Problem Set #1

Due Tuesday Sept 17^{th} by 12:30pm

Assume that 1 Kbps = 10^3 bits/sec, 1 Mbps = 10^6 bits/sec, 1 Gbps = 10^9 bits/sec, and 1MB = 10^6 x 8 bits. The capital 'B' typically means 'byte' while the lowercase 'b' indicates 'bit'.

1. (3pts) What advantage does a circuit-switched network have over a packet-switched network?

2. (3pts) What advantage does TDM have over FDM in a circuit switched network?

3. (21pts) Consider two hosts, A and B, which are connected by a link (**R** bps). Suppose that the two hosts are separated by **m** meters, and the speed along with link is **s** meters/sec. Host A is to send a packet of size **L** bits to Host B.

   a. Express the propagation delay, d_{prop}, in terms of m and s.
   b. Determine the transmission time of the packet, d_{trans}, in terms of L and R.
   c. Ignoring processing and queuing delays, obtain an expression for the end-to-end delay (one-way delay from Host A to Host B).
   d. Suppose Host A begins to transmit the packet at time t = 0, At time t = d_{trans}, where is the last bit of the packet?
   e. Suppose d_{prop} is greater than d_{trans} . At time t = d_{trans}, where is the first bit of the packet?
   f. Suppose d_{prop} is less than d_{trans} . At time t = d_{trans}, where is the first bit of the packet?
   g. Suppose s = 2.5 * 10^8, L = 120bits, and R = 56Kbps. Find the distance m so that d_{prop} equals d_{trans}.

4. (8pts) We consider sending real-time voice from Host A to Host B over a packet-switched network. Host A converts analog voice to a digital 65kbps bit stream and send these bits into 56-byte packets. There is one link between Hosts A and B and the transmission rate is 1 Mbps and its

propagation delay is 20 msec. As soon as Host A gathers a packet, it sends it to Host B. As soon as Host B receives an entire packet, it converts the packet's bits into an analog signal. How much time elapses from the time a bit is created (from the original analog signal at Host A) until the bit is decoded (as part of the analog signal at Host B)?

5. (12pts) Consider a Go-Back-N sliding window algorithm (1 packet is 250 bytes long) running over a 100km point-to-point fiber link with bandwidth of 100 Mbps.

    a. Compute the one-way propagation delay for this link, assuming that the speed of light is 2×10^8 m/s in the fiber.
    b. Suggest a suitable timeout value for the algorithm to use. List factors you need to consider.
    c. Suggest N to achieve 100% utilization in this link.

6. (12pts) Suppose a 1-Gbps point-to-point link is being set up between the Earth and a new lunar colony. The distance from the moon to the Earth is approximately 385,000 km, and data travels over the link at the speed of light—3×10^8 m/s.
    a. Calculate the minimum RTT for the link.

    b. Using the RTT as the delay, calculate the delay × bandwidth product for the link.

    c. What is the significance of the delay × bandwidth product computed in (b) ?

7. (12pts) Host A wants to send a 1,000 KB file to Host B. The Round Trip Time (RTT) of the Duplex Link between Host A and B is 160ms. Packet size is 1KB. A handshake between A and B is needed before data packets can start transferring which takes 2xRTT. Calculate the total required time of file transfer in the following cases. The transfer is considered complete when the acknowledgement for the final packet reaches A.
    a. The bandwidth of the link is 4Mbps. Data packets can be continuously transferred on the link.

b. The bandwidth of the link is 4Mbps. After sending each packet, A need to wait one RTT before the next packet can be transferred.

c. Assume we have "unlimited" bandwidth on the link, meaning that we assume transmit time to be zero. After sending 50 packets, A need to wait one RTT before sending next group of 50 packets.

d. The bandwidth of the link is 4Mbps. During the first transmission A can send one (2^{1-1}) packets, during the 2nd transmission A can send 2^{2-1} packets, during the 3rd transmission A can send 2^{3-1} packets, and so on. Assume A still need to wait for 1 RTT between each transmission.

8. (5pts) Determine the width of a bit on a 10 Gbps link. Assume a copper wire, where the speed of propagation is $2.3 * 10^8$ m/s.

9. (12 pts) Suppose two hosts, A and B, are separated by 20,000 kilometers and they are connected by a direct link of R=1Gbps. Suppose the propagation speed over the link is 2.5×10^8 meters/sec.

   a. Calculate the bandwidth delay product (BDP) of the link.
   b. Consider sending a file of 800,000 bits from Host A to Host B as one large message. What is the maximum number of bits that will be in the link at any given time?
   c. What is the width (in meters) of a bit in the link?
   d. Suppose now the file is broken up into 20 packets with each packet containing 40,000 bits. Suppose that each packet is acknowledged by the receiver and the transmission time of an acknowledgement packet is negligible. Finally, assume that the sender cannot send a packet until the preceding one is acknowledged. How long does it take to send the file?

10. (12 pts) Suppose there is a 10 Mbps microwave link between a geostationary satellite and its base station on Earth. Every minute the satellite takes a digital photo and sends it to the base station. Assume a propagation speed of 2.4×10^8 meters/sec. Geostationary satellite is 36,000 kilometers away from earth surface

a. What is the propagation delay of the link?
b. What is the bandwidth-delay product, R x (propagation delay)?
c. Let x denote the size of the photo. What is the minimum value of x for the microwave link to be continuously transmitting?

Problem Set #2

Due Tuesday Oct 8th before the class

Problem 1 (6pts)

Explain collision domain and broadcast domain with respect to a hub, switch, and a router.

