

# ***Computer Networking: A Top-Down Approach, 6<sup>th</sup> Edition***

## **Solutions to Review Questions and Problems**

**Version Date: May 2012**

### **Chapter 1 Review Questions**

1. There is no difference. Throughout this text, the words “host” and “end system” are used interchangeably. End systems include PCs, workstations, Web servers, mail servers, PDAs, Internet-connected game consoles, etc.
2. From Wikipedia: Diplomatic protocol is commonly described as a set of international courtesy rules. These well-established and time-honored rules have made it easier for nations and people to live and work together. Part of protocol has always been the acknowledgment of the hierarchical standing of all present. Protocol rules are based on the principles of civility.
3. Standards are important for protocols so that people can create networking systems and products that interoperate.
4. 1. Dial-up modem over telephone line: home; 2. DSL over telephone line: home or small office; 3. Cable to HFC: home; 4. 100 Mbps switched Ethernet: enterprise; 5. Wifi (802.11): home and enterprise; 6. 3G and 4G: wide-area wireless.
5. HFC bandwidth is shared among the users. On the downstream channel, all packets emanate from a single source, namely, the head end. Thus, there are no collisions in the downstream channel.
6. In most American cities, the current possibilities include: dial-up; DSL; cable modem; fiber-to-the-home.
7. Ethernet LANs have transmission rates of 10 Mbps, 100 Mbps, 1 Gbps and 10 Gbps.
8. Today, Ethernet most commonly runs over twisted-pair copper wire. It also can run over fibers optic links.
9. Dial up modems: up to 56 Kbps, bandwidth is dedicated; ADSL: up to 24 Mbps downstream and 2.5 Mbps upstream, bandwidth is dedicated; HFC, rates up to 42.8 Mbps and upstream

rates of up to 30.7 Mbps, bandwidth is shared. FTTH: 2-10Mbps upload; 10-20 Mbps download; bandwidth is not shared.

10. There are two popular wireless Internet access technologies today:

- a) Wifi (802.11) In a wireless LAN, wireless users transmit/receive packets to/from a base station (i.e., wireless access point) within a radius of few tens of meters. The base station is typically connected to the wired Internet and thus serves to connect wireless users to the wired network.
- b) 3G and 4G wide-area wireless access networks. In these systems, packets are transmitted over the same wireless infrastructure used for cellular telephony, with the base station thus being managed by a telecommunications provider. This provides wireless access to users within a radius of tens of kilometers of the base station.

11. At time  $t_0$  the sending host begins to transmit. At time  $t_1 = L/R_1$ , the sending host completes transmission and the entire packet is received at the router (no propagation delay). Because the router has the entire packet at time  $t_1$ , it can begin to transmit the packet to the receiving host at time  $t_1$ . At time  $t_2 = t_1 + L/R_2$ , the router completes transmission and the entire packet is received at the receiving host (again, no propagation delay). Thus, the end-to-end delay is  $L/R_1 + L/R_2$ .

12. A circuit-switched network can guarantee a certain amount of end-to-end bandwidth for the duration of a call. Most packet-switched networks today (including the Internet) cannot make any end-to-end guarantees for bandwidth. FDM requires sophisticated analog hardware to shift signal into appropriate frequency bands.

13. a) 2 users can be supported because each user requires half of the link bandwidth.

- b) Since each user requires 1Mbps when transmitting, if two or fewer users transmit simultaneously, a maximum of 2Mbps will be required. Since the available bandwidth of the shared link is 2Mbps, there will be no queuing delay before the link.

Whereas, if three users transmit simultaneously, the bandwidth required will be 3Mbps which is more than the available bandwidth of the shared link. In this case, there will be queuing delay before the link.

- c) Probability that a given user is transmitting = 0.2

- d) Probability that all three users are transmitting simultaneously =  $\binom{3}{3} p^3 (1-p)^{3-3}$

=  $(0.2)^3 = 0.008$ . Since the queue grows when all the users are transmitting, the fraction of time during which the queue grows (which is equal to the probability that all three users are transmitting simultaneously) is 0.008.

14. If the two ISPs do not peer with each other, then when they send traffic to each other they have to send the traffic through a provider ISP (intermediary), to which they have to pay for carrying the traffic. By peering with each other directly, the two ISPs can reduce their

payments to their provider ISPs. An Internet Exchange Points (IXP) (typically in a standalone building with its own switches) is a meeting point where multiple ISPs can connect and/or peer together. An ISP earns its money by charging each of the the ISPs that connect to the IXP a relatively small fee, which may depend on the amount of traffic sent to or received from the IXP.

15. Google's private network connects together all its data centers, big and small. Traffic between the Google data centers passes over its private network rather than over the public Internet. Many of these data centers are located in, or close to, lower tier ISPs. Therefore, when Google delivers content to a user, it often can bypass higher tier ISPs. What motivates content providers to create these networks? First, the content provider has more control over the user experience, since it has to use few intermediary ISPs. Second, it can save money by sending less traffic into provider networks. Third, if ISPs decide to charge more money to highly profitable content providers (in countries where net neutrality doesn't apply), the content providers can avoid these extra payments.
16. The delay components are processing delays, transmission delays, propagation delays, and queuing delays. All of these delays are fixed, except for the queuing delays, which are variable.
17. a) 1000 km, 1 Mbps, 100 bytes  
b) 100 km, 1 Mbps, 100 bytes
18. 10msec; d/s; no; no
19. a) 500 kbps  
b) 64 seconds  
c) 100kbps; 320 seconds
20. End system A breaks the large file into chunks. It adds header to each chunk, thereby generating multiple packets from the file. The header in each packet includes the IP address of the destination (end system B). The packet switch uses the destination IP address in the packet to determine the outgoing link. Asking which road to take is analogous to a packet asking which outgoing link it should be forwarded on, given the packet's destination address.
21. The maximum emission rate is 500 packets/sec and the maximum transmission rate is 350 packets/sec. The corresponding traffic intensity is  $500/350 = 1.43 > 1$ . Loss will eventually occur for each experiment; but the time when loss first occurs will be different from one experiment to the next due to the randomness in the emission process.
22. Five generic tasks are error control, flow control, segmentation and reassembly, multiplexing, and connection setup. Yes, these tasks can be duplicated at different layers. For example, error control is often provided at more than one layer.

