Assigned: April 1, 2013
Lab3 has three parts and the last part is extra credit. They are due on April 12 at 11:59pm (digital Dropbox)
Late submissions are accepted for two days only with a maximum penalty of 15% per day. For each day, submissions between 12 am- 1am: 3%, 1am-2am: 7%, 2-3am: 12%, and after 3am: 15%.

LAB3 – PART I

Ethernet

A Direct Link Network with Media Access Control

Objective

This lab is designed to demonstrate the operation of the Ethernet network. The simulation in this lab will help you examine the performance of the Ethernet network under different scenarios.

Overview

The Ethernet is a working example of the more general Carrier Sense, Multiple Access with Collision Detect (CSMA/CD) local area network technology. The Ethernet is a multiple-access network, meaning that a set of nodes sends and receives frames over a shared link. The “carrier sense” in CSMA/CD means that all the nodes can distinguish between an idle and a busy link. The “collision detect” means that a node listens as it transmits and can therefore detect when a frame it is transmitting has interfered (collided) with a frame transmitted by another node. The Ethernet is said to be a 1-persistent protocol because an adaptor with a frame to send transmits with probability 1 whenever a busy line goes idle.

In this lab you will set up an Ethernet with 14 nodes connected via a coaxial link in a bus topology. The coaxial link is operating at a data rate of 10 Mbps. You will study how the throughput of the network is affected by the network load as well as the size of the packets.

Procedure

Create a New Project

To create a new project for the Ethernet network:

1. Start **OPNET IT Guru Academic Edition** ⇒ Choose **New** from the **File** menu.
2. Select **Project** ⇒ Click **OK** ⇒ Name the project **<your initials>_Ethernet**, and the scenario **Coax** ⇒ Click **OK**.
3. In the *Startup Wizard: Initial Topology* dialog box, make sure that **Create Empty Scenario** is selected ⇒ Click **Next** ⇒ Choose **Office** from the *Network Scale* list ⇒ Click **Next** ⇒ Assign **200** to **X Span** and keep **Y Span** as **100** ⇒ Click **Next** twice ⇒ Click **OK**.
4. Close the *Object Palette* dialog box.

Local area networks (LANs) are designed to span distances of up to a few thousand meters.

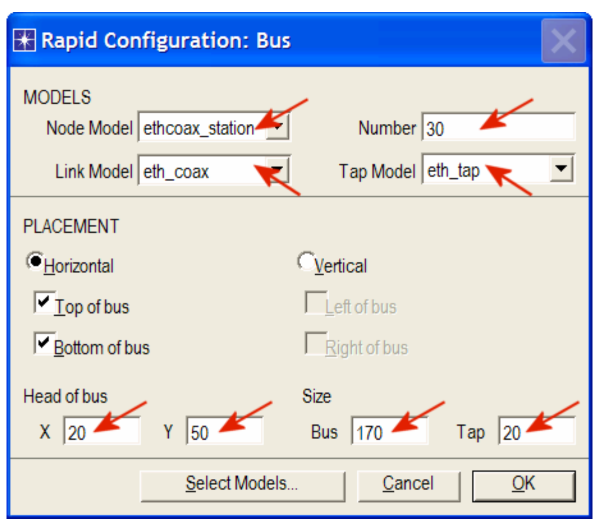
Create the Network

To create our coaxial Ethernet network:

1. To create the network configuration, select **Topology** ⇒ **Rapid Configuration**. From the drop-down menu choose **Bus** and click **OK**.
2. Click the **Select Models** button in the *Rapid Configuration* dialog box. From the *Model List* drop-down menu choose **ethcoax** and click **OK**.
3. In the *Rapid Configuration* dialog box, set the following eight values and click **OK**.

The **eth_tap** is an Ethernet bus tap that connects a node with the bus.

The **eth_coax** is an Ethernet bus that can connect nodes with bus receivers and transmitters via taps.

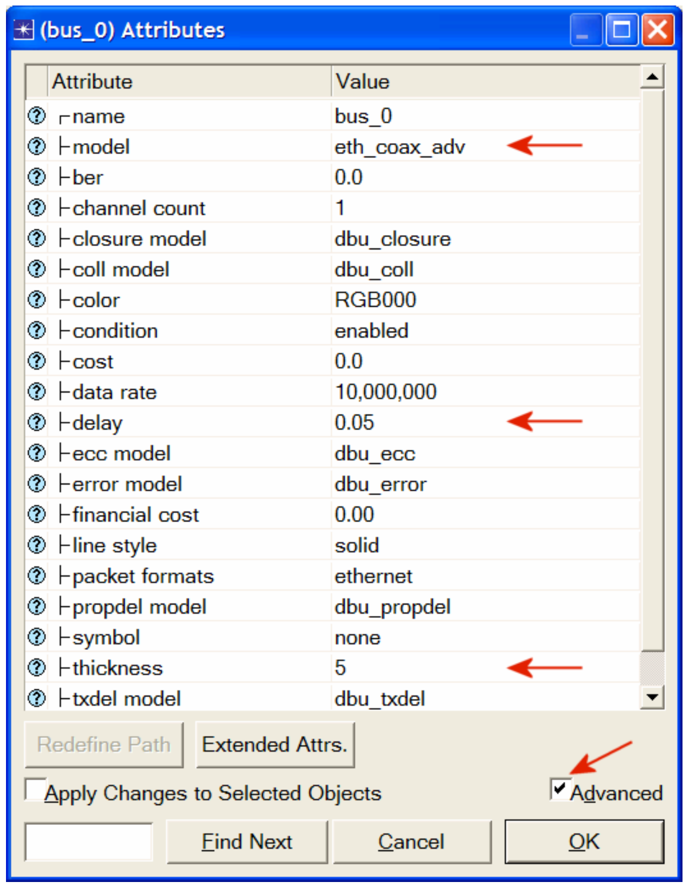


4. To configure the coaxial bus, right-click on the horizontal link ⇒ Select **Advanced Edit Attributes** from the menu:

    a. Click on the value of the **model** attribute ⇒ Select **Edit** from the drop-down menu ⇒ Choose the **eth_coax_adv** model.
    b. Assign the value **0.05** to the **delay** attribute (propagation delay in sec/m).
    c. Assign **5** to the **thickness** attribute.
    d. Click **OK**.

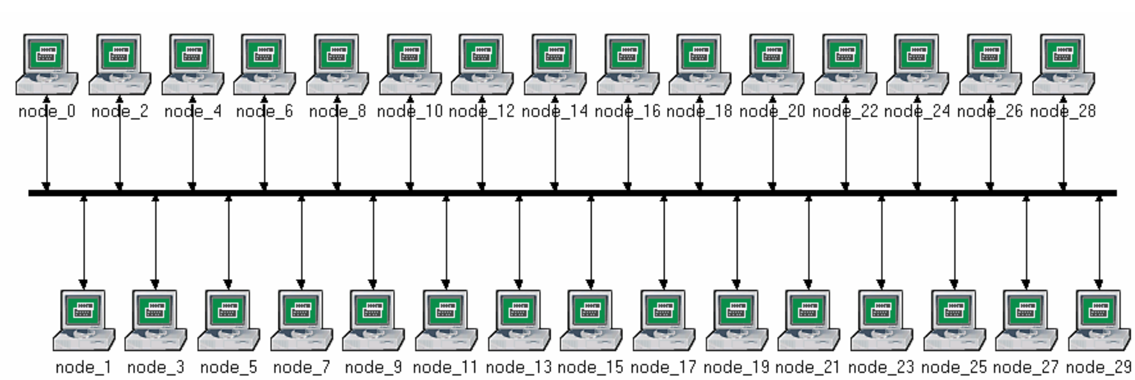
A higher delay is used here as an alternative to generating higher traffic which would require much longer simulation time.

Thickness specifies the thickness of the line used to "draw" the bus link.



5. Now you have created the network. It should look like the illustration below.

6. Make sure to save your project.



Configure the Network Nodes

To configure the traffic generated by the nodes:

1. Right-click on any of the 30 nodes ⇒ **Select Similar Nodes**. Now all nodes in the network are selected.

2. Right-click on any of the 30 nodes ⇒ **Edit Attributes.**

3. Check the **Apply Changes to Selected Objects** check box. This is important to avoid reconfiguring each node individually.

4. Expand the **Traffic Generation Parameters** hierarchy:

   a. Change the value of the **ON State Time** to **exponential(100)** ⇒ Change the value of the **OFF State Time** to **exponential(0)**. (*Note:* Packets are generated only in the "ON" state.)

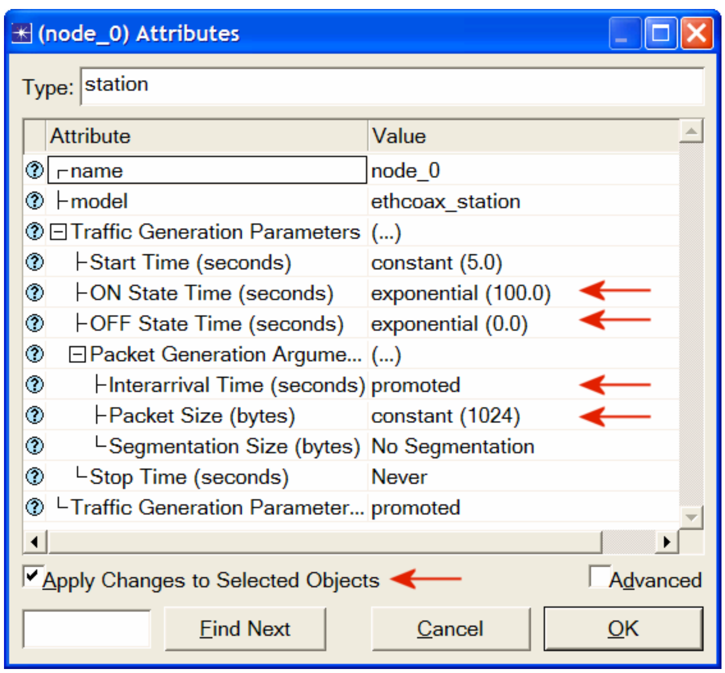
The argument of the **exponential** distribution is the mean of the interval between successive events. In the exponential distribution the probability of occurrence of the next event by a given time is not at all dependent upon the time of occurrence of the last event or the elapsed time since that event.

5. Expand the **Packet Generation Arguments** hierarchy:

   a. Change the value of the **Packet Size** attribute to **constant(1024)**.

   b. Right-click on the **Interarrival Time** attribute and choose **Promote Attribute to Higher Level**. This allows us to assign multiple values to the **Interarrival Time** attribute and hence to test the network performance under different loads.

The **interarrival time** is the time between successive packet generations in the "ON" state.



6. Click **OK** to return back to the *Project Editor*.

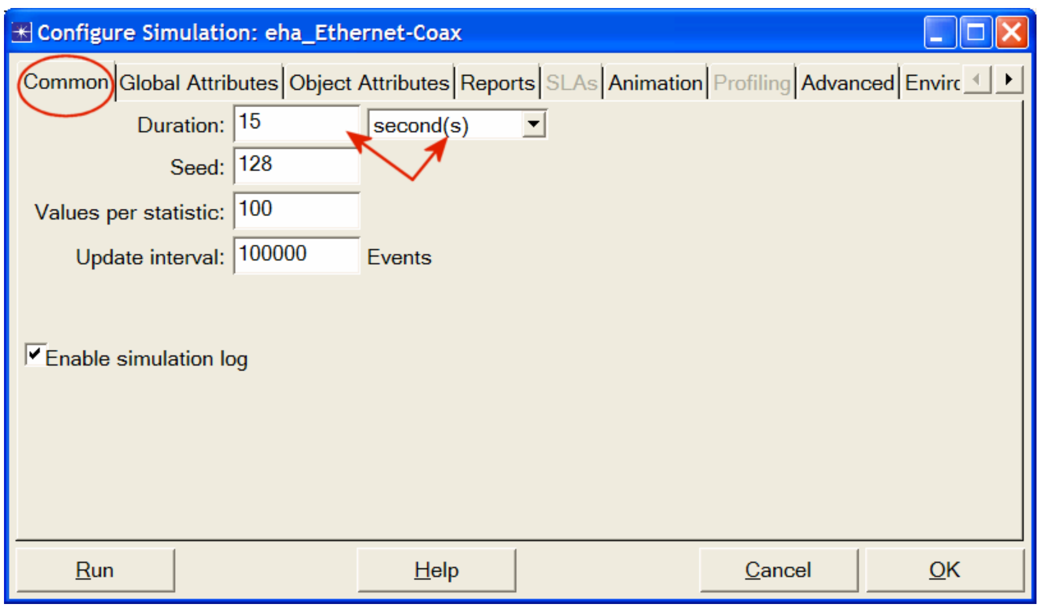
7. Make sure to save your project.

