LAB 8

BGP: Border Gateway Protocol

An Interdomain Routing Protocol

OBJECTIVES

The objective of this lab is to simulate and study the basic features of an interdomain routing protocol called Border Gateway Protocol (BGP).

OVERVIEW

The Internet is organized as a set of routing domains. Each routing domain is called an *autonomous system* (AS). Each AS is controlled by a single administrative entity (e.g., an AS of a single service provider). Each AS has a unique 16-bit identification number. This number is assigned by a central authority. An AS uses its own intradomain routing protocol (e.g., RIP or OSPF). An AS establishes routes with other ASs through interdomain routing protocols. The Border Gateway Protocol (BGP) is one of the well-known interdomain routing protocols.

The main goal of BGP is to find any path to the destination that is loop-free. This is different from the common goal of intradomain routing protocols, which is to find an optimal route to the destination based on a specific link metric. The routers that connect different ASs are called *border gateways*. The task of the border gateways is to forward packets between ASs. Each AS has at least one BGP speaker. BGP speakers exchange reachability information among ASs.

BGP advertises the complete path to the destination AS as an enumerated list. In this way, routing loops can be avoided. A BGP speaker can also apply some policies such as balancing the load over the neighboring ASs. If a BGP speaker has a choice of several different routes to a destination, it will advertise the best one according to its own local policies. BGP is defined to run on top of TCP, and hence BGP speakers do not need to worry about acknowledging received information or retransmission of sent information.

In this lab, you will set up a network with three different ASs. RIP will be used as the intra-domain routing protocol and BGP as the interdomain routing protocol. You will analyze the routing tables generated in the routers as well as the effect of applying a simple policy.

PRE-LAB ACTIVITIES

- Read Section 4.1.2 from *Computer Networks: A Systems Approach, 5th Edition*.
- Go to www.net-seal.net and play the following animation:
  - IP Subnets

The **ethernet4_slip8_gtwy** node model represents an IP-based gateway supporting four Ethernet hub interfaces and eight serial line interfaces. IP packets arriving on any interface are routed to the appropriate output interface based on their destination IP address.

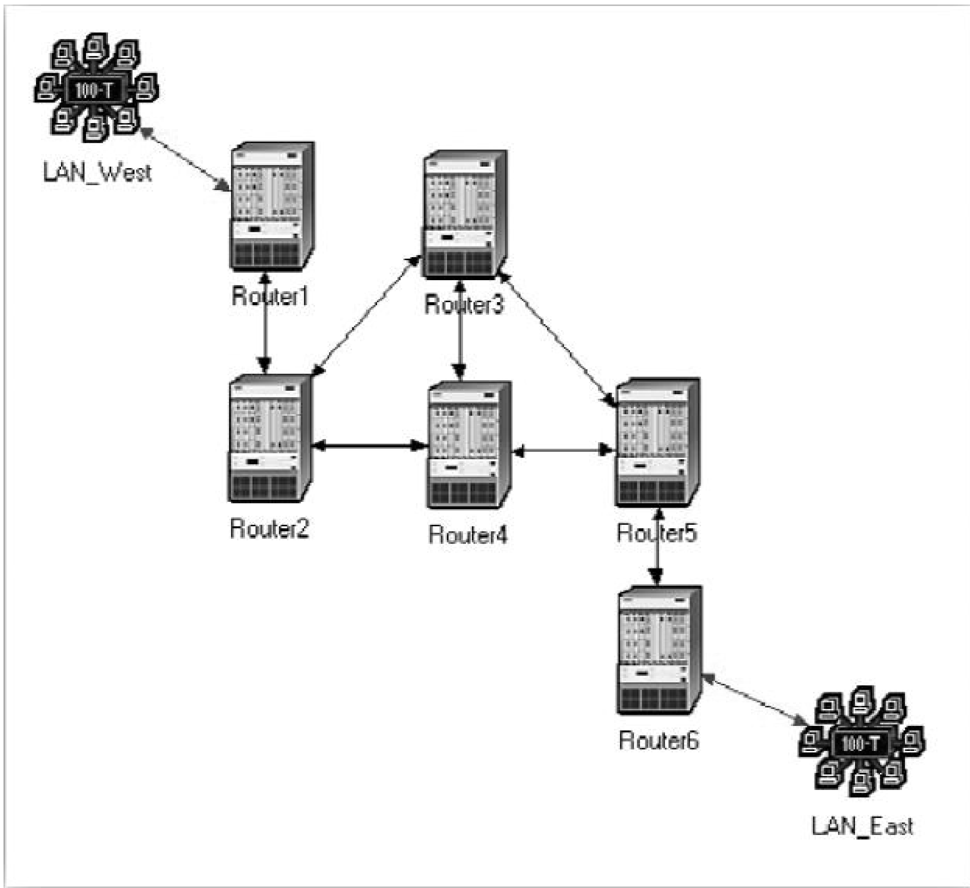
PROCEDURE

Create a New Project

1. Start **OPNET IT Guru Academic Edition** → Choose **New** from the **File** menu.
2. Select **Project** and click **OK** → Name the project **<your initials>_BGP**, and the scenario **No_BGP** → Click **OK**.
3. In the *Startup Wizard: Initial Topology* dialog box, make sure that **Create Empty Scenario** is selected → Click **Next** → Select **Enterprise** from the *Network Scale* list → Click **Next** four times → Click **OK**.

