Instructions

1. This is a **closed book** examination; no notes are to be used.
2. Calculators with cleared memory are allowed.
3. Place your WATCARD on the table and sign the attendance sheet when provided.
4. Answer all questions. **Clearly show all steps used in the solution process. No marks will be given for numerical results unless accompanied by a correct solution method.**
5. No question will be answered during the exam. Should there be a need, **make reasonable assumptions, write them down in your exam paper** and proceed.
6. Giga means 10^9, "Mega" means 10^6, and "Kilo" means 10^3.
7. All acronyms have their standard expansions as explained in class.

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Question 1 [20 marks]:

1- Protocols define the format, order of messages sent and received among network entities, and the actions taken on message transmission, receipt. (1.5 marks)

2- The two key network-core functions are forwarding and routing. (1 mark)

3- In packet-switching, the store-and-forward concept means that the *entire* packet must arrive at a node before it can be transmitted on next link. (1 mark)

4- The four types of delay that a packet can experience are: (just list them) (2 marks)

   a. Processing delay
   b. Propagation delay
   c. Transmission delay
   d. Queueing delay

5- The bottleneck link is defined as the link on end-end path that constrains end-end throughput. (1 mark)

6- The five layers of the Internet protocol stack **in-order from top to down** are: (just list them) (1 mark)

   a. Application
   b. Transport
   c. Network
   d. Link
   e. Physical

7- One advantage of encapsulation is modularization (protection of upper layer's data) and one disadvantage is overhead. (1 mark)

8- The four services offered by DNS are: (just list them) (2 marks)

   a. hostname-to-IP-address translation
   b. host aliasing
   c. mail server aliasing
   d. load distribution

9- The format of a DNS resource record (RR) is (name, value, type, ttl).
In DNS resource records of type A, the name field will indicate the host name
and the value field will indicate the IP address
In DNS resource records of type NS, the name field will indicate the domain
and the value field will indicate the hostname of authoritative name server for this domain.
(2 marks)

10- In order to perform demultiplexing, UDP uses two pieces of information which are destination IP address and destination port number
whereas TCP uses four pieces of information which are destination IP address, destination port number , sender IP address, sender port number (2 marks)

11- The UDP protocol does not provide any kind of communication reliability. However, UDP has its own advantages. Three advantages of UDP are (any three of the following) (1.5 marks)

a. no connection establishment
b. simple: no connection state at sender, receiver
c. small header size
d. no congestion control: UDP can blast away as fast as desired

12- The four types of error that can happen in a data transfer are: (just list them) (2 marks)

a. Packet corruption
b. Packet duplication
c. Packet loss
d. Packet reordering

13- TCP fast retransmit action refers to retransmitting a packet right after receiving triple duplicate acknowledgements. (1 mark)

14- In a TCP connection between a sender and a receiver, TCP flow control prevents overwhelming the receiver whereas TCP congestion control prevents overwhelming the network. (1 mark)

Question 2 [10 marks]: Packet-Switching

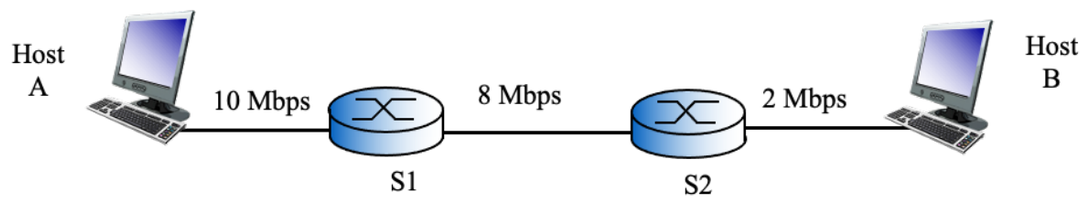


Figure 1. Question 1.