Configure the Simulation

To examine the network performance under different loads, you need to run the simulation several times by changing the load into the network. There is an easy way to do that. Recall that we promoted the **Interarrival Time** attribute for package generation. Here we will assign different values to that attribute:

1. Click on the **Configure/Run Simulation** button: 

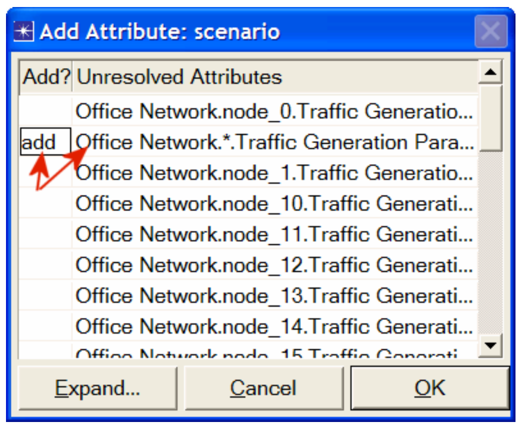
2. Make sure that the **Common** tab is chosen ⇒ Assign **15** seconds to the **Duration.**



3. Click on the **Object Attributes** tab.

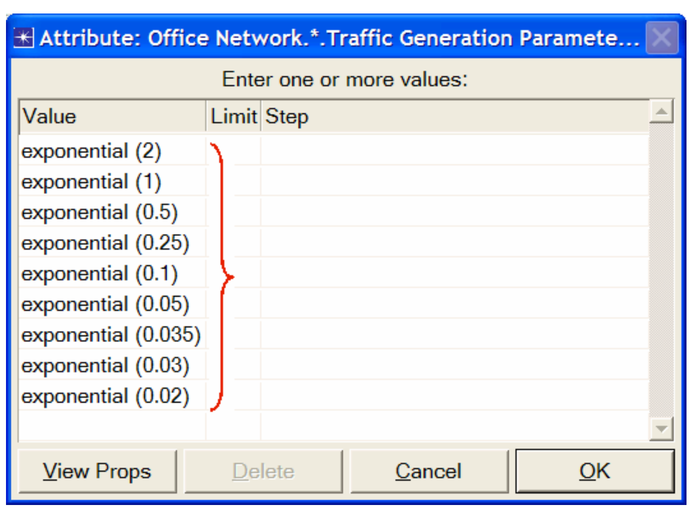
4. Click on the **Add** button. The *Add Attribute* dialog box should appear filled with the promoted attributes of all nodes in the network (if you do not see the attributes in the list, close the whole project and reopen it). You need to add the **Interarrival Time** attribute for all nodes. To do that:

   a. Click on the first attribute in the list (**Office Network.node_0.Traffic Generation** ….) ⇒ Click the **Wildcard** button ⇒ Click on **node_0** and choose the asterisk (*****) from the drop-down menu ⇒ Click **OK**.
   b. A new attribute is now generated containing the asterisk (the second one in the list), and you need to add it by clicking on the corresponding cell under the **Add?** column.
   c. The *Add Attribute* dialog box should look like the following. Click **OK**.

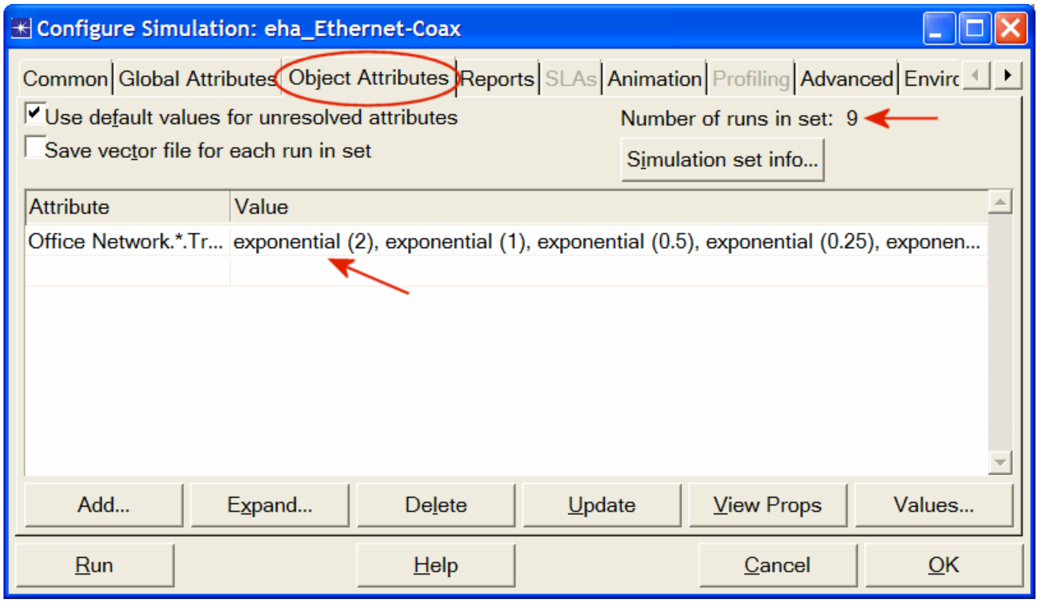


5. Now you should see the **Office Network.*.Traffic Generation Parameter …** in the list of simulation object attributes. Click on that attribute to select it ⇒ Click the **Values** button of the dialog box.

6. Add the following nine values. (*Note:* To add the first value, double-click on the first cell in the **Value** column ⇒ Type "exponential (2)" into the textbox and hit enter. Repeat this for all nine values.)

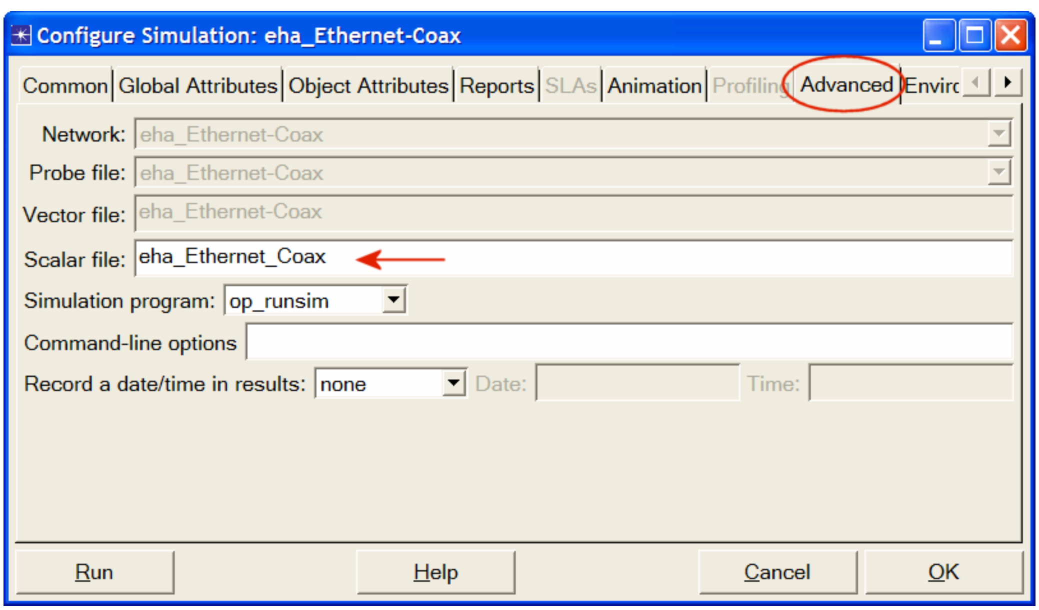


7. Click **OK**. Now look at the upper-right corner of the *Simulation Configuration* dialog box and make sure that the *Number of runs in set* is **9**.



8. For each simulation of the nine runs, we need the simulator to save a “scalar” value that represents the “average” load in the network and to save another scalar value that represents the average throughput of the network. To save these scalars we need to configure the simulator to save them in a file. Click on the **Advanced** tab in the *Configure Simulation* dialog box.

9. Assign **<your initials>_Ethernet_Coax** to the *Scalar file* text field.



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

Choose the Statistics

A **probe** represents a request by the user to collect a particular piece of data about a simulation.

To choose the statistics to be collected during the simulation:

1. Right-click anywhere in the project workspace (but not on one of the nodes or links) and select **Choose Individual Statistics** from the pop-up menu ⇒ Expand the **Global Statistics** hierarchy.

   a. Expand the **Traffic Sink** hierarchy ⇒ Click the check box next to **Traffic Received (packets/sec)** (make sure you select the statistic with units of packets/sec),

   b. Expand the **Traffic Source** hierarchy ⇒ Click the check box next to **Traffic Sent (packets/sec).**

   c. Click **OK**.

2. Now to collect the average of the above statistics as a scalar value by the end of each simulation run:

   a. Select **Choose Statistics (Advanced)** from the *Simulation* menu.

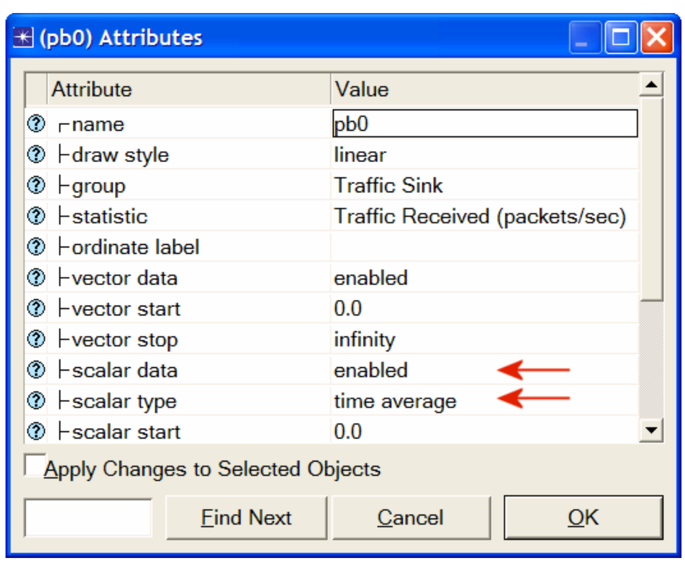
   b. The **Traffic Sent** and **Traffic Received** probes should appear under the **Global Statistic Probes**.

   c. Right-click on **Traffic Received** probe ⇒ **Edit Attributes**. Set the **scalar data** attribute to **enabled** ⇒ Set the **scalar type** attribute to **time average** ⇒ Compare to the following figure and click **OK**.

   d. Repeat the previous step with the **Traffic Sent** probe.

   e. Select save from the **File** menu in the *Probe Model* window and then close that window.

   f. Now you are back to the *Project Editor*. Make sure to save your project.



Run the Simulation

To run the simulation:

1. Click on the **Configure/Run Simulation** button:  ⇒ Make sure that **15 second(s)** (not hours) is assigned to the **Duration** ⇒ Click **Run**. Depending on the speed of your processor, this may take several minutes to complete.

2. Now the simulator is completing nine runs, one for each traffic generation interarrival time (representing the load into the network). Notice that each successive run takes longer to complete because the traffic intensity is increasing.

3. After the nine simulation runs complete, click **Close**.

4. Save your project.

When you rerun the simulation, OPNET IT Guru will “append” the new results to the results already in the scalar file. To avoid that, delete the scalar file *before* you start a new run. (*Note:* Deleting the scalar file *after* a run will result in losing the collected results from that run.)

- Go to the **File** menu ⇒ Select **Model Files** ⇒ **Delete Model Files** ⇒ Select **(.os): Output Scalars** ⇒ Select the scalar file to be deleted; in this lab it is **<your initials>_Ethernet_Coax_Scalar** ⇒ Confirm the deletion by clicking **OK** ⇒ Click **Close.**

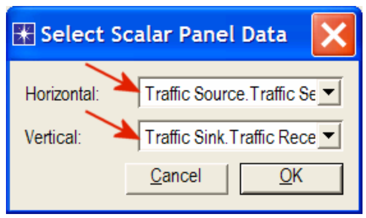
View the Results

To view and analyze the results:

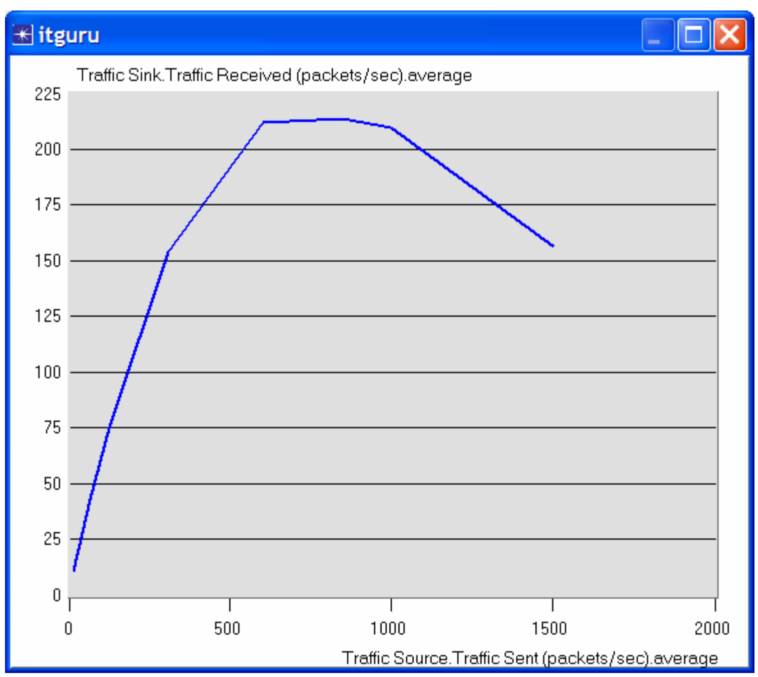
1. Select **View Results (Advanced)** from the **Results** menu. Now the **Analysis Configuration** tool is open.

2. Recall that we saved the average results in a scalar file. To load this file, select **Load Output Scalar File** from the **File** menu ⇒ Select **<your initials>_Ethernet-Coax** from the pop-up menu.

3. Select **Create Scalar Panel** from the **Panels** menu ⇒ Assign **Traffic Source.Traffic Sent (packets/sec).average** to **Horizontal** ⇒ Assign **Traffic Sink.Traffic Received (packets/sec).average** to **Vertical** ⇒ Click **OK**.