Create and Configure the Network

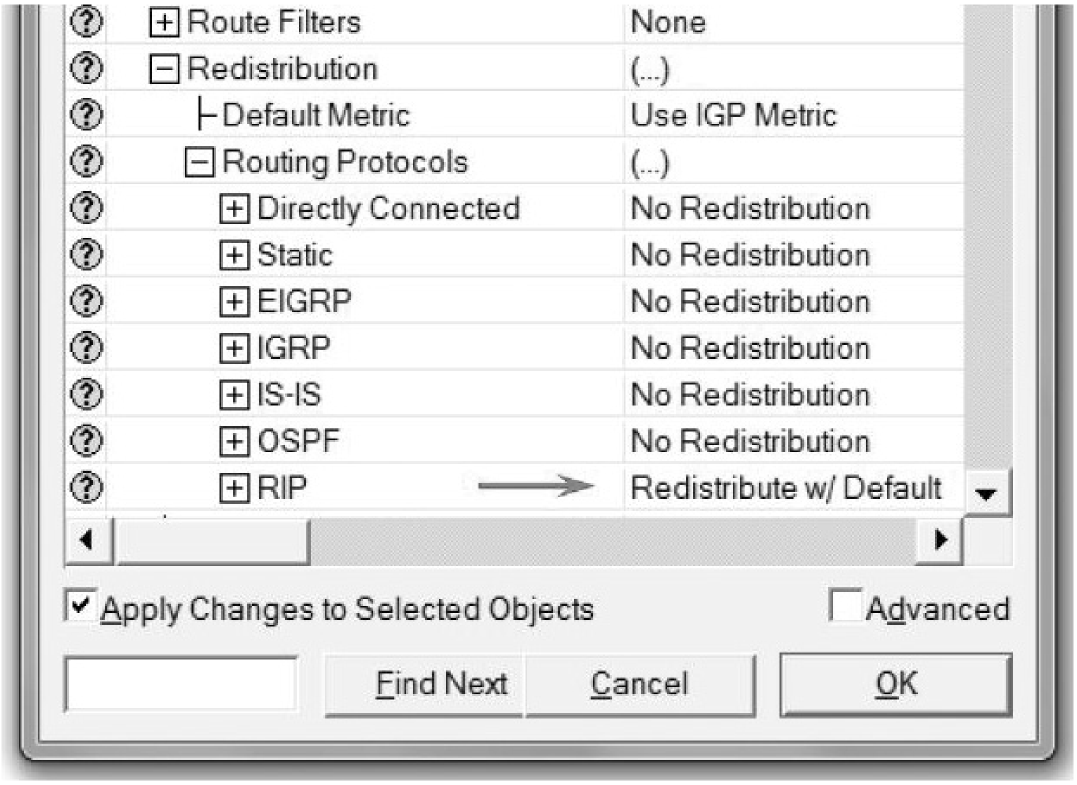
1. The *Object Palette* dialog box should now be on top of your project workspace. If it is not there, open it by clicking . Make sure that the **internet_toolbox** is selected from the pull-down menu on the object palette.
2. Add to the project workspace the following objects from the palette: six **ethernet4_slip8_gtwy** routers and two **100BaseT_LAN** objects.
   a. To add an object from a palette, click its icon in the object palette → Move your mouse to the workspace → Click to place the object → Right-click to stop creating objects of that type.
3. Use bidirectional **PPP_DS3** links to connect the routers you just added, as shown in the following figure. Rename the objects as shown (right-click on the node → **Set Name**).
4. Use a bidirectional **100BaseT** link to connect **LAN_West** to **Router1** and another **100BaseT** link to connect **LAN_East** to **Router6** as shown.
5. Close the *Object Palette* dialog box → **Save** your project.



Routers Configuration

1. Right-click on any router → Click **Select Similar Nodes** (make sure that all routers are selected) → Right-click on any router → **Edit Attributes** → Check the **Apply Changes to Selected Objects** check box.
2. Expand the **BGP Parameters** hierarchy and set the following:
   a. **Redistribution** → **Routing Protocols** → **RIP** → **Redistribute w/ Default** as shown.

Redistribute w/ Default allows a router to have a route to a destination that belongs to another autonomous system.



3. Expand the **IP Routing Parameters** hierarchy and set the following:
   a. **Routing Table Export = Once at End of Simulation**. This asks the router to export its routing table at the end of the simulation to the *simulation log*.
4. Expand the **RIP Parameters** hierarchy and set the following:
   a. **Redistribution** → **Routing Protocols** → **Directly Connected** → **Redistribute w/ Default**.
5. Click **OK**, and then **Save** your project.

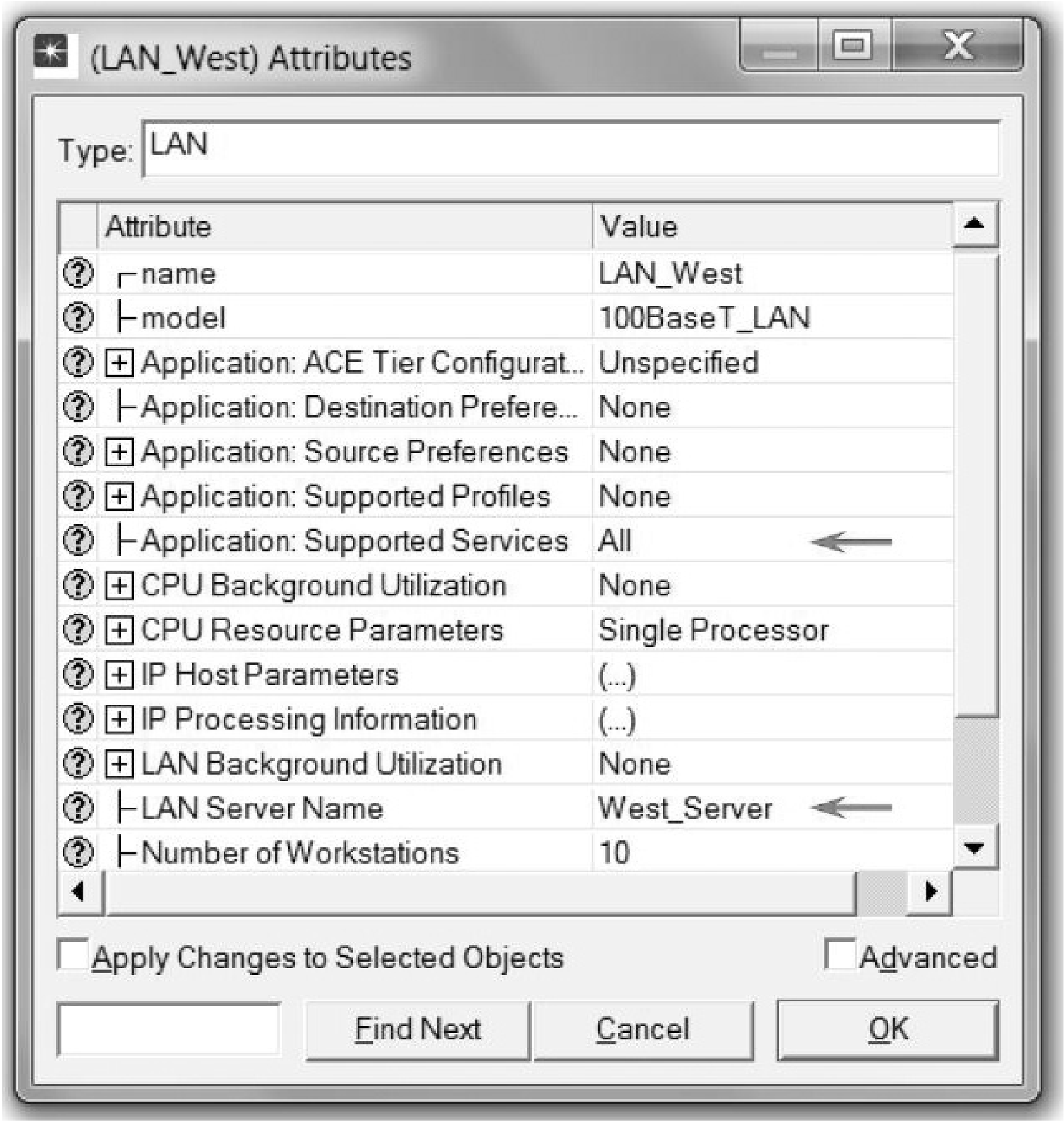
Application Configuration

1. Right-click on **LAN_West** → **Edit Attributes** → Assign **All** to **Application: Supported Services** → Assign **West_Server** to the **LAN Server Name** attribute as shown → Click **OK**.