In the **packet-switched** network shown in Figure 1, each link has its speed as shown in the figure. S1 – S2 are packet switches. Ignore all other sources of delay at all the switches.
Host A will **send** a file of size **100 KBytes** to Host B.
Host A has a fixed packet size of **1 KBytes**. Consider that the transmission of packet 1 will start at **time 0**.
Answer the following questions:

1. When will Host B completely receive the first packet? (3 marks)

$$T_{B-1st-packet} = d_{trans-10M} + d_{trans-8M} + d_{trans-2M}$$

$$T_{B-1st-packet} = \frac{1000 \times 8}{10 \times 10^6} + \frac{1000 \times 8}{8 \times 10^6} + \frac{1000 \times 8}{2 \times 10^6}$$

$$T_{B-1st-packet} = 0.8 + 1 + 4$$

$$T_{B-1st-packet} = 5.8\ msec$$

2. When will Host B completely receive the file? (3 marks)

$$T_{B-complete} = T_{B-1st-packet} + (number\ of\ packets - 1) \times d_{trans-2M}$$

$$T_{B-complete} = 5.8 + (100 - 1) \times 4$$

$$T_{B-complete} = 401.8\ msec$$

3. What is average throughput for Host B? (2 marks)

$$Throughput_B = \frac{100\ K\ Bytes}{T_{B-complete}} = \frac{100\ K\ Bytes}{401.8 \times 10^{-3}} = 0.248\ Mbytes/\sec = 1.99\ Mbps$$

4. Using the bottleneck link concept, calculate the approximate time required for Host B to receive all the packets? (2 marks)

   The bottleneck link is 2 Mbps.

$$T_{B-complete-Approximate} = number\ of\ packets \times d_{trans-2M}$$

$$T_{B-complete-Approximate} = 100 \times 4mesc$$

$$T_{B-complete-Approximate} = 400\ msec$$

Question 3 [8 marks]: DNS

A new start-up company would like to launch its domain yourcompany.com with its authoritative DNS dns.yourcompany.com at IP address 220.134.57.1 on the Internet. In order to be reachable on the Internet, the company domain has to be registered with a DNS registrar.

(1) Give the DNS Resource Records (RR's) to be inserted by the DNS registrar such that this domain can be reached on the Internet? Identify at which level in the DNS hierarchy these records will be inserted? (5 marks)

The registrar inserts two RRs into .com TLD server:
(yourcompany.com, dns.yourcompany.com, NS)
(dns.yourcompany.com, 220.134.57.1, A)

(2) If the start-up company needs to launch HTTP server at www.yourcompany.com with IP address 220.134.57.4, give the RR (if any) that needs to be added and identify at which DNS it should be added such that this HTTP server is reachable on the Internet? (3 marks)

create authoritative server type A record for www.yourcompany.com into the company's authoritative DNS server.
(www.yourcompany.com, 220.134.57.4, A)

Question 4 [13 marks]: HTTP

Consider a short, **100-meter link with a propagation speed 2 x 10^8 m/sec,** over which a sender can transmit at a **rate of 200 bits/sec** in both directions. Suppose that packets containing **data are 100,000 bits** long, and packets containing only **control** (e.g., ACK or handshaking) are **200 bits** long. Now consider the HTTP protocol and suppose that **each** downloaded **object** is **100 Kbits** long, and that the **initial base file** contains **20 referenced objects** from the same sender. Consider that every object will be sent using a **single transport-layer segment**.

Calculate the overall delay to finish downloading the initial base file and all the referenced objects in the following cases: (You must take into account the time required for establish the connection between the client the server.)

1- Non-persistent HTTP where parallel TCP connections are not allowed. (5 marks)

$$d_{prop} = \frac{d}{v} = \frac{100}{2 \times 10^8} = 0.5 \ \mu sec$$

$$d_{base-file} = TCP\ Req + TCP\ ACK + HTTP\ Req + Transmission\ of\ base\ file$$

$$d_{base-file} = \left(\frac{200}{200} + 0.5\mu s\right) + \left(\frac{200}{200} + 0.5\mu s\right) + \left(\frac{200}{200} + 0.5\mu s\right) + \left(\frac{100 \times 10^3}{200} + 0.5\mu s\right)$$

$$d_{base-file} = 3 \times 1.000005 + 500 + 0.000005 = 503\ Sec\ (approx)$$

Each of the remaining objects will be downloaded using the exact same steps as the base file

