Answer for EE3315 Test 2 2021-2022

Question 1A. **[20 marks]**

Suppose that within your web browser you click on a link to obtain a web page. Suppose that web page associated with the link contains some HTML text. Let *RTT* denote the round trip time between the local host and the server containing the HTML file with size 2*L*. Further suppose that the page references nine objects each with size 3*L* and the transmission rate *R*/2. Assuming the queueing time is 2*Q* for each object and zero for other messages, how much time is needed from when the client clicks on the link until the client receives all the nine referenced objects with

i) persistent HTTP with pipelining? [4 mark]
ii) persistent HTTP without pipelining? [4 mark]
iii) non-persistent HTTP with no parallel connections? [4 mark]
iv) non-persistent HTTP with parallel TCP connections but the maximum number of parallel connections is set to two? [4 mark]
v) non-persistent HTTP with parallel TCP connections but the maximum number of parallel connections is set to four? [4 mark]

i) 2RTT+2·2L/R+RTT+2·9·3L/R+18Q =3RTT+58L/R+18Q.
ii) 2RTT+2·2L/R+9RTT+2·9·3L/R+18Q =11RTT+58L/R+18Q.
iii) 2RTT+2·2L/R+9·2RTT+2·9·3L/R+18Q =20RTT+58L/R+18Q.
iv) 2RTT+2·2L/R+5·2RTT+2·5·3L/R+10Q =12RTT+34L/R+10Q.
v) 2RTT+2·2L/R+3·2RTT+2·3·3L/R+6Q =8RTT+22L/R+6Q.

Question 1B. **[20 marks]**

Suppose that within your web browser you click on a link to obtain a web page. Suppose that web page associated with the link contains some HTML text. Let *RTT* denote the round trip time between the local host and the server containing the HTML file with size 3*L*. Further suppose that the page references nine objects each with size 2*L* and the transmission rate *R*/2. Assuming the queueing time is 3*Q* for each object and zero for other messages, how much time is needed from when the client clicks on the link until the client receives all the nine referenced objects with

i) persistent HTTP with pipelining? [4 mark]
ii) persistent HTTP without pipelining? [4 mark]
iii) non-persistent HTTP with no parallel connections? [4 mark]
iv) non-persistent HTTP with parallel TCP connections but the maximum number of parallel connections is set to two? [4 mark]
v) non-persistent HTTP with parallel TCP connections but the maximum number of parallel connections is set to four? [4 mark]

i) 2RTT+2·3L/R+RTT+2·9·2L/R+27Q =3RTT+42L/R+27Q.
ii) 2RTT+2·3L/R+9RTT+2·9·2L/R+27Q =11RTT+42L/R+27Q.
iii) 2RTT+2·3L/R+9·2RTT+2·9·2L/R+27Q =20RTT+42L/R+27Q.
iv) 2RTT+2·3L/R+5·2RTT+2·5·2L/R+15Q =12RTT+26L/R+15Q.
v) 2RTT+2·3L/R+3·2RTT+2·3·2L/R+9Q =8RTT+18L/R+9Q.

<u>Question 2A</u>. **[24 marks]**

Consider Figure Q.2, in which there is an institutional network connected to the Internet. Suppose that the average object size is 375,000 bits and that the average request rate from the institution's browsers to the origin servers is 120 requests per minute. Also suppose that the amount of time it takes for the signal traveling from the router on the Internet side of the access link to the origin servers is two seconds on average and it takes three seconds for the signal coming back. Model the total average response time as the sum of the average access delay (that is, the delay from the Internet router to the institution router), and the average Internet delay, ignoring the delay in the LAN. For the average access delay, use $T/(1-TB)$, where T is the average time required to send an object over the access link and B is the arrival rate of objects to the access link. Note that the number of significant digits after the decimal point should be limited to four during the calculation.

i. Find the average total response time. **[8 marks]**

ii. Now suppose a cache is installed in the institutional LAN. Suppose that the miss rate is 0.3. Find the total average response time. **[8 marks]**

iii. What is the total average response time if we upgrade the access link with two parallel links, one with 5 Mbps and another with 10 Mbps, instead of installing a cache in the institutional LAN? Assume that 40% of the traffic is distributed on the 5 Mbps link and the remaining 60% of the traffic is on the 10 Mbps link.