4. The resulting graph should resemble the one below:



Further Readings

– OPNET Ethernet Model Description: From the **Protocols** menu, select **Ethernet** ⇒ **Model Usage Guide**.

Questions

1) Explain the graph we received in the simulation that shows the relationship between the received (throughput) and sent (load) packets. Why does the throughput drop when the load is either very low or very high?

2) Create three duplicates of the simulation scenario implemented in this lab. Name these scenarios **Coax_Q2a**, **Coax_Q2b**, and **Coax_Q2c**. Set the **Interarrival Time** attribute of the *Packet Generation Arguments* for all nodes (make sure to check **Apply Changes to Selected Objects** while editing the attribute) in the new scenarios as follows:

- **Coax_Q2a** scenario: exponential(0.1)
- **Coax_Q2b** scenario: exponential(0.05)
- **Coax_Q2c** scenario: exponential(0.025)

In all the above new scenarios, open the *Configure Simulation* dialog box and from the *Object Attributes* delete the multiple-value attribute (the only attribute shown in the list).

Choose the following statistic for node 0: **Ethcoax →Collision Count**. Make sure that the following global statistic is chosen: **Global Statistics→Traffic Sink→Traffic Received (packet/sec)**. (Refer to the *Choose the Statistics* section in the lab.)

Run the simulation for all three new scenarios. Get two graphs: one to compare node 0's collision counts in these three scenarios and the other graph to compare the received traffic from the three scenarios. Explain the graphs and comment on the results. (*Note:* To compare results you need to select **Compare Results** from the **Results** menu after the simulation run is done.)

3) To study the effect of the number of stations on Ethernet segment performance, create a duplicate of the **Coax_Q2c** scenario, which you created in Question 2. Name the new scenario **Coax_Q3**. In the new scenario, remove the odd-numbered nodes, a total of 15 nodes (node 1, node 3, …, and node 29). Run the simulation for the new scenario. Create a graph that compares node 0's collision counts in scenarios **Coax_Q2c** and **Coax_Q3**. Explain the graph and comment on the results.

4) In the simulation a packet size of 1024 bytes is used (*Note:* Each Ethernet packet can contain up to 1500 bytes of data). To study the effect of the packet size on the throughput of the created Ethernet network, create a duplicate of the **Coax_Q2c** scenario, which you created in Question 2. Name the new scenario **Coax_Q4**. In the new scenario use a packet size of 512 bytes (for all nodes). For both **Coax_Q2c** and **Coax_Q4** scenarios, choose the following global statistic: **Global Statistics→Traffic Sink→Traffic Received (bits/sec)**. Rerun the simulation of **Coax_Q2c** and **Coax_Q4** scenarios. Create a graph that compares the throughput as packets/sec and another graph that compares the throughput as bits/sec in **Coax_Q2c** and **Coax_Q4** scenarios. Explain the graphs and comment on the results.

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.

LAB3 – PART II

Wireless Local Area Network

Medium Access Control for Wirelessly Connected Stations

OBJECTIVES

This lab addresses the Medium Access Control (MAC) sublayer of the IEEE 802.11 standard for the wireless local area network (WLAN). Various options of this standard are studied in this lab. The performance of these options is analyzed under multiple scenarios.

OVERVIEW

The IEEE 802.11 standard provides wireless connectivity to computerized stations that require rapid deployment, such as portable computers. The Medium Access Control (MAC) sublayer in the standard includes two fundamental access methods: distributed coordination function (DCF) and point coordination function (PCF). DCF utilizes the carrier sense multiple access with collision avoidance (CSMA/CA) approach. DCF is implemented in all stations in the wireless local area network (WLAN). PCF is based on polling to determine the station that can transmit next. Stations in an infrastructure network optionally implement the PCF access method.

In addition to the physical CSMA/CA, DCF and PCF utilize a virtual carrier-sense mechanism to determine the state of the medium. This virtual mechanism is implemented by means of the network allocation vector (NAV), which provides each station with a prediction of future traffic on the medium. Each station uses NAV as an indicator of time periods during which transmission will not be initiated even if the station senses that the wireless medium is not busy. NAV gets the information about future traffic from management frames and the header of regular frames being exchanged in the network.

With DCF, every station senses the medium before transmitting. The transmitting station defers as long as the medium is busy. After deferral and while the medium is idle, the transmitting station has to wait for a random backoff interval. After the backoff interval and if the medium is still idle, the station initiates data transmission or optionally exchanges request to send (RTS) and clear to send (CTS) frames with the receiving station. The effect of RTS and CTS frames will be studied in the Mobile WLAN lab. With PCF, the access point (AP) in the network acts as a point coordinator (PC). The PC uses polling to determine which station can initiate data transmission. It is optional for the stations in the network to participate in PCF and hence respond to polls received from the PC. Such stations are called CF-Pollable stations. The PCF requires the PC to gain control of the medium. To gain such control, the PC utilizes the Beacon management frames to set the NAV in the network stations. Because the mechanism used to set NAV is based on the DCF, all stations comply with the PC request to set their NAV, whether or not they are CF-Pollable. This way the PC can control frame transmissions in the network by generating contention-free periods (CFPs). The PC and the CF-Pollable stations do not use RTS/CTS in the CFP.

The standard allows for fragmentation of the MAC data units into smaller frames. Fragmentation is favorable in case the wireless channel is not reliable enough to transmit longer frames. Only frames with a length greater than a fragmentation threshold will be fragmented. Each fragment will be sent independently and will be separately acknowledged. During a contention period, all fragments of a single frame will be sent as bursts with a single invocation of the DCF medium access procedure. In case of PCF and during a contention-free period, fragments are sent individually following the rules of the point coordinator (PC).

PRE-LAB ACTIVITIES

Read Section 2.7 from *Computer Networks: A Systems Approach, 5th Edition*.

Go to *www.net-seal.net* and play the following animation:

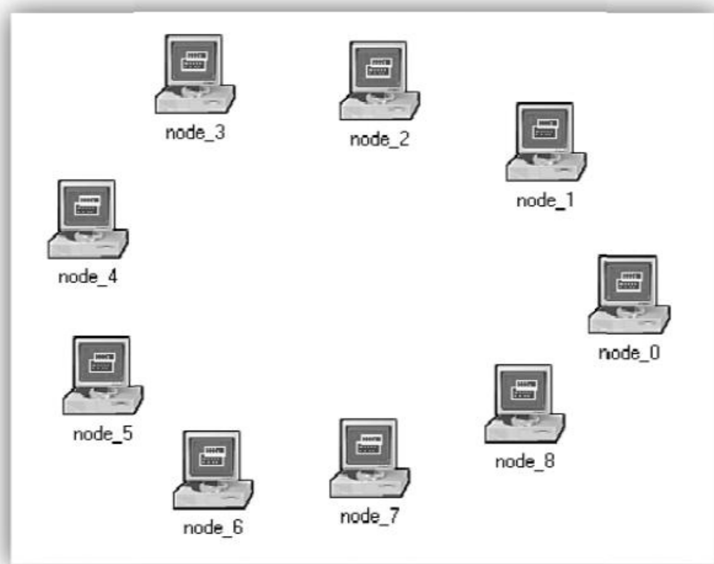
- Wireless Network and Multiple Access with Collision Avoidance

PROCEDURE

Create a New Project

To create a new project for the Ethernet network:

1. Start **OPNET IT Guru Academic Edition** → Choose **New** from the **File** menu.
2. Select **Project** → Click **OK** → Name the project **<your initials>_WirelessLAN**, and name the scenario **DCF** → Click **OK**.
3. In the *Startup Wizard: Initial Topology* dialog box, make sure that **Create Empty Scenario** is selected → Click **Next** → Choose **Office** from the *Network Scale* list and check **Use Metric Units** → Click **Next** twice → Click **OK**.



Create and Configure the Network

To create our wireless network:

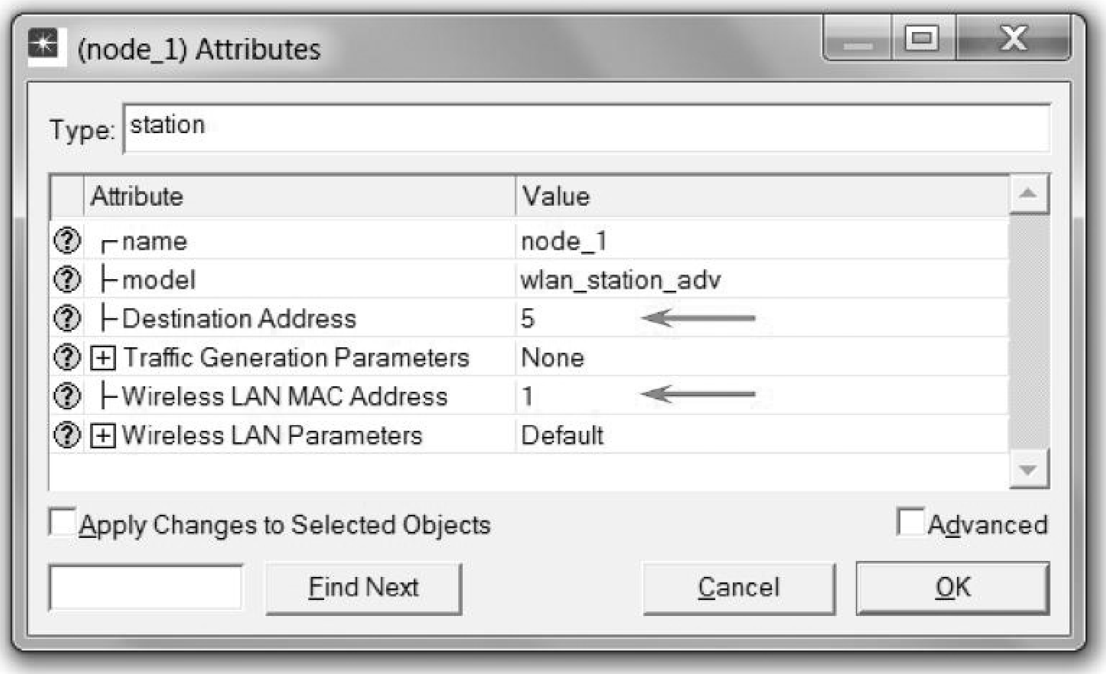
1. The *Object Palette* dialog box should be now on the top of your project space. If it is not there, open it by clicking . Make sure that the **wireless_lan** is selected from the pull-down menu on the object palette.
2. Add to the project workspace the nine **wlan_station_adv (fix)** from the palette.
   a. To add an object from a palette, click its icon in the object palette → Move your mouse to the workspace → Left-click to place the object. Right-click when finished.
3. Close the *Object Palette* dialog box → Arrange the stations in the workspace as shown in the following figure → **Save** your project.

Configure the Wireless Nodes

1. Repeat the following for each of the nine nodes:
Right-click on the node → **Edit Attributes** → Assign to the **Wireless LAN MAC Address** attribute a value equals to the node number (e.g., address 1 is assigned to node_1) → Assign to the **Destination Address** attribute the corresponding value shown in the following table → Click **OK**.

Node Name	Destination Address
node_0	Random
node_1	5
node_2	8
node_3	6
node_4	7
node_5	1
node_6	3
node_7	4
node_8	2

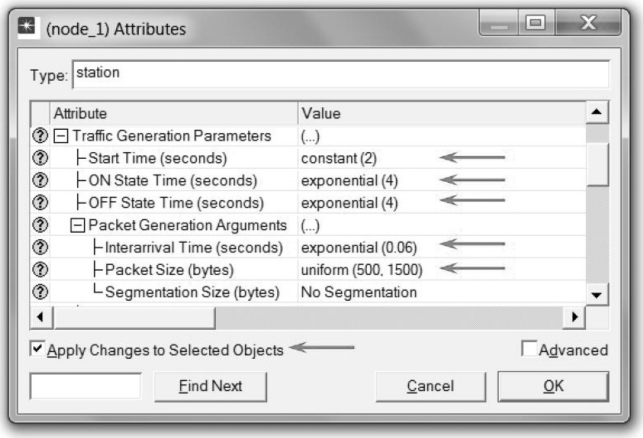
a. The following figure shows the values assigned to the **Destination Address** and **Wireless LAN MAC Address** attributes for node_1.

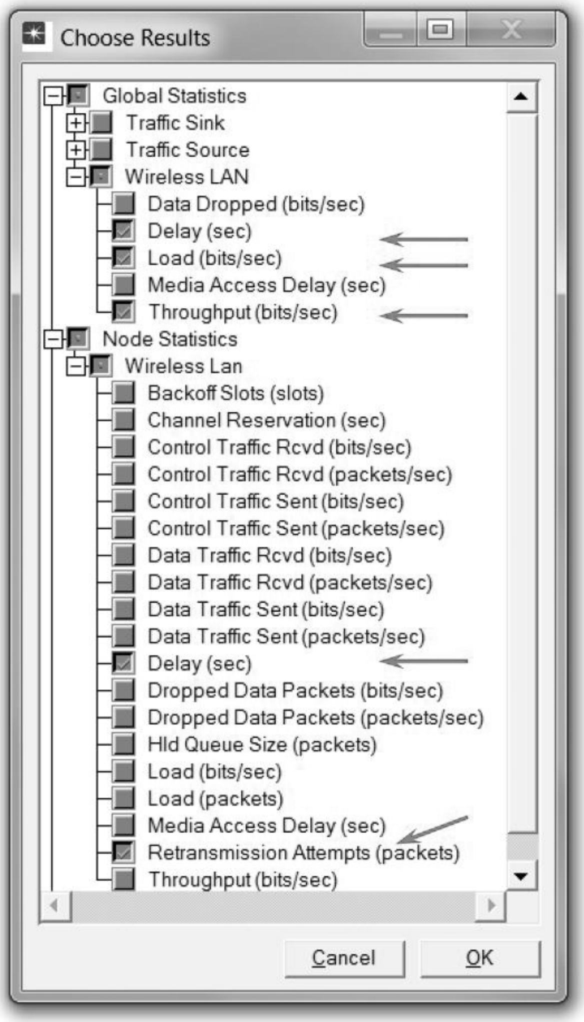


Traffic Generation Parameters

1. Select all nodes in the network simultaneously **except node_0** (click on all of them while holding the **Shift** key) → Right-click on any of the selected nodes → **Edit Attributes** → Check the **Apply Changes to Selected Objects** check box.
2. Expand the **Traffic Generation Parameters** and the **Packet Generation Arguments** hierarchies → Edit the attributes to match the following figure → Click **OK**.

