CS 655 Introduction to Computer Networks
Fall 2020 **Homework1**

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1. What is a network protocol? What is a network service? What is the difference between a service interface and implementation of a service? Discuss these concepts in the context of layered network architecture.

   A **protocol** defines the format and the order of messages exchanged between two or more communicating entities, as well as the actions taken on the transmission and/or receipt of a message or other event [1].

   Network protocols are the protocols implemented in the Internet. In the layered network architecture, each protocol belongs to one of the layers.

   A network service is an application running at the network application layer.

   A service is implemented in a form of protocol in each layer.

   The function of each layer in computer networking architecture is to provide services to the layer above it. The upper layer uses the **service interface** provided by the lower layer.

2. Consider the problem of 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 15 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 packet's 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)?

   Solution:
   Analog signal -> Digital signal -> 64kbps bit stream -> 56-byte packet -> transmission 2Mbps -> propagation 15ms -> Digital Signal -> Analog Signal

   56 * 8 bits / 64 kbps + 56 * 8 bits / 2Mbps + 15ms + 56 * 8bits / 64kbps = 29.224ms

3. (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?
Solution:
Average queuing delay = L * (0+1+ ⋯ + N-1) / (NR) = L*(N-1)/2R

(b) Now suppose that N such packets arrive to the link every LN/R seconds. What is the average queuing delay of a packet?
Solution:
We need LN/R seconds to send N such packets. Thus, the receiver buffer will not overflow.
The answer is the same as (a): L*(N-1)/2R.

4. Perform a Traceroute between source and destination on the same continent at three different hours of the day. (Hint: type 'man traceroute' on Linux.)
a) Find the average and standard deviation of the round-trip delays at each of the three hours.

00:05 Sept 16, 2020 EST
PS C:\Users\tanzi> tracert 45.32.195.233
Tracing route to 45.32.195.233.vultr.com [45.32.195.233]
over a maximum of 30 hops:

1	2 ms	4 ms	4 ms	192.168.7.1
2	14 ms	8 ms	6 ms	arrisatom.cable.rcn.com [192.168.0.1]
3	20 ms	27 ms	15 ms	10.18.208.1
4	17 ms	20 ms	14 ms	bdle6-sub211.oldaggr1.bos.ma.rcn.net [146.115.22.203]
5	16 ms	17 ms	15 ms	207.172.18.97
6	21 ms	20 ms	16 ms	hge0-2-0-0.border1.bos.ma.rcn.net [207.172.19.53]
7	25 ms	20 ms	17 ms	et-0-0-13.cr1-bos1.ip4.gtt.net [69.174.18.121]
8	66 ms	65 ms	65 ms	ae9.cr0-dal2.ip4.gtt.net [89.149.184.97]
9	*	*	65 ms	ip4.gtt.net [173.205.43.82]
10	*	*	*	Request timed out.
11	*	*	*	Request timed out.
12	*	*	*	Request timed out.
13	65 ms	67 ms	62 ms	45.32.195.233.vultr.com [45.32.195.233]

Trace complete.
Average RTT is 64.667ms. Standard deviation is 2.055.

The history of the route is recorded as the round-trip times of the packets received from each successive host (remote node) in the route (path); the sum of the mean times in each hop is a measure of the total time spent to establish the connection. --- From Wikipedia

1:57 Sept 16, 2020 EST
PS C:\Users\tanzi> tracert 45.32.195.233
Tracing route to 45.32.195.233.vultr.com [45.32.195.233]
over a maximum of 30 hops:

1	3 ms	8 ms	5 ms	192.168.7.1
2	15 ms	5 ms	118 ms	arrisatom.cable.rcn.com [192.168.0.1]
3	20 ms	21 ms	19 ms	10.18.208.1
4	126 ms	16 ms	18 ms	bdle6-sub211.oldaggr1.bos.ma.rcn.net [146.115.22.203]
5	31 ms	14 ms	15 ms	207.172.18.97
6	21 ms	16 ms	17 ms	hge0-2-0-0.border1.bos.ma.rcn.net [207.172.19.53]
7	118 ms	17 ms	13 ms	et-0-0-13.cr1-bos1.ip4.gtt.net [69.174.18.121]
8	166 ms	64 ms	160 ms	ae9.cr0-dal2.ip4.gtt.net [89.149.184.97]
9	177 ms	67 ms	134 ms	ip4.gtt.net [173.205.43.82]
10	*	*	*	Request timed out.
11	*	*	*	Request timed out.
12	*	*	*	Request timed out.
13	65 ms	63 ms	63 ms	45.32.195.233.vultr.com [45.32.195.233]

Trace complete.
Average RTT is 63.667ms. Standard deviation is 0.943.

