Solutions to Homework #1
Due 11:59pm, Monday, 5 February, 2017
Multiple submissions accepted.

1. Traceroutes

- Finding sites to traceroute can be tough. UH seems to block many, as does AT&T's U-Verse service.
- The last line of a successful traceroute will include the name of the target site. Example:

```
kevinlong$ traceroute www.rice.edu
traceroute to www.netfu.rice.edu (128.42.204.11), 64 hops max, 52 byte packets
 1  g1-cs5.sw-e.uh.edu (172.16.255.15)  13.414 ms  4.275 ms  1.092 ms
 2  172.25.255.254 (172.25.255.254)  8.971 ms  1.758 ms  9.812 ms
 3  547-pgh-ha0-t1-2-6.sw-e.uh.edu (172.16.106.152)  1.956 ms  1.754 ms  1.589 ms
 4  p2p-vesp-te4-7.e.uh.edu (172.16.102.93)  2.699 ms  3.546 ms  5.665 ms
 5  172.16.96.91 (172.16.96.91)  4.883 ms  15.234 ms  1.232 ms
 6  caesar-vlan1915.uh.edu (129.7.0.253)  3.203 ms  10.214 ms  3.058 ms
 7  caesar-junos_vlan2809.e.uh.edu (172.16.102.69)  7.948 ms  11.015 ms  10.506 ms
 8  hardy-rtr1.setg.net (198.32.228.129)  8.828 ms  1.721 ms  1.563 ms
 9  rice-1.setg.net (198.32.228.138)  1.851 ms  8.159 ms  6.020 ms
10  10.128.191.5 (10.128.191.5)  3.527 ms  11.316 ms  4.200 ms
11  172.16.191.241 (172.16.191.241)  13.887 ms  10.081 ms  10.427 ms
12  172.16.0.37 (172.16.0.37)  4.115 ms  7.203 ms  6.676 ms
13  www.netfu.rice.edu (128.42.204.11)  12.441 ms  2.734 ms  13.021 ms
```

- The last line of an unsuccessful traceroute will usually be asterisks. Either your network provider or the other end is blocking them.
- Examine your traceroute carefully -- if your traceroutes start spewing out asterisks before you ever leave your local network (you may see several lines but they seem to be uh-related, for example, or at the least, it's not clear they're some other ISP), then your local network is probably blocking the traceroute. Bypass this by installing a VPN or switching to another network. Most VPN services let you try things out for free. I found a list here: https://www.vpnranks.com/best-vpn-reviews/. VPN services will tunnel your traffic to their location and you'll be tracerouting from there. They usually don't block anything.
- If you examine your traceroute carefully, however, and believe it's the destination or someplace on the way that's blocking you, then try tracerouting to different sites. I had lots of luck tracerouting to Rice University from within UH, and terrible luck tracerouting to UH from within UH. Ironic, but not at all uncommon.
- The point is that you need to be able to do traceroutes for the homework. If you can't do it yourself, ask a friend to do it for you on their computer and send the results to you, maybe from their work, where sites are usually more open or from another part of the world, etc. The source and destination must be on different networks, especially topographically distant ones.
- As a last resort, you may traceroute from a tools web site, like here: https://mxtoolbox.com/NetworkTools.aspx (search for Trace). It's a good site to know anyway.
- Use traceroute to discover which routers are in a path between your computer and some web server, ideally an educational institution.
- If you don't know how to run a traceroute, these sites should help. For windows: https://support247webs.com/windows-traceroute/
  On a Mac, there are two methods:
  http://appletoolbox.com/2015/10/how-to-run-a-traceroute-in-mac-os-x/

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On a Mac, the two methods don't always produce the same results. Try both, and use the one that gives you a longer list of routers in your traceroute.

So here's the task:

What site did you traceroute?

