CS 655: Introduction to Computer Networks
Fall 2020

Solution to Sample Final Examination

NAME: MATTA

This exam is closed books and closed notes. Please write clearly and neatly. Be precise in your answers; do not just re-iterate what you know about the topic. Clearly state any assumptions you make. All questions are weighted equally. Answer all 5 questions.

Problem 1 (TCP Congestion Control):

Consider sending a large file from one host to another over a TCP-Reno connection. Assume that the connection has reached steady state, and its congestion window is now oscillating between 8 and 16 segments in AIMD (without slow start, i.e. a loss event at congestion window = 16 is always detected by triple duplicate acknowledgments). Assume the TCP source is not limited by flow control.

(a) Assuming approximately constant round-trip times (RTT), where RTT = 100ms, in steady state, how long does it take between two consecutive loss events? Assume that it takes roughly one RTT to detect loss.

Since the congestion window, cwnd, is increased linearly, i.e. by 1 segment every RTT, then starting from cwnd=8, we need 9 RTTs to detect the next loss event (when cwnd=16), thus it takes 9*100=900ms.

(b) What is the average sending rate for this connection?

Since cwnd oscillates linearly between 8 and 16, the average cwnd = (8+16)/2=12, so the average sending rate = cwnd/RTT = 12/0.1 = 120 segments/second.

(c) Now suppose this connection shares the bottleneck link with another long-lived TCP-Reno connection. What would be the average sending rate of each connection? Assume that both connections have the same RTT and are synchronized in their updates of their congestion windows.

Since TCP's AIMD is fair, each connection sends at 120/2 = 60 segments/second on average.

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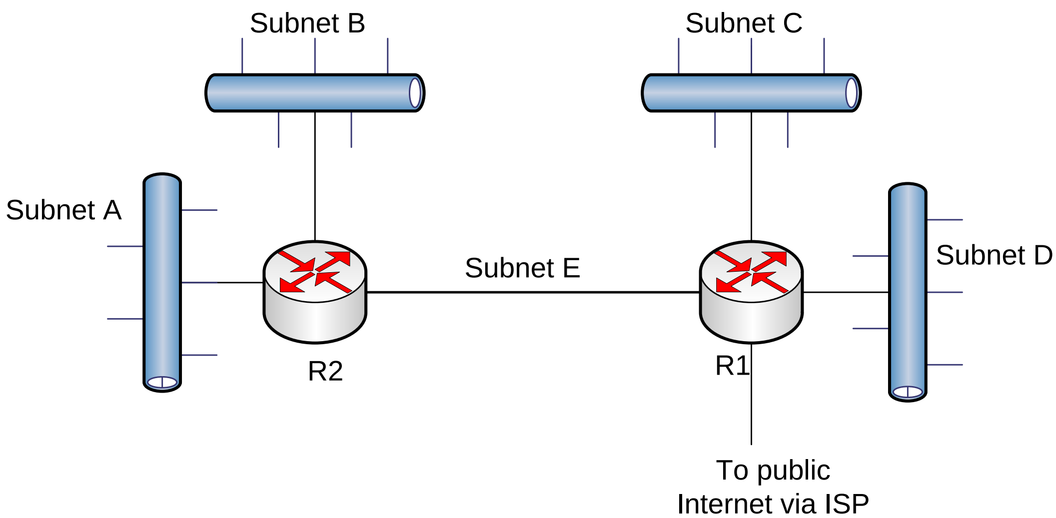
Problem 2 (IP Addressing):



Consider the network shown above. Each of the subnets A—D contains at most 19 hosts; subnet E connects routers R1 and R2. Assign an address range to each of the five subnets so that only a single aggregated address needs to be advertised by R1 to the public Internet, and that the size of the advertised aggregated address range is ***minimized***. In a sentence or two, explain how you arrived at your answer. (Feel free to use variable names in addresses if the precise bit values are *not* important.)

Aggregated CIDR address: We need a total of 19*4 (for subnets A-D)+2 (for E) = 78 addresses, so 7 bits suffice to obtain 2^7=128 addresses. Thus, R1 should advertise X.Y.Z.0/25, i.e. the high-order bit of the last byte is assigned the value 0.