[8 marks]

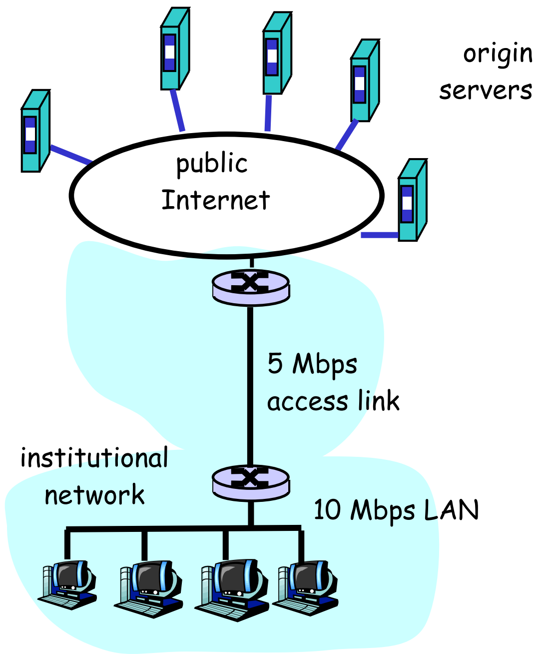


Figure Q.2

i. The time to transmit an object of size L over a link or rate R is L/R. The average time is the average size of the object divided by R:
For the access link,
T= (375,000 bits)/(5,000,000 bits/sec) = 0.075 sec
The traffic intensity on the link is TB = (120/60)(0.075) = 0.15. Thus, the average access delay is $T/(1-TB)$ = (0.075 sec)/(1– 0.15) = 0.0882 seconds.

The total average response time is therefore 0.0882 sec + 5 sec = 5.0882 sec.

ii. The traffic intensity on the access link is reduced by 70% since the 70% of the requests are satisfied within the institutional network. Thus the average access delay is $T/(1-TB)$=(0.075sec)/[1 – (0.3)(0.15)] = 0.0785 seconds. The response time is the LAN delay if the request is satisfied by the cache (which happens with probability 0.7); the average response time is 0.0785 sec + 5 sec = 5.0785 sec for cache misses (which happens 30% of the time). So the average response time is (0.3)(5.0785 sec) = 1.5236 seconds. Thus the average e response time is reduced from 5.0883 sec to 1.5236 sec.

iii. Now, the access link is updated with two parallel links, one with 5 Mbps and another with 10 Mbps, instead of installing a cache in the institutional LAN.
1) For the link with 5 Mbps:
T= (375,000 bits)/(5,000,000 bits/sec) = 0.075 sec
The traffic intensity on the link is TB = (0.4x120/60)(0.075) = 0.06. Thus, the average access delay is $T/(1-TB)$ = (0.075 sec)/(1– 0.06) = 0.0798 seconds.
2) For the link with 10 Mbps:
T= (375,000 bits)/(10,000,000 bits/sec) = 0.0375 sec
The traffic intensity on the link is TB = (0.6x120/60)(0.0375) = 0.045. Thus, the average access delay is $T/(1-TB)$ = (0.0375 sec)/(1– 0.045) = 0.0393 seconds.

The total average response time is therefore (0.4x0.0798 sec + 0.6x0.0393 sec) + 5 sec = 5.0555 sec.

Question 2B. **[24 marks]**

Consider Figure Q.2, in which there is an institutional network connected to the Internet. Suppose that the average object size is 375,000 bits and that the average request rate from the institution's browsers to the origin servers is 120 requests per minute. Also suppose that the amount of time it takes for the signal traveling from the router on the Internet side of the access link to the origin servers is two seconds on average and it takes four seconds for the signal coming back. Model the total average response time as the sum of the average access delay (that is, the delay from the Internet router to the institution router), and the average Internet delay, ignoring the delay in the LAN. For the average access delay, use $T/(1-TB)$, where T is the average time required to send an object over the access link and B is the arrival rate of objects to the access link. Note that the number of significant digits after the decimal point should be limited to four during the calculation.

