1. R22. List five tasks that a layer can perform. Is it possible that one (or more) of these tasks could be performed by two (or more) layers?

   Five tasks that a layer can perform are connection setup, multiplexing, segmentation and reassembly, flow control, and error control. Yes, it is possible for these tasks to be performed by multiple different layers; for example, error control is generally carried out in multiple layers.

   R23. What are the five layers in the Internet protocol stack? What are the principal responsibilities of each of these layers?

   The five layers within the Internet protocol stack are the physical, link, network, transport, and application layers. The physical layer is responsible for moving individual bits within the frame from one node to the next. The link layer's responsibility is to move entire frames from one network element to an adjacent network element. The network layer moves network-layer packets called datagrams from one host to another. The transport layer carries application-layer messages between application endpoints. Finally, the application layer is where network applications and their protocols reside.

   R24. What is an application-layer message? A transport-layer segment? A network-layer datagram? A link-layer frame?

   An application-layer message is data that a network application wishes to send and is passed to the transport layer to do so. A transport-layer segment is generated within the transport layer and contains an application-layer message along with a transport layer header. A network-layer datagram encapsulates the transport-layer segment with a network-layer header. A link-layer frame holds a network-layer datagram with a link-layer header.

   R25. Which layers in the Internet protocol stack does a router process? Which layers does a link-layer switch process? Which layers does a host process?

   Routers process the lowest three layers: the physical, link, and network layers. Link-layer switches process the lowest two layers: the physical and link layers. Hosts process all five layers: physical, link, network, transport, and application layers.

2. P6. This elementary problem begins to explore propagation delay and transmission delay, two central concepts in data networking. Consider two hosts, A and B, connected by a single link of rate R bps. Suppose that the two hosts are separated by m meters, and suppose the propagation speed along the link is s meters/sec. Host A is to send a packet of size L bits to Host B.

   a. Express the propagation delay, d_{prop}, in terms of m and s.

   $$d_{prop} = \frac{m}{s} \text{ seconds}$$

   b. Determine the transmission time of the packet, d_{trans}, in terms of L and R.

   $$d_{trans} = \frac{L}{R} \text{ seconds}$$

   c. Ignoring processing and queuing delays, obtain an expression for the end-to-end delay.

   $$d_{end-to-end} = d_{prop} + d_{trans} = \frac{m}{s} + \frac{L}{R} \text{ seconds}$$

d. Suppose Host A begins to transmit the packet at time t = 0. At time t = d_{trans}, where is the last bit of the packet?

The last bit of the packet is just leaving Host A.

e. Suppose d_{prop} is greater than d_{trans}. At time t = d_{trans}, where is the first bit of the packet?

The first bit of the packet is still in the link and hasn't yet reached Host B.

f. Suppose d_{prop} is less than d_{trans}. At time t = d_{trans}, where is the first bit of the packet?

The first bit of the packet has already reached Host B.

g. Suppose s = $2.5 \cdot 10^8$, L = 120 bits, and R = 56 kbps. Find the distance m so that d_{prop} equals d_{trans}.

$$d_{prop} = d_{trans} \rightarrow \frac{m}{s} = \frac{L}{R} \rightarrow m = \frac{L}{R} \cdot s = \frac{120}{56 \times 10^3} \cdot 2.5 \times 10^8 = \mathbf{536\ kilometers}$$

3. P25. Suppose two hosts, A and B, are separated by 20,000 kilometers and are connected by a direct link of R = 2 Mbps. Suppose the propagation speed over the link is $2.5 \cdot 10^8$ meters/sec.

a. Calculate the bandwidth-delay product, $R \cdot d_{prop}$.

$$R \cdot d_{prop} = R \cdot \frac{m}{s} = 2 \times 10^6 \cdot \frac{2 \times 10^7}{2.5 \times 10^8} = \mathbf{160,000\ bits}$$

b. Consider sending a file of 800,000 bits from Host A to Host B. Suppose the file is sent continuously as one large message. What is the maximum number of bits that will be in the link at any given time?

160,000 bits: this is what the bandwidth-delay product represents.

c. Provide an interpretation of the bandwidth-delay product.

The bandwidth-delay product is the max number of bits that can be in the link.

d. What is the width (in meters) of a bit in the link? Is it longer than a football field?

$$\text{Bit Width} = \frac{\text{Length of Link}}{\text{Bandwidth Delay Product}} = \frac{2\times10^7\,\text{meters}}{160{,}000\ \text{bits}} = \mathbf{125\ meters} = 136.7\ \text{yards};\ \mathbf{yes.}$$

e. Derive a general expression for the width of a bit in terms of the propagation speed s, the transmission rate R, and the length of the link m.

$$\text{Bit Width} = \frac{\text{Length of Link}}{\text{Bandwidth Delay Product}} = \frac{m}{R \cdot d_{prop}} = \frac{m}{R \cdot \frac{m}{s}} = \mathbf{\frac{s}{R}}$$

4. Consider a 3-hop communication path characterized as follows:

- All links operate at 48,000 bps.
- Propagation delay is 20 milliseconds per link.
- Connection set-up time is made of 23 sec for dialing and 100 milliseconds to send the request and receive the confirmation.
- Queuing as well as processing delays are negligible.

i. Using circuit switching, compute the total delay to transfer a 10,000 bytes long message.

T: time = ?
S: setup time = 23 seconds + 100 milliseconds = 23.1 seconds
M: message size = 10,000 bytes = 80,000 bits
B: bit rate = 48,000 bps
K: number of links = 3
D: propagation delay per link = 20 milliseconds = 2×10^{-2} seconds

$$\mathrm{T} = \mathrm{S} + \frac{\mathrm{M}}{\mathrm{B}} + \mathrm{KD} = 23.1 + \frac{80{,}000}{48{,}000} + (3 \cdot 2 \times 10^{-2}) = \mathbf{24.8267\ seconds}$$

ii. Assume that the message is divided into datagrams, each carrying 50 bytes of header information and P bytes of data information. Consecutive datagrams are submitted to the network 20 milliseconds apart of each other. What is the value of P that guarantees better delay for datagram service over circuit switching?

In order to calculate the value of P that guarantees a better delay, we can evaluate the efficiency of using datagram service over circuit switching by calculating the time it takes for each service. To calculate the total time required for circuit switching, we can divide the message size (M) in bits by the bit rate in bps. The additional factors of setup time and propagation delay can be removed as they are the same in datagram service. To calculate the total time required for datagram service, we can divide the message size (M) by the packet size (P) to find the number of packets in the message. The number of packets is then multiplied by the total size of a packet – the packet size (P) plus the header size (H). This total message size is then divided by the bit rate in bps to calculate the total time.

M: message size (bits)
B: bit rate (bits per second)
P: packet size (bits)
H: header size (bits)

$$E = \frac{\frac{M}{B}}{\frac{\frac{M}{P} \cdot (P + H)}{B}} = \frac{\frac{M}{B}}{\frac{M + \frac{H}{P}}{B}} = \frac{M}{M + \frac{H}{P}} \rightarrow E \cdot \left(M + \frac{H}{P}\right) = M \rightarrow M + \frac{H}{P} = \frac{M}{E} \rightarrow \frac{\mathrm{H}}{\mathrm{P}} = \frac{M}{E} - M$$

$$P = \frac{H}{\frac{M}{E} - M}$$