NATIONAL UNIVERSITY OF SINGAPORE

EXAMINATION FOR

(Semester I: 2021/2022)

EE4204/TEE4204 - COMPUTER NETWORKS

Nov/Dec 2021 - Time Allowed: 2 Hours

INSTRUCTIONS TO CANDIDATES:

1. This paper contains **4** questions and comprises **6** pages.
2. Each question carries **25** marks.
3. Programmable calculators are **NOT** allowed.
4. The Final Exam is open book. You **MAY** use any of the materials handed out in class and refer to any textbook. You **MAY** refer to your notes on the computer or tablet.
5. You **MAY NOT** consult Internet sources during the Exam. You are **NOT** allowed to communicate with anyone else about the Exam via forum, email, bulletin board, or any other electronic communication method.
6. You may **NOT** consult with any other person about the Exam or during the Exam. You may **NOT** cut-and-paste from the Internet or any other sources. All answers must be yours and in your own words.
7. Please abide by the Code of Student Conduct (http://nus.edu.sg/osa/resources/code-of-student-conduct).
8. Write your answers on fresh sheets of A4-size paper.
9. Typewritten or handwritten answers on tablets or any electronic devices are **NOT** acceptable.
10. Please start each question (Q1, Q2, Q3, and Q4) on a new page and clearly indicate the part, e.g., Q1(a), in the left margin.
11. Write your Student Number on every page. You should not write your name.
12. Scan/Photograph each page and combine into one PDF file in the given order: cover page, signed declaration form, and your answers.
13. For **EE4204** students, name your file: STUDENT_NUMBER-EE4204.pdf (e.g., A1234567R-EE4204.pdf).
14. For **TEE4204** students, name your file: STUDENT_NUMBER-TEE4204.pdf (e.g., A1234567R-TEE4204.pdf).
15. Upload the combined PDF file (cover_page + declaration form + answers) to the LumiNUS Files Folder labeled “Exam Group X Submission”, where X is your Final Exam Group Number.

Q.1(a) Consider a link-level flow control protocol wherein frames are sent and acknowledged in batches of eight 1000-Byte frames over a 100-km long link with infinite bandwidth. The sender sends one batch of frames, waits for an acknowledgment (ACK); sends the next batch of frames, waits for an ACK; and so on. The receiver sends an ACK as soon as it receives a batch of frames. Assume a propagation speed of 1 km per 5 μs and error-free transmission. What is the throughput achieved when a message of size $\boldsymbol{x}$ bytes is transferred? (5 marks)

Q.1(b) A frame is transmitted over a link using the divisor polynomial $C(x)=x^5+x^3+x+1$. During the propagation, 15 bits are damaged. Do you think the receiver can detect the error? Explain your answer. (5 marks)

Q.1(c) Consider a 100-Mbps broadcast link that uses the CSMA/CD protocol. If the minimum required frame size is 100 bytes, what should be the maximum one-way propagation time between any two nodes? (5 marks)

Q.1(d) Consider a broadcast network that is shared by 10 hosts. As a simplistic example, suppose that time is divided into discrete slots, with each of the 10 hosts attempting to use the channel with probability 0.1 during each slot. What is the probability that there is a successful frame transmission in a slot? (5 marks)

Q.1(e) Consider a network wherein two hosts are connected by multiple routers on a path with four 100-Mbps links. Suppose a message is split into ten 1000-byte packets which are sent from one host to another host through the above path. The network offers transport-layer end-to-end reliable data delivery and if there are any errors, only the damaged packets are retransmitted. What is the percentage of bandwidth wasted on each link due to retransmission, if the packet error probability on a link is given by 0.05? (5 marks)