Buffer Size specifies the maximum size of the higher-layer data buffer in bits. Once the buffer limit is reached, the data packets arriving from the higher layer will be discarded until some packets are removed from the buffer so that the buffer has some free space to store these new packets.





3. Select all nodes in the network simultaneously, including **node_0** → Right-click on any of the selected nodes → **Edit Attributes** → Check the **Apply Changes to Selected Objects** check box.
4. Expand the hierarchy of the **Wireless LAN Parameters** attribute → Assign the value 4608000 to the **Buffer Size (bits)** attribute → Click **OK**.
5. Right-click on **node_0** → **Edit Attributes** → Expand the **Wireless LAN Parameters** hierarchy and set the **Access Point Functionality** to **Enabled** → Click **OK**.
6. **Save** the project.

Choose the Statistics

To test the performance of the network in our DCF scenario, we will collect some of the available statistics as follows:

1. Right-click anywhere in the project workspace and select **Choose Individual Statistics** from the pop-up menu.
2. In the *Choose Results* dialog box, expand the **Global Statistics** and **Node Statistics** hierarchies → Choose the five statistics shown.
3. Click **OK**.

Configure the Simulation

Here we will configure the simulation parameters:

1. Click on [icon] and the *Configure Simulation* window should appear.
2. Set the duration to be **10.0 minutes**.
3. Click **OK** and then **Save** your project.

Duplicate the Scenario

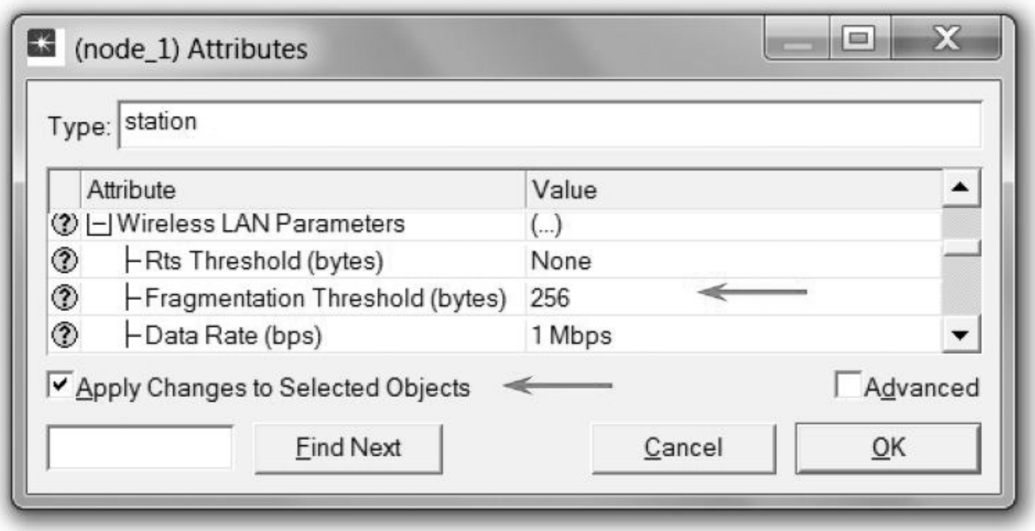
In the network we just created, we did not utilize many of the features explained in the overview section. By default, the distributed coordination function (DCF) method is used for the Medium Access Control (MAC) sublayer. We will create three more scenarios to utilize the features available from the IEEE 802.11 standard. In the DCF_Frag scenario, we will allow fragmentation of the MAC data units into smaller frames and test its effect on the network performance. The DCF_PCF scenario utilizes the point coordination function (PCF) method for the MAC sublayer along with the DCF method. Finally, in the DCF_PCF_Frag scenario we will allow fragmentation of the MAC data and check its effect along with PCF.

THE DCF_FRAG SCENARIO

1. Select **Duplicate Scenario** from the **Scenarios** menu and give it the name **DCF_Frag** → Click **OK**.
2. Select all the nodes in the DCF_ Frag scenario simultaneously → Right-click on any one of them → **Edit Attributes** → Check the **Apply Changes to Selected Objects** check box.
3. Expand the hierarchy of the **Wireless LAN Parameters** attribute → Assign the value **256** to the **Fragmentation Threshold (bytes)** attribute → Click **OK**.

Fragmentation Threshold specifies the fragmentation threshold in bytes. Any data packet received from a higher layer with a size greater than this threshold will be divided into fragments, which will be transmitted separately over the radio interface.

Regardless of the value of this attribute, if the size of a higher-layer packet is larger than the maximum MSDU size allowed by the IEEE 802.11 WLAN standard, which is 2304 bytes, then such a packet will not be transmitted by the MAC, and it will be immediately discarded when received.

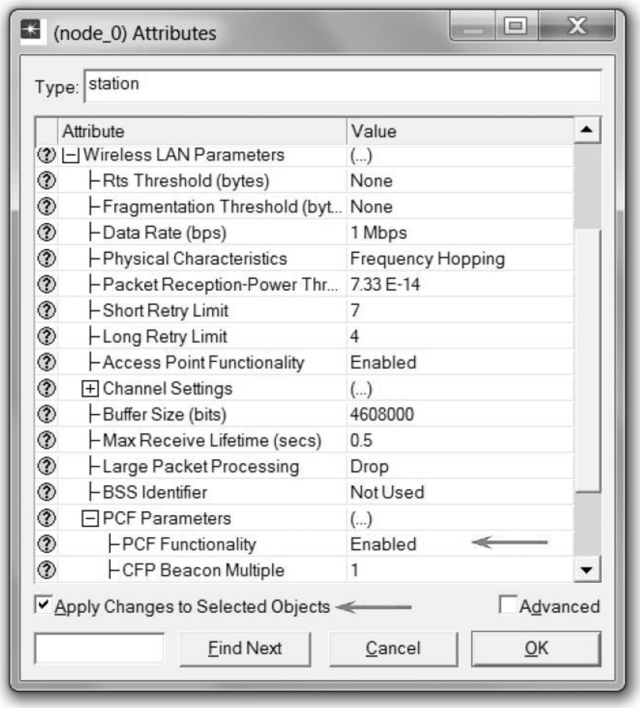


4. Right-click on **node_0** → **Edit Attributes** → Expand the **Wireless LAN Parameters** hierarchy and set the **Access Point Functionality** to **Enabled** → Click **OK**.

THE DCF_PCF SCENARIO

1. Switch to the **DCF scenario, s**elect **Duplicate Scenario** from the **Scenarios** menu and give it the name **DCF_PCF** → Click **OK** → **Save** your project.
2. Select **node_0**, **node_1**, **node_3**, **node_5**, and **node_7** in the DCF_PCF scenario simultaneously (click on these nodes while holding the **Shift** key) → Right-click on any one of the selected nodes → **Edit Attributes**.
3. Check **Apply Changes to Selected Objects** → Expand the hierarchy of the **Wireless LAN Parameters** attribute → Expand the hierarchy of the **PCF Parameters** attribute → **Enable** the **PCF Functionality** attribute → Click **OK**.

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



4. Right-click on **node_0** → **Edit Attributes** → Expand the **Wireless LAN Parameters** hierarchy and set the **Access Point Functionality** to **Enabled** → Click **OK**.

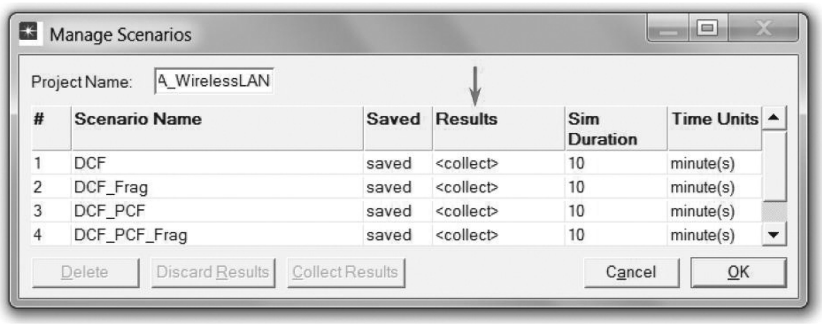
THE DCF_PCF_FRAG SCENARIO

1. Switch to the **DCF_Frag scenario,** select **Duplicate Scenario** from the **Scenarios** menu and give it the name **DCF_PCF_Frag** → Click **OK** → **Save** your project.
2. Select **node_0**, **node_1**, **node_3**, **node_5**, and **node_7** in the DCF_PCF_Frag scenario simultaneously → Right-click on any one of the selected nodes → **Edit Attributes**.
3. Check **Apply Changes to Selected Objects** → Expand the hierarchy of the **Wireless LAN Parameters** attribute → Expand the hierarchy of the **PCF Parameters** attribute → **Enable** the **PCF Functionality** attribute → Click **OK**.
4. Right-click on **node_0** → **Edit Attributes** → Expand the **Wireless LAN Parameters** hierarchy and set the **Access Point Functionality** to **Enabled** → Click **OK**.

Run the Simulation

To run the simulation for the four scenarios simultaneously:

1. Go to the **Scenarios** menu → Select **Manage Scenarios**.
2. Click on the row of each scenario and click the **Collect Results** button. This should change the values under the **Results** column to **<collect>** as shown.



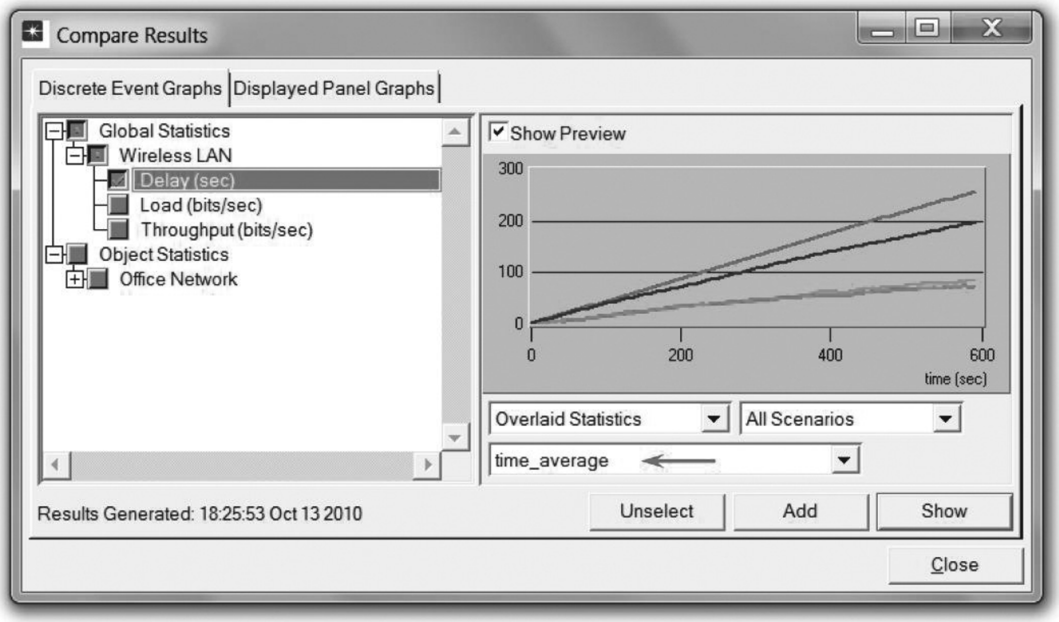
3. Click **OK** to run the four simulations. Depending on the speed of your processor, this process may take several seconds to complete.
4. After the simulation of the four scenarios completes, click **Close** → **Save** your project.

View the Results

To view and analyze the results (*Note:* Actual results will vary slightly based on the actual node positioning in the project):

1. Select **Compare Results** from the **Result** menu.
2. Change the drop-down menu in the lower-right part of the *Compare Results* dialog box from **As Is** to **time_average** → Select the **Delay (sec)** statistic from the **Wireless LAN** hierarchy as shown.

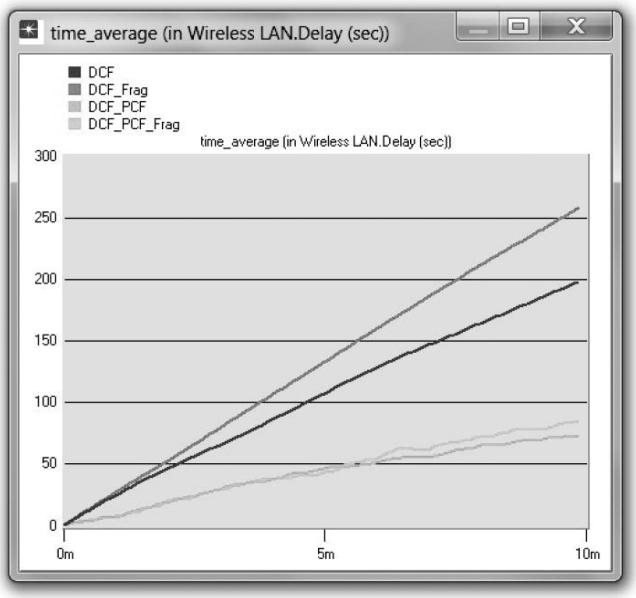
time_average is the average value over time of the values generated during the collection window. This average is performed assuming a "sample-and-hold" behavior of the data set (i.e., each value is weighted by the amount of time separating it from the following update and the sum of all the weighted values is divided by the width of the collection window).



