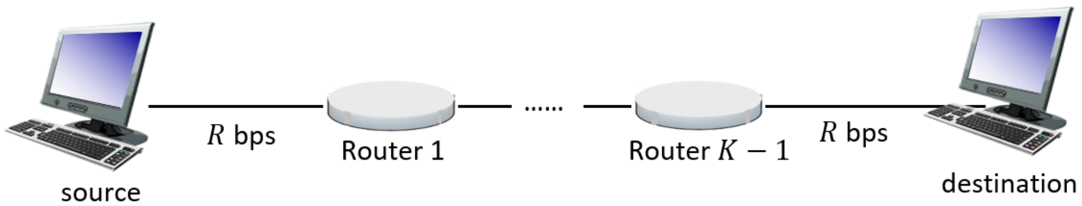
CS305: Computer Networking
2022 Fall Semester Written Assignment # 1

Due: Oct. 17th, 2022, please submit through Sakai

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

Q 1 *Consider a packet of L bits sending from the source to destination through a K-hop path. That is, there are $K-1$ routers between the source and destination. Suppose each link has a transmission rate of R bits per*



second (bps), and the propagation delay is d for each hop.

(a) *Consider a packet switching network. Suppose there is no nodal processing delay and queuing delay. What is the end-to-end delay?*

(b) *Consider a circuit switching network. Suppose the circuit setup time is τ secondsand links in the network use time division multiplexing (TDM) with M slots. What is the end-to-end delay?*

(c) *Consider a packet switching network with $L = 1000$ bits, $K = 2$, $R = 10$ Mbps, $d = 40\mu s$. There are two packets sent one after the other, and there are no other packet in the system. Let the nodal processing delay at the router be $25\mu s$. Compute the time required to send both packets from the source and destination.*

Solution:

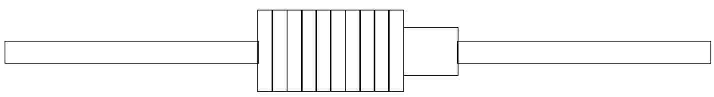
(a) The one-hop delay is equal to the one-hop transmission delay plus the one-hop propagation delay, i.e., $L/R + d$. Since packet switching exploits a store-and-forward scheme, the end-to-end delay along this K-hop path is equal to $K(L/R + d)$.

(b) Since the links uses TDM with M slots, the transmission rate of each slot is R/M bps. It takes τ seconds for circuit setup. Thus, the end-to-end delay is equal to $\tau + L/(R/M) + Kd$.

(c) Consider the first packet. It is received by the router at $L/R + d = 140\mu s$. The router starts to send the first packet at $140 + 25 = 165\mu s$ and finishes the sending at $165 + L/R = 265\mu s$. The destination completely receives the first packet at $265 + d = 305\mu s$. Now, consider the second packet. It is received by the router at $2L/R + d = 240\mu s$. Then, it is sent by the router at $\max\{265, 240 + 25\}\mu s = 265\mu s$. The second packet receives by the destination at $265 + L/R + d = 405\mu s$.

It is also fine if the student considers the processing delay at the source host. In that case, the answer would be $405\mu s + 25\mu s$. Please double check.

Q 2 *Consider a queue with a transmission rate of R bps. There are a set of packets with length L bits. Consider a time-slotted system with $\mathcal{T} = \{0, 1, \cdots\}$. Each time slot corresponds to a duration of L/R seconds.*



(a) *Suppose there is one packet arrival at the beginning of each time slot. What is the average queuing delay of these packets?*

(b) *Suppose N packets arrive simultaneously at the beginning of each of the time slots $t = kNL/R$, where k is a nonnegative integer. What is the average queuing delay of these packets? What is the average queuing delay when N approaches infinity?*

(c) *Derive the traffic intensity of the setting in (a) and (b) respectively. Any insights from the results?*

Solution:

(a) At the beginning of time slot $t = 0$, a packet arrives and is immediately served, so the queuing delay is zero. The transmission delay of this packet is L/R, which means that the entire packet can be sent by the end of the first time slot. Then, at the beginning of the time slot $t = 1$, no packet in the queue. When a new packet arrives, it is served immediately. So as the packets arriving in the following time slots. Thus, the average queuing delay is zero.

