CS305: Computer Networking
2024 Fall Semester Written Assignment # 1

Due: Oct. 22th, 2024, please submit through Blackboard

Please answer questions in English. Using any other language will lead to a zero point.

Q 1. List the five layers of the Internet protocol stack. For each layer, offer a concise explanation of less than 3 sentences of its function, and give an example of a protocol or specific networking technology of that layer.

Solution: (10 Points)

- Application Layer: user-to-user exchange of messages (e.g., SMTP) (network applications and services).
- Transport Layer: end-to-end exchange of segments (e.g., TCP) (process-to-process, using sockets).
- Network Layer: host-to-host movement of packets (e.g., IPv4) (datagrams).
- Datalink Layer: hop-by-hop exchange of frames (e.g., WiFi).
- Physical Layer: raw transmission of bits (e.g., optical fiber).

Q 2. List the different types of delays in a packet-switching network.

Solution: (10 Points)

- d_{proc}: nodal processing delay
- d_{queue}: queuing delay
- d_{trans}: transmission delay
- d_{prop}: propagation delay

Q 3. For the following pairs of technical terms, provide a definition for each and explain the primary differences between them. Your response should be clear and succinct. Should you be uncertain about your definitions, you may support them with relevant examples.

(a) "Circuit-switching" and "packet-switching"

(b) "Client-server" and "peer-to-peer"

(c) "Positive ACK" and "negative ACK"

Solution: (10 Points)

- Circuit-switching: 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-switching: 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.
- 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.
- 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.

Q 4. Suppose a lunar rover on the moon capturing a 2 MB "selfie" and sending this image back to its parent robot on Earth. This transmission occurs over an error-free direct link with a data transfer rate of $R = 4$Mbps.

(a) Determine the time required to transmit this file, given its size L (in bits), using the formula $t_{\text{trans}} = L/R$. Remember that 1 MB = 2^{20} bytes, and that 1 Mbps = 10^6 bits per second. Provide detailed calculations.

(b) Given that the Moon is roughly 385,000 kilometers away from Earth, determine the arrival time of the first bit of a photograph. Use the formula for propagation delay, $t_{\text{prop}} = \frac{\text{distance}}{\text{speed}}$, and remember that the speed of light is approximately 3 x 10^8 meters per second. Provide detailed calculations.

Solution: (10 Points)

- $t_{\text{trans}} = \frac{L}{R} = \frac{2 \cdot 2^{20} \text{ bytes } \cdot 8 \text{ bits / byte}}{4 \cdot 10^6 \text{ bits /sec}} = \frac{16{,}777{,}216 \text{ bits}}{4{,}000{,}000 \text{ bits /sec}} = 4.19$ seconds
- $t_{\text{prop}} = \frac{\text{distance}}{\text{speed}} = \frac{385{,}000 \text{ km} \cdot 10^3 \text{ m/km}}{3 \cdot 10^8 \text{ m/sec}} = \frac{385{,}000{,}000 \text{ m}}{300{,}000{,}000 \text{ m/sec}} = 1.28$ seconds

Q 5. Two endpoints in a voice-over IP session are connected by a path of 4 routers. All links are running at 1Mb/s and the hosts are separated by 3000km. All packets are of size 1500 bytes. Assume the bit propagation speed is 2×10^8m/s. Note that 1KB of data is 1024 bytes, but 1Mb/s is 10^6bits/s.

(a) What is the minimum round trip time (RTT), assuming there is no queueing delay and assuming processing time at each host is negligible?

(b) For this part only let us assume that one router on the path has a steady queue occupancy of 5 packets. What is the end-to-end delay (one way, not round trip) in this case?

(c) Now let us assume the maximum queue occupancy for *every* router queues is 5 packets. What is the maximum end-to-end delay?

(d) For part (c), how long should the playback buffer be at the destination voice-over IP client if each packet arrives successfully, without being dropped? Express your answer in bytes.

Solution: (20 Points)

(a) 150 milliseconds. $RTT = 2 \times (t_{\text{prop}} + 5 \times t_{\text{trans}})$. t_{trans} = 1500B/1e6 = 12ms per hop. For 5 hops = 60ms. The propagation delay = 3000km / 2e8 m/s = 15ms. Therefore, the RTT is 2×75ms = 150ms

(b) 135 milliseconds. Average queueing delay = 5 packets / (1 packet) $\times$ 12 ms = 60 ms. So, total end-to-end delay is 60+75ms = 135 ms.

(c) 315 milliseconds. Maximum queueing delay is 4×60 = 240ms. So, the maximum end-to-end delay is 240+75ms = 315ms.

(d) 30,000 bytes. The min end-to-end delay is 75ms, max end-to-end delay is 315ms. Therefore, we need 315 - 75 = 240ms of buffer. Put another way, the playback buffer needs to absorb the variation caused by the queueing delay. At 1Mb/s, 240ms corresponds to 240,000 bits, 30,000 bytes.