3. Click **Show** to show the result in a new panel. The resulting graph should resemble the following one.

Delay represents the end-to-end delay of all the packets received by the wireless LAN MACs of all WLAN nodes in the network and forwarded to the higher layer.

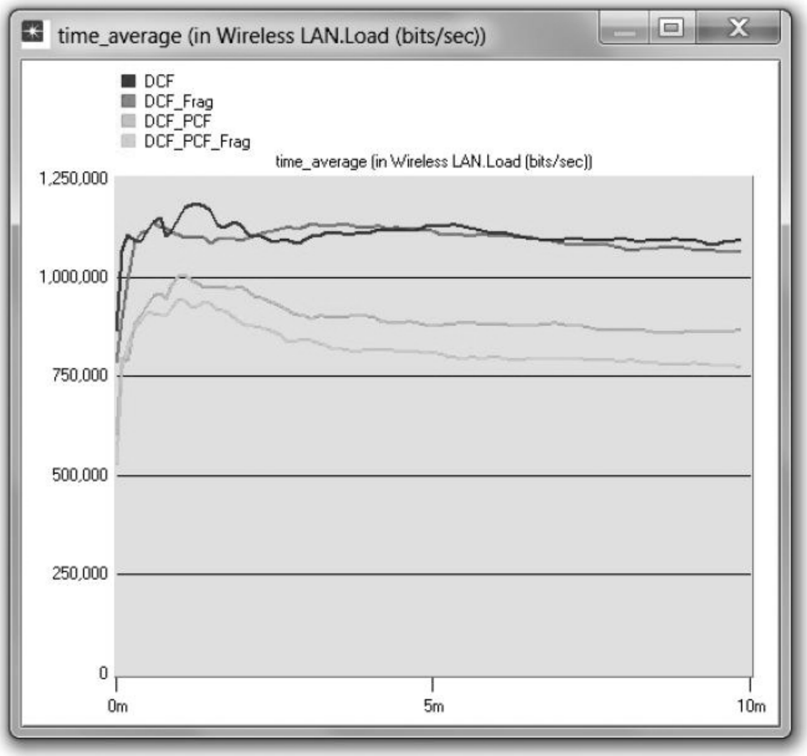
This delay includes medium access delay at the source MAC, reception of all the fragments individually, and transfer of the frames through AP, if access point functionality is enabled.



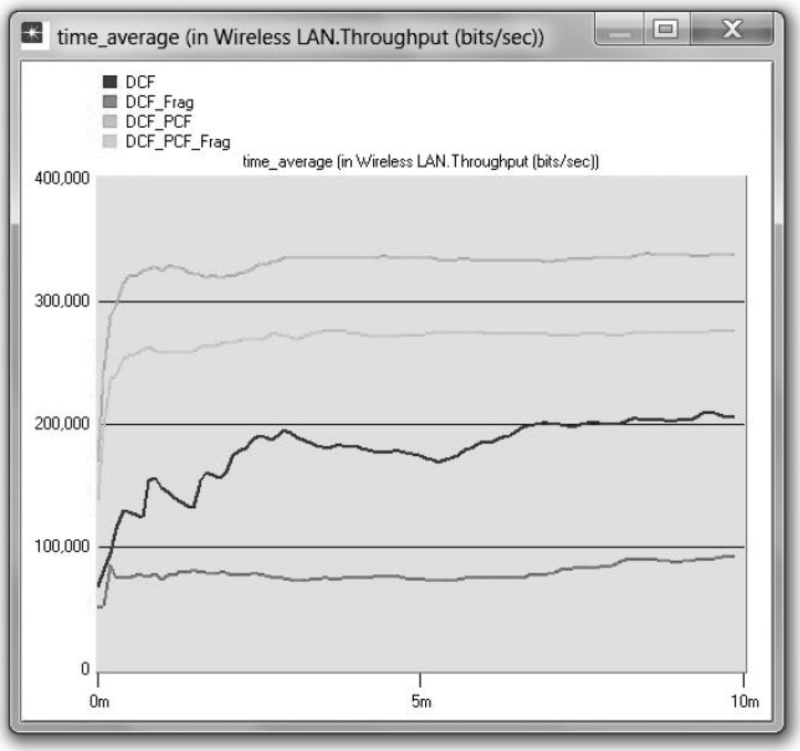
4. Go to the *Compare Results* dialog box → Follow the same procedure to show the graphs of the following statistics from the **Wireless LAN** hierarchy: **Load (bits/sec)** and **Throughput (bits/sec)**. The resulting graphs should resemble the following ones.

Load represents the total load (in bits/sec) submitted to wireless LAN layers by all other higher layers in all WLAN nodes of the network.

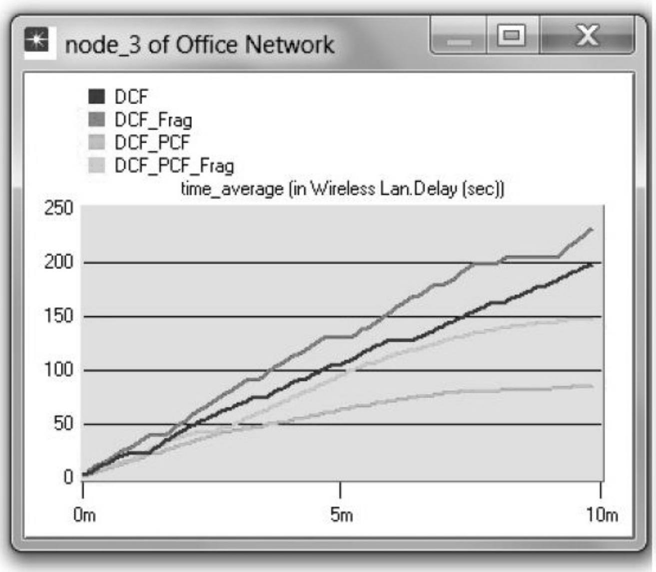
This statistic does not include the bits of the higher-layer packets that are dropped by WLAN MACs upon arrival and not considered for transmission because of, for example, insufficient space left in the higher-layer packet buffer of the MAC.

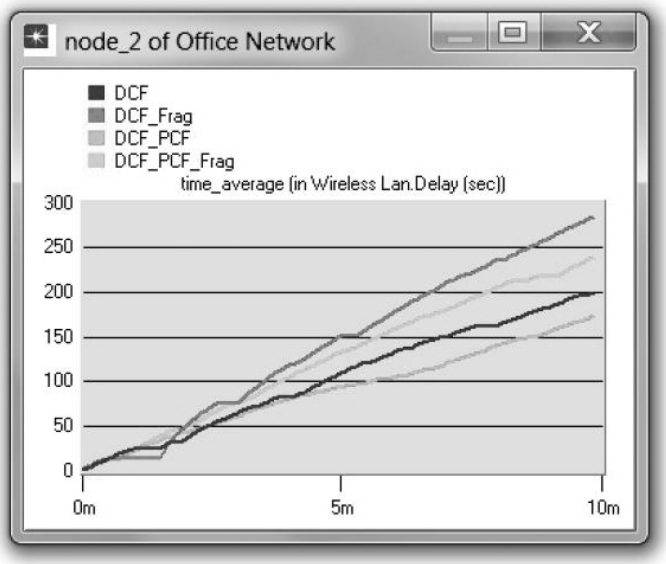


Throughput represents the total number of bits (in bits/sec) forwarded from wireless LAN layers to higher layers in all WLAN nodes of the network.

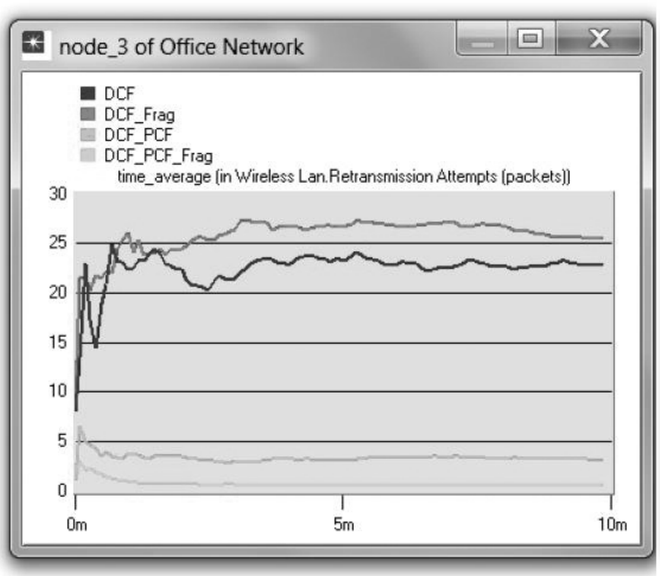


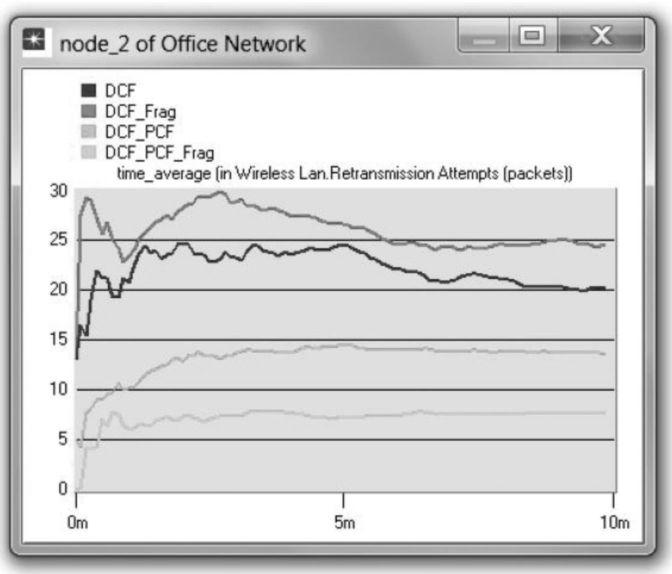
5. Go to the *Compare Results* dialog box → Expand the **Object Statistics** hierarchy → Expand the **Office Network** hierarchy → Expand the hierarchy of two nodes. One node should have PCF enabled in the DCF_PCF scenario (e.g., node_3) and the other node should have PCF disabled (e.g., node_2) → Show the result of the **Delay (sec)** statistic for the chosen nodes. The resulting graphs should resemble the following ones.





6. Repeat Step 5 above but for the **Retransmission Attempts (packets)** statistic. The resulting graphs should resemble the following ones.





7. Close all graphs and the *Compare Results* dialog box → **Save** your project.

FURTHER READING

ANSI/IEEE Standard 802.11, 1999 Edition: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications.

EXERCISES

1. Based on the definition of the statistic **Load**, explain why with PCF enabled the load is lower than if DCF is used without PCF.
2. Analyze the graphs that compare the **Delay** and **Throughput** of the four scenarios. What are the effects of utilizing PCF and fragmentation on these two statistics?
3. From the last four graphs, explain how the performance of a node without PCF is affected by having PCF enabled in other nodes in the network.
4. Create two new scenarios as duplicates of the DCF_PCF scenario. Name the first new scenario **DCF_allPCF** and the second new scenario **DCF_twoPCF**. In **DCF_allPCF**, enable the PCF attribute in all eight nodes: node_1 through node_8. (*Note:* Do not include node_0 in any of your attribute editing.) In **DCF_twoPCF**, disable the PCF attribute in node_3 and node_5 (this will leave only node_1 and node_7 with PCF enabled). Generate the graphs for the **Delay**, **Load**, and **Throughput** statistics, and explain how the number of PCF nodes might affect the performance of the wireless network.
5. For all scenarios, select the **Media Access Delay** statistic from the Global Statistics → **Wireless LAN hierarchy**. Rerun the simulation for all scenarios. Generate the graph that compares the **Media Access Delay** statistic of all scenarios. Analyze the graph, explaining the effect of PCF, fragmentation, and number of PCF nodes on media access delay.

LAB REPORT

Prepare a report that follows the guidelines explained in the Introduction Lab. The report should include the answers to the preceding exercises 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.

LAB3 – PART III (Extra Credit)

Token Ring

A Shared-Media Network with Media Access Control

Objective

This lab is designed to demonstrate the implementation of a token ring network. The simulation in this lab will help you examine the performance of the token ring network under different scenarios.

Overview

A token ring network consists of a set of nodes connected in a ring. The ring is a single shared medium. The token ring technology involves a distributed algorithm that controls when each node is allowed to transmit. All nodes see all frames, and the node identified as the destination in the frame header saves a copy of the frame as it flows past. With a ring topology, any link or node failure would render the whole network useless. This problem can be solved by using a star topology where nodes are connected to a token ring hub. The hub acts as a relay, known as a multistation access unit (MSAU). MSAUs are almost always used because of the need for robustness and ease of node addition and removal.

