Name: **V#:**

Mid-term Exam - Solution

CMSC 440, Spring 2023
Data Communications and Networking
Virginia Commonwealth University

Directions:

Question	Points	Score
I (3Px15Q)	45	
II.1	10	
II.2	6	
II.3	6	
II.4	9	
II.5	10	
II.6	6	
II.7	15	
II.8	10	
II.9	8	
Total	**125**	

1. This ***Instructions*** page is not part of the exam. ***Take your time reading these instructions carefully***. Do not flip it and start the exam until you are instructed to do so.
2. This is a closed book, closed notes, **closed mobile phone**, **closed Internet**, closed neighbor, **pencil and paper exam only**.
3. **You are allowed to use a single paper (A4 or Letter size) as a cheat-shee**t during this exam. **It must be a handwritten**.
4. This exam represents ***25% of the total CMSC440 grade.***
5. This exam is designed to be completed in **75 minutes**. Turn immediately the exam when we call for it.
6. The exam has two types of questions: *15 questions* of *Fill in the Blank* with a total of *45 points* and *9 questions* of *Short Answer* with a total of *80 points.* ***The total is 125 with a bonus of 25 points (the maximum grade you may receive is 100)***.
7. Read each question carefully, paying attention to detail, including the units given in the problem statement and the units asked for in the question.
8. Show your work and explain your reasoning where appropriate; this will help to earn partial credit.
9. **Write answers in the spaces provided on a neat way**. Indicate your final answer clearly. Cleanly erase or cross out any work you do not want graded. If you need additional space, use the back of the exam.
10. **Electronic devices except calculators must be completely turned off and stowed in your backpack**.
11. If you have any concerns about any questions, state your assumptions to help us understand your answers.
12. Write your name and V#

Good Luck!

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Part I: Terms [45 points] – Fill in the blank with the appropriate term. [3 points each]

Frequency Division Multiplexing (FDM), Time Division Multiplexing (TDM), Demultiplexing, Multiplexing, Checksum, Timeout, Domain Name Systems (DNS), Pipelining, Parallelism, Access Link, Network, Router, Transport, Application-layer Protocol, IP Address, Persistent HTTP, Non-Persistent HTTP, Port, Socket, Packet Switching, Circuit Switching, Transmission delay, Propagation delay, Queuing delay, Processing delay, Transmission delay, Go-Back-N, Selective Repeat, 3-way Handshake, 2-Way Handshake, Store-and-Forward, Stop-and-Wait, Request, Response, Proxy Server, Round-Trip Time (RTT), UDP Datagrams, TCP Segments, Authoritative, Top-Level Domain (TLD), Sliding Window, Web Server.

1) In ______**Persistent HTTP**_______, multiple HTTP GET messages can be sent over a single TCP connection, resulting in performance gains from not having to set up a new TCP foreach of the HTTP requests beyond the first.

2) The ___**Propagation delay**_____ over a link is the time it takes a bit to travel from one end of the link to the other.

3) _____**Time Division Multiplexing (TDM)**________ is an example of a channel partitioning protocol in which time is divided into timeframes and further divides each frame into N slots each is then assigned to one of the N nodes.

4) At the source host, the job of gathering data chunks from different sockets, adding header information, and passing the resulting segments to the network layer is called __**Multiplexing**____.

5) _____**Store-and-Forward**___ scheme means that the switch/router must receive the entire packet before it can begin to transmit the first bit of the packet onto the outbound link.

6) One of the major delays is ___**Queuing delay**___, which is variable and depend on the level of congestion in the network.

7) ______**Circuit Switching**______ is a type of networks in which the resources needed along a route between end systems are reserved for the duration of the communication session between the end systems.

Frequency Division Multiplexing (FDM), Time Division Multiplexing (TDM), Demultiplexing, Multiplexing, Checksum, Timeout, Domain Name Systems (DNS), Pipelining, Parallelism, Access Link, Network, Router, Transport, Application-layer Protocol, IP Address, Persistent HTTP, Non-Persistent HTTP, Port, Socket, Packet Switching, Circuit Switching, Transmission delay, Propagation delay, Queuing delay, Processing delay, Transmission delay, Go-Back-N, Selective Repeat, 3-way Handshake, 2-Way Handshake, Store-and-Forward, Stop-and-Wait, Request, Response, Proxy Server, Round-Trip Time (RTT), UDP Datagrams, TCP Segments, Authoritative, Top-Level Domain (TLD), Sliding Window, Web Server.

8) A ________**Socket**__________ is defined as "the endpoint" in a connection for sending and receiving data between two programs running on the network. It is created and used with a set of programming requests or "function calls".

