CS224M End-Semester Exam
Max. Marks: 64

1. (12 marks) Answer the following questions regarding **TCP Reno**.
   a. (2 marks) State the conditions for TCP Reno to be in Slow Start and also how and when Congestion Window (CW) is modified in Slow start phase.

      Condition: $CW < ss\_thresh$ ($\leq$ also okay)

      How: $CW += 1\ MSS$

      When: on receiving an ACK

   b. (2 marks) State the conditions for TCP Reno to be in Congestion Avoidance (AI) phase and also how and when CW is modified in the congestion avoidance phase.

      Condition: $CW \geq ss\_thresh$ ($>$ also okay)

      How: $CW += (MSS)^2/CW$

      When: on receiving an ACK

   c. (2 marks) If Timeout occurs for a particular TCP segment, state how CW and the parameter `ss_thresh` are modified.

      On timeout

      $ss\_thresh = CW/2$

      $CW = 1\ MSS$

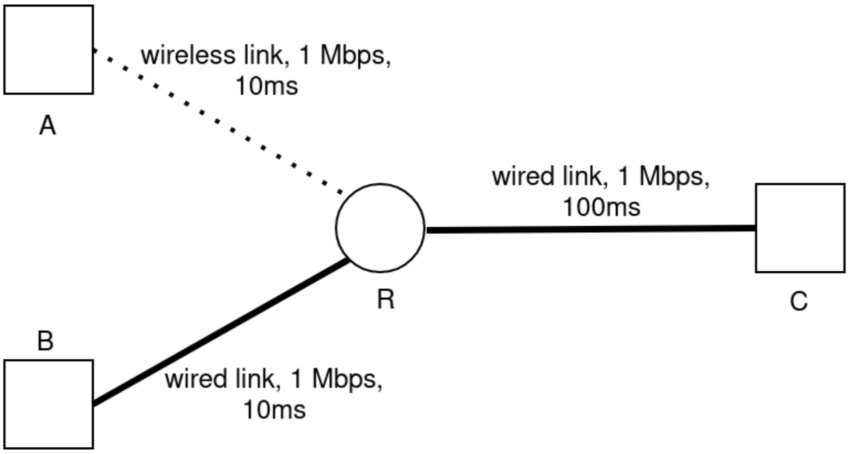
   d. (2 marks) If the sender of a TCP segment gets 3 DUP ACKs for that particular TCP segment, state how CW and the parameter `ss_thresh` are then modified.

      On TD Loss

      $ss\_thresh = CW/2$

      $CW = CW/2$

e. (4 marks) Consider the network topology shown below. A, B, and C are three hosts connected via router R. All links are assumed to be full-duplex, and the speed-of-light delays and link capacities between A--R, B--R and R–C are given in the diagram. We assume that the speed of light delays and link capacities in the opposite directions, that is, R--A, R--B, and C--R are the same as that of A--R, B--R and R--C respectively. Router R has a FIFO output queue (of size 1 MB) at each output interface.

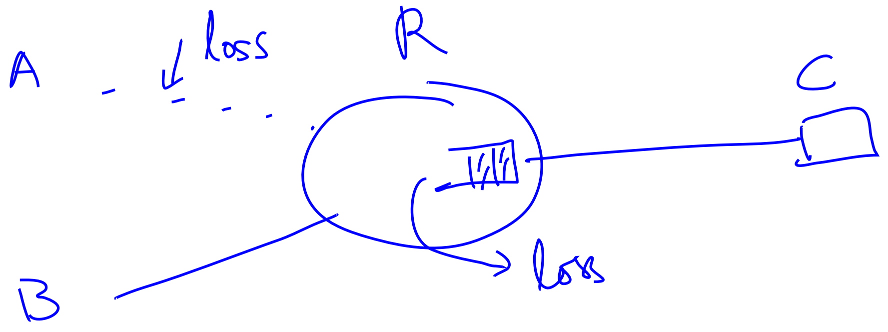


Suppose at time t=0, "A" starts a TCP Reno connection with C, and at the same time B starts a TCP Reno connection with C. Both TCP connections transfer files of infinite size. In other words, because of the infinite file size, the TCP connections never end. Assume that the wireless link A--R has a fixed packet drop probability of "p" (where 0<p<1). This means that when the PHY layer at A transmits a frame to R, then that frame is corrupted with probability "p" and does not reach R. Assume that there are no retransmissions at **the DLL** layer, that is, the DLL at A tries to transmit a frame only once and gives up if it does not reach R. The wireless link R–A has the same properties as that of A–R. Assume that there is no other data traffic besides these two TCP connections in the network.