Notice that two objects for *Applications* and *Profiles* will be added automatically to the project.

2. Right-click on **LAN_East** → **Edit Attributes**:
   a. Expand the **Application: Supported Profiles** hierarchy → Set **rows** to 1 → Expand the **row 0** hierarchy → Set **Profile Name** to **E-commerce Customer**.

Application: Destination Preferences provides mappings between symbolic destination names specified in the Application Definition or Task Definition objects and real names specified in Server Name or Client Name on each node.



b. Edit the **Application: Destination Preferences** attribute as follows: Set **rows** to **1** → Set **Symbolic Name** to **HTTP Server** → Edit **Actual Name** → Set **rows** to **1** → In the new row, assign **West_ Server** to the **Name** column.

3. Click **OK** three times, and **Save** your project.

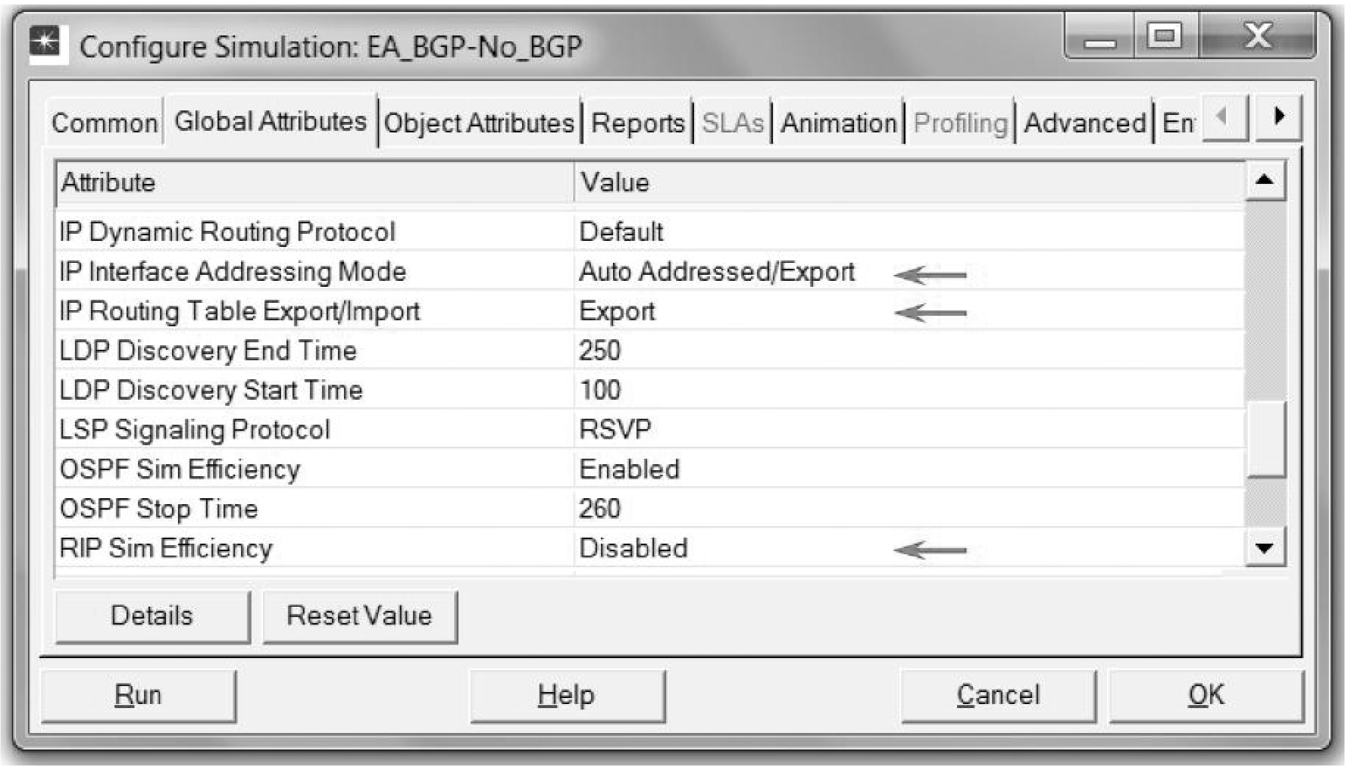
Auto Addressed means that all IP interfaces are assigned IP addresses automatically during simulation. The class of address (e.g., A, B, or C) is determined based on the number of hosts in the designed network. Subnet masks assigned to these interfaces are the default subnet masks for that class.

Configure the Simulation

Here, we need to configure some of the simulation parameters:

1. Click on and the *Configure Simulation* window should appear.
2. Set the duration to **10.0 minutes**.
3. Click on the **Global Attributes** tab and make sure that the following attributes are assigned as follows:
   - **a.** **IP Interface Addressing Mode = Auto Addressed/Export**.
   - **b.** **IP Routing Table Export/Import = Export**.
   - **c.** **RIP Sim Efficiency = Disabled**. If this attribute is enabled, RIP will stop after the "RIP Stop Time." But we need the RIP to keep updating the routing table in case there is any change in the network.

4. Click **OK**, and then **Save** the project.



Export causes the autoassigned IP interface to be exported to a file (name of the file is <net_name>-ip_addresses.gdf and it gets saved in the primary model directory).

Choose the Statistics

1. Right-click on **LAN_East** and select **Choose Individual Statistics** → From the **Client HTTP** hierarchy choose the **Traffic Received (bytes/sec)** statistic → Click **OK**.
2. Right-click on the link that connects **Router2** to **Router3** and select **Choose Individual Statistics** from the pop-up menu → From the **point-to-point** hierarchy choose the "**Throughput (bits/sec)** -->" statistic → Click **OK**.

Note: If the name of the link is "Router3 <-> Router2," then you will need to choose the "**Throughput (bits/sec)** <--" statistic instead.

3. Right-click on the link that connects **Router2** to **Router4** and select **Choose Individual Statistics** from the pop-up menu → From the **point-to-point** hierarchy choose the "**Throughput (bits/sec)** -->" statistic → Click **OK**.

Note: If the name of the link is "Router4 <-> Router2," then you will need to choose the "**Throughput (bits/sec)** <--" statistic instead.