(b) At the beginning of time slot 0, N packets arrive and hence are placed in the queue simultaneously. Then, the first packet in the queue is sent immediately after its arrival. The second packet waits for L/R seconds in the queue. The n^{th} packet waits for $(n-1)L/R$ seconds. Thus, the average queuing delay for these N packets arrived at time slot 0 is equal to

$$\frac{1}{N}\sum_{n=1}^{N}(n-1)L/R = \frac{(N-1)}{2}L/R \tag{1}$$

Since all these N packets can be sent before time slot NL/R, the queue is empty at the beginning of time slot NL/R. Thus, when new packets arrive at the beginning of time slot NL/R, the situation is exactly the same as the situation occurred at the beginning of time slot 0. As a result, the average delay is $(N-1)L/(2R)$. If N approaches infinity, the average delay also approaches infinity.

(c) For both (a) and (b), the packet arrival rate is $1/(L/R)$ packets per second, i.e., R/L packets per second. Thus, the traffic intensity is $R/L \times L/R = 1$.

Even if two systems have the same traffic intensity, the average delay highly depends on the arrivals of the packets, and the queuing delay can vary from packet to packet.

Q 3 *Explain the five-layer Internet protocol stack. Please include the following details:*

- *What are the five layers?*
- *What is the functionality or description of each layer?*
- *What are the typical protocols of each layer (if any)?*

Solution:

Layers	Functionality or Description	Protocols
Application layer	This layer is where network applications reside. Typical applications include web, email, video streaming, etc.	HTTP, FTP, SMTP, DNS
Transport layer	This layer transports application-layer messages between application endpoints, i.e., processes.	TCP, UDP
Network layer	This layer is responsible for moving network packets from one host to another.	IP
Link layer	This layer is responsible for moving a packet from one node (i.e., host or router) to another.	Ethernet, WiFi
Physical layer	This layer moves individuals bits from one node to another over the wire or wireless medium.	The protocols depend on the actual transmission medium (e.g., twisted-pair cooper wire, radio)

Q 4 *Consider the following message and answer questions.*

(a) *Does HTTP message run on top of TCP or UDP? Why is TCP or UDP a better choice? Please explain the reason by considering the features of TCP or UDP.*

(b) *Is this message an HTTP request message or an HTTP response message?*

(c) *Does this message corresponds to a non-persistent or a persistent connection?*

(d) *Suppose the browser who sent this message was assigned an identification number 1150 by the associated host. What is the corresponding entry in the cookie file of the browser? To specific its cookie, which header line (including header field name and value) should be included in the message?*

(e) *If the server receives this message successfully and is going to return the requested object in a message, what would be the status line? What would be included in the entity body?*

GET /cs453/index.html HTTP/1.1<cr><lf>Host: gaia.cs.umass.edu<cr><lf>User-Agent: Mozilla/5.0 (Windows;U; Windows NT 5.1; en-US; rv:1.7.2) Gecko/20040804 Netscape/7.2 (ax) <cr><lf>Accept:ext/xml, application/xml, application/xhtml+xml, text /html;q=0.9, text/plain;q=0.8, image/png,*/*;q=0.5<cr><lf>Accept-Language: en-us, en;q=0.5<cr><lf>Accept-Encoding: zip,deflate<cr><lf>Accept-Charset: ISO-8859-1, utf-8;q=0.7,*;q=0.7<cr><lf>Keep-Alive: 300<cr><lf>Connection:keep-alive<cr><lf><cr><lf>

Solution:

(a) HTTP runs on top of TCP. This is because many web services (e.g., web-based email, web-based online platform) require reliable data transfer, and TCP can provide reliable data transfer. In addition, those web services are usually elastic application, so there is no need to use UDP to reduce the latency and improve the throughput.

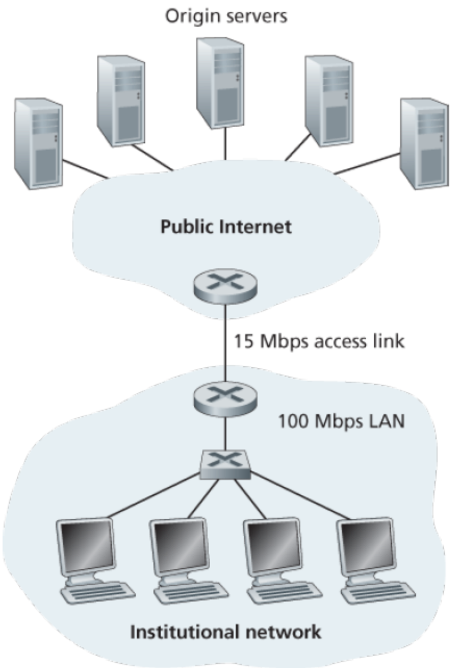
(b) HTTP request message.

(c) Persistent connection.