Suppose T_A and T_B are the goodputs observed by the TCP connections which have senders A and B respectively after 1 hour has elapsed. Recall that the goodput is the total data received excluding retransmissions and overheads.
per unit time

Explain which of T_A and T_B would be higher and why. Use a diagram to show how the CW of both connections might vary over time, in order to justify your answer. In your diagram, indicate clearly the various phases of slow start, congestion avoidance, and also show clearly when CW at "A" changes due to wireless packet loss or due to a queue at router R overflowing. **Note:** Your diagram does not have to show exact timings of when packets or ACKs reach various nodes. A rough diagram, such as those drawn in class, which qualitatively explains which of T_A and T_B would be higher, will suffice.

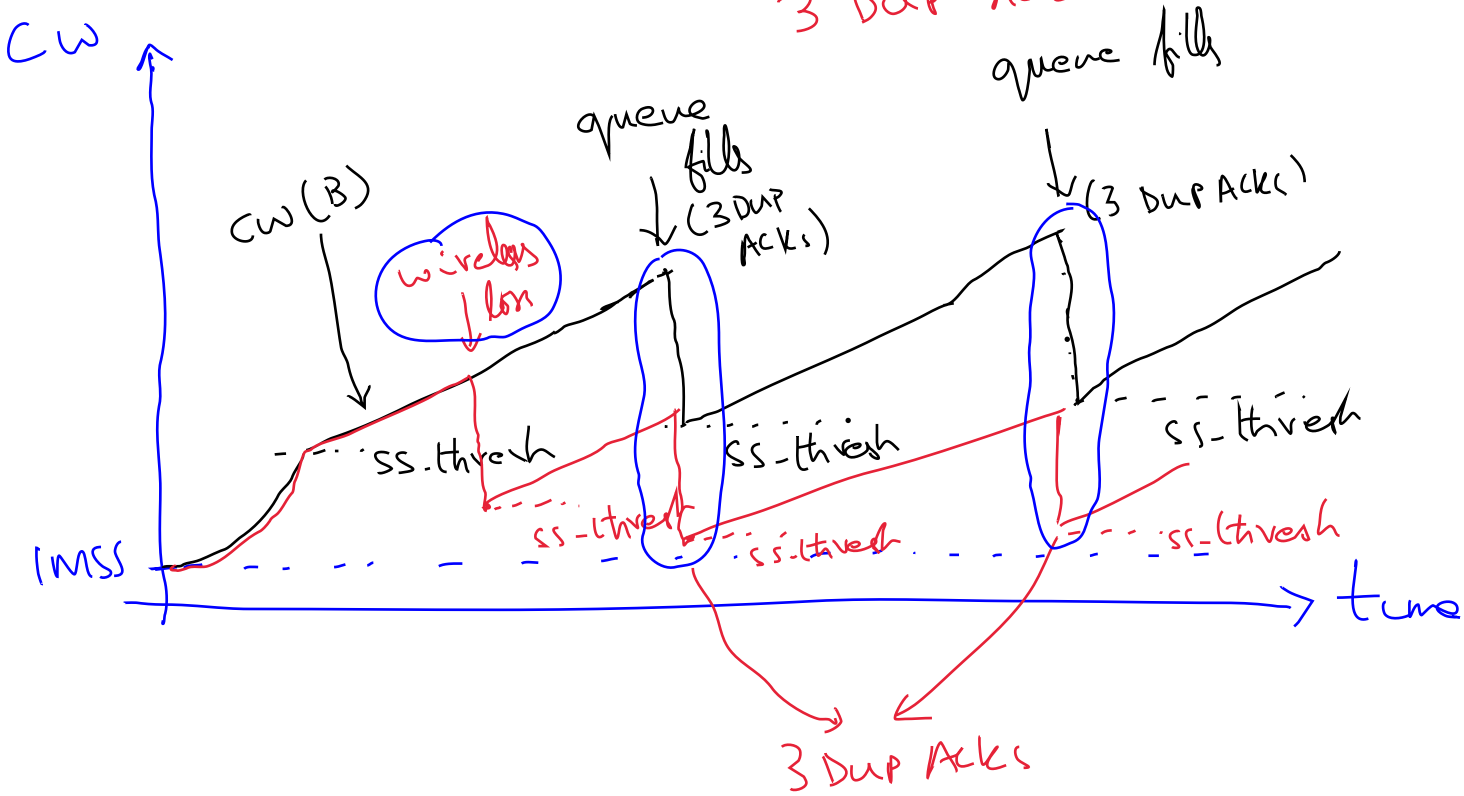
Ans: The TCP connection from A to C experiences packet losses due to wireless drops on the A-R link in addition to queue drops at the output link at the R-C link.



