Laboratory
8

TCP: Transmission Control Protocol

A Reliable, Connection-Oriented, Byte-Stream Service

Objective

This lab is designed to demonstrate the congestion control algorithms implemented by the Transmission Control Protocol (TCP). The lab provides a number of scenarios to simulate these algorithms. You will compare the performance of the algorithms through the analysis of the simulation results.

Overview

The Internet's TCP guarantees the reliable, in-order delivery of a stream of bytes. It includes a flow-control mechanism for the byte streams that allows the receiver to limit how much data the sender can transmit at a given time. In addition, TCP implements a highly tuned congestion-control mechanism. The idea of this mechanism is to throttle how fast TCP sends data to keep the sender from overloading the network.

The idea of TCP congestion control is for each source to determine how much capacity is available in the network, so that it knows how many packets it can safely have in transit. It maintains a state variable for each connection, called the *congestion window,* which is used by the source to limit how much data it is allowed to have in transit at a given time. TCP uses a mechanism, called *additive increase/multiplicative decrease,* that decreases the congestion window when the level of congestion goes up and increases the congestion window when the level of congestion goes down. TCP interprets timeouts as a sign of congestion. Each time a timeout occurs, the source sets the congestion window to half of its previous value. This halving corresponds to the *multiplicative decrease* part of the mechanism. The congestion window is not allowed to fall below the size of a single packet (the TCP maximum segment size, or MSS). Every time the source successfully sends a congestion window's worth of packets, it adds the equivalent of one packet to the congestion window; this is the *additive increase* part of the mechanism.

TCP uses a mechanism called *slow start* to increase the congestion window "rapidly" from a cold start in TCP connections. It increases the congestion window exponentially, rather than linearly. Finally, TCP utilizes a mechanism called *fast retransmit and fast recovery*. Fast retransmit is a heuristic that sometimes triggers the retransmission of a dropped packet sooner than the regular timeout mechanism

In this lab you will set up a network that utilizes TCP as its end-to-end transmission protocol and analyze the size of the congestion window with different mechanisms.

Procedure

Create a New Project

1. Start **Riverbed Modeler Academic Edition** ⇒ Choose **New** from the **File** menu.

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 **Finish**.

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.

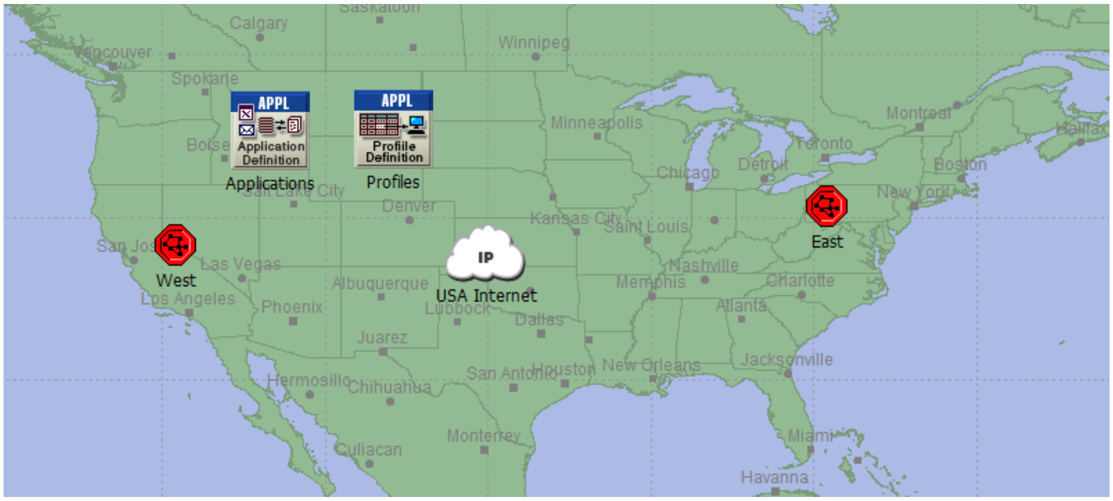
The **ip32_cloud** node model represents an IP cloud supporting up to 32 serial line interfaces at a selectable data rate through which IP traffic can be modeled. IP packets arriving on any cloud interface are routed to the appropriate output interface based on their destination IP address. The RIP or OSPF protocol may be used to automatically and dynamically create the cloud's routing tables and select routes in an adaptive manner. This cloud requires a fixed amount of time to route each packet, as determined by the **Packet Latency** attribute of the node.