i. Find the average total response time. **[8 marks]**

ii. Now suppose a cache is installed in the institutional LAN. Suppose that the miss rate is 0.4. Find the total average response time. **[8 marks]**

iii. What is the total average response time if we upgrade the access link with two parallel links, one with 5 Mbps and another with 10 Mbps, instead of installing a cache in the institutional LAN? Assume that 30% of the traffic is distributed on the 5 Mbps link and the remaining 70% of the traffic is on the 10 Mbps link. **[8 marks]**

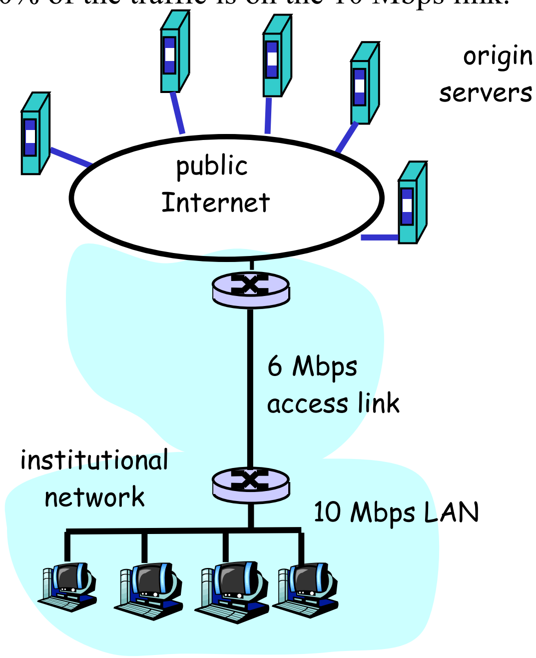


Figure Q.2

i. The time to transmit an object of size L over a link or rate R is L/R. The average time is the average size of the object divided by R:
For the access link,
T= (375,000 bits)/(6,000,000 bits/sec) = 0.0625 sec
The traffic intensity on the link is TB = (120/60)(0.0625) = 0.125. Thus, the average access delay is $T/(1-TB)$ = (0.0625 sec)/(1– 0.125) = 0.0714 seconds.

The total average response time is therefore 0.0714 sec + 6 sec = 6.0714 sec.

ii. The traffic intensity on the access link is reduced by 60% since the 60% of the requests are satisfied within the institutional network. Thus the average access delay is $T/(1-TB)$=(0.0625sec)/[1 – (0.4)(0.125)] = 0.0658 seconds. The response time is the LAN delay if the request is satisfied by the cache (which happens with probability 0.6); the average response time is 0.0658 sec + 6 sec = 6.0658 sec for cache misses (which happens 30% of the time). So the average response time is (0.4)(6.0658 sec) = 2.4263 seconds. Thus the average response time is reduced from 6.0714 sec to 2.4263 sec.

iii. Now, the access link is updated with two parallel links, one with 5 Mbps and another with 10 Mbps, instead of installing a cache in the institutional LAN.
1) For the link with 5 Mbps:

T= (375,000 bits)/(5,000,000 bits/sec) = 0.075 sec

The traffic intensity on the link is TB = (0.3x120/60)(0.075) = 0.045. Thus, the average access delay is $T/(1-TB)$ = (0.075 sec)/(1– 0.045) = 0.0785 seconds.

2) For the link with 10 Mbps:

T= (375,000 bits)/(10,000,000 bits/sec) = 0.0375 sec

The traffic intensity on the link is TB = (0.7x120/60)(0.0375) = 0.0525. Thus, the average access delay is $T/(1-TB)$ = (0.0375 sec)/(1− 0.0525) = 0.0396 seconds.

The total average response time is therefore (0.3x0.0785 sec + 0.7x0.0396 sec) + 6 sec = 6.0513 sec.