The “token,” which is just a special sequence of bits, circulates around the ring; each node receives and then forwards the token. When a node that has a frame to transmit sees the token, it takes the token off the ring and instead inserts its frame into the ring. When the frame makes its way back around to the sender, this node strips its frame off the ring and reinserts the token. The token holding time (THT) is the time a given node is allowed to hold the token. From its definition, the THT has an effect on the utilization and fairness of the network, where utilization is the measure of the bandwidth used versus that available on the given ring.

In this lab, you will set up a token ring network with 14 nodes connected in a star topology. The links you will use operate at a data rate of 4 Mbps. You will study how the utilization and delay of the network are affected by the network load as well as the THT.

Procedure

Create a New Project

To create a new project for the token ring network:

1. Start **OPNET IT Guru Academic Edition** ⇒ Choose **New** from the **File** menu.
2. Select **Project** and click **OK** ⇒ Name the project **<your initials>_Token**, and the scenario **Balanced** ⇒ Click **OK.**
3. In the *Startup Wizard: Initial Topology* dialog box, make sure that **Create Empty Scenario** is selected ⇒ Click **Next** ⇒ Choose **Office** for the Network scale ⇒ Click **Next** three times ⇒ Click **OK**.
4. Close the *Object Palette* and then save your project.

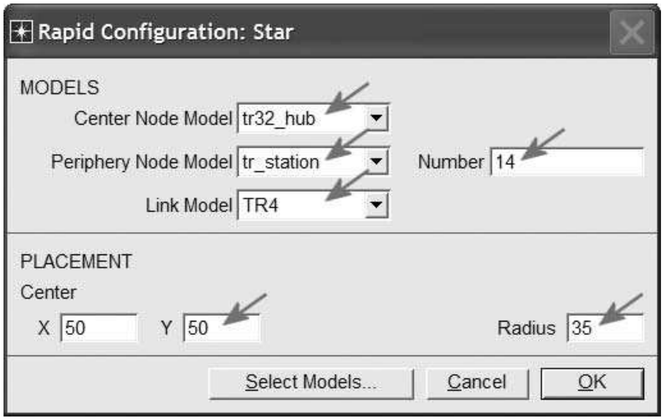
Create the Network

To create our token ring network:

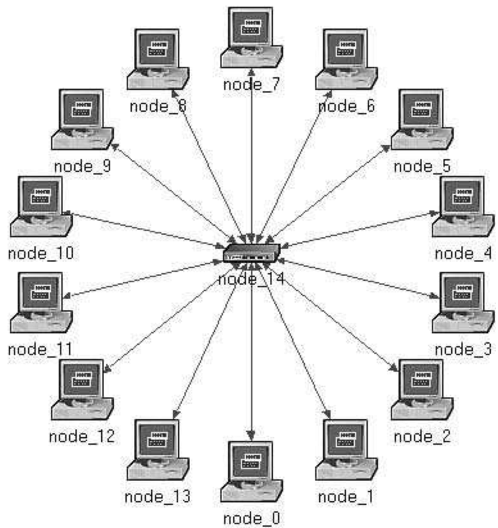
1. Select **Topology** ⇒ **Rapid Configuration**. From the drop-down menu choose **Star** and click **OK**.
2. Click the **Select Models** button in the *Rapid Configuration* dialog box. From the *Model List* drop-down menu choose **token_ring** and click **OK**.
3. In the *Rapid Configuration* dialog box, set the following six values and click **OK**.

The **tr32_hub** node model is a token ring hub supporting up to 32 connections at 4 or 16 Mbps. The hub forwards an arriving packet to the next output port. There is no queuing of packets in the hub itself as the processing time is considered to be zero.

The **TR4 link** connects two token ring devices to form a ring at 4 Mbps.



4. You have now created the network, and it should look like the following:



5. Make sure to save your project.

Configure the Network Nodes

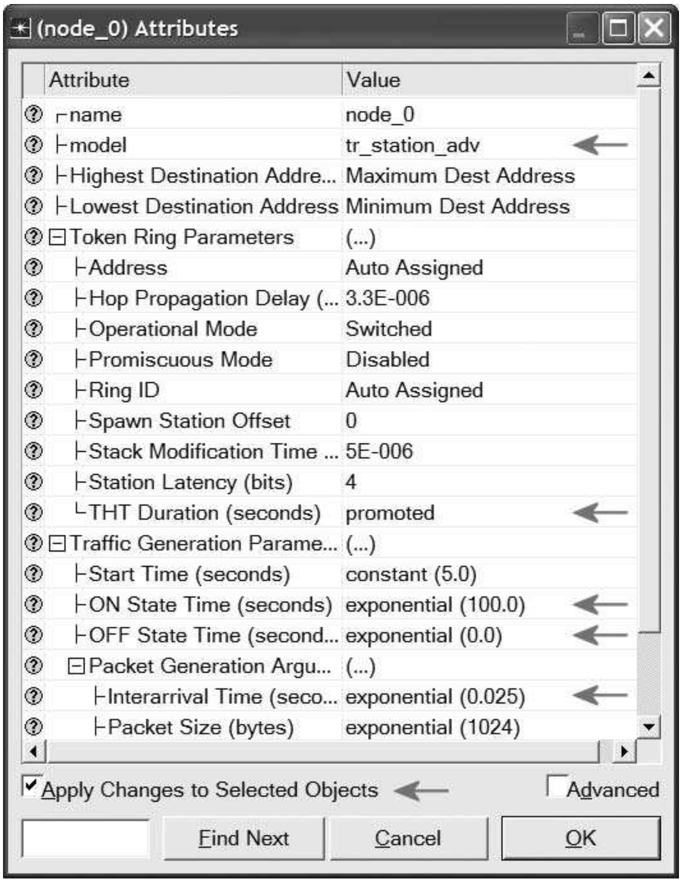
Here you will configure the THT of the nodes as well as the traffic generated by them. To configure the THT of the nodes, you need to use the **tr_station_adv** model for the nodes instead of the current one, **tr_station**.

1. Right-click on any of the 14 nodes ⇒ **Select Similar Nodes**. Now all nodes in the network are selected.
2. Right-click on any of the 14 nodes ⇒ **Edit Attributes**.
   a. Check the **Apply Changes to Selected Objects** check box. This is important to avoid reconfiguring each node individually.

The following figure shows the attributes we will change in steps 3 to 6:

The **THT** (token holding time) specifies the maximum amount of time a token ring MAC (media access control) may use the token before releasing it.

The **interarrival time** is the time between successive packet generations in the "ON" state.



3. Click on the model value: **tr_station** and select **Edit** from the drop-down menu. Now select **tr_station_adv** from the extended drop-down menu.
4. To test the network under different THT values, you need to "promote" the THT parameter. This allows us to assign multiple values to the THT attribute.

a. Expand the **Token Ring Parameters** hierarchy.

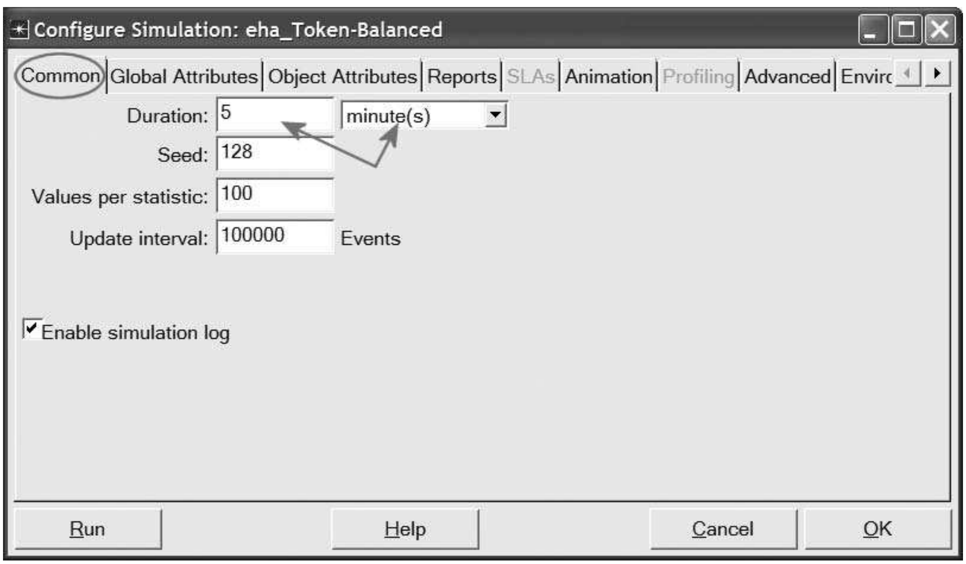
b. Right-click on the **THT Duration** attribute ⇒ Choose **Promote Attribute to Higher Level**.

5. Expand the **Traffic Generation Parameters** hierarchy ⇒ Assign **exponential(100)** to the **ON State Time** attribute ⇒ Assign **exponential(0)** to the **OFF State Time** attribute. (*Note:* Packets are generated only in the “ON” state.)
6. Expand the **Packet Generation Arguments** hierarchy ⇒ Assign **exponential(0.025)** to the **Interarrival Time** attribute.
7. Click **OK** to return back to the *Project Editor*.
8. Make sure to save your project.

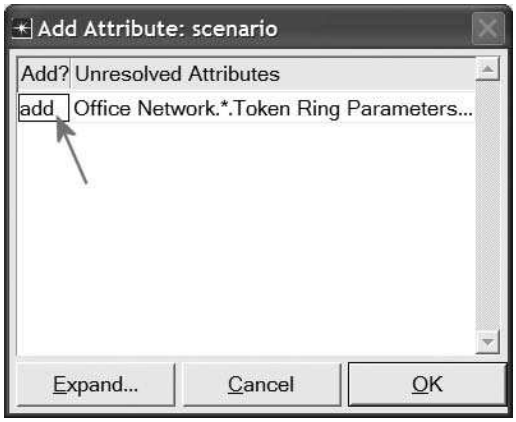
Configure the Simulation

To examine the network performance under different THTs, you need to run the simulation several times by changing THT with every run of the simulation. There is an easy way to do that. Recall that we promoted the **THT Duration** attribute. Here we will assign different values to that attribute:

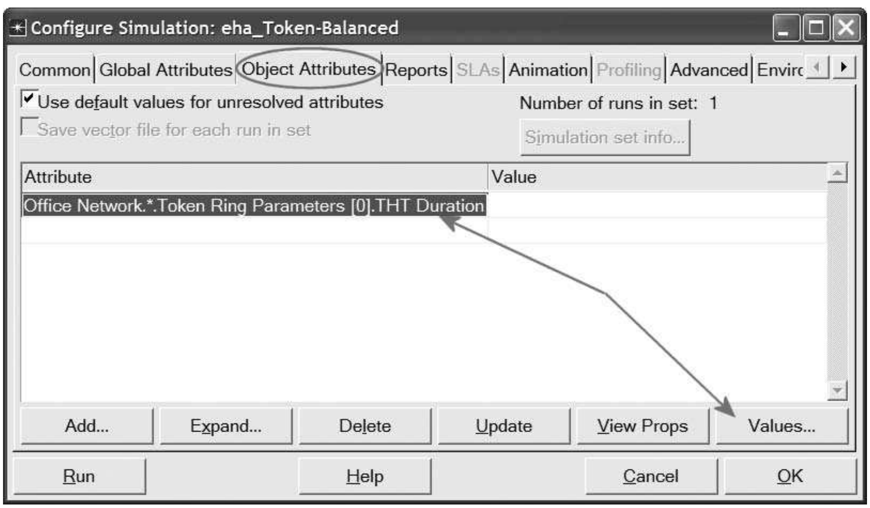
1. Click on the **Configure/Run Simulation** button: 
2. Make sure that the **Common** tab is chosen ⇒ Assign **5** minutes to the **Duration**.



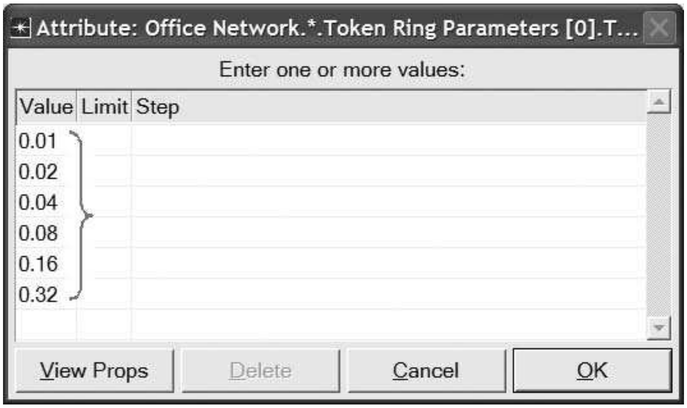
3. Click on the **Object Attributes** tab ⇒ Click the **Add** button.
4. As shown in the following *Add Attribute* dialog box, you need to add the **THT Duration** attribute for all nodes. To do that:
   a. Add the unresolved attribute: **Office Network.*.Token Ring Parameters[0].THT Duration** by clicking on the corresponding cell under the **Add?** column ⇒ Click **OK**



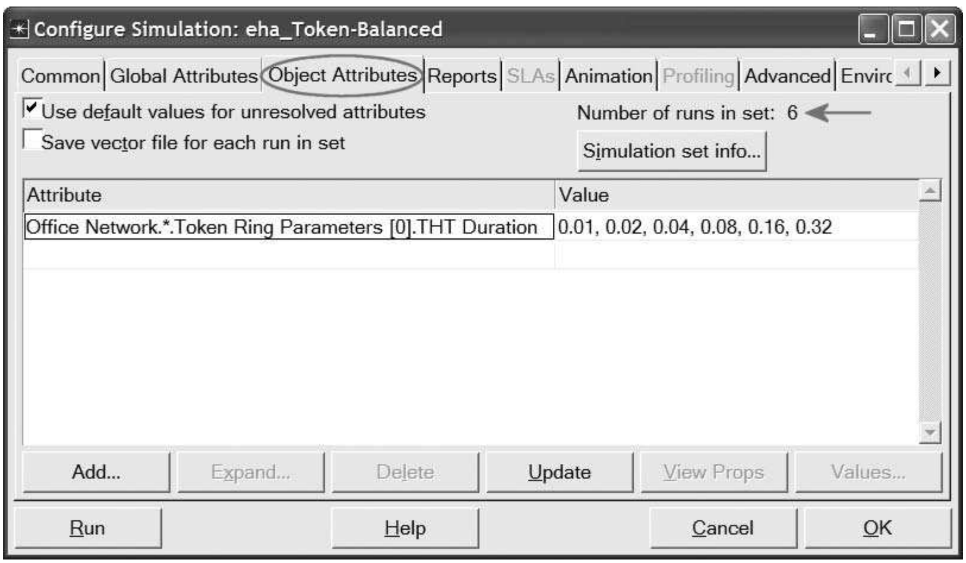
5. Now you should see the **Office Network.*.Token Ring Parameters[0].THT Duration** in the list of simulation object attributes (widen the "Attribute" column to see the full name of the attribute). Click on that attribute ⇒ Click the **Values** button, as shown below.