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.

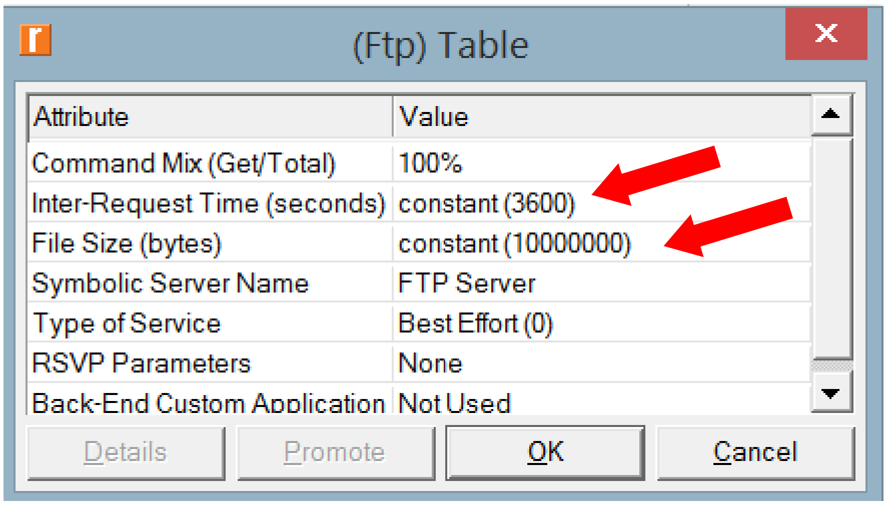
4. Rename the objects you added as shown and then save your project:



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 (there are **7** zeros in that number):



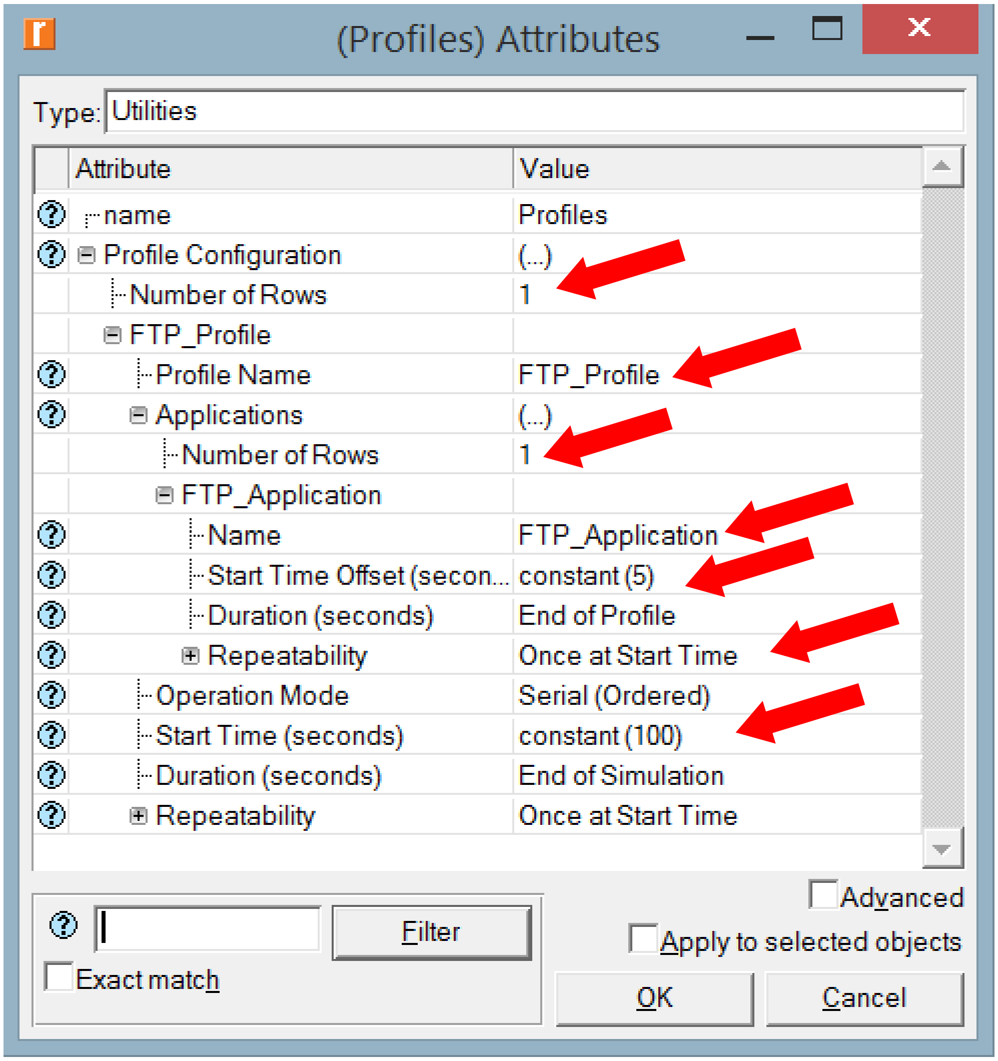
Attribute	Value
Command Mix (Get/Total)	100%
Inter-Request Time (seconds)	constant (3600)
File Size (bytes)	constant (10000000)
Symbolic Server Name	FTP Server
Type of Service	Best Effort (0)
RSVP Parameters	None
Back-End Custom Application	Not Used