Router Interfaces and IP Addresses

Before setting up the routers to use BGP, we need to get the information of the routers' interfaces along with the IP addresses associated to these interfaces. Recall that these IP addresses are assigned automatically during simulation, and we set the global attribute **IP Interface Addressing Mode** to export this information to a file.

1. First, we need to run the simulation. Click on [icon] and the *Configure Simulation* window should appear → Click on **Run**.
2. After the simulation run completes, click **Close**.

3. From the **File** menu choose **Model Files** → **Refresh Model Directories**. This causes OPNET IT Guru to search the model directories and update its list of files.
4. From the **File** menu choose **Open** → From the drop-down menu choose **Generic Data File** → Select the **<<your initials>_BGP-No_BGP -ip_addresses** file → Click **OK**.

The file that contains all the information about router interfaces and their IP addresses will open. Table 8.1 shows the interface number and IP addresses between the six routers in our projects. For example, Router1 is connected to Router2 through interface (IF) 11, which is assigned 192.0.1.1 as its IP address. A router is connected to itself by a Loopback interface as shown. Create a similar table for your project, but note that your result may vary due to different node placement.

TABLE 8.1 Interfaces That Connect the Routers and Their Assigned IP Addresses

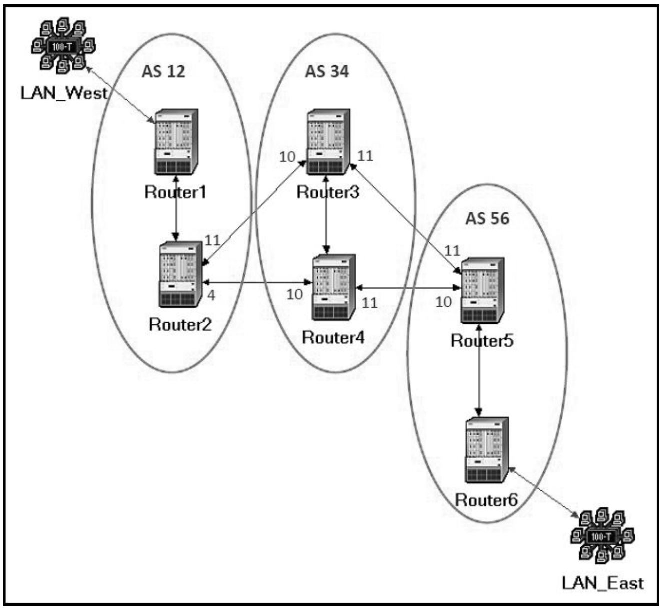
Routers	1	2	3	4	5	6
1	IF: 12 IP: 192.0.2.1	IF: 10 IP: 192.0.1.1				
2	IF: 10 IP: 192.0.1.2	IF: 12 IP: 192.0.5.1	IF: 11 IP: 192.0.4.1	IF: 4 IP: 192.0.3.1		
3		IF: 10 IP: 192.0.4.2	IF: 12 IP: 192.0.8.1	IF: 4 IP: 192.0.6.1	IF: 11 IP: 192.0.7.1	
4		IF: 10 IP: 192.0.3.2	IF: 4 IP: 192.0.6.2	IF: 12 IP: 192.0.10.1	IF: 11 IP: 192.0.9.1	
5			IF: 11 IP: 192.0.7.2	IF: 10 IP: 192.0.9.2	IF: 12 IP: 192.0.12.1	IF: 4 IP: 192.0.11.1
6					IF: 10 IP: 192.0.11.2	IF: 12 IP: 192.0.14.1

Creating the BGP Scenario

In the network we just created, all routers belong to the same autonomous system. We will divide the network into three autonomous systems and utilize BGP to route packets among these systems.

1. Select **Duplicate Scenario** from the **Scenarios** menu and name it **BGP_Simple** → Click **OK**.
2. Highlight or select simultaneously (using shift and left-click) **Router1** and **Router2** → Right-click on **Router1** → **Edit Attributes** → Check the **Apply Changes to Selected Objects** check box.
3. Expand the **IP Routing Parameters** hierarchy and set the **Autonomous System Number** to **12** → Click **OK**.
4. Repeat Steps 2 and 3 for routers **Router3** and **Router4**. Assign their **Autonomous System Number** to **34**.
5. Repeat Steps 2 and 3 for routers **Router5** and **Router6**. Assign their **Autonomous System Number** to **56**.

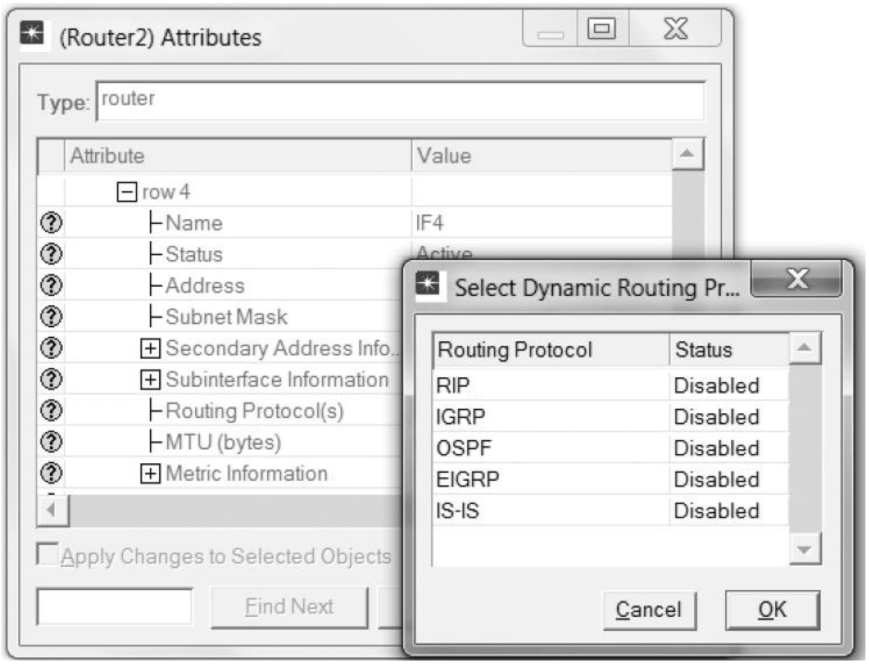
The following figure shows the created autonomous systems. The figure also shows the interfaces that connect routers across different autonomous systems. There interfaces are taken from Table 8.1. (*Note:* the interface numbers in your project may vary.)



6. The next step is to disable the RIP protocol on the interfaces shown in the previous figure (i.e., Router2: IF4 and IF11, Router3: IF10 and IF11, Router4: IF10 and IF11, Router5: IF10 and IF11).

Note: Make sure to apply the next step on the interfaces in your simulation because they might be different from the preceding interfaces.