(d) gaia.cs.umass.edu: 1150 (or umass.edu: 1150); Cookie: 1150.

(e) HTTP/1.1 200 OK; the base HTML file at URL gaia.cs.umass.edu/cs453/index.html

Q 5 *Consider the following figure with an institutional network connected to the Internet. Consider an object*



size of $650,000$ *bits. Suppose the institution's browsers has an average request rate of 20 requests per second, and all those requests are sent to the origin servers. Suppose the average Internet delay, i.e., the average round trip time that the router on the Internet side of the access link sends a requests to the origin servers, is three seconds. Let*

$$\texttt{Total Average Response Time} = \texttt{Average Access Delay} + \texttt{Average Internet Delay}. \quad (2)$$

The average access delay is the delay from Internet router to institution router. The average access delay is equal to $\Delta/(1-\Delta\beta)$*, where* Δ *is the average time required to send an object over the access link, and* β *is the arrival rate at the access link.*

(a) Derive the total average response time of the system.

(b) Suppose there is a cache installed in the institutional LAN, and the hit rate is 0.4. Derive the total response time.

Solution:

(a) The time to transmit an object of size L over a link or rate R is L/R. The average time is the average size of the object divided by R: $\Delta = (650,000bits)/(15,000,000bits/sec) = 0.0433sec$. The average access delay is $(0.04333sec)/(1 - (20requests/sec)(0.0433sec/request)) \approx 0.323sec$. The total average response time is therefore $0.323sec + 3sec = 3.323sec$.

(b) Since the arrival rate at the access link is reduced to 60%, the average access delay is $(0.0432sec)/[1 - (0.6 \times 20requests/sec)(0.0433sec)] = 0.090sec$. The response time is approximately zero if the request is satisfied by the cache (which happens with probability 0.4); the average response time is $0.090sec + 3sec = 3.90sec$ for cache misses (which happens 60% of the time). So the average response time is $(0.4)(0sec) + (0.6)(3.090sec) = 1.854sec$. Thus the average response time is reduced from 3.323 sec to 1.854 sec.

Q 6 *Suppose you click a web page within your Web browser, and your local DNS server does not have any related resource records. Assume that before your host receives the IP address from DNS, the successive visits incur RTT of $RTT_1, \ldots, RTT_n$. On the web page you visit, there are an HTTP basic file and ten referenced objects. Let RTT_0 denote the RTT between the local host and the Web server. We ignore the transmission time of the objects. Compute how much time elapses from when you click the link until your web browser receives the objects.*

(a) Non-persistent HTTP with no parallel TCP connections?

(b) Non-persistent HTTP with the browser configured for 4 parallel connections?

(c) Persistent HTTP? In this case, the client can send requests of referenced object back-to-back without waiting for the responses.

Solution:

(a) $\sum_{i=1}^{n} RTT_n + 2RTT_0 + 2 \times 10 \times RTT_0$

(b) $\sum_{i=1}^{n} RTT_n + 2RTT_0 + 2 \times \lceil \frac{10}{4} \rceil \times RTT_0$

(c) $\sum_{i=1}^{n} RTT_n + 2RTT_0 + RTT_0$

Q 7 *Answer the following questions:*

(a) Explain the differences between HTTP and SMTP

(b) Can SMTP be used as a mail access protocol? Why?

(c) Can we place the receiver's mail server at the receiver's PC? How about placing the sender's mail server at the sender's PC?

(d) Does DNS run on top of TCP or UDP? Why?

Solution:

(a)
- HTTP is a pull protocol; SMTP is a push protocol
- In HTTP messages, the headers should be encoded in ASCII; in SMTP messages, both the header and body must be encoded in ASCII
- With HTTP, each object is encapsulated in its own HTTP message; with SMTP, all objects of a message can be placed in one SMTP message

(b) No. For mail access, the receiver's user agent obains messages from the receiver's mail server using a pull operation. Since SMTP is a push protocol, it cannot be used.

(c) No, because the receiver's mail server should be always-on. No, because the sender's mail server may fail in sending messages sometimes, and it needs to try multiple times until it succeeds. Having the sender's mail sever locate at the sender's PC will put too much load on that PC.

(d) UDP. This is because DNS query and reply messages are usually small packets. Thus, it is more efficient to use to UDP to transfer, as UDP can achieve a lower latency than TCP.

Note: It is also OK if the students answered both TCP and UDP, and explain the scenarios where UDP or TCP is preferred.