In general both connections will see queue drops at roughly the same time, when the common bottleneck queue fills up at R.

Thus $T_A < T_B$ due to extra drops due to wireless errors.

Example below considers only 3 Dup Ack loss



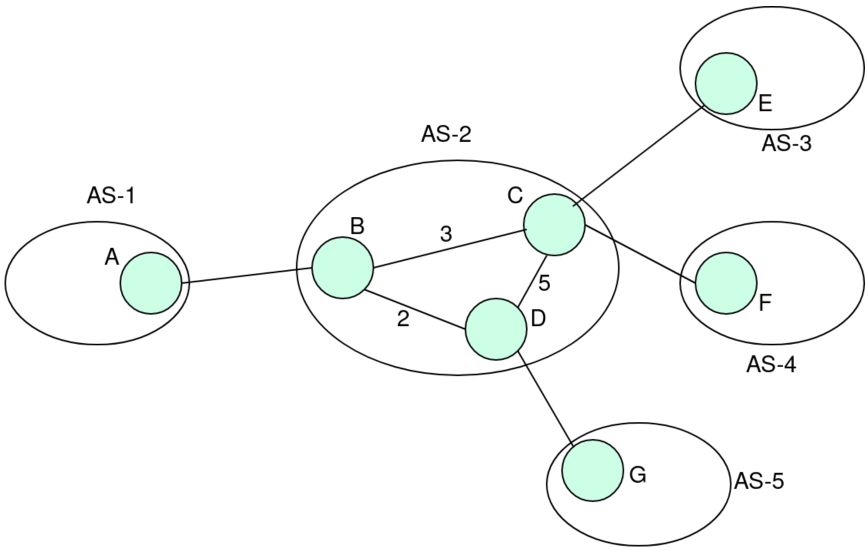
2. (9 marks) The following figure shows 5 Autonomous Systems (AS) and their BGP routers. Assume that there are no other layer-3 routers in the ASes other than the ones shown. The link costs for links in AS-2 for intra-domain routing (which uses any shortest path algorithm) are shown. Suppose that the IP prefixes 1.1/16, 2.2/16, 3.3/16, 4.4/16, and 5.5/16 belong to AS-1, AS-2, AS-3, AS-4, and AS-5 respectively. Assume that router ID of B is smaller than that of C, which is in turn smaller than that of D.

   The following BGP advertisements are sent out using eBGP.