6. Add the following six values. (*Note:* To add the first value, double-click on the first cell in the **Value** column ⇒ Type “0.01” into the textbox and hit enter. Repeat this for all six values.)

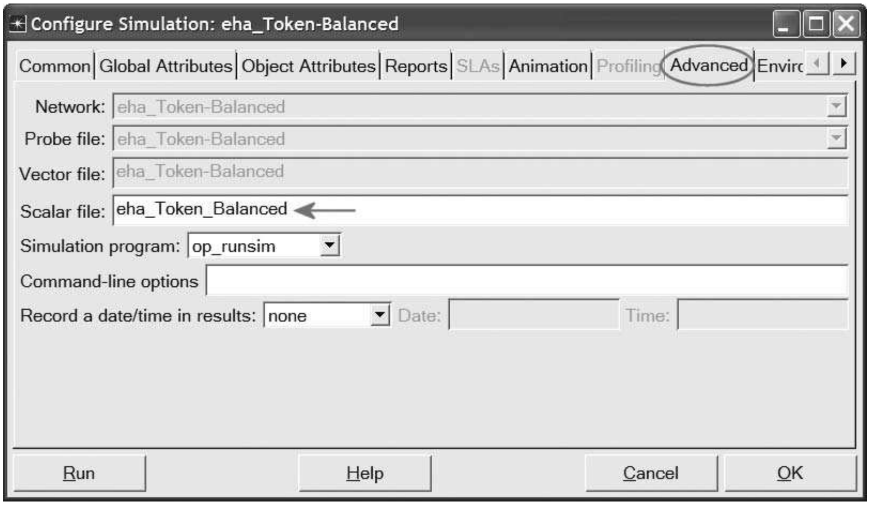


7. Click **OK**. Now look at the upper-right corner of the *Simulation Configuration* dialog box and make sure that the *Number of runs in set* is **6**.



8. For each of the six simulation runs we need the simulator to save “scalar” values that represent the “average” values of the statistics to be collected from the simulation. To save these scalars we need to configure the simulator to save them in a file. Click on the **Advanced** tab in the *Configure Simulation* dialog box.

9. Assign **<your initials>_Token_Balanced** to the *Scalar file* text field.



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

Choose the Statistics

To choose the statistics to be collected during the simulation:

1. Right-click anywhere in the project workspace (but not on a node or link) and select **Choose Individual Statistics** from the pop-up menu.
   a. Expand the **Global Statistics** hierarchy:
      – Expand the **Traffic Sink** hierarchy ⇒ Click the check box next to **Traffic Received (packets/sec)**.
      – Expand the **Traffic Source** hierarchy ⇒ Click the check box next to **Traffic Sent (packets/sec)**.

The **utilization** is a measure of the bandwidth used versus that available on the given ring.

   b. Expand the **Node Statistics** hierarchy:
      – Expand the **Token Ring** hierarchy ⇒ Click the check box next to **Utilization**.
   c. Click **OK**.

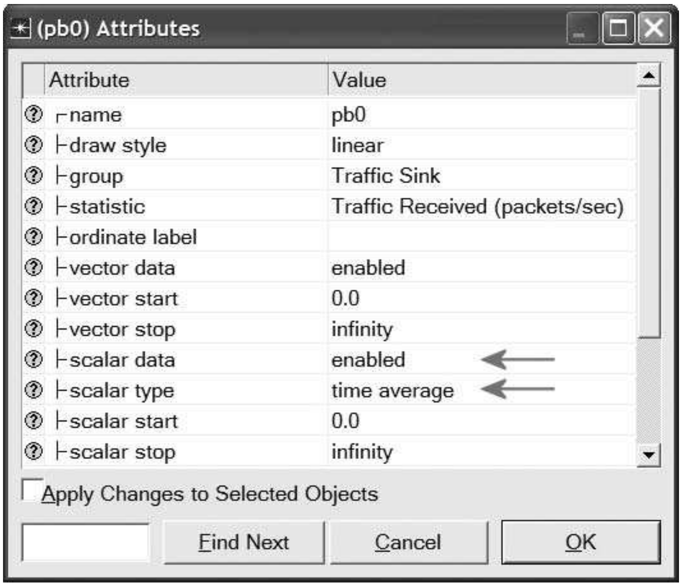
2. Now we want to collect the average of the above statistics as a scalar value by the end of each *simulation* run.

   a. Select **Choose Statistics (Advanced)** from the *Simulation* menu.

A **probe** represents a request by the user to collect a particular piece of data about a simulation.

   b. The **Traffic Sent** and **Traffic Received** probes should appear under the **Global Statistic Probes**. The **Utilization** probe should appear under the **Node Statistics Probes**.

   c. Right-click on **Traffic Received** probe ⇒ **Edit Attributes**. Set the **scalar data** attribute to **enabled** ⇒ Set the **scalar type** attribute to **time average** ⇒ Compare to the following figure and click **OK**.

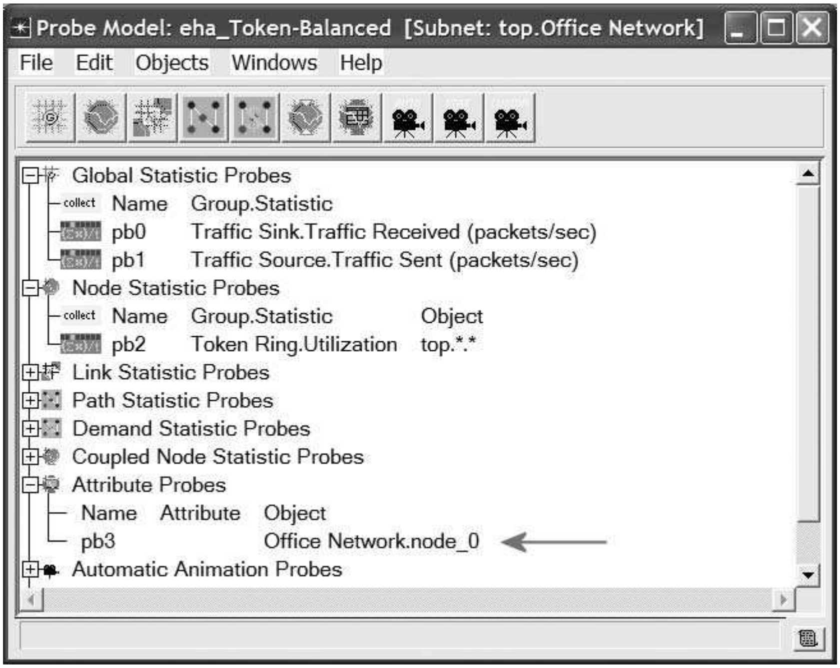


   d. Repeat the previous step with the **Traffic Sent** and **Utilization probes**.

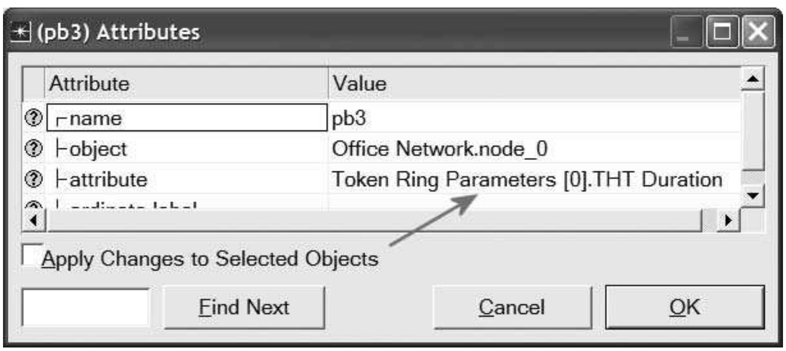
3. Since we need to analyze the effect of THT on the network performance, THT must be added as an "input" statistic to be recorded by the simulation. To do that:

   a. Select **Create Attribute Probe** from the **Objects** menu. Now a new attribute is created under the **Attribute Probes** hierarchy as shown.

   b. Right-click on the new attribute probe and select **Choose Attributed Object** from the pop-up menu ⇒ Expand the **Office Network** hierarchy ⇒ Click on **node_0** (actually you can pick any other node) ⇒ Click **OK**.



c. Right-click again on the new attribute probe and select **Edit Attributes** from the pop-up menu ⇒ Assign the **Token Ring Parameter[0].THT Duration** value to the "**attribute**" Attribute, as shown in the figure ⇒ Click **OK**.

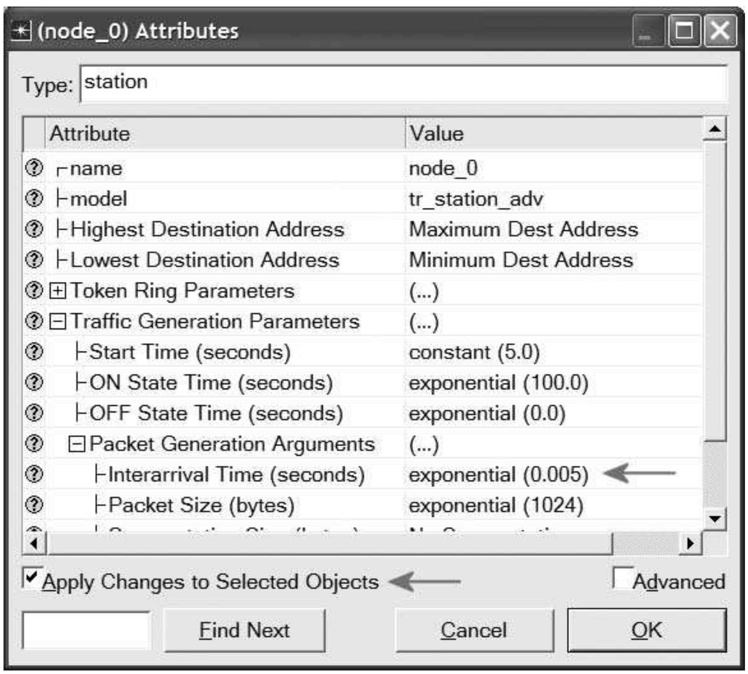


4. Select save from the **File** menu in the *Probe Model* window and then **Close** the window.
5. Now you are back to the *Project Editor*. Make sure to save your project.

Duplicate the Scenario

The token ring network scenario we just implemented is *balanced:* the distribution of the generated traffic in all nodes is the same. To compare performance, you will create an “unbalanced” scenario as follows:

1. Select **Duplicate Scenario** from the **Scenarios** menu and give it the name **Unbalanced** ⇒ Click **OK**.
2. Select **node_0** and **node_7** by shift-clicking on both nodes ⇒ Right-click on one of these two selected nodes and select **Edit Attributes** ⇒ Expand the **Traffic Generation Parameters** hierarchy ⇒ Expand the **Packet Generation Arguments** hierarchy ⇒ Change the value of the **Interarrival Time** attribute to **exponential(0.005)** as shown. Make sure to check the **Apply Changes to Selected Objects** box before you click **OK**.

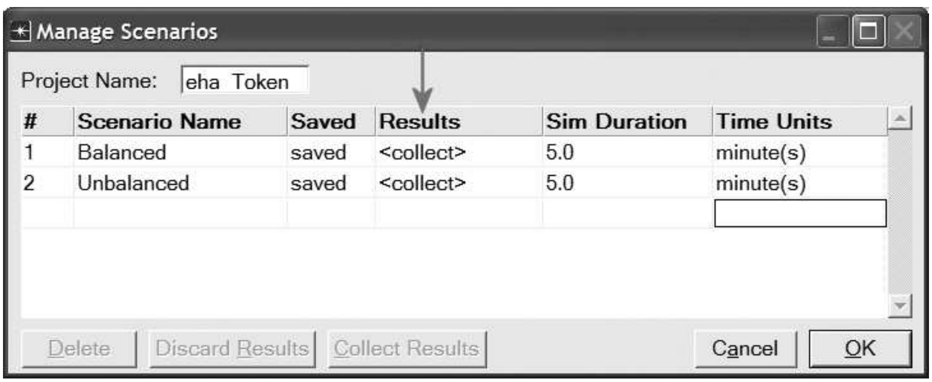


3. Select all nodes except **node_0** and **node_7** ⇒ Right-click on one of the selected nodes and select **Edit Attributes** ⇒ Change the value of the **Interarrival Time** attribute to **exponential(0.075)** as in the previous step. Make sure to check the **Apply Changes to Selected Objects** box before you click **OK**.
4. Click anywhere in the workspace to unselect objects.
5. Click on the **Configure/Run Simulation** button:  ⇒ Click on the **Advanced** tab in the Configure Simulation dialog box ⇒ Assign **<your initials>_Token_Unbalanced** to the *Scalar file* text field.
6. Click **OK** and then save your project.