Q 8 *Consider a server distributes a file of $F = 15$ Gbits to N peers. The server has a upload rate of $u_s = 30$ Mbps. Each peer has a upload rate of u Mbps and a download rate of $d = 2$ Mbps. Please plot or draw the following curves with x-axis corresponding to N (ranging from 1 to 1000) and y-axis corresponding to the minimum distribution time.*

(a) Client-server distribution

(b) P2P distribution with $u = 100$ Kbps, 600 Kbps, 4 Mbps, respectively.

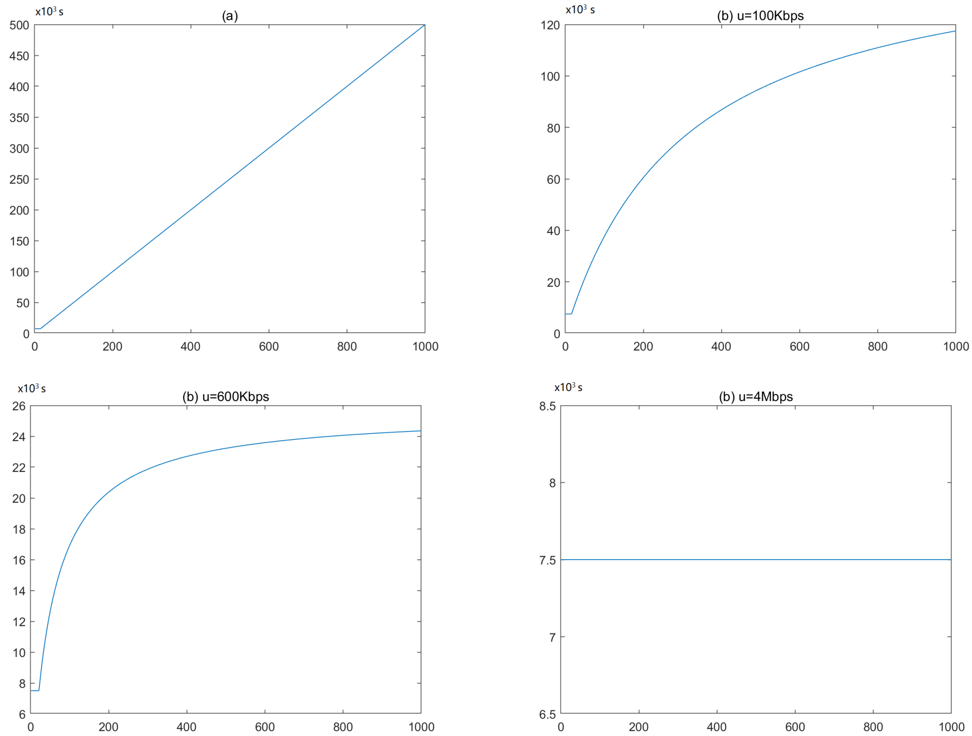
Solution:

(a) Client-server distribution: The minimum distribution time is equal to

$$\max\{\frac{NF}{u_s}, \frac{F}{d}\} = \max\{\frac{15000N}{30}, \frac{15000}{2}\} \tag{3}$$

(b) P2P distribution: The minimum distribution time is equal to

$$\max\{\frac{F}{u_s}, \frac{F}{d}, \frac{NF}{u_s + Nu}\} = \max\{\frac{15000}{30}, \frac{15000}{2}, \frac{15000N}{30 + Nu}\} \tag{4}$$



Q 9 *Consider distributing a file of F bits to N peers using a client-server architecture. Assume a fluid model where the server can simultaneously transmit to multiple peers, transmitting to each peer at different rates, as long as the combined rate does not exceed u_s.*

(a) Suppose that $u_s/N \leq d_{min}$. Specify a distribution scheme that has a distribution time of NF/u_s.

(b) Suppose that $u_s/N \geq d_{min}$. Specify a distribution scheme that has a distribution time of F/d_{min}.

(c) Conclude that the minimum distribution time is in general given by $\max\{NF/u_s, F/d_{min}\}$.

Solution:

(a) The bandwidth is evenly distributed. That is, the server transmits to N user at the same time, and the rate of each user is u_s/N. Thus, distribution time is equal to NF/u_s.

(b) The server transmits to N users at the same time. The rate assigned to each user is d_{min}. The distribution time is F/d_{min}.

(c) The total bits that the server needs to distribute is NF, and the server bandwidth is u_s, therefore $t \geq NF/u_s$. The client with the lowest download rate needs time $t \geq F/d_{min}$. Therefore, the minimum distribution time is in general given by $max\{NF/u_s, F/d_{min}\}$.