts)

Suppose that TCP uses the combination of quick acknowledgements (quick ack) and delayed acknowledgements (delayed ack). The quick ack only triggers up to 8 packets (the cwnd at the sender becomes 16 after receiving 8 quick acks) starting from 1 packet during slow start. The maximum capacity of the link is 5000 KBps, the RTT is 10ms, and 1MSS = 1KB. Note that KBps is KB per second).

(a) About what is cwnd at the time of first packet loss?

BDP = 40000000 bps * .01s = 50KB

Anything exceeding 50 MSS will result in a packet loss, from a slow start cwnd would be 1 -> 2 -> 4 -> 8 -> 16 -> 32 -> 64 and cwnd = 64 will result in loss.

(b) About how long until the sender discovers the first loss?

This process will take about 7 RTTs for the packet loss to be detected. So, 70ms.