23. The five layers in the Internet protocol stack are – from top to bottom – the application layer, the transport layer, the network layer, the link layer, and the physical layer. The principal responsibilities are outlined in Section 1.5.1.
24. Application-layer message: data which an application wants to send and passed onto the transport layer; transport-layer segment: generated by the transport layer and encapsulates application-layer message with transport layer header; network-layer datagram: encapsulates transport-layer segment with a network-layer header; link-layer frame: encapsulates network-layer datagram with a link-layer header.
25. Routers process network, link and physical layers (layers 1 through 3). (This is a little bit of a white lie, as modern routers sometimes act as firewalls or caching components, and process Transport layer as well.) Link layer switches process link and physical layers (layers 1 through 2). Hosts process all five layers.
26. a) Virus  
Requires some form of human interaction to spread. Classic example: E-mail viruses.
- b) Worms  
No user replication needed. Worm in infected host scans IP addresses and port numbers, looking for vulnerable processes to infect.
27. Creation of a botnet requires an attacker to find vulnerability in some application or system (e.g. exploiting the buffer overflow vulnerability that might exist in an application). After finding the vulnerability, the attacker needs to scan for hosts that are vulnerable. The target is basically to compromise a series of systems by exploiting that particular vulnerability. Any system that is part of the botnet can automatically scan its environment and propagate by exploiting the vulnerability. An important property of such botnets is that the originator of the botnet can remotely control and issue commands to all the nodes in the botnet. Hence, it becomes possible for the attacker to issue a command to all the nodes, that target a single node (for example, all nodes in the botnet might be commanded by the attacker to send a TCP SYN message to the target, which might result in a TCP SYN flood attack at the target).
28. Trudy can pretend to be Bob to Alice (and vice-versa) and partially or completely modify the message(s) being sent from Bob to Alice. For example, she can easily change the phrase “Alice, I owe you \$1000” to “Alice, I owe you \$10,000”. Furthermore, Trudy can even drop the packets that are being sent by Bob to Alice (and vice-versa), even if the packets from Bob to Alice are encrypted.

## Chapter 1 Problems

### Problem 1

There is no single right answer to this question. Many protocols would do the trick. Here's a simple answer below:

### Messages from ATM machine to Server

Msg name	purpose
HELO <userid>	Let server know that there is a card in the ATM machine
PASSWD <passwd>	ATM card transmits user ID to Server
BALANCE	User enters PIN, which is sent to server
WITHDRAWAL <amount>	User requests balance
BYE	User asks to withdraw money
	user all done

### Messages from Server to ATM machine (display)

Msg name	purpose
PASSWD	Ask user for PIN (password)
OK	last requested operation (PASSWD, WITHDRAWAL) OK
ERR	last requested operation (PASSWD, WITHDRAWAL) in ERROR
AMOUNT <amt>	sent in response to BALANCE request
BYE	user done, display welcome screen at ATM

### Correct operation:

client	server
HELO (userid)	-----> (check if valid userid)
	<----- PASSWD
PASSWD <passwd>	-----> (check password)
	<----- OK (password is OK)
BALANCE	----->
	<----- AMOUNT <amt>
WITHDRAWAL <amt>	-----> check if enough \$ to cover withdrawal
	<----- OK
ATM dispenses \$	
BYE	----->
	<----- BYE

### In situation when there's not enough money:

HELO (userid)	-----> (check if valid userid)
	<----- PASSWD
PASSWD <passwd>	-----> (check password)
	<----- OK (password is OK)
BALANCE	----->
	<----- AMOUNT <amt>
WITHDRAWAL <amt>	-----> check if enough \$ to cover withdrawal
	<----- ERR (not enough funds)
error msg displayed	
no \$ given out	

BYE                      ----->  
                                  <-----        BYE

## Problem 2

At time  $N*(L/R)$  the first packet has reached the destination, the second packet is stored in the last router, the third packet is stored in the next-to-last router, etc. At time  $N*(L/R) + L/R$ , the second packet has reached the destination, the third packet is stored in the last router, etc. Continuing with this logic, we see that at time  $N*(L/R) + (P-1)*(L/R) = (N+P-1)*(L/R)$  all packets have reached the destination.

## Problem 3

- a) A circuit-switched network would be well suited to the application, because the application involves long sessions with predictable smooth bandwidth requirements. Since the transmission rate is known and not bursty, bandwidth can be reserved for each application session without significant waste. In addition, the overhead costs of setting up and tearing down connections are amortized over the lengthy duration of a typical application session.
- b) In the worst case, all the applications simultaneously transmit over one or more network links. However, since each link has sufficient bandwidth to handle the sum of all of the applications' data rates, no congestion (very little queuing) will occur. Given such generous link capacities, the network does not need congestion control mechanisms.

## Problem 4

- a) Between the switch in the upper left and the switch in the upper right we can have 4 connections. Similarly we can have four connections between each of the 3 other pairs of adjacent switches. Thus, this network can support up to 16 connections.
- b) We can 4 connections passing through the switch in the upper-right-hand corner and another 4 connections passing through the switch in the lower-left-hand corner, giving a total of 8 connections.
- c) Yes. For the connections between A and C, we route two connections through B and two connections through D. For the connections between B and D, we route two connections through A and two connections through C. In this manner, there are at most 4 connections passing through any link.

## Problem 5

Tollbooths are 75 km apart, and the cars propagate at 100km/hr. A tollbooth services a car at a rate of one car every 12 seconds.

- a) There are ten cars. It takes 120 seconds, or 2 minutes, for the first tollbooth to service the 10 cars. Each of these cars has a propagation delay of 45 minutes (travel 75 km) before arriving at the second tollbooth. Thus, all the cars are lined up before the second tollbooth after 47 minutes. The whole process repeats itself for traveling between the second and third tollbooths. It also takes 2 minutes for the third tollbooth to service the 10 cars. Thus the total delay is 96 minutes.
- b) Delay between tollbooths is  $8 \times 12$  seconds plus 45 minutes, i.e., 46 minutes and 36 seconds. The total delay is twice this amount plus  $8 \times 12$  seconds, i.e., 94 minutes and 48 seconds.

## Problem 6

- a)  $d_{prop} = m / s$  seconds.
- b)  $d_{trans} = L / R$  seconds.
- c)  $d_{end-to-end} = (m / s + L / R)$  seconds.
- d) The bit is just leaving Host A.
- e) The first bit is in the link and has not reached Host B.
- f) The first bit has reached Host B.
- g) Want

$$m = \frac{L}{R} s = \frac{120}{56 \times 10^3} (2.5 \times 10^8) = 536 \text{ km.}$$

## Problem 7

Consider the first bit in a packet. Before this bit can be transmitted, all of the bits in the packet must be generated. This requires

$$\frac{56 \cdot 8}{64 \times 10^3} \text{ sec} = 7 \text{ msec.}$$

The time required to transmit the packet is

$$\frac{56 \cdot 8}{2 \times 10^6} \text{ sec} = 224 \mu \text{ sec.}$$

Propagation delay = 10 msec.

The delay until decoding is

$$7\text{msec} + 224\mu\text{sec} + 10\text{msec} = 17.224\text{msec}$$

A similar analysis shows that all bits experience a delay of 17.224 msec.

### Problem 8

a) 20 users can be supported.

b)  $p = 0.1$ .

c)  $\binom{120}{n} p^n (1-p)^{120-n}$ .

d)  $1 - \sum_{n=0}^{20} \binom{120}{n} p^n (1-p)^{120-n}$ .

We use the central limit theorem to approximate this probability. Let  $X_j$  be independent random variables such that  $P(X_j = 1) = p$ .

$$P(\text{"21 or more users"}) = 1 - P\left(\sum_{j=1}^{120} X_j \leq 21\right)$$

$$P\left(\sum_{j=1}^{120} X_j \leq 21\right) = P\left(\frac{\sum_{j=1}^{120} X_j - 12}{\sqrt{120 \cdot 0.1 \cdot 0.9}} \leq \frac{9}{\sqrt{120 \cdot 0.1 \cdot 0.9}}\right)$$

$$\approx P\left(Z \leq \frac{9}{3.286}\right) = P(Z \leq 2.74)$$

$$= 0.997$$

when  $Z$  is a standard normal r.v. Thus  $P(\text{"21 or more users"}) \approx 0.003$ .