*Subnet "**A**" CIDR address range:* Each of subnets A-D needs at least 19 addresses, so 5 bits will suffice, giving up to 32 addresses. Assigning the next 2 high-order bits of the last byte to be 00, this gives a prefix of X.Y.Z.0/27. If we assign subnet E the first 2 addresses from A's range (see below), then A's address range is X.Y.Z.0/27 - X.Y.Z.0/31 .

*Subnet "**B**" CIDR address range:* Assigning the next 2 high-order bits of the last byte to be 01, this gives X.Y.Z.32/27

*Subnet "**C**" CIDR address range:* Assigning the next 2 high-order bits of the last byte to be 10, this gives X.Y.Z.64/27

*Subnet "**D**" CIDR address range:* Assigning the next 2 high-order bits of the last byte to be 11, this gives X.Y.Z.96/27

*Subnet "**E**" CIDR address range:* Assigning E the first 2 addresses from A's range, we have X.Y.Z.0/31

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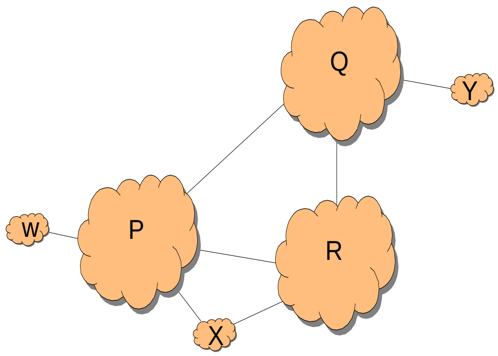
Problem 3 (BGP):



Consider the network shown above in which network W is a stub AS that is a customer of ISP P, network Y is a stub AS that is a customer of ISP Q, and network X is a stub AS that is a customer of both ISPs P and R. Assume that P, Q, and R are only transit ASs, and that each of the transit AS pair – P and Q, Q and R, and P and R – are peers, i.e. they only carry traffic for their own customers.

(a) What BGP routes will X advertise to P? (Note: a BGP route specifies a list of ASs on the path.) Provide a one-sentence explanation.

NONE, since X is a stub AS and does not carry transit traffic.

(b) Suppose that P, Q, and R have CIDR address allocations C1.0.0.0/8, C2.0.0.0/8, and C3.0.0.0/8 (using hexadecimal dotted notation with mask), respectively. Using provider-based address allocation, W is assigned C1.A3.0.0/16, X is assigned C1.B0.0.0/12 from P's address space, and Y is assigned C2.0A.10.0/20. Use the CIDR longest prefix match rule to give the routing table for a router in **Q.** Assume that entries have addresses that are aggregated as much as possible.

CIDR address	next-hop (AS name)
C2.0A.10.0/20	Y // to its customer
C1.0.0.0/8	P // to any destination in P's address range
C3.0.0.0/8	R // to any destination in R's address range
C1.B0.0.0/12	R // longest prefix match to // any destination in X

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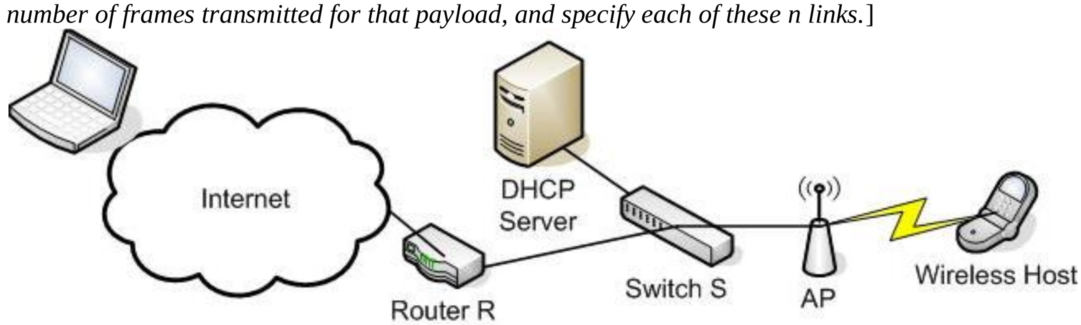
Problem 4 (Extended Wireless and Ethernet LAN):