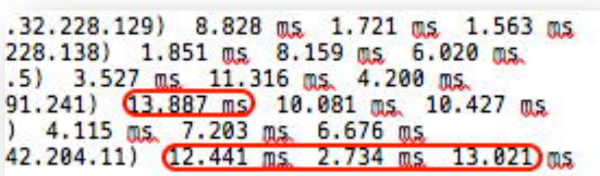
(2x9 pts)

a. An acceptable traceroute is one that completes successfully. Copy and paste your results below.

b. Sometimes sites use an alias for the real name of their server. According to the first row of the traceroute, what's the actual name of the host?

c. How many hops/routers were involved?

d. Do any of the steps report taking longer to reach than the final destination? Many traceroutes do, such as the one below.



```
.32.228.129)  8.828 ms  1.721 ms  1.563 ms
228.138)  1.851 ms  8.159 ms  6.020 ms
.5)  3.527 ms  11.316 ms  4.200 ms
91.241)  13.887 ms  10.081 ms  10.427 ms
)  4.115 ms  7.203 ms  6.676 ms
42.204.11)  12.441 ms  2.734 ms  13.021 ms
```

How is this possible?

e. The routers and hosts you are reaching have IP addresses. Pick two from your traceroute, write them down and report who owns each. Use https://mxtoolbox.com/arin.aspx.

f. Often we find that we have been assigned an IP address that starts with 10. For example, I am assigned "`10.137.64.1`" by AT&T at home. Search the WHOIS database at www.arin.net and report the Name of the network:

g. What is the Name of the Organization that owns the address?

h. Back to your site from (a). Use https://www.bitcatcha.com/ to report how long the web page takes to load.

i. Does it appear that more time is spent traversing the network or loading the page? Remember that web site response time includes network traversal.

2. (10 pts) Complete the first Wireshark lab in the Google Drive folder "Wireshark Labs". The lab is named "01 Wireshark_Intro_v7.0". Despite being an introduction, there are still answers to turn in.

3. (5 pts) What are the five layers in the Internet protocol stack? What are the principal responsibilities of each of these layers?

Answer: 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.

4. (5x2 pts)What is the unit of information called that each layer produces in the TCP/IP model?

a. Application layer:

b. Transport layer:

c. Network layer:

d. Data Link layer:

e. Physical layer:

Answer: a. Message, b. Segment, c. Datagram, d. Frame, e. Bit

5. (6x2 pts) Not all devices process all layers all the time.
   a. Which layers in the Internet protocol stack does a router process?

   b. Which layers does a link-layer switch process?

   c. Which layers does a host process?

   d. If we have a device that receives an electrical signal on a twisted pair cable, filters off high frequencies to remove noise, and amplifies the signal strength, but is completely passive and otherwise knows of the meanings of the signals, at what layer does it operate?

   e. A router offers a way for an administrator to log in and manage the device. Code to run a secure shell has been added to the router, and the administrator can log into the router remotely and change the configuration. This is an example of the router running what layers of the stack?

   f. We want to build a device that runs only the application layer. Is this possible?

   Answer:
   a. Routers process network, link and physical layers (layers 1 through 3).
   b. Link layer switches process link and physical layers.
   c. Hosts process all five layers.
   d. A repeater operates at the physical layer.
   e. Router with secure shell is all five.
   f. Application layer only is not possible.

6. (2x3 pts) Equation 1.1 gives a formula for the end-to-end delay of sending one packet of length L over N links of transmission rate R which ignores propagation delay:

$$d_{end-to-end} = N\frac{L}{R}$$

Consider a network 2 two hosts, 2 switches and thus 3 links, and 10 packets.
At time 0, all 10 packets are at Host A.

L/R is the transmission delay, so we have to wait that amount of time for a packet to leave a device. Therefore, at time 1*L/R, one packet has moved to the first switch, and 9 packets remain at Host A. At time 2*L/R packets have advanced one position, but none have reached Host B yet:

Not until time 3*L/R does a packet arrive at Host B. (10-1) packets remain in transit or awaiting transmission.