### Problem 9

a) 10,000

b)  $\sum_{n=N+1}^M \binom{M}{n} p^n (1-p)^{M-n}$

### Problem 10

The first end system requires  $L/R_1$  to transmit the packet onto the first link; the packet propagates over the first link in  $d_1/s_1$ ; the packet switch adds a processing delay of  $d_{proc}$ ; after receiving the entire packet, the packet switch connecting the first and the second link requires  $L/R_2$  to transmit the packet onto the second link; the packet propagates over the second link in  $d_2/s_2$ . Similarly, we



can find the delay caused by the second switch and the third link:  $L/R_3$ ,  $d_{proc}$ , and  $d_3/s_3$ .

Adding these five delays gives

$$d_{end-end} = L/R_1 + L/R_2 + L/R_3 + d_1/s_1 + d_2/s_2 + d_3/s_3 + d_{proc} + d_{proc}$$

To answer the second question, we simply plug the values into the equation to get  $6 + 6 + 6 + 20 + 16 + 4 + 3 + 3 = 64$  msec.

## Problem 11

Because bits are immediately transmitted, the packet switch does not introduce any delay; in particular, it does not introduce a transmission delay. Thus,

$$d_{end-end} = L/R + d_1/s_1 + d_2/s_2 + d_3/s_3$$

For the values in Problem 10, we get  $6 + 20 + 16 + 4 = 46$  msec.

## Problem 12

The arriving packet must first wait for the link to transmit  $4.5 * 1,500$  bytes = 6,750 bytes or 54,000 bits. Since these bits are transmitted at 2 Mbps, the queuing delay is 27 msec. Generally, the queuing delay is  $(nL + (L - x))/R$ .

## Problem 13

- a) The queuing delay is 0 for the first transmitted packet,  $L/R$  for the second transmitted packet, and generally,  $(n-1)L/R$  for the  $n^{th}$  transmitted packet. Thus, the average delay for the  $N$  packets is:

$$\begin{aligned} & (L/R + 2L/R + \dots + (N-1)L/R)/N \\ &= L/(RN) * (1 + 2 + \dots + (N-1)) \\ &= L/(RN) * N(N-1)/2 \\ &= LN(N-1)/(2RN) \\ &= (N-1)L/(2R) \end{aligned}$$

Note that here we used the well-known fact:

$$1 + 2 + \dots + N = N(N+1)/2$$

- b) It takes  $LN/R$  seconds to transmit the  $N$  packets. Thus, the buffer is empty when a each batch of  $N$  packets arrive. Thus, the average delay of a packet across all batches is the average delay within one batch, i.e.,  $(N-1)L/2R$ .

### Problem 14

- a) The transmission delay is  $L/R$ . The total delay is

$$\frac{IL}{R(1-I)} + \frac{L}{R} = \frac{L/R}{1-I}$$

- b) Let  $x = L/R$ .

$$\text{Total delay} = \frac{x}{1-ax}$$

For  $x=0$ , the total delay  $=0$ ; as we increase  $x$ , total delay increases, approaching infinity as  $x$  approaches  $1/a$ .

### Problem 15

$$\text{Total delay} = \frac{L/R}{1-I} = \frac{L/R}{1-aL/R} = \frac{1/\mu}{1-a/\mu} = \frac{1}{\mu-a}.$$

### Problem 16

The total number of packets in the system includes those in the buffer and the packet that is being transmitted. So,  $N=10+1$ .

Because  $N = a \cdot d$ , so  $(10+1)=a \cdot (\text{queuing delay} + \text{transmission delay})$ . That is,  $11=a \cdot (0.01+1/100)=a \cdot (0.01+0.01)$ . Thus,  $a=550$  packets/sec.

### Problem 17

- a) There are  $Q$  nodes (the source host and the  $Q-1$  routers). Let  $d_{proc}^q$  denote the processing delay at the  $q$ th node. Let  $R^q$  be the transmission rate of the  $q$ th link and let

$d_{trans}^q = L/R^q$ . Let  $d_{prop}^q$  be the propagation delay across the  $q$ th link. Then

$$d_{end-to-end} = \sum_{q=1}^Q [d_{proc}^q + d_{trans}^q + d_{prop}^q].$$

- b) Let  $d_{queue}^q$  denote the average queuing delay at node  $q$ . Then

$$d_{end-to-end} = \sum_{q=1}^Q [d_{proc}^q + d_{trans}^q + d_{prop}^q + d_{queue}^q].$$

## Problem 18

On linux you can use the command

```
traceroute www.targethost.com
```

and in the Windows command prompt you can use

```
tracert www.targethost.com
```

In either case, you will get three delay measurements. For those three measurements you can calculate the mean and standard deviation. Repeat the experiment at different times of the day and comment on any changes.