2:45 Sept 16, 2020 EST
PS C:\Users\tanzi> tracert 45.32.195.233
Tracing route to 45.32.195.233.vultr.com [45.32.195.233]
over a maximum of 30 hops:

1	6 ms	6 ms	5 ms	192.168.7.1
2	13 ms	14 ms	4 ms	arrisatom.cable.rcn.com [192.168.0.1]
3	17 ms	37 ms	23 ms	10.18.208.1
4	63 ms	20 ms	16 ms	bdle6-sub211.oldaggr1.bos.ma.rcn.net [146.115.22.203]
5	34 ms	19 ms	17 ms	207.172.18.107
6	17 ms	18 ms	17 ms	207.172.18.70
7	16 ms	14 ms	18 ms	et-0-0-13.cr1-bos1.ip4.gtt.net [69.174.18.121]
8	65 ms	73 ms	64 ms	ae9.cr0-dal2.ip4.gtt.net [89.149.184.97]
9	79 ms	68 ms	61 ms	ip4.gtt.net [173.205.43.82]
10	*	*	*	Request timed out.
11	*	*	*	Request timed out.
12	*	*	*	Request timed out.
13	142 ms	141 ms	65 ms	45.32.195.233.vultr.com [45.32.195.233]

Trace complete.
Average RTT is 116ms. Standard deviation is 36.065.

b) Find the number of routers in the path at each of the three hours. Did the paths change during any of the hours?

The first time: 10, the second time: 10, the third time: 10.

The path changed for the third time.

c) Try to identify the number of ISP networks that the Traceroute packets pass through from source to destination. Routers with similar names and/or similar IP addresses should be considered as part of the same ISP. In your experiments, do the largest delays occur at the peering interfaces between adjacent ISPs?

Exactly.

It occurs from ae9.cr0-dal2.ip4.gtt.net [89.149.184.97] to ip4.gtt.net [173.205.43.82].

d) Repeat the above for a source and destination on different continents. Compare the intra-continent and inter-continent results.

IP 101.4.117.185 locates in Beijing, China, Asia.

2:20 Sept 16, 2020 EST
PS C:\Users\tanzi> tracert 101.4.117.185
Tracing route to 101.4.117.185 over a maximum of 30 hops

1	69 ms	3 ms	5 ms	192.168.7.1
2	8 ms	6 ms	5 ms	arrisatom.cable.rcn.com [192.168.0.1]
3	20 ms	17 ms	17 ms	10.18.208.1
4	17 ms	26 ms	15 ms	bdle6-sub211.oldaggr1.bos.ma.rcn.net [146.115.22.203]
5	26 ms	33 ms	71 ms	207.172.18.99
6	20 ms	18 ms	17 ms	207.172.18.72
7	60 ms	17 ms	14 ms	10ge5-7.core1.bos1.he.net [206.108.236.30]
8	36 ms	46 ms	33 ms	e0-36.core2.nyc4.he.net [184.104.192.242]
9	26 ms	21 ms	20 ms	100ge8-2.core1.nyc4.he.net [184.104.192.241]
10	28 ms	38 ms	26 ms	100ge16-1.core1.ash1.he.net [184.105.223.165]
11	81 ms	83 ms	84 ms	100ge2-1.core1.lax1.he.net [184.105.80.202]
12	87 ms	87 ms	86 ms	100ge14-1.core1.lax2.he.net [72.52.92.122]
13	341 ms	318 ms	268 ms	216.218.244.106
14	298 ms	268 ms	311 ms	101.4.117.185

Trace complete.
Average RTT is 292.33ms. Standard deviation is 18.