   A sends to B: 1.1/16, AS_PATH= AS-1, MED=100
   B sends to A: 2.2/16, AS_PATH= AS-2, MED=50
   D sends to G: 2.2/16, AS_PATH= AS-2, MED=50
   C sends to F: 2.2/16, AS_PATH= AS-2, MED=50
   C sends to E: 2.2/16, AS_PATH= AS-2, MED=50
   G sends to D: 5.5/16, AS_PATH= AS-5, MED=50
   F sends to C: 4.4/16, AS_PATH= AS-4, MED=50
   E sends to C: 3.3/16, AS_PATH= AS-3, MED=50

   Now due to improper BGP configuration, router "A" sends out the following incorrect BGP advertisements to router "B". These messages are incorrect because they imply that the prefixes 3.3/16, 4.4/16, and 5.5/16 belong to AS-1 when in fact they do not. Such incorrect messages may be sent out in the real Internet too due to misconfiguration of BGP routers.

   A sends to B: 3.3/16, AS_PATH= AS-1, MED=50
   A sends to B: 4.4/16, AS_PATH= AS-1, MED=50
   A sends to B: 5.5/16, AS_PATH= AS-1, MED=30



Suppose that AS-2 accepts all BGP advertisements received by its routers and is unaware that any of them have incorrect information. Given this information, routers in AS-2 decide on which paths to use for different IP prefixes using standard BGP rules. We assume that AS-2 compares MED across all advertisements for the same prefix, no matter which AS it heard the announcement from.

a. (3 marks) Explain which is the EXIT router chosen by router D for prefix 3.3/16. Recall that EXIT router is the last router in AS-2 for the path that is chosen (by D, in this case). You must explain using BGP rules for choosing paths.

D hears: 3.3/16 AS-3 MED = 50 from C
3.3/16 AS-1 MED = 50 from B

Since LOCAL-PREF, AS_PATH length, MED are same and both are learned by iBGP, D chooses based on Hot-potato routing. Hence B (distance 2) is the EXIT router

b. (3 marks) Explain which is the EXIT router chosen by router C for prefix 5.5/16.

E hears: 5.5/16 AS-1 MED = 30 from B
5.5/16 AS-5 MED = 50 from D

Since LOCAL-PREF and AS-PATH length are the same, the path with lower MED is chosen.
Hence B is the exit router chosen

c. (3 marks) Explain which is the EXIT router chosen by router B for prefix 4.4/16.

B hears: 4.4/16 AS-1 MED = 50 from A
4.4/16 AS-4 MED = 50 from C

Both have same LOCAL_PREF, AS_PATH length and MED.
The first advertisement is learned from eBGP and the second from iBGP.
Hence B is itself the EXIT router (as 'A' is the NEXT_HOP of path chosen)

There is no unique solution to this question.

3. (16 marks) A peer-to-peer file-sharing network has the following properties.
   - Each file is stored (replicated) in at least 5 peer nodes. Assume that there are more than 5 nodes in the network at all times.
   - Unlike Napster, this application uses no centralized server that stores the location(s) of different files.
   - Any peer (person wanting a file) may download a *chunk* (i.e. a portion) of a file using TCP-Reno from another peer who has this file. He can specify the starting and ending byte of the chunk he wants. For example, he can state that he wants a particular file from byte 1200 to byte 1999. We assume byte 0 represents the first byte of a file.
   - Every client wishes to download a file from his peers as fast as possible. Simultaneous downloads from multiple peers is allowed.
   - The peer may not know the exact bit-rate in the near future for data transfer from another peer to itself but can predict this from recent downloads from that peer.
   - Nodes may occasionally join and leave the P2P network.

   Design such a P2P network and describe briefly the following aspects of your design. State any assumptions you make clearly. Solutions which are more elegant will receive more marks. **Note:** You cannot simply state that you use a particular protocol described in class; even if you do re-use such a protocol, you must describe its details in your answer. If you are reusing some algorithm which you have already described earlier in your answer, then you need not repeat all the details again – just state which part of your answer from an earlier sub-question you are reusing.

   a. (3 marks) How does a node join the P2P network? How many messages (at application layer) are sent when a node joins? You can give the answer in big-O notation, assuming there are "N" peers in the network.

One solution is given below.

picture showing distance on circle is also okay

We hash IPs and keywords to the same 256-bit space using SHA-256 hashing algorithm.