Here is an example solution:

```
traceroute to www.poly.edu (128.238.24.40), 30 hops max, 40 byte packets
 1 thunder.sdsc.edu (132.249.20.5)  2.802 ms  0.645 ms  0.484 ms
 2 dolphin.sdsc.edu (132.249.31.17)  0.227 ms  0.248 ms  0.239 ms
 3 dc-sdg-aggr1--sdsc-1.cenic.net (137.164.23.129)  0.360 ms  0.260 ms  0.240 ms
 4 dc-riv-core1--sdg-aggr1-10ge-2.cenic.net (137.164.47.14)  8.847 ms  8.497 ms  8.230 ms
 5 dc-lax-core1--lax-core2-10ge-2.cenic.net (137.164.46.64)  9.969 ms  9.920 ms  9.846 ms
 6 dc-lax-px1--lax-core1-10ge-2.cenic.net (137.164.46.151)  9.845 ms  9.729 ms  9.724 ms
 7 hurricane--lax-px1-ge.cenic.net (198.32.251.86)  9.971 ms  16.981 ms  9.850 ms
 8 10gigabitethernet4-3.core1.nyc4.he.net (72.52.92.225)  72.796 ms  80.278 ms  72.346 ms
 9 10gigabitethernet3-4.core1.nyc5.he.net (184.105.213.218)  71.126 ms  71.442 ms  73.623 ms
10 lighttower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net (216.66.50.106)  70.924 ms  70.959 ms  71.072 ms
11 ae0.nycmnyzrj91.lighttower.net (72.22.160.156)  70.870 ms  71.089 ms  70.957 ms
12 72.22.188.102 (72.22.188.102)  71.242 ms  71.228 ms  71.102 ms
```

```
traceroute to www.poly.edu (128.238.24.40), 30 hops max, 40 byte packets
 1 thunder.sdsc.edu (132.249.20.5)  0.478 ms  0.353 ms  0.308 ms
 2 dolphin.sdsc.edu (132.249.31.17)  0.212 ms  0.251 ms  0.238 ms
 3 dc-sdg-aggr1--sdsc-1.cenic.net (137.164.23.129)  0.237 ms  0.246 ms  0.240 ms
 4 dc-riv-core1--sdg-aggr1-10ge-2.cenic.net (137.164.47.14)  8.628 ms  8.348 ms  8.357 ms
 5 dc-lax-core1--lax-core2-10ge-2.cenic.net (137.164.46.64)  9.934 ms  9.963 ms  9.852 ms
 6 dc-lax-px1--lax-core1-10ge-2.cenic.net (137.164.46.151)  9.831 ms  9.814 ms  9.676 ms
 7 hurricane--lax-px1-ge.cenic.net (198.32.251.86)  10.194 ms  10.012 ms  16.722 ms
 8 10gigabitethernet4-3.core1.nyc4.he.net (72.52.92.225)  73.856 ms  73.196 ms  73.979 ms
 9 10gigabitethernet3-4.core1.nyc5.he.net (184.105.213.218)  71.247 ms  71.199 ms  71.646 ms
10 lighttower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net (216.66.50.106)  70.987 ms  71.073 ms  70.985 ms
11 ae0.nycmnyzrj91.lighttower.net (72.22.160.156)  71.075 ms  71.042 ms  71.328 ms
12 72.22.188.102 (72.22.188.102)  71.626 ms  71.299 ms  72.236 ms
```

```

1 thunder.sdsc.edu (132.249.20.5) 0.403 ms 0.347 ms 0.358 ms
2 dolphin.sdsc.edu (132.249.31.17) 0.225 ms 0.244 ms 0.237 ms
3 dc-sdg-aggr1--sdsc-1.cenic.net (137.164.23.129) 0.362 ms 0.256 ms 0.239 ms
4 dc-riv-core1--sdg-aggr1-10ge-2.cenic.net (137.164.47.14) 8.850 ms 8.358 ms 8.227 ms
5 dc-lax-core1--lax-core2-10ge-2.cenic.net (137.164.46.64) 10.096 ms 9.869 ms 10.351 ms
6 dc-lax-px1--lax-core1-10ge-2.cenic.net (137.164.46.151) 9.721 ms 9.621 ms 9.725 ms
7 hurricane--lax-px1-ge.cenic.net (198.32.251.86) 11.345 ms 10.048 ms 13.844 ms
8 10gigabitethernet4-3.core1.nyc4.he.net (72.52.92.225) 71.920 ms 72.977 ms 77.264 ms
9 10gigabitethernet3-4.core1.nyc5.he.net (184.105.213.218) 71.273 ms 71.247 ms 71.291 ms
10 lighttower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net (216.66.50.106) 71.114 ms 82.516 ms 71.136 ms
11 ae0.nycmnyzrj91.lighttower.net (72.22.160.156) 71.232 ms 71.071 ms 71.039 ms
12 72.22.188.102 (72.22.188.102) 71.585 ms 71.608 ms 71.493 ms

```

### Traceroutes between San Diego Super Computer Center and [www.poly.edu](http://www.poly.edu)

- The average (mean) of the round-trip delays at each of the three hours is 71.18 ms, 71.38 ms and 71.55 ms, respectively. The standard deviations are 0.075 ms, 0.21 ms, 0.05 ms, respectively.
- In this example, the traceroutes have 12 routers in the path at each of the three hours. No, the paths didn't change during any of the hours.
- Traceroute packets passed through four ISP networks from source to destination. Yes, in this experiment the largest delays occurred at peering interfaces between adjacent ISPs.

```

traceroute to www.poly.edu (128.238.24.40), 30 hops max, 60 byte packets
1 62-193-36-1.stella-net.net (62.193.36.1) 0.500 ms 0.415 ms 0.440 ms
2 62.193.33.29 (62.193.33.29) 0.910 ms 1.065 ms 1.026 ms
3 bg1.stella-net.net (62.193.32.254) 0.972 ms 1.026 ms 1.078 ms
4 62.193.32.66 (62.193.32.66) 1.021 ms 0.988 ms 0.947 ms
5 10gigabitethernet2-2.par2.he.net (195.42.144.104) 1.537 ms 1.752 ms 1.714 ms
6 10gigabitethernet7-1.core1.ash1.he.net (184.105.213.93) 80.273 ms 80.103 ms 79.971 ms
7 10gigabitethernet1-2.core1.nyc4.he.net (72.52.92.85) 86.494 ms 85.872 ms 86.223 ms
8 10gigabitethernet3-4.core1.nyc5.he.net (184.105.213.218) 85.248 ms 85.424 ms 85.388 ms
9 lighttower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net (216.66.50.106) 86.194 ms 85.864 ms 86.116 ms
10 ae0.nycmnyzrj91.lighttower.net (72.22.160.156) 85.796 ms 85.823 ms 85.766 ms
11 72.22.188.102 (72.22.188.102) 87.717 ms 86.817 ms 86.774 ms

```

```

traceroute to www.poly.edu (128.238.24.40), 30 hops max, 60 byte packets
 1 62-193-36-1.stella-net.net (62.193.36.1) 0.375 ms 0.397 ms 0.355 ms
 2 62.193.33.29 (62.193.33.29) 0.810 ms 0.877 ms 0.836 ms
 3 bg1.stella-net.net (62.193.32.254) 1.098 ms 0.991 ms 1.055 ms
 4 62.193.32.66 (62.193.32.66) 0.994 ms 0.960 ms 1.157 ms
 5 10gigabitethernet-2-2.par2.he.net (195.42.144.104) 1.679 ms 1.816 ms 1.768 ms
 6 10gigabitethernet7-1.core1.ash1.he.net (184.105.213.93) 80.416 ms 90.573 ms 90.659 ms
 7 10gigabitethernet1-2.core1.nyc4.he.net (72.52.92.85) 85.933 ms 95.987 ms 96.087 ms
 8 10gigabitethernet3-4.core1.nyc5.he.net (184.105.213.218) 90.268 ms 90.229 ms 90.030 ms
 9 lighttower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net (216.66.50.106) 85.833 ms 85.448 ms 85.418 ms
10 ae0.nycmnyzrj91.lighttower.net (72.22.160.156) 87.067 ms 86.025 ms 85.962 ms
11 72.22.188.102 (72.22.188.102) 86.542 ms 86.369 ms 86.170 ms

```

```

traceroute to 128.238.24.40 (128.238.24.40), 30 hops max, 60 byte packets
 1 62-193-36-1.stella-net.net (62.193.36.1) 0.396 ms 0.284 ms 0.239 ms
 2 62.193.33.29 (62.193.33.29) 0.817 ms 0.786 ms 0.848 ms
 3 bg1.stella-net.net (62.193.32.254) 1.150 ms 1.216 ms 1.265 ms
 4 62.193.32.66 (62.193.32.66) 1.002 ms 0.963 ms 0.923 ms
 5 10gigabitethernet-2-2.par2.he.net (195.42.144.104) 1.573 ms 1.534 ms 1.643 ms
 6 10gigabitethernet7-1.core1.ash1.he.net (184.105.213.93) 88.738 ms 82.866 ms 82.783 ms
 7 10gigabitethernet1-2.core1.nyc4.he.net (72.52.92.85) 94.888 ms 90.936 ms 90.877 ms
 8 10gigabitethernet3-4.core1.nyc5.he.net (184.105.213.218) 90.498 ms 90.543 ms 90.482 ms
 9 lighttower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net (216.66.50.106) 85.716 ms 85.408 ms 85.637 ms
10 ae0.nycmnyzrj91.lighttower.net (72.22.160.156) 85.779 ms 85.290 ms 85.252 ms
11 72.22.188.102 (72.22.188.102) 86.217 ms 86.652 ms 86.588 ms

```

**Traceroutes from [www.stella-net.net](http://www.stella-net.net) (France) to [www.poly.edu](http://www.poly.edu) (USA).**

- d) The average round-trip delays at each of the three hours are 87.09 ms, 86.35 ms and 86.48 ms, respectively. The standard deviations are 0.53 ms, 0.18 ms, 0.23 ms, respectively. In this example, there are 11 routers in the path at each of the three hours. No, the paths didn't change during any of the hours. Traceroute packets passed three ISP networks from source to destination. Yes, in this experiment the largest delays occurred at peering interfaces between adjacent ISPs.