Q 6. A user in Chicago accesses the Internet with a 100 Mb/s (b=bits) connection and downloads a webpage (base html file) of 250 KB (B=bytes) from a server based in London. The webpage includes three images, each 500 KB. Assume a one-way propagation delay of 75 ms and that the bandwidth bottleneck is the user's access link. Estimate the time required for the entire webpage, including the images, to be displayed on the user's screen, under the assumption of non-persistent HTTP with one connection at a time (neglect queuing and transmission delays on other network links).

Additionally, calculate the time taken if persistent HTTP is utilized with a single connection.

Solution: (10 Points)

With non-persistent HTTP, there is one TCP connection for the page and one for each one of the images. Each connection incurs a delay of $2 \times RTT$ plus transmission time. Hence the total time until the page+images shows up on the user's screen is calculated as follows: $RTT = 2 \times 75$ms = 150ms. Transmission Time = (Amount of data)/(data rate) = ((250 Kbytes $\times$ 8 bits/byte) + (3 $\times$ 500 Kbytes $\times$ 8 bits/byte))/(100 Mbits/sec)= (2 Mbits + 3 $\times$ 4 Mbits) / (100 Mbits/s), (#RTT)$\times$(RTT) + Transmission Time = $2 \times (3+1) \times 150$ ms + (14 Mb)/(100 Mb/s) = 8 $\times$ 150ms + (14 $\times$ 10e6 bits)/(100 $\times$ 10e6 bits/sec) = 1200 ms + 0.14 sec = 1200 ms + 140 ms = 1.34 seconds

With persistent HTTP, there is only one TCP connection. The TCP connection handshake takes one RTT, this is followed by one more RTT to request the page, one more RTT to request the images, plus the transmission time for the page+images. Hence the total time for the page+images to show up on the user's screen is equal to, 3 RTTs plus transmission time which is: $3\times(2\times75$ ms$) + 140$ ms $= 450$ ms $+ 140$ ms $= 590$ ms

Q 7. What are the key components of an email system? Explain each component with an example.

Solution: (10 Points)

- user agents (e.g. Outlook)
- mail servers (def: physical servers as mail receivers or senders)
- simple mail transfer protocol: SMTP (def: network protocol between mail servers)

Q 8. The questions below are related to DNS: (i) Explain in a few sentences how caching functions within the DNS system. You do not need to explain the entire DNS process. Also, consider whether the data retrieved from a DNS cache is always current. (ii) Define a recursive name query. (iii) Define an iterative name query.

Solution: (10 Points)

(i) A host will maintain a cache of recent DNS-translated address/name pairs. If a name is found in the cache, the DNS system will not be consulted to perform the mapping. NO. Cached values have a time-to-live value and will remain in the cache until they time out. If the name/address pair is changed in the DNS, the cached value will not change, and the current mapping will only become known after the old mapping times out of the cache, and a new mapping is retrieved from the DNS.

(ii) A recursive name query is one in which a DNS client requires that the DNS server respond to the client with either the requested resource record or an error message stating that the record or domain name does not exist. The DNS server cannot just refer the DNS client to a different DNS server.

(iii) An iterative name query is one in which a DNS client allows the DNS server to return the best answer it can give based on its cache or zone data. If the queried DNS server does not have an exact match for the queried name, the best possible information it can return is a referral (that is, a pointer to a DNS server authoritative for a lower level of the domain namespace). The DNS client can then query the DNS server for which it obtained a referral. It continues this process until it locates a DNS server that is authoritative for the queried name, or until an error or time-out condition is met.

Q 9. Suppose you click on a link in your Web browser to load a webpage located on server S_0. Although the webpage (base html file) is small, it contains four objects hosted on servers S_1, S_2, S_3 and S_4. Each of these objects is 1000 bits in size. Assume each TCP connection from your device has a throughput of 10000 bits per second. Let RTT_i represent the round-trip time between your local device and server S_i. How long will it take from the moment you click the link until you receive all the objects? For this question, assume (i) all IP addresses are already cached on your local device, eliminating the need for DNS lookups, and (ii) your browser does not use persistent connections or parallel connections.

Solution: (10 Points)

Once the IP address is known, RTT_0 elapses to set up a TCP connection and another RTT_0 elapses to request and receive the small object from S_0. The time needed to bring an object of size 1000bits is 0.1s. For get object i it is necessary to use $2RTT_i$ (seting up the connection) + transmission time for the object. So, the total response time is therefore; $2RTT_0 + 2RTT_1 + 0.1 + 2RTT_2 + 0.1 + 2RTT_3 + 0.1 + 2RTT_4 + 0.1$.