Let dist(P1, P2) give the distance between points P_1 and P_2 in the 256-bit space,

i.e. $\text{dist}(P_1, P_2) = \min\left(|P_1 - P_2|, 2^{256} - |P_1 - P_2|\right)$

Let Leaf(B) be the peers that B is connected to.

We consider peer IPs and keywords already in 256-bit space.

Initially Leaf(A) = B.

'A' knows only B and wants to join. B gives B_1 to A, where $B_1 = \arg\min_{j \in \text{Leaf}(B)} \text{dist}(A, j)$. A adds B_1 to its leafset.

This continues till the node does not know any nearer peer to A. Call this node C. A gets the nearest L/2 nodes to

C on either side and adds them to its leaf set. It gets all keyword info from those nodes as well. (Message complexity $O(N)$)

b. (2 marks) How is a given file stored in multiple locations?

Suppose file 'k' is stored at node A. (k is in 256-bit space)
Then 'A' finds peers closest to k,
$k_1 = hash(k)$, $k_2 = hash(k_1)$, $k_3 = hash(k_2)$, $k_4 = hash(k_4)$.
The closest peers are found using the method in part-a. Then 'A' tells all these peers that it has 'k'.
Each of them stores the file and also stores it at L/2 peers on either side in 256-bit space

c. (3 marks) How does a client wanting a file determine which peer(s) possess it? How many messages (at application layer) are sent ~~when a node joins~~? for this?

If B wants k, it finds the nodes using same method described in part-b.
The number of messages to find each peer is $O(N)$.
Thus $5 \times O(N) = O(N)$ messages are sent in total.

d. (2 marks) How is the P2P network robust to node failure or node leaving the network?

Since while joining, a peer collects keyword (file) information from nearest L/2 peers on either side,
AND as in part-b, the file 'k' is stored in L/2 neighbours closest to 5 peers who are selected to store it,
if any node leaves, the nearest peers to k, $k_1, \ldots, k_4$ will still have the file.

e. (6 marks) How does a client (i.e. peer wanting a file) minimize the total time to obtain a particular file? You should state what information a peer stores and give the algorithm it uses to determine which chunks to download from which peer.

Suppose peer X wants file 'k'.

Let P, P_1, P_2, P_3, P_4 be the nearest peers to k, k_1, k_2, k_3, k_4 respectively.

Let chunk size = α bytes

X downloads the 1st chunk from P, and from P_1 and so on. At any time it downloads only 1 chunk from any peer.

As soon as any chunk completes downloading from any peer, the next chunk not downloading (or downloaded) is begun to be downloaded from this peer.

Automatically faster peers will send more data. Since TCP is used, it will use the bandwidth to each peer.

4. (10 marks) Answer the following questions about HTTP.

a. (2 marks) Give the general formatting structure of a HTTP message. State clearly what is there on each line and how each line is terminated.