## Problem 19

An example solution:



```

traceroute to www.poly.edu (128.238.24.30), 30 hops max, 60 byte packets
 1 62-193-36-1.stella-net.net (62.193.36.1) 0.426 ms 0.329 ms 0.284 ms
 2 62.193.33.25 (62.193.33.25) 0.810 ms 0.771 ms 0.878 ms
 3 62.193.32.66 (62.193.32.66) 0.815 ms 0.840 ms 0.801 ms
 4 10gigabitethernet-2-2.par2.he.net (195.42.144.104) 1.387 ms 1.506 ms 1.467 ms
 5 10gigabitethernet7-1.core1.ash1.he.net (184.105.213.93) 85.402 ms 85.553 ms 85.353 ms
 6 10gigabitethernet1-2.core1.nyc4.he.net (72.52.92.85) 94.360 ms 96.220 ms 96.355 ms
 7 10gigabitethernet3-4.core1.nyc5.he.net (184.105.213.218) 90.279 ms 87.459 ms 87.709 ms
 8 lighttower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net (216.66.50.106) 85.474 ms 85.450 ms 85.983 ms
 9 ae0.nycmnyzrj91.lighttower.net (72.22.160.156) 86.160 ms 85.768 ms 86.016 ms
10 72.22.188.102 (72.22.188.102) 124.111 ms 89.340 ms 89.556 ms

```

```

 1 vl200.hs01.mar01.jaguar-network.net (85.31.192.253) 0.552 ms 0.414 ms
 2 ae1.cr01.mar01.jaguar-network.net (85.31.194.9) 0.340 ms 0.213 ms
 3 xe2-0-0.cr01.par02.jaguar-network.net (78.153.231.201) 9.933 ms 9.841 ms
 4 te1-3.er01.par02.jaguar-network.net (85.31.194.14) 9.828 ms 9.962 ms
 5 10gigabitethernet-2-2.par2.he.net (195.42.144.104) 10.456 ms 10.332 ms
 6 10gigabitethernet7-1.core1.ash1.he.net (184.105.213.93) 88.793 ms 96.781 ms
 7 10gigabitethernet1-2.core1.nyc4.he.net (72.52.92.85) 94.651 ms 99.654 ms
 8 10gigabitethernet3-4.core1.nyc5.he.net (184.105.213.218) 94.786 ms 94.755 ms
 9 lighttower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net (216.66.50.106) 91.935 ms 91.776 ms
10 ae0.nycmnyzrj91.lighttower.net (72.22.160.156) 91.909 ms 91.784 ms
11 72.22.188.102 (72.22.188.102) 93.791 ms 93.515 ms

```

## Traceroutes from two different cities in France to New York City in United States

- a) In these traceroutes from two different cities in France to the same destination host in United States, seven links are in common including the transatlantic link.

```

traceroute to www.poly.edu (128.238.24.30), 30 hops max, 60 byte packets
 1
 2 hos-tr3.juniper2.rz10.hetzner.de 213.239.224.65 de 0.224 ms *
   hos-tr2.juniper1.rz10.hetzner.de 213.239.224.33 de 0.174 ms 0.176 ms
 3 hos-bb1.juniper1.ffm.hetzner.de 213.239.240.224 de 4.746 ms 4.780 ms
   hos-bb1.juniper4.ffm.hetzner.de 213.239.240.230 de 4.823 ms
 4 20gigabitethernet4-3.core1.fra1.he.net 80.81.192.172 de 5.462 ms 5.461 ms 5.456 ms
 5 10gigabitethernet1-4.core1.ams1.he.net 72.52.92.94 us 12.899 ms
   10gigabitethernet5-3.core1.ams1.he.net 72.52.92.77 us 13.197 ms
   10gigabitethernet5-3.core1.lon1.he.net 184.105.213.145 us 26.110 ms
 6 10gigabitethernet1-4.core1.lon1.he.net 72.52.92.81 us 18.720 ms 18.871 ms 18.862 ms
 7 10gigabitethernet7-4.core1.nyc4.he.net 72.52.92.241 us 86.677 ms 85.580 ms 86.560 ms
 8 lighttower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net 216.66.50.106 us 118.500 ms
   10gigabitethernet3-4.core1.nyc5.he.net 184.105.213.218 us 90.346 ms
   lighttower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net 216.66.50.106 us 118.500 ms
 9 ae0.nycmnyzrj91.lighttower.net 72.22.160.156 us 85.289 ms 85.552 ms 85.283 ms

```

```

traceroute to www.poly.edu (128.238.24.30), 30 hops max, 60 byte packets
 1 62-193-36-1.stella-net.net (62.193.36.1) 0.426 ms 0.329 ms 0.284 ms
 2 62.193.33.25 (62.193.33.25) 0.810 ms 0.771 ms 0.878 ms
 3 62.193.32.66 (62.193.32.66) 0.815 ms 0.840 ms 0.801 ms
 4 10gigabitethernet-2-2.par2.he.net (195.42.144.104) 1.387 ms 1.506 ms 1.467 ms
 5 10gigabitethernet7-1.core1.ash1.he.net (184.105.213.93) 85.402 ms 85.553 ms 85.353 ms
 6 10gigabitethernet1-2.core1.nyc4.he.net (72.52.92.85) 94.360 ms 96.220 ms 96.355 ms
 7 10gigabitethernet3-4.core1.nyc5.he.net (184.105.213.218) 90.279 ms 87.459 ms 87.709 ms
 8 lighttower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net (216.66.50.106) 85.474 ms 85.450 ms 85.983 ms
 9 ae0.nycmnyzrj91.lighttower.net (72.22.160.156) 86.160 ms 85.768 ms 86.016 ms
10 72.22.188.102 (72.22.188.102) 124.111 ms 89.340 ms 89.556 ms