Question 3A. **[20 marks]**

In this problem we consider the delay introduced by the TCP slow-start phase. Consider a client and a Web server directly connected by one link of rate $R/4$. Suppose the client wants to retrieve an object whose size is exactly equal to $14S$, where S is the maximum segment size (MSS). Denote the round-trip time between client and server as RTT (assume to be constant). Ignoring protocol headers, determine the time to retrieve the object (**including** TCP connection establishment) when 12 S/R > RTT > 4 S/R and RTT ≥ 12 S/R, respectively.

i) If 12 S/R > RTT > 4 S/R, the total delay is

2RTT + 4 S/R + RTT + 4 S/R + RTT + 16S/R + 28S/R = 4RTT + 52 S/R

ii) If RTT ≥ 12 S/R, the total delay is

2RTT + 4 S/R + RTT + 4 S/R + RTT + 4 S/R + RTT + 28 S/R = 5RTT + 40 S/R

Question 3B. **[20 marks]**

In this problem we consider the delay introduced by the TCP slow-start phase. Consider a client and a Web server directly connected by one link of rate $R/4$. Suppose the client wants to retrieve an object whose size is exactly equal to $15S$, where S is the maximum segment size (MSS). Denote the round-trip time between client and server as RTT (assume to be constant). Ignoring protocol headers, determine the time to retrieve the object (**including** TCP connection establishment) when 12 S/R > RTT > 4 S/R and RTT ≥ 12 S/R, respectively.

i) If 12 S/R > RTT > 4 S/R, the total delay is

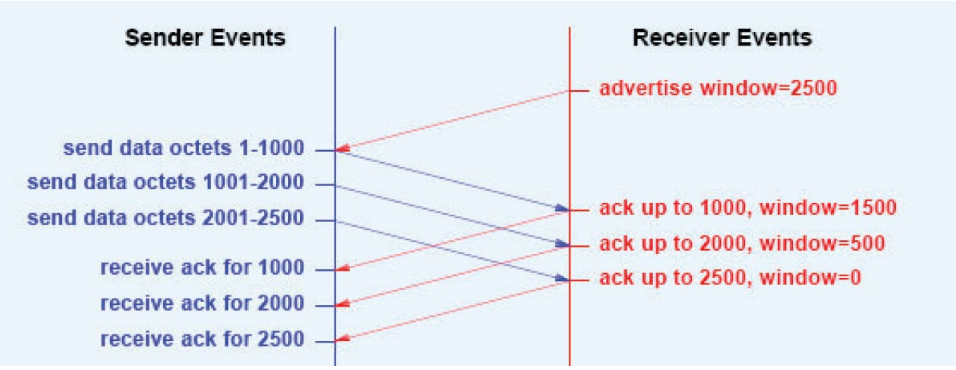
2RTT + 4 S/R + RTT + 4 S/R + RTT + 16S/R + 32S/R = 4RTT + 56 S/R

ii) If RTT ≥ 12 S/R, the total delay is

2RTT + 4 S/R + RTT + 4 S/R + RTT + 4 S/R + RTT + 32 S/R = 5RTT + 44 S/R

Question 4A. TCP flow control: **[20 marks]**

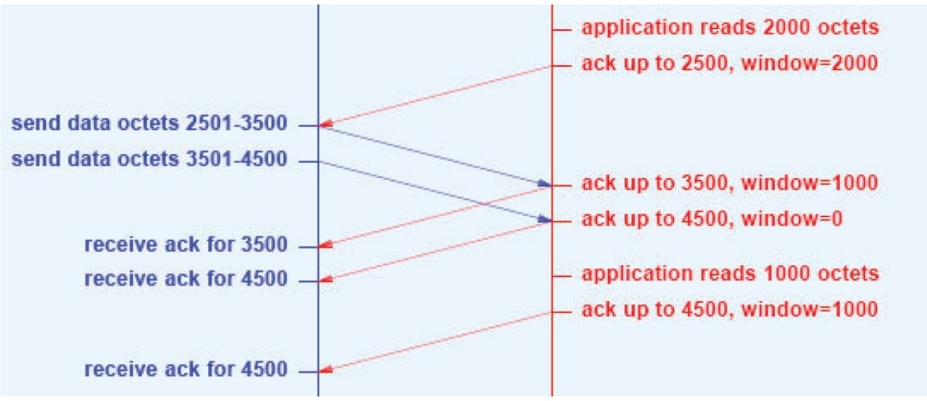
(i) According to the figure below, if advertise window is changed from 2500 to 2400, list out in sequence the modified Sender Events and the modified Receiver Events, respectively.



