Question 1 [15 Marks]

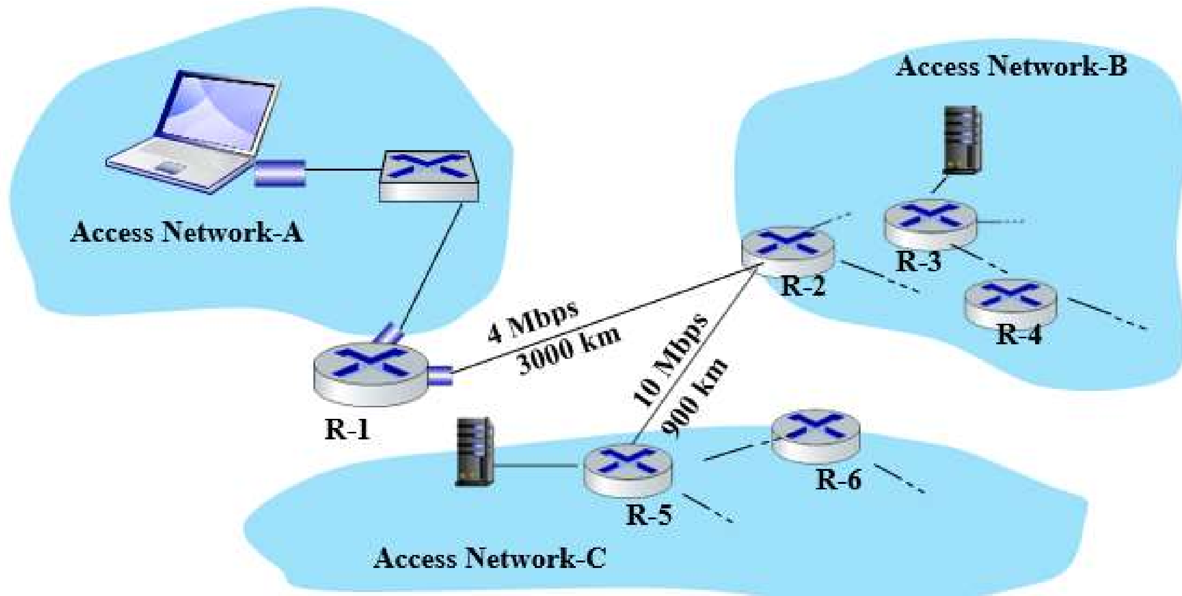


Figure 1

Consider Figure 1 with Link-1 between Router R-1 and Router R-2 having the distance d = 3000 km and propagation speed s = 3×10^5 m/s and Link-2 between Router R-2 and Router R-5 having the distance d = 900 km and propagation speed s = 3×10^5 m/s.

a. **[3 Marks]** What is the transmission delay if

    i. A sends a 500 byte packet to B

    ii. B sends a 125 byte packet to C

  Transmission Delay = Size of Transfer / Link Bandwidth
  A → B: Transmission Delay = $(500/ ((4/8) \times 10^6)) = 1$ ms
  B → C: Transmission Delay = $(125/ (10/8) \times 10^6) = 100$ µs (or 0.1 ms)

b. **[3 Marks]** What is the propagation delay between

    i. A to B

    ii. B to C

  Propagation Delay = Distance of link / Speed
  A → B: Propagation Delay = $(3000 \times 10^3) / (3 \times 10^5) = 10$ sec
  B → C: Propagation Delay = $(900 \times 10^3) / (3 \times 10^5) = 3$ sec

c. **[4 Marks]** A wants to send a 500 byte packet to C through B. B is supposed to follow the store-and forward model, that is, B will receive the whole packet from A and then start transmitting the packet to C. What is the end-to-end delay seen by the packet?

  End to end delay between A→C = (Delay between A→B) + (Delay between B→C)
  Delay on a link = Transmission Delay + Propagation Delay
  Therefore, Delay between A→B = 0.001 + 10 = 10.001 sec, and Delay between B→C = 0.0004 + 3 = 3.0004 sec
  End to end delay between A→C = 10.001 sec + 3.0004 sec = 13.0014 sec

d. **[5 Marks]** Now, A wants to send a 5 MB file to C in chunks of 500 byte packets. To prevent any packet loss, when A sends a 500 byte packet to C (same way as explained in (c)), C responds with a 50 byte packet to A (through B) acknowledging that it has successfully received the packet. Only after receiving the acknowledgement does A send the next 500 byte packet. Assuming no losses, how long will it take A to send the file to C?

