National University of Computer and Emerging Sciences
Lahore Campus

Computer Networks (CS3001)

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Course Instructor(s)

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Sessional-I Exam

Total Time: 1 Hours
Total Marks: 30
Total Questions: 5

__________ Roll No   __________ Section   ________________ Student Signature

Instruction/Notes:
- Attempt all questions on the provided separate answer sheet.
- Clearly write corresponding question number and part number at the top center of the answer sheet with a thick pen / marker before starting a new question / answer.
- In case you have used rough sheets, they should **NOT** be attached to the answer sheet.

CLO 1 (Q1 to Q2): **Describe** utilization of network protocol concepts vis-a-vis OSI and TCP/IP stack. **[11+4 = 15 Marks]**

Q1: You are a network analyst at a company tasked with optimizing web performance and email delivery. This question involves calculating delays based on DNS resolution, HTTP requests, and SMTP transactions. Assume negligible transmission, processing, and queuing delays in all cases. Use the following RTTs values:
RTT between user's host and local DNS server: 5 ms
RTT between company's email server and local DNS server: 5 ms (same as above)
RTT between local DNS server and any other DNS server (root, TLD, authoritative): 30 ms
RTT between user's host and web server (for www.company.com): 150 ms
RTT between company's email server and recipient's email server (for example.net): 100 ms
Moreover, assume that the browser uses HTTP/1.1 with persistent connections and pipelining and the company website www.company.com has a homepage with one base HTML file and 10 embedded images.
Answer the following questions for each task: **[2+2+3+2+2 = 11 Marks]**

Answer: Given Information
RTT (user ↔ local DNS) = 5 ms
RTT (local DNS ↔ any other DNS server i.e., root/TLD/auth) = 30 ms
RTT (user ↔ web server www.company.com) = 150 ms
RTT (company email server ↔ local DNS) = 5 ms
RTT (company email server ↔ recipient's email server) = 100 ms
Web page: 1 base HTML + 10 images
Browser: no cache unless stated otherwise.

(I) A user wants to access www.company.com. The user's host does not have the IP address cached. Calculate the total time required for DNS resolution to obtain the IP address of www.company.com. Note that the client sends recursive resolution query to Local DNS, that does iterative queries to find the answer.

Answer: Time required for DNS resolution

When local DNS does not have the answer, the local DNS will typically query root → TLD → authoritative sequentially (each is one RTT between local DNS and the other DNS server).
Time for the three external queries (local DNS ↔ any other DNS server) = 3 * 30 = 90 ms
Round trip time from user's host to local DNS: 5 ms
Total DNS time = 90 + 5 = *95 ms*

(II) After DNS resolution (in (I) above), the browser needs to load the homepage and then all embedded images. Assume the browser does not have any resources cached. Calculate the total time (including DNS resolution time) from when the user clicks the link until all objects are received.

Answer: Web page loading time (no caching; HTTP/1.1 persistent + pipelining)

Sequence (serial, because the browser must get and parse base HTML to see image URLs):
Time for DNS resolution = **95 ms**
TCP connection establishment time to web server = 1 RTT = 150 ms
Request and receive base HTML (HTTP request → response) = 1 RTT= 150 ms
Note: Only after the base HTML arrives, the browser can learn the 10 image URLs
Browser issues pipelined GETs for the 10 images on the already-open connection; server sends back the image responses.
With pipelining the round-trip to request + receive all images is effectively = 1 RTT = 150 ms
Total Time (from click until all objects received)= **95 + 150 + 150 +1 150 = *545 ms***
Note: images cannot be requested until base HTML is parsed, so pipelining helps after the base HTML but does not remove the need to fetch the base HTML first

(III) Now assume that the user's local DNS server has the IP address of www.company.com cached, and the browser has the base HTML file cached but not the images. How long does it take to load the page if the browser already had

a. no open TCP connection to the server.
b. an open persistent TCP connection to the server.

Answer: Effect of caching (local DNS has IP cached; browser has base HTML cached but not images)

Local DNS already has IP cached

(a) When there is no open TCP connection to the server

DNS time: one client↔local DNS query/response = **5 ms**
Need to fetch images (browser has base HTML locally, so no HTML fetch). Must open (or reuse) a TCP connection to the web server:
TCP handshake: **150 ms** (assume no existing TCP connection)
After handshake, browser issues pipelined GETs for 10 images = 1 RTT = **150 ms**
Total time = DNS time + TCP handshake + pipelined images = 5 + 150 + 150 = ***305 ms***

(b) with an open persistent TCP connection to the server

The browser already had an open persistent TCP connection to the server, then there would be saving of 150 ms TCP handshake and 5 ms DND resolution

So the total time would drop to ***150 ms*** (305 – 5- 150)

(IV) The company's email server needs to send an email to customer@example.net. The email server must resolve the MX record for example.net. Assume the local DNS server has no cached information for example.net. Calculate the time required for DNS resolution to get the MX record.