(i)
Sender Events:
Send data octets 1-1000
Send data octets 1001-2000
Send data octets 2001-2400
Receive ack for 1000
Receive ack for 2000
Receive ack for 2400

Receiver Events:
advertise window=2400
ack up to 1000, window=1400
ack up to 2000, window=400
ack up to 2400, window=0

(ii) According to the figure below, if the application reads 1900 octets instead of 2000 octets, list out in sequence the modified Sender Events and the modified Receiver Events, respectively.



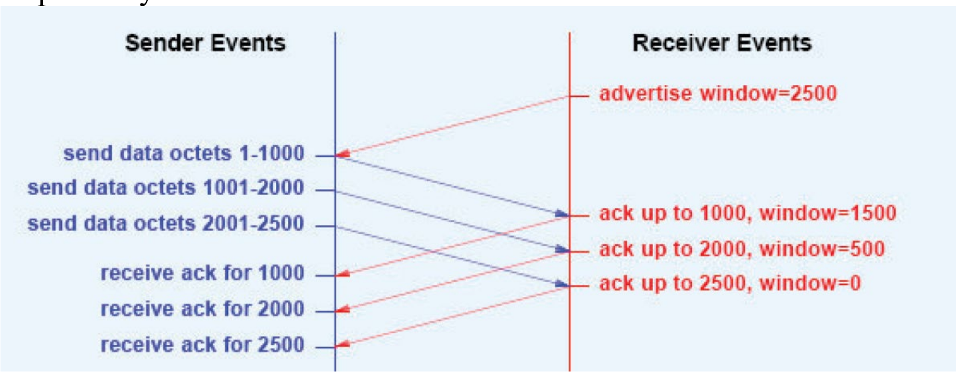
(ii)
Sender Events:
Send data octets 2501-3500
Send data octets 3501-4400
Receive ack for 3500
Receive ack for 4400

Receive ack for 4400

Receiver Events:
application reads 1900 octets
ack up to 2500, window=1900
ack up to 3500, window=900
ack up to 4400, window=0
application reads 1000 octets
ack up to 4400, window=1000

<u>Question 4B</u>. TCP flow control: **[20 marks]**

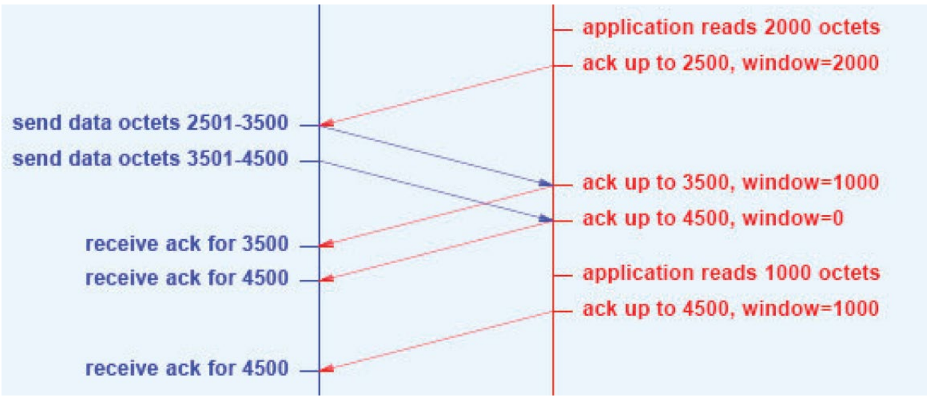
(i) According to the figure below, if advertise window is changed from 2500 to 2300, list out in sequence the modified Sender Events and the modified Receiver Events, respectively.



(i)
Sender Events:
Send data octets 1-1000
Send data octets 1001-2000
Send data octets 2001-2300
Receive ack for 1000
Receive ack for 2000
Receive ack for 2300

Receiver Events:
advertise window=2300
ack up to 1000, window=1300
ack up to 2000, window=300
ack up to 2400, window=0

(ii) According to the figure below, if the application reads 1800 octets instead of 2000 octets, list out in sequence the modified Sender Events and the modified Receiver Events, respectively.



(ii)
Sender Events:
Send data octets 2501-3500
Send data octets 3501-4300
Receive ack for 3500
Receive ack for 4300
Receive ack for 4300

Receiver Events:
application reads 1800 octets
ack up to 2500, window=1800
ack up to 3500, window=800
ack up to 4300, window=0
application reads 1000 octets
ack up to 4300, window=1000

<u>Question 5A</u>. **[16 marks]**

Assuming TCP Reno is the protocol experiencing the behavior shown in Table 1, answer the following questions. In all cases, you should provide a short explanation justifying your answer.