Run the Simulation

To run the simulation for both scenarios simultaneously:

1. Go to the **Scenarios** menu ⇒ Select **Manage Scenarios**.
2. Change the values under the **Results** column to `<collect>` (or `<recollect>`) for both scenarios. Compare to the following figure.



3. Click **OK** to run the simulations. Depending on the speed of your processor, this may take several minutes to complete.
4. After the simulation completes the 12 runs, 6 for each scenario, click **Close**.
5. Save your project.

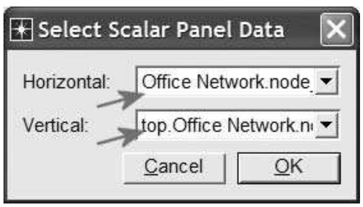
When you rerun the simulation, OPNET IT Guru will “append” the new results to the results already in the scalar file. To avoid that, delete the scalar file before you start a new run.

- Go to the **File** menu ⇒ Select **Model Files** ⇒ **Delete Model Files** ⇒ From the list, choose **other model types** ⇒ Select **(···.os): Output Scalars** ⇒ Select the scalar file to be deleted; in this lab they are **<your initials>_Token_Balanced** and **<your initials>_Token_ Unbalanced** ⇒ Click **Close**.

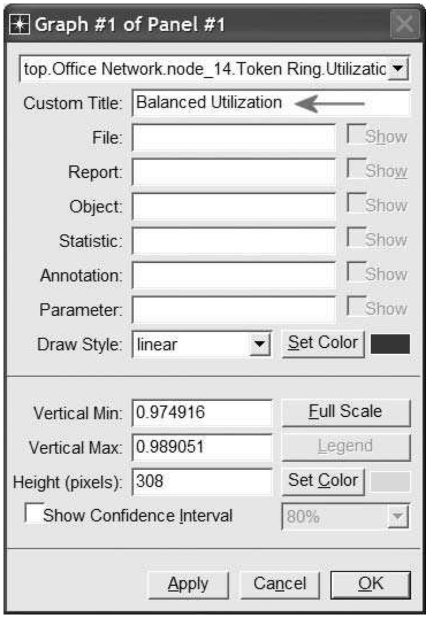
View the Results

To view and analyze the results:

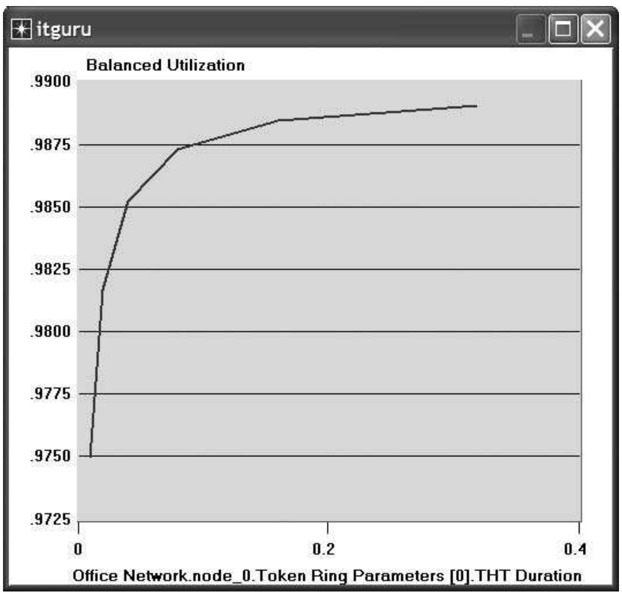
1. Select **View Results (Advanced)** from the **Results** menu. Now the **Analysis Configuration** tool is open.
2. Recall that we saved the average results in two scalar files, one for each scenario. To load the scalar file for the **Balanced** scenario, select **Load Output Scalar File** from the **File** menu ⇒ Select **<your initials>_Token_Balanced** from the pop-up menu.
3. Select **Create Scalar Panel** from the **Panels** menu ⇒ Select the scalar panel data as shown in the following dialog box: **THT** for **Horizontal** and **Utilization** for **Vertical**. (*Note:* If any of the data is missing, make sure that you carried out steps 2.c and 2.d in the *Choose the Statistics* section.)



4. Click **OK**.
5. To change the title of the graph, right-click on the graph area and choose **Edit Graph Properties** ⇒ Change the **Custom Title** to **Balanced Utilization** as shown.



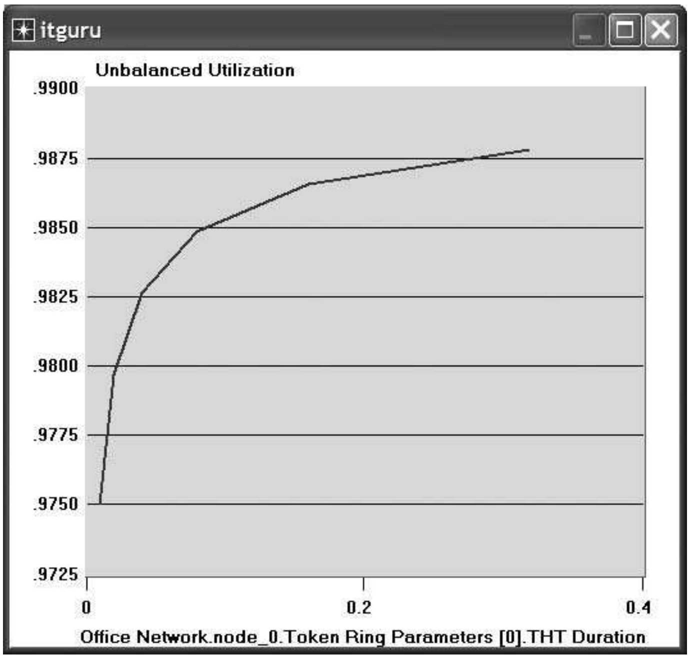
6. Click **OK**. The resulting graph should resemble the one shown below. Do not close the graph and continue with the following step.



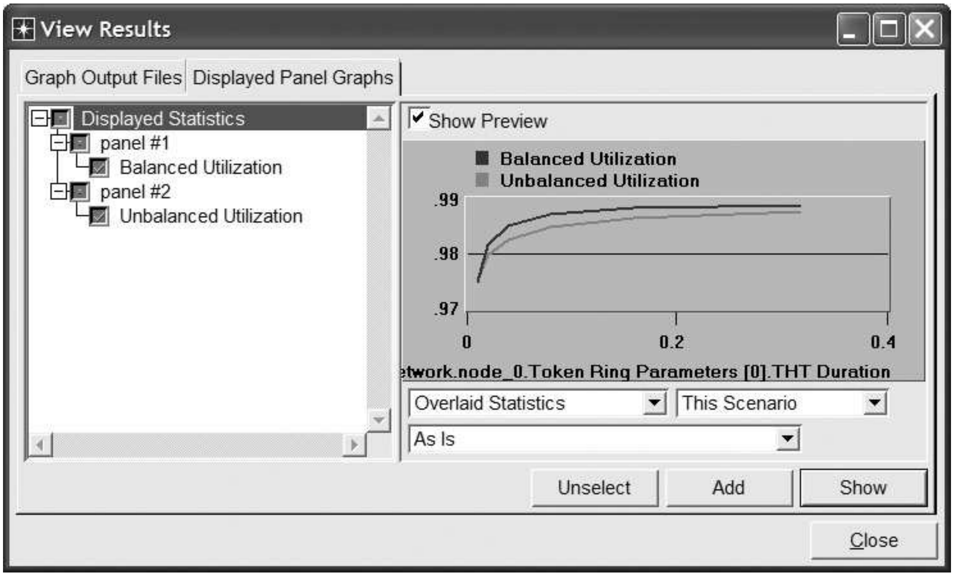
7. To compare with the **Unbalanced** scenario, load its scalar file, select **Load Output Scalar File** from the **File** menu ⇒ Select **<your initials>_Token_Unbalanced** from the pop-up menu.

8. Select **Create Scalar Panel** from the **Panels** menu ⇒ Select the scalar panel data as in step 3.

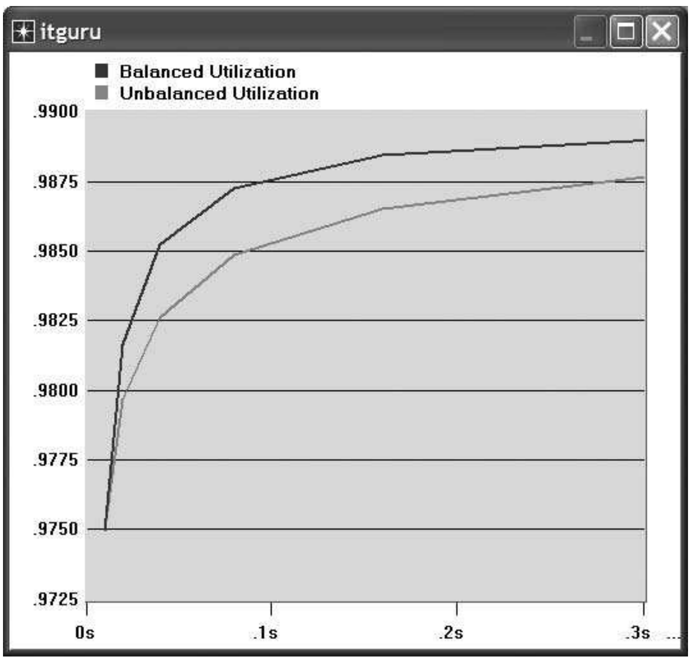
9. Click **OK** ⇒ Change the graph title to **Unbalanced** as in step 5 ⇒ Click **OK**. The resulting graph should resemble the one shown below. Do not close this graph or the previous one and continue with the following step.



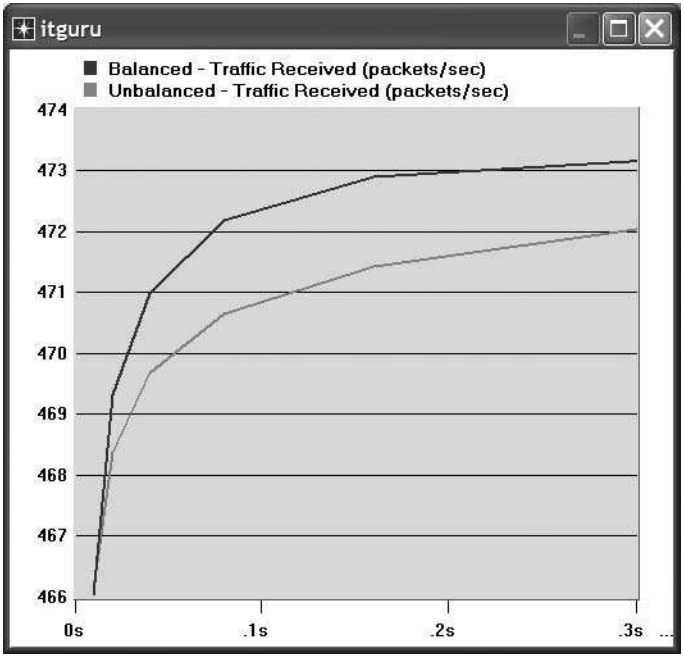
10. To combine the above two graphs on a single graph, select **Create Vector Panel** from the **Panels** menu ⇒ Click on the **Display Panel Graphs** tab ⇒ Select both **Balanced** and **Unbalanced** statistics ⇒ Choose **Overlaid Statistics** from the drop-down menu in the right-bottom area of the dialog box as shown.



11. Click **Show** and the resulting graph should resemble the one shown below.



12. Repeat the same process to check the effect of the THT on Traffic Received for both scenarios. Assign the appropriate titles to the graphs.
13. The resulting graph, which combines the Traffic Received statistic for both the Balanced and Unbalanced scenarios, should resemble the following one:



Further Readings

– OPNET Token Ring Model Description: From the **Protocols** menu, select **Token Ring** ⇒ **Model Usage Guide**.

Questions

1) Why does the utilization increase with higher THT values?

2) Create a duplicate scenario of the **Balanced** scenario. Name the new scenario **Q2_HalfLoad**. In the **Q2_HalfLoad** scenario, decrease the load into the network (i.e., load from all nodes in the network) by half and repeat the simulation. Compare the utilization and traffic received in the **Q2_HalfLoad** scenario with those of the **Balanced** scenario.

Hints:

– Decreasing the load from a node by half can be done by doubling the "Interarrival Time" of the node's **Packet Generation Arguments**.

– Do not forget to assign a separate "scalar file" for the new scenario.

3) Create a duplicate scenario of the **Balanced** scenario. Name the new scenario **Q3_OneNode**. In the **Q3_OneNode** scenario, reconfigure the network so that **node_0** generates a traffic load that is equivalent to the traffic load generated by all nodes in the **Balanced** scenario combined. The rest of the nodes, **node_1** to **node_13**, generate no traffic. Compare the utilization and traffic received in **Q3_OneNode** scenario with those of the **Balanced** scenario.

Hints:

– One way to configure a node so that it does not generate traffic is to set its **Start Time** (it is one of the **Traffic Generation Parameters**) to the special value **Never**.

– Do not forget to assign a separate "scalar file" for the new 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.