ECE/CS 438: Communication Networks **Fall 2022**

Homework 3

Handed Out: October 3^{rd}, 2022 *Due: 11:59pm, October* 19^{th}, 2022

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- Homework assignments must be submitted online through Canvas. Hard copies are not accepted. Please submit a pdf file to Canvas (`https://canvas.illinois.edu/courses/30870`). You can either type your solution or scan a **legible** hand-written copy. We will not correct anything we do not understand. Contact the TAs via email if you face technical difficulties in submitting the assignment.
- While we encourage discussion within and outside of the class, cheating and copying is strictly prohibited. Copied solutions will result in the entire assignment being discarded from grading at the very least and a report filed in the FAIR system. It is also your responsibility to ensure that your partner obeys the academic integrity rules as well.
- This assignment has a total of 110 points. The grade will be capped at 100 points.
- **Please write your answer in the white space to the right of the corresponding problem.**
- **We only allow at most 2-day late submission (either from requested exemption, or penalized) for this assignment.** All the submissions after 11:59pm, October 21^{st}, 2022 **WILL BE REJECTED (0 points)**.

1 Choose all the correct answers - 3×4 points

1. Assume TCP is in the Slow Start phase, with SSThreshold as 32. At some time instant, the congestion window is 16. When the congestion window increases the next time, it becomes 32. Assume TCP is ACKing all packets and that no ACKs are getting lost

   (a) True

   (b) False

   Answer: b

2. A TCP socket is an end to end connection between two ______.

   (a) threads

   (b) processes

   (c) devices

   (d) hosts

   Answer: b

3. Flow control regulates the congestion window, i.e., the congestion window is not increased when the receiver does not have adequate buffer space.

   (a) True

   (b) False

   Answer: b

4. In Selective Repeat, the lower end of the transmitter's window can be ______the lower end of the receiver's window.

(a) greater than

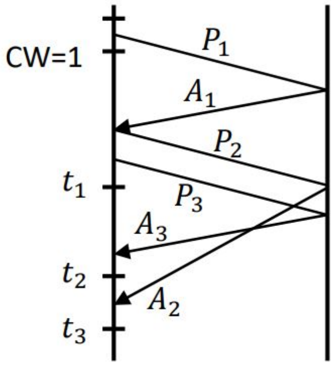
(b) equal to

(c) smaller than

Answer: b c

2 TCP example 1 - 2×5 points

Assume TCP is at slow start phase.



1. CW at time t1 =

   Answer: 2

2. CW at time t2 =

   Answer: 4

3. CW at time t3 =

   Answer: 4

4. How should the TCP transmitter react after receiving A3? Please give CW_head, CW_tail, and Send

   NOTE: For questions that ask how TCP reacts, the following fields are defined as:

   - CW_head: Congestion Window Head (also called Base); An integer
   - CW_tail: Congestion Window Tail; An integer
   - SSthresh: Slow Start Threshold; Numerical answers round to 1 decimal place.
   - Send: The packets that need to be transmitted by the TCP transmitter. A sequence of numbers. When the transmitter has no packets to send, write [].

   Example: If CW=[4,5,6,7,8], then you should answer CW_head as 4 and CW_tail as 8.

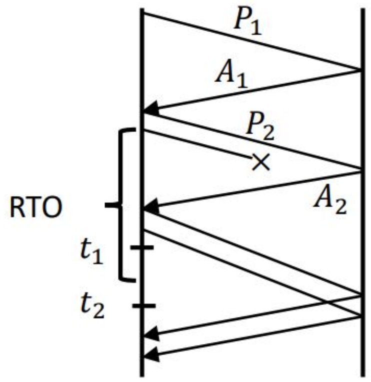
   Answer: CW_head = 4, CW_tail = 7, Send = 4,5,6,7,

5. How should the TCP transmitter react after receiving A2? Please give CW_head, CW_tail, and Send

   Answer: CW_head = 4, CW_tail = 7, Send = []

3 TCP example 2 - 2×5 points

Assume TCP is at slow start phase from CW=1.