```

- b) In this example of traceroutes from one city in France and from another city in Germany to the same host in United States, three links are in common including the transatlantic link.

```

Tracing route to www.autoisp.shu.edu.cn [27.115.83.251]
over a maximum of 30 hops:
 1      9 ms      8 ms      10 ms    10.40.32.1
 2      12 ms     12 ms     9 ms     gig-3-0-4-nycmnyj-rtr1.nyc.rr.com [24.29.119.189]
 3      21 ms     20 ms     22 ms     tenge-0-6-0-0-nyquny91-rtr001.nyc.rr.com [24.29.100.122]
 4      19 ms     21 ms     22 ms     bun6-nyquny91-rtr002.nyc.rr.com [24.29.148.254]
 5      11 ms     11 ms     19 ms     ae-3-0-cr0.nyc20.tbone.rr.com [66.109.6.76]
 6      14 ms     18 ms     14 ms     ae-0-0-pr0.nyc30.tbone.rr.com [66.109.6.159]
 7      14 ms     11 ms     10 ms     xe-9-0-0-edge2.Newark1.Level3.net [4.59.20.29]
 8      12 ms     10 ms     13 ms     ae-31-51.ebr1.Newark1.Level3.net [4.69.156.30]
 9      10 ms     15 ms     13 ms     ae-2-2.ebr1.NewYork1.Level3.net [4.69.132.97]
10      11 ms     17 ms     14 ms     ae-81-81.csw3.NewYork1.Level3.net [4.69.134.74]
11      12 ms     14 ms     11 ms     ae-82-82.ebr2.NewYork1.Level3.net [4.69.148.41]
12      83 ms     83 ms     88 ms     ae-2-2.ebr4.SanJose1.Level3.net [4.69.135.185]
13      91 ms     87 ms     84 ms     ae-71-71.csw2.SanJose1.Level3.net [4.69.153.6]
14      83 ms     83 ms     88 ms     ae-2-70.edge3.SanJose1.Level3.net [4.69.152.82]
15      595 ms    593 ms    600 ms    CHINA-NETCO.edge3.SanJose1.Level3.net [4.79.54.6]
16      594 ms    591 ms    592 ms    219.158.96.213
17      539 ms    540 ms    540 ms    219.158.11.173
18      593 ms    586 ms    585 ms    219.158.19.93
19      585 ms    585 ms    584 ms    219.158.21.246
20      568 ms    587 ms    569 ms    112.64.243.62
21      570 ms    566 ms    568 ms    112.64.243.146
22      342 ms    341 ms    347 ms    112.65.183.106
23      574 ms    571 ms    573 ms    27.115.83.251

Trace complete.

```

```

Tracing route to www.lb.pku.edu.cn [162.105.131.113]
over a maximum of 30 hops:
 1      8 ms      8 ms      8 ms     10.40.32.1
 2      14 ms     9 ms     10 ms     gig-0-3-0-18-nycmnyj-rtr1.nyc.rr.com [24.168.138.85]
 3      21 ms     10 ms     11 ms     tenge-0-6-0-0-nyquny91-rtr001.nyc.rr.com [24.29.100.122]
 4      13 ms     22 ms     22 ms     bun6-nyquny91-rtr002.nyc.rr.com [24.29.148.254]
 5      11 ms     18 ms     12 ms     ae-3-0-cr0.nyc20.tbone.rr.com [66.109.6.76]
 6      43 ms     38 ms     41 ms     ae-8-0-cr0.chi10.tbone.rr.com [66.109.6.25]
 7      86 ms     88 ms     88 ms     ae-6-0-cr0.sjc30.tbone.rr.com [66.109.6.14]
 8      86 ms     89 ms     91 ms     ae-1-0-pr0.sjc10.tbone.rr.com [66.109.6.137]
 9      87 ms     86 ms     86 ms     66.109.10.210
10      257 ms    258 ms    258 ms     ge3-0-0.gw4.hkg3.asianetcom.net [61.14.157.250]
11      298 ms    296 ms    295 ms     CER-0002.gw4.hkg3.asianetcom.net [203.192.137.198]
12      297 ms    305 ms    305 ms    202.112.61.13
13      295 ms    296 ms    296 ms    202.112.61.157
14      *          *          *          Request timed out.
15      298 ms    302 ms    298 ms    202.112.41.178
16      308 ms    300 ms    300 ms    202.112.41.182

```

## Traceroutes to two different cities in China from same host in United States

- c) Five links are common in the two traceroutes. The two traceroutes diverge before reaching China

### Problem 20

$$\text{Throughput} = \min\{R_s, R_c, R/M\}$$

### Problem 21

If only use one path, the max throughput is given by:

$$\max\{\min\{R_1^1, R_2^1, \dots, R_N^1\}, \min\{R_1^2, R_2^2, \dots, R_N^2\}, \dots, \min\{R_1^M, R_2^M, \dots, R_N^M\}\}.$$

If use all paths, the max throughput is given by  $\sum_{k=1}^M \min\{R_1^k, R_2^k, \dots, R_N^k\}.$

### Problem 22

Probability of successfully receiving a packet is:  $p_s = (1-p)^N.$

The number of transmissions needed to be performed until the packet is successfully received by the client is a geometric random variable with success probability  $p_s$ . Thus, the average number of transmissions needed is given by:  $1/p_s$ . Then, the average number of re-transmissions needed is given by:  $1/p_s - 1$ .

### Problem 23

Let's call the first packet A and call the second packet B.

- a) If the bottleneck link is the first link, then packet B is queued at the first link waiting for the transmission of packet A. So the packet inter-arrival time at the destination is simply  $L/R_s$ .
- b) If the second link is the bottleneck link and both packets are sent back to back, it must be true that the second packet arrives at the input queue of the second link before the second link finishes the transmission of the first packet. That is,

$$L/R_s + L/R_s + d_{prop} < L/R_s + d_{prop} + L/R_c$$

The left hand side of the above inequality represents the time needed by the second packet to arrive at the input queue of the second link (the second link has not started transmitting the



second packet yet). The right hand side represents the time needed by the first packet to finish its transmission onto the second link.

If we send the second packet  $T$  seconds later, we will ensure that there is no queuing delay for the second packet at the second link if we have:

$$L/R_s + L/R_s + d_{prop} + T \geq L/R_s + d_{prop} + L/R_c$$

Thus, the minimum value of  $T$  is  $L/R_c - L/R_s$ .

## Problem 24

40 terabytes =  $40 * 10^{12} * 8$  bits. So, if using the dedicated link, it will take  $40 * 10^{12} * 8 / (100 * 10^6) = 3200000$  seconds = 37 days. But with FedEx overnight delivery, you can guarantee the data arrives in one day, and it should cost less than \$100.

## Problem 25

- a) 160,000 bits
- b) 160,000 bits
- c) The bandwidth-delay product of a link is the maximum number of bits that can be in the link.
- d) the width of a bit = length of link / bandwidth-delay product, so 1 bit is 125 meters long, which is longer than a football field
- e)  $s/R$

## Problem 26

$s/R = 200000\text{km}$ , then  $R = s/200000\text{km} = 2.5 * 10^8 / (2 * 10^7) = 12.5$  bps

## Problem 27

- a) 80,000,000 bits
- b) 800,000 bits, this is because that the maximum number of bits that will be in the link at any given time =  $\min(\text{bandwidth delay product, packet size}) = 800,000$  bits.
- c) .25 meters

## Problem 28

- a)  $t_{trans} + t_{prop} = 400 \text{ msec} + 80 \text{ msec} = 480 \text{ msec}$ .
- b)  $20 * (t_{trans} + 2 t_{prop}) = 20 * (20 \text{ msec} + 80 \text{ msec}) = 2 \text{ sec}$ .

- c) Breaking up a file takes longer to transmit because each data packet and its corresponding acknowledgement packet add their own propagation delays.

### Problem 29

Recall geostationary satellite is 36,000 kilometers away from earth surface.

