Question 1: In this problem we will compare file transfer over circuit-switched versus packet-switched networks. Assume propagation, queueing and processing delays are all 0. **(10 points)**

File size: 800,000 bits
Link transmission rate is 10Mbps
<u>A user at Host A wants to send a file to Host B over the network.</u>

For (a) thru (e) assume a circuit-switched network which is shared by 20 users and it takes 500msec to establish a connection.

a. What is the transmission rate available to each user?
R= 10^6/20 = 500kbps

b. What is the transmission time to send the file?
Solution: D = L/R = 800,000 / 500,000 = 1.6 seconds

c. What is the total time to send the file? 1.6 + 500msec = 2.1sec

d. If the only active connection over this network is between Host A and Host B, can they utilize some of the extra available bandwidth to speed up their transmissions? Why or not? (explain) No, resources pre-allocated in circuit-switching.

e. State one advantage and one disadvantage of the circuit-switched method and explain your answer. Adv – guarantees (throughput, delay, reliability etc) Dis – cannot reclaim unused bandwidth (wasted resources)

For (f) thru (h) assume the network is a <u>packet-switched network</u> using statistical multiplexing.

f. What is the transmission rate available to Host A? 10Mbps

g. What is the total time to transmit the file from Host A to Host B (assuming no other traffic on the network)? 800,000/10Mbps = 0.08 seconds = 80msec

h. State one benefit and one disadvantage of a packet-switched approach in this context.
Adv – support more users, no wasted bandwidth, whole bandwidth available to user
Dis – No guarantees in terms of delay or throughput, no path guarantees

Question 4: We have discussed several measurements of network performance, namely delay and throughput. **(10 points)**

a. What is instantaneous throughput?
Rate at which receiver is receiving data bits/sec

b. What is average throughput?
F/T considered over time

c. What is a bottleneck link and how does it affect throughput?

Rate-limiting link, minimum of all links on path

d. A nice aspects of living on a campus is the high speed 100Mps LAN. However, the access link to the Internet is 10Mbps. If you are the only one using the Internet, what would you expect your average throughput to be? Explain.]

10Mbps – cannot achieve throughput higher than bottleneck link

e. On a Friday night, you and 4 friends are all watching movies on the same network described in (d) at the same time. If you are the only users, what would you expect the average throughput for each user to be?

10/5 = 2Mbps

f. What network appliance could the network administrators install in the network to insure the access link is not over-ulitilized? How does this appliance help?

Cache – distribute content locally; reduce usage on access link

Question 5: Consider a situation in which a hacker makes all the DNS servers in the world crash simultaneously. **(5 points)**

a. How does this change one's ability to use the web browser to access sites on the Internet?

Would need to know the IP address of any site you wanted to visit. Addresses could still be cached for a while…

b. Is DNS organized in a way to prevent this kind of attack? Explain your answer.

Yes – both the <u>hierarchy</u> of name servers and the <u>replication</u> of content help to make the system fault tolerant. DNS is organized to be resilient to this kind of attack.

Question 2: Consider two hosts connected to each other through a router. Demonstrate your understanding of delay by describing the following: **(8 points)**

a. What is the meaning of nodal delay and write the equation for it:
Packet delay through router on path.
Dnodal = Dproc + Dq + Dprop + Dtrans

b. Define <u>each component</u> of the nodal delay.
Dproc: examine pkt header, checksum, forwarding etc.
Dq: waiting for transmission in queue
Dprop: prop delay of link (e.g. speed of light)
Dtrans: time to pump out bits onto link (link capacity)

c. Are all of the terms constant over time? Explain.
No, Dq depends on changing network conditions.

d. Is it possible for packets transmitted over the Internet to be dropped by routers? Why or why not and where does this happen? Yes, as congestion builds, delay increases and packets begin to fill up the queues in the routers. Packets dropped when queue capacity exceeded.

Questions 3: (8 points)

a. How long does it take a packet of length 500 bytes to propagate over a link of distance 10,000 km, propagation speed 2.5 x 10^8 m/s, and transmission rate 1 Gbps?

Dtrans = 500*8/10^9 = 0.004msec + Dprop = 10000/2.5x10^8 = 40msec

b. What contributes more to the overall delay in this example, transmission or propagation delay? Propagation

c. What would be the link utilization for Stop and Wait?

U = (L/R)/(RTT+L/R) = 0.004/0.044 = 0.009

d. How could the link utilization be increased? pipeline

Question 6: Short answers (**10 points**)

a. Give an example of a hierarchy that we discussed in class and briefly explain why a hierarchy is useful in your example. DNS, IP address space, postal addresses, network of networks (internet structure) – all discussed in class.

b. Why are GoBackN and Selective repeat better protocols than Stop and Wait?
They use the capacity of the network to allow more than one unacknowledged packet to be transmitted, i.e. pipelining. Increases utilization and throughput.

c. Suppose 10 packets are being transmitted between two hosts using GoBackN with a window size of 10. All of the packets are transmitted before any acknowledgements arrive. Suppose the 2nd packet transmitted is lost.

i. How will the sender know that a packet was lost? timeout

ii. How many packets will be retransmitted? State your assumptions. 9 or 10 (for 9 it could be ack1 received and window about to slide but sn11 not yet transmitted, so 9 are outstanding. Alternatively, sn11 is transmitted, which causes 10 packets to be outstanding)

iii. What is one benefit of this protocol? Higher throughput, ease of implementation, no buffers at receiver required, no state except last received

d. Suppose 10 packets are being transmitted between two hosts using Selective Repeat with a window size of 10. All of the packets are transmitted before any acknowledgements arrive. Suppose the 2nd packet transmitted is lost.

i. How will the sender know that a packet was lost? timeout

ii. How many packets will be retransmitted? Just one

iii. What additional work does Selective Repeat have to do compared to GoBackN?