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 as shown ⇒ Click **OK**.



(Profiles) Attributes

Type: Utilities

Attribute	Value
name	Profiles
⊟ Profile Configuration	(...)
Number of Rows	1
⊟ FTP_Profile	
Profile Name	FTP_Profile
⊟ Applications	(...)
Number of Rows	1
⊟ FTP_Application	
Name	FTP_Application
Start Time Offset (secon...	constant (5)
Duration (seconds)	End of Profile
⊞ Repeatability	Once at Start Time
Operation Mode	Serial (Ordered)
Start Time (seconds)	constant (100)
Duration (seconds)	End of Simulation
⊞ Repeatability	Once at Start Time

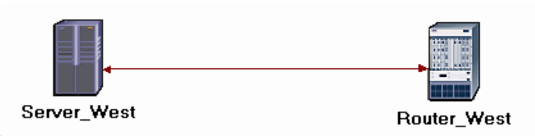
Configure the West Subnet:

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.

The **ethernet4_slip8_gtwy** node model represents an IP-based gateway supporting four Ethernet hub interfaces and eight serial line interfaces.

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.



4. Right-click on the **Server_West** node ⇒ **Edit Attributes**:
   i. Edit **Application: Supported Services** inside **Applications** ⇒ 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 inside **TCP** ⇒ Set **Flavor** to **Tahoe**.

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

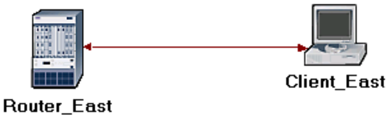
Now, you have completed the configuration of the **West** subnet. To go back to the top level of the project, click the **Go to next higher level** button.

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.



4. Right-click on the **Client_East** node ⇒ **Edit Attributes**:

   i. Expand the **Application: Supported Profiles** hierarchy in **Application** ⇒ Set **rows** to 1 ⇒ Set **Profile Name** to **FTP_Profile.**

   ii. 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.

   iii. Assign **Client_ East** to the **Client Address** attributes.