- a) 150 msec
- b) 1,500,000 bits
- c) 600,000,000 bits

### Problem 30

Let's suppose the passenger and his/her bags correspond to the data unit arriving to the top of the protocol stack. When the passenger checks in, his/her bags are checked, and a tag is attached to the bags and ticket. This is additional information added in the Baggage layer in Figure 1.20 that allows the Baggage layer to implement the service of separating the passengers and baggage on the sending side, and then reuniting them (hopefully!) on the destination side. When a passenger then passes through security and additional stamp is often added to his/her ticket, indicating that the passenger has passed through a security check. This information is used to ensure (e.g., by later checks for the security information) secure transfer of people.

### Problem 31

- a) Time to send message from source host to first packet switch =  $\frac{8 \times 10^6}{2 \times 10^6} \text{ sec} = 4 \text{ sec}$  With store-and-forward switching, the total time to move message from source host to destination host =  $4 \text{ sec} \times 3 \text{ hops} = 12 \text{ sec}$
- b) Time to send 1<sup>st</sup> packet from source host to first packet switch =  $\frac{1 \times 10^4}{2 \times 10^6} \text{ sec} = 5 \text{ msec}$ . Time at which 2<sup>nd</sup> packet is received at the first switch = time at which 1<sup>st</sup> packet is received at the second switch =  $2 \times 5 \text{ msec} = 10 \text{ msec}$
- c) Time at which 1<sup>st</sup> packet is received at the destination host =  $5 \text{ msec} \times 3 \text{ hops} = 15 \text{ msec}$ . After this, every 5msec one packet will be received; thus time at which last (800<sup>th</sup>) packet is received =  $15 \text{ msec} + 799 * 5 \text{ msec} = 4.01 \text{ sec}$ . It can be seen that delay in using message segmentation is significantly less (almost 1/3<sup>rd</sup>).
- d)
  - i. Without message segmentation, if bit errors are not tolerated, if there is a single bit error, the whole message has to be retransmitted (rather than a single packet).
  - ii. Without message segmentation, huge packets (containing HD videos, for example) are sent into the network. Routers have to accommodate these huge packets. Smaller packets have to queue behind enormous packets and suffer unfair delays.
- e)
  - i. Packets have to be put in sequence at the destination.

- ii. Message segmentation results in many smaller packets. Since header size is usually the same for all packets regardless of their size, with message segmentation the total amount of header bytes is more.

### Problem 32

Yes, the delays in the applet correspond to the delays in the Problem 31. The propagation delays affect the overall end-to-end delays both for packet switching and message switching equally.

### Problem 33

There are  $F/S$  packets. Each packet is  $S=80$  bits. Time at which the last packet is received at the first router is  $\frac{S+80}{R} \times \frac{F}{S}$  sec. At this time, the first  $F/S-2$  packets are at the destination, and the  $F/S-1$  packet is at the second router. The last packet must then be transmitted by the first router and the second router, with each transmission taking  $\frac{S+80}{R}$  sec. Thus delay in sending the whole

$$\text{file is } \text{delay} = \frac{S+80}{R} \times \left( \frac{F}{S} + 2 \right)$$

To calculate the value of  $S$  which leads to the minimum delay,

$$\frac{d}{dS} \text{delay} = 0 \Rightarrow S = \sqrt{40F}$$

### Problem 34

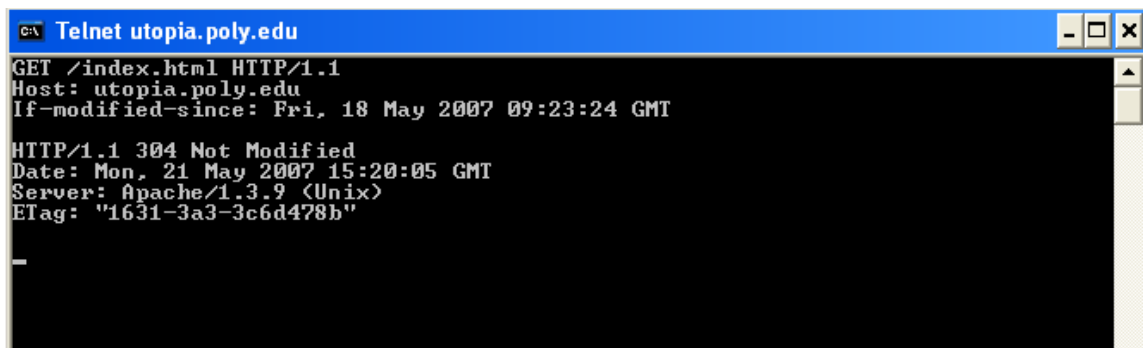
The circuit-switched telephone networks and the Internet are connected together at "gateways". When a Skype user (connected to the Internet) calls an ordinary telephone, a circuit is established between a gateway and the telephone user over the circuit switched network. The skype user's voice is sent in packets over the Internet to the gateway. At the gateway, the voice signal is reconstructed and then sent over the circuit. In the other direction, the voice signal is sent over the circuit switched network to the gateway. The gateway packetizes the voice signal and sends the voice packets to the Skype user.

## Chapter 2 Review Questions

1. The Web: HTTP; file transfer: FTP; remote login: Telnet; e-mail: SMTP; BitTorrent file sharing: BitTorrent protocol
2. Network architecture refers to the organization of the communication process into layers (e.g., the five-layer Internet architecture). Application architecture, on the other hand, is designed by an application developer and dictates the broad structure of the application (e.g., client-server or P2P).
3. The process which initiates the communication is the client; the process that waits to be contacted is the server.
4. No. In a P2P file-sharing application, the peer that is receiving a file is typically the client and the peer that is sending the file is typically the server.
5. The IP address of the destination host and the port number of the socket in the destination process.
6. You would use UDP. With UDP, the transaction can be completed in one roundtrip time (RTT) - the client sends the transaction request into a UDP socket, and the server sends the reply back to the client's UDP socket. With TCP, a minimum of two RTTs are needed - one to set-up the TCP connection, and another for the client to send the request, and for the server to send back the reply.
7. One such example is remote word processing, for example, with Google docs. However, because Google docs runs over the Internet (using TCP), timing guarantees are not provided.
8. a) Reliable data transfer  
TCP provides a reliable byte-stream between client and server but UDP does not.  
  
b) A guarantee that a certain value for throughput will be maintained  
Neither  
  
c) A guarantee that data will be delivered within a specified amount of time  
Neither  
  
d) Confidentiality (via encryption)  
Neither
9. SSL operates at the application layer. The SSL socket takes unencrypted data from the application layer, encrypts it and then passes it to the TCP socket. If the application developer wants TCP to be enhanced with SSL, she has to include the SSL code in the application.