End to end delay between A→C for a 500 byte packet = 13.0014 sec
End to end delay between A→C for a 50 byte ACK = (0.0001 + 10) + (0.00004+3)=13.00014 sec
Total delay for a packet and ACK = 13.0014 + 13.00014 = 26.00154 sec
# of packets in a 5MB transfer = $(5 \times 10^6) / 500 = 10{,}000$
Therefore, total time for transfer = $10000 \times 26.00154 = 260015.4$ sec

Question 2 [4 Marks]

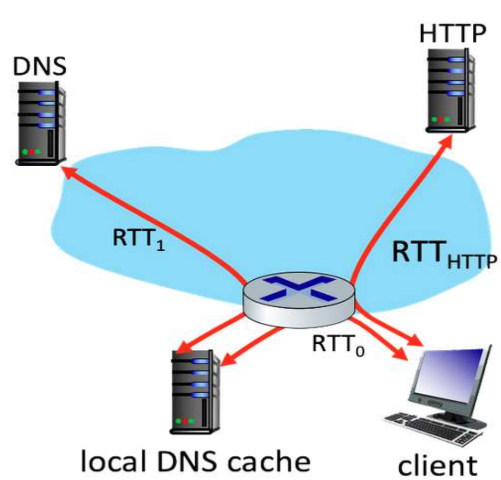
Emaan, Mutahar, and Ahmed are working on reducing the overall delays in their network and make the following suggestions. Which of their claims are correct? Mark all that apply. (Hint: 4 out of 8 are correct so mark only 4)

a. Emaan claims that increasing the link capacities will reduce the propagation delays since each bit will be able to move from one end of the link to another faster.
b. They all believe that, assuming their network has one packet switch and consequently two links connecting the source and destination, increasing the capacity of the incoming link only will reduce the queuing delays.
c. Emaan also proposes that assuming their network has one packet switch and consequently two links connecting the source and destination, decreasing the capacity of the incoming link only will reduce the queuing delays.
d. Ahmed claims that assuming their network has one packet switch and consequently two links connecting the source and destination, decreasing the capacity of the incoming link while increasing the capacity of the outbound link will reduce the queuing delays.
e. One of them suggests moving the source and destination node closer, reducing the link lengths in between to reduce the propagation delay.
f. Analyzing their network architecture, they realize that given that the transmission rates along the different links are 10Mbps, 20Mbps, 30Mbps, 40Mbps, the throughput is usually 100Mbps.
g. Ahmed and Mutahar think that increasing the buffer size of the output queue will reduce the queuing delays.
h. Emaan claims increasing the capacity of the links will decrease the time needed to push all of the packet's bits into the link.

Answer: c, d, e, and h are correct.

Question 3 [7 Marks]

Suppose within your Web browser you click on a link to obtain a Web page. The IP address for the associated URL is not cached in your local host, so a DNS lookup is necessary to obtain the IP address. Suppose that two DNS servers are visited before your host receives the IP address from DNS. The first DNS server visited is the local DNS cache, with an RTT delay of RTT_0 = 4 msecs. The second DNS server contacted has an RTT_1 of 43 msecs. Initially, let's suppose that the Web page associated with the link contains exactly one object, consisting



of a small amount of HTML text. Suppose the RTT between the local host and the Web server containing the object is RTT_{HTTP} = 17 msecs.

a) Assuming zero transmission time for the HTML object, how much time (in msec) elapses from when the client clicks on the link until the client receives the object? **[1 Mark]**

$RTT_0 + RTT_1 + 2*RTT_{HTTP} = 4 + 43 + 2*17 = 81$ msecs

b) Now suppose the HTML object references 9 very small objects on the same server. Neglecting transmission times, how much time (in msec) elapses from when the client clicks on the link until the base object and all 9 additional objects are received from web server at the client, assuming non-persistent HTTP and no parallel TCP connections? **[3 Marks]**

$RTT_0 + RTT_1 + 2*RTT_{HTTP} + 2*9*RTT_{HTTP} = 4 + 43 + 2*17 + 2*9*17 = 387$ msecs

c) Suppose the HTML object references 9 very small objects on the same server, but assume that the client is configured to support a maximum of 5 parallel TCP connections, with non-persistent HTTP. What will be the total delay in msec? **[2 Marks]**

The total delay time is: 47 + 34 + 34 + 34 = 149 msec

d) Suppose the HTML object references 9 very small objects on the same server, but assume that the client is configured to support a maximum of 5 parallel TCP connections, with persistent HTTP. What will be the total delay in msec? **[1 Mark]**

The total delay is: 47 + 34 + 34 = 115 msec

Detailed answers: (Solution)

1. The time from when the Web request is made in the browser until the page is displayed in the browser is: $RTT_0 + RTT_1 + 2*RTT_{HTTP} = 4 + 43 + 2*17 = 81$ msecs. Note that 2 RTT_{HTTP} are needed to fetch the HTML object - one RTT_{HTTP} to establish the TCP connection, and then one RTT_{HTTP} to perform the HTTP GET/response over that TCP connection.