Problem 2 (5pts)

Consider the following networked computers connected by Bridge X and Y. Bridge X has interface 1,2 and3. Bridge Y has interface 1 and 2. Assume at the beginning the address tables of Bridge X and Y are all empty. Write down the address tables of Bridge X and Y after the following communication finished.

1. A send a packet to C
2. B send a packet to D
3. C send a packet to E
4. E send a packet to A
5. D send a packet to A

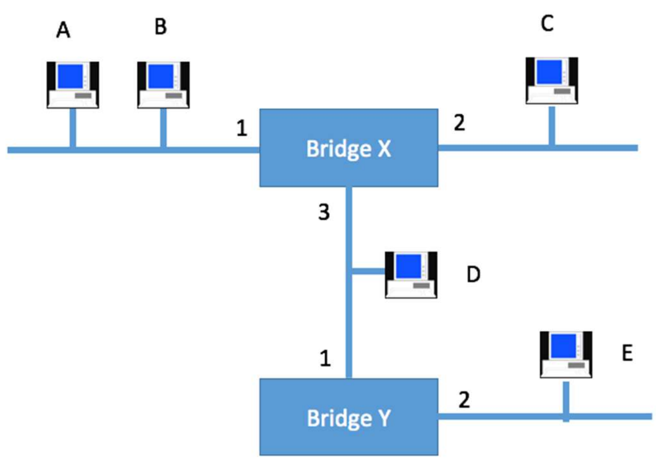


Figure 1

Bridge X

Address	Interface

Bridge Y

Address	Interface

Problem 3 (5pts)

Given the extended LAN shown in Figure 2, indicate which ports are not selected by the spanning tree algorithm. Note that the bridge with the smallest ID becomes a root.

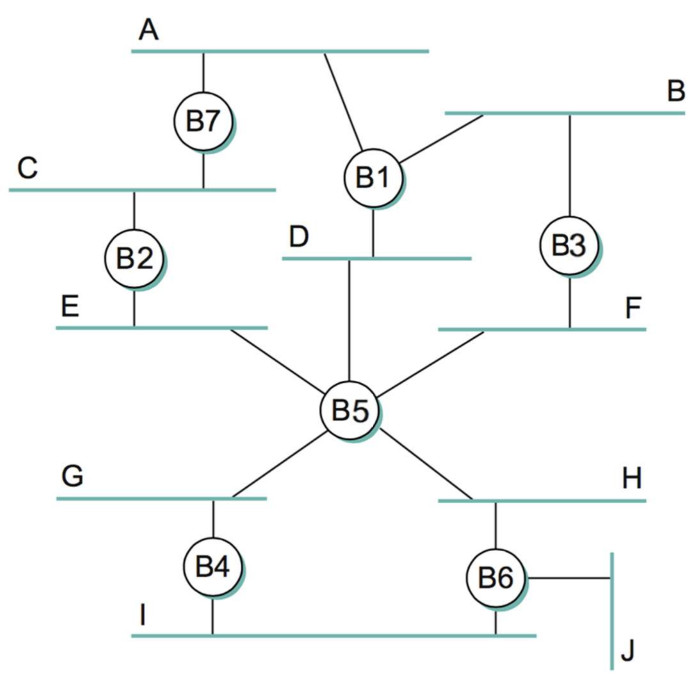


Figure 2

Problem 4 (5pts)

Still considering Figure 2. If Bridge B1 suffers catastrophic failure. Again indicate which ports are not selected by the spanning tree algorithm.

Problem 5 (6pts)

Draw a time line diagram for the sliding window algorithm with SWS = RWS = 3 frames, for the following situations. Use a timeout interval of about 2 × RTT. And assume 2 frames must be send ½ RTT apart which means if everything is normal Sender will receive ACK and then immediately send the next frame.

Frames 3 and 6 are lost on their first transmissions. Draw the algorithm with time line diagram till Frame 6 is sent. (6pts)

Problem 6 (6pts)

Consider the GBN protocol with a sender window size of N=4 and a sequence number range of 1,024. Suppose that at time t, the next in-order packet that the receiver is expecting has a sequence number of k. Assume that the medium does not reorder messages. Answer the following questions:

(a) What are the possible sets of sequence numbers inside the sender's window

at time t? Justify your answer. (2 pts)

(b) What are all possible values of the ACK field in all possible messages currently

propagating back to the sender at time t? Justify your answer. (2 pts)

(c) With the Go-Back-N protocol, is it possible for the sender to receive an ACK for a packet that falls outside of its current window? Justify your answer with an example. (2 pts)

Problem 7 (10 points)

(a) Is 10.72.0.255/255.255.254.0 a valid IP address for a host? **[2pts]**

(b) Divide the 10.72.0.0/16 subnets into five large networks of 8192 IPs each, 8 medium-sized networks of 2048 IPs each, and 10 small sized networks of 128 IPs each. **[6pts]**

(c) Is 192.168.2/23 and 192.168.3/23 representing the same subnet? Please justify your answer. **[2pts]**

Problem 8 (8 points)

An organization has been assigned the prefix 192.168.1.0/23 and wants to form subnets for 4 departments which have the following number of hosts:

Department A:	130 hosts
Department B:	120 hosts
Department C:	60 hosts
Department D:	31 hosts

(a) Give a possible arrangement of subnet masks to make this possible. **[5pts]**

(b) Suggest what the organization might do if department C grows to 65 hosts. **[3pts]**

Problem 9 (12 points)

For the network given below in Figure 3, give global distance-vector tables for each node when**:**