7. Right-click on **Router2** → **Edit Attributes** → Expand the **IP Routing Parameters** hierarchy → Expand the **Interface Information** hierarchy → Expand **row 4** hierarchy → Click on the values of the **Routing Protocol(s)** attribute → Disable **RIP** as shown → Click **OK** twice.



8. Repeat Step 7 for all other interfaces that connect routers across autonomous systems (i.e., all the remaining seven interdomain interfaces listed in Step 6).
9. **Save** your project.

Configuring the BGP Neighbor Information

If you try to run the simulation of the BGP_Simple scenario, you will receive hundreds of errors! This is because there is no routing protocol running between the interdomain routers. Therefore, no routing tables are created to deliver packets among autonomous systems. The solution is to utilize BGP by defining the neighbors of interdomain routers. Table 8.2 shows the neighbors of the routers that will run BGP. Neighbors are defined by their interface IP addresses and the AS numbers. For each router in Table 8.2, carry out the following step:

1. Right-click on the router → **Edit Attributes** → Expand the **BGP Parameters** hierarchy → Expand the **Neighbor Information** hierarchy → Assign to the **rows** attribute the value **1** for **Router1** and **Router6**. For all other routers, assign the value **3** to the **rows** attribute → Utilize Table 8.2 to assign the corresponding values to the **IP Address**, **Remote AS**, and **Update Source** attributes for each of the added rows.

Note: The values to be assigned to the IP Address attribute have to match the values you collected in your Table 8.1.

IBGP stands for Internal BGP, where BGP runs between two routers belonging to the same autonomous system. When a BGP speaker receives an update from an IBGP neighbor, the speaker will not redistribute the route advertisement to its other IBGP peers. To make sure that the routing information is consistently distributed throughout the network, each BGP speaker should maintain an IBGP connection to all the BGP speakers in its own autonomous system.

EBGP stand is for external BGP.

IP Address here is the IP address of the neighbor. The node should have knowledge of a valid route to reach this address. For IBGP connections, it is recommended that a Loopback interface address of the neighbor be used. For EBGP connections, a physical interface address that is within one IP hop is used.

Remote AS specifies the autonomous system number of the neighbor.

TABLE 8.2 Neighbors' Info for Interdomain Routers

	BGP Parameters ⇒ Neighbor Information		
Routers	*row 0*	*row 1*	*row 2*
Router1	IP Address: 192.0.5.1 Remote AS: 12 Update Source: Loopback		
Router2	IP Address: 192.0.4.2 Remote AS: 34 Update Source: Not Used	IP Address: 192.0.3.2 Remote AS: 34 Update Source: Not Used	IP Address: 192.0.2.1 Remote AS: 12 Update Source: Loopback
Router3	IP Address: 192.0.4.1 Remote AS: 12 Update Source: Not Used	IP Address: 192.0.7.2 Remote AS: 56 Update Source: Not Used	IP Address: 192.0.10.1 Remote AS: 34 Update Source: Loopback
Router4	IP Address: 192.0.3.1 Remote AS: 12 Update Source: Not Used	IP Address: 192.0.9.2 Remote AS: 56 Update Source: Not Used	IP Address: 192.0.8.1 Remote AS: 34 Update Source: Loopback
Router5	IP Address: 192.0.7.1 Remote AS: 34 Update Source: Not Used	IP Address: 192.0.9.1 Remote AS: 34 Update Source: Not Used	IP Address: 192.0.14.1 Remote AS: 56 Update Source: Loopback
Router6	IP Address: 192.0.12.1 Remote AS: 56 Update Source: Loopback		

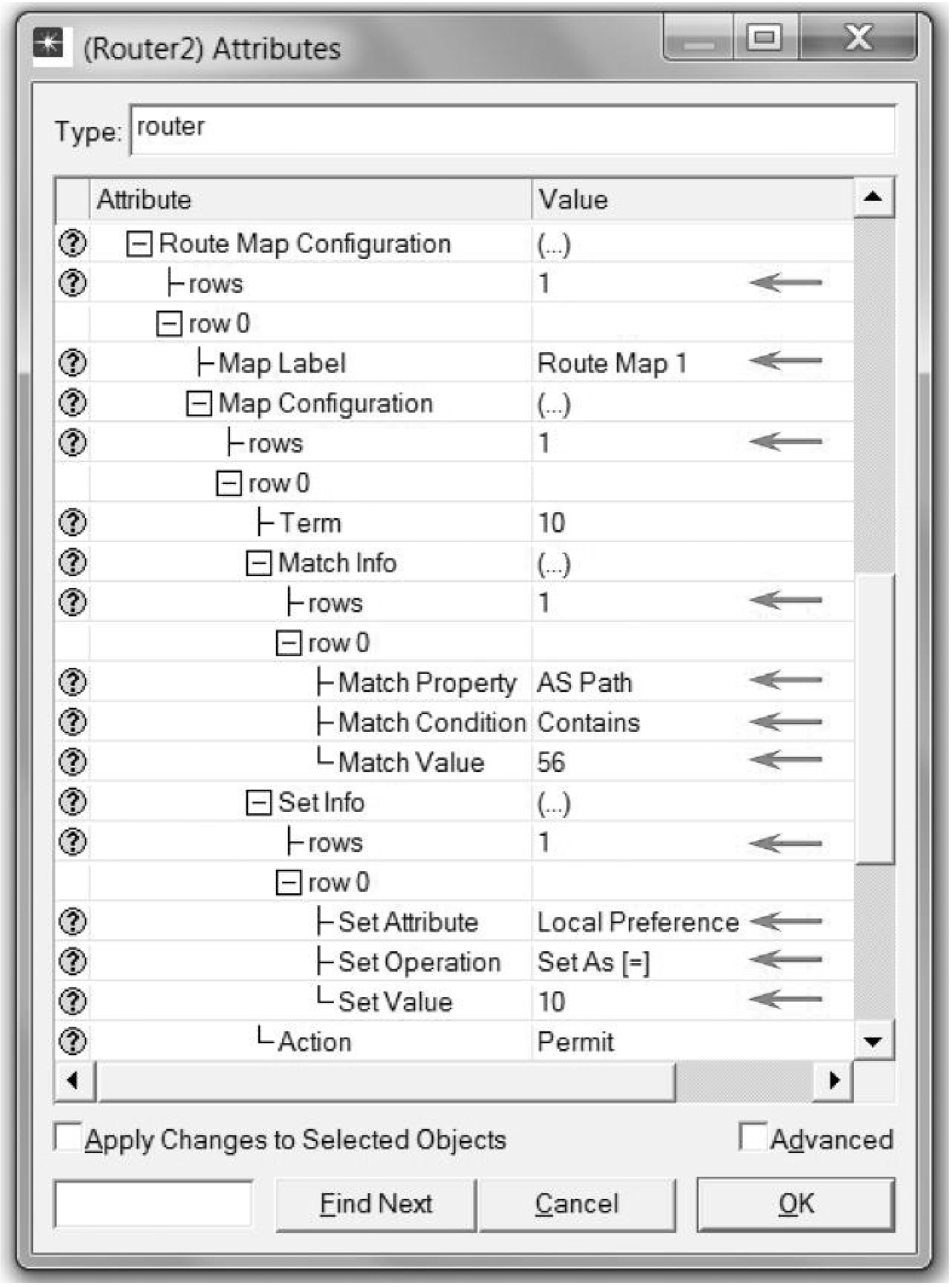
Creating the BGP with Policy Scenario

BGP allows for routing policies that can be enforced using route maps. We will utilize this feature to configure Router2 to redirect its load on the two egress links of its autonomous system.