$$d_{remaining-objects} = 20 \times 503 = 10060\ Sec\ (approx)$$

$$d_{overall-delay} = d_{base-file} + d_{remaining-objects}$$

$$d_{overall-delay} = 503 + 10060 = 10563\ Sec\ (approx)$$

2- Persistent HTTP where the referenced objects will be downloaded one after the other (similar to what is taught in class). (3 marks)

$$d_{overall-delay} = TCP\ Req + TCP\ ACK + HTTP\ Req + Transmission\ of\ base\ file + 20\ (HTTP\ Req + Transmission\ of\ a\ referenced\ object)$$

$$d_{overall-delay} = 2 \times \left(\frac{200}{200} + 0.5\mu s\right) + 21 \times \left[\left(\frac{200}{200} + 0.5\mu s\right) + \left(\frac{100 \times 10^3}{200} + 0.5\mu s\right)\right]$$

Ignoring the $0.5\mu s$ in the equation since all the other values are in seconds

$$d_{overall-delay} = 2 + 21 \times 501 = 10523\ Sec\ (approx)$$

3- Non-persistent HTTP with parallel downloads to get the referenced objects. **Assume that N parallel connections each get 1/N of the link bandwidth**. (5 marks)

$$d_{base-file} = TCP\ Req + TCP\ ACK + HTTP\ Req + Transmission\ of\ base\ file$$

$$d_{base-file} = 3 \times 1.000005 + 500 + 0.000005 = 503\ Sec\ (approx)$$

The remaining objects will be downloaded via 20 parallel TCP connections using the exact same steps as the base file

$$d_{remaining-objects} = \left(\frac{200}{(\frac{200}{20})} + 0.5\mu s\right) + \left(\frac{200}{(\frac{200}{20})} + 0.5\mu s\right) + \left(\frac{200}{(\frac{200}{20})} + 0.5\mu s\right) + \left(\frac{100 \times 10^3}{(\frac{200}{20})} + 0.5\mu s\right)$$

$$d_{remaining-objects} = 3 \times 20.000005 + 10000 + 0.000005 = 10060\ Sec\ (approx)$$

Ignoring the $0.5\mu s$ in the equation since all the other values are in seconds

$$d_{overall-delay} = d_{base-file} + d_{remaining-objects}$$

$$d_{overall-delay} = 503 + 10060 = 10563\ Sec\ (approx)$$

Question 5 [9 marks]: Automatic Repeat Request Protocols

Assume that a source sends a packet with a length $\boldsymbol{L = 1500}$ **bits** over a link with a rate $R = \boldsymbol{100\ Mbps}$, the distance between the source and the destination hosts is $\boldsymbol{d = 1000\ m}$ and the bits travel at a speed of $\boldsymbol{2 \times 10^8\ m/s}$. Ignoring other delays, answer the following:

1. **Assuming a stop-and-wait protocol**, what is the time taken by the source frame to reach the destination? (2 marks)

$$d_{trans} + d_{prop} = \frac{L}{R} + \frac{d}{v} = \frac{1500}{10^8} + \frac{1000}{2 \times 10^8} = \frac{2000}{10^8} = 20\ \mu s$$

2. **Assuming a stop-and-wait protocol**, what is the average time spent till an acknowledgment reach back to the source? (1 mark)

$$d_{trans} + 2\ d_{prop} = \frac{L}{R} + 2\ \frac{d}{v} = \frac{1500}{10^8} + 2\ \frac{1000}{2 \times 10^8} = \frac{2000}{10^8} = 25\ \mu s$$

3. What is the **utilization** of the stop-and-wait protocol? (3 marks)

$$U = \frac{\frac{L}{R}}{\frac{L}{R} + RTT} = \frac{\frac{L}{R}}{\frac{L}{R} + 2\frac{d}{v}} = \frac{15}{25} = 60\%$$

4. **Assuming one of the pipelining ARQ protocols is used**, e.g., Selective-Repeat**,** and we would like to achieve a **utilization** of at least $\boldsymbol{99\%}$ is required, what is the required window size to achieve this utilization? (3 marks)