START LINE <CRLF>

MESSAGE HEADER LINE1 <CRLF>

—"— LINE2 <CRLF>

Can also say MESSAGE HEADER <CRLF> as in text book

<CRLF>

MESSAGE BODY <CRLF>

Not mentioned in RFC 7230 so give marks whether stated or not

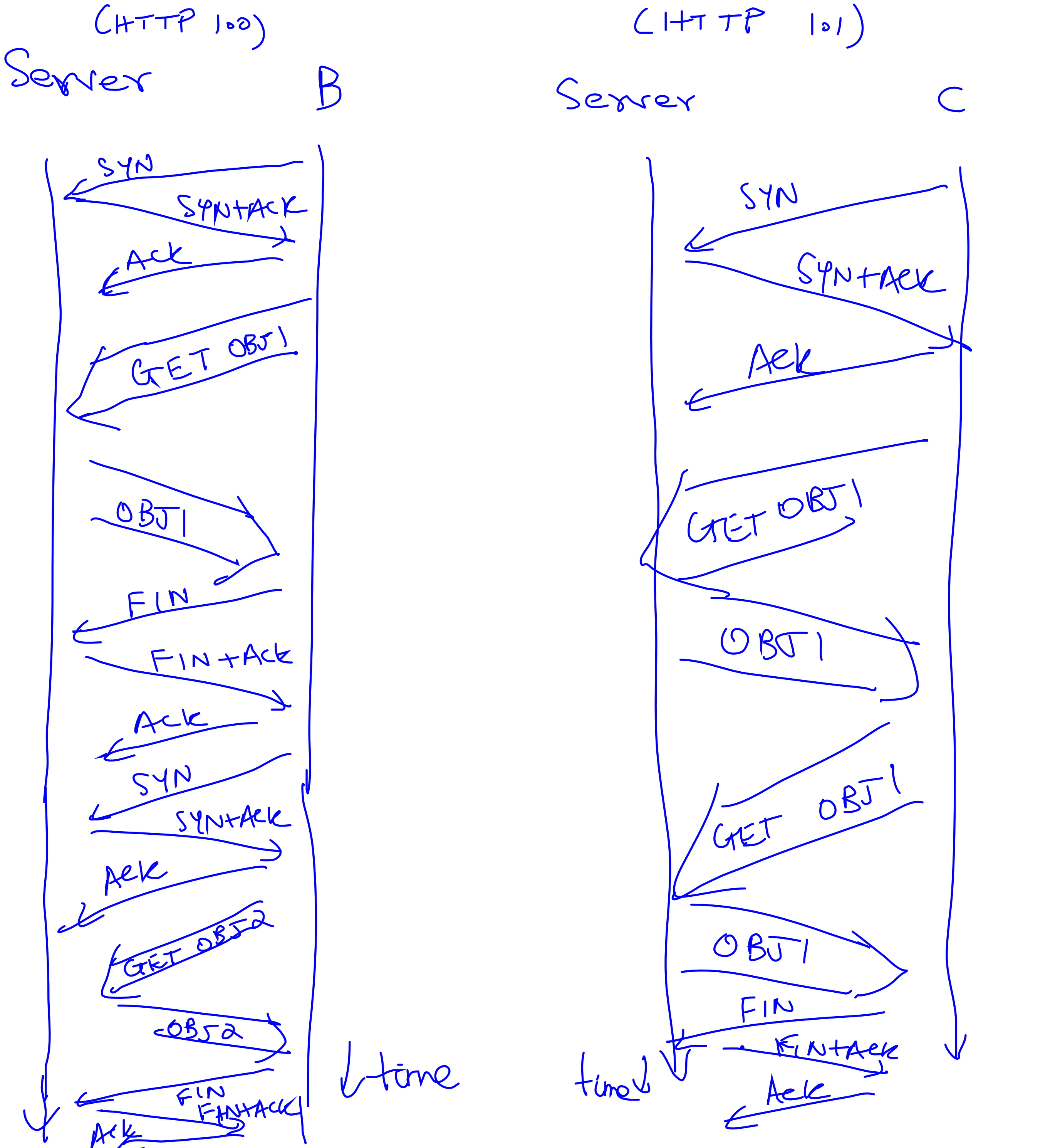
b. (3 marks) What are requests GET, HEAD, and POST used for?

GET : Retrieve document

HEAD : Retrieve Meta Information about document

POST : Give/Write Information

c. (3 marks) Suppose a particular webpage on a server consists of 2 different objects (for example, the first object could be a text file and the second one an image). The server supports both HTTP-1.0 and HTTP-1.1. The server transfers the page (i.e. the 2 objects) to client B using HTTP-1.0 and the server transfers the same page to another client C using HTTP-1.1. Explain with the help of timing diagrams, how the two HTTP protocols transfer the page to B and C using TCP connections. The timing diagram should show how many TCP connections are opened by the two HTTP protocols, and which object(s) are requested and downloaded in which TCP connections.



d. (2 marks) Mention two advantages of the method used by HTTP-1.1 over the method of HTTP-1.0.

(1) Less overheads due to SYN, FIN Handshakes

(2) Congestion window does not start from 1 MSS for OBJ2, so download will likely be faster (No need to re-learn correct window size)

5. (7 marks) Explain the following regarding Distance Vector routing protocols.
   a. (4 marks) Using an example, explain the "count to infinity" problem.