Buffers at receiver, accounting at both sender and receiver to keep track of what's been acked; timer for every packet

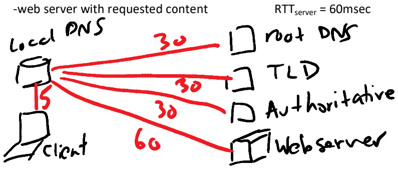
iv. What is a benefit of Selective Repeat over GoBackN? Avoid unnecessary retransmissions

Question 7: Suppose within your web browser you enter a URL to obtain a Web page. The IP address for the web server is not cached in your local host and 3 DNS servers must be visited (e.g. root, TLD and authoritative) before the address is finally resolved. **(15 points)**

a. Draw a picture with all of the end systems and mark the RTT between devices:

RTT from client to device

-your client/browser	
-local DNS Server	$RTT_{LocalDNS}$ = 5msec
-3 additional DNS servers	RTT_{DNS} = 30msec (same RTT for each of the 3 servers)
-web server with requested content	RTT_{server} = 60msec



b. Enumerate all of the steps that need to be taken by the application (i.e. the browser) from the time you enter the URL until the base HTML page can arrive back to your browser:
1. Resolve DNS 2. Open TCP connection to web server 3. Request web page

c. How long does it take from the time the URL is first entered until the base HTML web page reaches your browser? (Assume 0 transmission time for all transfers). Show ALL YOUR CALCULATIONS.

Resolve DNS + Open TCP connection to web server + Request web page from web server

95 + 60 + 60 = 215msec

d. Suppose there are 5 embedded objects in the base HTML page that must be retrieved from the web server. How long does it take IN TOTAL (include your answer is b)to display the full web page if your client is using:

i.Non-persistent HTTP with no pipelining (show all work):

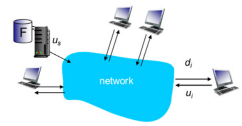
(c) + 5x(open tcp + http request of object) = 215 + 5(120) = 815msec

ii. Persistent HTTP with pipelining (show all work):

(c) + http request (pipelined) = 215 + 60 = 275msec

e. There are 2 ways the time to load this page could be reduced using caching. Describe one of the ways cacheing could be used and how it reduces the latency to load the web page.
DNS cache or web cache

Question 8: In class we discussed the file distribution time in a network using the Client-Server architecture compared to a Peer to Peer. We want to determine the time required to distribute a file from one Server to N clients. The distribution is complete when **all** clients have received the file. **(15 points)**



The network is shown on the left; the upload rate for the Server (u_s) and clients(u_i) as well the Client download rates (d_i) are indicated.

Consider a Client-Server architecture in questions (a) through (f):

a. If *N* clients request the same file (F bytes), how many copies of the file must the Server transmit? N

b. What is the total time requirement for the server to complete its required upload? NF/u_s

c. Let d_{min} be the bottleneck link among the clients. How does d_{min} affect the download time of all the clients? Limits→distribution not complete until slowest client receives

d. Considering only the client download time, what is the minimum time it takes for the file to be distributed to all of the clients? F/d_i where d_i is the bottleneck

e. Considering your answer in (b) and (d), finish the equation for the distribution time $D_{c\text{-}s}$ below (possible terms are F, u_s, u_i, d_i, N, F):

$D_{c\text{-}s} \geq max\{ NF/u_s, F/d_i \}$

f. How does the distribution time increase as the number of clients requesting the file grows? Grows with N

Now we consider the same problem using a P2P architecture, i.e. one server and N peers requesting the file of size F bits:

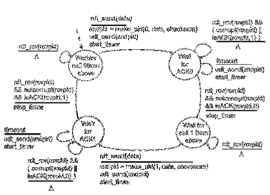
a. How many copies of the file (F bytes) is the server required to upload? 1

b. How does the role of the clients change in this P2P architecture? Become servers

c. What can any peer receiving the file from the Server do as bits of the file begin to arrive? Upload content

d. How does the distribution time increase as the number of clients/peers requesting the file grows? Nearly constant with N

Question 9: Below is the state machine for rdt 3.0 which provides for reliable data transfer given both transmission errors and data loss over an unreliable data channel. **(10 points)**



a. What mechanism does rtd 3.0 use to check for transmission errors? checksum

b. What mechanism did we need to introduce so that the protocol includes the capability for the receiver to detect duplicate packets? Sequence numbers

c. What mechanism is included so that the Sender knows when a packet has been dropped or lost? timer

d. For what two events does the Sender remain in a "Wait for ACK" state? (explain your answer)
1. Corrupted ACK packet || wrong SN
2. timeout

e. What event causes the Sender to transition out of a "Wait for ACK" state? (explain your answer) Correct SN in ACK and uncorrupted ACK received

f. How were negative acknowledgements eliminated from the protocol? SNs in ACK packets

Question 10: In class, we discussed three different locations for Web caches, namely on the client's host, in the Internet service provider's network, and in the content provider's network. Explain how each of these caches can improve performance in terms of user response time, Internet traffic load, and content provider server load. Pictures help! **(9 points)** see class notes

Host: decrease response time, dec Internet and content provider

ISP: middle. Response time can be reduced (avoid origin server). Reduce traffic on ISP->ISP access link

Content Provider: cache can serve as a load balancer… time savings in response time due to decreased load on server can be passed on to client . No Internet savings

Extra Credit: see class notes. If underlying channel is reliable NACK can be used to indicate bit errors. On lossy channel Sender and Receiver can become disconnected.