Table 1: TCP congestion control

NTR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
CWS	30	31	32	1	2	4	8	16	17	18	9	10	11	12	6	7

NTR – number of transmission round
CWS – congestion window size

i. Identify the one/two interval(s) of time when TCP slow start is operating.
ii. Identify the one/two interval(s) of time when TCP congestion avoidance is operating.
iii. After the 3th transmission round, how segment loss is detected?
iv. After the 10th transmission round, how segment loss is detected?
v. What is the maximum possible initial value of Threshold at the first transmission round?
vi. What is the value of Threshold at the 4th transmission round?
vii. What is the value of Threshold at the 11th transmission round?
viii. What will be the congestion window size and the value of Threshold at the 16^{th} transmission round if a segment is lost after the 15^{th} transmission round due to a triple duplicate ACK?

Answer:

i. TCP slowstart is operating in the interval [4,7]: double the previous window size
ii. TCP congestion avoidance is operating in the intervals [1,3] and [8,16]: linearly increase the window size
iii. After the 3th transmission round, packet loss is detected due to timeout, and hence the congestion window size is set to 1.
iv. After the 10th transmission round, segment loss is recognized by a triple duplicate ACK. If there was a timeout, the congestion window size would have dropped to 1.
v. The maximum possible initial value of the threshold at the first transmission round is 30 since when the congestion window size is 30, TCP congestion avoidance is operating.
vi. The threshold is set to half the value of the congestion window when packet loss is detected. When loss is detected during transmission round 3, the congestion windows size is 32. Hence the threshold is 16 during the 4th transmission round.
vii. The threshold is 9 during the 11th transmission round since packet loss is detected. When loss is detected during transmission round 10, the congestion windows size is 18. Hence the threshold is 9 during the 11th transmission round.
viii. The congestion window size and the threshold value are both 3, which is half of the previous congestion window size (i.e. 6) due to a triple ACK.

<u>Question 5B</u>. **[16 marks]**

Assuming TCP Reno is the protocol experiencing the behavior shown in Table 1, answer the following questions. In all cases, you should provide a short explanation justifying your answer.

Table 1: TCP congestion control

NTR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
CWS	14	15	16	1	2	4	8	9	10	11	12	6	7	8	4	5

NTR – number of transmission round
CWS – congestion window size

i. Identify the one/two interval(s) of time when TCP slow start is operating.
ii. Identify the one/two interval(s) of time when TCP congestion avoidance is operating.
iii. After the 3th transmission round, how segment loss is detected?
iv. After the 11th transmission round, how segment loss is detected?
v. What is the maximum possible initial value of Threshold at the first transmission round?
vi. What is the value of Threshold at the 4th transmission round?
vii. What is the value of Threshold at the 12th transmission round?
viii. What will be the congestion window size and the value of Threshold at the 16^{th} transmission round if a segment is lost after the 15^{th} transmission round due to a triple duplicate ACK?

Answer

i. TCP slowstart is operating in the interval [4,6]: double the previous window size
ii. TCP congestion avoidance is operating in the intervals [1,3] and [7,16]: linearly increase the window size
iii. After the 3th transmission round, packet loss is detected due to timeout, and hence the congestion window size is set to 1.
iv. After the 11th transmission round, segment loss is recognized by a triple duplicate ACK. If there was a timeout, the congestion window size would have dropped to 1.
v. The maximum possible initial value of the threshold at the first transmission round is 14 since when the congestion window size is 14, TCP congestion avoidance is operating.
vi. The threshold is set to half the value of the congestion window when packet loss is detected. When loss is detected during transmission round 3, the congestion windows size is 16. Hence the threshold is 8 during the 4th transmission round.
vii. The threshold is 6 during the 12th transmission round since packet loss is detected. When loss is detected during transmission round 11, the congestion windows size is 12. Hence the threshold is 6 during the 12th transmission round.
viii. The congestion window size and the threshold value are both 2, which is half of the previous congestion window size (i.e. 4) due to a triple ACK.