Please type your homework. We will discuss each problem in class but you must do your own work for submission.

**Homework**

1) (10/9, 10 points) Consider transferring an enormous file of \( L \) bytes from Host A to Host B. Assume an MSS of 536 bytes.
   a) What is the maximum value of \( L \) such that TCP sequence numbers are not exhausted? Recall that the TCP sequence number field has 4 bytes.
   b) For the \( L \) obtained in a), find how long it takes to transmit the file. Assume that a total of 66 bytes of transport, network, and data-link header are added to each segment before the resulting packet is sent out over a 155Mbps link. Ignore flow and congestion control so A can pump out the segments back to back and continuously.

2) (10/9, 10 points) Suppose that the five measured \( \text{SampleRTT} \) values are 106ms, 120ms, 140ms, 90ms, and 115ms. Compute the \( \text{EstimatedRTT} \) after each of these \( \text{SampleRTT} \) values is obtained, using a value of \( \alpha=0.125 \) and assuming that the value of \( \text{EstimatedRTT} \) was 100ms just before the first of these five samples were obtained. Compute also the \( \text{DevRTT} \) after each sample is obtained, assuming a value of \( \beta=0.25 \) and assuming the value of \( \text{DevRTT} \) was 5ms just before the first of these five samples was obtained. Last, compute the TCP \( \text{TimeoutInterval} \) after each of these samples is obtained.

3) (10/11, 20 points) Consider the figure below.

Assuming TCP-Reno is the protocol experiencing the behavior shown here, answer the following questions. In all cases, you should provide a short discussion justifying your answer.
   a. Identify the intervals of time when TCP slow start is operating.
   b. Identify the intervals of time when TCP congestion avoidance is operating.
   c. After the 16th transmission round, is segment loss detected by a triple duplicate ACK or by a timeout?
   d. After the 22nd transmission round, is segment loss detected by a triple duplicate ACK or by a timeout?
e. What is the initial value of ssthresh at the first transmission round?

f. What is the value of ssthresh at the 18th transmission round?

g. What is the value of ssthresh at the 24th transmission round?

h. During what transmission round is the 70th segment sent?

i. Assuming a packet loss is detected after the 26th round by the receipt of a triple duplicate ACK, what will be the values of the congestion window size and of ssthresh?

j. Suppose TCP-Tahoe is used (instead of TCP-Reno), and assume that triple duplicate ACKs are received at the 16th round. What are the ssthresh and the congestion window size at the 19th round?

k. Again suppose TCP-Tahoe is used, and there is a timeout event at 22nd round. How many packets have been sent out from 17th round till 22nd round, inclusive?

4) (10/11, 10 points) Recall the macroscopic description of TCP throughput. In the period of time from when the connection’s rate varies from \( W(2RTT) \) to \( W/RTT \), only one packet is lost (at the very end of the period).

a) Show that the loss rate (fraction of packets lost) is equal to

\[
L = \frac{1}{3\frac{W^2}{8} + \frac{3}{4}W}
\]

b) Use the result from a) to show that if a connection has loss rate \( L \), then its average rate is approximately given by

\[
\frac{1.22 \cdot MSS}{RTT\sqrt{L}}
\]

5) (10/11 20 points) Consider a simplified TCP’s AIMD algorithm where the congestion window size is measured in number of segments, not in bytes. In additive increase, the congestion window size increases by one segment in each RTT. In multiplicative decrease, the congestion window size decreases by half (if the result is not an integer, round down to the nearest integer). Suppose that two TCP connections, C1 and C2, share a single congested link of speed 30 segments per second. Assume that both C1 and C2 are in the congestion avoidance phase. Connection C1’s RTT is 50 ms and connection C2’s RTT is 100 ms. Assume that when the data rate in the link exceeds the link’s speed, all TCP connections experience data segment loss.

a) If both C1 and C2 at time \( t=0 \) have a congestion window of 10 segments, what are their congestion window sizes after 1000 msec? Show your work by filling in the following table. The first two rows have been filled for you.

<table>
<thead>
<tr>
<th>Time (msec)</th>
<th>Window Size (# segments sent in next 50ms)</th>
<th>Avg. data sending rate (segments/sec = window/0.1)</th>
<th>Window Size (# segments sent in next 200msec)</th>
<th>Avg. data sending rate (segments/sec = window/0.2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10</td>
<td>200 (in [0-50] ms)</td>
<td>10</td>
<td>100 (in [0-50] ms)</td>
</tr>
<tr>
<td>50</td>
<td>5</td>
<td>100 (in [50-100] ms)</td>
<td>10</td>
<td>100 (in [50-100] ms)</td>
</tr>
<tr>
<td></td>
<td>(decreases window size as the avg. total sending rate to the link in last 50msec is 300= 200+100)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
b) In the long run, will these two connections get the same share of the bandwidth of the congested link? Explain.