5. Click **OK** 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.

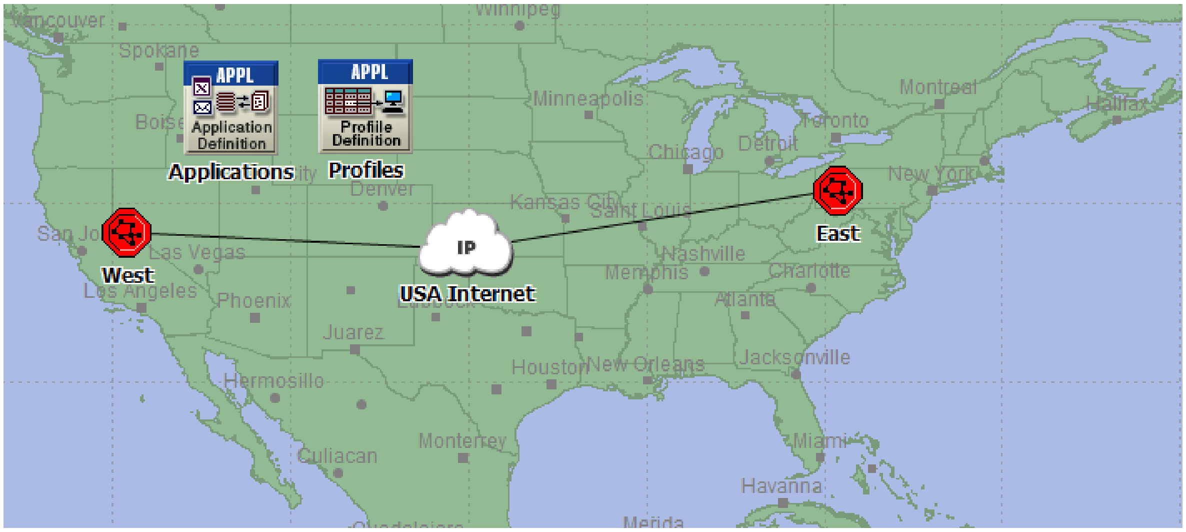
Connect the Subnets to the IP Cloud:

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

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**.

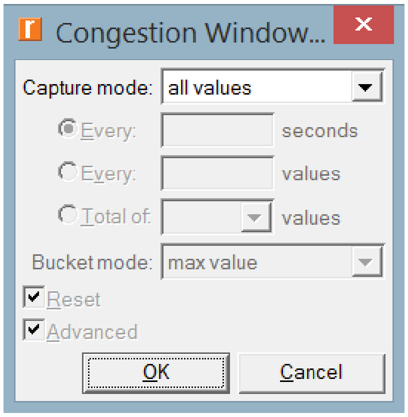
Modeler provides the following capture modes:

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.

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**.



Capture mode: all values

● Every: seconds

○ Every: values

○ Total of: values

Bucket mode: max value

☑ Reset

☑ Advanced

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.

Configure the Simulation

Here we need to configure the duration of the simulation:

1. Click on and the *Configure Simulation* window should appear.

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

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

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.

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

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

The fast retransmit and fast recovery algorithms are usually implemented together (RFC 2001).

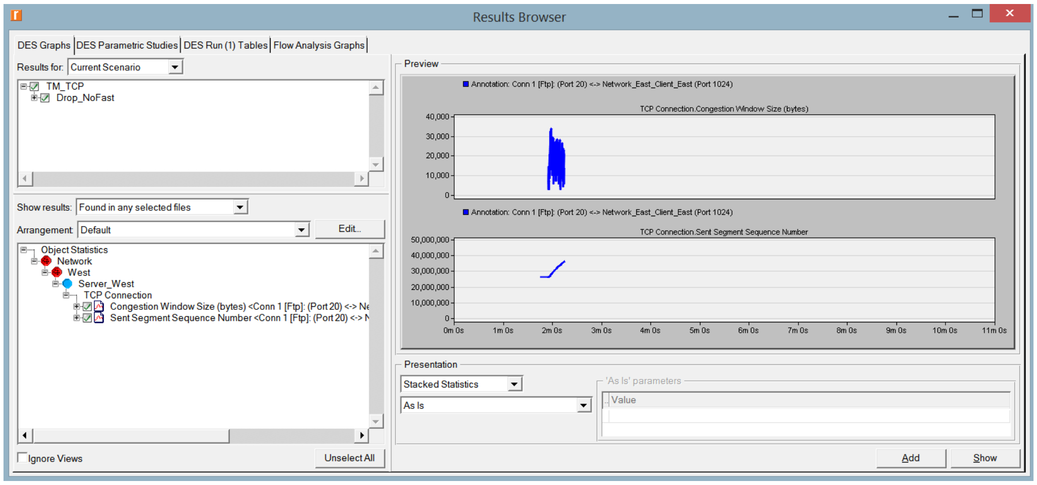
1. Select **Duplicate Scenario** from the **Scenarios** menu and give it the name **Drop_NoFast** ⇒ Click **OK**.
2. In the new scenario, right-click on the **IP Cloud** ⇒ **Edit Attributes** ⇒ Assign **0. 5%** to the **Packet Discard Ratio** attribute in the **Performance Metrics**.
3. Click **OK** and then **Run** a simulation 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 inside **TCP** ⇒ Set **Flavor** to **Reno**.
6. Click **OK** and then **Run** a simulation and then save your project.