2:20 Sept 16, 2020 EST
PS C:\Users\tanzi> tracert 101.4.117.185
Tracing route to 101.4.117.185 over a maximum of 30 hops

1	5 ms	6 ms	16 ms	192.168.7.1
2	5 ms	5 ms	6 ms	arrisatom.cable.rcn.com [192.168.0.1]
3	21 ms	32 ms	20 ms	10.18.208.1
4	16 ms	17 ms	16 ms	bdle6-sub211.aggr1.bos.ma.rcn.net [146.115.22.203]
5	20 ms	20 ms	15 ms	207.172.18.99
6	18 ms	20 ms	14 ms	207.172.18.72
7	18 ms	19 ms	22 ms	10ge5-7.core1.bos1.he.net [206.108.236.30]
8	29 ms	23 ms	23 ms	e0-36.core2.nyc4.he.net [184.104.192.242]
9	20 ms	20 ms	26 ms	100ge8-2.core1.nyc4.he.net [184.104.192.241]

10	31 ms	30 ms	37 ms	100ge16-1.core1.ash1.he.net [184.105.223.165]
11	80 ms	91 ms	90 ms	100ge2-1.core1.lax1.he.net [184.105.80.202]
12	100 ms	106 ms	94 ms	100ge14-1.core1.lax2.he.net [72.52.92.122]
13	248 ms	255 ms	248 ms	216.218.244.106
14	252 ms	254 ms	253 ms	101.4.117.185

Trace complete.
Average RTT is 253ms. Standard deviation is 0.81

PS C:\Users\tanzi> tracert 101.4.117.185
Tracing route to 101.4.117.185 over a maximum of 30 hops

1	2 ms	1 ms	5 ms	192.168.7.1
2	3 ms	10 ms	5 ms	arrisatom.cable.rcn.com [192.168.0.1]
3	100 ms	69 ms	62 ms	10.18.208.1
4	37 ms	28 ms	18 ms	bdle6-sub211.oldaggr1.bos.ma.rcn.net [146.115.22.203]
5	13 ms	128 ms	75 ms	207.172.18.99
6	23 ms	18 ms	20 ms	207.172.18.72
7	21 ms	33 ms	124 ms	10ge5-7.core1.bos1.he.net [206.108.236.30]
8	22 ms	28 ms	16 ms	e0-36.core2.nyc4.he.net [184.104.192.242]
9	73 ms	32 ms	145 ms	100ge8-2.core1.nyc4.he.net [184.104.192.241]
10	28 ms	33 ms	69 ms	100ge16-1.core1.ash1.he.net [184.105.223.165]
11	201 ms	116 ms	149 ms	100ge2-1.core1.lax1.he.net [184.105.80.202]
12	95 ms	96 ms	99 ms	100ge14-1.core1.lax2.he.net [72.52.92.122]
13	343 ms	379 ms	251 ms	216.218.244.106
14	243 ms	250 ms	235 ms	101.4.117.185

Trace complete.
Average RTT is 242.667ms. Standard deviation is 6.13

The number of hops is 14 at each time. The routes are the same.

The largest delays occur at the peering interfaces between adjacent ISPs.
It occurs from 100ge14-1.core1.lax2.he.net [72.52.92.122] to 216.218.244.106.

5. Suppose two hosts, A and B, are separated by 20,000 kilometers and are connected by a direct link of R = 4 Mbps. Suppose the propagation speed over the link is 2.5×10^8 meters/sec.
   a) Calculate the bandwidth-delay product, R x dprop. (Hint: dprop here represents the one way propagation delay from A to B.)
   R x dprop = 4 Mbps x 20000 x 1000 / (2.5×10^8) = 3.2×10^5 bits

   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?
   The first bit needs 20,000 km / (2.5×10^8) m/s = 80 ms to reach Host B.
   The last bit of this large message has a queueing delay of 800, 000 bits / 4 Mbps = 200ms, which is longer than 80 ms.