9) The ___**Round-Trip Time (RTT)**___ is the time it takes for a small packet to travel from client to server and then back to the client.

10) In DNS, __**Top-Level Domain (TLD)**__ servers are responsible for domains such as com, org, net, edu, and gov, and all of the country domains such as uk, fr, ca, and jp.

11) The ___**Checksum**__ field is used to determine whether bits within the UDP or TCP segment have been altered.

12) In the __**Go-Back-N**___ protocol, an acknowledgment for a packet with sequence number N will be taken to be a cumulative acknowledgment.

13) ___Multiplexing___ is the process of collecting the data from multiple application processes of the sender, enveloping that data with headers and passing the resulting segments to the network layer.

14) HTTP _____**Pipelining**____ is a technique in which multiple HTTP requests are sent on a single TCP (transmission control protocol) connection without waiting for the corresponding responses.

15) A Web cache, also called a ___**Proxy Server**___, is a network entity that satisfies HTTP requests on the behalf of an origin Web server.

Part II: Short Answer [80 points]

1. [10 points] Briefly in a sentence or two, explain the following networking terms:

a. [2 point] Bandwidth:
Bandwidth refers to the **maximum** amount of data that can be transmitted over a **network link** in a given period of time.

b. [2 point] Throughput:
Throughput refers to the **actual** amount of data that is successfully transmitted over a **network connection** in a given period of time.

c. [2 point] Propagation:
Propagation refers to the physical process of transmitting a signal over a communication medium such as copper wire, fiber optic cable, or radio waves.

d. [2 point] End-2-End Delay:
E2E Delay refers to the time it takes for data to travel from the source to the destination over a network.

e. [2 point] Bottleneck Link:
A bottleneck link refers to a network link or segment that has a lower data transfer capacity than other links in the network, which can lead to congestion and slower data transfer speeds overall.

2. [6 points] In the Go-Back-N protocol:

a. [2 point] Does the protocol must have a timer for each unacknowledged packet?

No, A single timer could be used to retransmit all transmitted and unacknowledged packets once it times out.

b. [2 point] When an acknowledgment for the oldest unacknowledged packet arrives at the sender, what happens?

The oldest unacknowledged packet is the first packet in the sender sliding window. When the sender receives its corresponding acknowledgement: 1) slide its sliding window by one, 2) reset the timer if the buffer becomes empty, and 3) check for a new packet from the application layer and 4 transmit it.

c. [2 point] When a packet arrives out of order at the receiver side, what happens?
The receiver: 1) discard it (drop it), and 2) retransmit the last acknowledgment again to the sender.

3. [6 points] Identify three important differences between a circuit switching network and a packet switching network.

a. A circuit switching requires call setup.
b. A circuit switching requires end-2-end resource reservations.
c. Links' capacities in circuit switching are shared/split between multiple users concurrently, while it is dedicated in packet switching.
d. In circuit switching, data is handled as a continuous stream of bits while in packet data are handled as chunks (i.e. packets)

4. [9 points] Consider a network with two routers R1 and R2, and two end systems A and B as follows: (A ---- R1---- R2 ---- B). The link between A and R1 has bandwidth 100 Mbps and a propagation delay of 10 microseconds. The link between R1 and R2 has bandwidth 50 Mbps and a propagation delay of 20 microseconds. The link between R2 and B has bandwidth 10 Mbps and a propagation delay of 30 microseconds. The processing delay at each router is negligible.

a. **[3 points]** What is the end-to-end delay for a ***single packet*** of size 1000 bytes sent from A to B through the two routers?

Transmission delay of link (A-R1) = packet size / bandwidth = 8000 bits / 100 Mbps = 80 micro-sec.
Propagation delay of link (A-R1) = 10 micro-sec.
Transmission delay of link (R1-R2) = packet size / bandwidth = 8000 bits / 50 Mbps = 160 micro-ses.
Propagation delay of link (R1-R2) = 20 micro-sec
Transmission delay of link (R2-B) = packet size / bandwidth = 8000 bits / 10 Mbps = 800 micro-sec.
Propagation delay of link (R2-B) = 30 micro-sec.

Therefore, the total end-to-end delay: 80 + 10 + 160 + 20 + 800 + 30 = 1100 micro-sec
Enough to answer: 8000/100,000,000 + 10 + 8000/50,000,000 + 20 + 8000/10,000,000 +30 micro-sec

b. **[3 points]** What is the end-to-end delay for ***5 packets*** each of size 1000 bytes sent from A to B through the two routers?

The bottleneck link is the last link that has a (transmission + propagation) delay = 830 micro-sec.
Hence, after arriving the first packet at B,
a new packet of the remaining ones will arrive at B every 830 micro-sec.