   $U = \frac{\frac{L}{R}W}{\frac{L}{R}+2\frac{d}{v}}$ and thus $W = \left\lceil \frac{0.99}{0.6} \right\rceil = 2$

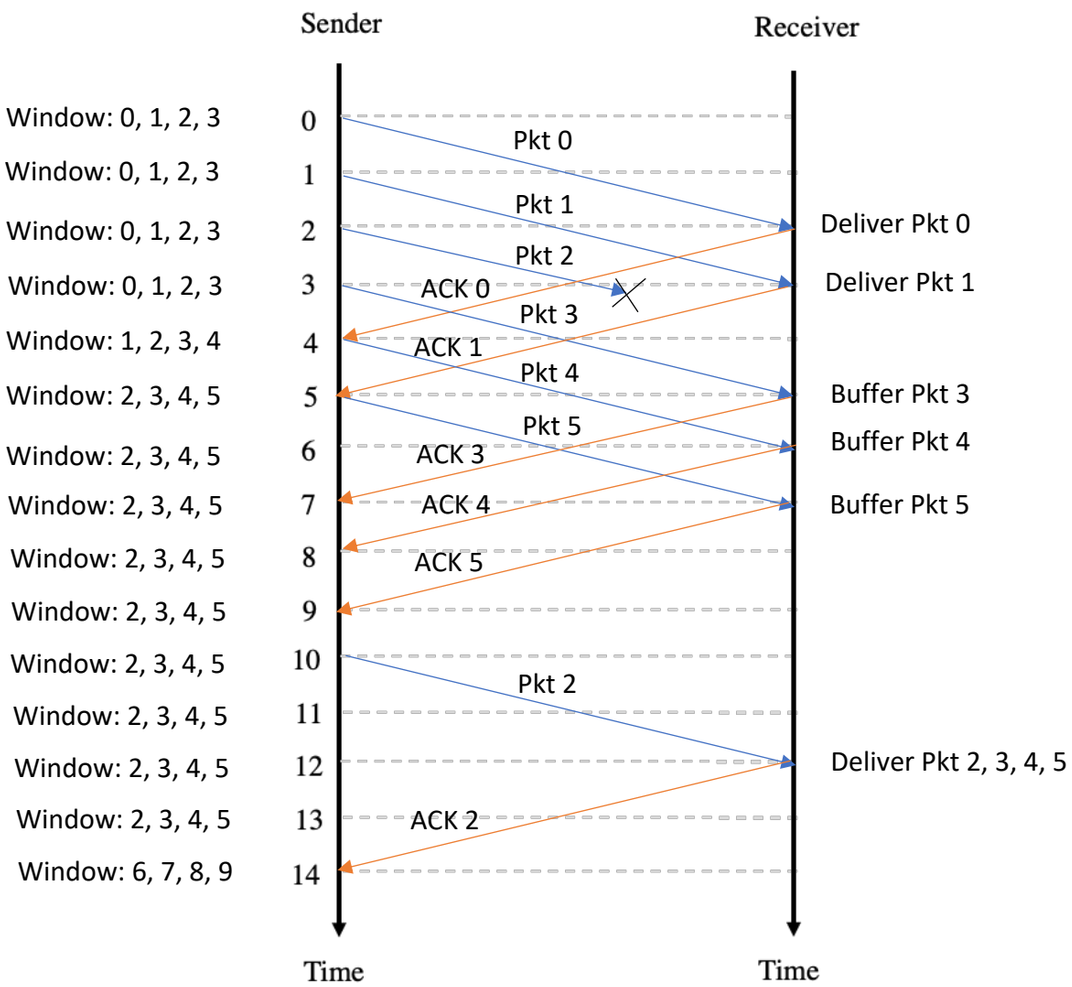
Question 6 [7 Marks]: Automatic Repeat Request Protocols

A sender and a receiver are communicating using **an Automatic Repeat Request (ARQ)** protocol with the following parameters:

- The sequence number space is **modulo 10**, i.e., packet sequence numbers will be 0, 1, 2, 3, …., 9, 0, 1, 2, etc.
- The sender **window size** is 4 packets.
- The **timeout** period is set to 8 msec.
- The one-way **propagation delay** is 2 msec.
- Ignore all the other delays unless otherwise stated.
- The time is divided into **time slots of 1 msec**, where the sender and receiver can send **only one packet** at the **beginning** of each time slot. **When a timeout happens, the packet that triggered the timeout will be retransmitted in the same time slot as that of the timeout.**

The sender will start transmitting at time 0 sec. **Only the first transmission of the packet with sequence number 2, i.e., Pkt2, will be lost and it will never reach the receiver. All the other packets**, acknowledgements and retransmissions will be received **without any errors**.

1. If the ARQ protocol used between the sender and the receiver is **Selective Repeat (SR)**, show the steps involved in the selective repeat protocol from 0 msec till 14 msec on the sender side by completing the diagram in Figure 2. **You need to clearly indicate the following in Figure 2**:
    - label the packets and acknowledgements with their sequence numbers as shown in Figure 2 for Pkt 0.
    - Indicate the sequence numbers included in the sender window at every 1 msec in the duration from 0 – 14 msec.
    - At the receiver side, indicate whether the received packet (if any) will be delivered, buffered or dropped in the duration from 0 – 14 msec. If more than one packet will be delivered to the upper layers, indicate their sequence numbers.


Sender
Receiver
Window: 0, 1, 2, 3
Window: 0, 1, 2, 3
Window: 0, 1, 2, 3
Window: 0, 1, 2, 3
Window: 1, 2, 3, 4
Window: 2, 3, 4, 5
Window: 2, 3, 4, 5
Window: 2, 3, 4, 5
Window: 2, 3, 4, 5
Window: 2, 3, 4, 5
Window: 2, 3, 4, 5
Window: 2, 3, 4, 5
Window: 2, 3, 4, 5
Window: 6, 7, 8, 9
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Pkt 0
Pkt 1
Pkt 2
ACK 0
Pkt 3
ACK 1
Pkt 4
Pkt 5
ACK 3
ACK 4
ACK 5
Pkt 2
ACK 2
Deliver Pkt 0
Deliver Pkt 1
Buffer Pkt 3
Buffer Pkt 4
Buffer Pkt 5
Deliver Pkt 2, 3, 4, 5
Time
Time

Question 7 [5 marks]: TCP

In Figure 3, a TCP sender and receiver communicate over a connection in which segments may be lost between the sender and the receiver. The TCP sender sends an i**nitial window of 3 segments**. Suppose the initial value of the sender to receiver **sequence number is 219** and the first 3 segments each contain **640 bytes**. The delay between the sender and receiver is 7 time units, and so the first segment arrives at the receiver at t=8. As shown in the figure below, the second segment is lost between the sender and receiver.

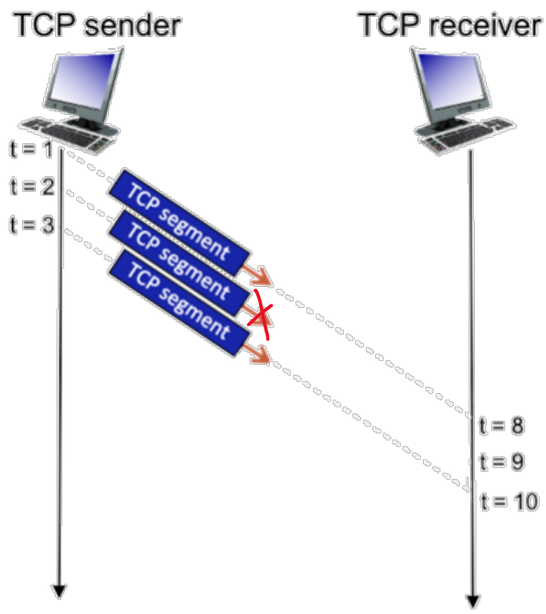


Figure 3. Question 7

1. Give the sequence numbers associated with each of the 3 segments sent by the sender. (3 marks)

The sender's sequence numbers are: 219,859,1499

2. Give the ACK numbers the receiver sends in response to each of the segments. If a segment never arrives use 'x' to denote it. (2 marks)