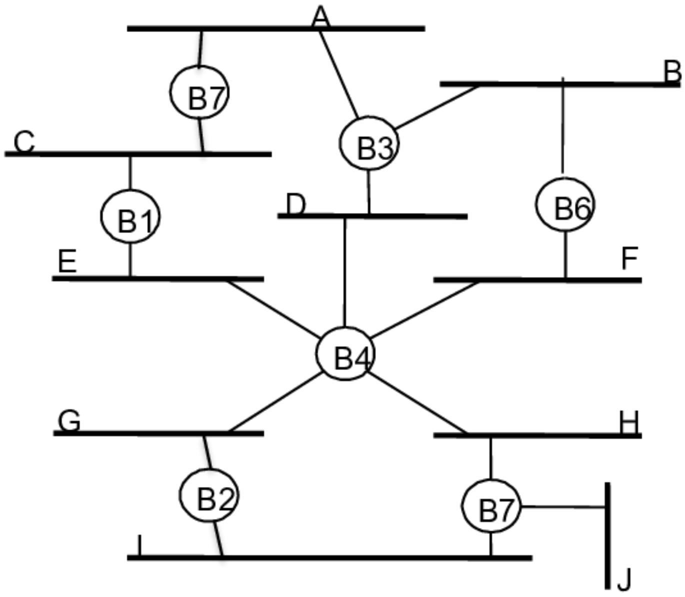
Q.2(a) Consider a sliding-window-based Go-back-N ARQ that uses a 3-bit sequence number and a window of size 7. At a given instant of time, at the sender, the window size is 2 and the window contains two frames with sequence numbers {4,5}. The following four events happen in the given order. Show the content of the window at the sender just after each of the four events and the window expand/shrink updates made, if any. Briefly explain the reason.

i. receiver sends RR1, but it is lost
ii. sender sends frame 4
iii. receiver sends RR3
iv. sender receives RR3

(5 marks)

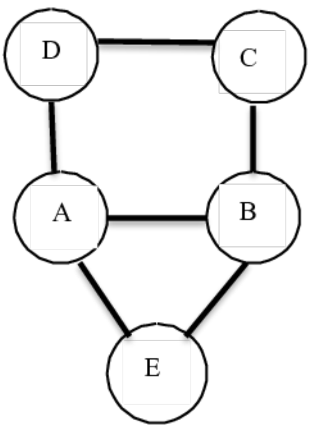
Q.2(b) Node A transmits 500-byte frames to node B using a sliding window protocol over a 10 Mbps link with a window size of 15. The link is 500-km long. The propagation delay on the link is 5μs/km. Assume that the communication is error-free. Determine the throughput in terms of number of frames per second. (5 marks)

Q.2(c) Consider the extended LAN with seven bridges labeled B1 through B7 and nine LANs labeled A through I as shown in the figure below. Assume that bridge B1 becomes faulty. Draw the spanning tree generated by the distributed spanning tree algorithm by removing the ports and bridges that are not part of the tree. (5 marks)



Q.2(d) Consider a wireless network with 5 nodes labeled A, B, C, D, and E, as shown in the figure below. An edge between two nodes indicates that the nodes can directly reach each other and the absence of an edge between two nodes indicates that they cannot directly reach each other. Nodes A, C, B, and C want to transmit data for 20 units of time to B, B, E, and D, respectively, starting at time T=0, 15, 50, 65. The network uses the collision avoidance algorithm MACA with RTS and CTS frames. Assume that the transmission time of RTS/CTS and propagation time are negligible compared to the time (20 units) for data frame transmissions. State the events that take place at each of the above four time instants in the table format as shown below. (10 marks)

T	RTS sent? Sender and receivers?	CTS sent? Sender and receivers?	Any successful data transmission? Sender and receiver?	Reason for no collision (or) simultaneous transmission
0				
15				
50				
65				



Note: Please start this question on a new page.

