ECE/CS 372–Introduction to Computer Networks

Assignment # 1

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(Textbook Version 7)

1. **(P6, Page71)**
   This elementary problem begins to explore propagation delay and transmission delay, two central concepts in data networking. 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.
   (b) Determine the transmission time of the packet, d_{trans}, in terms of L and R.
   (c) Ignoring processing and queuing delays, obtain an expression for the end-to-end delay.
   (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?
   (e) Suppose d_{prop} is greater than d_{trans}. At time t=d_{trans}, where is the first bit of the packet?
   (f) Suppose d_{prop} is less than d_{trans}. At time t=d_{trans}, where is the first bit of the packet?
   (g) Suppose s=$2.5 * 10^8$, L=120 bits and R=56 kbps. Find the distance, m, so that d_{prop} equals d_{trans}.

2. **(P7, Page71)**
   In this problem, we consider sending real-time voice from Host A to Host B over a packet-switched network (VoIP). Host A converts analog voice to a digital 64 kbps bit stream on the fly. Host A then groups the bits into 56-byte packets. There is one link between Hosts A and B; its transmission rate is 2 Mbps and its propagation delay is 10 msec. As soon as Host A gathers a packet, it sends it to Host B. As soon as Host B receives an entire packet, it converts the packets bits to an analog signal. How much time elapses from the time a bit is created (from the original analog signal at Host A) until the bit is decoded (as part of the analog signal at Host B)?

3. **(P8, Page71)**
   Suppose users share a 3 Mbps link. Also suppose each user requires 150 kbps when transmitting, but each user transmits only 10 percent of the time.
   (a) When circuit switching is used, how many users can be supported?
   (b) For the remainder of this problem, suppose packet switching is used. Find the probability that a given user is transmitting.
   (c) Suppose there are 120 users. Find the probability that at any given time, exactly n users are transmitting simultaneously. (Hint: Use the binomial distribution.)
   (d) Find the probability that there are 21 or more users transmitting simultaneously.

4. **(P10, Page72)**
Consider a packet of length L that begins at end system A and travels over three links to a destination end system. These three links are connected by two packet switches. 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. The packet switch delays each packet by d_{proc}. Assuming no queuing delays, in terms of d_i, s_i, R_i, (i=1,2,3), and L, what is the total end-to-end delay for the packet? Suppose now the packet is 1,500 bytes, the propagation speed on all three links is $2.5*10^8 m/s$, the transmission rates of all three links are 2 Mbps, the packet switch processing delay is 3 msec, the length of the first link is 5,000 km, the length of the second link is 4,000 km, and the length of the last link is 1,000 km. For these values, what is the end-to-end delay?

5. **(P11, Page72)**
In the above problem, suppose R_1=R_2=R_3=R and 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?

6. **(P12, Page72)**
A packet switch receives a packet and determines the outbound link to which the packet should be forwarded. When the packet arrives, one other packet is halfway done being transmitted on this outbound link and four other packets are waiting to be transmitted. Packets are transmitted in order of arrival. Suppose all packets are 1,500 bytes and the link rate is 2 Mbps. What is the queuing delay for the packet? More generally, what is the queuing delay when all packets have length L, the transmission rate is R, x bits of the currently-being-transmitted packet have been transmitted, and n packets are already in the queue?

7. **(P13, Page72)**

   (a) Suppose N packets arrive simultaneously to a link at which no packets are currently being transmitted or queued. Each packet is of length L and the link has transmission rate R. What is the average queuing delay for the N packets?

   (b) Now suppose that N such packets arrive to the link every LN/R seconds. What is the average queuing delay of a packet?

8. **(P14, Page73)**
Consider the queuing delay in a router buffer. Let I denote traffic intensity; that is, I=La/R. Suppose that the queuing delay takes the form IL/R(1-I) for I<1.

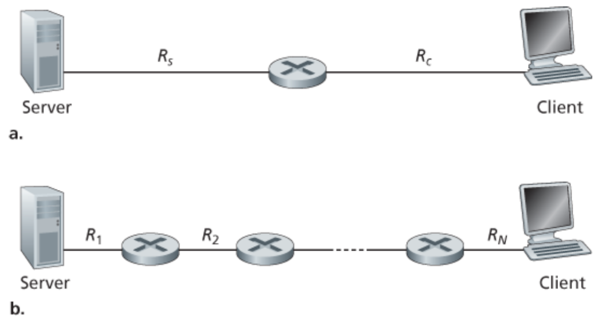
   (a) Provide a formula for the total delay, that is, the queuing delay plus the transmission delay.

   (b) Plot the total delay as a function of L/R (assume a=10).