1. Make sure that your project is in the **BGP_Simple** scenario. Select **Duplicate Scenario** from the **Scenarios** menu and name it **BGP_Policy** → Click **OK**.

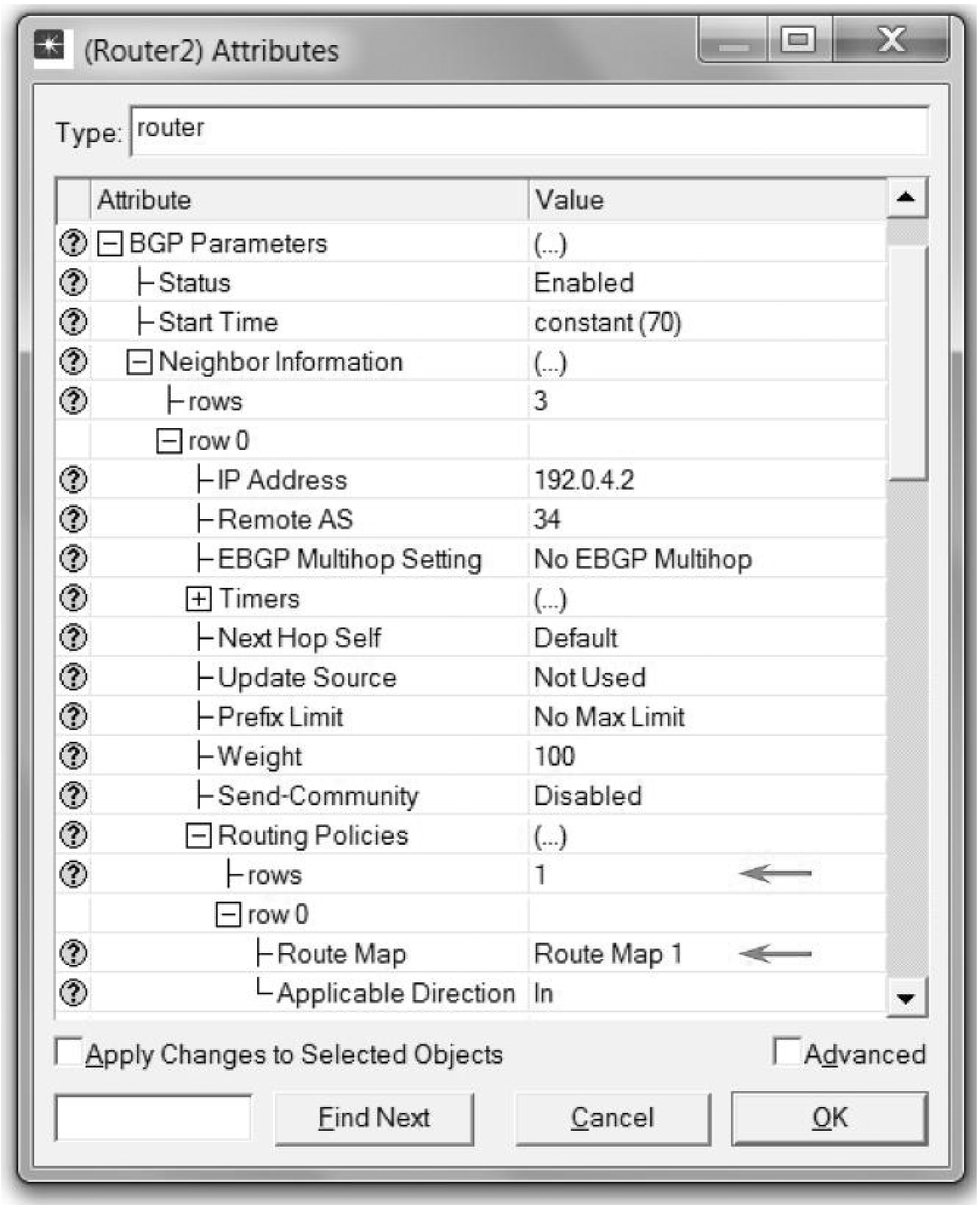
2. Right-click on **Router2** → **Edit Attributes** → Expand the **IP Routing Parameters** hierarchy → Expand the **Route Map Configuration** hierarchy → Set the attributes as shown in the following figure.

The purpose of the created route map is to reduce the degree of preference of the "route to AS 56" to the value 10. (*Note:* The normal value is 99, which is calculated as 100 – number of ASs that should be crossed to reach the destination.)



The next step is to assign the preceding route map to the link connecting Router2 to Router3. This way traffic from Router2 to AS 56 will be preferred to go through Router4 instead.

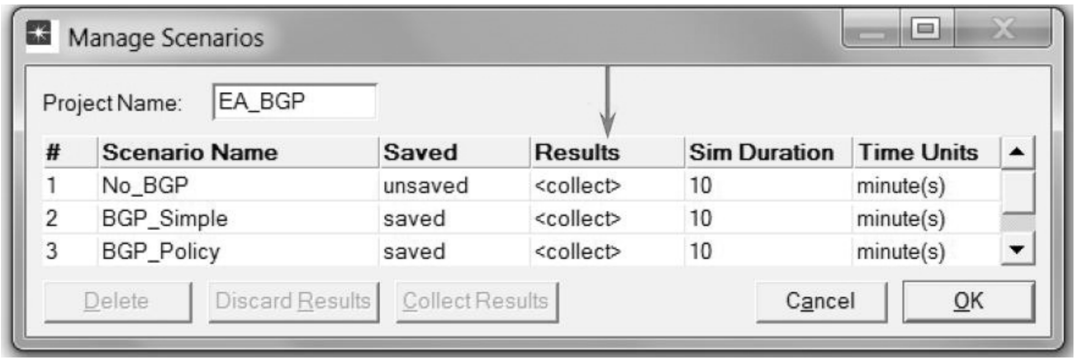
3. Right-click on **Router2** → **Edit Attributes** → Expand the **BGP Parameters** hierarchy → Expand the **Neighbor Information** hierarchy → Expand the row that has the IP address of Router3 interface (it is row 0 in my project) → Expand the **Routing Policies** hierarchy → Set its attribute as shown in the following figure.
4. Click **OK**, and **Save** your project.