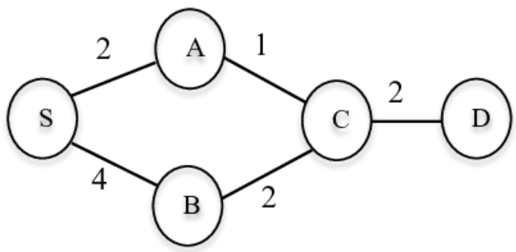
Q.3(a) Suppose a host on a local network has the IP address 192.168.128.144. You are told that the subnet that host resides in can support up to a maximum of 30 hosts.
(i) Determine the network id of the subnet, including the subnet mask.
(ii) What are the starting & ending IP addresses of the subnet?
(iii) What is the subnet mask of the subnet (in dotted decimal notation)?
(iv) What is the broadcast address of the subnet (in dotted decimal notation)?
(iv) State one disadvantage of splitting the network protocol stack into separate layers.

(5 marks)

Q.3(b) Consider the following CIDR IPv4 address block 192.168.128.0/24. Can you divide this address block into 3 subnets, A, B, and C, such that subnet A has 125 hosts, subnet B has 60 hosts, and subnet C has 60 hosts? Please indicate Yes/No and explain why.

(5 marks)

Q.3(c) Consider the network shown on the right. Suppose we are using *distance vector routing*. Assume that the algorithm has been running for some time and it has stabilized. At some time after stabilization, a failure occurs and some edges are removed. Explain if removing the following edges will result in the *count-to-infinity problem*. Please reproduce the following table in your written answers.



(5 marks)

Edges to Remove	count-to-infinity (Yes/No)
Removing Edge C-D	
Removing Edge S-A	
Removing Edge S-A and Edge S-B	
Removing Edge S-B and Edge B-C	
Removing Edge A-C and Edge B-C	

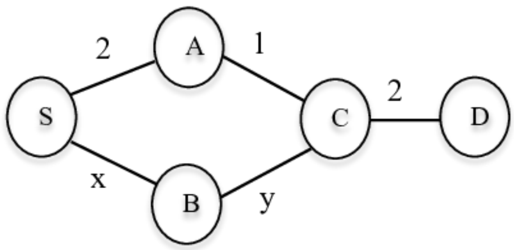
Q.3(d) Consider the network shown on the right Assume x = 3 and y = 2.

(i) Using *Dijkstra's algorithm*, find the shortest path spanning tree (Tree 1) from S to all other nodes. In the table below, put a '✓' when an edge is in Tree 1.

(ii) State the order in which edges are added in the running of Dijkstra's algorithm, e.g., put a 1, 2 in the row for the edge.

(iii) Determine the routing/forwarding table at S.

(iv) Assume x=10. Find <u>all</u> values of y for which Dijkstra's algorithm finds the correct shortest path spanning tree.



(10 marks)

Please reproduce the following tables in your written answers.

Edge	(i) Tree 1	(ii) Order of edges
S-A		
S-B		
A-C		
B-C		
C-D		

(iii) Routing Table at S:		
Destination	Next Hop	Cost to Destination
A		
B		
C		
D		

(iv)

Note: Please start this question on a new page. You may use the simple first order approximation of TCP throughput we studied in class.

Q.4(a) Consider two subnets on campus (each with multiple hosts) which are connected via a router R. The router has a link capacity of 60 Mbps and is the bottleneck link for any traffic between these subnets. Suppose there are 4 TCP flows (TCP-1, TCP-2, TCP-3, TCP-4) and 1 UDP flow (UDP-1) traversing through the bottleneck router. The TCP flows have a maximum data rate of 25 Mbps and the UDP flow has a constant data rate of 20 Mbps. Assuming that all flows have the same RTT, what is the average throughput of the TCP and UDP flows? Express your answer in Mbps. (5 marks)