View the Results

To view and analyze the results:

To switch to a scenario, choose **Switch to Scenario** from the **Scenarios** menu or just press **Ctrl+<scenario number>.**

1. Switch to the **Drop_NoFast** scenario (the second one) and choose **View Results** from the **Results** in the **DES** menu.
2. Fully expand the **Object Statistics** hierarchy and select the following two results: **Congestion Window Size (bytes)** and **Sent Segment Sequence Number**.



Results Browser

Results for: Current Scenario

☑ TM_TCP
☑ Drop_NoFast

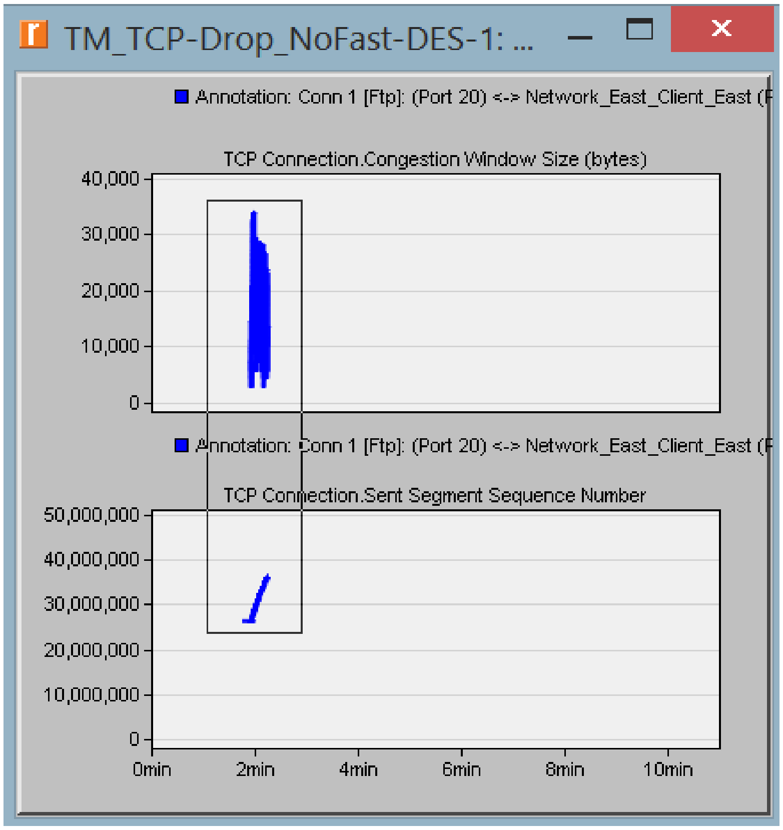
Show results: Found in any selected files

Arrangement: Default

Object Statistics
Network
West
Server_West
TCP Connection
☑ Congestion Window Size (bytes) <Conn 1 [Ftp]: (Port 20) <-> Ne
☑ Sent Segment Sequence Number <Conn 1 [Ftp]: (Port 20) <-> N