So, the total end-to-end delay for the 5 packets = 1100 + 4 * 830 = 4420 micro-sec
Enough to answer: answer of part (a) + 4 * (8000/10,000,000 + 30) micro-sec

[3 points] Suppose the three links (A-R1, R1-R2, & R2-B) has the same bandwidth of 100Mbs. Furthermore, suppose the ***routers DO NOT store-and-forward packets*** but instead immediately transmits each bit it receives before waiting for the packet to arrive. What is the end-to-end delay for a single packet of size 1000 bytes sent from A to B through the two routers?

Given no Store-and-Forward is used, a single transmitted bit from A will only observe three propagation delays till reaching B with a total propagation delay = 10+20+30 = 60 micro-sec
The packet will have a single transmission delay at A = = 8000 bits / 100 Mbps = 80 micro-sec

Hence, the total end-to-end delay for a single packet = 80 + 60 = 140 micro-sec
Enough to answer: 8000/100,000,000 + 10 + 20 + 30 micro-sec

5. [10 points] Indicate whether TCP or UDP (or both or neither) provide the following services to applications:

a. [1.5 point] Reliable data transfer between processes.
TCP provides a reliable byte-stream between client and server.

b. [1.5 point] Minimum data transmission rate between processes.
Neither

c. [1.5 point] Congestion-controlled data transfer between processes.
TCP

d. [1.5 point] A guarantee that data will be delivered within a specified amount of time.
Neither

e. [1.5 d point] Guaranteed in-order delivery of data to the receiver.
TCP

6. [6 points] Describe how the Domain Name Server system is hierarchically organized?

The Domain Name System (DNS) is the hierarchical and decentralized naming system used to convert a hostname (such as www.example.com) into a computer-friendly IP address (such as 192.168.1.1). The nodes of DNS are organized in a hierarchal tree. The **top** of the hierarchy is served by the **root name servers**, the servers to query as the first step in translating the hostname. The root servers return reference to the **second level** of DNS nodes; the **top level domain servers (TLD**) that hosts the last portion of a hostname (In example.com, the TLD server is "com") and return reference to the third level of DNS nodes. The **third level** DNS nodes are the **authoritative servers** that are the last stop in the nameserver query and will return the IP address for the requested hostname back.

7. [15 points] Suppose a client requests a webpage from a server. The webpage consists of a base HTML file, and 5 embedded images (with file names img01.jpg, img02.jpg, …, img05.jpg). The size of the base file is 400 KB, and the size of each image file is 200 KB. The base file and the embedded images are stored on the same server The client and the server are connected by a 1 Gbps link with a round-trip time (RTT) of 100 ms. Assume the link has no other traffic. You can assume that the time it takes to transmit a GET message into the link is zero, but you should account for the time it takes to transmit the base file and the embedded images into the "link." This means that the server-to-client "link" has both a 50msec one-way propagation delay, as well as a transmission delay associated with it. Be sure to account for the time needed to set up a TCP connection (1 RTT).

a. [5 points] Suppose the client and the server use non-persistent HTTP with a single TCP connection (no parallel connections are allowed). What is the minimum amount of time it will take to download the entire webpage?

The delays associated with this scenario are:

- 100 msec (RTT) to set up the TCP connection that will be used to request the base file.
- 50 msec (one way delay) to send the GET message for the base file, and have the message propagate to the server, plus 400,000*8/1,000,000 msec to transmit the base file, plus 50 msec for the base file to propagate back to the client (for a total of 103.2 msec).
- 100 msec (RTT) to set up TCP connection that will be used to request the img.01.jpg file.
- 50 msec (one way delay) to send the GET message for img01.jpg and have it propagate to the server, plus 200,000*8/1,000,000 msec to transmit the img01.jpg file, plus 50 msec for the img01.jpg file to propagate back to the client (for a total of 101.6 msec).
- The last two steps above are repeated for the remaining 4 image files img02.jpg through img05.jpg.

→ The total download time is therefore 100 + 103.2 + 5 * (100 + 101.6) = 1,211.2 msec

b. [5 points] Again, assume non-persistent HTTP, but now assume that the browser can open as many parallel TCP connections to the server as it wants. What is the minimum amount of time it will take to download the entire webpage?

- Similar to the above, you have to establish TCP connection (203.2 msec) and request and download the base file (201.6 msec).
- The client now sets up 5 parallel TCP connections. Since these parallel connections happen in parallel over the same link, they will share the link capacity. In other words, each connection will observe only 1/5 Gbps.
- For each of these 5 connections:
  - 100 msec (RTT) is needed to set up a TCP connection (remember the 5 connections are set up in parallel).
  - 50 msec (one way delay) to send and propagate GET message to the server (the 5 Gets are sent in parallel).