X ...... A ---- B

Dest	Cost	Next
A	1	A
B	2	A

Dest	Cost	Next
X	1	X
B	1	B

Dest	Cost	Next
A	1	A
X	2	A

Suppose link X...A fails and A sends (X,∞) to B but it gets lost. B sends a periodic update (A, 1), (X, 2) to A.

A updates its table to show

Dest	Cost	Next
X	3	B
B	1	B

Each of A and B think the other is the next hop to X. Thus when A sends (X,3) to B it updates its own cost to X to 4. This continues with costs going to infinity, and a loop exists from A to B for packets destined for X.

b. (3 marks) Explain what is the "split horizon" method. Give an example where the split horizon method prevents a count-to-infinity problem (you may reuse the example in part-a or give a new example if required).

Split Horizon rule: Do not advertise information about a particular destination to a neighbour if that neighbour is the next-hop to that destination.

In the example above, B does not send (x,2) to A.

Hence A retains (x,∞) in its table. Even if the message (x,∞) to B is initially lost, subsequent periodic updates will ensure the message reaches B and B sets its cost to X to ∞.

There will be no count-to-infinity or its accompanying routing loop.

6. (10 marks) Short answer questions. You need not give lengthy explanations. Answer to the point.
    a. (3 marks) Construct DNS resource records (RRs) which mean the following. Each RR should be of the form `(Name, Value, Type, Class)`.
        i. The IP address of `penguin.cs.princeton.edu` is `128.112.155.166`.

(penguin.cs.princeton.edu, 128.112.155.166, A, IN)

        ii. The Email Server of domain `cs.princeton.edu` is `mail.cs.princeton.edu`.

(cs.princeton.edu, mail.cs.princeton.edu, MX, IN)

        iii. An alias of `www.cs.princeton.edu` is `coreweb.cs.princeton.edu`.

(www.cs.princeton.edu, coreweb.cs.princeton.edu, CNAME, IN)

    b. (2 marks) Give any two reasons for why Ethernet has a maximum frame size and does not allow arbitrarily large frame sizes.

(1) Do not want any one terminal to grab the channel for arbitrarily long time

(2) The longer the frame, the higher the chance of bit errors in the frame. Too many bit errors lead to frame drops

c. (3 marks) Explain what the Exposed Terminal problem is in the context of WiFi. Does the virtual carrier sensing protocol of WiFi which uses RTS-CTS solve the exposed terminal problem? Why or why not?

A ⟵ B   C ⟶ D

Suppose each node can hear only its immediate neighbours. In theory B can send a message to A and C to D simultaneously. However with carrier sense, when B transmits then C remains silent, and vice versa. This is the exposed terminal problem. RTS-CTS does not solve the problem, as anyone hearing an RTS or CTS must remain silent for NAV duration

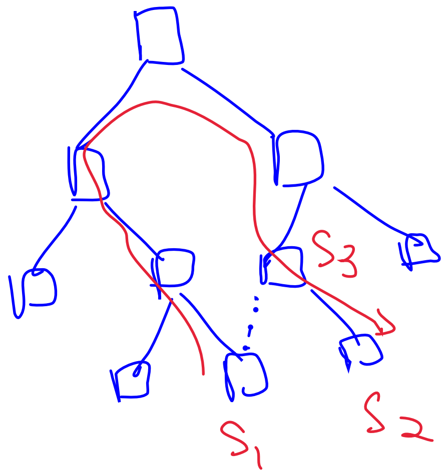
d. (2 marks) State any two technical reasons why Ethernet's spanning tree protocol does not scale to networks consisting of many thousands of switches. You need not give a very detailed explanation. A short explanation will do.

(1) Failure of any switch requires rerunning entire spanning tree protocol which takes some time to converge.

(2) paths taken can be very long and suboptimal

Eg:

path from S_1 to S_2 is 6 hops. (S_1---S_3 is disabled)



Direct $S_1-S_3-S_2$ path is only 2 hops long

(3) (Note: only 2 reasons asked)
Routing tables are $O(N)$ for N terminals in network.
This leads to large tables.