Presentation: Stacked Statistics, As Is

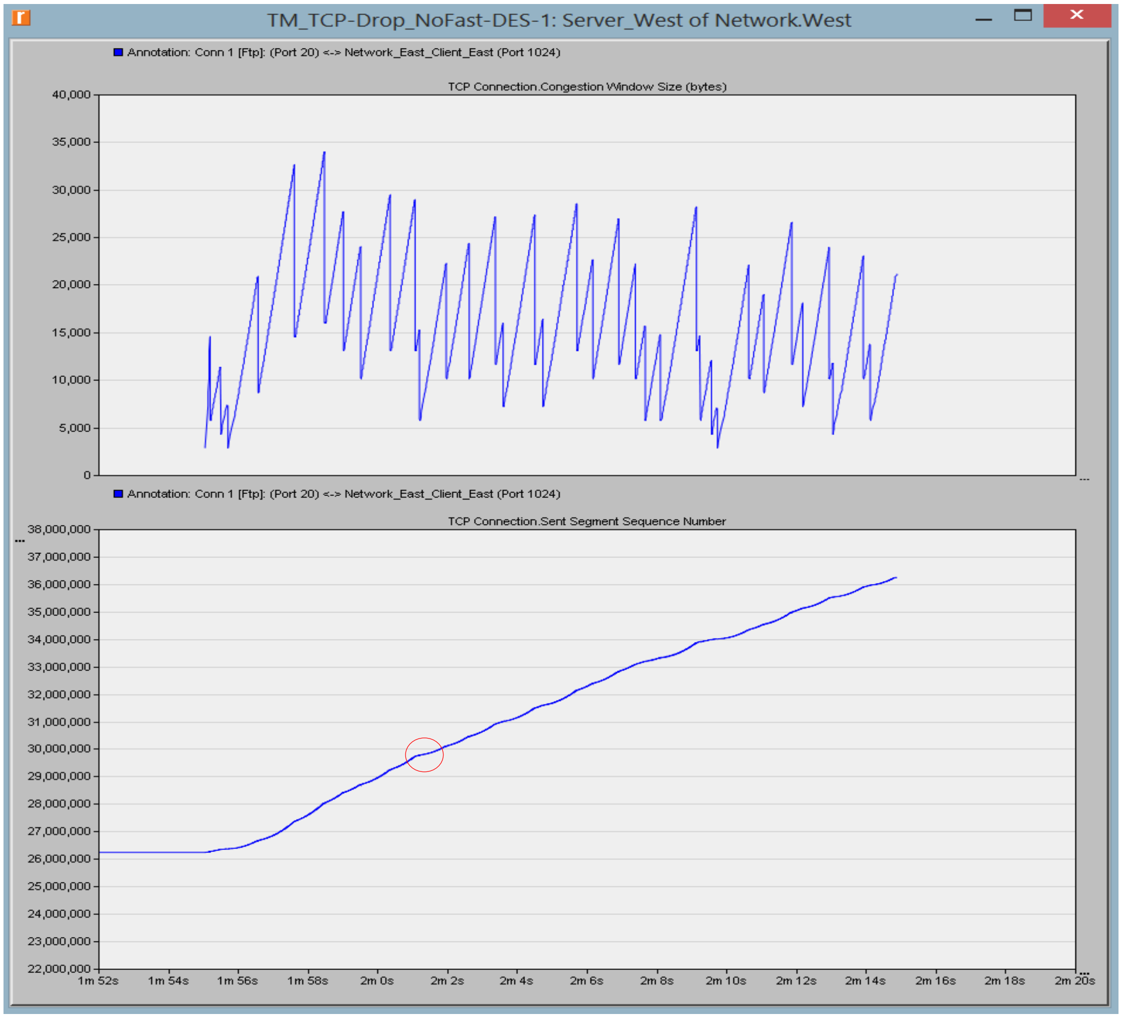
3. Click **Show**. The resulting graphs should resemble the ones below.



TM_TCP-Drop_NoFast-DES-1: ...