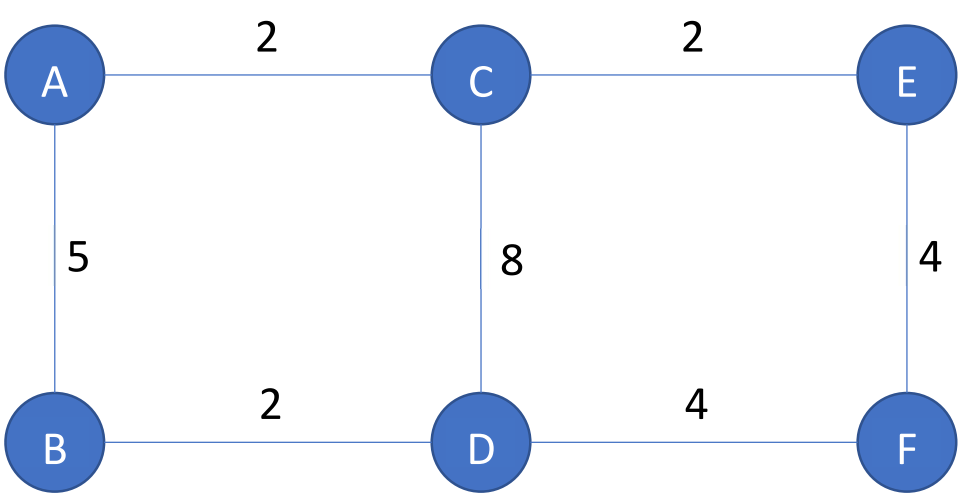


Figure 3

(a) Each node knows only the distance of its immediate neighbors. **[4pts]**

(b) Each node has reported the information it had in the first step (a) to its immediate neighbors. **[4pts]**

(c) Repeat step (b) one more time. **[4pts]**

Problem 10 (8 points)

Again for the network graph in Figure. 3. Show how the link-state algorithm builds the routing table for node D.

(a) Show the detailed steps with the link-state algorithm. **[5pts]**

(b) Show the final routing table of node D. **[3pts]**

Problem 11 (6 points)

The network graph is shown in Figure. 4.

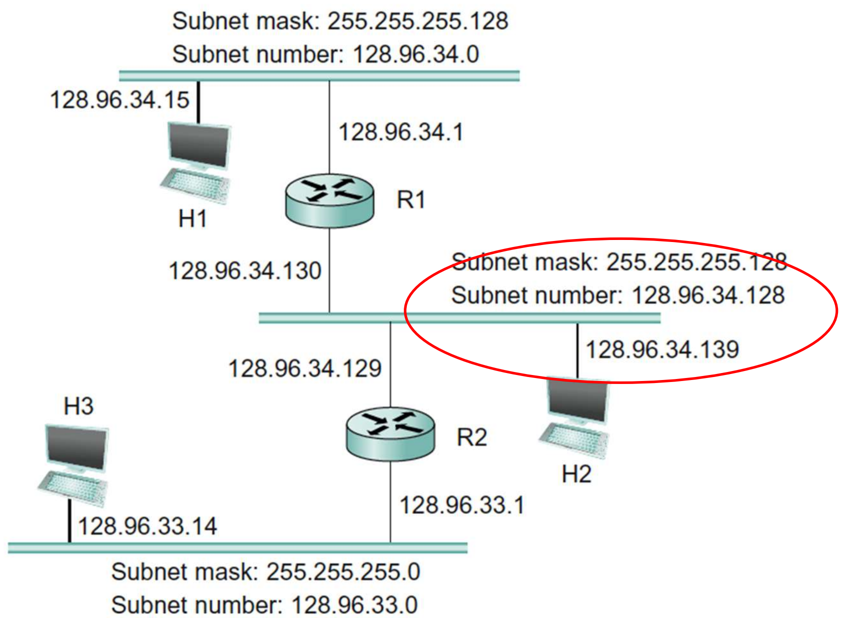


Figure 4

(a) Host H1 sends a packet to the destination 128.96.34.126. Explain how this packet traverses in the network described below. You need to describe who received the packet and what are their reactions. **[2pts]**

(b) Host H3 sends a packet to the destination 128.96.34.250. Explain how this packet traverses in the network. **[2pts]**

(c) The subnet of H1 has now two different teams and would like to split it into two subnets. Please add one more subnet and add R3 and change the network configurations as you need. Note that you are allowed to modify the network as least disruptive as possible. **[2pts]**

Problem 12 (8 points)