The 2nd packet is at S2, only one transmission away from Host B, and after it arrives, the 3rd packet will be at S2, one transmission away. So after the first packet arrived at Host B, we need 9 more rounds of L/R to bring the remaining packets to Host B.

a. Can you generalize the equation to 2 hosts, N links (and so N-1 network devices), and P packets?
Answer: The first packet took N*L/R, and the rest require (P-1)(L/R) = (N+P-1)*(L/R) total time.

b. If we add propagation delay d_{prop} to each link, can you generalize the equation further?
Answer: $N*(L/R+ d_{prop}) + (P-1)(L/R + d_{prop}) = (N+P-1)*((L/R) + d_{prop})$

7. (2x3 pts) Review the car-caravan analogy in Section 1.4. Assume a propagation speed of 100 km/hour.
   a. Suppose the caravan travels 150 km, beginning in front of one tollbooth, passing through a second tollbooth, and finishing just after a third tollbooth. What is the end-to-end delay? Hint: assume tollbooths are 75km apart. Then calculate how many seconds a tollbooth needs to service one car. Then you can work out how many seconds to service all cars, and how long each car's propagation delay is for the 75km before arriving at the second tollbooth. How long before they're all in front of the second tollbooth? You repeat the whole process again from the second to the third tollbooth, where there is a servicing delay once again. That's your total.
   Answer:
   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. Repeat (a), now assuming that there are 12 cars in the caravan instead of ten.

Answer: Delay between tollbooths is 12*12 seconds plus 45 minutes, i.e., 47 minutes and 24 seconds. The total delay is twice this amount plus 12*12 seconds, i.e., 94 minutes and 48 seconds.

8. (8x2 pts) Consider two hosts, A and B, connected by a single link of rate R bps. Suppose that the two hosts are separated by m meters, and suppose the propagation speed along the link is s meters/sec. Host A is to send a packet of size L bits to Host B.
   a. Express the propagation delay, d_{prop}, in terms of m and s.
   Answer: $d_{prop} = m/s$ seconds.
   b. Determine the transmission time of the packet, d_{trans}, in terms of L and R.
   Answer: $d_{trans} = L/R$ seconds.
   c. Ignoring processing and queuing delays, obtain an expression for the end-to-end delay.
   Answer: $d_{end\text{-}to\text{-}end} = (m/s + L/R)$ seconds.

d. Suppose Host **A** begins to transmit the packet at time $t = 0$. At time $t = d_{trans}$, where is the last bit of the packet?
Answer: The bit is just leaving Host A

e. Suppose d_{prop} is greater than d_{trans}. At time $t = d_{trans}$, where is the first bit of the packet?
Answer: The first bit is in the link and has not reached Host B.

f. Suppose d_{prop} is less than d_{trans}. At time $t = d_{trans}$, where is the first bit of the packet?
Answer: The first bit has reached Host B.

g. After how much time will the first bit be delivered to the waiting application on Host B?
Answer: Only after all bits have arrived, at time $d_{prop} + d_{trans}$.

h. Suppose $s = 2.5 \times 10^8 m/s$, $L = 200$ bits, and $R = 56$ kbps. Find the distance m so that d_{prop} equals d_{trans}. Round to the nearest kilometer.
Answer:

$$m = \frac{L}{R} \times s = \frac{200\ bits}{56000\ bits/second} \times \left(2.5 \times 10^8 \frac{meters}{second}\right) \approx 893\text{km}$$

9. (2x3 pts) Consider a packet of length L which begins at end system A and travels over l links to a destination end system B. These three links are connected by $(l-1)$ routers. Let d_i, s_i, and R_i denote the length, propagation speed, and the transmission rate of link i, for $i = 1, 2, 3$. Each router adds d_{proc} processing delay, and d_{queue} queueing delay.

a. What is the total end-to-end delay d_t for the packet?