  Then, 200,000*8/200,000 msec to transmit the img01.jpg file, plus 50 msec for the img01.jpg file to propagate back to the client (for a total of 108 msec). Recall that the other images are transmitted in parallel too with image01.jpg.

→ Hence, the total download time is 203.2 + 100 + 108 = 411.2 seconds.

c. [5 points] Now, suppose the client and the server use persistent HTTP with a single TCP connection (no parallel connections or pipelining are allowed).. What is the minimum amount of time it will take to download the entire webpage?

- Similar to the above, you have to establish TCP connection (203.2 msec) and request and download the base file (201.6 msec).
- To download each image, it takes 50 msec (one way delay) to send the GET message for img01.jpg and have it propagate to the server, plus 200,000*8/1,000,000 msec to transmit the img01.jpg file, plus 50 msec for the img01.jpg file to propagate back to the client (for a total of 101.6 msec).
- The last step above is repeated for the remaining 4 image files img02.jpg through img05.jpg.

→ The total download time is 203.2 + 5 * 101.6 = 711.2 seconds.

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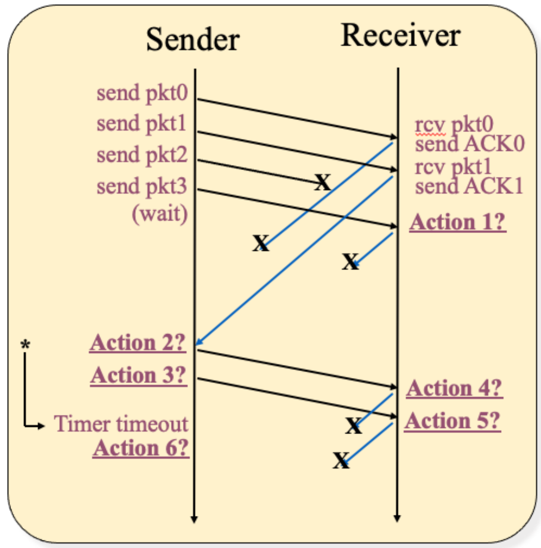
8. [10 points] Consider the Go-Back-N Sliding Window Protocol:

a. [6 points] Consider the figure on the right. Suppose the sender sliding windows is of size N = 4 and suppose the sequence number space goes from 0 to 15. Also assume that the receiver ignores out-of-order packets. In the following table, describe each of the missing actions (#1 - #6) in terms of combinations of one or more of the following actions: "rcv pkt<**X**>", "send pkt<**X**>", "discard pkt<**X**>", "rcv ACK<**X**>", "send ACK<**X**>".



Action #	Action(s)
#1	rcv pkt3, discard pkt3, send ACK1
#2	rcv ACK1, send pkt4
#3	send pkt5
#4	rcv pkt4, discard pkt4, send ACK 1
#5	rcv pkt5, discard pkt5, send ACK 1
#6	send pkt2, additionally, it will: send pk3, send pkt4, send pkt5

b. [4 points] Suppose that it takes 1 ms to transmit a packet, with a 10 ms one-way propagation delay between the sender and receiver. The sliding windows size is again N = 4. What is the channel/link utilization?

The utilization is 4*1/(1+20) or 0.19 or 19%.

9. [8 points] Suppose an application uses the stop-and-wait protocol (rdt 3.0) as its transport layer protocol. Recall that the stop-and-wait protocol uses only two sequence numbers (0 & 1). When the receiver receives a correct packet (non-corrupted with the expected sequence number), it sends back a **positive acknowledgement** in form of ACK0 or ACK1 if it was expecting packet with sequence 0 or 1, respectively. Otherwise, the receiver sends back a **negative acknowledgement** in form of ACK1 or ACK0 if it was expecting packet with sequence 0 or 1, respectively.

a. **[4 points]** Assume the application modified the receiver actions by **sending only positive acknowledgements** in case of receiving correct packets, and do nothing (**not sending negative acknowledgements**) otherwise. Would this still be a reliable transport protocol? Why?

   Yes, it is still a reliable protocol. While the negative acknowledgment is not used for delivered corrupted packets, the timer mechanism will guarantee to retransmit any packet delivered corrupted.

b. **[4 points]** Are there any drawbacks with this modification? Explain.

   The protocol will be slowed down if packet corruption will happen so often since the protocol will have to wait for the timer to times out to retransmit and recover from the corrupted one.

Scratch page