Therefore, this link will be full of bits stream after 80 ms. The maximum number of bits that will be in the link after 80ms is **80ms x 4 Mbps = 3.2 x 10^5 bits**.

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

From what we just calculate in a) and b), it is obvious to find that bandwidth-delay product indicates the number of bits that can be filled into this link. We could think about this metaphor. The link can be considered as a pipeline which transports bits. The bandwidth-delay product is the number of bits in the pipeline when the pipeline is full of bits.

d) What is the width (in meters) of a bit in the link? Is it longer than a football field? (Hint: the length of a football (not soccer!) field is 100 yards, which is 91.44 meters.)

The width of a bit is 20,000 km / 3.2 x 10^5 = 62.5 m, which is longer than half of a football field. That is really impressive.

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.

The width of a bit is m / (m/S x R) = S / R

6. 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 (a) without and (b) with message segmentation. Consider a message that is 8 x 10^6 bits long that is to be sent from source to destination in the figure below. Suppose each link in the figure is 2 Mbps. Ignore propagation, queuing, and processing delays. Also ignore the transmission of header bits in your calculations.
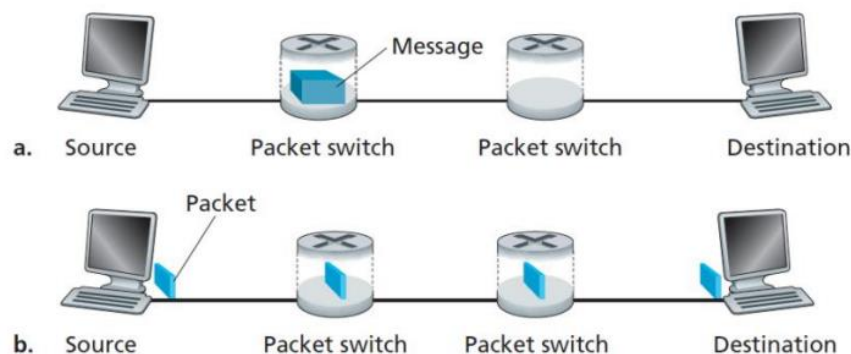
a. Consider sending the message from source to destination without message segmentation. How long does it take to move the message from the source host to the first packet switch? Keeping in mind that each switch uses store-and-forward packet switching, what is the total time to move the message from source host to destination host?

It takes **8 x 10^6 bits / 2 Mbps = 4s** to move the message from the source host to the first packet switch.

It takes **4s x 3 = 12s** to reach the destination.

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?

Each packet is 1×10^4 bits.

It takes 1×10^4 / 2 Mbps = 5 ms to move the first packet from source host to the first switch.

Right after **5 ms x 2 = 10 ms**, the second packet will 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.

It takes 15ms for a packet to reach the destination host.

The total time to move the file to the destination is **(800-1) x 5 ms + 15 ms = 4.01 s**, which is much shorter than what we get in part (a).

Message segmentation can reduce delay.

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

One purpose is to control the packet loss. If a packet loses when routing, we do not have to re-send the whole big file but only a small packet.

e. Discuss the drawbacks of message segmentation.

The packets need to be sorted at the destination.

7. Suppose that a certain communications protocol involves a per-packet overhead of 120 bytes for headers. We send 1 million bytes of data using this protocol; however, when one data byte is corrupted, the entire packet containing it is lost. Give the total number of overhead + loss bytes for packet data sizes (i.e. the size of only the data portion of the packet) of 1000, 5000, 10000, and 20000 bytes, assuming a) the connection loses a single byte of data, and b) the sender does not retransmit lost packets. Which of these sizes is optimal?

Size of Packet	Number of packets	Overheads and loss bytes
1000	1M / 1000 = 1000	120 x 1000 + 1000 = 121000
5000	1M / 5000 = 200	120 x 200 + 5000 = 29000
10000	1M / 10000 = 100	120 x 100 + 10000 = 22000
20000	1M / 20000 = 50	120 x 50 + 20000 = 26000

Therefore, the optimal size of a packet should be 10000.

Reference:

[1] James F. Kurose, Computer Networking A Top-Down Approach, University of Massachusetts, Amherst