Consider a switched Ethernet LAN with a single switch that connects to a DHCP server, a wireless access point (AP), and a router that connects the LAN to the rest of the Internet. A wireless host "X" enters the cell of the AP and associates with the AP. Suppose X wants to first acquire an IP address using a DHCP four-message broadcast exchange, and then to TCP three-way handshake with another host "B" on the Internet. Assuming this is the only traffic on both Ethernet and wireless LAN, and there are no packet errors or losses, how many frames will be *transmitted* in the process of DHCP exchange and TCP handshaking exchange over both wireless and Ethernet LAN? Assume X learns the IP addresses of the router and host B from DHCP and that no fragmentation is needed. Suppose the switch's forwarding table and ARP tables are initially empty. Indicate what kind of higher layer protocol / data (payload) will each frame carry, and on which link it is transmitted: denote by "all" all links, by D-S the link between the DHCP server and switch, by R-S the link between the router and switch, by S-A the link between the switch and AP, and by A-X the wireless link between the AP and the wireless host. [***Note***: *Fill out the table below so if some payload is carried by frames that get transmitted over n links, then you should specify n as the number of frames transmitted for that payload, and specify each of these n links.*]



Higher Layer Protocol / Data (payload)	Number of Frames (transmitted)	Link(s): all, D-S, R-S, S-A, A-X (on which frames are transmitted)
DHCP (4 broadcast messages) [switch learns how to reach wireless host]	4*4 = 16 frames	All links (2 points)
ARP broadcast request (for R's MAC address) [switch learns how to reach wireless host. R learns of wireless host's IP to MAC address mapping]	4 frames	All links (2 points)
ARP (direct reply to wireless host) [switch learns how to reach R; wireless host learns of R's IP to MAC address mapping]	3 frames	R-S, S-A, A-X (2 points)
TCP (3 handshake messages)	3*3 = 9 frames	R-S, S-A, A-X (2 points)

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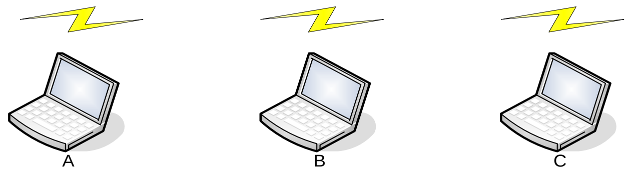
Problem 5 (Wireless MAC):



Consider this wireless scenario: when A transmits, it can only be heard/received by B; both A and C can hear/receive from B; when C transmits, it can only be heard/received by B.

Suppose now that each node has an infinite supply of messages to send to other nodes. If a message's destination is not an immediate neighbor, then the message must be relayed. For example, if A wants to send to C, the message from A must be first sent to B, then B sends it to C. Assume time is slotted, and during each slot, a node can do one of the following: (i) send a message, (ii) receive a message (if exactly one message is sent to it), or (iii) remain silent. Thus, a node cannot send and receive at the same time. And if a node hears two or more simultaneous transmissions, a collision occurs. Assume here that there are no bit-level errors, thus if exactly one message is sent, it will be received correctly by those within the sender's transmission range. Answer the following questions assuming an ideal collision-free MAC controller that knows the state of every node in the network and can command each node to do whatever it (the controller) wishes, i.e. to send a message, to receive a message, or to remain silent.

(a) What is the maximum (steady-state) rate (expressed in messages/slot) at which data messages can be transferred from C to A, given that there are no other messages between any other source/destination pairs? 1 message every 2 slots, i.e. 0.5 message/slot [a message from C needs to be sent to B (one time slot) and then sent to A (a second slot) before any other message can be sent, otherwise collisions happen. In particular, while B sends a message to A, it can NOT receive another message from C at the same time, since in this wireless setting, a node can NOT send and receive at the same time.]

(b) Suppose now that A and C both send messages to B. What is the combined maximum rate at which data messages can flow from A and C to B? 2 messages/2 slots, i.e. 1 message/slot [only one message from either A or C can be sent at a time (same time slot), otherwise a collision happens at B; B can not receive more than one message at the same time.]

(c) Suppose now that the wireless links are replaced by wired full-duplex links. Repeat questions (a) and (b) again in this wired scenario. [Since now links are wires, there are no collisions.]
(a) 1 [A can receive a message every time slot] (b) 2 [two messages can be sent in the same time slot without the possibility of collisions.]