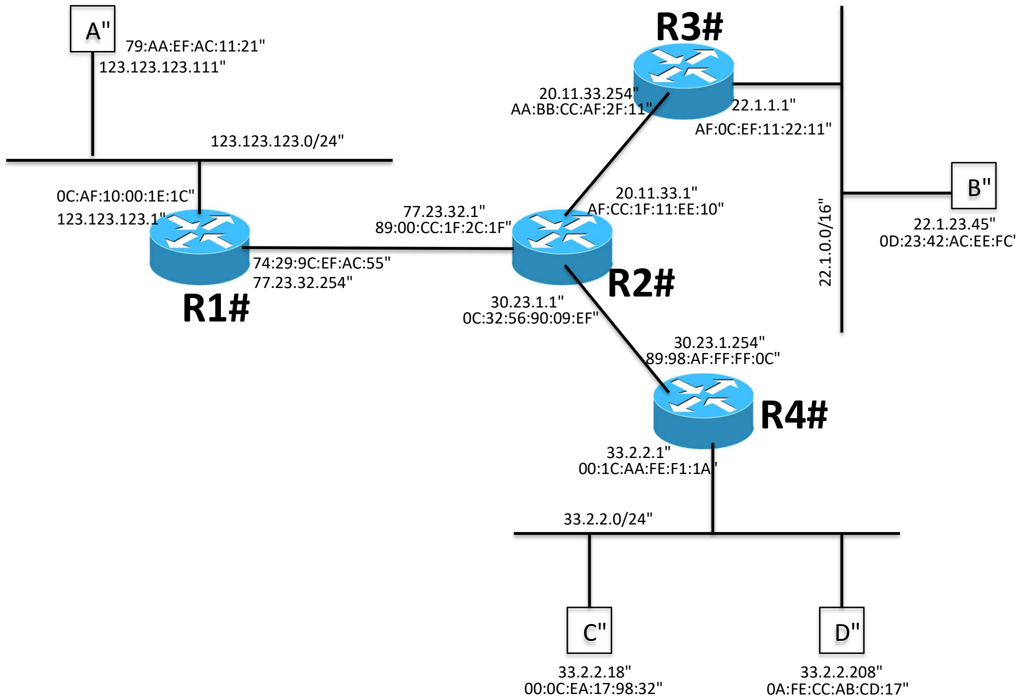


Figure. 5

Above in Figure 5 is the network graph with 4 routers (R1, R2, R3, R4) and 4 hosts (A, B, C, D). Each router interfaces and hosts are labeled with both IP and MAC address, Routing is enabled so that any two hosts can communicate with each other and also the default gateway of each host is set to its gateway router.

(a) Suppose that B send an IP packet to C through R3, R2, R4. Write down the IP packet's content (src MAC, dst MAC, src IP, dst IP) along the path in the Table given below: **[4pts]**

	src MAC	dst MAC	src IP	dst IP
B -> R3				
R3 -> R2				
R2 -> R4				
R4 -> C				

Table. 1

(b) When A sends out an ARP query for its default gateway, what is the reply to that query? **[2pts]**

(c) Suppose the routers use link-state routing protocol, what will be R3's routing table entries? **[2pts]**

Problem 13 (6 points)

Suppose a computer just boot up, connected to wireless network and successfully obtained IP, gateway and DNS address. Now it wants to access www.yahoo.com from its browser. Describe the sequence of packets exchanged to and from this computer until the webpage starts to load. (include what kind of protocol is used and what is the content of the packets)

Problem 14 (9 points)

Consider the simple network in Figure 5 below. X, Y and Z are routers and their link costs are as specified. Assume the network uses a Distance Vector algorithm is used. Y's and Z's routing tables are look like Table 2.

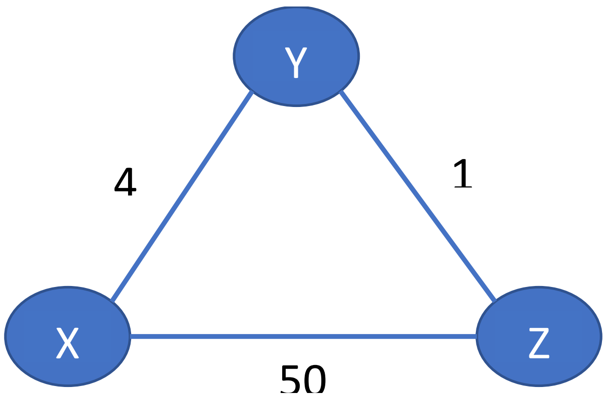


Figure. 5

Node Y/Distance	Via X	Via Z
X	4	6

Node Z/Distance	Via X	Via Y
X	50	5

Table. 2

(a) Now Let assume the cost of link X-Y suddenly changed to 100. Please write down the Y's and Z's routing table regarding distance to X, after Y updates this information to Z and then Z updates its information back. **[3pts]**

(b) Please write down the Y's and Z's routing table regarding X after Y updates this information to Z again and then Z updates back again. **[3pts]**

(c) How many updates did Y get until its distance to X have converged with Distance Vector algorithm? **[3pts]**

Problem Set #3

Due Tuesday, November 12th (before the class)

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.

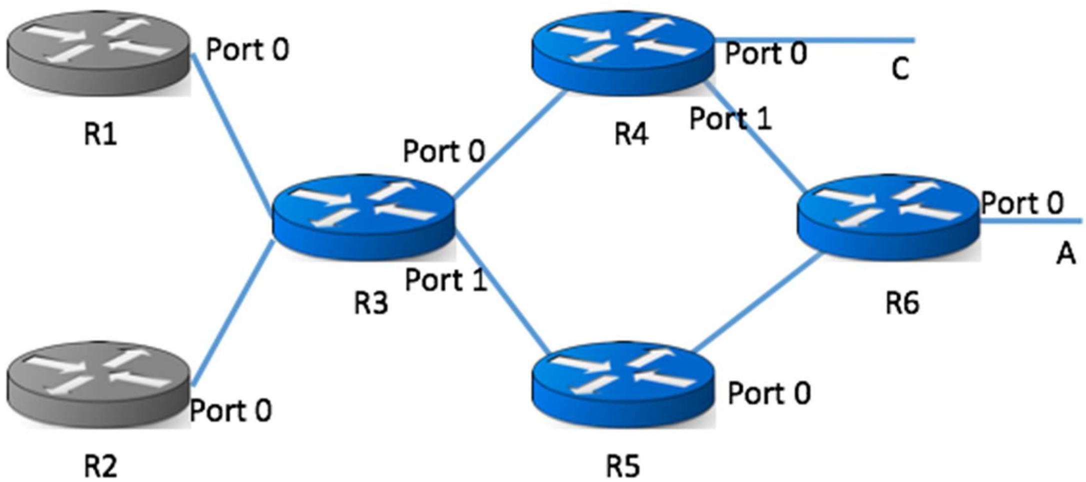


Figure 1. MPLS enabled network for Problem 1

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

R4			
In label	Out label	Dst	Out interface
3	-	C	0

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

R6			
In label	Out label	Dst	Out interface

Problem 2 (20pts)