Answer: **DNS resolution to get MX for example.net (local DNS has no cache)**

local DNS → root: 1 RTT = 30 ms
local DNS → TLD: 1 RTT = 30 ms
local DNS → authoritative: 1 RTT = 30 ms
subtotal for external DNS = 3 * 30 = 90 ms
Finally, the company email server must query its local DNS and receive the answer:
Host↔local DNS RTT = **5 ms**
Total DNS resolution time = 90 + 5 = ***95 ms***

(V) After DNS resolution, the email server establishes a TCP connection to the recipient's email server and sends the email. Assume the SMTP transaction involves the following steps: HELO, MAIL FROM, RCPT TO, DATA, and QUIT. Each command and response takes one RTT between the email servers. The DATA command involves sending the email content, which takes negligible time. Calculate the total time for the SMTP transaction after DNS resolution.

Answer: **SMTP transaction time after DNS resolution**

Sequence: the server first establishes a TCP connection, then the SMTP commands: EHLO, MAIL FROM, RCPT TO, DATA, and QUIT. Each command/response pair takes one RTT between the mail servers. TCP handshake is counted as 1 RTT.
RTT between mail servers = **100 ms**. (given)

RTTs counting

TCP handshake: 1 RTT = 100 ms
HELO → 250 reply: 1 RTT = 100 ms
MAIL FROM → 250 reply: 1 RTT = 100 ms
RCPT TO → 250 reply: 1 RTT = 100 ms
DATA → 354 (then send body) → 250: 1 RTT = 100 ms (DATA content is negligible but the command/response consumes an RTT)
QUIT → 221 reply: 1 RTT = 100 ms
Total RTTs = 6
Total SMTP transaction time = **6 * 100 = 600** ms for SMTP transaction after DNS resolution

Q2: Answer the following questions: **[2+ 2 = 4 Marks]**

(A) Imagine that Internet works like a **postal service**. Answer the following in the context of postal service.

- What would represent the **hosts (end systems)**?
- What would represent the **communication links**?

Answer: Hosts (end systems): The houses and offices where letters are sent from and received.
Communication links: The roads, railways, or air routes that carry mail trucks, trains, or planes.

(B) Write actual packet name corresponding to a given TCP/IP layer provided in **Layer** column.

Layer	**Packet Name**
Application Layer	***Message***
Transport Layer	***Segment***
Network Layer	***Datagram***
Data Link Layer	***Frame***

***CLO 2* (Q3 to Q5): Demonstrate** the basics of network concepts using state-of-the-art network tools/techniques. **[3+8+4 = 15 Marks]**

Q3: Host A and Host B are connected via a point-to-point link of capacity **b** bps. A packet of size **x** bits is sent from A to B. The link propagation delay is **d** seconds. We want to calculate the total time from when Host A starts transmitting the first bit until Host B has received the entire packet. One possible solution goes like this:

- The first bit of the packet takes time equal to 1/b to be put on the wire.
- This bit then takes d seconds to reach B.
- Host B then needs another 1/b second to sense the bit on the link.
- Finally, the rest of the packet (x – 1 bits) takes (x–1)/b seconds to arrive.

Therefore, the total time = 1/b + d + 1/b + (x–1)/b = d + x/b + 1/b
Do you agree with this reasoning?
If not, explain what's wrong and write the correct total time expression. **[3 Marks]**
<u>**Answer:**</u> There is over-counting of time (1/b factor).
After time 1/b, the first bit will be on the wire.
This bit will reach the destination in time (d – (1/b))
Receiver can sense this bit in 1/b second
Receiver can sense the remaining (x – 1) bits in (x-1)/b seconds
Total time = 1/b + d – (1/b) + 1/b + (x-1)/b = d + x/b

Alternate explanation:
The leading edge of the physical wave form of the first bit will reach the destination after d seconds.
The trailing edge of the last bit signal will arrive at the destination after additional x/b seconds

Another solution (explanation): An extra 1/b time is counted for the following: Host B needs another 1/b1/b1/b second to sense the bit. In fact, the receiver does **not** need a full extra bit-time beyond propagation to sense the arriving bit. When the bit arrives at B, it is already on the link and can be observed/received. In the pipeline model the arrival of the first bit is at 1/b +d and the rest of the bits arrive continuously over the next (x−1)/b seconds, so the final arrival time is
(1/b + d) + (x-1)/b = d + x/b (with no extra +1/b)

Q4: Answer the following questions: **[4 + 4 = 8 Marks]**

(A): A campus proxy caches HTTP objects and forwards misses to origin server over a single uplink with bandwidth of 100 Mbps (where 1 Mbps = $1 * 10^6$ bits per second). One way propagation delay = 20 ms. Proxy serves 7200 HTTP requests from clients per hour for three static objects as per below: **[2 + 2 = 4 Marks]**

- Object A: size = 100 KB, requests = 3600 / hour
- Object B: size = 500 KB, requests = 2400 / hour
- Object C: size = 2000 KB, requests = 1200 / hour (where 1 KB = $1 * 10^3$ bytes.)