4. To zoom in on the details in the graph, click and drag your mouse to draw a rectangle, as shown above.

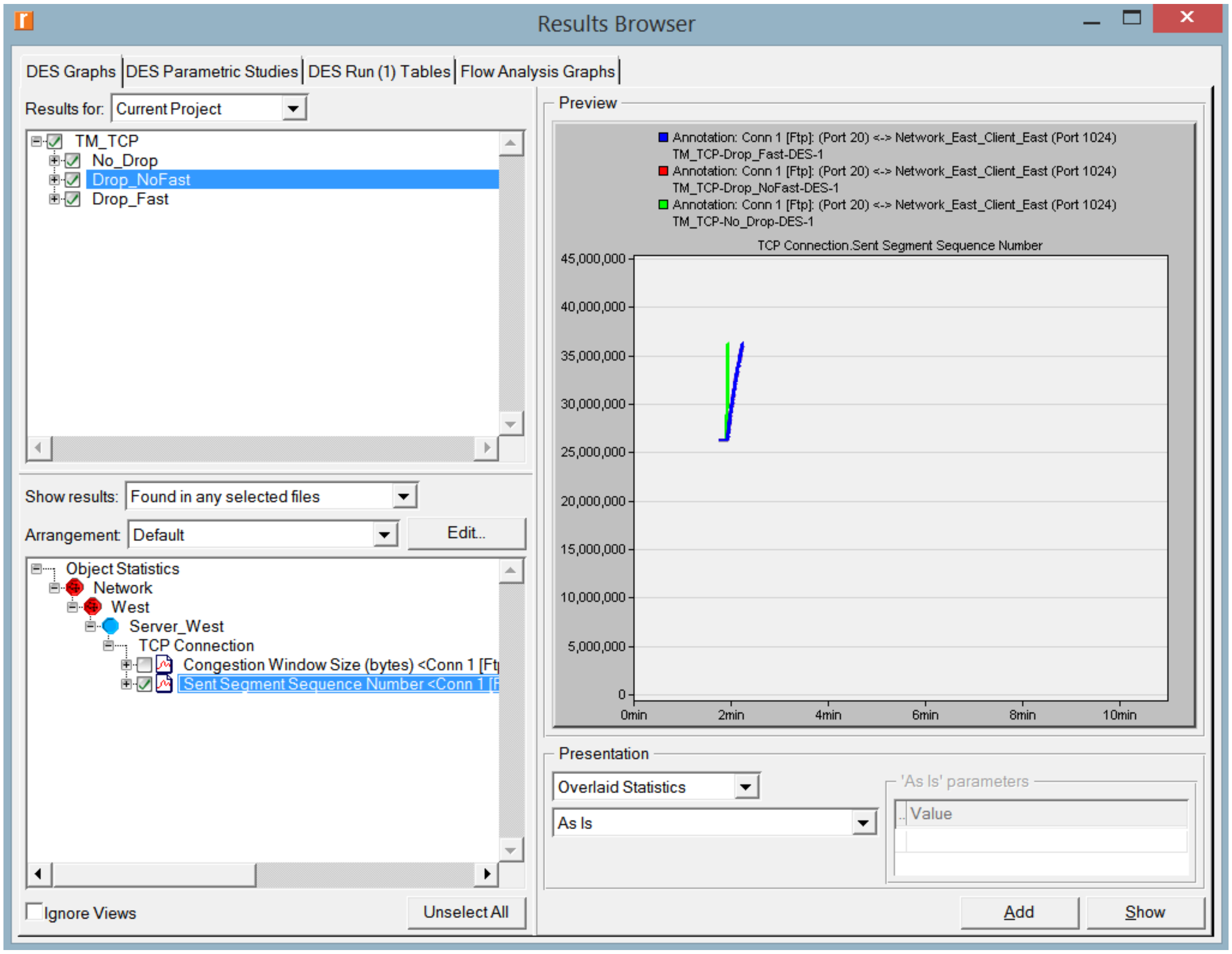
5. The graph should be redrawn to resemble the following one:



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**.



Results for: Current Project

- ☑ TM_TCP
  - ☑ No_Drop
  - ☑ Drop_NoFast
  - ☑ Drop_Fast

Show results: Found in any selected files

Arrangement: Default

- Object Statistics
  - Network
    - West
      - Server_West
        - TCP Connection
          - □ Congestion Window Size (bytes) <Conn 1 [Ft
          - ☑ Sent Segment Sequence Number <Conn 1 [F

□ Ignore Views

🟦 Annotation: Conn 1 [Ftp]: (Port 20) <-> Network_East_Client_East (Port 1024)
TM_TCP-Drop_Fast-DES-1