10. A protocol uses handshaking if the two communicating entities first exchange control packets before sending data to each other. SMTP uses handshaking at the application layer whereas HTTP does not.
11. The applications associated with those protocols require that all application data be received in the correct order and without gaps. TCP provides this service whereas UDP does not.
12. When the user first visits the site, the server creates a unique identification number, creates an entry in its back-end database, and returns this identification number as a cookie number. This cookie number is stored on the user's host and is managed by the browser. During each subsequent visit (and purchase), the browser sends the cookie number back to the site. Thus the site knows when this user (more precisely, this browser) is visiting the site.
13. Web caching can bring the desired content "closer" to the user, possibly to the same LAN to which the user's host is connected. Web caching can reduce the delay for all objects, even objects that are not cached, since caching reduces the traffic on links.
14. Telnet is not available in Windows 7 by default. to make it available, go to Control Panel, Programs and Features, Turn Windows Features On or Off, Check Telnet client. To start Telnet, in Windows command prompt, issue the following command  
> telnet webserver 80

where "webserver" is some webserver. After issuing the command, you have established a TCP connection between your client telnet program and the web server. Then type in an HTTP GET message. An example is given below:



```
C:\> Telnet utopia.poly.edu
GET /index.html HTTP/1.1
Host: utopia.poly.edu
If-modified-since: Fri, 18 May 2007 09:23:24 GMT

HTTP/1.1 304 Not Modified
Date: Mon, 21 May 2007 15:20:05 GMT
Server: Apache/1.3.9 (Unix)
ETag: "1631-3a3-3c6d478b"
```

Since the index.html page in this web server was not modified since Fri, 18 May 2007 09:23:34 GMT, and the above commands were issued on Sat, 19 May 2007, the server returned "304 Not Modified". Note that the first 4 lines are the GET message and header lines inputted by the user, and the next 4 lines (starting from HTTP/1.1 304 Not Modified) is the response from the web server.

15. FTP uses two parallel TCP connections, one connection for sending control information (such as a request to transfer a file) and another connection for actually transferring the file.

Because the control information is not sent over the same connection that the file is sent over, FTP sends control information out of band.

16. The message is first sent from Alice's host to her mail server over HTTP. Alice's mail server then sends the message to Bob's mail server over SMTP. Bob then transfers the message from his mail server to his host over POP3.

17.

Received: from 65.54.246.203 (EHLO bay0-omc3-s3.bay0.hotmail.com) (65.54.246.203) by mta419.mail.mud.yahoo.com with SMTP; Sat, 19 May 2007 16:53:51 -0700  
Received: from hotmail.com ([65.55.135.106]) by bay0-omc3-s3.bay0.hotmail.com with Microsoft SMTPSVC(6.0.3790.2668); Sat, 19 May 2007 16:52:42 -0700  
Received: from mail pickup service by hotmail.com with Microsoft SMTPSVC; Sat, 19 May 2007 16:52:41 -0700  
Message-ID: <BAY130-F26D9E35BF59E0D18A819AFB9310@phx.gbl>  
Received: from 65.55.135.123 by by130fd.bay130.hotmail.msn.com with HTTP; Sat, 19 May 2007 23:52:36 GMT  
From: "prithula dhungel" <prithuladhungel@hotmail.com>  
To: [prithula@yahoo.com](mailto:prithula@yahoo.com)  
Bcc:  
Subject: Test mail  
Date: Sat, 19 May 2007 23:52:36 +0000  
Mime-Version: 1.0  
Content-Type: Text/html; format=flowed  
Return-Path: [prithuladhungel@hotmail.com](mailto:prithuladhungel@hotmail.com)

**Figure: A sample mail message header**

Received: This header field indicates the sequence in which the SMTP servers send and receive the mail message including the respective timestamps.

In this example there are 4 "Received:" header lines. This means the mail message passed through 5 different SMTP servers before being delivered to the receiver's mail box. The last (forth) "Received:" header indicates the mail message flow from the SMTP server of the sender to the second SMTP server in the chain of servers. The sender's SMTP server is at address 65.55.135.123 and the second SMTP server in the chain is by130fd.bay130.hotmail.msn.com.

The third "Received:" header indicates the mail message flow from the second SMTP server in the chain to the third server, and so on.

Finally, the first "Received:" header indicates the flow of the mail messages from the forth SMTP server to the last SMTP server (i.e. the receiver's mail server) in the chain.

Message-id: The message has been given this number BAY130-F26D9E35BF59E0D18A819AFB9310@phx.gbl (by bay0-omc3-s3.bay0.hotmail.com. Message-id is a unique string assigned by the mail system when the message is first created.

From: This indicates the email address of the sender of the mail. In the given example, the sender is “prithuladhungel@hotmail.com”

To: This field indicates the email address of the receiver of the mail. In the example, the receiver is “prithula@yahoo.com”

Subject: This gives the subject of the mail (if any specified by the sender). In the example, the subject specified by the sender is “Test mail”

Date: The date and time when the mail was sent by the sender. In the example, the sender sent the mail on 19th May 2007, at time 23:52:36 GMT.

Mime-version: MIME version used for the mail. In the example, it is 1.0.

Content-type: The type of content in the body of the mail message. In the example, it is “text/html”.

Return-Path: This specifies the email address to which the mail will be sent if the receiver of this mail wants to reply to the sender. This is also used by the sender’s mail server for bouncing back undeliverable mail messages of mailer-daemon error messages. In the example, the return path is “prithuladhungel@hotmail.com”.

18. With download and delete, after a user retrieves its messages from a POP server, the messages are deleted. This poses a problem for the nomadic user, who may want to access the messages from many different machines (office PC, home PC, etc.). In the download and keep configuration, messages are not deleted after the user retrieves the messages. This can also be inconvenient, as each time the user retrieves the stored messages from a new machine, all of non-deleted messages will be transferred to the new machine (including very old messages).
19. Yes an organization’s mail server and Web server can have the same alias for a host name. The MX record is used to map the mail server’s host name to its IP address.
20. You should be able to see the sender's IP address for a user with an .edu email address. But you will not be able to see the sender's IP address if the user uses a gmail account.
21. It is not necessary that Bob will also provide chunks to Alice. Alice has to be in the top 4 neighbors of Bob for Bob to send out chunks to her; this might not occur even if Alice provides chunks to Bob throughout a 30-second interval.
22. Recall that in BitTorrent, a peer picks a random peer and optimistically unchokes the peer for a short period of time. Therefore, Alice will eventually be optimistically unchoked by one of her neighbors, during which time she will receive chunks from that neighbor.
23. The overlay network in a P2P file sharing system consists of the nodes participating in the file sharing system and the logical links between the nodes. There is a logical link (an “edge”

in graph theory terms) from node A to node B if there is a semi-permanent TCP connection between A and B. An overlay network does not include routers.

24. Mesh DHT: The advantage is in order to route a message to the peer (with ID) that is closest to the key, only one hop is required; the disadvantage is that each peer must track all other peers in the DHT. Circular DHT: the advantage is that each peer needs to track only a few other peers; the disadvantage is that  $O(N)$  hops are needed to route a message to the peer that is closest to the key.
- 25.
- a) File Distribution
  - b) Instant Messaging
  - c) Video Streaming
  - d) Distributed Computing
26. With the UDP server, there is no welcoming socket, and all data from different clients enters the server through this one socket. With the TCP server, there is a welcoming socket, and each time a client initiates a connection to the server, a new socket is created. Thus, to support  $n$  simultaneous connections, the server would need  $n+1$  sockets.
27. For the TCP application, as soon as the client is executed, it attempts to initiate a TCP connection with the server. If the TCP server is not running, then the client will fail to make a connection. For the UDP application, the client does not initiate connections (or attempt to communicate with the UDP server) immediately upon execution



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