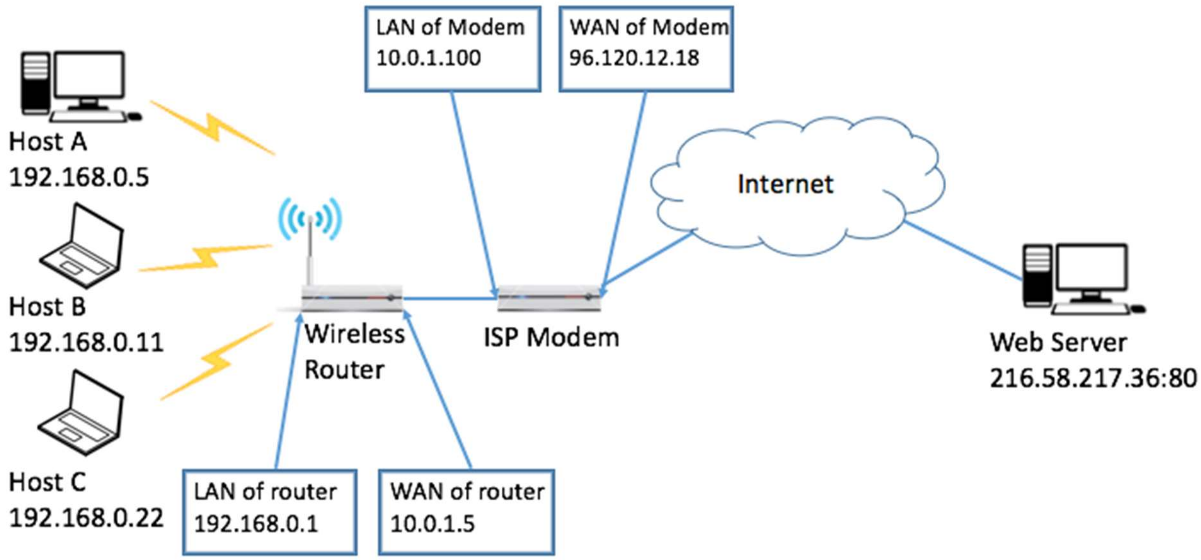


Figure 2. Network setup for Problem 2.

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

NAT Table of ISP Modem	
LAN side	WAN side

(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	
Src Port	
Dst IP	
Dst Port	

HTTP request After exiting Router	
Src IP	
Src Port	
Dst IP	
Dst Port	

HTTP request After exiting Modem	
Src IP	
Src Port	
Dst IP	
Dst Port	

HTTP response Before entering Modem	
Src IP	
Src Port	
Dst IP	
Dst Port	

HTTP response After exiting Modem	
Src IP	
Src Port	
Dst IP	
Dst Port	

HTTP response After exiting Router	
Src IP	
Src Port	
Dst IP	
Dst Port	

(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 assess this webserver via URL. You can assume that the above domain name is registered properly.

(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?

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:

(a) Fair queuing

(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.

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)