1. CW at time t1 =

   Answer: 3

2. CW at time t2 =

   Answer: 1

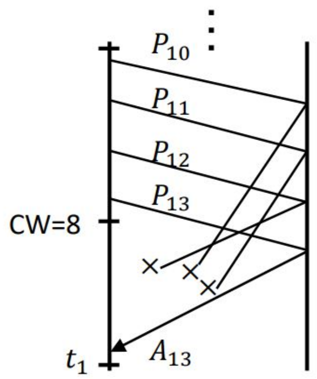
3. How should the TCP transmitter react after packet P3's timeout (shown in the figure)? Please give CW_head, CW_tail, SSthresh, and Send

   Answer: CW_head = 3, CW_tail = 3, SSthresh = 1.5, Send = [3]

4. How should the TCP transmitter react when each of the last two ACKs (shown in the figure) arrive? Please give CW_head, CW_tail, SSthresh, and Send
   Answer: CW_head = 3, CW_tail = 3, SSthresh = 1.5, Send = []

4 TCP example 3 - 3×2 points

Assume packets before P10 have already been acknowledged in the past and TCP is in slow start.



1. CW at time t1 =

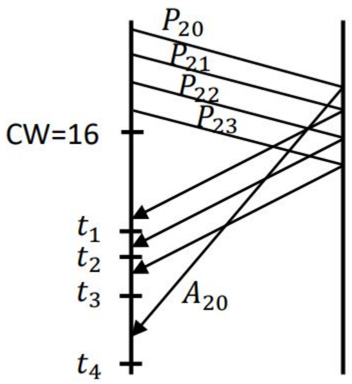
Answer: 12

2. How should the TCP transmitter react upon receiving A13? Please give CW_head, CW_tail, and Send

   Answer: CW_head = 14, CW_tail = 25, Send = [14,15,16,17,18,19,20,21,22,23,24,25]

5 TCP example 4 - 2×8 points

Assume packets before P20 have already been acknowledged in the past and TCP is in slow start.



1. CW at time t1 =

   Answer: 18

2. CW at time t2 =

   Answer: 19

3. CW at time t3 =

   Answer: 20

4. CW at time t4 =

   Answer: 20

5. How should the TCP transmitter react upon receiving A21? Please give CW_head, CW_tail, and Send

   Answer: CW_head = 22, CW_tail = 39, Send = [24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39]

6. How should the TCP transmitter react upon receiving A22? Please give CW_head, CW_tail, and Send

   Answer: CW_head = 23, CW_tail = 41, Send = [40,41]

7. How should the TCP transmitter react upon receiving A23? Please give CW_head, CW_tail, and Send

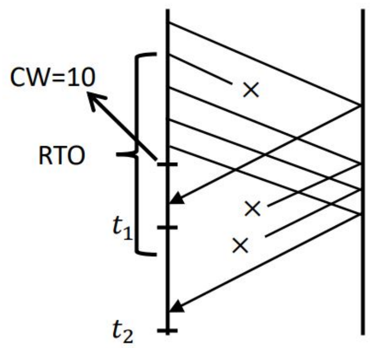
Answer: CW_head = 24, CW_tail = 43, Send = [42,43]

8. How should the TCP transmitter react upon receiving A20? Please give CW_head, CW_tail, and Send

   Answer: CW_head = 24, CW_tail = 43, Send = []

6 TCP example 5 - 2×5 points

Assume that the first ACK that is shown to arrive at the TCP transmitter is A5 and TCP is in slow start. Also assume packets before P5 have already been acknowledged in the past.