9. **(P15, Page73)**
Let a denote the rate of packets arriving at a link in packets/sec, and let μ denote the links transmission rate in packets/sec. Based on the formula for the total delay (i.e., the queuing delay plus the transmission delay) derived in the previous problem, derive a formula for the total delay in terms of a and μ. Note that the link's transmission rate in packet/sec is R/L.

10. **(P23, Page74)**
Consider the figure (a) below. Assume that we know the bottleneck link along the path from the server to the client is the first link with rate R_s bits/sec. Suppose we send a pair of packets back to back from the server to the

client, and there is no other traffic on this path. Assume each packet of size L bits, and both links have the same propagation delay d_{prop}.



(a) What is the packet inter-arrival time at the destination? That is, how much time elapses from when the last bit of the first packet arrives until the last bit of the second packet arrives?

(b) Now assume that the second link is the bottleneck link (i.e., R_c¡R_s). Is it possible that the second packet queues at the input queue of the second link? Explain. Now suppose that the server sends the second packet T seconds after sending the first packet. How large must T be to ensure no queuing before the second link? Explain.

11. **(P25, Page75)**
Suppose two hosts, A and B, are separated by 20,000 kilometers and are connected by a direct link of R=2 Mbps. Suppose the propagation speed over the link is $2.5 * 10^8$ meters/sec.

(a) Calculate the bandwidth-delay product, $R \cdot d_{\text{prop}}$

(b) Consider sending a file of 800,000 bits from Host A to Host B. Suppose the file is sent continuously as one large message. What is the maximum number of bits that will be in the link at any given time?

(c) Provide an interpretation of the bandwidth-delay product.

(d) What is the width (in meters) of a bit in the link? Is it longer than a football field?

(e) Derive a general expression for the width of a bit in terms of the propagation speed s, the transmission rate R, and the length of the link m.

12. **(P29, Page75)**
Suppose there is a 10 Mbps microwave link between a geostationary satellite and its base station on Earth. Every minute the satellite takes a digital photo and sends it to the base station. Assume a propagation speed of $2.4 * 10^8$ meters/sec. Note that geostationary satellite is d = 36,000 kilometers away from earth surface.

(a) What is the propagation delay of the link?

(b) What is the bandwidth-delay product, $R \cdot d_{\text{prop}}$?

(c) Let x denote the size of the photo. What is the minimum value of x for the microwave link to be continuously transmitting?

13. **(P31, Page76) (BONUS)**
In modern packet-switched networks, including the Internet, the source host segments long, application layer messages (for example, an image or a music file) into smaller packets and sends the packets into the network.

The receiver then reassembles the packets back into the original message. We refer to this process as message segmentation. The figure below illustrates the end-to-end transport of a message with and without message segmentation. Consider a message that is $8 * 10^6$ bits long that is to be sent from source to destination in the figure. Suppose each link in the figure is 2 Mbps. Ignore propagation, queuing, and processing delays.

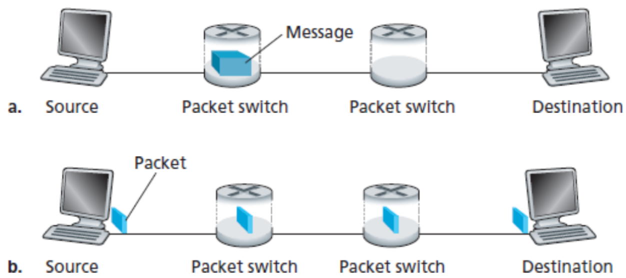


Figure 1: (a) without message segmentation; (b) with message segmentation

(a) Consider sending the message from source to destination without message segmentation. How long does it take to move the message from the source host to the first packet switch? Keeping in mind that each switch uses store-and-forward packet switching, what is the total time to move the message from source host to destination host?

(b) Now suppose that the message is segmented into 800 packets, with each packet being 10,000 bits long. How long does it take to move the first packet from source host to the first switch? When the first packet is being sent from the first switch to the second switch, the second packet is being sent from the source host to the first switch. At what time will the second packet be fully received at the first switch?

(c) How long does it take to move the file from source host to destination host when message segmentation is used? Compare this result with your answer in part (a) and comment.

(d) In addition to reducing delay, what are reasons to use message segmentation?

(e) Discuss the drawbacks of message segmentation.

14. **(P33, Page77) (BONUS)**
Consider sending a large file of F bits from Host A to Host B. There are three links (and two switches) between A and B, and the links are uncongested (that is, no queuing delays). Host A segments the file into segments of S bits each and adds 80 bits of header to each segment, forming packets of L=80 + S bits. Each link has a transmission rate of R bps. Find the value of S that minimizes the delay of moving the file from Host A to Host B. Disregard propagation delay.