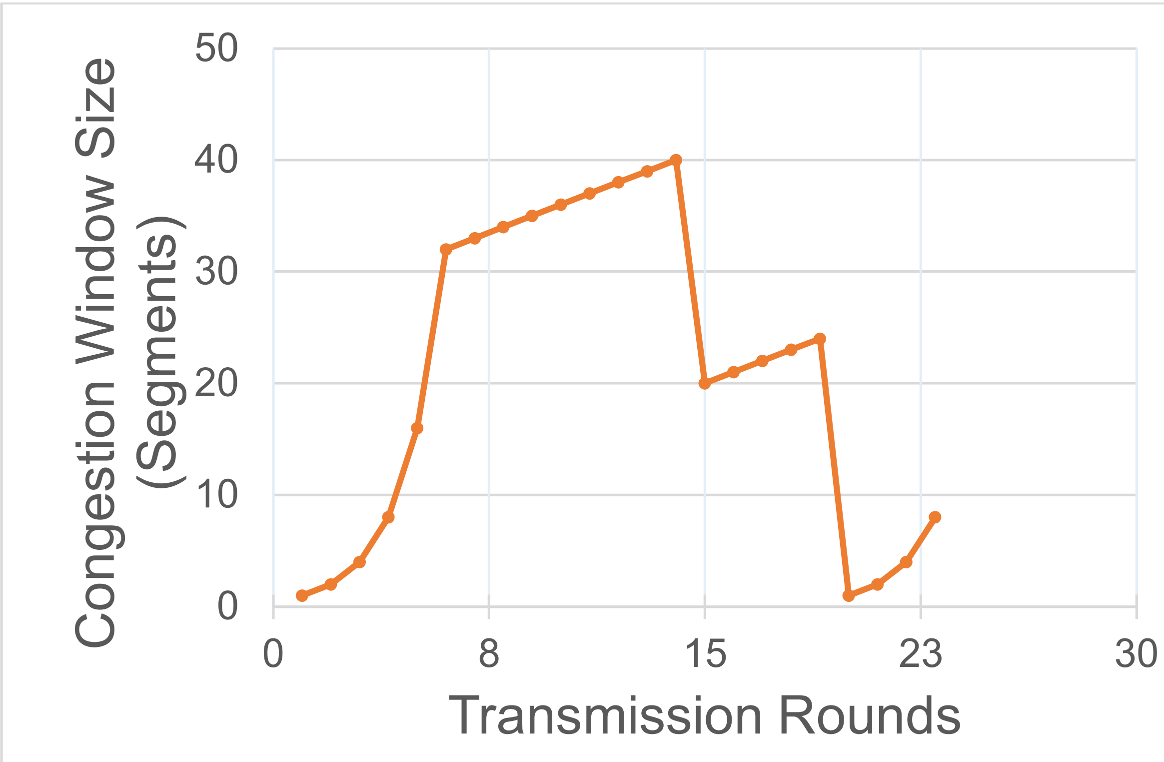


Figure 3. Congestion Window Size

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?)

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

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

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

(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?

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)

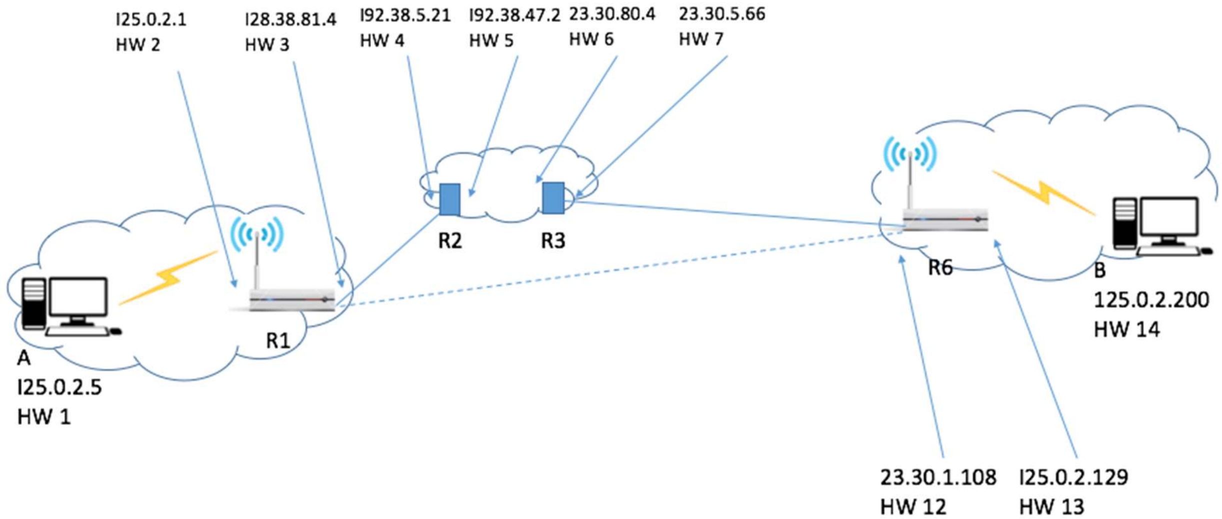


Figure 4. Network setup for Problem 5

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.

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 windows 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 set to (1-b)W from W when the loss happens.

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}

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?

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

Problem Set #4

Due Tuesday, December 10th

Problem 1 Hashing (20 pts)

The hash table has 13 slots, and integer keys are hashed into the table with the following hash function H

```
int H (int key)
{
        x = ( key + 5 ) * ( key - 3 );
        x = int( x / 7 ) + key;
        x = x % 13;
        return x;
}
```

(a) Fill in the final hash table with the following keys: 17, 22, 73, 56, 310, 100, 230, 12, 42, 18, 19, 24, 49.

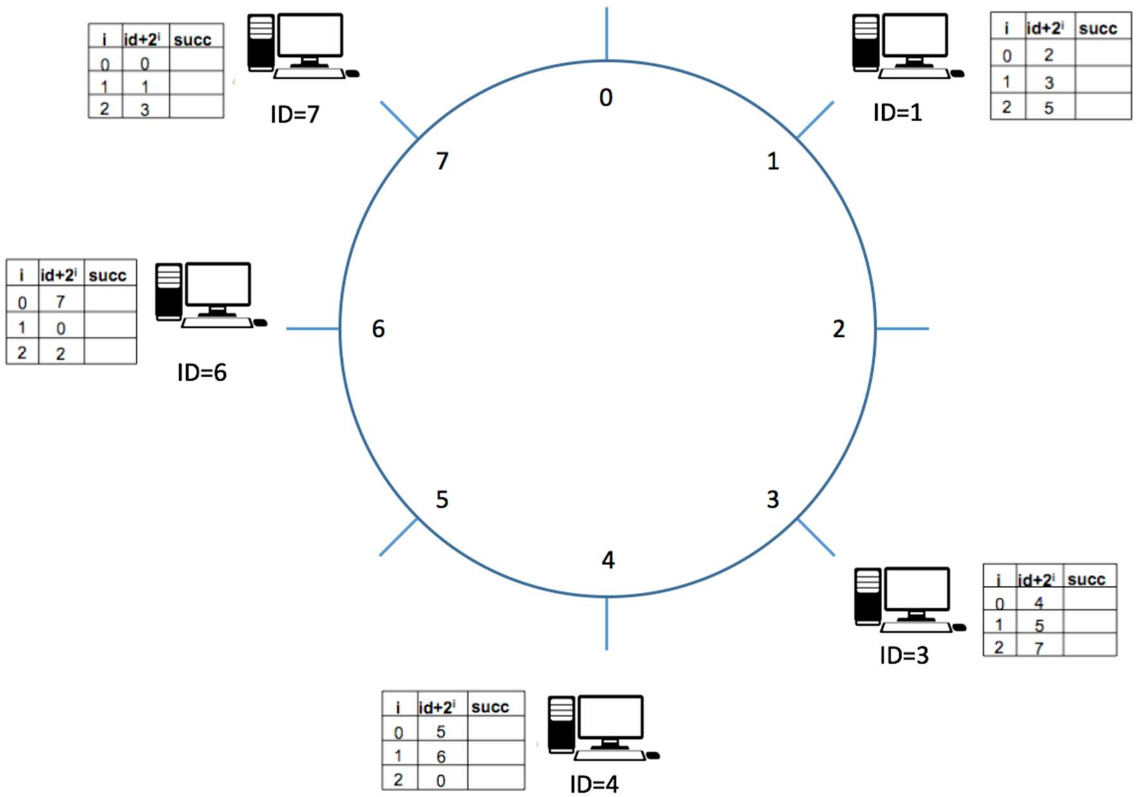
Slot	0	1	2	3	4	5	6	7	8	9	10	11	12
Contents													