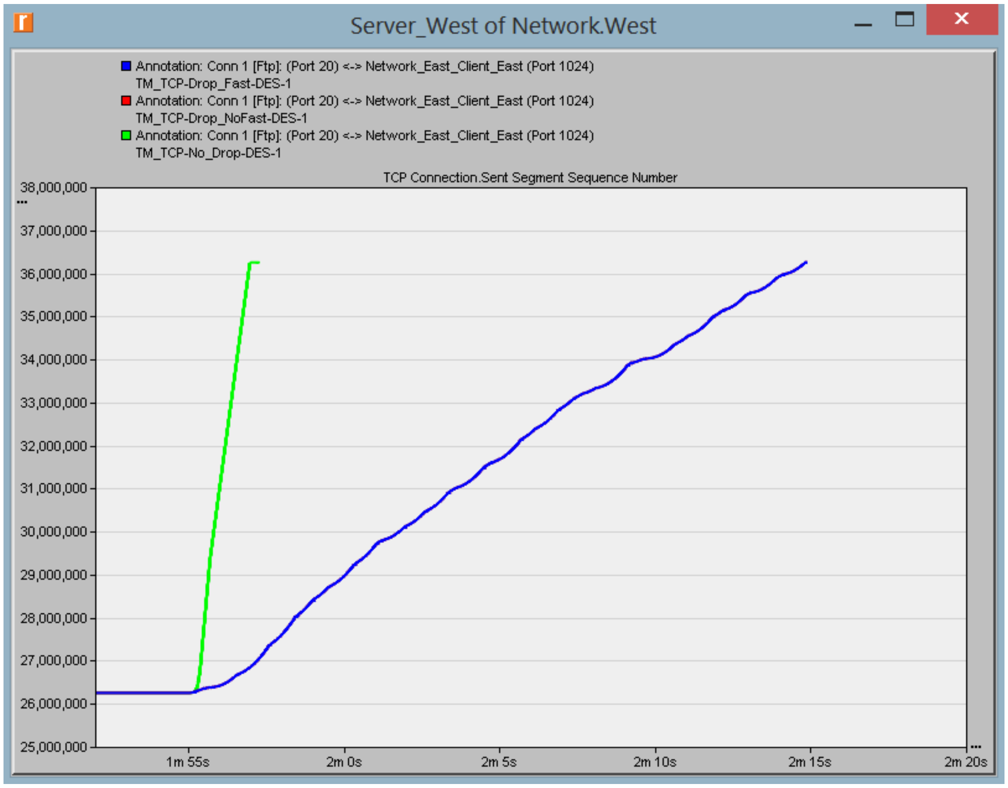
🟥 Annotation: Conn 1 [Ftp]: (Port 20) <-> Network_East_Client_East (Port 1024)
TM_TCP-Drop_NoFast-DES-1

🟩 Annotation: Conn 1 [Ftp]: (Port 20) <-> Network_East_Client_East (Port 1024)
TM_TCP-No_Drop-DES-1

Overlaid Statistics

As Is

9. Click **Show**. After zooming in, the resulting graph should resemble the one below.


Server_West of Network.West
🟦 Annotation: Conn 1 [Ftp]: (Port 20) <-> Network_East_Client_East (Port 1024)
TM_TCP-Drop_Fast-DES-1
🟥 Annotation: Conn 1 [Ftp]: (Port 20) <-> Network_East_Client_East (Port 1024)
TM_TCP-Drop_NoFast-DES-1
🟩 Annotation: Conn 1 [Ftp]: (Port 20) <-> Network_East_Client_East (Port 1024)
TM_TCP-No_Drop-DES-1
TCP Connection.Sent Segment Sequence Number
38,000,000
37,000,000
36,000,000
35,000,000
34,000,000
33,000,000
32,000,000
31,000,000
30,000,000
29,000,000
28,000,000
27,000,000
26,000,000
25,000,000
1m 55s
2m 0s
2m 5s
2m 10s
2m 15s
2m 20s

Further Readings

- Transmission Control Protocol: IETF RFC number 793 (www.ietf.org/rfc.html).

Questions

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.)

Lab Report

Prepare a report that follows the guidelines explained in Lab 0. The report should include the answers to the above questions 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.