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 with the following figure.

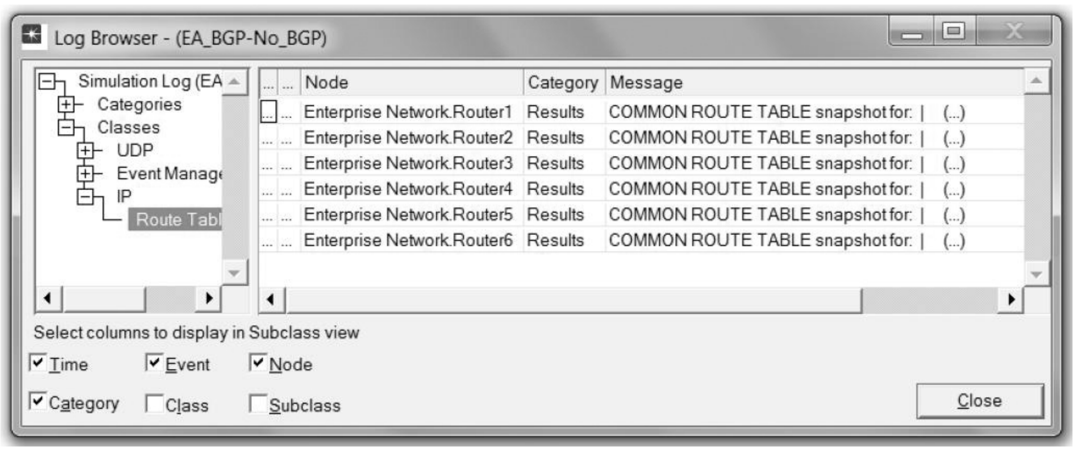


3. Click **OK** to run the three simulations.
4. After the three simulation runs complete, one for each scenario, click **Close** → **Save** your project.

View the Results

Compare the routing tables content:

1. To check the content of the routing tables in **Router2** for **No_BGP** scenario:
   a. Click **Ctrl + 1** → Go to the **Results** menu → **Open Simulation Log** → Expand the hierarchy on the left as shown in the following figure → Click on the field **COMMON ROUTE TABLE** in the row that corresponds to Router2.



2. Carry out the previous step for scenario **BGP_Simple** by clicking **Ctrl + 2** at the beginning. The following are partial contents of **Router2**'s routing table for both scenarios. (*Note:* Your results may vary due to different node placement.)

Routing table of **Router2** for the **No_BGP** scenario:

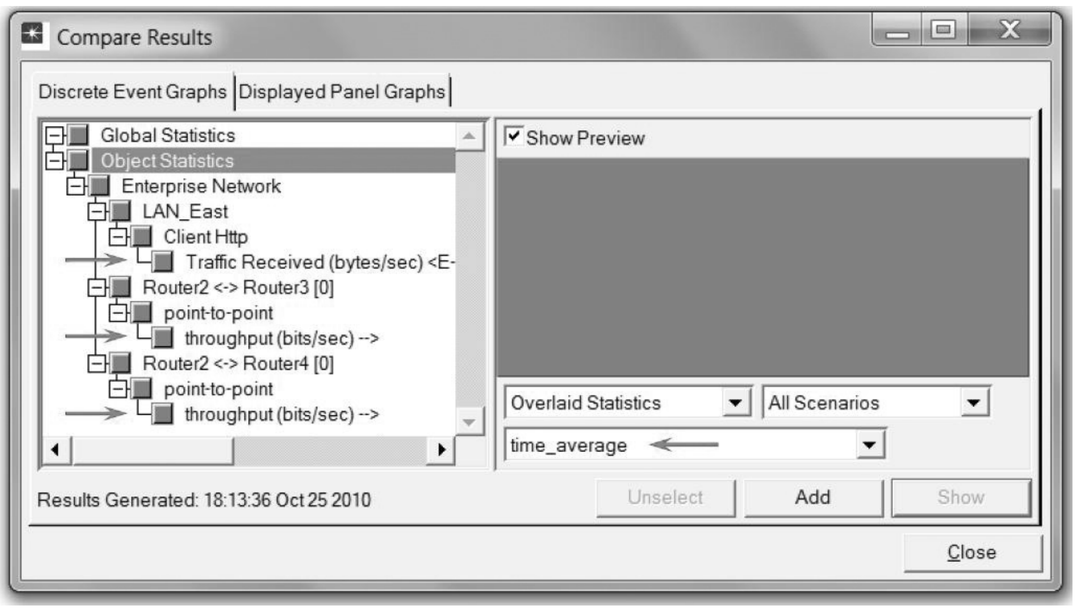
Dest. Address	Subnet Mask	Next Hop	Interface Name	Metric	Protocol
192.0.3.0	255.255.255.0	192.0.3.1	IF4	0	Direct
192.0.1.0	255.255.255.0	192.0.1.2	IF10	0	Direct
192.0.4.0	255.255.255.0	192.0.4.1	IF11	0	Direct
192.0.5.0	255.255.255.0	192.0.5.1	Loopback	0	Direct
192.0.6.0	255.255.255.0	192.0.3.2	IF4	1	RIP
192.0.9.0	255.255.255.0	192.0.3.2	IF4	1	RIP
192.0.10.0	255.255.255.0	192.0.3.2	IF4	1	RIP
192.0.0.0	255.255.255.0	192.0.1.1	IF10	1	RIP
192.0.2.0	255.255.255.0	192.0.1.1	IF10	1	RIP
192.0.7.0	255.255.255.0	192.0.4.2	IF11	1	RIP
192.0.8.0	255.255.255.0	192.0.4.2	IF11	1	RIP
192.0.11.0	255.255.255.0	192.0.3.2	IF4	2	RIP
192.0.12.0	255.255.255.0	192.0.3.2	IF4	2	RIP
192.0.13.0	255.255.255.0	192.0.3.2	IF4	3	RIP
192.0.14.0	255.255.255.0	192.0.3.2	IF4	3	RIP

Routing table of **Router2** for the **BGP_Simple** scenario:

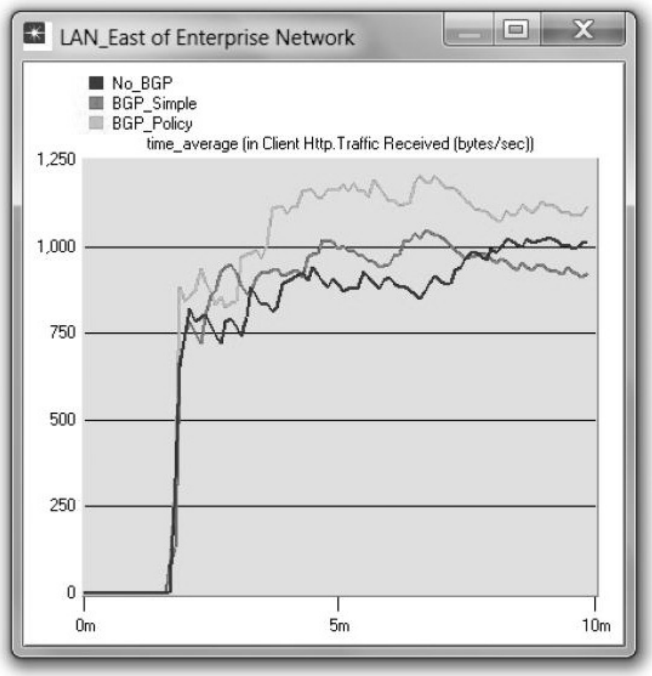
Dest. Address	Subnet Mask	Next Hop	Interface Name	Metric	Protocol
192.0.1.0	255.255.255.0	192.0.1.2	IF10	0	Direct
192.0.5.0	255.255.255.0	192.0.5.1	Loopback	0	Direct
192.0.3.0	255.255.255.0	192.0.3.1	IF4	0	Direct
192.0.4.0	255.255.255.0	192.0.4.1	IF11	0	Direct
192.0.0.0	255.255.255.0	192.0.1.1	IF10	1	RIP
192.0.2.0	255.255.255.0	192.0.1.1	IF10	1	RIP
192.0.10.0	255.255.255.0	192.0.3.2	IF4	0	BGP
192.0.6.0	255.255.255.0	192.0.4.2	IF11	0	BGP
192.0.8.0	255.255.255.0	192.0.4.2	IF11	0	BGP
192.0.9.0	255.255.255.0	192.0.4.2	IF11	2	BGP
192.0.7.0	255.255.255.0	192.0.4.2	IF11	2	BGP
192.0.11.0	255.255.255.0	192.0.4.2	IF11	0	BGP
192.0.12.0	255.255.255.0	192.0.4.2	IF11	0	BGP
192.0.13.0	255.255.255.0	192.0.4.2	IF11	0	BGP
192.0.14.0	255.255.255.0	192.0.4.2	IF11	0	BGP

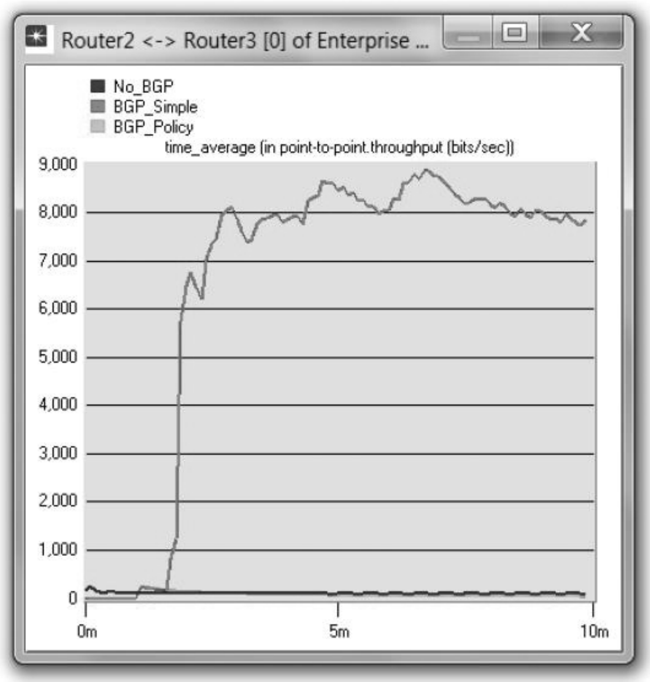
Compare the load in the network:

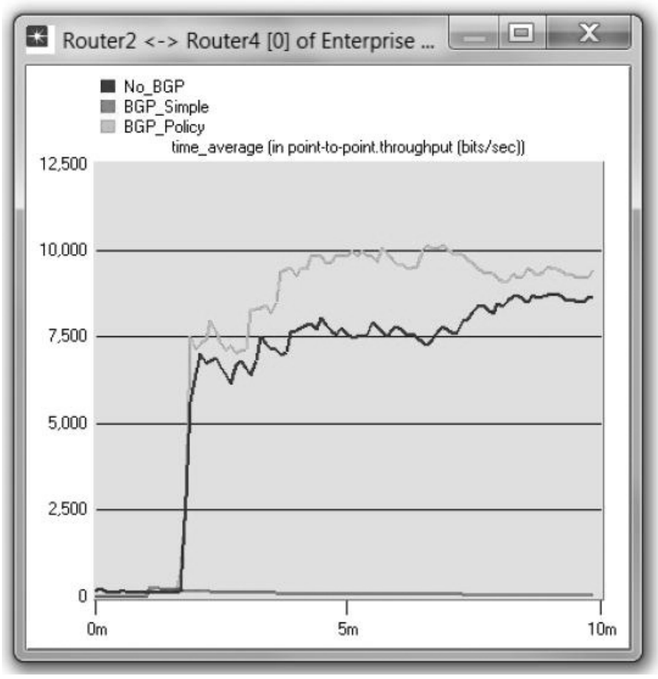
1. Select **Compare Results** from the **Results** menu.
2. Change the drop-down menu in the right-lower part of the *Compare Results* dialog box from **As Is** to **time_average** as shown.



3. Select and show the graphs of the statistics shown previously: **Traffic Received** in LAN_East, **throughput in the Router2-Router3** link, and **throughput in the Router2-Router4** link. The resulting graphs should resemble the graphs that follow.







FURTHER READINGS

A Border Gateway Protocol 4 (BGP-4): IETF RFC number 1771 (www.ietf.org/rfc.html).

Application of the Border Gateway Protocol in the Internet: IETF RFC number 1772 (www.ietf.org/rfc.html).

BGP-4 Protocol Analysis: IETF RFC number 1774 (www.ietf.org/rfc.html).

EXERCISES

1. Obtain and analyze the routing table for **Router5** in the project before and after applying BGP.
2. Analyze the graphs that show the throughput in both the Router2–Router3 link and Router2–Router4 link. Explain the effect of applying the routing policy on these throughputs.
3. Create another scenario as a duplicate of the **BGP_Simple** scenario. Name the new scenario **BGP_OSPF_RIP**. In this new scenario change the intradomain routing protocol in **AS 56** to **OSPF** instead of **RIP**. Run the new scenario and check the contents of **Router5**'s routing table. Analyze the content of this table.

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.