(b) List one or two methods that can handle collision in hashing.

Problem 2 Distributed Hash Tables (20 pts)

There is a Chord DHT in Figure 1. with 5 nodes. The finger tables are listed beside the nodes. Each node may be storing some items according to the Chord rules (Chord assigns keys to nodes in the same way as consistent hashing)

Figure 1. Chord DHT for Problem 2



(a) Fill in the table for node id=1 and 7

	ID＋2^i	successor
0	2	
1	3	
2	5	

Table for ID=1

	$ID+2^i$	successor
0	0	
1	1	
2	3	

Table for ID=7

(b) List the node(s) that will receive a query from node 1 for item 5 (item named by key 5)

Problem 3 Bloom Filters (10 pts)

Derive the probability of false positive rate after 10 keys (or elements) are inserted into a table of size 100. Assume that 5 hash functions are used to setup bit positions in the table for the keys (elements).

5 Hashing functions means: For each key (element) there will be 5 bits to be set to 1 in the table (it can also be less than 5 if the hash functions generate same outputs).

Hint:
Assume **m** is the number of bits in the filter, **n** is the number of elements and k is the number of hash functions used.
After inserting one key, the probability of a particular bit being 0 is $(1-\frac{1}{m})^k$. This is because k hash functions are independent, and each hash function will have $(1-\frac{1}{m})$ probability for a particular bit remain 0. Then after inserting n keys, the probability for a particular bit remain 0 is $(1-\frac{1}{m})^{kn}$
Now you have to apply this to the case of false positive.

Problem 4 P2P system (10 pts)

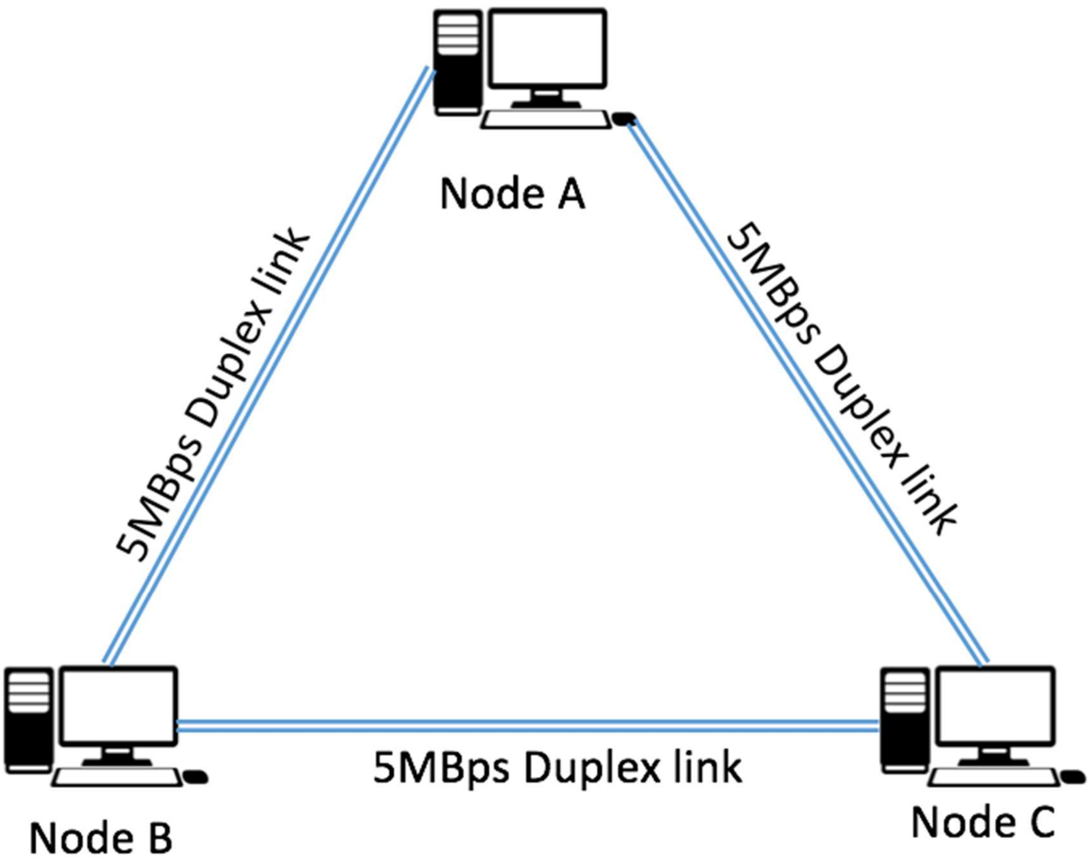


Figure 2. Network topology for Problem 4

3 nodes A, B and C are connected with each other via 5MBps duplex link as is now in Figure 2. Node A want to share a 2500MB file to Node B and C. During the actual transmission 2.5MB piece of the file can be send on the links each time. In the problem we ignore the RTT delay.