15. **(Not from textbook)**
Hands-on Activity: tracing end-to-end paths and measuring network delays

The objective of this hands-on activity is to learn about and experiment with two popular packet diagnostic tools: `tracert` (or `traceroute` in Linux) and `ping` windows commands. The following exercises are specified for windows users, though it can also be done using Linux-based platforms.

(a) Start a windows command prompt from your computer and type `ping n 10 google.com`. This returns the destination IP address (google.com address) and the round-trip time (RTT) of 10 ping packets, as well as some delay statistics. What is the IP address of google.com? Run this command for 3 other servers at your choice (US based, Europe based, Asia based, etc.) and see how the delay changes. For each of your chosen server, report its name, its IP address, and the average RTT. Change the number '10' in the command to the number '5', run again, and observe what happens. What does this number do?

(b) If you need more familiarity with `tracert` command, I encourage you to first take a look at **Quick explanation on the use of Time-to-live (TTL) and tracert** given below before you do this part. Open another windows command prompt and type `tracert google.com`. How many hops did you observe? Here 'hop 1' is from your machine to the first router in the path, 'hop 2' is from the first router in the path to the second router in the path, and so on. Provide a table that reports the source IP address, the destination IP address, the value of the measured RTT (averaged over the three samples) for each hop. (An IP address should look like 68.87.219.197). Also, report a '*' when there is no response/information.

Hop No.	Source IP Address	Destination IP Address	Round Trip Time(RTT)
1			
2			
3, etc.			

(c) Now repeat 2) above, but while running `wireshark` on the background to capture the traces. First, lookup your machine's (source) IP address. You can do this by typing `ipconfig` as a command line and figure out the IP associated with the LAN adapter. Also, from 2) above you should know the destination IP address of google.com. Enter 'icmp' in the filter display window of wireshark to keep 'ICMP' protocol packets only.

Now observe that when using `tracert`, the first packet that was sent (that is, Echo (ping) request) has your machine's IP address as the source address and the google.com address as the destination address. But note that another machine (another IP address) has replied to your machine, not the google.com machine. What is the IP address of this machine? Go back to your findings in 2) and see where does this machine fit into the path? Which hop does it belong to? Observe that this process repeats 3 times. After the first router in the path sends back to your machine three 'Time-to-live (TTL) exceeded' messages, then the same thing repeats but with the second router in the path being the one replying to your machine. What is the IP of this second router/machine in the path? Observe that this repeats for each router/machine in the path that was returned in 2) above.

Again, for each router in the path, three 'Time-to-live (TTL) exceeded' messages are sent back from the router to the source machine, each being a response to one ping packet sent by the source. Observe and track the 'Time to Live' field value in the 'Internet Protocol Version 4' associated with each of the ping packets sent by the source. Note that for the first 3 ping request packets, the 'Time to Live' value is set to 1; for the next 3 ping request packets, the 'Time to Live' value is set to 2; for the next 3 ping request packets, the 'Time to Live' value is set to 3, and so on.

Quick explanation on the use of Time-to-live (TTL) and tracert:

`tracert` relies on the packet's Time-to-live (TTL) field to collect the RRTs between the source and all routers in the path. Let's briefly see how it works. Each packet contains a TTL field, and every time a packet passes by a router, the router decrements that field value by 1 before forwarding it to the next router. But when the TTL value reaches 0, instead of forwarding it, the router drops the packet and instead sends a 'Time-to-live exceeded' ICMP (Internet Control Message Protocol) message back to the source, notifying the source that its packet did not make it to the destination. The main purpose of this TTL is to prevent packets from looping forever in the network.

Now let's get back to `tracert`. In the case of `tracert`, to calculate the RRT between the source machine and the first router in the path, the source machine (i.e., your machine) sends a ping packet but with its TLL field set to 1, forcing the first router to drop the packet and instead sends back to the source machine a 'Time-to-live exceeded' ICMP message. The source machine uses it to calculate the RTT. Then, to estimate the RTT from the source to the second router in the path, the source machine sends another ping packet but this time with the TTL value being set to 2, forcing the second router to drop the packet and send back a 'Time-to-live exceeded' ICMP message to the source machine (since the first router would have decremented the TTL value by 1 already, and by the time the packet reaches the second router, the TTL would reach 0 after being decremented again by 1 by this second router), allowing to calculate the RTT between the source and the second router in the path. This process continues for all intermediate routers until all RTTs between the source machine and each of the router in between are calculated. When the last ping packet (with TTL value set to the number of hops between the source and destination) finally reaches the destination machine (i.e., google.com), the destination machine will reply with a 'ping reply' message. This is briefly how `tracert` works.