Lab Exercises

6) (10/9, 30 points) OPNET simulation of the Congestion Control Mechanism of TCP Prepare a report that includes the answers to all exercises within as well as the graphs you generated from the simulation scenarios. Discuss the results you obtained and compare these results with your expectations. Mention any anomalies or unexplained behaviors. Here is the full description of the experiments.

Create a New Project


2. Select Project and click OK ⇒ Name the project <your initials>_TCP, and the scenario No_Drop ⇒ Click OK.

3. In the Startup Wizard: Initial Topology dialog box, make sure that Create Empty Scenario is selected ⇒ Click Next ⇒ Select Choose From Maps from the Network Scale list ⇒ Click Next ⇒ Choose USA from the Map List ⇒ Click Next twice ⇒ Click OK.
Create and Configure the Network

Initialize the Network:

1. The Object Palette dialog box should now be on the top of your project space. If it is not there, open it by clicking . Make sure that the internet_toolbox item is selected from the pull-down menu on the object palette.

2. Add to the project workspace the following objects from the palette: Application Config, Profile Config, an ip32_Cloud, and two subnets.
   a. To add an object from a palette, click its icon in the object palette ⇒ Move your mouse to the workspace ⇒ Click to drop the object in the desired location ⇒ Right-click to finish creating objects of that type.

3. Close the palette.

4. Rename the objects you added as shown and then save your project:

![Diagram of the United States showing network components including Applications, Profiles, USA Internet, and East and West nodes.]
Configure the Applications:

1. Right-click on the Applications node ⇒ Edit Attributes ⇒ Expand the Application Definitions attribute and set rows to 1 ⇒ Expand the new row ⇒ Name the row FTP_Application.
   
   i. Expand the Description hierarchy ⇒ Edit the FTP row as shown (you will need to set the Special Value to Not Used while editing the shown attributes):

   ![FTP Table Diagram]

   ![Inter-Request Time Specification Diagram]

2. Click OK twice and then save your project.
Configure the Profiles:

1. Right-click on the Profiles node ⇒ Edit Attributes ⇒ Expand the Profile Configuration attribute and set rows to 1.
   i. Name and set the attributes of row 0 as shown ⇒ Click OK.

![Profiles Attributes](image)

Configure the West Subnet:

1. Double-click on the West subnet node. You get an empty workspace, indicating that the subnet contains no objects.

2. Open the object palette and make sure that the internet_toolbox item is selected from the pull-down menu.

3. Add the following items to the subnet workspace: one ethernet_server, one ethernet4_slip8_gtwy router, and connect them with a bidirectional 100_BaseT link ⇒ Close the palette ⇒ Rename the objects as shown.

![Diagram](image)
4. Right-click on the Server_West node ⇒ Edit Attributes:
   i. Edit Application: Supported Services ⇒ Set rows to 1 ⇒ Set Name to FTP_Application ⇒ Click OK.
   ii. Edit the value of the Server Address attribute and write down Server_West.
   iii. Expand the TCP Parameters hierarchy ⇒ Set both Fast Retransmit and Fast Recovery to Disabled.

5. Click OK and then save your project.

Now, you have completed the configuration of the West subnet. To go back to the top level of the project, click the Go to next higher level button.

Configure the East Subnet:

1. Double-click on the East subnet node. You get an empty workspace, indicating that the subnet contains no objects.

2. Open the object palette and make sure that the internet_toolbox item is selected from the pull-down menu.

3. Add the following items to the subnet workspace: one ethernet_wkstn, one ethernet4_slip8_gtwy router, and connect them with a bidirectional 100_BaseT link ⇒ Close the palette ⇒ Rename the objects as shown.

   ![Diagram of East Subnet Configuration](image)

4. Right-click on the Client_East node ⇒ Edit Attributes:
   i. Expand the Application: Supported Profiles hierarchy ⇒ Set rows to 1 ⇒ Expand the row 0 hierarchy ⇒ Set Profile Name to FTP_Profile.
   ii. Assign Client_East to the Client Address attributes.
   iii. Edit the Application: Destination Preferences attribute as follows:

   Set rows to 1 ⇒ Set Symbolic Name to FTP Server ⇒ Edit Actual Name ⇒ Set rows to 1 ⇒ In the new row, assign Server_West to the Name column.

5. Click OK three times and then save your project.

6. You have now completed the configuration of the East subnet. To go back to the project space, click the Go to next higher level button.
Connect the Subnets to the IP Cloud:

1. Open the object palette.

2. Using two PPP_DS3 bidirectional links connect the East subnet to the IP Cloud and the West subnet to the IP Cloud.

3. A pop-up dialog box will appear asking you what to connect the subnet to the IP Cloud with. Make sure to select the "routers."

4. Close the palette.

Choose the Statistics

OFNET provides the following capture modes:

All values—collects every data point from a statistic.

Sample—collects the data according to a user-specified time interval or sample count. For example, if the time interval is 10, data is sampled and recorded every 10th second. If the sample count is 10, every 10th data point is recorded. All other data points are discarded.

Bucket—collects all of the points over the time interval or sample count into a "data bucket" and generates a result from each bucket. This is the default mode.