   2. The time from when the Web request is made in the browser until the page is displayed in the browser is: $RTT_0 + RTT_1 + 2*RTT_{HTTP} + 2*9*RTT_{HTTP} = 4 + 43 + 2*17 + 2*9*17 = 387$ msecs. Note that two RTT_{HTTP} delays are needed to fetch the base HTML object - one RTT_{HTTP} to establish the TCP connection, and one RTT_{HTTP} to send the HTTP request, and receive the HTTP reply. Then, serially, for *each* of the 9 embedded objects, a delay of $2*RTT_{HTTP}$ is needed - one RTT_{HTTP} to establish the TCP connection and then one RTT_{HTTP} to perform the HTTP GET/response over that TCP connection.

   3. Since there are 9 objects, there's a delay of 47 msec for the DNS query, two RTT_{HTTP} for the base page, and $4*RTT_{HTTP}$ for the objects since the requests for 5 of these objects can be run in parallel (2 RTT_{HTTP}) and the rest can be done after (2 RTT_{HTTP}). The total is 47 + 34 + 34 + 34 = 149 msec. As in 2 above, 2 RTT_{HTTP} are needed to fetch the base HTML object - one RTT_{HTTP} to establish the TCP connection, and one RTT_{HTTP} to send the HTTP request and receive the HTTP reply containing the base HTML object. Once the base object is received at the client, the 9 HTTP GETS for the embedded objects can proceed in parallel. Each (in parallel) requires two RTT_{HTTP} delays - one RTT_{HTTP} to set up the TCP

connection, and one RTT_{HTTP} to perform the HTTP GET/response for an embedded object.

4. Since there are 9 objects, there's a delay of 47 msec for the DNS query. There's also a delay of two RTT_{HTTP} for the base page, and 2 RTT_{HTTP} for the objects. The total is 47 + 34 + 34 = 115 msec.As in 2 and 3 above, two RTT_{HTTP} delays are needed to fetch the base HTML object - one RTT_{HTTP} to establish the TCP connection, and one RTT_{HTTP} to send the HTTP request, and receive the HTTP reply containing the base HTML object. However, with persistent HTTP, this TCP connection will remain open for future HTTP requests, which will therefore not incur a TCP establishment delay. Once the base object is received at the client, the maximum of five requests can proceed in parallel, each retrieving one of the 9 embedded objects. Each (in parallel) requires only one RTT_{HTTP} delay to perform the HTTP GET/response for an embedded object. Once these first five objects have been retrieved, (if necessary) the remaining embedded objects can be retrieved (in parallel). This second round of HTTP GET/response to retreive the remaining embedded objects takes only one more RTT_{HTTP}, since the TCP connection has remained open.

Question 4 [9 Marks]

1. Which layer of Internet is responsible for addressing and routing packets across multiple networks?
   a) Transport Layer
   b) Network Layer
   c) Data Link Layer
   d) Application Layer
   Solution: b) Network Layer

2. In the context of email, which protocol is responsible for retrieving messages from a mail server?
   a) SMTP
   b) POP3
   c) IMAP
   d) HTTP
   Solution: b) POP3 or c) IMAP

3. What does SMTP stand for in the context of email communication?
   a) Secure Mail Transfer Protocol
   b) Simple Mail Transfer Protocol
   c) System Mail Transfer Protocol
   d) Secure Message Transfer Protocol
   Solution: b) Simple Mail Transfer Protocol

4. Which DNS record type is used to specify the mail server responsible for receiving email for a domain?
   a) A Record
   b) MX Record
   c) CNAME Record
   d) PTR Record
   Solution: b) MX Record

5. Which Internet layer is responsible for end-to-end communication, data encryption, and application-specific protocols?
   a) Data Link Layer
   b) Physical Layer

c) Application Layer
d) Transport Layer
Solution: c) Application Layer

6. Which of the following is not a valid top-level domain (TLD) for domain names on the Internet?
a) .com
b) .net
c) .ftp
d) .org
Solution: c) .ftp

7. What is the primary role of the DNS (Domain Name System) in Internet communication?
a) Resolving domain names to IP addresses
b) Ensuring data encryption for web traffic
c) Managing email communication
d) Establishing network connections
Solution: a) Resolving domain names to IP addresses

8. Which email header field is used to indicate the recipients who should receive a copy of the message without other recipients knowing?
a) To
b) CC
c) BCC
d) From
Solution: c) BCC

9. What is the primary function of the Transport Layer in the Internet layered model?
a) Physical data transmission
b) Logical addressing
c) End-to-end communication and error correction
d) Data link control
Solution: c) End-to-end communication and error correction