(a) What is the time of the sharing process using centralized approach? (The process ends when B and C all received the file, and the centralized approach means B and C are communicating with A independently and there is no communication between B and C)

(b) What is the ideal minimum time of the sharing process using P2P approach? (P2P approach means after B and C received a piece from A, they immediately share the their piece to other party)

Problem 5 File Distribution (10 pts)

Consider distributing a file of F = 20 Gbits to N peers. The server has an upload rate of u_s = 30 Mbps, and each peer has a download rate of d_i = 2 Mbps and an upload rate of u. For N = 10 and 100 and u = 300 Kbps and 2 Mbps, prepare a chart giving the minimum distribution time for each of the combination of N and u for both client-server distribution and P2P distribution.

Client Server

U	N= 10	N= 100
300 Kbps		
2 Mbps		

Peer to Peer

U	N= 10	N= 100
300 Kbps		
2 Mbps		

Problem 6 BGP (20 pts)

1. Give the types of business relationships in BGP peering and mention who pays whom. What conditions make the Internet stable? Explain each condition in a line or two.

2. Please identify which of the following paths are valid, which of them are invalid based on the network topology of Figure 3.

Path 1 3 d
Path 1 4 d
Path 8 d
Path 6 d
Path 4 d
Path 7 5 d
Path 7 5 3 d
Path 2 1 3 d
Path 1 4 6 d

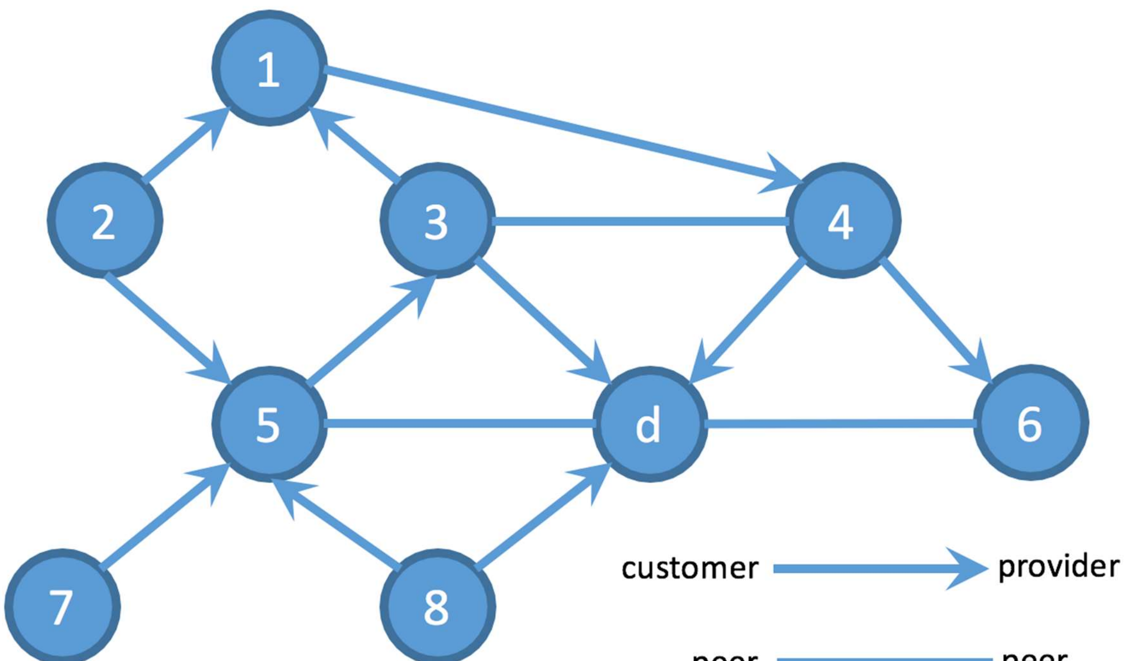


Figure 3. Network topology for Problem 6

Problem 7 Security (10 pts)

Diffie-Hellman Symmetric Key Exchange solves key the distribution issue of symmetric keys. Fill in the brackets below. Assume that Alice and Bob know p-ordered group G and a generator g, and Alice's and Bob's random seeds are ***a*** and ***b*** and their public keys are ***A*** and ***B***, respectively, and computes a shared key **s**. Please use ***p*** = 23, ***g*** = 11, ***a***= 13, and ***b*** = 8. Note that Eve is an eavesdropper and can see any communication between Alice and Bob.

Alice		**Bob**		**Eve**	
Known	Unknown	Known	Unknown	Known	Unknown
p = 23 ***g*** = 11 ***a*** = 13	***b***	***p*** = 23 ***g*** = 11 ***b*** = 8	***a***	***p*** = 23 ***g*** = 11	***a, b***
1. Alice chooses a private key ***a*** and sends its public key ***A*** to Bob					
A = [ ]					
2. Bob chooses a private key ***b*** and sends its public key ***B*** to Alice					
		B = [ ]			
3. Eve knows Alice's public key ***A*** and Bob's public key ***B***					
A, B		***A, B***		***A, B***	
4. Alice and Bob calculate its shared key ***s***					
***s* = [ ]**		***s*** = [ ]			***s***