1. CW at time t1 =

   Answer: 11

2. CW at time t2 =

   Answer: 1

3. How should the TCP transmitter react upon receiving A5, when the timeout occurs, and upon receiving the last shown ACK (just before t2)? Please give CW_head, CW_tail, and Send

   Answer: CW_head = 6, CW_tail = 16, Send = [10,11,12,13,14,15,16]

4. How should the TCP transmitter react after timeout: ? Please give CW_head, CW_tail, **SSthresh**, and Send

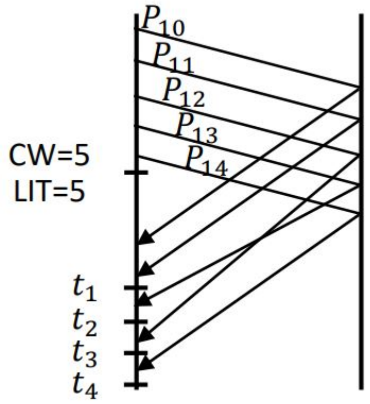
   Answer: CW_head = 6, CW_tail = 6, SSthresh= 5.5, Send = [6]

5. How should the TCP transmitter react after receiving last shown ACK: Please give CW_head, CW_tail, **SSthresh**, and Send

   Answer: CW_head = 6, CW_tail = 6, SSthresh= 5.5, Send = []

7 TCP example 6 - $5 + 2 * 5$ points

SSThresh is also sometimes known as "linear increase threshold (LIT)". The LIT shown in the figure means SSThresh. Assume packets before P10 have already been acknowledged in the past.



1. What should the values of CW be at times t1, t2, t3, and t4? (Round to 1 decimal place)

   Answer: 5.4, 5.8, 5.8, 6.0

2. How should the TCP transmitter react upon receiving A10? Please give CW_head, CW_tail, **SSthresh**, and Send

   Answer: CW_head = 11, CW_tail = 15, SSthresh= 5, Send = [15]

3. How should the TCP transmitter react upon receiving A11? Please give CW_head, CW_tail, **SSthresh**, and Send

   Answer: CW_head = 12, CW_tail = 16, SSthresh= 5, Send = [16]

4. How should the TCP transmitter react upon receiving A13? Please give CW_head, CW_tail, **SSthresh**, and Send

   Answer: CW_head = 14, CW_tail = 18, SSthresh= 5, Send = [17,18]

5. How should the TCP transmitter react upon receiving A12? Please give CW_head, CW_tail, **SSthresh**, and Send

   Answer: CW_head = 14, CW_tail = 18, SSthresh= 5, Send = []

6. How should the TCP transmitter react upon receiving A14? Please give CW_head, CW_tail, **SSthresh**, and Send

   Answer: CW_head = 15, CW_tail = 20, SSthresh= 5, Send = [19,20]

8 T/F Question - 4×4 points

Considering the Selective ACK protocol, please answer following question and justify your answer.

1. Can Receiver's base sequence number be smaller than transmitter's base sequence number? **Answer: False. Suppose we have:**

   Tx: pkt 7, pkt 8, pkt 9, pkt 10
   Rx: pkt 6, pkt ______(expecting P7), pkt 8,
   Tx start at pkt 7. This means the pkt 6 has been acked. So, the receiver cannot include pkt 6, because receiver has ack pkt 6 before. (In SACK, the Ai indicates that Rx has received packet Pi)

2. Receiver's base sequence number can be smaller than transmitter's tail sequence number? **Answer: True. Suppose P4 loss and A1 loss, then:**

   Tx: pkt 1, pkt 2, pkt 3, pkt 4
   Rx: pkt 5, pkt 6, pkt 7, pkt 8

3. Receiver's base sequence number can be larger than transmitter's tail sequence number. **Answer: True. If first ACK loss:**

   Tx: pkt 1, pkt 2, pkt 3, pkt 4
   Rx: pkt 5, pkt 6, pkt 7, pkt 8

4. Receiver's base sequence number can be larger than transmitter's tail sequence number plus one. **Answer: False. Suppose it is:**

   Tx: pkt 1, pkt 2, pkt 3, pkt 4
   Rx: pkt 6, pkt 7, pkt 8, pkt 9
   Then, it means P5 not sent but has been received, contradict.

9 Sequence Number Space - 3×5 points

Consider the Go-Back-N protocol with a send window size of N and a large sequence number range. 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 may drop packets but does not reorder messages. Also, "window-base" as taught in class is also called the "window-head".

