8 9. List, in order, the five layers of the Internet protocol stack. For each layer, provide a brief description (1-2 sentences) of what that layer does, and provide an example of a protocol or specific networking technology associated with that layer.

5. Application Layer: user-to-user exchange of messages (e.g., SMTP)
   (useful network applications and services)

4. Transport Layer: end-to-end exchange of segments (e.g., TCP)
   (process to process, using sockets)

3. Network Layer: host-to-host movement of packets (e.g., IPv4)
   (datagrams)

2. Datalink Layer: hop-by-hop exchange of frames (e.g., WiFi)

1. Physical Layer: raw transmission of bits (e.g., optical fiber)

Networking Delays

5 10. Suppose that a lunar rover robot on the Moon takes a 2 MB "selfie" photo and transmits it home to its parent robot on Earth. The transmission uses an error-free direct link with a data transmission rate of $R = 4$ Megabits per second (Mbps).

(a) (3 marks) Using the relationship $t_{trans} = \frac{L}{R}$, calculate the transmission time for this file, which has size L (in bits). Recall that 1 MB $= 2^{20}$ bytes, and that 1 Mbps $= 10^6$ bits per second. Show your work.

$$t_{trans} = \frac{L}{R} = \frac{2 \cdot 2^{20}\ bytes \cdot 8\ bits/byte}{4 \cdot 10^6\ bits/sec} = \frac{16,777,216\ bits}{4,000,000\ bits/sec} = 4.19\ seconds$$

(b) (2 marks) Assuming that the Moon is approximately 385,000 kilometers from the Earth, at what time would the very first bit of the photo arrive? Recall that propagation delay $t_{prop} = \frac{distance}{speed}$, and that the speed of light is approximately 3 x 10^8 meters per second. Show your work.

$$t_{prop} = \frac{distance}{speed} = \frac{385,000\ km \cdot 10^3\ m/km}{3 \cdot 10^8\ m/sec} = \frac{385,000,000\ m}{300,000,000\ m/sec} = 1.28\ seconds$$

Networking Concepts and Definitions

9 11. For each of the following pairs of technical terms, **define** each term, and **clarify** the key difference(s) between the two terms. Be clear and concise. If in doubt about your definition, feel free to supplement with a relevant example.

(a) (3 marks) "circuit-switched" and "packet-switched"

Circuit-switched: traditional telephone network design; end-to-end call setup; single path for duration of call; switches maintain important state about calls; dumb devices at network edge; all the smarts are in the network core.

Packet-switched: data network design for Internet; data is split into packets, which are independently addressed and routed through the network; simple core; routers maintain minimal state about active calls; smarts are at network edge.

(b) (3 marks) "client-server" and "peer-to-peer"

Client-server: traditional paradigm for network applications; server is special and well-resourced; clients are simple and numerous; client requests service from the server. Example: World Wide Web

Peer-to-peer: alternative paradigm for network applications; all nodes are equal each node can function both as a client (requesting service or resources) and as a server (providing service or resources). Example: BitTorrent.

(c) (3 marks) "positive ACK" and "negative ACK"

Positive ACK: a control packet that conveys "good news" about the successful delivery of data; used in the PNA protocol for RDT.

Negative ACK: a control packet that conveys "bad news" about the unsuccessful delivery of data; used in the PNA protocol for RDT to indicate corrupted data.

Key difference: ACK triggers new data, while NAK triggers retransmission.

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