Answer:

$$d_t = \sum_{i=1}^{l-1} (d_{proc} + d_{queue}) + \sum_{i=1}^{l} (d_{trans_i} + d_{prop_i})$$

The keys are the term d_{trans_i} and d_{prop_i} which change from one link to the next. We can substitute for $d_{trans} = L/R_i$ and $d_{prop} = d_i/s_i$ and get the final formula:

$$d_t = \sum_{i=1}^{l-1} (d_{proc} + d_{queue}) + \sum_{i=1}^{l} \left(\frac{L}{R_i} + \frac{d_i}{s_i}\right)$$

b. Suppose now there are 2 routers and 3 links. The packet is 1,500 bytes, the propagation speed on all links is 2.5×10^8 m/s, the transmission rates of all the links are 2 Mbps, the router processing delay is 1ms for processing, 2ms for queueing, the length of the first link is 5,000 km, the length of the second link is 4,000 km and the last 1,000km. For these values, what is the end-to-end delay?
Answer:

$$d_t = 2 * (1\text{ms} + 2\text{ms}) + \frac{1500\ bytes * 8\frac{bits}{byte}}{2Mbps} \times \left(\frac{5{,}000km \times \frac{1000m}{km}}{2.5 \times 10^8 \frac{m}{s}} + \frac{4{,}000km \times \frac{1000m}{km}}{2.5 \times 10^8 \frac{m}{s}} + \frac{1{,}000km \times \frac{1000m}{km}}{2.5 \times 10^8 \frac{m}{s}}\right) +$$
$$= 6ms + 6ms \times (20ms + 16ms + 4ms)$$
$$= 246ms$$

10. (3 pts) In the above problem, suppose all transmission rates $R_i = R$, and $d_{queue} = d_{proc} = 0$. Further suppose the packet switch does not store-and-forward packets but instead immediately transmits each bit it receives before waiting for the entire packet to arrive. What is the end-to-end delay?

Answer: Because bits are immediately transmitted, the packet switch does not introduce any delay; in particular, it does not introduce a transmission delay. So we have just the propagation delay of 9000 km of cable, and the time to get the bits on the wire from A, which is 1,500 bytes * 8 bits/byte / 2 Mbps for transmission and 36ms for propagation, or 42ms.

11. (3 pts) Consider a router buffer preceding an outbound link. Let N denote the average number of packets in the buffer plus the packet being transmitted. Let a denote the rate of packets arriving at the link. Let d denote the average total delay (processing, queueing, and transmission delay) per packet. Little's formula is

$$N = a \times d$$

Suppose that on average, the buffer contains 10 packets, and the average packet queuing delay is 10 msec. The link's transmission rate is 100 packets/sec.
Using Little's formula, what is the average packet arrival rate, assuming there is no packet loss?
Answer: the arrival rate is *a*, so solving for that variable gives us

$$a = \frac{N}{d} = \frac{10\frac{p}{s}}{10\frac{ms}{p}} = \frac{10\frac{p}{s}}{.01\frac{s}{p}} = 1{,}000\,\frac{pkts}{s}$$

12. (5 pts) A packet arrives at a router which makes a decision about the next link over which it is to travel. There is a buffer for that link which currently holds 4 packets. There is one packet that is 50% transmitted. Assume packets are all 1,500 bytes, and the link has a bandwidth of 2 Mbps.
    a. How long will this packet have to wait before its transmission can begin? This is the queueing delay.
    Answer:

$$\frac{1500\,\frac{bytes}{packet} \times 8\,\frac{bits}{byte} \times 4.5\,packets}{\frac{2 \times 10^6 bits}{sec} \times 1000\,\frac{ms}{sec}} = 27ms$$

    b. Can you generalize the equation for queueing delay for a particular queue if arriving packets have length *L bits*, the transmission rate is *R*, *x* bits of the currently-being-transmitted packet have been transmitted, and *n* packets are already in the buffer (queue)?
    Answer:

$$\frac{Ln + (L - x)\ bits}{R\ bits/sec}$$