1. What is the lower bound of sequence number (inclusive) for the head of the sender's window at time t? **Answer: k-N**

2. What is the upper bound of sequence number (inclusive) for the head of the sender's window at time t? **Answer: k**

   Here we have a sender window size of N. We are given that the next in-order packet that the receiver is expecting to receive has a sequence number of k. Hence this implies that the receiver received the packet with sequence number k-1, as well as all the preceding packets (i.e. packets with sequence number smaller than k-1). Additionally the receiver would have sent ACKs for all packets upto k-1 back to the sender. On the sender side, we can be sure that all packets upto sequence number k-N-1 must have been ACKed. Because if packet k-N-1 was not ACKed, then the sender would never have sent packet k-1 to the receiver.
   Let us consider the two extreme cases. If all of the ACKs sent by the receiver reach the sender, then the senders window would be [k,

k+N-1]. However, on the other hand, if none of the ACKs for k-N to k-1 reach the sender, then the sender's window would contain k-1 and the N packets up to and including k-1. Therefore the sender window would be [k-N, k-1] in this case.
Hence the possible sets of sequence numbers inside the sender's window would be contiguous sequences of integers with the integer taking values from the set [k-N,k]

3. What is the lower bound of the ACK sequence number field (inclusive) in the message currently propagating back to the sender at time t? **Answer: k-N**

   or k-N-1
   We have argued that the sender has already received ACKs for packets upto sequence number k-N-1. Also, since the receiver is waiting for packet k, there is no way it could have already sent an ACK for packet k. Therefore the possible values of the ACK in the message currently propagating back to the sender could be [k-N,k-1]
   Some students hold argument that k-N-1 is valid. We examine it, and accept this answer as well.

4. What is the upper bound of the ACK sequence number field (inclusive) in the message currently propagating back to the sender at time t? **Answer: k-1**

   We have argued that the sender has already received ACKs for packets upto sequence number k-N-1. Also, since the receiver is waiting for packet k, there is no way it could have already sent an ACK for packet k. Therefore the possible values of the ACK sequence number field in the message currently propagating back to the sender could be [k-N,k-1]

5. 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?

   Answer: Possible
   Suppose the sender has a window size of 3 and sends packets 1, 2, 3 at t0. At t1 (t1 > t0) the receiver ACKS 1, 2, 3. At t2 (t2 > t1) the sender times out and resends 1, 2, 3. At t3 (t3 > t2) the sender receives the ACKs that the receiver sent at t1 and advances its window to 4, 5, 6. At t4 (t4 > t3) the receiver receives the duplicates (that the sender sent at t2) and re-acknowledges 1, 2, 3 (although in this case the receiver will acknowledge packet 3 three times because it uses cumulative ACKs). At t5 (t5 > t4) the sender receives the ACKs for packet 3 (the ACKs that the receiver sent at t4). Therefore currently, the ACKs for packet 3 are outside the sender's window.

10 Self-practice Question (0 points) - 0 points

These questions are for you to think and answer but has no points associated to them. The solutions to these questions will be released with the HW solutions.

Please identify if each statement is true or false, and use one sentence within 20 words to justify your reason.

1. Although small, the TCP ACKs still consume some bandwidth. It would be better if the TCP receiver only sends NACKs upon receiving out of order (or corrupted) packets. (T/F) **Answer: False. If NACKs fail, reliability is violated.**

2. The TCP sender has packets 20 to 30 in its congestion window (CW), all waiting for ACKs, when a timeout occurs. The sender will cut down CW to 1 and will have to gradually retransmit each of these packets (from 20 to 30). **Answer: False. A cumulative ACK might arrive, making the TCP receiver skip one or more retransmissions.**

3. TCP can cope with any amount of losses, and hence, TCP should work without modifications on lossy wireless networks. **Answer: False. TCP is designed under the assumption that losses are due to congestion. If losses happen due to bit errors in the network, TCP will unnecessarily cut back on CW. On the other hand, it make sense if you claim: this statement is true because TCP will still work without modifications but the performance will be poor.**

4. The Selective Repeat receiver need not send an ACK if the received packet is less than its lower end of the (current) receive window. **Answer: False. The receiver needs to send an ACK since prior ACKs may not have been received by the transmitter.**