1. Right-click on Server_West in the West subnet and select Choose Individual Statistics from the pop-up menu.

2. In the Choose Results dialog box, choose the following statistic:

TCP Connection ⇒ Congestion Window Size (bytes) and Sent Segment Sequence Number.

3. Right-click on the Congestion Window Size (bytes) statistic ⇒ Choose Change Collection Mode ⇒ In the dialog box check Advanced ⇒ From the drop-down menu, assign all values to Capture mode as shown ⇒ Click OK.
4. Right-click on the **Sent Segment Sequence Number** statistic ⇒ Choose **Change Collection Mode** ⇒ In the dialog box check **Advanced** ⇒ From the drop-down menu, assign all values to Capture mode.

5. Click **OK** twice and then save your project.

6. Click the **Go to next higher level** button.

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**Configure the Simulation**

Here we need to configure the duration of the simulation:

1. Click on ![Simulate](image) and the **Configure Simulation** window should appear.

2. Set the duration to be **10.0 minutes**.

3. Click **OK** and then save your project.

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**Duplicate the Scenario**

In the network we just created we assumed a perfect network with no discarded packets. Also, we disabled the fast retransmit and fast recovery techniques in TCP. To analyze the effects of discarded packets and those congestion-control techniques, we will create two additional scenarios.

1. Select **Duplicate Scenario** from the **Scenarios** menu and give it the name **Drop_NoFast** ⇒ Click **OK**.

2. In the new scenario, right-click on the **IP Cloud** ⇒ **Edit Attributes** ⇒ Assign 0.05% to the **Packet Discard Ratio** attribute.

3. Click **OK** and then save your project.

4. While you are still in the **Drop_NoFast** scenario, select **Duplicate Scenario** from the **Scenarios** menu and give it the name **Drop_Fast**.

5. In the **Drop_Fast** scenario, right-click on **Server_West**, which is inside the West subnet ⇒ **Edit Attributes** ⇒ Expand the **TCP Parameters** hierarchy ⇒ Enable the **Fast Retransmit** attribute ⇒ Assign **Reno** to the **Fast Recovery** attribute.

6. Click **OK** and then save your project.

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With fast retransmit, TCP performs a retransmission of what appears to be the missing segment, without waiting for a retransmission timeout to expire.

After fast retransmit sends what appears to be the missing segment, congestion avoidance last not slow start is performed. This is the fast recovery algorithm.

The fast retransmit and fast recovery algorithms are usually implemented together (RFC 201).
Run the Simulation

To run the simulation for the three scenarios simultaneously:

1. Go to the Scenarios menu ⇒ Select Manage Scenarios.

2. Change the values under the Results column to `<collect>` (or `<recollect>`) for the three scenarios. Compare to the following figure.

![Manage Scenarios Table](image)

3. Click OK to run the three simulations. Depending on the speed of your processor, this may take several minutes to complete.

4. After the three simulation runs complete, one for each scenario, click Close ⇒ Save your project.

View the Results

To view and analyze the results:

1. Switch to the Drop_NoFast scenario (the second one) and choose View Results from the Results menu.

2. Fully expand the Object Statistics hierarchy and select the following two results: Congestion Window Size (bytes) and Sent Segment Sequence Number.
3. Click **Show**. The resulting graphs should resemble the ones below.
4. To zoom in on the details in the graph, click and drag your mouse to draw a rectangle, as shown above.

5. The graph should be redrawn to resemble the following one:

6. Notice the Segment Sequence Number is almost flat with every drop in the congestion window.

7. Close the View Results dialog box and select Compare Results from the Result menu.

8. Fully expand the Object Statistics hierarchy as shown and select the following result: Sent Segment Sequence Number.
9. Click Show. After zooming in, the resulting graph should resemble the one below.
Further Readings

- OPNET TCP Model Description: From the Protocols menu, select TCP ⇒ Model Usage Guide.


Exercises

1) Why does the Segment Sequence Number remain unchanged (indicated by a horizontal line in the graphs) with every drop in the congestion window?

2) Analyze the graph that compares the Segment Sequence numbers of the three scenarios. Why does the Drop_NoFast scenario have the slowest growth in sequence numbers?

3) In the Drop_NoFast scenario, obtain the overlaid graph that compares Sent Segment Sequence Number with Received Segment ACK Number for Server_West. Explain the graph.

   Hint:
   - Make sure to assign all values to the Capture mode of the Received Segment ACK Number statistic.

4) Create another scenario as a duplicate of the Drop_Fast scenario. Name the new scenario Q4_Drop_Fast_Buffer. In the new scenario, edit the attributes of the Client_East node and assign 65535 to its Receiver Buffer (bytes) attribute (one of the TCP Parameters). Generate a graph that shows how the Congestion Window Size (bytes) of Server_West gets affected by the increase in the receiver buffer (compare the congestion window size graph from the Drop_Fast scenario with the corresponding graph from the Q4_Drop_Fast_Buffer scenario.)