The proxy has objects A and B in cache, but C is not cached (thus A & B = hits, C = miss). Moreover, response times are as follows:

- Cache hit: proxy → client latency = 10 ms (where 1 ms = $1 * 10^{-3}$ seconds)
- Cache miss: proxy → origin **RTT** + object transmission time over uplink + proxy → client latency.

Your task is to

I. Compute the cache hit ratio (in terms of number of requests).

<u>**Answer:**</u> **Cache hit ratio**

Total requests / hour = 3600 + 2400 + 1200 = 7200
Hits per hour = requests for A + requests for B = 3600 + 2400 = 6000 / hour
Hit ratio = hits per hour / total requests per hour = 6000 ÷ 7200 = 5 / 6 = 0.83333 = <u>***83.33%***</u>

II. Compute the total bytes saved on the uplink per hour because of caching (answer in MB/hour i.e. Mega bytes per hour saved).

Answer: Bytes saved on the uplink per hour (because A and B are cached)

Bytes saved per hour = (size of A * requests for A per hour) + (size of B * requests for B per hour)

= (100000 bytes * 3600 requests)+(500000 bytes * 2400 requests)=1560000000 bytes/hour = ***1560 MB / hour.***

(B) A client establishes a single HTTP/2 connection to a web server. It requests two objects A & B, each of size 10 KB & 15 KB respectively (where 1 KB = 1 * 10^3 bytes.) The server sends these two objects broken into frames (with the frame size of 5 KB) via two possible scenarios, i.e.

- Scenario 1) No interleaving, i.e. Object 1 frames transmitted first followed by Object 2 frames.
- Scenario 2) Frames of each object are transmitted interleaved.

The link bandwidth is 10 Mbps (where 1 Mbps = 1 * 10^6 bits per second.) The single HTTP/2 connection is already established (so no RTT required for establishing connection.) Also, consider transmission delay and ignore all other delays. Consider the starting time of transmission to be t = 0 sec, fill in the table below with the appropriate time stamps (in seconds or msec.) **[4 Marks]**

Timeline	Scenario 1 (without interleaving)	Scenario 2 (with interleaving)
1st frame of Object A transmission complete at t =	***4 ms (0.004 sec)***	***4 ms (0.004 sec)***
Entire Object A transmission complete at t =	***8 ms (0.008 sec)***	***12 ms (0.012 sec)***
1st frame of Object B transmission complete at t =	***12 ms (0.012 sec)***	***8 ms (0.008 sec)***
Entire Object B transmission complete at t =	***20 ms (0.02 sec)***	***20 ms (0.02 sec)***

Q5: Two hosts are connected via a packet switch with 10^6 bits per second links. The packet switch implements store-and-forward scheme, and each link has a propagation delay of 20 microseconds. The switch begins forwarding a packet 35 microseconds (time incurred on processing) after it receives that packet. If 10000 bits of data are to be transmitted between the two hosts using a packet size of 5000 bits. Ignoring any queuing delays, determine the time required to receive 10,000 bits at the destination. **[4 Marks]**

Answer:

Packet size: L = 5,000 bits
No. of packets = 10,000/5,000 = 2
No. links = 2
Transmission rate of each link: R = 10^6 bps
Transmission delay for one packet = d_{trans} = 5,000/10^6 = 5ms
Processing delay at the switch: d_{proc} = 35 microseconds = 0.035ms
Propagation delay of each link: d_{prop} = 20 microseconds = 0.02ms

Time required to receive the 1st packet arrives at the destination = $d_{trans} + d_{prop} + d_{proc} + d_{trans} + d_{prop}$
=5ms+0.02ms+0.035ms+5ms+0.02ms
= 10.075ms

After transmitting the 1st packet, the source starts transmitting the 2nd packet. Since the switch implements store and forward scheme, 2nd packet arrives at destination at time = d_{trans}+10.075ms
=5ms+10.075ms
=***15.075ms***

Thus, it takes 15.075ms to receive 10,000 bits.