The receiver's ACKs are: 859, x, 859

Question 8 [13 marks]: TCP

Consider the evolution of TCP's congestion window in Figure 4. **The initial value of cwnd is 1 and the initial value of ssthresh is 8 MSS.**

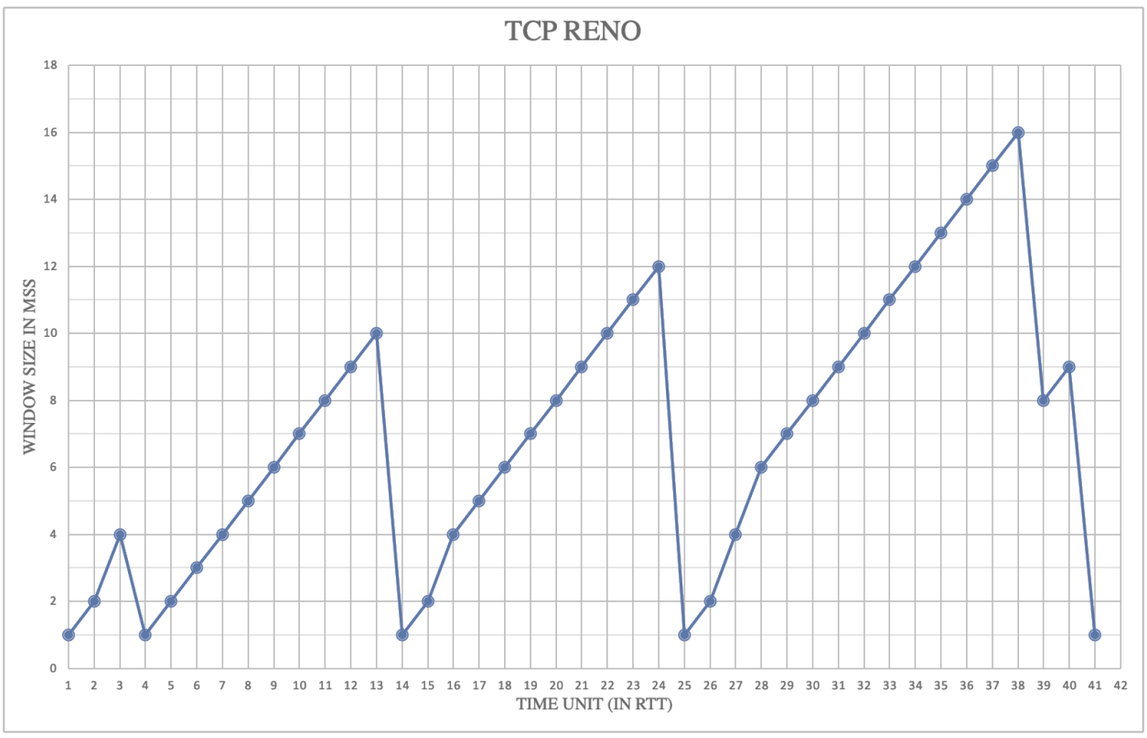


Figure 4. Question 8

Assuming TCP Reno, answer the following questions:

1. Give the time intervals at which TCP is in slow start. (2 marks)

   1 – 3, 4 - 5, 14 – 17, 25 – 28, 41

2. Give the time intervals at which TCP is in congestion avoidance. (2 marks)

   5 – 13, 17 – 24, 28 – 38, 39 - 40

3. Give the times at which TCP is in fast recovery. (2 mark)

38

4. Give the times at which the sender is not receiving any acknowledgements. (2 marks)

3, 13, 24, 40

5. Give the times at which the value of ssthresh changes (if it changes between t=3 and t=4, use t = 4 in your answer) (3 marks)

   4, 14, 25, 39, 41

6. When is the 27^{th} segment sent where the first segment is transmitted at time unit 1? (2 marks)

   9^{th} Segment