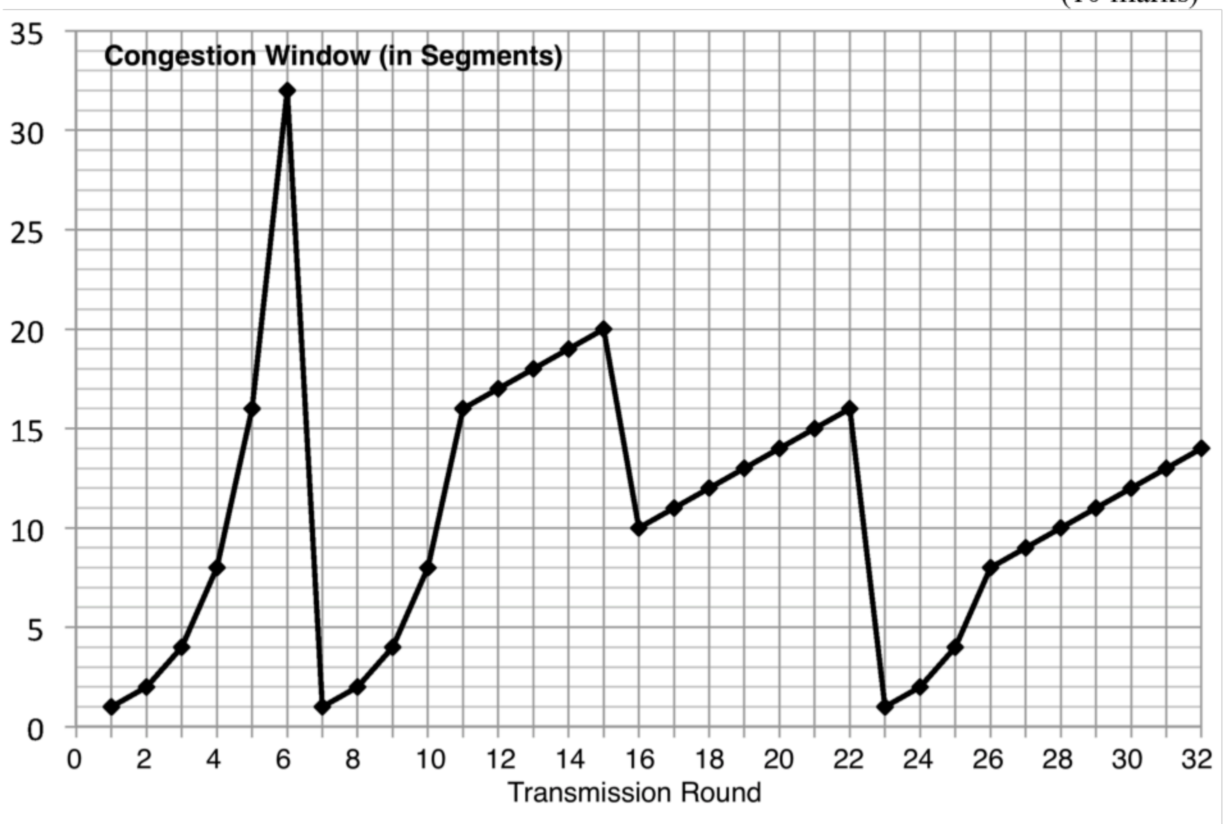
Q.4(b) For the scenario in Q.4(a), suppose that the router implements ***max-min fair*** allocation. Assuming that all flows have the same RTT, what is the average throughput of the TCP and UDP flows? Express your answer in Mbps. (5 marks)

Q.4(c) For the scenario in Q.4(a), suppose that TCP-1, TCP-2, and UDP-1 have RTT of 100ms and TCP-3 and TCP-4 have RTT of 200ms. What is the average throughput of the TCP and UDP flows? Express your answer in Mbps. (5 marks)

Q.4(d) The figure below shows the evolution of the TCP congestion control window as a function of round-trip time for a TCP Reno flow.

(i) Identify all instances when there was a packet loss in the network.
(ii) Identify all instances when there was a packet timeout at the sender.
(iii) Identify all instances when there was a triple duplicate acknowledgement received by the sender.
(iv) What mode is TCP in during Rounds 1 – 6, Rounds 7 – 11, and Rounds 23 – 26?
(v) What mode is TCP in during Round 11 – 22 and Rounds 26 – 32?

(10 marks)



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